WILDLIFE MORTALITY CAUSED BY HIGHWAY VEHICLES AND RAILROADS: A COMPREHENSIVE LITERATURE REVIEW AND PROPOSED METHOD FOR EXTRAPOLATION TO TRAFFIC INCREASES AND BETWEEN SPECIES

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EXECUTIVE SUMMARY

This review attempted to gather most of the research published in the open literature on mortality of terrestrial vertebrates caused by vehicle traffic and railroads. The primary focus of this review is deer, but studies of other ungulates, mammals, and non-mammalian vertebrates are also reviewed. Published data on invertebrate mortality are scarce, and are also summarized.

In 1992 it was estimated that over 500,000 deer were killed annually by vehicular traffic in the United States, and by 1995 this estimate was 750,000 deer killed by vehicles. The Fatal Accident Reporting System (FARS) of the U. S. National Highway Traffic Safety Administration reported 112 persons killed in large animal/vehicle accidents in 1993. In many areas of the United States, vehicles have decimated or exterminated populations of amphibians, mammals, birds, and insects. The total cost in human injury and property damage for all animal-vehicle accidents is estimated (1995) to be about $1.2 *billion* per year.

Minnesota is ranked sixth in the United States for deer/vehicle accidents, numbering from 12,000 to 16,000 per year. For the UMRS states combined (Illinois, Iowa, Minnesota, Missouri, Wisconsin), the 5-year average is >60,000 deer/year killed in 23 billion vehicle-miles driven per year. This is approximately 1 deer killed per 2 million vehicle-miles. The average vehicle damage is estimated to be $2,000 per accident and the recreational cost of a deer estimated to be $500, so the cost of vehicular accidents with white-tailed deer in the UMRS states is over $150,000,000 per year.

With the exception of data on moose, there are few published reports of animals killed by trains. We assume (based on the limited comparison data available) that a motor vehicle and a train have the same probability of killing a deer or other animal on a vehicle-mile basis. The annual total train miles in the United States is approximately the same as the total number of rural vehicle miles traveled in Illinois. Therefore, nationally, the total number of deer killed by trains will be similar to the total number of deer killed on rural roads in Illinois.

This review discusses wildlife mortality caused by road and railroad traffic. Wildlife mortality from habitat fragmentation and landscape changes produced by developing road and railroad corridors are not reviewed. However, without roads vehicles would kill fewer wildlife and with fewer vehicles habitats would not be destroyed and fragmented to develop new roads. Therefore, the Corps' planning effort should also address the losses of wildlife that undoubtedly would occur due to landscape changes resulting from the creation and enlargement of highway and railroad corridors.

There are no statewide or national figures available for the number of small animals killed on the highways, but in a 14 county study in Virginia, the ratios of small animals killed compared to deer killed were: opossum 95%, dogs 88%, raccoons 76%, cats 65%, skunks 26%, and rabbits 20%. The ratio implies that if nationally there are $^{2}/_{3}$ to ¾ million deer killed every year on highways, tens of millions of smaller animals and birds are killed by motor vehicles. A 1981 study of national road-kills had collected data in selected areas in the southeast, midwest, Oregon, and California in June of 1978. For country roads, 12% of the kill was "large animals", 47% amphibians and reptiles, 12% "small mammals", 32% birds, and 1% "other" species. In this study, "large mammals" were defined as species at least as large as chipmunks, and included specifically deer, elk, rabbits, hares, fur-bearers, porcupines, chipmunks, tree squirrels, ground squirrels, mountain beaver, moles, and gophers. We tabulated road-kill data from North America and computed ratios of deer killed by vehicles to another species killed by vehicles as: small mammals 0.1, coyote 2.75, and opossum 0.62. Extensive Illinois data (1976-1997) for fur-bearers were used to calculate road-kill ratios, relative to each other, for opossum, raccoon, striped skunk, rabbit, pheasant, and woodchuck. For opossum, raccoon, and striped skunk, ratios were calculated both within a year (1995) and from 1976-1997.

LITERATURE REVIEW

INTRODUCTION

A 1975 "state of the art" report begins: "A U. S. Fish and Wildlife Service biologist estimates the current annual mortality of *birds* on United States roads at 57,179,366; less than 40 years ago, a writer estimated a loss of 6,000,000 *total vertebrates* per year on the highway" (Leedy, 1975), italics added). The toll has risen each year since, approximately in proportion to the total number of vehicles, and more specifically, to the total number of vehicle miles driven each year. The studies reported below provide estimates of $\geq$5% per year as the rate at which vertebrate mortality has increased in the intervening decades. If this rate is taken as 6.6% (see text), in the 22 years since 1975 the total vertebrate mortality has increased 4-fold to 0.22 billion animals per year, and rising. A 1960s estimate was that over one million vertebrates are killed on roads each *day* in the United States (Lalo, 1987). Many researchers have proposed that highway mortality is a significant cause of the decline in the numbers of numerous species, including amphibians, birds, and many small mammals.

The total cost in human injury and property damage for all animal-vehicle accidents is estimated (1995) to be about $1.2 *billion* per year (Cook and Daggett, 1995). In the United States alone, the Fatal Accident Reporting System (FARS) of the National Highway Traffic Safety Administration reported 112 persons killed in large animal/vehicle accidents in 1993 (Cook and Daggett, 1995), and human deaths are reported in all other countries, including those on the African and on the Indian continents. For the UMRS states (Illinois, Iowa, Minnesota, Missouri, Wisconsin), the 5-year average is >60,000 deer killed/year, in 23 billion vehicle-miles driven/year, which is an average of 1 deer killed per 2 million vehicle-miles (see Section 2). And this is just one species.

This report is a comprehensive literature review concerning vehicular road traffic and railway related mortality of terrestrial vertebrates. A few citations included data for terrestrial invertebrates, and these are included for completeness. To the extent possible, the report identifies terrestrial mortality associated with increases in vehicular traffic on existing roadways and railways for terrestrial vertebrates. The Corps identified the species of emphasis in this study as deer. Published data, and data obtained from the Upper Mississippi River System (UMRS) states were used to develop a simple relationship between traffic levels and deer mortality. Relationships between deer mortality and mortality for other species are discussed. It was not the purpose of this study to develop an economic model, nor a site-specific model of mortality for deer or other terrestrial vertebrates. However, an illustration is provided that gives one way in which the Corps might use the data in this report to estimate potential effects of shifting goods from the UMRS to roads and railroads.

This review has attempted to gather the majority of research published in the open literature on the mortality effects of highway and train traffic on terrestrial vertebrates. The data were used to devise a model to estimate mortality due to future changes in traffic (Section 2). The author has attempted to obtain and review most of the papers cited here. When possible, gray literature has been obtained. However, there are numerous reports, both published and unpublished, by state and federal agencies in the United States and in other countries which the author did not attempt to obtain, primarily because the citations to these references, and often the data, were in the published studies reviewed for this report. Also, some papers were published in very obscure journals or magazines, and these were unavailable to the author In these instances, the author has relied on abstracts and summaries presented in obtainable sources, such as an annotated bibliography prepared for the Federal Highway Administration (Leedy, 1975; Leedy *et al.* 1975). During this research, a few papers were found on invertebrate mortality, and these are included.

Sources of information used to prepare this review include:

- bibliographic searches of several electronic data bases (e.g., Science Citation Index, Wilson Index, NISC Disc Report: Wildlife Worldwide, Wildlife Society)
- several federal and international databases on the internet
- reference in published papers and reports
- contact with experts in natural resource departments in various states and countries
- e-mail.
- correspondence (telephone and written) with officials in state and federal agencies, insurance companies, and railroad companies.

Sources of information, or types of information not included in this review are:

- state reports, published and unpublished were not systematically searched for or collected
- NEPA studies were not considered
- symposia were obtained if feasible, but conference proceedings abstracts were not systematically searched
- no systematic search was made for books
- no search was made for theses, and no attempt was made to obtain theses cited in published reports; however, theses are cited in this review based on the citation in a published, reviewed, article
- no specific search was made for endangered species, but information on endangered species was included as encountered
- mitigation and avoidance measures, such as fencing, tunnels, sirens, and other measures were not specifically considered, although some reference is made to these types of measures in the text.

This review does *not* include discussion of:

- effects of highway construction on wildlife
- effects of highways, or highway construction, on fish and other wholly aquatic species
- effects of chemicals used on roads (e.g., deicers, herbicides), or running off of road surfaces (e.g., oil, grease, rubber, etc.)
- waste disposal from roadside rest areas and parks
- effects of right-of-way management (e.g., fencing, under- and overpasses, traffic warning signs for animals, highway lighting, roadside mirrors, other measures), except as cited in individual studies (however, the present author's coverage of this information is not complete even for the papers reviewed).

Limitations of this report

The author of this report extensively paraphrased the articles cited. Tables in this report were either reproduced directly from a published table or were synthesized by the present author from tables, graphs and text in the original article. Figures in this report were redrawn (and sometimes modified) from the original, or originated with the present author.

RAILROADS VERSUS HIGHWAYS AS CAUSES OF MORTALITY

An effort was made to locate all available data on vertebrate mortality due to trains. Some data on the numbers of animals killed by trains have been published, and these reports are discussed below. The expert in the U. S. Department of Transportation, Robert Finkelstein, replied (23 September) to a request for information on train-deer (and/or other species) accidents as follows: “Our data base does not have that kind of information. I know of no other data base with that information. Some railroads might have accident information about it, but I have never heard about it.” Repeated attempts to contact specific officials in England and France using e-mail, phone, and fax were not successful.

Based on the literature we assume that a motor vehicle and a train have the same probability of killing a deer or other animal on a vehicle miles basis (see p. 52). Support for this assumption comes, for example, from a multiyear study in Brno, Czechoslovakia that quantified avian and mammalian mortality due to trains (Havlín,1987a) and highways (Havlín,1987b). "The results, obtained under quite comparable conditions and practically at the same time, show…that there is no major difference in the number of vertebrates killed per unit length between the motorway (86.34 per 100 km) and the railway (76 per 100 km), in spite of great differences in the density of traffic, mostly also in speed and in the width (which is always greater in the case of motorways)" (Havlín,1987a). Ruediger (1996) cites John Weaver's unpublished study of wolves in Jasper National Park and Paquet and Hackman's (1995) in Banff National Park, which found that highway and railroad mortality averaged 1-2 per pack per year. Ruediger also cites a study by Dave Lewis (Western Forest Carnivore Committee Management Conference, 1996) who observed 1 of 13 radio-collared wolverine was killed on a highway and 1 killed on a railroad.

The annual total train miles is approximately the same as the total number of rural vehicle miles traveled in Illinois. Therefore, nationally, the total number of deer killed by trains will be similar to the total number of deer killed on rural roads in Illinois. This is likely to be an overestimate for at least the following reasons. (1) Not all train miles are on rural tracks, and the probability of killing deer in urban settings is very low. (2) Most regions have multiple highway corridors but none or few railroad corridors. Given that the number of animals killed is a function of traffic (i.e., of opportunity), the number of individuals of a species which are at risk due to trains is less than the number at risk due to motor vehicles. (3) A recent questionnaire to which 43 states responded showed only 4 states (Massachusetts, Michigan, Oklahoma, and Wisconsin) having a maximum deer kill count larger than Illinois (Romin and Bissonette, 1996). Therefore, using Illinois mortality rates will, for both the United States and the UMRS states, overestimate the number of deer killed (Table 1).

Table 1. Number of deer killed on roads in UMRS states from 1989 to 1995. (Data supplied by the Department of Transportation in each state.)						
Year	**Illinois**	**Iowa**	**Minnesota**	**Missouri**	**Wisconsin**	**All**
89	12152		13040	8827	20307	42174
90	14012		15940	8075	21909	45924
91	15660	5150	16280	8254	21028	66463
92	16541	5628	16594	8096	22957	69908
93	16504	6294	15072	7386	24812	70161
94	17118	4627	14855	8384	26567	71645
95	17537	7201		7706	25917	33623
Geometric mean	15537	5712	15249	8093	23247	12055[1]

[1]This value is the geometric mean of the state geometric means = $(15537 \times 5712 \times \ldots 23247)^{1/5}$.

Munro (1998) assessed the impact of the Trans-Canada Highway (TCH) (8,000 cars/day) and the Canadian Pacific Railway (CPR) on bear movements and habitat use patterns in the Beaver Valley, British Columbia. Beaver Valley is 40 km in length. Of 27 collared bears, 6 were killed from 1994-1996: 0 were killed on the TCH and 2 were killed on the 15 km study section of the CPR. Records by Pat Wells, a train engineer for the CPR, were examined for the CPR main-line between Golden and Revelstoke from 1994 to 1996. Of 20 bears killed by trains, 11 were in the study area, 1 elsewhere in the Park, and 8 were outside the Park. Highway mortality was 4 bears killed in the study area, 2 killed elsewhere in the Park, and 5 killed outside the Park. (These distributions did not differ significantly using an exact Kruskal-Wallace nonparametric analysis of variance.)

van der Grift and Kuijsters (1998) reported that the extent of the mortality due to railway lines in the Netherlands is not known because there are no systematic registrations of accidents with fauna. Based on incidental reports from 1996 and 1997, the 151 fauna victims were: birds (20 species; 57%), mammals (9 species; 34%); domestic animals (9%), rodents (2%) and insectivores (1%). Amphibians and reptiles were not reported.

EFFECTS OF ROADS AND VEHICLE TRAFFIC ON WILDLIFE

Reh and Seitz (1990) observe: "Three reasons for the increased rate of extinction of animal and plant species are commonly accepted: the decrease of suitable areas; the reduction of the size of local habitats; and changes in biotic and abiotic properties of habitats. However, even if all these factors are constant, <u>a further parameter may play an important role for the persistence of populations: the arrangement and connectivity of habitats</u>" (emphasis added.)

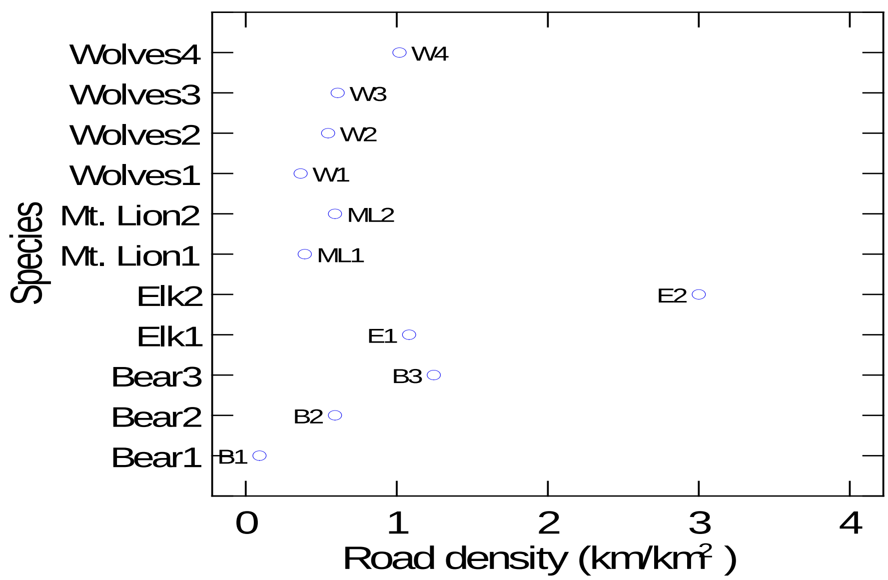
A landscape has many land uses, such as housing developments and agricultural fields within a predominant forested matrix (Forman and Hersperger, 1996). Roads cause more effects and have a greater cumulative effect than vehicles (Forman and Hersperger, 1996). Ecological structure and processes differ sharply with landscape, so road effects are quite distinctive (Table 2).

Table 2. Major road (R) and vehicle (V) effects in suburban+urban, forested, and open (agricultural, cultivation, rangeland, desert, tundra) landscapes. (Forman and Hersperger, 1996).

Suburban	Open	Forest	Ecological Effect	Agent
			Habitat and Species	
*	-	-	Road network removes & dissects scarce natural habitat, leaving nature fragmented	**R**
*	*	-	Roads disrupt species movement, especially in wildlife corridors	**R, V**
*	-	-	Traffic noise levels reduce biodiversity	**V**
-	*	-	New road lead to development & thus loss of key habitats, species, & natural flows	**R**
-	*	-	Road-kills threaten some rare populations	**V, R**
-	*	*	Introduced exotic species & pest invade cultivation, rangeland, & natural ecosystems	**R**
-	*	*	Road penetrates remote areas, thus reducing wildlife, habitat quality and biodiversity	**R, V**
			WATER AND SOIL	
-	-	*	Disrupt natural flows: groundwater, surface water, fire	**R**
-	-	*	Higher peak flows of streams & rivers, and thus more floods & damage & floodplain changes	**R**
-	-	*	Accelerated soil erosion & mudslides	**R**
-	-	*	More stream sedimentation, pollution, & fish loss	**R**
			ATMOSPHERE	
-	*	*	NOX emissions: more N input, growth, & damage proneness in production & natural systems	**V**
-	-	*	O_3 emissions damage trees & natural systems, especially in the mountains	**V**
-	*	*	Greenhouse gas & particulate emissions cause change in climate, vegetation, & production	**V**

Primarily: * = effect.; - = no effect. NOX = nitrogen oxides

Understanding spatial pattern of the broad landscape is essential for addressing the ecological impacts of roads. Most important are flows and movements, e.g., in wildlife corridors, across the land. Landscape ecology provides a useful theoretical framework for such a transportation analysis. Road density (e.g., mi/mi^2 or km/km^2) is a useful summary index because it integrates so many ecological impacts of roads and vehicle. Suburban, open, and forested landscapes result in markedly different road effects on species and habitats, and on water, soil, and atmosphere. Different species are readily compared for their sensitivity to roads using road density, as shown in Figure 1. For example, in the forested counties of the Adirondack Mountains of New York, there are many times more bears in low than high road-density areas.



B1, B2, B3 – bears harvested in New York per 100 mi2 per year
E1 - 50% of Rocky Mountains area remains as suitable elk habitat
E2 - 25% of Rocky Mountains area with 3.0 km/km^2 is suitable elk habitat (not shown)
M1 – typical mountain lion habitat in southern Utah in forest with logging
M2 – maximum threshold for mountain lions to maintain a home range in southern Utah
W1 – average for wolves across northern Minnesota
W2 – wolves in 6 northern Great Lakes areas peripheral to and disjunct from primary habitat
W3 – maximum threshold for breeding populations of wolves, Wisconsin, 1926-1960
W4 – no wolves in 2 areas of northern Great Lakes contiguous to primary habitat

Figure 1. Wildlife populations related to road density for wolves (*Canis lupus*), elk (*Cervus canadensis*), black bear (*Ursus americanus*) and mountain lion (*Felis concolor*). (See Forman and Hersperger, 1996 for data sources and discussion.)

Ruediger (1996) states that there are five factors involved with how highways negatively affect some carnivores, and “believe[s] the impacts are severe – even where human population densities are relatively low.” Factors Ruediger identifies as affecting carnivores are given below, and specific citations are given in following sections.

- **Direct Mortality**. This factor is exceedingly difficult to quantify, document and understand. The existing information is imperfect, but points in a singular direction. Rare carnivores (mostly large, e.g., bears, wolverines) are particularly susceptible to highway mortality because of their large home ranges, low biological productivity and the enormous sized areas required to sustain populations and individuals. Due to the long life spans (over 30 years for grizzly bear), carnivores can continue existing as individuals – without persisting as populations. "In [John] Weaver's unpublished study of wolves in Jasper National Park and Paquet and Hackman's (1995) in Banff National Park, highway and railroad mortality averaged 1-2 per pack per year" (Ruediger, 1996, p. 27).

- **Displacement and Avoidance**. The impacts of forest roads on carnivores have been studied for decades, but information on highways is much less documented. Recent information suggests that wolves (*Canis lupis*) (Mech et al., 1988; Thiel, 1985), grizzly bears (*Ursus arctos* Ord) (McLellan and Shackleton, 1988), bobcats (*Lynx rufus*) (Lovallo and Anderson, 1996), mountain lions (*Felis concolor*) (van Dyke et al., 1986), and black bears (*Ursus americanus*) (Brody and Pelton, 1989) are displaced by highways and generally avoid crossing them.

- **Habitat Fragmentation.** Highways, and other human developments, tend to create boundaries for both individuals and populations. Rare carnivores, such as lynx (*Lynx canadensis)*, wolverine (*Gulo gulo*), and Fisher (*Martes pennanti*), are generally present only in locations with the lowest highway densities. Fragmentation affects other carnivores, including wolves (Mech et al., 1988; Thiel, 1985) and bears (Apps, 1997).

- **Direct Habitat Loss.** This is an obvious impact that is rarely documented. Ruediger (1996) states that a 300 foot cleared section of right-of-way would consume 5.7% of each section it crosses. Indirect habitat loss due to displacement and avoidance likely averages 1 km on each side of a highway in heavily forested or vegetated areas to 3 km on each side in open habitats. This loss should be considered permanent and significant on a cumulative basis. It affects carnivores and herbivores (e.g., elk), both large (e.g., grizzly bears, caribou (Woods and Munro, 1996), and small (e.g., bats, (Woods and Munro, 1996).

- **Associated Human Development.** As access increases, the amount of associated development increases. This impact is severe and permanent for carnivore communities.

This review is limited to direct vehicle-caused mortality of wildlife. However, the indirect mortality of wildlife produced by fragmentation and landscape effects due to the development of roads and railroads can be very large. For example, Paquet and Hackman (1995) cite Foreman (1992), who speculated that protecting habitat and landscape linkages for large predators would protect more 0than 90% of biodiversity, including ungulate prey species. Paquet's (unpublished) "preliminary analysis of niche overlap for 410 terrestrial vertebrates using the Central Rockies of Canada indicates that protecting the habitat needs of grizzly bear, lynx, and wolves will conserve habitat for 403 additional species" (Paquet and Hackman, p. 3). Consequently, the reader should maintain the perspective that direct and indirect mortality of wildlife due to roads and railroads are not separable: roads make it possible for vehicles to kill wildlife, and vehicles make it necessary to destroy and fragment habitat by building roads. Therefore, the Corps' estimates of wildlife mortality due to traffic should include the losses of wildlife that will occur due to landscape changes resulting from the creation and enlargement of highway and railroad corridors.

EFFECTS OF ANIMAL-VEHICLE ACCIDENTS ON HUMANS

1) A 1972 report estimated that in Colorado between 5,000 and 6,000 deer-vehicle accidents occur annually, and result in about 1.6 million dollars of property damage annually. In deaths of deer, they result in loss of between 5 and 10 percent of the annual legal harvest. The mean actual cost to repair 903 vehicles involved in collisions with deer during 1967-1969 being $293. (Pojar *et al.* 1972, cited in Leedy, 1975, p. 29.)

2) A 1975 review of the literature on highway-wildlife relationships (Leedy, 1975) cites a letter (May 8, 1975) and other information provided by Reuben M. Harding (Statistical Information Staff, Mathematical Analysis Division, U.S. Department of Transportation National Highway Traffic Safety Administration). For 1973, the number of human fatalities resulting from accidents involving the striking of animals (presumably, mostly deer), totaled 118 on or off roadways; 7,778 accidents resulted in injury to humans; and 65,381 accidents resulted in property damage.

3) A 1974 paper (Puglisi *et al.* 1974) stated that approximately 130,000 deer-vehicle collisions occur annually, resulting in national property loss in excess of $34,500,000. In Pennsylvania, deer-vehicle collisions increased 218% from 1960-1967, and 17 percent from 1967 to 1972, with a total of 26,435 accidents.

4) A 1977 study estimated that each deer-vehicle accident cost $730 (Hanson, 1977) (cited in (Cook and Daggett, 1995; Reed *et al.* 1982; Schafer and Penland, 1985).

