Testing Potential Repellents for Mitigation of Vehicle - Induced Mortality of Wild Ungulates in Ontario

by

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ABSTRACT

The present study attempted to identify effective repellents and methods of application along travel corridors in order to elicit avoidance by wild ungulates and prevent accidents.

Eighteen potential repellents were identified and tested on wild ungulates between December 1996 and March 1998. Commercial and home made repellents were selected on the basis of their reported effectiveness in other studies. They belong in the category of area repellents (not needing to be contacted or ingested by the subjects) supposedly acting on the basis of odor or visual properties. Because predator related stimuli have been frequently considered effective, 5 of the presumptive repellents tested were selected on this basis. Another 8 potential repellents were selected for their human simulating properties, 2 were derivatives of putrescent eggs, and the other 3 were commercial repellents and/or strong odor-emanating chemicals.

Repellents were tested near Sudbury, Ontario, on captive elk and three free-ranging ungulate species (deer, elk and moose). Two experimental approaches were employed: (a) a winter study compared differences between repellent-treated and control travel trails in the snow in terms of usage intensity and (b) a summer study, monitored the usage of a mineral lick and compared the frequency of visits between days with repellent applied and days with no repellent.

Two conclusions were drawn: 1) the materials tested in winter did not deter ungulates from using treated trails; 2) repellents tested in summer did not prevent wild ungulates from using mineral supplements.

Although some of the materials may have been effective as contact repellents, preventing damage to vegetation, they did not prove effective as area repellents for large scale application on travel corridors, and are therefore judged unsuitable for use in reducing animal-traffic collisions.

DEDICATION

I would like to dedicate this thesis to all of those who struggle for wildlife

preservation in a fast-changing and menacing world. It sometimes may be a frustrating

work, but how much beauty it has in itself!

ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1. Wild ungulate-vehicle collisions:

The effects of heavily used transportation corridors on wildlife distribution, movement, and mortality are a growing concern throughout the world (Allen and McCullough, 1976; Reed *et al.*, 1982). Wildlife mortality caused by motor vehicles was a problem in North America as early as 1924 when mammalian, avian, and reptilian mortalities were reported (Puglisi *et al.*, 1974). This loss mounted as both speed and volume of traffic increased on a rapidly expanding highway network.

Collisions between vehicles and wild ungulates in Ontario frequently cause property damage, human injuries and fatalities, as well as important loss of wildlife resources. Not only moose (*Alces alces americana*), white-tailed deer (*Odocoileus virginianus*), and black bear (*Ursus americanus*) are killed in such instances, but also species rare in the province, including woodland caribou (*Rangifer tarandus caribou*) and elk (*Cervus elaphus nelsoni*). In February 1996, eight elk (out of an estimated herd of 25-30 animals) were killed by a Canadian National Railway train in the vicinity of Estaire, about 30 km south of Sudbury, Ontario (Fig. 1). Elk mortality due to train collisions has occurred in the Estaire area on at least two other occasions during the past 10 years (J. Hamr, pers. comm.).

The effects of environmental conditions during winter on moose-train collisions were investigated along a 92.2 km section of the Nordlandsbanen Railway in Norway (Andersen *et al.*, 1991). The authors showed that the annual loss of moose to train

collisions in Norway was approximately 500 animals from 1980 to 1990. Train kills were causing a variety of problems: damage to trains, longer travel times due to delays, reduced income for landowners with hunting rights, and negative consequences for the management of local and regional moose populations. More than 56% of 262 closely investigated train kills occurred in January and February, whereas less than 1% occurred in April. The annual variation in train-killed moose was greatly influenced by the snow depth. A high proportion (44%) of the moose were killed when the snow depth exceeded 100 cm, whereas only 11% were killed when snow depths were ≤ 35 cm. Mean winter snow depth accounted for 84% of the annual variation in train kills. Three factors may be responsible for this close correlation: (i) early winter snowfall forcing moose to migrate to lower elevation winter ranges; (ii) restriction of movement and increased use of the plowed railbed for movements between feeding sites at snow depths above 100 cm, and (iii) failure of moose to escape from the tracks in deep snow. Frequency distribution of train-killed moose in periods with different ambient temperatures showed that temperatures below -20°C increased the risk of collisions, whereas temperatures above 0 °C had the opposite effect. For wild ruminants, the lower critical limit is usually defined as the temperature at which metabolic rate increases to maintain homeothermy, and similarly, the upper critical temperature is defined as the temperature at which respiration rate increases for evaporative cooling to occur (Renecker and Hudson, 1986). Adult moose are extremely tolerant to cold, and temperatures as low as -30°C do not increase metabolic rate (Renecker and Hudson, 1986). However, moose are intolerant of heat. The winter upper critical temperature for adult cows and calves was found to be -5° to 0°C (Renecker *et al.*, 1979; Renecker and Hudson, 1986). These data may explain the

observed frequency distribution of train kills at different ambient temperatures. Thus, high ambient temperatures cause the moose to reduce their foraging activity in order to decrease heat production, while low ambient temperatures allow the moose to maintain high levels of foraging activity, subsequently increasing the use of tracks and the risk of collisions.

Jaren *et al.*, (1991) reported that the number of moose killed annually in collisions along Norwegian railroads averaged about 500 in the late 1980's. Almkvist *et al.*, (1980) and Lavsund and Sandegren (1991) studied moose-vehicle accidents in Sweden concluding that the phenomenon was important for both the local moose population and human activity. Moose-vehicle collisions have also been studied by Oosenbrug *et al.*, (1986) in Newfoundland and Modafferi (1991), McDonald (1991), Schwartz and Bartley (1991), Del Frate and Spraker (1991), in Alaska, resulting in similar conclusions to those from Ontario, Quebec, and British Columbia.

Child *et al.*, (1991) estimated that at least 200 moose were killed annually on the Canadian National Railway tracks in the central interior of British Columbia. Moose in British Columbia and elsewhere migrate annually from traditional summer ranges to lower elevation winter ranges with snowfall governing the onset and magnitude of these seasonal movements. The winter ranges are characterized by snow conditions that favor daily and seasonal movements and facilitate escape from predators. Man-made transportation corridors such as snow-free roadways and railbeds can substitute for natural routes. Child (1983) reported that fatalities could exceed a thousand moose in record snowfall winters in the BC interior. Until recently, vehicle-collision losses of moose have been considered of little consequence to the resource management programs,

and to recreational opportunity. Adjustments to the annual harvest and/or the regulations, if made, are therefore subjective and conservative. But with increasing volume of traffic, proliferation of new transportation facilities, increasing cost of property damage, human injury and death, and increasing recreational demands, the recurrent problem of moose-vehicle collisions is receiving more attention (Child *et al.*, 1991).

Accidents involving moose and motor vehicles or trains in British Columbia were studied by other authors (Walker *et al.*, 1978; Child *et al.*, 1991). Stuart (1984) suggested that about 200 moose were killed on the major highways in British Columbia each year. These moose-vehicle collisions occurred most frequently between 1800 hr and 0200 hr, under poor to no light conditions, on straight and relatively flat stretches of highway at vehicle speeds in excess of 80 km/hr.

In Ontario, Canadian National Railway personnel have estimated that on a stretch of tracks between Sioux Lookout and Armstrong, a distance of approximately 225 km, 40 to 50 moose are struck and killed each year (approx. 0.20/km). Rail crews operating between Cartier and White River, Ontario, estimated that 0.24 moose were killed each year per kilometer of track (Fraser, 1979; J. Hamr, pers. comm.).

During the period of the present study at least 6 moose were struck and killed by vehicles on a 50 km stretch of Highway 69, south of Sudbury, Ontario (Fig.2). All of these accidents happened at night, supporting the observations of the previously mentioned authors.

Road accidents involving moose are a hazard to motorists and an unwanted source of moose mortality in much of Ontario. Most of these accidents occur in May, June, and July, when moose are most likely to frequent roads.

Figure 1. Elk killed by a CNR train in Ontario. February, 1996.

Figure 2. Moose killed by a vehicle on Highway 69, south of Sudbury, Ontario in May, 1997.

It is not well understood why moose are attracted to roads during these months, although it has been suggested that they are forced into open areas by insects (Fraser, 1979). However, Grenier (1974) noted that moose in Quebec seemed to be attracted to accumulations of highway salt in roadside ponds. In Sweden, spring moose-vehicle accidents are blamed partly on the disoriented behavior of yearling moose, newly abandoned by their mothers (Almkvist *et al.* 1980).

Bubenik (1987) stated that "fully mature and healthy moose stand their ground when confronting wolves and inexperienced moose generally run and are killed." Apparently, moose behave in similar fashion toward approaching locomotives, vehicles and wolves (Stringham, 1973; Child, 1983; Halter, 1983; Surrendy, 1983).

Normal defensive behaviors are of low survival value when moose are on the tracks or highways, especially at night, when blinding headlights "hypnotize" moose and suppress normal flight response. Bubenik (1987) suggested that "fighters" may be more susceptible to collisions because they have little fear of moving objects, whereas the "runners" flee and escape.