   - Using this figure ($730/accident), Schafer and Penland, (1985) estimated that the 108 deer-vehicle accidents since 1977 on one 48-km stretch of a Washington state highway resulted in $82,000 in auto damages and six human injuries.

   - A 1980 report estimated 200,000 deer-vehicle accidents (Williamson, 1980), which, at $730/accident, is $146,000,000

5) Feldhamer *et al.* (1986) cite the following figures. A 1966 estimate of the number of deer killed nationally was 119,200. In 1974, state officials removed 146,229 deer carcasses from highways across the United States. A 1983 study (Hansen, 1983) estimated the average cost of a deer-vehicle accident as $650. “If the number of reported road-kills in 1983 remained at 1974 levels, the national monetary loss would be >$95 million.”

6) A 1995 report (Cook and Daggett, 1995) cites the following figures for personal injury and property damage from large animal/vehicle accidents.

A. In Virginia in 1990, in 3,427 reported deer/vehicle accidents that were studied, 242 persons were injured and 3 were killed. In 1986, Michigan reported 24,252 deer/vehicle accidents which resulted in 1469 injuries, 5 deaths, and $75 million in societal costs. Utah experience about 1 death for each 1,000 deer/vehicle accidents. The Fatal Accident Reporting System (FARS) of the National Highway Traffic Safety Administration reported 112 persons killed in large animal/vehicle accidents in 1993.

B. A study of moose-vehicle interactions on the Kenai Peninsula, Alaska (Del Frate and Spraker, 1991) estimated that the 1989-1990 kill of 366 moose resulted in two deaths and property damage averaging $4,000.

C. A study in New York that deer accidents caused an estimated average vehicle damage cost per accident of almost $900.

D. An insurance company survey in Wisconsin indicated that the average cost in 1992 to the vehicle and the driver for a deer accident was $1,241.

E. William Porter of Syracuse University estimates $2,000 as the average cost of a deer/vehicle accident.

F. The cost for a contractor to pick up a dead deer in Wisconsin averages $16.50 each or $310, per year.

G. Moose/vehicle accidents in Alaska cost an estimated $15,000 each in property damage and injury (Cook and Daggett, 1995).

H. The total cost in human injury and property damage for all animal/vehicle accidents is estimated (1995) to be about $1.2 *billion* per year (Cook and Daggett, 1995).

7) A Parks Canada (1981) study calculated the economic loss associated with the level of mortality reported in Table 7, in Canadian dollars, as:

Vehicle damage		
9,000 reported accidents @ 1,200 each		$10,800,000
37,000 unreported accidents @ assumed $100 each		3,600,000
Human Injury and Fatality		
17 fatalities @ $222,000 each		$ 3,700,000
1,000 injuries @ $2,500 each		$ 2,500,000
Hunting Losses		
Estimated 45,000 animals @ $1,000 each		$45,000,000
	Total cost	$65,600,000*

*Should the higher estimate of 90,000 animals apply the total would be $115,100,000.

8) During 1987 and 1988, in Newfoundland, 661/24,000 (3%) motor-vehicle accidents involved a moose; 133 people were injured and 3 died. A cost analysis (in Canadian dollars) of the initial emergency care and hospital admission showed: $48 as the cost of an emergency assessment, $69 as the cost of an emergency assessment with a cast or minor operative procedure, $25 for each radiograph, and $635 (ward) and $920 (intensive care) per day for patients who were admitted. The cost of operative treatment or follow-up was not included. For the two-year period, the Department of Heath estimated $19,000 to treat patients involved in a primary collision (i.e., caused by the moose) and $358,000 to treat patients in the secondary-collision group (i.e., caused by hitting something else after hitting the moose) (Rattey and Turner, 1991).

9) A 1991 report of moose-vehicle accidents in Newfoundland from 1983-1989 estimated that approximately $600,000 (Canadian) is lost in vehicle-destroyed moose, and vehicle damage is more than $1 million (Canadian) annually (Oosenbrug *et al.* 1991). The cost in human injury and lost life was not estimated.

10) Some papers dealing with cost-benefit analysis of vehicle-wildlife accidents are Langford and Cochera (1978) and Reed *et al.* (1982), and others are cited in Schafer and Penland (1985).

11) A 1976 study of deer-vehicle accidents in southern Michigan reported that in 332/1335 (2.49%) of accidents in 1967 the car was towed away. Of the 1,335 accidents in 1967, only 50 (3.7%) involved personal injuries. The total number of people hurt was 65; 12 accidents involved 1 injury to more than 1 person. Four accidents involved more than one car. Most injuries were due to secondary collisions. Three people died from secondary accidents caused by loss of control of the car. The percentage of accidents involving injuries increased with speed up to 96-111 km/hr, and the percentage of occupants injured increased up to 80-95 km/hr. These trends were expected to continue at higher speeds, but the data were not sufficient to reach conclusions. The dollar costs of these accidents were not calculated.

12) Minnesota is ranked sixth in the United States for deer/vehicle accidents, with rates of from 12,000 to 16,000 per year (Pafko and Kovach, 1996). The average vehicle damage is estimated to be $2,000 per accident and the recreational cost of a deer estimated to be $500, the road-kill of white-tailed deer in Minnesota is about $35,000,000 per year.

13) More than 24,000 deer-vehicle collisions (DVCs) took place in Ohio in 1996 (Wu, 1998). Ohio primarily uses deer warning signs to reduce deer-vehicle collisions. The effectiveness and economic efficiency of four mitigation approaches were determined for two stretches of highway (US-33 and US-50) in Athens County, Ohio. Deer value in terms of hunting recreation is

$182.54/deer (1996 costs), based on: (1) opportunity cost of time, transportation cost, lodging cost, supplies and other costs ($40.77/deer); (2) license cost ($86.71/deer); venison value ($55.06/deer).

DEER

This section is divided into the following topics: estimates of annual deer kills, ways to reduce roadkills, and factors associated with patterns of roadkill.

Estimates of Annual Deer Kills

1) In the first national survey of deer loss resulting from deer-vehicle accidents (1963), the deer loss was reported to be 71,073. By 1966, the 48 states reported the actual or estimated loss of deer to be 119,198, minimum count, because injured deer may die at some distance from the highway. Other big game animals killed in 1966 from highway accidents included 108 elk, 229 antelope, 37 bear, and 4 mountain lions. (Thompson, 1966, cited in Leedy, 1975, p. 28).

2) In 1974, state officials removed 146,229 deer carcasses from highways across the United States (Feldhamer *et al.* 1986).

3) It was estimated in 1980 that there were 200,000 annual deer-vehicle collisions on the nation's highways (Williamson, 1980, cited in Schafer and Penland, 1985).

4) Romin and Bissonette (1996) sent questionnaires to 50 state natural resource agencies in October 1992 requesting estimates of deer (*Odocoileus* spp.)killed annually on highways, the source of the estimates, and information about methods used to reduce vehicle collisions with deer; 43 agencies responded. Statistics on deer killed by vehicles were highly variable among agencies and were inconsistent among agencies. Despite a limited quantitative basis, the national deer road-kill for 1991 conservatively totaled at least 500,000 deer. Deer road-kills had increased during 1982-1991 in 26 of 29 states that had suitable trend data. Nearly all states had used some type of signs, modified speed limits, fencing, over- and underpasses, reflective apparatus, habitat alteration, or public awareness programs, but few agencies had evaluated performance of those techniques. Approaches that alter deer behavior and movement patterns appear to be the most fruitful for future application and evaluation.

5) A 1995 survey of 17 states (Cook and Daggett, 1995) reported 270,000 known deer kills, and estimated that an additional 20% (50,000) died off the roadway. "If this rate is the same for the uncounted states, the total number of roadkills of deer alone is more than ¾ million animals per year." Most states reported that deer road-kills have increased 30% to 50% in the past ten years. Michigan had the highest number of deer killed, and reported a 116% increase to 46,000 deer per year. The rate in Illinois increased 224% and in Iowa 75 percent. In Wisconsin, a 30% increase in deer kills reflects a

26% increase in the number of deer and a 39% increase in the total vehicle miles of traffic. In Pennsylvania, the deer population increased 30%, vehicle miles of traffic increased 40%, and deer road-kills increased 68%.

6) Collisions of cars with white-tailed deer (*Odocoileus virginianus*) were studied in southern Michigan in 1966 and 1967 (Allen and McCullough, 1976). Most of the 2,566 accidents studied occurred at dawn, dusk, or after dark with peaks at sunrise and 2 hours after sunset. Accidents were highest on weekends when evening traffic was greatest. A low seasonal peak in collisions occurred in May and a high one in November. Sex ratio of the annual kill was predominantly female, but it shifted in favor of males during seasonal peaks. Causes of the peaks seemed to be primarily rutting activities, with hunter disturbance and food of lesser importance. Accidents were related to habitat type approximately according to the prevalence of the type. Accidents were most common at speeds of 80-95 km/hr (50-59 mph) (42.8%), fewer at both 64-79 km/h (24.0%) and 96-111 km/hr (16.3%), and rare at other speeds (<11% 0-63 km/hr, and <8.7% ≥112 km/hr). The deer was killed in 92 percent of the accidents. Human injuries occurred in fewer than 4 percent of the accidents, and most resulted from secondary collisions.

7) Yearly totals of white-tailed deer killed by automobiles were compiled for a 13 year period (1960-1972) in a northern white cedar (*Thuja occidentalis*) deer wintering area in Upper Michigan's Mackinac County. The study area was bounded by the Pine and Carp Rivers on the north and south, respectively, and the Mackinac Trail and M-134 at the Pine River, on the west and east, respectively (Reilly and Green, 1974). Mackinac Trail, a two-lane highway (formerly US 2), intersects approximately a 5-mile stretch of this wintering area. In 1963, I-75 was constructed roughly parallel to US 2 and about 0.25 mile east of it and thus intersected the wintering area. In 1964, car-deer kills in the study area increased by approximately 500 percent over the average of the previous 4 years. This car-deer kill declined slightly through 1967, and has recently fluctuated about an average which is approximately twice that of the pre-Interstate yearly mortality figure. The increase in highway deer kills with construction of I-75 cannot be attributed to an increase in traffic since 1962, 2,300 vehicles traveled US 2 per day while 2,100 traveled I-75 per day in the study area in 1964. However, highway mortality before construction of I-75 was negligible. Average vehicle traffic counts are given for each year.

8) Using improved records and regression analysis, McCaffrey (1973) found that the numbers of road-killed white-tailed deer indexed deer population changes in Wisconsin between 1960 and 1970 (McCaffrey, 1973). Since 1966, annual summaries have been compiled showing the number of deer picked up from roadways in each county, and by management units. The number of road kills ranged from 3,046 in 1960 to 12,701 in 1967, and declined to 11,688 in 1970. Road-kill trends correlated extremely well with

trends in registered buck harvests. Hunter compliance with legally killed deer registration is believed to be over 95 percent. Buck harvests ranged from 32,838 in 1960 to 71,302 in 1967, and 50,308 in 1970. Only two ingredients are needed for a road-kill index: accurately reported road-kills and an estimate of percent change in annual traffic volume. Increased traffic volume has increased the number of road kills. Statewide estimates of total miles driven were used and the percent change assumed to reflect traffic for all counties. Total miles traveled increased 4% to 6% in most years between 1960 and 1970. A uniform 5% annual rate of increase was used. Each successive road-kill sample was adjusted for traffic volume by dividing by $(1.05)^n$, where n is the number of years since 1960. For example, a 1970 road-kill of 163 would adjust back to a 1960 equivalent of 100 or $163/(1.05)^{10}$.

9) Jahn (1959) graphically compared trends in Wisconsin deer road-kills (1946-1955) total deer harvested. Raw kill rates were corrected by total vehicle miles by region of the State (Table 3). Road-kill trends compared favorably with deer observations during hunting seasons, but the poor agreement between road-kills and harvest trends led to the conclusion that road-kills did not accurately reflect population trends. The statewide average deer kill rate computed from Table 3 is 1.32×10^{-7} deer/vehicle mile. Current averages for the UMRS states and Wisconsin are 5×10^{-7} and 8.54×10^{-7}deer/vehicle mile (**Error! Reference source not found.**). The rate of increase between 1948 and 1997 (49 years) is thus between 2.8% (UMRS rate) and 3.9% (Wisconsin rate) per annum.

Table 3. Annual change in reported deer road-kill in Wisconsin, 1948-1953 (from Table 3 of Jahn, 1959).

	Corrected Highway Deer Kill[1]						Change Between Years (%)				
	1948	**1949**	**1950**	**1951**	**1952**	**1953**	**1948**	**1949**	**1950**	**1951**	**1952**
NW	104	93	95	63	51	80	-11	+2	-34	-19	+61
NE	164	168	133	87	75	175	+2	-21	-35	-14	+133
W-C	214	204	153	145	173	223	-5	-25	-5	+19	+29
E-C	35	35	56	61	67	102	0	+60	+9	+10	+52
S	34	27	27	32	24	41	+21	0	+19	-25	+71
State	551	527	464	388	390	621	-5	-14	-20	+1	+60

[1]Expressed per stated vehicle miles each year: 500,000,000 used for the northwest (NW) and northeast (NE), 1,000,000,000 used for the west-central (W-C) and east-central (E-C), and 1,500,000,000 used for the southern (S) game area. Corrections are based on variations in traffic pressure in each game area and the entire state. Traffic-pressure records taken from Wisconsin Highway Commission (1949-1954).

10) Distribution and activity of white-tailed deer were studied on a 12.9-km sector of Interstate Highway 80 in a forested region ("Snow Shoe") of central Pennsylvania from May 1968 to May 1969 and on a 12.4-km agricultural section ('Berwick") of the highway from April 1968 to May 1969 (Carbaugh *et*

al. 1975). Observations of deer were made from a vehicle equipped with a spotlight for nighttime observing. Deer tended to move into study areas at dawn. Over 6,500 deer were observed and categorized as to location, behavior, sex, and age. Numbers of deer seen were related to time of day, topography, vegetation, traffic, and meteorological factors. Neither traffic volume nor weather correlated strongly with numbers of deer seen; spring and fall were times of great deer abundance in both study areas, but vegetation type and topography were more important factors in the forested area than in the agricultural area. Feeding behavior of deer in both areas dominated all other activities.

The impact of the highway itself on deer abundance and distribution and the relationship between deer activity and deer-automobile collisions are functions of highway location relative to deer requisites such as feeding and resting sites and to relative availability of feeding areas other than rights-of-way. In the Snow Shoe segment, the number of deer killed (286) (Bellis and Graves, 1971) was closely related to the number observed adjacent to the highway during the 7 months the two studies were concurrent; the correlation between deer killed per month and deer seen per month was 0.90 ($P < 0.01$), but there was no significant correlation between the number killed in each 61.0 m sector and the number observed per sector. During the same period, 40 deer were killed in the Berwick area. Most of the deer seen in the forested area were grazing on the highway rights-of-way; most of those seen in the agricultural areas were grazing in fields and rarely were seen on the rights-of-way. Deer tended to move into study areas at dawn.

No definite relationship was found between the number of deer sited and meteorological variables (temperature, wind velocity or direction, cloud cover, relative humidity, presence of moonlight). "Relationships between the number of cars, the number of trucks, or the total number of vehicles on the highway with the number of deer seen per run in either area were not significant ($P > 0.05$)."

11) During 14 months following the opening of an 8-mile section of I-80 in Pennsylvania in 1968, 286 deer were killed by vehicles (Bellis and Graves, 1971). Mortality among fawns and yearlings was not significantly different between the sexes, but among adults many more females than males were killed. Mortality was highest in the fall, high in spring, and low in summer and winter. The numbers killed per month were strongly correlated with the numbers seen grazing on the planted right-of-way. Mortality was highest in sections of highway that lay in troughs formed by steep median strips and steep right-of-way, where troughs ended by a lowering of the median strips, and through flat areas where both sides of the highway and the median strip provided good pasture.

The number of deer killed and the number seen on the right-of-way on runs were not correlated, suggesting that something other than deer abundance was the prime cause of mortality. The number of deer seen on the highway progressively decreased over time. The original survey before the 8-mile section was opened to traffic saw 13.7 percent of 1,227 deer observed on the highway traffic lanes (Peek and Bellis, 1969). Immediately after the highway opened in 1968, 4.2 percent of deer were on the highway traffic lanes (Carbaugh *et al.* 1975). In 1970-1971, there were 0.3 percent (Tubbs, 1972), and a few years later high traffic densities resulted in no deer seen on traffic lanes during 16 months and only six killed by traffic (Bellis and Graves, 1978). The ability of fencing along this stretch to reduce collisions with deer was also investigated (Bellis and Graves, 1978; Falk, 1975; Tubbs, 1972). The critical weakness is the underside of the fence, but many deer will cross a fully repaired and sealed 7.2-ft fence.

12) Bashore *et al.* (1985) evaluated 19 habitat and highway characteristics thought to influence numbers of white-tailed deer vehicle collisions along Pennsylvania two-lane highway. The significance of the factors was tested using stepwise logistic regression (kill site = 1, control site = 0). The model identified factors predictive of high deer kills at specific sections of highways. Two variables (in-line visibility and non-wooded) increased the probability of a section of highway being a high kill site. Seven variables (residences, commercial buildings, other buildings, shortest visibility, speed limit, distance to woodland, and fencing) decreased the probability. Removal of the variables speed limit and other buildings did not significant change the model. The model showed strong discrimination between high kill and low kill ("control") sections of highway.

13) Pennsylvania reported collisions of vehicles with white-tailed deer increased 218 percent from 1960 to 1967 and 5 percent from 1967 to 1971, stabilizing around 22,000 annually. This increase was likely due to an increase in the deer herd, an expanding highway system, and better reporting of deer-vehicle collisions. It is likely that these are low tallies of the actual number of collisions because these figures do not include injured deer that struggle or are thrown clear of the highway, and deer picked up by persons other than game protectors (Puglisi *et al.* 1974).

During 18 months (August 1970-January 1972), 874 white-tailed deer were killed by vehicles on the 313-mile (500-km) length of Pennsylvania Interstate 80 (Puglisi *et al.* 1974). Male and female mortality were generally similar; however, during December male mortality decreased while female mortality increased and during May and June there was an unexpected and unexplained increase in male mortality while female mortality remained essentially stable. The location of highway fencing was the most significant of the factors studied. Generally, high deer mortality occurred where the fence was located at the edge of a wooded area or within 25 yd (23 m) of the nearest wooded area. The lowest deer mortality occurred where the fence as located over 25 yd from the nearest wooded area. Low mortality also occurred where the fence was located within the woods. The effect of vegetation on deer mortality was significant only when fencing was absent.

14) Using data in Cook and Daggett (1995) and Romin and Bissonette (1996), I estimate the annual rate of increase in deer kills in the 32 years between 1963 and 1995 as 10[log(750,000/71,073)/32] = 1.0764, that is 7.64 percent per year. Figure 2 shows the relationships between year and both the reported and estimated total numbers of deer killed by vehicles. Although the reported data from 1963 and 1966 are for 48 states, the underestimate is small: the total number of deer reported killed in Alaska during the period 1982-1991 ranged from 51 to 77 per year (Romin and Bissonette, 1996).

The increase in the number of deer killed is largely, but not entirely due to the increase in the number of vehicles, and hence vehicle miles accumulated, each year. From 1980-1993, the total number of vehicle miles traveled (automobiles + buses + trucks) increased at approximately 2.2% per annum (table 986, Statistical Abstract of the United States 1996-1997) and about 45% of total highway mileage was rural during this period (table 987). Thus, if deer are only killed on rural highways, another estimate of the rate at which deer kill increased is 1 + 0.022/0.45 = 1.049. It was estimated that 200,000 deer were killed in 1980 (Williamson, 1980). Thus, the estimated number of deer killed in any year is $200,000/1.048^{(1980\text{-}year)}$. This equation underestimates the reported total deer kill from 1980-1995, and by 1995 the estimated value (404,000) is only 53% of the reported value (750,000). This result supports the conclusion of many independent studies that the number of vehicles is one factor in the increased rate of kill, the other primary factor being vehicle speed.

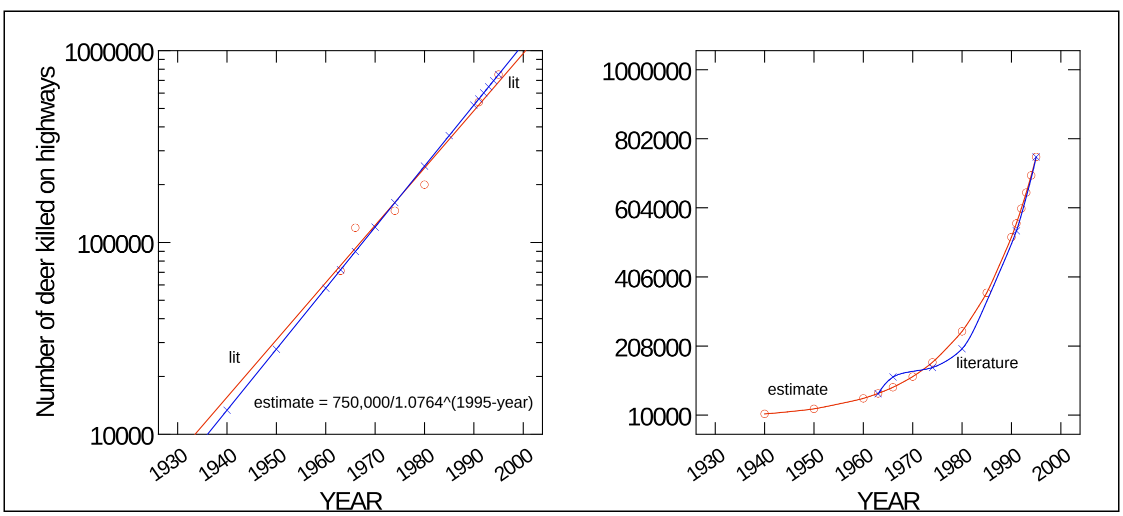


Figure 2. Reported (various studies) and estimated (Schaeffer, this report) numbers of deer killed on highways during 32 years, 1963 to 1995. The two plots show the same data using logarithmic (left) and linear (right) Y-axis.

15) Wu (1998, p. 46) noted: "Experts estimate that actual roadkill in most states is two times greater than reported."

Ways to Reduce Roadkill

16) Locations of white-tailed deer along a 41.4 km section of I-84 right-of-way in Pike County, Pennsylvania, were determined by radio telemetry and spotlight surveys (Feldhamer *et al.* 1986). Bucks crossed roads more often ($P < 0.05$) than does. Two of 22 radio-collared deer were killed by vehicles during the study period. Hourly telemetry fixes showed that deer movements were not oriented in any general pattern relative to a highway. During 36 spotlight surveys 2,045 deer sightings were made, of which 1,687 were on the I-84 right-of-way. More deer were on the right-of-way in fall than summer.

Most of the 100 road-kills recorded from 1981-1983 occurred in fall and winter. From 1976-1980, an additional 22 deer, which could be sexed, had been killed along the 2.7 m fenced location. A 2.7 m deer-proof fence reduced the number of deer on the right-of-way compared to an alternative 2.2 m (Type 4) fence, but it was not effective in reducing the number of road-kills. (In contrast to these findings, see (Puglisi *et al.* 1974), above.) More females ($N = 80$) than males ($N = 40$) were killed ($P < 0.01$). There was no significant relationship ($P > 0.05$) between road-kills and highway direction, habitat, topography, or fence placement. However, deer were killed more often than expected (50/216; $P < 0.01$) $\leq$0.48 km of an interchange. Management efforts to reduce the incidence of road-killed deer include increasing the effectiveness of deer fence by repairing holes and sealing the base, decreasing the incentive for deer to enter the right-of-way, and installing one-way deer gates (Reed *et al.* 1974).

17) A study at Crab Orchard National Wildlife Refuge, Illinois, (Waring *et al.* 1991) reported that the use of Swareflex Wildlife Highway Warning Reflectors did not change the deer road kills occurring between dusk and dawn, even though the deer population had decreased (Waring *et al.* 1991). The efficacy of Swareflex reflectors was evaluated by comparing the number of deer killed along roadways in the 2 years before and 14 months after reflector installation. “But annual variations of considerable magnitude exist in rates of deer-vehicle collisions, which obscure the relationship between reflectors and deer-vehicle collision rates are made over period of time” (Schafer and Penland, 1985).

18) Swareflex reflectors significantly reduced the number of deer killed by vehicles on a Washington state highway. (Schafer and Penland, 1985). Use

of an alternating present-absent study design compensated for the wide variations in rates of deer-vehicle collisions and allowed a statistical evaluation of reflector effectiveness.

19) Minnesota is ranked sixth in the United States for deer/vehicle accidents, with rates of from 12,000 to 16,000 per year (Pafko and Kovach, 1996). There was a dramatic reduction in the deer/vehicle accident rate after installation of Swareflex reflectors in the rural Minnesota northern coniferous forest (90%), central hardwoods (87%), and “farmland” (79%) habitats. In contrast, the four installations in the Twin Cities suburban metropolitan area (central hardwoods) all experienced an 87% average increase in the deer/vehicle accident rate after installation of reflectors.

20) Ungulate traffic collisions in Europe were evaluated (Groot Bruinderink and Hazebroek, 1996). They recommend a combination of fencing and wildlife passages for roads and railroads in Europe that have high traffic volume and speed. Secondary roads would have seasonal application of intermittently lighted warning signs triggered, if possible, by the ungulates. The need for a public relations/educational program is emphasized.

21) Calvo and Silvy (1996) studied alternatives to reduce the mortality of Key deer (*Odocoileus virginianua clavium*) along U.S. Highway 1 on Big Pine Key, Florida. A large portion of the overall deer population, which is estimated at about 250 to 300 deer, resides on Big Pine Key. From 1970 to 1992, a total of 1,923 mortalities was recorded of which 526 occurred along U.S. 1 on Big Pine Key. Road mortality contributes 75-80% of all known deaths, with an average of about 44 animals per year; since 1968 half of these occur on U.S. 1 (Drummond, 1989; Hardin, 1974; Silvy, 1975). Despite losses due to highway mortality, the Key deer population on Big Pine Key appears to have stabilized; however, current assessments of the population size are not available. The Key deer's small size (adult males average 80 pounds, 36 kg, and adult females 63 pounds, 28 kg, and fawns about 3.5 pounds, 1.5 kg, at birth), and color that tends to blend in with the environment, increases their susceptibility to highway mortality.

22) Wu (1998) reported that, of 404 DVCs in Athens County, Ohio in 1996, 389 resulted in vehicle damages and possible deer kill, and there were 15 nonfatal human injuries. In 1996, the 40 DVCs in 9 miles of highway 33 used for testing resulted in 24 deer kill, 40 vehicles damaged, and 2 human injuries. The economic damage was $140,784. The second testing section, on US 50, had 46 DVCs, killing 31 deer, damaging 46 vehicles, and causing 3 human injuries, at a cost of $187,088. The cost-benefit ratio of reducing DCVs in these sections were: Swareflex Reflector (11.81, 15.71), fencing (0.46, 0.61), underpasses (0.64, 0.85), and crosswalks (1.35, 4.81)

Factors Associated with Patterns of Roadkill

23) Traffic characteristics and vegetative and topographic features associated with mule deer kills on segments of 3 highways, totaling 47.3 km, (US 40 4-lane; SR 32 and SR 248 – 2 lane) in northeastern Utah, were evaluated (Romin and Bissonette, 1996). The number, and sex and age composition of road-kills were also compared to that of the living population observed during spotlight counts. From 15 October 1991 to 14 October 1993, there were 397 deer road-kills (4.2 kills/km/yr): 51.6% were does, 18.9% bucks, 21.7% fawns, and 7.8% could not be classified. Most adult kills (67%) were <=2.5 yr of age. Kill composition compared closely to spotlight counts. Of 1,515 spotlighted deer, 65.2% were does, 8.9% bucks, and 25.9% fawns. Spotlight density and deer mortality were strongly correlated from summer 1992 through summer 1993 (r = 0.94). Traffic conditions, topographic features, and vegetative characteristics contributed to mortality levels. Large drainages intersected highways in 78% of designated kill zones. Roads adjacent to agricultural areas along all routes sustained the fewest highway mortalities. Percent cover was higher (40%) in kill zones than in other areas (29%). Road-kills were highest along US 40 (68% year 1, 55% year 2), where traffic volume and speed were significantly higher than along either state route (Table 4). However, seasonal deer densities and highway mortalities were not significantly correlated.

Table 4. Traffic conditions and annual deer kill on 3 Utah highways (Romin and Bissonette, 1996).

		Speed (MPH)			Annual Deer Kill[1]	
Date (1992)	**Location**	**Mean**	**Maximum**	**Vehicles/hr**	**1991-1992**	**1992-1993**
11-15 March	US 40	69.3	76.0	172.2	189 (68%)	66 (55%)
	SR 248	56.9	72.0	37.9	50 (18%)	30 (25%)
	SR 32	54.0	68.0	17.3	39 (14%)	23 (19%)
29 June-5 July	US 40	58.9	68.0	264.6		
	SR 248	59.1	63.8	71.4		
	SR 32	55.0	68.0	37.8		

[1]Deer kill values are totals for the year.

24) Some authors have used road-killed deer and other species (Loughry and McDonough, 1996; Salwasser *et al.* 1980) to assess reproductive potential, herd size, and animal condition. Some of the papers cited below have also made use of deer-kill data for population or condition estimates, but no attempt was made to index papers for this topic.

25) Vehicle-deer collisions are not random in time or space (Allen and McCullough, 1976; Bashore *et al.* 1985; Bellis and Graves, 1971; Case, 1978). T. L. Bashore (Bashore, 1981, cited as unpublished in Bashore *et al.*

1985) examined reported deer kill for 18 states and 4 Canadian provinces and concluded that the monthly proportions of the yearly highway deer kill do not significantly change from year to year within a state or province. Rather, seasonal patterns prevail, with significantly more highway kills in spring and autumn.

26) Other studies of deer: (Adams and Geis, 1981; Evink, 1996; Leedy, 1975; Myers, 1969; Pojar *et al.* 1972; Williams, 1964).

MOOSE, ELK, AND OTHER UNGULATES

1) Several studies of big game have been carried out in Canada. The impact of collision on moose (*Alces alces*) population dynamics is unknown. Research of moose behavior in moose-vehicle and moose-train encounters is needed to understand the collision problem, the demographic implications of collision losses, and to enable the discovery of solution(s) to this management problem (Child *et al.* 1991).

   A. Railway accidents resulting in the fatality of big game may have a substantial impact on populations in the vicinity of the railroad right-of-way. An estimated 0.24 moose are killed each year per kilometer of track (Heerschap, 1982; cited in Muzzi and Bisset, 1990). Ontario rail personnel have estimated that 40-50 moose are killed each year on a 225 km stretch of track, which is 0.20 moose killed/km (cited in (Muzzi and Bisset, 1990). A study was made of the effectiveness of a commercially available wildlife warning device (Hobi Ultrasonic Whistle) when mounted on Canadian National Railway locomotives (Muzzi and Bisset, 1990). These trains cross the northwestern section of Ontario, where moose are the principle big game species. Trains with whistles hit and killed significantly fewer moose than those not utilizing the devices ($P < 0.05$). Also, the crew of locomotives with the devices attached took significantly fewer preventative actions to scare wildlife away from the tracks. Table 5 summarizes some of the wildlife data collected by train crews during 81 trips. Of the 227 animals encountered, there were 125 moose (55.1%), 90 deer (39.6%), 11 bear (4.8%), and 1 caribou (0.4%). With the device, 153/159 (96.2%) animals of all species ran away and 2/159 (1.25%) were hit and killed. Without the device, 52/68 (76.5%) animals ran away and 8/68 (11.8%) were hit and killed[1].

Table 5. Data for train crews running through Sioux Lookout between Armstrong and Redditt, Ontario from February 7 to June 14, 1989 (Muzzi and Bisset, 1990).

	With Device	Without Device	Total
Total Trips	42	39	81
Total Wildlife Seen	159	68	227
Total Kilometer	10,278	8,704	18,982
Wildlife Seen per Trip	3.8	1.7	2.8
Wildlife Seen per Km	0.015	0.08	0.012

[1] An exact Jonckheere-Terpstra test that the two populations ("with" and "without" device) have identically distributed outcomes ("ran away", "no reaction" and "hit and killed") is statistically significant $P < 0.0001$).

B. A minimum of 1,200 moose, approximately 10% of the provincial annual allowable harvest, may die on the highways and railways in British Columbia each year (Child *et al.* 1991).

C. Wildlife-train collisions are reported daily by Canadian National (CNR), Canadian Pacific (CPR) and BC Rail (BCR) and summarized monthly by the Wildlife Branch, Victoria. Collision reports give the accident date, species, number and sex of animals, and location to the nearest "mile post". From 1983 to 1990, 949 moose-train collisions were reported (Child *et al.* 1991).

D. From 1983-1987, total kills on all railways ranged from 40 to 100 moose annually, but this increased to average 200 moose annually from 1988-1990. Moose-vehicles collisions ranged from 111 in 1983 to 234 in 1990. Except for 1986 and 1990, the number of moose-vehicle collisions was fewer than 150 per year (Child *et al.* 1991).

E. The monthly pattern for vehicle-moose and train-moose collisions is similar, but off-set (Figure 3) (Child *et al.* 1991). Moose-vehicle accidents peak in December and January and moose-train accidents peak in January and February (54% of all reported collisions). Vehicle collisions may underestimate by two to six times the numbers of moose killed on the highways because some injured moose leave the site, or are quickly removed, salvaged, or scavenged. If so, road kills may number from 400 to 1200 moose annually. A minimum of 700 moose may die on the highways and 500 may die on the railways each year (Child *et al.* 1991).

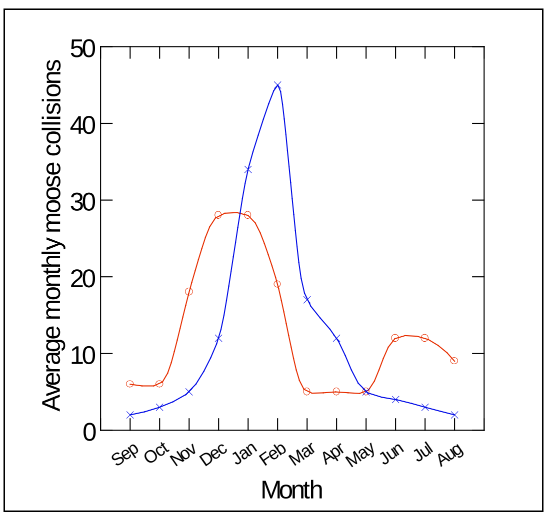


Figure 3. Average monthly moose collisions for the period 1983-1990 for automobiles and trains, as a monthly percentage of all accidents for each transportation type (from figure 3 of Child *et al.* 1991).

F. The numbers and rates of kill/year/1000 km were: CNR - 655 killed (69%), 39.8/yr/1000 km; BCR - 246 killed (26%), 1.48/yr/1000 km (BCR); and CPR – 48 (5%) killed, 3.1/yr/1000 km. These may reflect differences in the regions traveled by the railroads, numbers of trains, or train speeds, but no information is given. Reports of annual kills per 1000 km may be misleading because they include numerous kilometers of track in areas with relatively low numbers, so these ratios might minimize or mask impacts of rail kills on local moose populations.

G. Table 6 reports data from a 1981-1982 study of Canadian parks which summarized data on the numbers of animals killed, usually by species (Parks Canada, 1981). The data for Banff National Park come from the same data effort cited above for this park.

Table 6. Animal kills in Canadian Parks, 1970-1980 (Parks Canada, 1981).

Park	Comments
Terra Nova National Park, Newfoundland	Total of 110 moose and 2 black bear. In 1980, there were 11 moose mortalities, and this level of mortality is considered to have a significant effect on the population levels present in the park. Most accidents occurred June-October, and there were distinct early morning and evening peaks. The accidents occurred on the Trans Canada Highway, which has a design speed of 100 kph and carries up to 100 vehicles/hour during the dusk period.
Gros Morne National Park, Newfoundland	From 1975-1980, 11 moose were killed. Most collisions occurred between May and October, with 8/11 occurring on weekends. The highway has a design speed of 80 kph and carries 50-100 vehicles/hr during the evening hours.
Cape Breton Highlands National Park, Nova Scotia	From 1971 to1980, there were 62 white-tailed deer, 2 black bear and 1 moose killed. Most kills occurred from July to October, inclusive, and between 6:00 pm and midnight. The road has a design speed from 60 to 80 kph,. The east side carried 50-100 vehicles/hr during the evening hours in October and the west carried 10-15 vehicles/hr.
Kejimkujik National Park, Nova Scotia	From 1972-1980, 18 white tailed deer were killed, and most at night. The roadway has a design speed of 60 kph.
Fundy National Park, New Brunswick	From 1971-1980, 31 white-tailed deer and 8 moose were killed, most from June to September, and in the evening. The road has a low deign speed (60 kph), but carries “considerable” traffic, with evening peaks of 50-200 vehicles/hr.
Forillon National Park, Quebec	From 1973-1980, 10 moose, 5 white-tailed deer and 1 black bear were killed, most (15.16) from July to November, inclusive. Roadway design speed is 65 kph, and total traffic is 200 vehicles/day.
La Mauricie National Park, Quebec	The scenic parkway through the park was opened for its entire length in the fall of 1980, and there were no recorded kills of large mammals at the time of this study. The roadway design speed is 60 kph.
Riding Mountain National Park, Manitoba	From 1973-1980, 21 moose, 21 white-tailed deer, 12 elk, and 1 black bear were killed. The two distinct peaks are spring/early summer and in the fall. The major highway has a design speed of 80 kph and summer daily traffic volumes average 1,000 vehicle/day.
Prince Albert National Park, Saskatchewan	From 1973-1978, 4 moose, 1 elk, and 2 deer were killed. The major highway carries 300 vehicles/day.

Table 6. Animal kills in Canadian Parks, 1970-1980 (Parks Canada, 1981).	
Park	**Comments**
Wood Buffalo National Park, Alberta and Northwest Territories	From 1974-1980, 10 bison, 2 wolves, 1 moose and 1 bear were killed. The highway has a design speed of 90 kph, but traffic volume is 150 vehicles/day during summer and 40 vehicles/day during October-December when the fall peak in kills occurs.
Glacier/Revelstoke National Parks, British Columbia	From 1970-1980, 60 animals were killed on the highway and 7 on the railway. Killed were 29 black bear, 11 mountain goat, 9 moose, 6 mule deer, 2 white-tailed deer, 5 grizzly bear.
Jasper National Park, Alberta	From 1970-1980, there were 617 highway kills and 255 railway kills. In 1980, there were 70 highway and 30 railway. total kills by species for 1970-1980 were: 302 elk, 186 mule deer, 179 bighorn sheep, 72 moose, 60 coyote, 27 black bear, 17 white-tailed deer, and 15 grizzly bear. Significant impact on bighorn sheep, elk and moose populations have been estimated or determined. Total highway mortality for all species combined peaks from September to December, when traffic volumes are at their lowest. There were morning and evening peaks. There were no peaks in railroad mortalities.
Kootenay National Park, British Columbia	From 1970-1980, 252 large mammals were killed on the highway. The species were: 112 elk, 56 mule deer, 40 white-tailed deer, 18 bighorn sheep, 9 moose, 9 black bear, 8 coyote. Mortality peaks occur in the spring, summer and fall. Elk mortality peaks October-December, mule deer mortality peeks May-July, white-tailed deer mortality peaks in July. The roadway has a design speed of 90 kph and summer average daily traffic is 3,500 vehicles/day.
Pacific Rim National Park, British Columbia	From 1972-1980, 18 black tailed deer and 3 black bears were killed, all between April and October, with June being the peak month. The roadway has a design speed of 80 kph and a summer average daily traffic volume of 2,300 vehicles/day.
Wateron Lakes National Parks, Alberta	From 1975-1980, 35 mule deer, 3 white-tailed deer, 2 bighorn sheep, 4 elk, 2 coyote and 1 black bear were killed. Totals peak May-August, with July being the peak month. This coincides with the peak traffic period.
Yoho National Park, British Columbia	From 1970-1980, 180 elk, 47 mule deer, 16 moose, 16 coyote, 16 black bear, 12 white-tailed deer, 4 grizzly bear, and 2 mountain goats were killed. In 1980, 1/23 kills were on the railway. The highways design speed is 100 kph, and carries 6,500 vehicles/day. During the fall period in the evenings, when the majority of the elk kills occur, traffic volumes are 100-200 vehicles/hour. Highway kills are distributed throughout the year with a small peak in November and December. Railroad kills occur mainly during the winter months.
Banff	During the period 1970-1980, a total of 1,191 mortalities were recorded; 921 on highways and 270 on railways (80% are elk). For all species combined, kills peak in the 6 a.m. to 8 a.m. and 6 p.m. to midnight periods. Species were: 543 elk (highway kills peak October to December, railway kills peak in winter); 310 mule deer (mostly vehicles, peaks from May to June; railway kills rare); 96 bighorn sheep (mostly vehicles, railway kills rare); 79 moose; 79 coyotes; 38 white-tailed deer (mortalities occur June-November); 32 black bear (definite July/August peak); 9 grizzly bear.
Elk Island National Park, Alberta	Between 1977-1981, a total of 12 large mammal roadway mortalities, an average of 2.4/yr. Species were: 7 bison, 2 moose, 2 deer, 1 elk.

H. A nontechnical article reported that use of fences and underpasses reduced road kills of elk along a four-lane highway through Banff National Park (Leighton, 1988). From 1945 to 1963 (the year following completion of the Trans-Canada Highway), only 29 road kills were recorded. As traffic volumes and speeds increased, the number of kills rose to 139 in 1978, of which there were 54 mule deer, 47 elk, 11 big-horn sheep, 11 coyotes, 2 grizzly bears, and a great horned owl. In 1985, following installation of fencing and over- and underpasses, 64 elk (5% of the late winter population of the Bow Valley) were radio-collared and tracked for the next three years. The animals learned to use the over- and underpasses. For example, one animal crossed the highway one-tenth as often as she did before the fences were built. No mortality data are given, but computer projections show that the population will increase for a few years (beyond 1988) and then level off.

I. A study of Canadian parks (Parks Canada, 1981) determined the number of accidents involving animals, and the numbers of humans injured and killed in these accidents are summarized in Table 7.

Table 7. Number of accidents with domestic and wild animals, personal injury, and death, in Canadian Parks 1975-1979 (tables 4.2.1-4.2.2 of Parks Canada, 1981).

Province	1975	1976	1977	1978	1979
1. Nova Scotia[1]	267	319	379	507	528
2. Nova Scotia[2]	11	16	17	24	34
3. Nova Scotia[3]	2	0	0	0	0
4. New Brunswick[1]	248	219	274	348	403
5. Quebec[1]		824	913	1051	1032
6. Quebec[2]		74	80	124	124
7. Quebec[3]		6	1	6	6
8. Ontario[1]	2159	1792*	1879	1361	1460
9. Ontario[2]	265	192	211	229	196
10. Ontario[3]	7	1	2	2	1
11. Saskatchewan[1]		1642	1837	1843	2662*
12. Saskatchewan[2]		75	68	52	127
13. Saskatchewan[3]		1	0	0	5
14. Alberta[1]				1849	2037
15. Alberta[2]				111	118
16. Alberta[3]				2	1
17. British Columbia[1]		1056			
18. Manitoba[1]			1237	948	
19. Manitoba[2]				70	

*Due to changes in reporting procedures, these figures are not comparable to previous years totals.
1,2,3: 1 = number of accidents, 2 = number of personal injuries, 3 = number of deaths.

J. A moose carcass census along a 210 km section of the CNR railway in the Skeena region (Canada) concluded that CNR reports document only 58% of actual kills (Child *et al.* 1991) For instance, in 1986, CNR reported a total of only 36 moose collisions. However, Marshall (Marshall, 1987) estimated 106 kills had occurred in the Skeena region, while CNR had previously reported 62 fatalities along the same section. Consequently, biologists estimate that a minimum of 500 moose may be killed on the railways annually.

K. Bertwistle (1998) discussed methods used to reduce wildlife-vehicle accidents in Jasper National Park (JNP). A GIS-based system has 2500 data points for highway and railroad wildlife-vehicle collisions from 1951.

L. Kerr (1998) presented mortality data for wildlife along highway 93 south, 10 km of which is in Banff National Park and 98 km is in Kootenay National Park. Accident data from the BC Ministry of transportation and Highways (BCMoTH) and the Parks Canada database were used. Accidents involving damages of $1,000 or personal injury wind up in the BC database. All accidents involving wildlife, regardless of damage or injury, are in the Parks Canada database. From 1988-1994, BCMoTH recorded 160 incidents (Table 8) and Parks Canada recorded 312 wildlife traffic accidents (Table 9). Except in 1990, the ratio of the number of accidents using BCMoTH records to the number of mortalities using park records is about 0.5. (The ratio in 1990 is 1.13, which suggests either reporting errors in the databases or a tabulation error in Kerr's paper.)

Table 8. Kootenay Parkway accidents involving wildlife from 1988 to 1994 using BC MoTH records (Kerr, 1998).

Type of accident data	Year							
	1988	1989	1990	1991	1992	1993	1994	Total
Number of accidents	33	21	36	21	28	20	20	179
Number of injuries	1	3	9	7	4	1	2	27
Number of damaged vehicles	32	19	30	16	24	20	19	160

Table 9. Kootenay Parkway wildlife mortalities from 1988 to 1994 using Park records (Kerr, 1998).

Species	Year							
	1988	1989	1990	1991	1992	1993	1994	Total
Elk	18	4	5	11	14	5	9	66
Mule deer	15	9	4	3	4	3	1	39
White-tailed deer	22	16	17	17	19	17	25	133
Moose	4	1	3	3	4	6	4	25
Bighorn sheep	4	6	0	4	1	3	3	21
Black bear	0	0	2	0	2	2	2	8
Coyote	8	4	1	0	3	3	1	20
Year totals	71	40	32	38	47	39	45	312

2) The number of moose killed annually in collisions along Norwegian railroads averaged about 500 in the late 1980's, representing 2% of the total annual hunting bag (25,000 moose) in the same period (Jaren *et al.* 1991). Most kills occur in winter (November-April), and peak December-February. Consequences for management of local and regional moose populations can be considerable in certain areas where collisions are concentrated. In the period 1980-1988, a field experiment was carried out in order to test a conflict reducing method. The total numbers of moose killed were recorded in the first 4-year period in the treated (87 kills, 22 km; 3.95 kills/km) and control sections (47 kills, 38.8 km; 1.2 kills/km), and in the treated (22 kills; 1.0 kills/km) and control (27 kills; 0.7 kills/km) sections following vegetation removal in the treated sections in the second 4-year period. A bootstrap method was used to estimate the effect of method, and cost-benefit method was used to estimate the profitability of vegetation removal along the Norwegian railways. Bootstrapping showed vegetation removal in a 20-30 m wide sector on each side of the railway line caused a 56% (±16%) reduction in the number of train kills. Benefits exceed cost of removal of vegetation where the annual number of collision is higher than 0.3/km.

3) The effects of environmental conditions during winter on moose-train collisions was investigated along a 92.2 km section of the Nordlandsbanen railway, in Norway between 1980 and 1988 (Andersen *et al.* 1991). The total number of train kills was 262 (average = 0.36 kills/yr/km), and ranged from 8 to 71 kills/yr (0.09 to 0.77 kills/yr/km) Mean winter snow depth explained 84% of the annual variation. A high proportion of moose were killed when snow depth exceeded 100 cm. High ambient temperatures reduced the risk of collisions, while low temperatures had the opposite effect.