Other species of wild ungulates are also involved in vehicle accidents as documented by various authors. Accidents involving caribou occur in different parts of the world. Bergerud *et al.*, (1984) reported that the migration of the Snøhetta caribou herd in Norway, across the nearby railroad was a common phenomenon, with 1/3 of the winter population migrating. Most of the crossing took place at night when traffic was lightest. Different methods were tried to prevent caribou crossing and subsequent accidents. Various technical installations produced no immediate avoidance reactions if they did not physically restrict the animals' movement.

During the winters 1991-92 and 1992-93, mortality of caribou due to vehicle collisions was extremely high in west-central Alberta (Brown and Ross, 1994). At least 32 caribou were hit by vehicles, resulting in 27 known deaths. Woodland caribou are threatened in Alberta and vulnerable nationally, requiring measures to reduce the incidence of vehicle-induced collisions. Highway 40 bisects the traditional winter range of the A la Peche caribou herd, and the behavior of the animals indicated that they may be increasingly attracted to road salt. In both 1991-92 and 1992-93 winters, the annual rate of mortality due to vehicle collisions alone was about 11% of the total population of 100-150 animals (Brown and Ross, 1994). This high mortality rate, combined with natural mortality of at least 10% and average calf recruitment of only about 14%, produced a substantial population decline (Edmonds and Smith, 1991).

Studying the impact of highway traffic on caribou populations in the Fraser River valley, BC, Bergerud et al., (1984) concluded that the Yellowhead Highway and nearby railroad were not barriers to caribou movement. The caribou sought both the road and railroad corridors in periods of deep snow. There were a number of collisions of caribou with trains described by Child (1982). The caribou also risked death on the paved highway, which they sought out to escape adjacent deep snow and possibly to lick salt. The animals were habituated to the heavy traffic and remained on the paved surface (Child, 1983).

Caribou may be most active at sunrise and sunset, but also show peaks of activity during daylight hours. Therefore, the frequency distribution of caribou-vehicle accidents may be different from other species (Russel et al., 1993).

Highway mortality of deer (*Odocoileus* spp.) is a nation-wide concern for the USA (Romin and Bissonette, 1996). These authors reported that 200,000 deer were killed on the nation's roadways in 1980. Property damage to vehicles, human injuries and fatalities, and potential reductions of local deer populations resulted from deer-vehicle collisions. As a rough approximation of worth, each harvested deer could be valued at about $1,400. The cost of damaged property resulting from deer-vehicle collisions has also been calculated by other authors. Average property damage cost estimates in Colorado were $500/accident in 1978 (Reed *et al.*, 1982), $1,600 in Michigan in 1986 (Gutos, 1987), $1,415 in New York in the late 1980's (Decker *et al.*, 1990), and $760 in eastern Washington in the late 1970's (Schafer and Penland, 1985). In Utah, auto insurance claims associated with deer collisions during 1985-1986 averaged $635/vehicle (Wood and Wolfe, 1988) and $1,200/vehicle in 1992.

An estimated 120 people/year were killed between 1981 and 1982 in US animal-vehicle collisions (Romin and Bissonette, 1996). Arnold (1978) reported that from 1972 to 1976, Michigan State police recorded 63,184 collisions involving deer; 3,289 motorists were injured and 17 were killed. In Vermont, 11 people were killed and 1,886 were injured from 1981 to 1991. Hansen (1983) in Michigan and Stoll *et al.*, (1985) in Ohio reported that 4-5% of deer-vehicle collisions resulted in human injury.

According to Reed (1981), an estimated 50% of deer-vehicle collisions go unreported. Decker *et al.*, (1990) determined that actual deer-vehicle collisions were at least 6 times those reported as carcass possession tags by wildlife officers in Tompkins County, New York. Despite under-representation, the US-wide deer road-kill for 1991 totalled at least 500,000.

Mule deer (*Odocoileus hemionus*) in south-western Lincoln County, Wyoming, cross U.S. Highway 30 and the Union Pacific Railroad during their migrations between summer and winter ranges. In doing so, deer are killed by vehicles and trains, mostly during fall and spring migratory periods (Reeve and Anderson, 1993). Romin and Dalton (1992) reported that between 1980 and 1990, a mean of 3,075 mule deer/year were killed on roadways in Utah. Williamson (1980) estimated that 200,000 deer are killed on highways in the US each year. The Humane Society estimated that nearly 1.5 million wild animals were killed on USA highways each day. Deer accounted for 126,000 of the deaths annually and the resulting vehicle damage was estimated at $34 million (Case, 1978).