4) Several studies have been carried out of moose-train and moose-vehicle kills in Alaska.

   A. A workshop (Schwartz and Bartley, 1991) was held to address the problems of road and railroad mortality of moose in Alaska. Most road and railroad kills of moose occur during the winter months of December through March (Modafferi, 1991; Schwartz and Bartley, 1991). Extreme snow depths during the winter of 1989-1990 forced moose to use road and railroad rights-of-way.

   B. There were 731 moose killed along the railroad and 665 killed along roads in south-central Alaska, almost twice the usual number (Schwartz and Bartley, 1991). From 1963 to 1990, the Alaska Railroad recorded 3,054 moose-train collisions along 756 km of railway (0.14 kills/yr/km); there was a positive correlation between snowpack depth and train moose-kill (Modafferi, 1991).

C. During the winter of 1987-1988, 173 moose were killed by trains in Game management Unit 14 B, a 5594 km^2 area in south central Alaska. In comparison, 40 moose were killed by automobiles and 140 were killed by hunters (Grauvogel, 1990; cited in Becker and Grauvogel, 1991). Record snowfalls in the winter of 1989-1990 resulted in 351 moose killed by trains, 47 by automobiles, and 173 by hunters (Becker and Grauvogel, 1991).

D. An experiment was conducted to test the effect of track site, train speed, direction of train travel, and train run (first versus second round trip of the day) on moose-train collision mortality along the Alaska Railroad in the Lower Susitna River Valley (Becker and Grauvogel, 1991). Reduction of train speed from 79 km/hr to 40 km/hr did not result in a significant reduction in the number of moose hit by trains ($P > 0.4$). Significantly more moose were hit in the northern test section than along the southern test section of track ($P < 0.1$) of the Alaska Railroad. This study, and others, found that moose have a strong tendency to stay on the tracks when fleeing trains when there is snow on the ground.

E. Survival and cause-specific mortality rates were determined for 51 radio-collared adult female moose on Kenai National Wildlife Refuge (KNWR), Alaska from 1980 to 1986 (Bangs *et al.* 1989). The mean annual survival rate was 0.92; collision with a vehicle was the primary cause of death (0.04/yr). Other mortality factors were natural accidents (0.01), old age (0.01), brown bear (*Ursus arctos*) predation (0.01), and hunting (0.01). Moose wearing non-functional collars died from poaching, vehicle collisions, starvation, and unknown causes. Collared moose were not killed by wolves (*Canis lupus*) although wolves were common. Survival rates were unaffected by area, year, or season and only decreased slightly as moose aged. Human-caused mortality was associated with roads, occurred at nearly twice the rate reported to authorities, and appeared non-selective to moose age or condition. Adult female moose survival was enhanced by restricted harvest and wolf control and was not limiting growth of the moose population on the Kenai lowlands.

F. A study of moose-vehicle interactions was carried out on the Kenai Peninsula, Alaska (Del Frate and Spraker, 1991). Access to the Kenai Peninsula is primarily along 1,450 miles of state-maintained roads and 2-lane highways, in addition to city and borough roads. Moose road-kill information was presented for the years 1977-1991. Mean numbers of moose killed were 111.7 ± 19 for 1977-1982 and 216.3 ± 25 for 1984-1989. The 1989-1990 kill of 366 moose was extremely high because of severe winter conditions and high moose concentrations along highways. Property damage was high, averaging $4,000 at one auto body shop, and 2 human lives were lost. A public awareness program was initiated in October 1990 to increase the understanding of potential hazards of encountering moose on Peninsula roads and to reduce moose road-kills. Figure **4** shows the percentage of road-kills of moose by month (K), monthly average daily traffic (MADT) volume on the Kenai Peninsula, Alaska 1989-1990 (T). The ratio of percent-kills to MADT is not constant but varies with month according to the percent killed (dashed line).

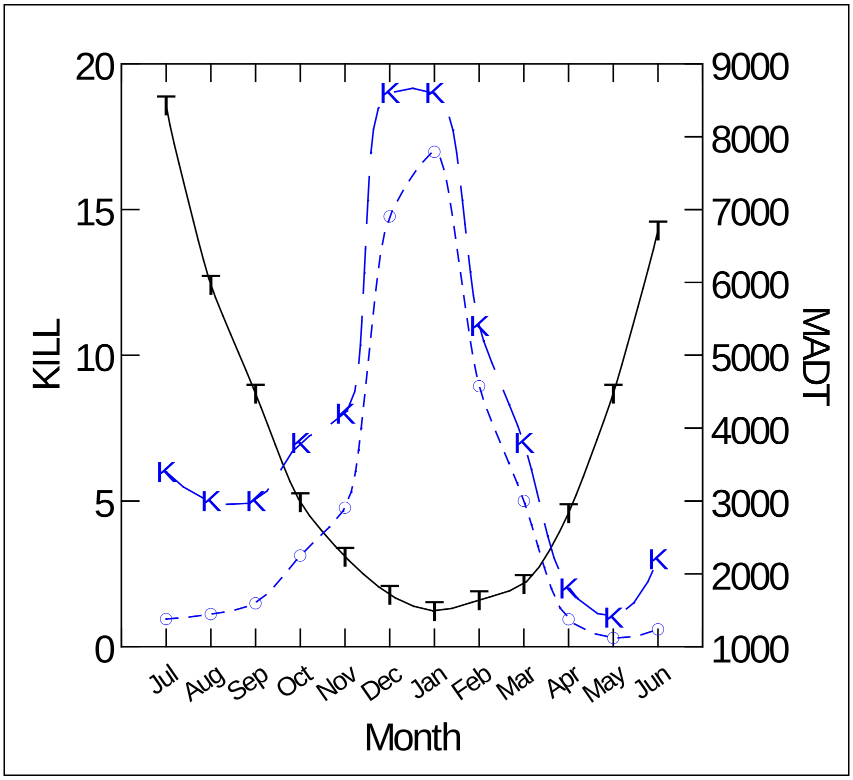


Figure 4. Percentage of road-kills of moose by month (K), monthly average daily traffic (MADT) volume on the Kenai Peninsula, Alaska 1989-1990 (T), and the ratio of kills to MADT (dashed line, ratio×1000). Modified from (Del Frate and Spraker, 1991).

G. Moose-vehicle collisions on Newfoundland highways increased 6% annually, from 228 in 1983 to 432 (89%) in 1989, an increase from 2.3% to 2.9% of total accidents between these years (Oosenbrug *et al.* 1991). The increase in moose-vehicle collisions has been partially attributed to greater traffic speeds, more vehicles, and an increase in truck transport brought on by the closing of the Newfoundland railway in 1987. The best predictor of moose-vehicle collisions was the number of registered vehicles, accounting for 58% of the variation. The largest contributing factor is a 26% increase in moose numbers, especially in areas traversed by roadways. In 1990, 4 people were killed in collisions with moose. Approximately $600,000 is lost in vehicle-destroyed moose, and vehicle damage is more than $1 million annually; the cost of human injuries and loss of life cannot be evaluated in dollars.

H. A study along mileposts 132 to 140 of the Glenn Highway in Alaska (McDonald, 1991) reported that 6 of 66 moose tagged during the period 1986-1987 were struck by highway vehicles, 3 of which were within a study area having fences, an underpass and one-way gates. During the period from 1977 through 1986, highest cumulative mortalities (Figure 5) were in October and December (51 each), and the lowest was in April (8).

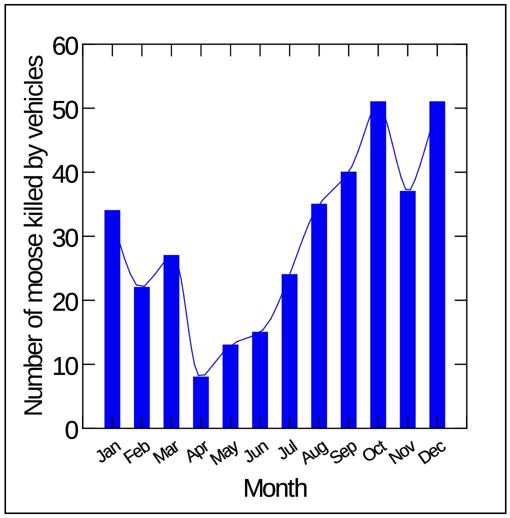


Figure 5. Total number of moose killed by month within the Glenn Highway, Alaska project area from 1977 through 1986 (McDonald, 1991).

5. Pronghorn antelope (*Antilocarpra americana*), mule deer (*Odocoileus hemionus*), and elk (*Cervus canadensis*) are affected by right-of-way fences and highway traffic (Ward *et al.* 1976). Interstate 80 passes through the winter range of approximately 900 elk, 600 mule deer, and 1,000 antelope (1973-1975 averages) (1973-1975 averages). During construction of a 55-mile (88.5 km) section of I-80 west of Laramie, Wyoming, 16 mule deer were killed by construction activities (1967-1969). In the 5.5 year period (1969-1975) following the opening of this stretch, at least 153 antelope (0.31/km/yr), 561 mule deer (1.15/km/yr), and 10 elk (0.02/km/yr) have been killed by vehicles. The average daily traffic over three years was 4,231 vehicles with at least 15% consisting of large trucks. The normal heaviest traffic occurred during August (7,584) and the lowest in January (2,012). The highest mortality occurs during fall and spring migrations. During the fall migration, 30% of the accidental deer mortality was fawns, but in the spring only 7% were fawns. Because antelope are reluctant to jump fences and use underpasses, I-80 is a barrier and the herds are managed accordingly. Antelope can be kept off of, or prevented from going over, the right-of-way fence. Mule deer jump right-of-way fence, but can be forced to use

underpasses by using deer-proof fencing. Both resident and migratory mule deer are affected by roads and traffic.

6. In Oregon, 179 of 752 marked mule deer died over a period from June 1960 to October 1963. Five of the 179 (2.8%) were killed by automobiles, compared with 126 (70.4%) taken legally by hunters. (Zalunardo, 1965) cited in (Leedy, 1975), p. 29.)

7. A study of mortality of northern Montana pronghorn antelopes concluded that malnutrition was a principle cause of death, but at least 300 pronghorns had been killed along railroads and highways in that area (Martinka, 1967).

8. Woods and Munro (1996) state that most kills along the Canadian Pacific Railroad (CPR) occur in the winter, but road-kills peak on the Trans Canada Highway (TCH) are in spring and autumn. Of the large mammals, elk are the principle road-kill species in the Rocky mountains and black bears are the most frequent road-kills in the Columbia mountains.

9. Other studies of moose-vehicle and elk-vehicle collisions include: Adams and Geis, 1981; Erriksson *et al.* 1985; Oosenbrug *et al.* 1986; Rattey and Turner, 1991; Singer and Doherty, 1985.

10. During the 8 year (1989-1996) study period, 939 large mammals (adults attain a weight of ≥13.6 kg) were killed by vehicles on roads within Yellowstone National Park (Gunther et al., 1998). Elk (n=375, 40%) and mule deer (n=286, 30%) were the species most often killed by vehicles on park roads. Other species killed on park roads included bison (n=79, 8%), moose (n=76, 8%), coyote (n=66, 7%), antelope (n=19, 2%), beaver (n=11, 1%), whitetail deer (n=9, 1%), bighorn sheep (n=5, <1%), black bear (n=5, < 1%), bobcat (n=2, <1%), grizzly bear (n=2, <1%), raccoon (n=1, <1%), and wolf (n=3, <1%). The number of road-kills per year were 97, 102, 121, 110,110, 148, 120, and 131. The proportion of the park's large mammal populations killed by vehicles each year was estimated. Overall, vehicle-caused wildlife mortality does not appear to have a significant negative impact on large mammal populations in the park. The speed of vehicles was the primary factor contributing to vehicle-wildlife collisions. Most wildlife species were killed significantly more often in non-forested cover types than in forested types. Wildlife species with the highest population numbers were also the species most often killed by vehicles.

OTHER MAMMALS

1) A 1996 report examined the effects of transportation corridors on large carnivores in the Bow River Valley, Alberta, Canada (Gibeau and Heuer, 1996). The authors state that transportation routes have affected large carnivores throughout North America. The literature varies with regard to the amount of displacement and other impacts, but there is irrefutable evidence that roads and their associated disturbances reduce habitat effectiveness resulting in reduced fitness and increased risk of mortality. Highway and railway mortality of large carnivores in the Bow River Valley, Alberta, 1985-1995 are given in Table 10.

Table 10. Highway and railway mortality of large carnivores in the Bow River Valley, Alberta, Canada, 1985-1995 (Gibeau and Heuer, 1996).

Species	Inside Banff National Park		Outside Banff National Park		Total
	Highway	Rail	Highway	Rail	
Coyote	117	7	39	1	164
Black bear	12	5	8	2	27
Cougar	1	0	2	0	03
Grizzly bear	1	0	0	0	1
Wolverine	2	0	0	0	2
Lynx	0	0	4	0	4

2) Rolley and Lehman (1992) reported on relationships among raccoon (*Procyon lotor*) road-kill surveys, harvests, and traffic in Indiana. From 1966-1985, 13,777 road-killed raccoons were observed during 19,844,007 km of travel. The statewide mean March index peaked in 1968 at 7.3 raccoons/10,000 km and then gradually declined to a low of 1.1 in 1981. From 1981-1985, the March index increased slightly. Both the July and August indices peaked in 1974, with 22.0 and 12.2 raccoons/10,000 km, respectively. The July index reached a low of 5.7 in 1978, and the August index was lowest (3.5) in 1979 and 1980. The statewide March road-kill index was not positively correlated with traffic volume (1-tailed test, $N = 17$, $r = -0.473$, $P = 0.9$). The road-kill index during March was correlated with speed of passenger car ($N = 20$, $R = 0.7$, $P = 0.001$). Average car speed declined sharply after imposition of the 89 km/hr speed limit in 1973.

3) Loughry and McDonough (1996) collected 3 years of data on road-killed and adjacent live-caught nine-banded armadillos (*Dasypus novemcinctus*) along a 5 km stretch of road in Florida. There were no differences in sex ratios or the reproductive condition of adult females. However, there was a significant difference in the age structure of the two groups, with almost no juvenile road kills. The age structures, but not sex ratios or proportion of females in each reproductive condition, differed. The results indicate that adult armadillos are

more at risk from automobiles than are juveniles. Adult male and female armadillos are equally likely to be killed by automobiles. Because of the long-term nature of the study, the cumulative record of live captures (186 total, 126 adults) represents a nearly complete census of all the individuals in the population, and the sample of road kills (27 total, 23 adults) is a complete record of all animals hit by automobiles during the summers. Traffic data were not collected and these data cannot be used to estimate the number of deaths per km-traveled.

4) The Tanzania-Zambia highway crosses Mikumi National Park over a stretch of 50 km. Drews (1995) reported that vehicles killed 183 mammals, birds, and reptiles killed within the park boundaries between May 1990 and November 1991. The road-kill rate was estimated to be a minimum of 3 per day (21.8 road kills/km/yr). This was an increase from previous, and was attributed to higher average driving speeds following road improvement.

5) A 14-month survey on foot on each side of a 1.6 km (1 mile) stretch of dual lane highway provided 188 vertebrate (Table 11) and 1,162 invertebrate victims (Seibert and Conover, 1991). Of the invertebrates,1,069 were insects (at least 249 species belonging to 84 families, 48 were spiders, 213 were Lepidoptera, and the remainder were worms, myriapods, harvestmen, and snails. No attempt was made to extrapolate or quantify the data in terms of numbers/km highway.

Table 11. Vertebrate road-kills on an Ohio highway (Seibert and Conover, 1991).

Mammals	**N**	**Birds**	**N**	**Reptiles**	**N**	**Amphibians**	**N**
Didelphis virginiana	19	*Coccygus americanus*	1	*Sternotherus odoratus*	1	*Notophthalmus viridescens*	16
Blarina brevicauda	1	*Otus asio*	2	*Terrapene carolina*	9	*Eurycea longicauda*	3
Eptesicus fuscus	1	*Zenaida macroura*	1	*Chrysemys picta*	1	*Bufo fowleri*	9
Felis catus	2	*Columba livia*	1	*Lampropeltis triangulum*	1	*Bufo americanus*	5
Procyon loto	18	*Sturnus vulgaris*	4	*Elaphe obsoleta*	1	*Bufo* sp.	1
Marmota monax	18	*Vireo olivaceus*	1	*unidentified*	1	*Rana palustris*	11
Sciurus niger	5	*Dumetella carolinensis*	2			*Rana catesbeiana*	1
Sciurus carolinenis	2	*Oporornis formosus*	1			*Rana sylvatica*	1
Peromyscus sp.	1	*Passerina cyanea*	1			*Rana* sp.	1
Sylvilagus floridanus	7	*Spinus tristis*	1			*Hyla crucifer*	12
Odocoileus virginianus	1	*Cardinalis cardinalis*	1			*Hyla chrysoscelis*	104
unidentified	4	*Corvus brachyrhynchos*	2			unidentified	10
		unidentified	3				
Total	**79**		**21**		**14**		**74**

6) According to Cook and Daggett (1995), there are no statewide or national figures available for the number of small animals killed on the highways. In a 14 county study in Virginia, the ratios of small animals killed to deer-killed

were: opossum 0.95, dogs 0.88, raccoons 0.76, cats 0.65, skunks 0.26, and rabbits 0.20. The ratios imply that if nationally there are $^{2}/_{3}$ to ¾ million deer killed every year on highways, tens of millions of smaller animals and birds are killed by motor vehicles.

In 1981, the report *Effects of Highways on Wildlife* (Adams and Geis, 1981) included national road-kill data. The study included selected areas in the southeast, midwest, Oregon, and California in June of 1978. In this study, "large mammals" were defined as species at least as large as chipmunks, and included specifically deer, elk, rabbits, hares, furbearers, porcupines, chipmunks, tree squirrels, ground squirrels, mountain beaver, moles, and gophers. There were the following road-kill ratios on interstate highways compared to country roads (Table 12):

Table 12. Road-kill ratios on interstate highways compared to country roads in June of 1978 (Adams and Geis, 1981; Cook and Daggett, 1995).

Type of animal	Interstates, %	Country Roads, %
Amphibians & reptiles	13	47
Birds	54	32
Large animals	14	12
Small animals	17	12
Other	1	1

7) Several studies in England and Scotland by Trewhella and Harris (1990)and others evaluated the effect of railway lines on urban fox (*Vulpes vulpes*) numbers and dispersal movements. None of the studies evaluated mortality due to trains. Railway lines may influence the movements of individuals within their home ranges but have little effect on the distance or direction of dispersal movements.

8) Buchanan (1987) documented seasonal variation in the number of long-tailed weasels (*Mustela frenata*) apparently killed by automobiles. Between 1982 and 1986 17 dead long-tailed weasels were found along highways and secondary roads with speed limits ranging from 35 to 55 mph in lowland areas of western Washington. All kills occurred between 26 May and 3 August, the breeding season, but not in other months. Traffic information and highway lengths are not provided.

9) The first major survey of road-killed animals in Denmark (Aaris-Sorensen, 1995) was conducted in 1991 (by "Falck", the Danish Rescue service). A total of 777,000 animals were killed in 1991. More than 3,600 badgers (*Meles meles*), equal to 10-15% of the badger population, had been killed. In 1992 and 1993, Falck continued the survey of road-killed animals on 90 chosen road stretches, representing different types of roads over the whole

country. A total of 1,800 km, equal to 2.5% of the total road system, was surveyed. Road-killed badgers were logged in 1992 (109) and 1993 (172). Most badgers were killed during the summer when traffic intensity was highest, but there is not a simple relationship between car traffic and the number of badgers killed. The traffic victims were unevenly distributed across the country. This is not explained by differences in local traffic intensities alone, but also by differences in population density of the badger and the surroundings of the roads. Almost all road-killed badgers in 1992-1993 were adult, and female badgers were killed most frequently during spring whereas male badgers were killed throughout the year. The left side of Figure 6 plots the road-kill and traffic data from figure 2 of Aaris-Sorensen (1995). From these data, the numbers of badgers killed per 10^6 km traveled were calculated (right side of Figure 6). The minimum kill (20×10^{-6}) occurred in December and January, the maximum in June (190×10^{-6}), and the median ($80\text{-}90 \times 10^{-6}$) in April and September. For comparison, our estimate of the rate of deer kill in the UMRS states is 1 per 2×10^{-6} miles = 1 per 1.2×10^{-6} km, which is one-fortieth the median for the badger kills.

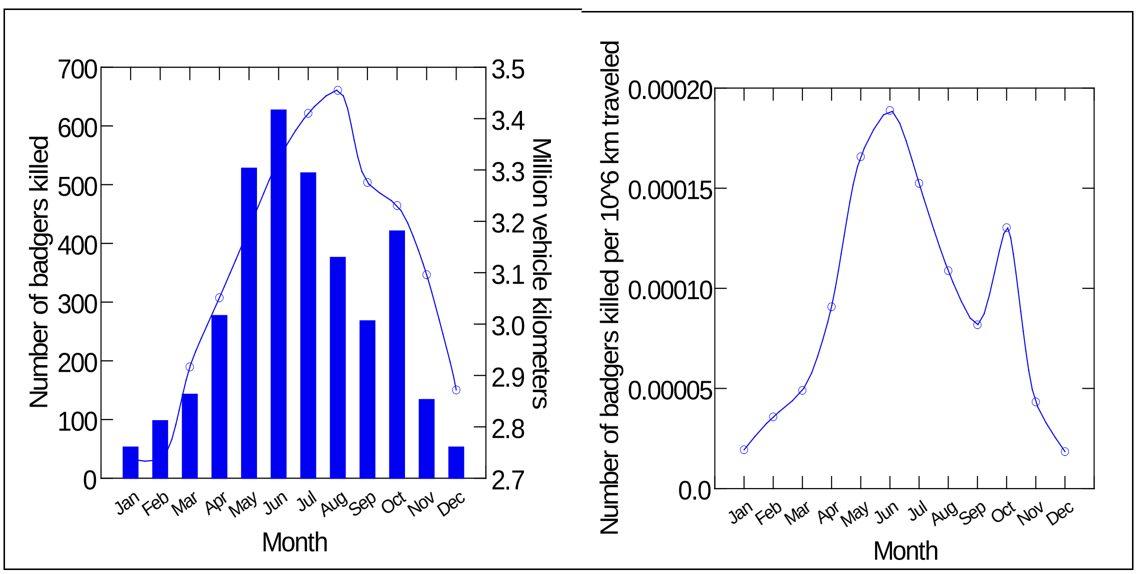


Figure 6. Monthly badger kills and total road traffic in The Netherlands in 1991. Left, from figure 2 of Aaris-Sorensen (1995). Right, values expressed as monthly variability in badger kills per 10^6 km traveled (Schaeffer, this review).

10) Badgers have been the focus of several studies:

- In the Netherlands, 220 badgers, equal to 10% of the total population, were killed by cars in 1990 (Wiertz, 1993).

- In Britain, 50,000 badgers, equal to 20% of the total population, are killed on the roads and road-kills are the greatest single known cause of badger mortality (Harris *et al.* 1992).

- Data from 984 road-killed badgers collected in the south of England during 1984 show a bimodal distribution of mortality of both sexes, with peaks in mortality occurring in spring and late summer (Davies *et al.* 1987). There was no significant difference between the total number of males and females killed, and no difference in the seasonal distribution of deaths between the two sexes. Nor was there evidence that dispersal of young animals contributes to either of the seasonal peaks of mortality. The seasonal peaks in mortality reflect increased activity in conjunction with mating.

- Other studies of badgers: (Gallagher and Nelson, 1979; Jefferies, 1975; Killingley, 1973; Long and Killingley, 1983; Neal, 1977).

11) Several studies evaluated the interaction of wolves with roads. Most studies were concerned with the effects of roads on habitat usage, and are not considered in this review. A few studies have reported mortality data.

A) de Vos (1949) reported that from March 1, 1947 to March 1, 1948 "not less than fourteen timber wolves and seven coyotes were run down by cars" in Northern Ontario. He suggested that the increased number of wolves killed by vehicles were possibly due to changes in wolf behavior or population pressure, in addition to "an increase in the speed of travel of cars and an increase in the numbers of cars on the northern highways."

B) In March 1974, Weise et al. (1979) released two male and two female eastern timber wolves (*Canis lupus lycaon*), live-trapped in Minnesota, in the Upper Peninsula of Michigan. Their movements were monitored by aerial radio-telemetry. In early July, one male was killed by an automobile. Over the next several months, three animals were shot.

C) Paquet and Callaghan (1996) found than an unfenced portion of the Trans Canada Highway was a serious barrier that wolves seldom crossed. At least 9 wolves were killed by traffic during the study period.

D) From 1968 to 1976, Mech (1977) determined population parameters, mortality causes, and mechanisms of a population decline in wolves in the Superior National Forest. The main method was aerial radio-tracking of 129 wolves and their packmates. Due to a decline in white-tailed deer, the wolf population decreased during most of the study. Thirty wolves were found dead of non-capture-related causes while their radios were transmitting. Of these, one was roadkilled. Another 14 were reported killed by humans after the transmitters had expired. Of these, one was roadkilled.

E) From 1970 to 1979, Berg and Kuehn (1982) tracked 44 wolves in North-Central Minnesota, using radiotelemetry. Data for 15 wolves were inadequate. Excluding capture-related mortality (n=4), 16 of 21 (76%) of documented cases of wolf mortality were caused by humans. Five wolves were killed by cars.

F) Clevenger (1998) summarized highway-related mortality of wildlife on the Trans-Canada Highway (TCH) in Banff National Park (BNP) during the last 15 years. Over this period, traffic volumes have increased steadily and frequent highway upgrades were necessary. For some species highway related mortality is extremely high. For coyotes, 25-30% of the population is killed each year, while for black bears and wolves roughly 10-20%.

12) Studies of other mammals include:

A) Goats – (Brockie, 1960; Singer, 1978; Singer and Doherty, 1985).

B) A study evaluated the habitat factors that influence fox crossings, but did not report mortality data (Stanley and Barr, 1991).

C) A study of 1,768 km of roadway in Texas during 1975-1976 recovered a total of 286 carcasses of mammals (65%), reptiles and amphibians (17%), and birds (17%) (Wilkins and Schmidly, 1980). The mammals included: armadillo (41), opossum (51), striped skunk (20), Eastern cottontail (17), Jackrabbit (1), domestic cat (14), domestic dog (10), coyote (3), gray fox (1), raccoon (8), white-tailed deer (6), cattle (1), plains pocket gopher (1), fox squirrel (2), and hispid cotton rat (11).

D) Studies in Czechoslovakia along motorways (Havlín, 1987) document the effects of highway traffic on birds and other vertebrates.

E) Between 1984 and 1990, 75 koalas from the central northern coast of New South Wales (Australia) were presented for necropsy due to motor vehicle accidents (Canfield, 1991).

F) In order to reduce the impact of a new railway on migrating large mammals through Kaziranga National Park, in the Indian State of Assam, three 30-m wide underpasses were constructed (Choudhury, 1987).

G) A 1939 study recorded the number of animals (birds, mammals, other vertebrates) that apparently had been killed during the 24-hour period immediately preceding the observation (Dickerson, 1939). Data are presented as a function of month and number of miles traveled. The total number of victims/mile ranged from 0.0117 (November) to 0.1099 (May). The study encompassed several years, and more then 75,000 miles in the States of Virginia, Tennessee, Georgia, Florida, Alabama, Mississippi, Arkansas, Missouri, Illinois, Oklahoma, Texas, New Mexico, Arizona, and California.

H) A 1979 study reported that the Tanzania-Zambia railway, which now bisected the Magombera Forest Reserve in Tanzania, seriously threatened the most viable surviving population of the rare endemic Iringa colobus monkey (Rodgers *et al.* 1980). No mortality data are given.

I) Between March 1, 1961 and March 1, 1962 an accurate count was kept of animals killed each month along a 20-mile stretch of U.S. 46 in New Jersey (MacNamara, 1962). A total of 476 mammals and birds were found during the year, averaging 23.8/mile of 1.9 animals/mile/month. Cottontail rabbits (173) were most frequently killed, with squirrels (86), opossums (54) and skunks (50) in descending order of abundance.

J) Black bear (*Ursus americanus*) mortality data were collected in eastern North Caroline from 1976 to 1992. These data included registered harvest totals from mandatory hunter-harvest records, field reports, and tooth samples from bears dying from all causes (N=1,107 for harvest; N=350 for vehicle-kill). Vehicle-kills increased until 1990 but declined during 1991-1992. Peak vehicle-kills occurred from June to December (Warburton et al., 1993).

K) Vehicle collisions are a significant cause of mortality for the endangered ocelot (*Pardus pardalis*) in southern Texas (Hewitt et al., 1998). From 1982-1996, twelve out of twenty 27 (44%) recorded ocelot mortalities were likely vehicle-related. On a 20-mile stretch of U.S. Highway 281 in Live Oak County, mammal mortalities from May-November 1997 were: rodent (n=340), rabbit (n=79), nine-banded armadillo (n=45), raccoon (n=26), coyote (n=16), domestic dog (n=4), domestic cat (n=4), striped skunk (n=3), opossum (n=3), and badger, bobcat, domestic goat, whitetail deer, gray fox (n=1).

L) Road kill data from the period *circa* 1930 are given in: Davis, 1934; Dreyer, 1935; Gordon, 1932; Knobloch, 1939; Simmons, 1938; Starrett, 1938; Stoner, 1925; Warren, 1936; Sharp (1930).

M) Other studies: Abbott (1958); Adams and Geis (1981); Haas (1964); Haugen (1944); Hodson (1966); Oxley *et al.* (1974; see below); Evenden (1971); Lechleitner (1958); Williams and Nelson (1939); Whitehead (1998); Buckingham (1998), Kerr (1998); Sargeant and Forbes (1973).

OTHER VERTEBRATES

1) Scott (1938) determined the 1,239 wildlife mortalities on Iowa highways (period May 1936-April 1937) for travel on rural roads of 2,944.1 miles, e.g., 0.429 casualties/mile. Fifty seven species were represented: 3 amphibians, 8 reptiles, 16 mammals, and 30 birds. The length of time that the vertebrate body remained on the highway after death varied with the species, but recognizable forms were not usually found after 4 days exposure. A reasonable casualty age class was thus established.

$$\text{number of animals killed/mile/yr} = (365/4) \times 0.429 = 39.1462.$$

In 1938, there were about 4,820 miles of hard-surface highway in Iowa similar to that on which the investigations were made, and these comprised about one-sixth of the total number of miles of all roads in the State. A conservative estimate of the annual toll of wildlife on the improved highways of Iowa is $(39.1462) \times (4{,}820) = 188{,}685$. Scott states this is a 10% underestimate.

2) A survey lasting 40 months (January 1941-April 1944) covered 77,000 miles of Nebraska highways (McClure, 1951).

- More than 100 species, and a total of 6,723 individual animals (other than invertebrates), were noted. Twenty-six species made up 89.8% of the total kill and the other 75 species accounted for only 10.2%. The breakdown by species is given in the paper. In summary, amphibia were 17.4% of the total. Reptilia were 18.2% of the total, and the predominant species were the bull snake (5.9%) and the garter snake (4.7%). Turtles made up 4.0% of the total, and half of these were box turtles. Fifty-six species of birds, made up 23.5% of the total, and included pheasant (5.7%), burrowing owls (1.3%), red-headed woodpecker (2.7%), prairie horned lark (1.6%), English sparrow (4.0%), and western meadowlark (1.3%). Of the mammals, 29 species made up 40.5% of the total and the bulk was lagomorphs, 25.1%. Seven species were in excess of 100 individuals: domestic cat (3.4%), striped skunk (1.1%), 13-lined ground squirrel (2.6%), kangaroo rat (4.7%), cottontails (9.1%), black-tailed jackrabbits (6.1%), and white-tailed jackrabbits (2.3%). To the rabbits should be added unidentified rabbit remains, totaling 7.3%.

- McClure (1951) reported that road-kills of bull snakes, garter snakes, pheasants and toads were proportional to the density of cover, age composition, and density of the wildlife population rather than to the amount of traffic and degree of road improvement (increasing speed of traffic). Table 13 and Figure 7 give highway mortality (dead animals/100 miles driven) in central Nebraska for the period March 1941 through March 1944. In 1941, mortality was 9.6 animals/100 miles, which increased to 12.1 in 1942 and decreased to 5.7 in 1943, giving a 3-year average of 9.1 animals/100 miles, with a July peak of 22.0. The percentage of the year's losses that occurred each month for each species constituted essentially a graph of its season activity and population density. The percentages of highway victims and living individuals are compared for some avian species.

Table 13. Dead animals/100 miles of driving in central Nebraska, March 1941 to March 1944. (From Table 1 of McClure, 1951).

Month	1941	1942	1943	1944	Average
January		2.1	1.2	2.0	1.8
February		1.4	2.5	1.0	1.6
March	6.5	9.9	3.0	1.1	5.1
April	3.3	3.1	6.6		4.3
May	6.1	6.4	7.0		6.5
June	9.3	14.0	6.3		9.9
July	27.1	26.6	12.3		22.0
August	15.2	21.6	12.1		16.3
September	16.3	32.2	5.0		17.8
October	5.6	7.4	4.0		5.7
November	2.1	5.8	1.9		3.3
December	4.4	1.2	1.8		2.5
Average	9.6	12.1	5.7	1.4	9.1

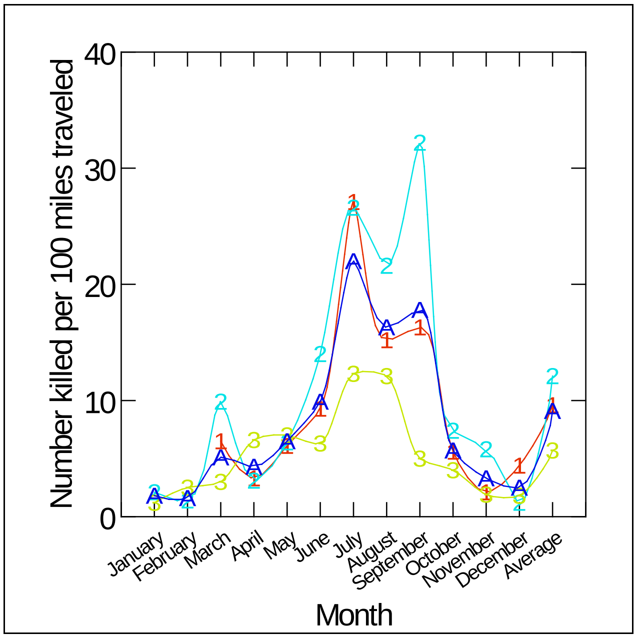


Figure 7. Number of dead animals/100 miles of highway driving in central Nebraska from March 1941-March 1944. 1 = 1941-1942, 2 = 1942-1943, 3 = 1943-1944, A = average for 1941-1944. (Data from Table 1 of McClure, 1951.)

- In 1942 there were approximately 101,000 mile of roads in Nebraska, of which 80.0% were sand or dirt, 1.2% concrete, 15.7% gravel, and 2.6% black-top or macadam (McClure, 1951). The proportions of road surfaces traveled by McClure were 2.0% concrete, 44% gravel, 52.0% black-top, and 2.0% sand or dirt. Correcting the kills for the amount of driving made on each type of road, gives the correlation in Table 14. For each one percent of the total mileage traveled over concrete roads, 4.6% of the total pheasant kill was counted, whereas for each one percent of travel on gravel roads 0.87% of the total pheasant kill was noted. Of the total mileage traveled, 16.3% of the game animals were found dead along concrete roads totaling 2.0% of the travel, 39.4% along the black-top making up 44% of the travel, 43.0% along gravel roads making up 52% of the travel, and 1.1% along dirt roads making up 2.0% of the total travel. Apparently an animal crossing concrete has one-eighth the chance of survival as it would crossing other types of road surfaces. In Nebraska, the average yearly loss per 100 miles was 9.1 vertebrates, in Iowa it was 42.9 (Martin, 1939), in New England it was 70.5, and based upon a small sample in Wisconsin it was 249.9.

Table 14. Mortality on road surfaces in Nebraska, 1941-1943. Values are relative to concrete = 100 (McClure, 1951).

Species	Black-top	Gravel	Dirt or Sand
Ring-neck pheasant	20	19	14
Striped skunk	3.8	2.3	3.7
Mourning dove	21	45	0
Fox squirrel	7.3	11.5	0
Spotted skunk	3	2.5	0

- Scott (1938) determined that animal remains were recognizable for approximately 4 days, and obtained corrected counts using the formula:

Yearly Loss per Mile = Average Number of Animals per Mile $\times$ number of days in year/4.

A loss of 0.024 pheasants/mile corrected to 2.22/mile/yr. Using this method for Nebraska data, the loss of pheasants was 0.42/mile/yr (Scott, 1938). As there were more than 20,000 mile of improved roads in Nebraska, a highway loss of nearly 9,000 birds is indicated. This is probably an underestimate because the survival time of a carcass on the Nebraska roads was about 2 days (McClure, 1951), half that reported by Scott (1938).

3) McClure (1951) cites the following reports.

A. A 1932 study reported kills of jackrabbits as great as 100 per mile were in the vicinity of Thousand Springs, Idaho.

B. A 1933 study in Idaho reported 763 lagomorphs killed in 685 miles in one locality and 598 in 50 miles near Boise.

C. A 1938 study of 10 years of observations in New England reported 51 species of birds and 15 species of mammals killed by cars, with peak kill coming between July 15 and August 15.

D. A 1938 study in Iowa found an average of 0.429 animals killed per mile of rural paved highway, involving as many as 57 species in one year.

E. In New Mexico, a 1939 study reported the summer loss on concrete was 4.1 animals per mile, and 0.45 per mile on gravel.

F. A 1939 study reported losses in Michigan of approximately 1000 deer per year, with proportionately heavy losses of rabbits, pheasants, and fox squirrels (Martin, 1939).

G. It was reported (1939) that losses to animals were three times greater west of the Mississippi River than east of it (Dickerson, 1939).

H. A 1945 report stated that in 260 miles of driving along gravel and asphalt roads in Kansas, 57 snakes were observed that had been killed by automotive vehicles under wartime reduced traffic; losses of snakes were greater on asphalt pavements than on gravel roads in Kansas (Bugbee, 1945).

4) As discussed above, data are given in Table 11 (Seibert and Conover, 1991) and Table 12 (Adams and Geis, 1981; Cook and Daggett, 1995). Cook and Daggett (1995) cite the Illinois Department of Transportation that the replacement of forage crops (grazing crops) with row crops (corn and soybeans) reduced the pheasant population in Illinois by two-thirds between 1961 and 1975. Because roadsides provide 8 acres of grazing land per square mile, mowing becomes a prime issue in the preservation and propagation of birds and small wildlife. Increasing the use of brome, timothy, orchard grass, alfalfa, and clover, increased bird nesting by 2.7 times but also attracted more deer. Illinois currently delays mowing operations until August 1 to protect nesting birds.

5) The effects of highways on the diversity and spatial distribution of wildlife in various types of geomorphic and ecological settings was determined (Adams and Geis, 1981). From June 1975 and June 1980, a multi-state study was carried out in southern Piedmont Virginia, North Carolina and South Carolina; the Midwest Tillplain of Illinois; the valley region of Oregon between

the Cascade and Coastal ranges; and central portion of northern California. Sample plots were distributed in relation to interstate highways and county roads. Nine bird species were positively influenced and nine species negatively influenced by one or both road types during either the breeding or winter season. No differences were detected in the distributions of the majority of bird species with respect to roads.

- A total of 1,174 animal carcasses was recorded in this study (Table 15). Their tables 78-84 gives the species composition, by state and road type. An average of 85% were killed on interstate highways. In regard to Table 15, the authors state that, because certain species persist for a long period of time, the data in the "total" columns are biased toward large mammals, and that a more accurate reflection of the total kill by major animal group is obtained by looking at the estimated kill on a "daily" basis. Seventy-six percent of the road wildlife mortality was on the interstate highways. Birds made up the largest percentage (38%) of the kill on interstates and amphibians and reptiles made up the largest percentage (51%) on county roads. Roads appeared to act in a density-dependent manner-species killed in greatest numbers were those attracted to roadsides (e.g., meadowlark, indigo bunting, field sparrow, red-winged and Brewer's blackbird, deer mouse, several vole species, and rabbits).

Table 15. Estimated total and daily road wildlife mortality by major animal group in relation to road type, 1978-1979. (From Tables 64-65[1], Adams and Geis, 1981).

	Interstate Roads				County Roads			
Animal group	**Number killed**		**Percent**		**Number killed**		**Percent**	
	Total	**Daily**	**Total**	**Daily**	**Total**	**Daily**	**Total**	**Daily**
Amphibians & reptiles	182	35	18.6	13.0	99	40	50.8	47.0
Birds	371	143	37.9	54.0	47	27	24.1	32.0
Large mammals	303	38	30.9	14.0	30	7	15.4	8.0
Small mammals	117	46	12.0	17.0	18	10	9.2	12.0
Unidentified	6	1	0.6	1.0	1	1	0.5	1.0
Total	979	263	100.	99.	195	85		100.

[1]The authors state that the data in the "daily" columns are more accurate than the data in the "total" columns because of the persistence of some large mammals. See text.

- Not all road-killed animals remained on the road after they were struck (Table 16). The distributional pattern is similar for all animal groups. Carcasses located on the roadway made up 44% of the total kill, and those located on the edge and ROW vegetation made up 35% of the total, and those located on the median side of the road (including the median edge and median vegetation) up 19% of the total kill. Two factors contribute to the greater kill on the outer edge of the road: traffic use of the outside lane is generally higher on the interstate highways and animals approach the roadway in greater frequency from the outside edge than they do from the median side.

Table 16. Spatial distribution (%) of wildlife mortality on interstate highways and on rural roads by major animal group, 1978-1979. (Tables 66-67 of Adams and Geis, 1981).

Species	Median vegetation		Median edge		Road proper		Roadside edge		Roadside vegetation	
	Hiway	Rural	Hiway	Rural	Hiway	Rural	Hiway	Rural	Hiway	Rural
Amphibians & Reptiles	9		9		40	82	37	10	6	8
Birds	10		16		35	37	32	52	6	11
Small mammals	2		2		76	60	20	20	0	20
Large mammals	6		6		42	43	28	43	19	14

- No significant difference was detected in deer distribution in relation to interstates in the Southeast and Northwest; however, for county roads, more deer utilized habitat away from this type of road than near it. Thus, the data indicate that road size and traffic volume *per se* are not critical disturbing factors to deer.

- Elk tend to avoid habitat adjacent to interstates and forest roads.

- Cottontail rabbits utilized areas adjacent to interstate highways to a greater extent than they did areas farther away from this road type in both the Southeast and Midwest. Rabbit distribution was uniform in relation to county roads.

- Salamanders (woodland and stream) made up over one-half of the total observations along both interstate and county roads in the Southeast and Northwest (Oregon) study areas. However, salamanders were not found during the road mortality survey along interstates in either study area. Salamanders also were not recorded in interstate ROW habitat in the Southeast and a low percentage were recorded in this habitat in Oregon. Therefore, during the road mortality survey in June, salamanders did not readily cross interstate highways, and were not attracted to ROW habitat.

- In the Southeast, turtles had the highest mortality on interstate highways and the box turtle was the most common species killed. Along county roads, frogs and toads made up the majority of the herpetological road mortality.

- In the Northwest (Oregon), snakes made up the largest percentage of the road amphibian and reptile mortality for both interstates and county roads, greatly exceeding their proportional makeup of the herpetological fauna of the area.

- Small mammal community structure and abundance were influenced by roads. Grassland species generally preferred right-of-way (ROW) habitat and many less-habitat-specific species were distributed in ROW and adjacent habitat. Evidence was obtained indicating that large roads (with accompanying ROW habitat) inhibited movement of 11 of the 40 small mammal species studied.

6) A 21.5-mile section of the Northern Pacific Railway's main line right-of-way in the Missouri coteau of North Dakota was studied to determine waterfowl production on both hayed and unhayed acreage (Page and Cassel, 1971). Overall nest success was 83 percent. Nest densities were 9.6 nests/100 acres on hayed areas and 55.6 nests/100 acres on unhayed areas. The acres mowed for hay produced 0.64 duckling per acre, and the unmowed acres produced 3.93 ducklings for each acre.

7) Transects totaling 314 km in length were monitored along railway lines in the broader vicinity of Brno, Czechoslovakia in 1981-1986 (Havlín, 1987a). In all, 96 avian species (17,199 individuals) were found in the area of the tracks with a density of 54.8 birds per km length and a species diversity of H' = 3.32. A total of 91 birds (19 species; 0.5% of all live birds) and 149 mammals (11 species) were found killed by trains (tabled in the paper); the most frequent were the mammals *Lepus europaeus* (121/240) and *Felis catus* (16/240), and birds *Phasianus colchicus* (40/91) and *Buteo buteo* (14/91). The average per km track length was 0.29 birds and 0.47 mammals, in all, 0.76 vertebrates. There were considerable differences in dependence on the abundance of avifauna and the amount of traffic (directly proportional). The importance of railway lines for the occurrence of birds seems to be primary, a condition rather than a consequence in relation to losses. Havlín (1987a) cites other papers in German and Slovak on the relation of birds to rail traffic.

- Results obtained under quite comparable conditions and practically at the same time, show that there is no major difference in the number of vertebrates killed per unit length between railways (76/100 km) (Havlín, 1987a) and roadways (86.34/100 km (Havlín, 1987b). In making a comparison, one must also take into account the fact that on railways there are practically no small mammals found among the victims. Various reasons have been given for the absence of small mammals in track surveys: small mammals are not inventoried as train victims because they are thrown far from the track; torn into small, unrecognizable, pieces; are not looked for during surveys; not known to, or inventoried by train crews because they did not damage the train.

8) Several studies have evaluated the effect of traffic intensity on local abundance of anurans.

   A. During the breeding migration of *Bufo bufo* (toad) in The Netherlands in 1971, the number of females killed by traffic on a 1.5 km asphalt road with about 10 cars/hour, were counted (Rosen and Lowe, 1994). A 1.7 km section of woodland paths, which did not carry traffic, was used as a reference. The number of observed live adults was about equal for the asphalt (407) and woodland (396) sections. On the asphalt road, 250 live male and 157 live females were observed, and 73 dead male and 49 dead females were found. By counting egg-strings, the total number of females along the entire route was estimated to be 280. Because the same numbers of animals were observed on the asphalt and woodland parts, the authors assumed that about 140 females crossed the asphalt road. The number of females run over before spawning was 30. Therefore, if there had been no traffic, 170 females would have crossed the asphalt road. Before spawning, 18% of the females crossing the asphalt were therefore run over. After spawning, another 18 females of those coming from the water (about 140) were run over (14%). In all, 49 of 170 females (29%) crossing the asphalt road were run over during migration to and from the water. A similar percentage is expected for the males.

   B. When movements occur across roads, mortality can be substantial (Oldham and Swan, 1991; Rosen and Lowe, 1994). Reh and Seitz (1990) and Fahrig *et al.* (1995) cite a study by Kuhn (1987). Kuhn estimated that 24-40 cars per hour killed 50% of migrating *Bufo bufo* individuals. A study by Heine (1987) calculated that 26 cars per hour could reduce the survival rate of toads crossing roads to zero.

   C. Another study estimated conservatively that 5,480,000 reptiles and frogs are killed annually by traffic in Australia (Ehmann and Cogger, 1985).

   D. A recent study in Canada counted dead (1856) and live (591) frogs and toads for a total of 506 km traveled (Fahrig *et al.* 1995). Frog and toad local abundance were estimated using breeding chorus intensities on similar roads through similar habitats, but with different levels of traffic intensity. After correcting for effects of date, local habitat, time, and region, analysis demonstrated that (1) the number of dead and live frogs and toads per km decreased with increasing traffic intensity; (2) the proportion of dead frogs and toads increased with increasing traffic intensity; and (3) the frog and toad density, as measured by the chorus intensity, decreased with increasing traffic intensity. Taken together, the results indicate that traffic mortality has a significant negative effect on the local density of anurans. The results suggest that recent increases in traffic volumes worldwide are probably contributing to declines in amphibian populations, particularly in populated areas.

E. A recent study determined road mortality of amphibians, reptiles and other wildlife (Ashley and Robinson, 1996). The Big Creek wetland is part of a 1200 ha wetland at the head of Long Point Bay on Lake Erie, Canada. This ecosystem provides habitat for 34 species of amphibians and reptiles. Wildlife road mortality on a 3.6 km section of a two-lane paved causeway adjacent to Big Creek National Wildlife Area on Lake Erie was censused from spring to autumn for two 2-year periods, 1979-1980 and 1992-1993. Total recorded mortality exceeded 32,000 individuals, 27,846 (85.4%) being young of the year Leopard Frogs. One hundred vertebrate species were recorded, 8 amphibians (N = 30,034; 92.1%), 10 reptiles (N = 864; 2.7%), 21 mammals (N = 282; 0.9%) and 62 birds (N = 1302; 4.3%). For the four year study period between April and October, road mortality on the causeway averaged: 11.65 amphibians/km/d, 0.11 mammals/km/d, 0.51 birds/km/d, and 0.34 reptiles/km/d.

F. A 1974 study (Oxley *et al.* 1974) observed road mortality at the following rates over 116 days (1 June-18 September 1972): 0.02 amphibians/km/d, 0.03 reptiles/km/d, 0.03 birds/km/d and 0.04 mammals/km/d.

G. A study of 1,768 km of roadway in Texas during 1975-1976 recovered a total of 286 carcasses of all species (Wilkins and Schmidly, 1980). Of these, 16 were anurans, 27 were turtles, 7 were snakes, and 49 were birds. (The other 187 were mammals, see above.)

H. During the breeding migration of *Bufo bufo* (toad) in 1971 (February 22-May 15) the number of males and females killed by traffic on an asphalt road with about 10 cars/hour were counted (van Gelder, 1973). The ratios of live to dead toads were similar, 3.4 for males and 3.2 for females. By counting egg-strings, the total number of females was estimated to be 280. The number of females run over before spawning was 30 and after spawning 19 as the toads returned from the water. By comparing both data, it appeared that 29% of the females passing the road were run over. A similar percentage is expected for the males. On this basis, if the traffic volume were one car a minute, rather than 10 cars/hr, as many as 9 adult toads out of 10 might be killed under the conditions described.

I. Bekker (1998) cites two studies. Vos and Chardon (1994) describe how amphibians are suffering high mortality rates as a result of the high density of roads in the Netherlands. Vos (1995) indicates that field-frog occupation of marshland pools in the Dutch province of Drenthe is highly correlated with road density within a 750 m radius.

J. Other studies of anurans include: Carpenter and Delzell, 1951; Havlín, 1987; Hodson, 1966; Means, 1996; Moore, 1954; Oxley *et al.* 1974; Palis, 1994; Pickles, 1942; Reh and Seitz, 1990; Sermet, 1971; Stoner, 1936.

9) An algebraic method was developed for estimating highway mortality of snakes, based on careful data collection during low-speed driving on paved roads (Rosen and Lowe, 1994). A total of 368 snakes (104 live, 264 dead) were recorded over four years (August 1987-July 1991) in Pima Co., Arizona, during 15,525 km of road-cruising on a state road. The computed total snake highway-mortality over the four-year period is 2,383, or 596/yr (13.5/km/yr). Taking account of road-killed snakes that were removed by any means before they were counted, the actual number killed is about 4,000 (22.5/km/year). Overall, along the 44.1 km transect used, the estimated highway mortality amounts to removal of 5 km^2 of snake population over the four years of study. It is clear that roadways, especially if paved, substantially damage snake populations. (Extrapolating these values, "tens to hundreds of millions of snakes have been killed by automobiles in the United States" (Fahrig *et al.* 1995).) A comparison of abundance data from this study with unpublished data from 1950 on the same highway transect-three years after the road was originally paved-confirms that there were many more snakes (perhaps 10-fold) around Route 85 prior to the increased traffic of recent decades.

10) According to Rosen and Lowe (1994), one 1953 study attempted to compute total road mortality in snakes (Campbell, 1956; Campbell, 1953). This study estimated a maximum of 0.16 'dead on road' (DOR) snakes/km/yr for New Mexico highways in 1951-1953. (Rosen and Lowe, 1994) remark that this estimate, which is 100 times less than theirs, may reflect lower road mortality in the early 1950s in New Mexico, but is more likely an underestimate (in the 1953 study) resulting from high driving speed (35-55 mph), lack of consideration of the completeness of the observation of DOR snakes passed on the highway, and that all DOR snakes did not remain on the highway until they were found and collected.

11) Other reports of reptile snake kills are: Bugbee, 1945; Davis, 1940; Dodd *et al.* 1989; Evenden, 1971; Havlín, 1987; Krivda, 1993; Stoner, 1936; Sargeant and Forbes (1973).

12) During a 10-yr study in southern New Jersey (Loos and Kerlinger, 1993), 250 road-killed raptors of 6 owl and 6 hawk species were found during 145 km of road travel between mid-October and early April. Northern Saw-whet Owls (*Aegolius acadicus*) and Eastern Screech-Owls *(Otus asio*) accounted for 45% (N = 114) and 36% (N = 91) of all road kills, respectively. A large percentage of the saw-whet (79%) and screech-owls (88%) found were less than 1 yr old. More than 87% of road-killed saw-whet owls and 71% of Eastern Screech-Owls were found between November and January, with

December accounting for 41% of all road kills. Slightly fewer than one-half of all road kills of these two species occurred within the southernmost 15 km of the Cape May peninsula. Collisions with automobiles kill a significant number of wintering migrating saw-whet owls and resident screech-owls in Southern New Jersey.

13) In addition to cited studies of birds killed on roads, studies of birds include:

A. Abbott, 1958; Beckmann, 1961; Bergmann, 1974; Brautigam, 1978; Broekhuysen, 1965; Brown *et al.* 1986; Cottam, 1931; Davis, 1940; Dhindsa *et al.* 1988; Dickerson, 1939; Dunthorn and Errington, 1964; Evenden, 1971; Finnis, 1960; Fremlin, 1985; Govet, 1960; Hansen, 1969; Harding, 1986; Haug, 1985; Havlín, 1987; Havlín, 1986; Heldt, 1961; Hernandez, 1988; Hodson, 1962; Holbrook and Vaughan, 1985; Jennings, 1961; Linsdale, 1929; Martens, 1962; Nicholson, 1978; Oxley *et al.* 1974; Pickles, 1942; Russell, Jr. and Amadon, 1938; Sargeant, 1981; Sazaki *et al.* 1995; Schorger, 1954; Spencer, 1965; Stoner, 1936; Stout and Cornwell, 1976; Sutton, 1927; Weir, 1971; Sargeant and Forbes (1973), Smith (1981); Sharp (1930).

B. A 1965 study estimated that 2,500,000 birds are killed annually on the estimated 195,217 miles of classified and unclassified roads in Great Britain (Hodson and Snow, 1965).

C. Results of data collected from 27 weekly surveys at 3 sites along 2 California four lane divided highways (236 km) in rural areas near Sacramento from May 25, 1995 to November 26, 1995 showed that of the 227 owls collected, 61% were juveniles and 39% were adults (Moore and Mangel, 1996). There was a significantly skewed sex ratio: 74% of the collected owls were female. There was a temporal (month) pattern of kills, and the type of adjacent habitat was related to the percent of owls collected. A life history model was constructed in order to assess the impact of traffic related mortality on the growth rate of these owl populations. Results from the model predict that when about 48% of adult mortality of owls is due to traffic or 27% of the hatching year mortality is due to traffic, the population growth rate drops below one and the population is in decline. Fifty six other birds from 12 species were also collected, the majority being red-tailed hawk (12), mallard (12) and ringed-neck pheasant (17).

D. From 1980 to 1985, an average of 150 owls per year were collected along roads of the California central valley (Schulz, 1986).

E. A study (Jonkers and Vries, 1977) is reported (Dhindsa *et al.* 1988) to have concluded that 6,530,000 birds and 159,000 mammals are killed annually on the roads in the Netherlands.

F. A study estimated that the annual total of bird casualties on roads in Bulgaria is more than 7 million (Nankinov and Todorov, 1983).

G. Studies in Czechoslovakia along motorways (Havlín, 1987) and dams (Havlín, 1986) document the effects of highway traffic on birds and other vertebrates.

H. A 1975 study (under a section 'Man-caused mortality of birds') provided the following estimates: the number of birds killed by flying into TV towers each year may average around 1,250,000, mortality at picture windows may be around 3,500,000 and from traffic on highways 57,179,000 (Aldrich, 1975).

I. Regular counts were made in 1959 on a two-mile section of rural, arterial roadway of the number of vertebrates killed. Normal traffic averaged 101 vehicles/hr, 180 on normal weekends, and 244 on holidays. During the year, 288 birds of 26 species, and 295 other vertebrates of 16 species, including mammals, amphibians, and snakes, were killed (Hodson, 1959).

J. Along a 2-mile section of rural roadway in rural England, 644 birds of 31 species were killed during 1960-1961, of which 320 were house sparrows. The number of dead house sparrows observed during comparable periods of time (summer and fall) was compared with those observed along lengths of roads with bordering grain fields in 1959, tabulating an average of 5.3 per 100 yards in 1959 and 10.2 in 1962. The population of house sparrows increased as urban development extended towards the road. House sparrows were especially vulnerable to vehicles as they flocked to the various grain fields. The position of the dead birds was recorded in relation to the various types of cover on both sides of the road and analysis showed that much higher numbers of deaths occur opposite gaps and openings than along stretches of roadway with a uniform border (Hodson, 1962).

K. In 46,000 km of travel on European highways during 1956-1963, highway casualties were 1,850 birds of 97 species and 832 mammals of 22 species (Haas, 1964).

L. In 4 round trips between Albany, New York and Iowa City, Iowa, 2,975 freshly killed vertebrates were seen on highways, of which 1,781 were birds (Stoner, 1941).

M. A recent paper (Woods and Munro, 1996) cites reports of the authors. Most kills along the Canadian Pacific Railroad (CPR) occur in the winter, but road-kills peak on the Trans Canada Highway (TCH) are in spring and autumn. Highway and railway collisions with small mammals and birds are generally poorly documented. A notable exception is the known mortality of pine siskins on the TCH in winter when thousands of birds may be attracted to the road surface by salt and sand and hundreds may be killed by a single passing vehicle.

N. Stout and Cornwell (1976) carried out a survey of nonhunting mortality of wild waterfowl. Records of reported mortality (N = 2,108,880) for the period 1930-1964 were assembled from the open literature, unpublished federal reports, and a questionnaire. Nonhunting mortality band recoveries (N = 25,817) for the period 1930-1963 were analyzed. Automobile collision mortality (N = 539) was 0.026% of the total sample and 0.93% (N = 239) of the band recoveries. Collisions with farm machinery accounted for an additional 0.0045% (N = 95) in the survey and 0.57% (N = 147) in the band survey. Collisions of all types were 1% (N = 2,299) of the total survey mortality data and 2.8% (N = 716) of the band recoveries. Thus, for the survey data, collisions with automobiles and farm machinery were 23.0% and 4.0%, respectively, of collisions of all types. For the band recovery, collisions with automobiles and farm machinery were 33.0% and 21.0% of collisions of all types.

14) Birds killed on railroads were studied by Barbour (1895) and Pickles (1942).

15) Linear strips of vegetation on road reserves have been documented as contributing to the conservation both of flora and fauna. Rail reserves have been identified as important sites for the survival and conservation of some rare plant species and communities, particularly native grasslands. Limited observations of wildlife made along a section of railway reserve in south-western Victoria identified 39 species of birds, 6 species of mammals, 4 species of reptiles, and 4 species of frogs using the reserve (Bennett, 1992). Road and rail reserves have the potential to, and must serve as, small refugia for threatened and endangered species an must be managed for conservation purposes (Dennis, 1992).

16) Mortalities along the route of Highway 93 on the Flathead Indian Reservation, near Missoula, Montana include a wide variety of smaller birds, mammals, amphibians, and reptiles, and large species such as white-tailed deer, mule deer, elk, moose, black bears, and mountain lions. High mortality levels of nongame birds, upland game birds, waterfowl, small mammals, amphibians and reptiles have been documented in the segment of the highway that passes through the glaciated wetland complex (Tribal Wildlife Management Program, unpublished data) (Becker, 1996).

- Fowle (1996) documented 205 road-killed painted turtles (*Chrysemys picta*) killed in one 4.5 mile (7.2 km) section of this highway corridor. The spatial distribution of road-killed turtles by age implied that vehicles may be killing proportionately more adult or sub-adult turtles. Roadkill mortality may also be significant enough to cause a decrease in turtle density, thereby decreasing juvenile-adult competition for resources and increasing juvenile survival rates.

17) Annual road kill surveys were begun in Florida State parks in 1988. Paynes Prairie has the distinction of having more recorded road kills than any of the 68 parks where surveys are conducted. It is common for over 1,000 dead birds, mammals and reptiles to be recorded annually. Few observations are recorded on I-75 because of the danger of surveying this very congested, high speed highway. It is unlikely that any mammal, reptile, or amphibian is able to cross this wildlife killing zone (Stevenson, 1996).

18) Road-kills of 37 species (other than bears, discussed below under endangered species) were documented on SR 46 in Florida between November, 1993 and December, 1995 (Roof and Wooding, 1996). Species found were 95 opossums, 74 raccoons, 25 rabbits, 22 armadillos, and 20 gopher tortoises. Other species include snakes, birds, turtles, alligators (1), deer (7), and domestic dogs (2) and cats (6). Ninety-eight animals were road-killed in the 11 month pre-fence period (1 December 1993-30 November 1994, minus July, 1994). Eighty-eight of these were killed outside the area that was to be fenced (17.5 km of highway), and 10 were killed in 1.75 km area of the highway that was to be fenced (2 raccoons, 3 opossums, 2 rabbits, 1 deer, 1 armadillo, 1 box turtle). One hundred eight-eight animals were killed in the 11 month post-fence period (1 December 1994-30 November 1995, minus July, 1995). One hundred seventy-five of these were killed outside the fenced area and 13 were killed inside the fenced area (3 raccoons, 4 opossums, 1 rabbit, 1 armadillo, 2 box turtles, 1 cooter, and 1 gopher tortoise-all are believed to have crawled under the fence). Statistical analysis found no significant difference in road-kills in the fenced area before and after the fence and wildlife crossing were completed. Although the fence was ineffective for keeping some of the smaller species off the road, there were no instances in which bears, deer, foxes, or bobcats traveled under or over the fence, and in only 1 of 69 coyote-fence encounters did the coyote travel under the fence.

19) Studies of other vertebrates include: Bennett, 1991; Boarman and Sazaki, 1996; Brockie, 1960; Cottam, 1931; Coulson, 1982; Davis, 1946; Davis, 1940; Goodman *et al.* 1994; Haugen, 1944; Hodson, 1966; Means, 1996; Osawa, 1989; Pickles, 1942; Spiker, 1927; Stoner, 1936.

20) Stoner (1936) compared vertebrate casualties from reports since 1924. In 8,303 miles of highway traveled, 1277 dead vertebrates were counted: 435 mammals, 519 birds, 231 reptiles, 21 amphibians, 71 miscellaneous. The average vertebrate per mile was 0.153. This paper has an extensive list of

reports in the period 1920-1936. Several of these are cited in the foregoing sections, but the majority are not specifically cited in the present review.

21) Roadkill is undoubtedly the greatest human-caused source of direct mortality to vertebrate animals in many parks and reserves, yet its overall impact remains poorly documented (Kline and Swann, 1998). To begin to quantify the effects of roadways on wildlife in Saguaro National Park, Arizona, park staff initiated regular roadkill surveys in January 1994. These surveys have documented 2,030 wildlife mortalities during a three year period. Nevertheless, the number of individual animals observed are clearly only a small fraction of the number killed on roads in and adjacent to the park. To calculate a more accurate estimate of the total annual road mortality, we conducted studies to determine the effect of stochastic, short-term weather events; the length of time carcasses persist on roadways; and the observer error associated with our studies. Preliminary results of these studies provide what we consider a very conservative estimate of 7,155 vertebrates killed on Park through- and boundary-roads annually. Data were obtained for amphibians, reptiles, birds, and mammals. From 5 August to 7 October 1997, roadkilled vertebrates observed on all-night surveys were: 72 amphibians, 18 reptiles, 12 birds, and 11 mammals. The extent to which the thousands of documented roadkills affect wildlife populations in Saguaro National Park are not known, but are likely to result in population declines in certain species with low reproductive rates, including: Sonoran desert tortise (*Gopherus agassizii*), gila monster (*Heloderma suspectum*), tiger rattlesnakes (*Crotalus tigris*), Sonoran desert toads, and mountain lion (*Felis concolor*).

22) Hedgehogs (*Erinaceus europaeus*) are frequently killed by traffic throughout their range in western Europe. Minimum estimates reported in various studies vary between 0.3 and 2.9 victims per km road per year (Huijser et al., 1998).

INVERTEBRATES

Invertebrate mortality has been reported in a few studies. Invertebrates are not of direct concern to this report, but a large decrease in invertebrates might affect food chains in complicated ways. For example, decreases of some species might reduce or increase damage to leaves and crops used by deer, or reduce reproduction by plants that rely on insects or bats for cross pollination. Reduced numbers of insects might decrease bat populations. Bats are primary pollinators and seed dispersers for many of the most ecologically important plants of the desert Southwest. Additionally, 100 Brown bats can eat 18 million cucumber beetles in a summer to protect farmers rootworm larva.

1) A 14-month survey (Seibert and Conover, 1991) on the foot of each side of a 1.6 km (1 mile) stretch of dual lane highway provided 1,162 invertebrate victims (Table 11). Of the invertebrates,1,069 were insects (at least 249 species belonging to 84 families), 48 were spiders, 213 were Lepidoptera, and the remainder were worms, myriapods, harvestmen, and snails. The authors concluded that finding of rare and unusual species of invertebrates suggests that their technique be used as a supplementary faunal survey. The authors did not extrapolate or quantify the data in terms of numbers per km of highway. The value is1162/(2 $\times$ 1.6) = 363.1 invertebrates per km.

2) Transects made beside 12 main roads in Dorset and Hampshire (UK) showed that central reservations supported a wide variety of butterflies and burnets (Zygaenidae) (Munguira and Thomas, 1992). One site had 23 species of butterfly (=40% of British species), while the average was nine (16%) species per 100-m transect. For one species, mark-recapture estimates of adult densities were up to 2,774 adults ha^{-1}, and other species were in the hundreds to thousands. Most were common species, but some rarities were present. Wide busy roads were no barrier to the movements of species living in open populations, but slightly impeded those with closed populations. Mark-recapture showed that 10-30% of adults of three species with closed populations crossed the road. Roads cannot be considered as a barrier to gene flow in any species in this study. At one site, a total of 144 adults of 18 species of butterfly and burnet were killed. Over all sites, vehicles killed 0.6-1.9% of adults of species from closed populations, and about 6% of those from open populations. These mortalities were insignificant compared to those caused by natural factors.

3) Throughout 1938, the total number of animals killed on 3 miles of Yorkshire roads was 687, covering 42 species (Pickles, 1942). Ninety-four were vertebrates (mammals (2.9%), birds (7.3%) amphibians (3.5%) and 523 were invertebrates (worms (12.9%), Coleoptera (10.5%), Hymenoptera (49.5%), Diptera (2.5%), and 70 were “various” (10.9%).. This is a total of 229 per mile, of which 113.3/mi were Hymenoptera and 31.3/mi were vertebrates.

ENDANGERED SPECIES KILLED ON HIGHWAYS

1) Animal and bird accidents with motor vehicles contribute to the loss of endangered species. Cook and Daggett (1995) provide the following summary.

   A. The following species are being further endangered because of deaths caused by motor vehicles:

      - Desert tortoise in California, Nevada, and Utah
      - Panther, Black Bear, Key Deer in Florida
      - Timber Rattlesnake, Rat and Coachwhip Snakes, and Chorus Frog in Illinois
      - Spotted Skunk and Blackfooted Ferret in Kansas
      - Wolf in Michigan
      - Bald Eagle in Utah, Delaware, and Maryland
      - River Otter and Wolverine in Colorado
      - Delmarva Fox Squirrel in Delaware and Maryland
      - Swift Fox in South Dakota
      - Tiger Salamanders and Bog Turtle in New York

   B. Since 1976, 317 endangered Florida black bears have been killed on highways. In 1989, one of five populations of Florida black bear lost 20 of 125 total animals to road-kill. Since 1979, 54% of the endangered Florida panthers that have died in road-kills. Sixty-five of 300 endangered Key Deer were killed in highway accidents in 1990. Similarly, highway accidents are the number one cause of death of the Florida Panther.

2) The Florida black bear is listed by the State of Florida as a threatened species and is a candidate for listing by the U.S. Fish and Wildlife service as a federally threatened species. From 1976 to 1986, 99 black bears (*Ursus americanus*) killed by motor vehicles were collected from roadsides throughout Florida (Wooding and Brady, 1987). Males (N =66) were killed approximately twice as frequently as females (N =30). Males of dispersal age were killed more frequently than bears in other age classes. Seasonal peaks in road-kills occurred in May-July and in October-December. Figure 8 shows that there was a steep increasing trend in the number of male and female bears killed. The graph includes a smoothed time series for “total” (median smoother = 5), which makes the annual trend increase very evident. (An explanation for the alternating approximately biennial cycles is not apparent to the present compiler and was not addressed by the author, but the fact that it seems to be similar for both sexes suggests a real phenomenon.)

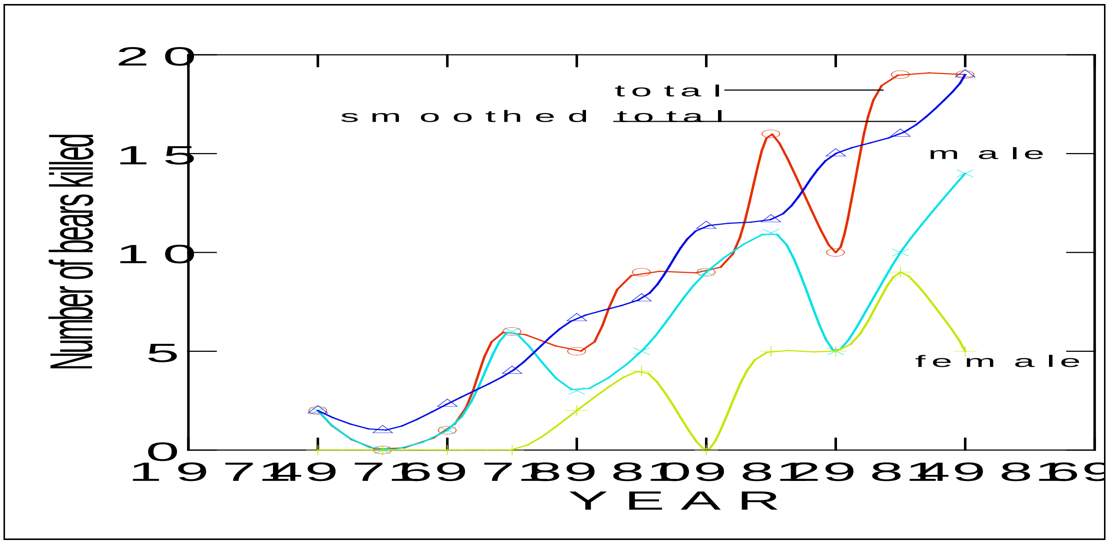


Figure 8. Black bear road-kills in Florida, 1976-1986 (Wooding and Brady, 1987).

3) Seven bears were killed on SR 46 in Florida between November, 1993 and December, 1995 (Roof and Wooding, 1996). Two of these bears were killed before a wildlife crossing was built. No bears were killed in a fenced area in this period, but 5 bears were killed in an unfenced area after the crossing was completed. Bear movements in the study area were documented using radio telemetry. Sixteen (39%) of the 41 radio-instrumented bears were documented crossing highways in the study area a total of 105 times. The home ranges of another 25 bears did not contain highways. Eight collared bears were documented crossing SR 46 at least 26 times after the wildlife crossing was completed. Only three (12%) of the 26 crossings were through the underpass. Many of the other highway crossings occurred 100-300 m from the fence and at a river.

4) Data on black bear road-kills has been collected by the Florida Game and Fresh Water Fish Commission since 1976 (Gilbert and Wooding, 1996; Roof and Wooding, 1996). For each of the 463 road-kills (1976-1995), the distance of the kill to the nearest highway landmark was recorded, and the carcass was retrieved for determination of age, sex, weight, and other life history information (Gilbert and Wooding, 1996). The trend shown in Figure 8 continued through 1995, but at a much slower rate from 1988-1995 than from 1976-1988.

5) Figure 9 shows the steep upward trend in the number of bears killed as traffic has increased in the 5 counties accountings for 60% of the kills. The road-kills are probably symptomatic of the much larger and more serious problem of habitat loss and fragmentation: 209 acres of habitat is lost to bears for every mile of roadway due to right-of-way footprint, and the avoided

zone adjacent to the highway due to human use of the road (Gilbert and Wooding, 1996).

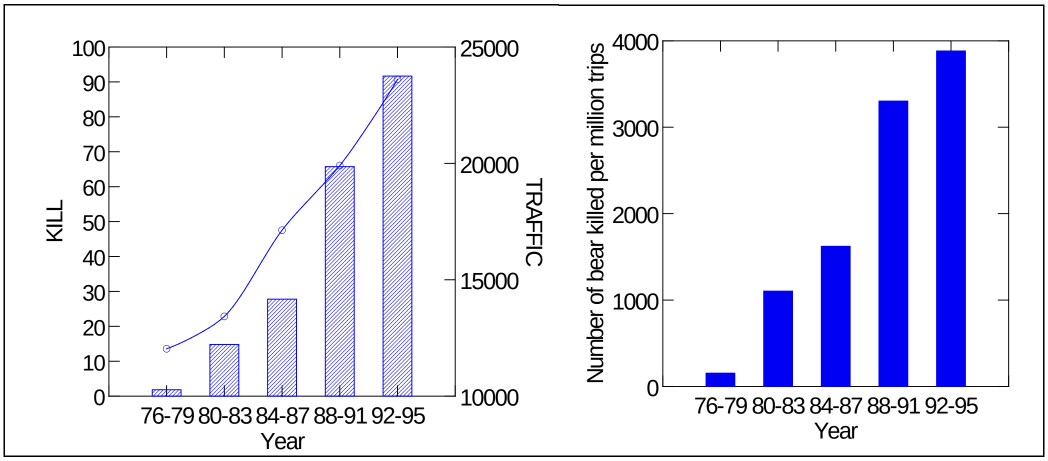


Figure 9. Number of Florida black bears killed (left panel, bars), number of daily trips (line) and number of bears killed per million daily vehicle trips (right panel) in 5 counties from 1976-1995. (From figure 6 of Gilbert and Wooding, 1996.)

6) Road-kill accounted for approximately 20% of 39 deaths of collared Florida panthers (*Felis concolor coryi*) (Land and Lotz, 1996; Maehr *et al.* 1991). To reduce road-kill, the placement of wildlife crossings (Foster and Humphrey, 1995) was determined by examining radio-telemetry data for Florida panthers (15 years) and black bears (5 years), locations of road-kills, and habitat characteristics. White-tailed deer, raccoons, and bobcats were the most common species detected using wildlife crossings, but they are also used by amphibians.

7) Vehicle collisions are a significant cause of mortality for the endangered ocelot (P*ardus pardalis*) in southern Texas (Hewitt, et al., 1998). From 1982-1996, twelve out of twenty 27 (44%) recorded ocelot mortalities were likely vehicle-related.

SPECIES RATIOS OF ROAD-KILL

The review focused on the mortality of deer due to vehicles. However, many studies collected road-kill data for other vertebrate species. These data can be used to estimate the numbers of a given species killed using available data for other species. Assumptions have to be made to use published data to develop projections for other species:

(1) the frequency with which a species is killed is proportional to the population density of the species;
  - numbers of individuals vulnerable to vehicles are linked among species;

(2) for a given species, the fraction of the population that crosses roads is independent of locality;
  - relationship is consistent between geographic areas;

(3) across species, at a given location, temporal trends in mortality (e.g., due to increasing traffic density and average speed(are similar;

(4) the observer counted all species with similar accuracy;

(5) the numbers of dead counted on the road versus the numbers missed due to their dying off-road or destruction of the carcass, represent similar fractions over all species.

The data presented by Kerr (1998) in Table 9 give the species ratios of road mortalities shown in Table 17. The ratio of white-tailed deer killed to all animals killed is 0.43.

Table 17. Ratios of animals killed to white-tailed deer killed on the Kootenay Parkway from 1988-1994 derived from Table 9 (from data in Kerr, 1998).

Species	Total	Ratio of number killed to white-tailed deer killed
Elk	66	0.50
Mule deer	39	0.29
White-tailed deer	133	1.00
Moose	25	0.19
Bighorn sheep	21	0.16
Black bear	8	0.06
Coyote	20	0.15
Year totals	312	2.35

Cook and Daggett (1995, p. 5), citing the 1981 report *Effects of Highways on Wildlife*, tabulate road-kill data in the southeast, midwest, Oregon, and California. The road-kill ratios on interstate highways compared to country roads are given in Table 12 (p. 41), Table 15 (p. 50), and Table 16 (p. 51). A 14 county study in Virginia found ratios of small animals killed to deer of: opossum 95%, dogs 88%, raccoons 76%, cats 65%, skunks 26%, and rabbits 20%.

Table 18 summarizes the data from United States and Canadian reports, for deer, small mammals, birds, amphibians, and reptiles. The category “small mammals” has been broken out as squirrels, opossums, and “other” small mammals. The table gives mortality ratios for selected pairs of species. Other ratios can be estimated from the data. The bottom of the table gives summary information for the computed ratios: the shape of the distribution, the arithmetic mean and standard error on the mean (SEM), median, and the geometric mean and 95% confidence limits on the geometric mean. With the exception of the ratio “deer/opossum”, the ratios are best characterized as log-normal distributions. For these ratios, the arithmetic mean and SEM are biased, as can be seen by comparison of the mean and median. For a Normal distribution the sample mean . sample median, but for a lognormal distribution the sample mean > median. Excepting the “deer/opossum” ratio, for which the arithmetic mean and SEM should be used (shaded), the geometric mean and 95% confidence limits (shaded) should be used to characterize the ratios of species-mortality.

Use of the *lower* bound provides a conservative estimate of the average numbers of a species killed given data for another species. For example, if an average of 12,000 deer are killed in each of the UMRS states annually, then a conservative estimate of the numbers of small mammals killed in each state is 12,000/0.06 . 200,000, or a total of 10^6 per year. If the geometric mean is used in this calculation, the “expected value” is 12,000/0.1 = 120,000 per state, and using the *upper* 95% bound liberal estimate of 12,000/0.15 = 80,000 small mammals killed per state.

Table 18. Frequency of road-kill for selected species, and for selected ratios of species.

SPECIES										RATIOS OF SPECIES							
Reference	Year	Deer	Squirrel	Opossum	Other Small Mammals	Amphibian	Reptile	Coyote	Birds	Squirrel/Small Mammals	Deer/Opossum	Deer/Small Mammals	Deer/Coyote	Birds/Small Mammals	Birds/ Squirrels	Birds/ Opossum	Birds/ Reptiles
47	1978	54						11				.	4.91	.	.	.	.
123	1969	158		186	2,033			113	.	.	0.85	0.071	1.40	.	.	.	.
123	1970	151		311	1,899			134	.	.	0.49	0.068	1.13	.	.	.	.
123	1971	210		318	1,713			134	.	.	0.66	0.103	1.57	.	.	.	.
123	1972	163		374	1,,912			155	.	.	0.44	0.071	1.05	.	.	.	.
123	1973	248		384	2343			192	1326	.	0.65	0.091	1.29	.	.	.	.
123	1974	218		250	1,700			121	654	.	0.87	0.112	1.80	.	.	.	.
123	1975	170		139	1,241			79	354	.	1.22	0.123	2.15	.	.	.	.
122	1976	6	2	51	83	16	34	3	49	0.015	0.12	.	2.00	.	.	.	.
110	1970-80	348						79	.	.		.	4.41	.	.	.	.
110	1970-80	203						60	.	.		.	3.38	.	.	.	.
110	1970-80	96						8	.	.		.	12.00	.	.	.	.
110	1970-80	38						2	.	.		.	19.00	.	.	.	.
110	1970-80	59						16	.	.		.	3.69	.	.	.	.
271	1938				20	24			.	.		.		.	.	.	.
234	1935		7	5	140	2	23		163	0.046		.		1.07	23.29	32.60	7.09
228	1969-70		14	5	15				11	0.412		.		0.32	0.79	2.20	.
227	1961-62	18	86	54	370		5		35	0.169	0.33	.		0.07	0.41	0.65	7.00
222	1956-57		91	22	77				138	0.479		.		0.73	1.52	6.27	.
203	1935		2		23		21		9	0.080		.		0.36	4.50	.	0.43
202	1934		6		49		9		60	0.109		.		1.09	10.00	.	6.67
199	1924		2		20		29		142	0.091		.		6.45	71.00	.	4.90
198			10	4	203	2	64		607	0.046		.		2.80	60.70	151.75	9.48
190	1941		1,422	399	6,262				3,775	0.176		.		0.47	2.65	9.46	.
188	1938-39			11	34				.	.		.		.	.	.	.
173	1964					150	228		217	.		.		.	.	.	0.95
158	1938		163	5	17,888	1	59		818	0.637		.		2.36	5.02	163.60	13.86
156	1934		11	6	680		27		153	0.016		.		0.22	13.91	25.50	5.67
139	1941-44		239	5	1975	1,181	1,116	2	1,583	0.089		.		0.71	6.62	316.60	1.42

Table 18. Frequency of road-kill for selected species, and for selected ratios of species.

SPECIES										RATIOS OF SPECIES							
Reference	Year	Deer	Squirrel	Opossum	Other Small Mammals	Amphibian	Reptile	Coyote	Birds	Squirrel/Small Mammals	Deer/Opossum	Deer/Small Mammals	Deer/Coyote	Birds/Small Mammals	Birds/ Squirrels	Birds/ Opossum	Birds/ Reptiles
125	1979				34	10,040	237		502	.		.		14.76	.	.	2.12
125	1980				19	11,466	219		287	.		.		15.11	.	.	1.31
125	1992		2	12	38	711	180		289	0.038		.		5.56	144.50	24.08	1.61
125	1993			7	12	7,817	228		224	.		.		11.79	.	32.00	0.98
201	1936	32			53		1		3					0.06	.	.	3.00
200	1935	12			73		4		7					0.10	.	.	1.75
23	1987-88					74	14		21								
210	1938		5		118		1		3								
Shape										**LN**	**N**	**LN**	**LN**	**LN**	**LN**	**LN**	**LN**
Mean ± SEM										**0.15 ± 0.04**	**0.62 ±0.11**	**0.14 ±0.05**	**4.27±1.36**	**2.85 ± 0.98**	**24.67±10.24**	**51.62±23.25**	**3.90±0.82**
Median										**0.09**	**0.65**	**0.09**	**2.08**	**0.49**	**6.62**	**9.46**	**2.12**
GM (95% CI)										**0.09 (0.05,0.15)**	**-----------**	**0.10 (0.06,0.15)**	**2.75 (1.73,4.37)**	**0.72 (0.35,1.51)**	**7.1 (2.8, 17.8)**	**11.5 (4.2, 31.6)**	**2.63 (1.74,3.98)**

Distribution: N = normal, LN = lognormal, as determined from probability plots, skew and divergence of median and mean.

Mean ± SEM = arithmetic mean and standard error on the mean; GM (95% CI) were calculated from the logarithms of the values.

47 (Leighton, 1988); 103 (Leedy, 1975); 110 (Parks Canada, 1981); 122 (Wilkins and Schmidly, 1980); 123 (Case, 1978); 125 (Ashley and Robinson, 1996); 139 (McClure, 1951); 156 (Dickerson, 1939); 158 (Scott, 1938); 173 (Oxley *et al.* 1974); 188 (Davis, 1940); 190 (Haugen, 1944); 198 (Starrett, 1938); 199 (Stoner, 1925); 200 (Warren, 1936); 201 (Warren, 1936); 202 (Davis, 1934); 203 (Dreyer, 1935); 222 (Abbott, 1958); 227 (MacNamara, 1962);228 (Evenden, 1971); 234 (Stoner, 1936); 271 (Pickles, 1942).

A common practice of conservation biologists is to estimate the size of a population using hunting-season and sight records. “If the annual changes in the road-kill reflect deer [a species] population trends, the percentage changes must be biologically possible in terms of deer [the species] reproduction and mortality” (Jahn, 1959). Hubert (1989), considering raccoon road-kill in Illinois, remarked: “A major problem associated with the road-kill index is minimal knowledge of the exact relationship between the frequency of road-kills and animal density. This problem must be resolved on a species by species basis…through a long-term monitoring program.” To possibly assist in the interpretation of road-kill data in subsequent tables, Table 19 gives the number of fur-bearer pelts taken in Illinois in the 1995-1996 and 1996-1997. Pelt prices are also provided to assist any economic analysis made using these data.

Table 19. Number of fur-bearer pelts taken, and average price per pelt, in Illinois (1995-1997). (Data from Bob Bluett, Illinois Department Natural Resources, Springfield.)

Species	Number of pelts taken		Average pelt price, $		Total fur value, $	
	1995-96	1996-97	1995-96	1996-97	1995-96	1996-97
Muskrat	50,631	41,167	2.1	4.2	106,325	172,901
Mink	3,185	3,948	7.4	13.05	23,569	51,521
Raccoon	153,052	229,805	7.6	12	1,163,195	2,757,660
Opossum	9,509	16,693	1.1	1.3	10,460	21,701
Red fox	1,525	2,103	13.2	14.55	20,130	30,599
Gray fox	340	257	8.75	8.75	2,975	2,249
Beaver	3,902	6,310	9.5	13.35	37,069	84,239
Striped skunk	164	214	1.75	2.5	287	535
Weasel	15	6	0.65	0.5	10	3
Coyote	8,001	5,289	7.1	8.35	56,807	44,163
Badger		50		9.95	0	498
Total/Mean	**230,324**	**305,842**	**6.15**	**10.35**	**1,420,827**	**3,166,068**

Road-kill data for Illinois collected by Illinois Department of Conservation were provided by George Hubert, Jr. and Bob Bluett (Illinois Department of Conservation). Table 20 presents the number of road-kills in 1995 in Illinois by month. Table 21 summarizes the number of road-kills, by year, for several species for the years 1976-1997. Table 22 presents various species ratios of road-kills unadjusted for the number of miles traveled. The summary statistics at the bottom of the table give the mean for the unweighted ratios and for ratios weighted by the number of miles traveled in the month. It can be seen that the un-weighted and weighted means are essentially the same. The statistics include the standard deviation and the standard deviation on the mean (SEM) for the un-weighted ratios. The SEM is used to calculate the confidence limits on the unadjusted mean.

Table 20. Road-kills, by month, in Illinois during 1995.

Month	Miles	Rabbit	Raccoon	Skunk	Opossum	Pheasant	Woodchuck
Jan	43,174	108	50	46	98	3	2
Feb	35,742	130	117	125	158	6	4
Mar	39,588	261	182	132	198	24	16
Apr	32,035	195	237	62	238	25	22
May	37,079	166	274	45	310	26	21
Jun	40,202	156	427	82	167	16	55
Jul	43,917	180	572	83	169	20	40
Aug	56,096	111	331	54	220	28	31
Sep	42,035	81	514	69	327	20	17
Oct	33,882	129	579	63	302	21	8
Nov	26,992	97	130	41	158	13	5
Dec	17,029	51	36	15	52	3	1
Mean	37,314	138.8	287.4	68.1	199.8	17.1	18.5
SD	9,661	56.8	196.8	33.8	84.4	8.9	16.7
SEM	2,789	16.4	56.8	9.8	24.4	2.6	4.8
CV, %±SD	25.9	41.0±8.7	68.5±14.6	49.7±10.6	42.3±9.0	52.3±11.2	90.1±19.2

It is instructive to compare the coefficient of variations (CV = SD/mean, %) for a given species in Table 21 with values in Table 20. Annual (monthly) $CV \pm SD_{CV}$[2] are: raccoon 44±6.8% (69±14.6%), skunk 43±6.7% (50±10.6%), opossum 32±5.2% (42±9.0%). For these three species, the monthly variability is numerically larger than the annual variability. For skunk and opossum, these values are subjectively "similar", but the similarity for raccoon is less obvious. For a species, a formal statement of "similarity" requires a statistical test of the pair of CV values. In lieu of a formal test of equivalence of the CVs, we note that the confidence regions overlap, which implies "similarity."

[2] The variance of the coefficient of variation is given by CV/[2(n-1)]. See National Bureau of Standards Special Publication 300, Volume 1, p. 337-269 (1969).

Table 21. Number of opossum, raccoon, and striped skunk road kills in Illinois between 1976 and 1997.

Year	Opossum			Raccoon			Striped Skunk			Opossum/ Raccoon	Opossum/ Skunk	Raccoon Skunk
	Miles	Killed	Kill/mile	Miles	Killed	Kill/mile	Miles	Killed	Kills/mile			
1976	538,681	1,642	0.0030	430,537	1,464	0.0034	430,537	912	0.0021	0.90	1.44	1.61
1977	530,470	873	0.0016	485,263	1,219	0.0025	485,263	1,136	0.0023	0.66	0.70	1.07
1978	520,345	703	0.0014	531,772	1,263	0.0024	531,772	1,339	0.0025	0.57	0.54	0.94
1979	509,615	958	0.0019	530,616	1,215	0.0023	530,616	1,791	0.0034	0.82	0.56	0.68
1980	509,516	1,427	0.0028	520,843	1,042	0.0020	52,084	2,302	0.0442	1.40	0.06	0.05
1981	508,282	1,542	0.0030	505,095	1,218	0.0024	505,095	2,616	0.0052	1.26	0.59	0.47
1982	470,425	2,482	0.0053	509,321	1,137	0.0022	509,321	2,590	0.0051	2.36	1.04	0.44
1983	509,131	1,945	0.0038	503,302	1,067	0.0021	503,302	2,244	0.0045	1.80	0.86	0.48
1984	529,734	2,172	0.0041	472,524	1,379	0.0029	472,524	1,276	0.0027	1.40	1.52	1.08
1985	507,663	2,673	0.0053	514,162	1,377	0.0027	514,162	954	0.0019	1.97	2.84	1.44
1986	515,082	2,925	0.0057	532,904	1,293	0.0024	532,904	1,233	0.0023	2.34	2.45	1.05
1987	541,980	2,351	0.0043	502,226	1,681	0.0033	502,226	1,155	0.0023	1.30	1.89	1.46
1988	551,168	2,040	0.0037	515,224	1,551	0.0030	515,224	1,027	0.0020	1.23	1.86	1.51
1989	494,220	2,718	0.0055	554,070	2,015	0.0036	554,070	958	0.0017	1.51	3.18	2.10
1990	503,141	2,557	0.0051	546,628	2,573	0.0047	546,628	1,105	0.0020	1.08	2.51	2.33
1991	437,494	2,260	0.0052	494,709	2,850	0.0058	494,709	1,383	0.0028	0.90	1.85	2.06
1992	422,842	2,137	0.0051	502,525	2,853	0.0057	502,525	1,210	0.0024	0.89	2.10	2.36
1993	457,710	2,662	0.0058	430,787	2,926	0.0068	430,787	848	0.0020	0.86	2.95	3.45
1994	457,559	2,439	0.0053	426,918	3,008	0.0070	426,918	868	0.0020	0.76	2.62	3.47
1995	415,037	2,059	0.0050	458,334	3,254	0.0071	458,334	1,073	0.0023	0.70	2.12	3.03
1996				442,207	3457	0.0078	442,207	799	0.0018			4.33
1997				416,541	3285	0.0079	416,541	754	0.0018			4.36
Mean	**496,505**	**2,028**	**0.00414**	**492,114**	**1,960**	**0.00410**	**470,807**	**1,344**	**0.00452**	**1.23**	**1.68**	**1.81**
SD	**39,780**	**646**	**0.00142**	**41,265**	**866**	**0.00208**	**102,021**	**579**	**0.00892**	**0.54**	**0.93**	**1.26**
SEM	**8,895**	**144**	**0.00032**	**8,798**	**185**	**0.00044**	**21,751**	**124**	**0.00190**	**0.12**	**0.21**	**0.27**
CV, %±SD	**8.0**	**31.9± 5.2**	**34.2**	**8.4**	**44.2± 6.8**	**50.8**	**21.7**	**43.1± 6.7**	**197.5**	**43.5**	**55.2**	**69.5**

Table 22. Species ratios of road-kills calculated from the 1995 monthly Illinois road-kill data.

Month	Opossum/ Raccoon	Opossum/ Skunk	Raccoon/ Skunk	Opossum/ Rabbit	Raccoon/ Rabbit	Skunk/ Rabbit	Opossum/ Pheasant	Raccoon/ Pheasant	Skunk/ Pheasant	Rabbit/ Pheasant
Jan	1.96	2.13	1.09	0.91	0.46	0.43	32.67	16.67	15.33	36.00
Feb	1.35	1.26	0.94	1.22	0.90	0.96	26.33	19.50	20.83	21.67
Mar	1.09	1.50	1.38	0.76	0.70	0.51	8.25	7.58	5.50	10.88
Apr	1.00	3.84	3.82	1.22	1.22	0.32	9.52	9.48	2.48	7.80
May	1.13	6.89	6.09	1.87	1.65	0.27	11.92	10.54	1.73	6.38
Jun	0.39	2.04	5.21	1.07	2.74	0.53	10.44	26.69	5.13	9.75
Jul	0.30	2.04	6.89	0.94	3.18	0.46	8.45	28.60	4.15	9.00
Aug	0.66	4.07	6.13	1.98	2.98	0.49	7.86	11.82	1.93	3.96
Sep	0.64	4.74	7.45	4.04	6.35	0.85	16.35	25.70	3.45	4.05
Oct	0.52	4.79	9.19	2.34	4.49	0.49	14.38	27.57	3.00	6.14
Nov	1.22	3.85	3.17	1.63	1.34	0.42	12.15	10.00	3.15	7.46
Dec	1.44	3.47	2.40	1.02	0.71	0.29	17.33	12.00	5.00	17.00
Mean	**0.98**	**3.39**	**4.48**	**1.58**	**2.23**	**0.50**	**14.64**	**17.2**	**5.97**	**11.67**
SD[1]	0.49	1.66	2.74	0.92	1.80	0.21	7.71	8.03	5.90	9.25
SEM[2]	**0.14**	**0.48**	**0.79**	**0.26**	**0.52**	**0.06**	**2.23**	**2.32**	**1.70**	**2.67**
Weighted mean[3]	0.93	3.35	4.67	1.62	2.38	0.51	14.41	17.63	5.99	11.44

[1]Sample standard deviation for the unweighted mean.
[2]Standard error on the unweighted mean. This is the value that has to be used to calculate confidence intervals on the mean.
[3]Weighted mean calculated as the average of: ratio × miles/(total miles = 447,771).

Table 23. Annual pelt prices in Illinois, annual inflation rate, and cumulative inflation rate from 1975 to 1997. Pelt prices were obtained from Bob Bluett, Illinois Department of Natural Resources (December 11, 1998). Annual inflation rate was obtained from the Internet (www.mfs.com/education/work_calc/infldef.html). Cumulative inflation rate was calculated by author from annual inflation rates.

Year	Annual inflation	Cumulative inflation	Raccoon $/pelt	Possum $/pelt	Beaver $/pelt	Muskrat $/pelt	Mink $/pelt	Weasel $/pelt	Skunk $/pelt	Red fox $/pelt	Grey fox $/pelt	Coyote $/pelt
1975	**1**	**1.00**	14.00	1.10	4.50	2.90	6.00	0.55	1.00	34.00	16.00	8.00
1976	**1.05**	**1.05**	17.17	1.20	7.00	4.44	13.95	0.54	2.25	45.60	27.65	16.07
1977	**1.07**	**1.12**	18.00	2.05	6.60	5.10	13.20	0.60	2.20	47.45	31.05	16.75
1978	**1.09**	**1.22**	27.25	2.65	7.25	5.00	15.20	0.65	2.55	61.50	42.95	31.35
1979	**1.13**	**1.38**	25.20	3.35	14.40	6.35	20.15	0.50	2.60	48.40	43.80	22.85
1980	**1.12**	**1.55**	19.40	1.45	10.60	6.50	18.90	0.60	2.00	44.80	36.40	19.25
1981	**1.09**	**1.69**	22.50	1.05	6.40	4.30	17.45	0.50	2.15	46.75	28.75	24.45
1982	**1.04**	**1.76**	14.55	0.95	4.95	2.75	13.90	0.50	1.50	30.40	26.35	13.85
1983	**1.04**	**1.83**	13.15	0.85	5.45	3.15	15.15	0.65	1.55	30.90	27.35	9.40
1984	**1.04**	**1.90**	17.25	0.95	6.80	3.55	16.60	0.55	1.05	27.20	24.10	8.30
1985	**1.04**	**1.98**	13.80	0.95	9.45	2.50	14.70	0.45	2.50	17.55	16.15	9.25
1986	**1.01**	**2.00**	18.95	1.15	12.40	3.70	21.05	0.55	1.85	22.15	23.40	13.70
1987	**1.04**	**2.08**	14.10	1.00	10.50	4.00	23.05	0.80	1.40	16.75	25.05	9.35
1988	**1.04**	**2.16**	6.40	0.80	7.80	2.40	23.60	0.60	2.10	11.45	11.70	3.50
1989	**1.05**	**2.27**	4.00	0.50	7.00	1.15	17.85	0.55	1.95	9.60	5.85	3.05
1990	**1.06**	**2.40**	2.95	0.70	5.00	0.95	15.85	0.50	1.95	6.25	3.45	4.10
1991	**1.03**	**2.48**	6.45	1.05	3.85	1.75	19.35	-	1.65	12.90	8.20	10.45
1992	**1.03**	**2.55**	5.05	1.00	3.30	1.65	18.30		1.70	10.65	6.65	10.85
1993	**1.03**	**2.63**	5.85	1.25	6.60	1.90	13.75	0.50	2.30	10.25	8.00	8.75
1994	**1.03**	**2.70**	6.70	1.20	8.50	1.85	11.40	0.75	1.75	11.80	9.65	7.30
1995	**1.02**	**2.76**	7.60	1.10	9.50	2.10	7.40	0.65	1.75	13.20	8.75	7.30
1996	**1.03**	**2.84**	12.00	1.30	13.35	4.20	13.05	0.50	2.50	14.55	8.75	8.35
1997	**1.02**	**2.90**	10.50	1.05	12.65	2.90	9.50	3.40	3.55	11.95	7.30	5.90
		Mean	**13.17**	**1.25**	**7.99**	**3.26**	**15.62**	**0.68**	**1.99**	**25.48**	**19.45**	**11.83**
		Median	**13.80**	**1.05**	**7.00**	**2.90**	**15.20**	**0.55**	**1.95**	**17.55**	**16.15**	**9.35**

In order to examine the stability of the mean ratios, a Monte Carlo simulation was carried out for the opossum-to-raccoon ratio using the Illinois 1976-1997 road kill data (Table 21. Each of the 4 variables, road miles and numbers killed for opossums, and road miles and numbers killed for raccoons, fitted a Normal distribution. The ratio of interest was calculated as (opossums killed per mile)/(raccoons killed per mile), where the four values for a given sample were independently drawn from their respective distributions. A total of 2,100 ratios were drawn, from which ratios <0 and >3 were dropped. (Negative values occur because the range of the Normal distribution is $-\infty$ to $+\infty$. Values >3 were dropped because actual ratios from 1975-1977 were <3.) Table 24 shows the remaining 1,948 values had a mean ± SEM of 1.10 ± 0.013 (shaded row), which results in a 95% confidence interval about the mean (SEM) of 1.07 to 1.120 (shaded rows). Table 24 and Figure 10 show that the skew is high for a Normal distribution, and the ratios appear to have a log-normal distribution. The values in Table 21 had a mean ± SEM of 1.23 ± 0.12. (The SEM for the simulation is based on 1,948 values whereas there are 20 actual values.) The simulation suggests that the ratios in Table 21 are fairly stable, which implies that other data from Illinois in other tables also provide stable ratios. It is not appropriate to carry out a similar simulation using the data in Table 18 because the samples were collected in different areas of the country, over several decades, using inconsistent methods.

Figure 10. Histogram of 1,948 Monte Carlo simulations of opossum/raccoon road-kill ratios and overlayed Normal distribution. Data distributions used in the simulation were from 1976-1997 Illinois road-kills from Table 21

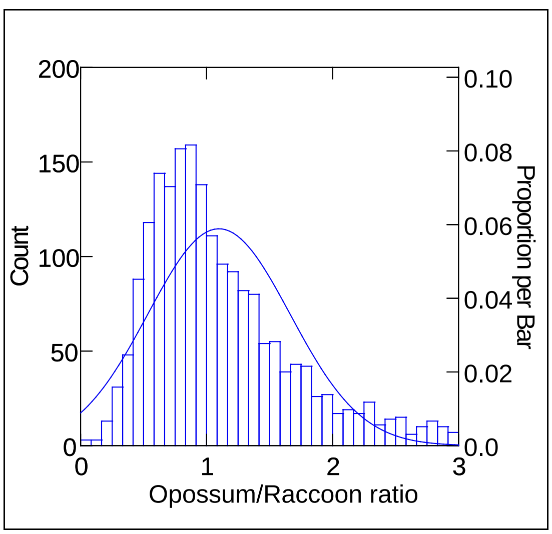


Table 24. Summary statistics for Monte Carlo simulation of opossum/raccoon road-kill ratios. Data distributions used in the simulation were 1976-1997 Illinois road-kill data used in the simulation were from Table 21.

N of cases	1948
Minimum	0.0184
Maximum	2.9976
Median	0.9622
Mean	1.0981
95% CI Upper	1.1232
95% CI Lower	1.0730
Std. Error	0.0128
Standard Dev	0.5647
Variance	0.3189
C.V.	0.5142
Skewness(G1)	1.0703
SE Skewness	0.0555
Kurtosis(G2)	0.8860
SE Kurtosis	0.1109

Table 25 uses the 1976-1997 road-kill data for opossum, raccoon, and striped skunk from Table 21 and the price per pelt from Table 23 to estimate the annual and long-term average value (in constant dollars) of animals killed by vehicles in Illinois. The average annual *total* value (1975-1995) was $50,838. The totals for 1996 and 1997 in Table 25 omit opossum. Time series analysis showed annual variability in each series (Figure 11). Furthermore, the price-adjusted values followed a decreasing trend from 1976-1995 (Figure 11), and this trend was statistically significant (Figure 12). Analysis of covariance (ANCOVA) showed that most of the trend was due to a decrease in the inflation-adjusted pelt prices from 1975 to 1997. Thus, although the total number of animals killed by vehicles increased during this period, the declining inflation-adjusted value of a pelt resulted in a decrease in the total fur values for road-killed animals.

Table 25. Average economic value of fur-bearers killed by vehicles in Illinois from 1976-1997, calculated from the number of animals killed from Table 21 and the average pelt price for 1995-1997 in Table 23.

Year	Inflation factor, Cumulative	Opossum			Raccoon			Skunk			Total value $
		# Road-killed	Pelt price $	Road-kill value $	# Road-killed	Pelt price $	Road-kill value $	# Road-killed	Pelt price $	Road-kill value $	
1975	2.90		1.10	-		14.00	-		1.00	-	-
1976	2.84	1,642	1.20	5,599	1,464	17.17	71,423	912	2.25	5,830	82,852
1977	2.76	873	2.05	4,937	1,219	18.00	60,529	1,136	2.20	6,894	72,360
1978	2.70	703	2.65	5,038	1,263	27.25	93,080	1,339	2.55	9,234	107,353
1979	2.63	958	3.35	8,427	1,215	25.20	80,395	1,791	2.60	12,227	101,048
1980	2.55	1,427	1.45	5,275	1,042	19.40	51,533	2,302	2.00	11,737	68,544
1981	2.48	1,542	1.05	4,007	1,218	22.50	67,828	2,616	2.15	13,920	85,755
1982	2.40	2,482	0.95	5,666	1,137	14.55	39,752	2,590	1.50	9,335	54,754
1983	2.27	1,945	0.85	3,748	1,067	13.15	31,807	2,244	1.55	7,885	43,440
1984	2.16	2,172	0.95	4,455	1,379	17.25	51,357	1,276	1.05	2,893	58,704
1985	2.08	2,673	0.95	5,271	1,377	13.80	39,448	954	2.50	4,951	49,670
1986	2.00	2,925	1.15	6,714	1,293	18.95	48,909	1,233	1.85	4,553	60,176
1987	1.98	2,351	1.00	4,646	1,681	14.10	46,843	1,155	1.40	3,196	54,685
1988	1.90	2,040	0.80	3,101	1,551	6.40	18,863	1,027	2.10	4,098	26,063
1989	1.83	2,718	0.50	2,483	2,015	4.00	14,727	958	1.95	3,413	20,624
1990	1.76	2,557	0.70	3,145	2,573	2.95	13,336	1,105	1.95	3,786	20,266
1991	1.69	2,260	1.05	4,009	2,850	6.45	31,055	1,383	1.65	3,855	38,919
1992	1.55	2,137	1.00	3,312	2,853	5.05	22,330	1,210	1.70	3,188	28,830
1993	1.38	2,662	1.25	4,605	2,926	5.85	23,687	848	2.30	2,699	30,991
1994	1.22	2,439	1.20	3,584	3,008	6.70	24,680	868	1.75	1,860	30,125
1995	1.12	2,059	1.10	2,545	3,254	7.60	27,785	1,073	1.75	2,110	32,439
1996	1.05		1.30		3457	12.00	43,558	799	2.50	2,097	45,656[1]
1997	1.00		1.05		3285	10.50	34,493	754	3.55	2,677	37,169[1]
	Mean, $			4,313			40,757			5,323	50,838[2]
	SD, $			1,719			22,919			3,716	28,111[2]
	SEM, $			375			4,779			775	6,134[2]
	CV, %			40			56			70	55[2]

[1]Does not include opossum.
[2]Values are for 1975-1995, due to the missing values for opossum in 1996-1997.

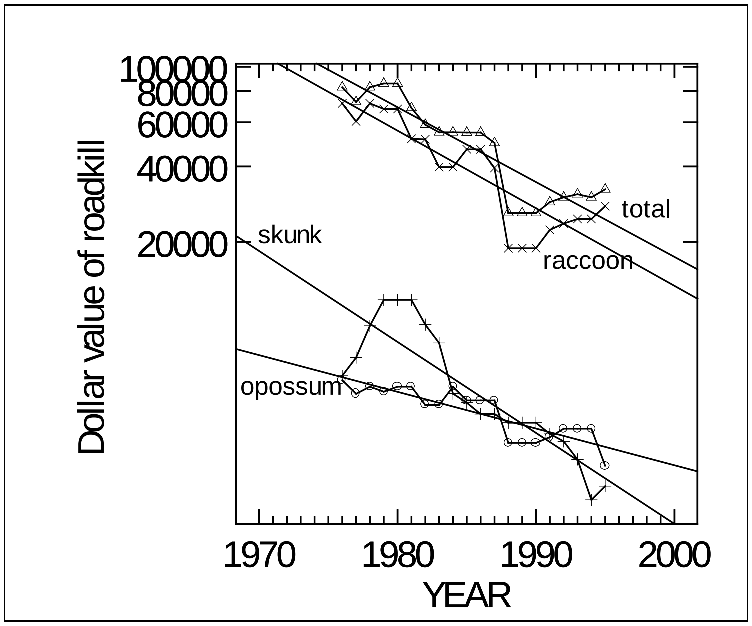


Figure 11. Smoothed time series (median smoother, n=5) for the pelt value of road-killed opossum, skunk, raccoon, and total, in Illinois from 1976-1995.

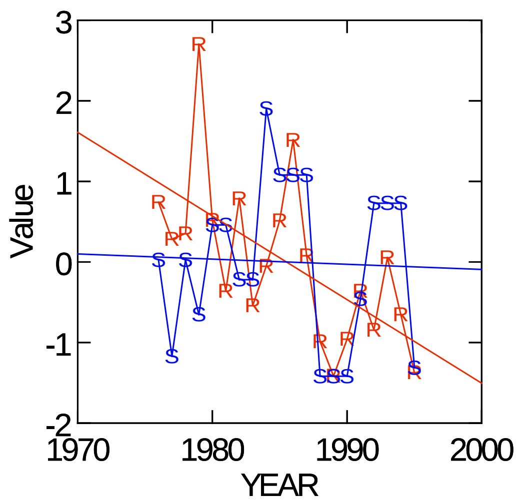


Figure 12. Time series and regression for smoothed, standardized, pelt values for road-killed raccoon, without (R) and with (S) detrending. The detrended and raw regression lines differ significantly (P < 0.001).

MODELING HUMAN IMPACTS ON WILDLIFE: HABITAT FRAGMENTATION AND LINKAGE ZONES

As a preface to the next chapter, this section briefly reviews one method that is being used to assess the effects of transportation corridors on wildlife. The next chapter gives a simple model for estimating increases in wildlife mortality along the UMRS transportation corridor as a result of shipping goods *via* highways and railroads. The GIS approach can be adapted to produce a more geographically specific analysis of impacts in the UMRS corridor. The example is Apps (1997), who used GIS to determine human impacts on grizzly bears in British Columbia.

> A "GIS-based modeling methodology for identifying grizzly bear linkage zones has been developed through the Grizzly Bear Recovery Program of the US Fish and Wild Service (USFWS). The resulting linkage zone prediction (LZP) model is intended for application along major valley bottoms and transportation corridors that represent potential population fractures at a regional scale. The LZP approach has largely evolved from earlier cumulative effects analysis (CEA) models….However, its focus is more specific to human disturbance and influence, while inherent habitat quality is of lesser consequence. It is assumed that in areas of high human development, human-influence will limit bear persistence and movement potential, as opposed to seasonal food availability" (Apps, 1997, p. 8).

The four components of the LZP each give a GIS layer scored according to human-influence on bears: developed human features, linear disturbance, visual cover, and riparian areas. Summing the layers produces a scored map depicting cumulative human-influence on grizzly bear habitat use and mortality risk.

Terrain Resource Information Management (TRIM) data from 1:2000 maps were used to derive planimetric features of human development, linear disturbance, and hydrography. Human features were categorized (an scored) as: >200 m from influence zone (2); 100-200 m from influence zone (4); <100 m from influence zone (5); within influence zone (6). The linear disturbance feature types are given in Table 26. Human-influence scores were assigned to linear disturbance density (mi/mi^2) classes. For density in km/2.25 km^2, the scores are: 0 (2); 0-1.6 (3); 1.6-3.2 (4); >3.2 (5). Human-influence scores assigned to visual cover classes are: cover or edge or non-cover >500 m from roads (2); cover[3] or edge <500 m from roads (30; and non-cover <500 m from roads (5). Riparian areas and lake scores are: riparian areas (1); non-riparian areas (2); lakes (4).

Table 26. Linear disturbance feature types and relative weightings for density calculations (Apps, 1997, Table 5-3).

Disturbance Class	Specific Feature Types	Weight
Primary	all paved roads	2
Secondary	all gravel and 2 lane loose roads and rail lines	1
Tertiary	all rough, loose dry weather and 4-wheel drive roads	0.5
Quaternary	"cart-tracks", seismic lines, and all above ground transmission and pipe lines	0.25

[3] Apps (1997) Table 5-5 gives this cover score as 2, but this is inconsistent with other values.

Summing the scored layers at each point produces an image with scores ranging from 7 to 20. The values were grouped into four human-influence levels, which are "assumed to equate with the degree to which bears are influenced, through either direct displacement or increased mortality risk" (Apps, 1997, p. 14). The cumulative scores and corresponding influence level ratings for grizzly bears are: 7-10 minimal influence; 11-12 low influence; 13-14 moderate influence; ≥15 high influence.

The values used for Canadian grizzly bears in the four human-influence layers and the cumulative influence rating, are probably not ideal for deer (or other species) in the UMRS corridor. However, they provide a starting point for an iterative process of mapping of features, calculation, mapping of linkage and habitat fragmentation zones, review by wildlife experts, and revision of scores. "Linkage zones are assumed to represent those areas with minimal movement restrictions (habitat displacement) and lowest mortality risk to [a specific species]" (Apps, 1997, p. 14).

> "GIS output is notorious for being misperceived as reality….Results of GIS based models must therefore be interpreted with caution and assumptions explicitly understood where used in planning applications. Moreover, a model should be expected to evolve and adapt as assumptions and output are tested against real data. Therefore, a model's efficacy as a conservation tool relies also on planning that is committed to maximizing future options….Finally, it must be recognized that GIS-based models are developed and/or tested relative to specific sources of geographic data. They are thus only truly repeatable, with comparability of output, as applied to data of the same scale, accuracy, and detail" (Apps, 1997, p. 8).

A related application of GIS was reported by Carr et al. (1998). They used GIS for identifying the interface between ecological greenways and roadway systems at the state and sub-state scales. They concluded that GIS is useful for identification of interfaces at these scales for at least four stages of transportation planning and design. These are: (1) identification of alternative corridors; (2) design for new horizontal and vertical roadway alignments within selected corridors; (3) detailed design of existing roadway expansions and new roadway construction, especially taking into consideration opportunities for bridges, underpasses and overpasses created by grade separations; and (4) determining and designing environmental mitigation strategies.

PERCEPTIONS OF RISK FROM DEER-RELATED VEHICLE ACCIDENTS

Stout et al. (1993) hypothesized that public preferences for deer population levels are influenced by perceptions of risk from deer-related vehicle accidents (DRVA's). Responses to mail questionnaires from 397 residents (66% response rate) in Tompkins County, New York, indicated most (88%) were aware of DRVA's in the county, and 28% had been involved in a DRVA. Preferences for decreasing the size of the deer herd were based on respondents' perceptions of social benefits from deer and probability of DRVA occurrence, tolerance of deer-related problems, and personal involvement with DRVA's. These findings have implications for identifying deer-population-management and risk-communication strategies that foster congruency between public perception of risk and the actual incidence of the risk-producing event. A logistic regression model with 4 significant independent variables was used to predict preference for reducing the deer population. The four variables are: (1) degree to which the respondent perceived few social benefits from deer (SOCALB), (2) degree of problem-intolerance toward deer (INTOL), perceived probability of DRVA occurrence (OCCUR), and personal involvement DRVA's (INVOL). The categorical variable of personal involvement as regressed using contrast variables ($INVOL_1$ and $INVOL_2$) for low (1,0), moderate (0,1) and high (-1,-1) categories. Defining P_i as the probability that a respondent *will prefer a reduction* in the deer population, the standardized model parameters from the logistic regression (with standard errors in parentheses), were:

$$ln[(P_i)/(1-P_i)] = -8.41(1.23) + 0.177\ (0.0476)\ SOCALB + 0.197\ (0.0400)\ INTOL + 0.267\ (0.0843)\ OCCUR – 0.994\ (0.427)\ INVOL_1 + 0.642\ (0.262)\ INVOL_2.$$

This equation is the natural log of the "odds ratio" $[P_i/(1-P_i)]$. Denoting the "log-odds" value for respondent *i* by Z_i, the probability that a respondent preferred a reduction in the size of the deer population is $P_i = \exp(Z_i)/[1+\exp(z_i)]$.

The meaning of the logistic model equation can be determined using the values for an average respondent, where the log-odds value is:

$$ln[(P_i)/(1-P_i)] = -8.41 + 0.177(9.047) + 0.197(14.9) + 0.267(10.4) – 0.99427(0) + 0.642(1) = -0.455.$$

Thus, the respondent having these average values had a probablity of preferring a decrease in the deer herd of $P_i = 0.388$, or about a 39% chance of preferring a decrease. If, as a result of a DRVA, a respondent's risk perception increased, then the log-odds value = 0.434 and $P_i = 0.607$. This probability will increase if a person's perception of deer-related benefits (SOCALB) or tolerance to deer-related problems (INTOL) decrease with risk-evoking experience.

$$ln[(P_i)/(1-P_i)] = -8.41 + 0.177(9.047) + 0.197(14.9) + 0.267(10.4) – 0.99427(-1) + 0.642(-1) = 0.434.$$

The authors present social and biological deer management alternatives for different levels of perceived risks compared to actual incidence of deer-related vehicle accidents (Table 27). The logistic regression equation can be used to calculate a reference value ($OCCUR_{ref}$) for discriminating high versus low risk perception. The authors give the following example. Define $P_{standard}$ as the acceptable probability that the public prefers a reduction in the size of the deer herd. Assume a wildlife manager sets $P_{standard} = 0.65$, then substitution gives $OCCUR_{ref} = 14.4$ (see below). As given above, for the average resident P =

0.388 and OCCUR = 10.4. Comparing $OCCUR_{ref}$ to OCCUR, the manager goes to the "low perceived risk" portion of the decision matrix.

$$OCCUR = \ln[0.65/(1-0.65)] - [-8.41 + 0.177(9.047) + 0.197(14.9) + 0.642(1)]/0.267 = 14.4.$$

Table 27. Social and biological deer management alternatives for different levels of perceived risks compared to actual incidence of deer-related vehicle accidents (Stout et al., 1993).

Perceived risk associated with DRVA's	**Actual incidence of DRVA's**	
	Low	**High**
Low	Social Approach Communicate benefits of alternative population levels. Biological Approach Increase or maintain population.	Social Approach Communicate risk avoidance behaviors to reduce incidence *and* information about high incidence. Biological Approach Decrease population.
High	Social Approach Communicate low incidence *and* benefits of alternative population levels. Biological Approach Increase or maintain population.	Social Approach Communicate risk avoidance behaviors to reduce incidence. Biological Approach Decrease population.

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