Motor-vehicle collisions involving deer are a safety concern anywhere deer and people coexist (Connelly *et al.*, 1987; Decker and Gavin, 1987; Stout *et al.*, 1993). At least 7 white-tailed deer were killed by automobiles on a short stretch (≈20 km) of Highway 522 in Loring, Ontario (Fig. 3) during a period of this study (January-February, 1997), and it was very likely that more such events went unrecorded.

Runway collisions of aircraft with white-tailed deer are of major concern to airport managers and pilots in Pennsylvania, with its large deer population and many airports in close proximity to forests (Bashore and Bellis, 1982). Deer were responsible for 65% of aircraft-mammal collisions (Belant *et al.*, 1996).

Several explanations have been given by different authors trying to determine the cause of wildlife-vehicle accidents. Oosenbrug *et al.*, (1991) attributed an increase in collisions with wild ungulates in part to greater traffic speed. This view was supported by Del Frate and Spraker (1991), who noted that a switch to a "dry road" policy for winter

Figure 3. White-tailed deer killed by an automobile in Loring, Ontario in February, 1997.

highway maintenance on the Kenai Peninsula of Alaska resulted in faster vehicle traffic

and a significantly greater number of road-kills. Increased vehicle speeds may have also

enhanced white-tailed deer road-kills in the lower peninsula of Michigan (Arnold, 1978).

Case (1978) analysed road-kill reports for 9 wildlife species on a Nebraska Interstate

highway and found a significant linear correlation between traffic speed and annual road-

kills for all species.

Another important factor suggested by various authors as determinant for

ungulate-vehicle collisions was the use of salt as road de-icer. Grenier (1974) and Fraser

(1979) both implicated road salt as the major factor attracting moose to roadways. De-icer

(usually containing salt) is commonly applied to roads in winter, at least in northern areas.

During spring snowmelts, salt may accumulate on right-of-ways, attracting ungulates

(Feldhamer et al., 1986). Salt may be especially attractive to ungulates where there are

few or no natural mineral licks. Moose are strongly attracted to salt (NaCl) during the

spring and early summer in most parts of their North American range (Fraser and

Hristienko, 1982). This specific appetite appears to account for their attraction to mineral-

rich bogs (Fraser and Reardon, 1980; Tankersley, 1981) and may explain their use of Na-

rich aquatic plants (Jordan et al., 1973). Quebec moose were attracted to roadside pools

that had a high concentration of dissolved salt, and such pools were thought to contribute

to the frequency of traffic accidents involving moose (Grenier, 1974). Fraser and Thomas

(1982) reported on moose activity and moose-vehicle accidents in relation to roadside salt

accumulations on a section of Highway 17, Ontario. Moose activity at pools increased

from mid- to late May, fluctuated in June, and then declined throughout July to very low

levels in August and September. Between May and September of 1979 and 1980, 39

moose-vehicle accidents in or near the study area were accurately located and inspected. Most of them were located near saltwater pools. Many such pools were trampled and accessed by distinct wildlife trails.

Fraser (1979) concluded that Ontario moose migrate to mineral-rich springs in a manner similar to that reported by Best et al., (1977) for animals in Alberta. He also considered that behavior and presence of moose on the roads between May and July deserved special study because this activity coincided with the peak time of collisions between moose and vehicles in Ontario.

To animals, sodium is an essential mineral for maintaining physiological parameters and processes such as osmotic and pH balance, blood-fluid volume, muscle contraction, and nerve transmission (Robins, 1983). Sodium is scarce in northern environments (Jordan et al., 1972; Botkin et al., 1973), and many ungulates appear to have a seasonal dependency on its supplement (Herbert, 1967; Weeks and Kirkpatrick, 1976; Belovsky and Jordan, 1981; Fraser and Thomas, 1982). Sodium was the element common to all natural ungulate licks sampled by Cowan and Brink (1949) in the Rocky Mountains, and probably was the element sought by A la Peche caribou using licks as documented by Edmonds (1988). Road surfaces are readily available sources of abundant sodium to ungulates. For example, bighorn sheep and elk are attracted to salted highways in Kootenay and Jasper National Parks, leading to increased road-kills (Bradford, 1988; Pool, 1989). Higher sodium concentrations in roadside vegetation (due to uptake of sodium flushed from the road surface) also may contribute to the presence of ungulates within right-of-ways (Pletscher, 1987). Whatever the reason for the presence of ungulates

on travel corridors (snow, salt, food or migration/dispersal), the only effective way of avoiding accidents would be to prevent ungulates from entering the travel-ways.

1.2. Potential deterrents:

A search for effective mammalian deterrents has been instigated by the problem of cervid depredation on crops. Growing populations of deer, elk and other species of wild ungulates are increasingly recognized as nuisance in certain parts of the world. Depredation to agricultural crops, sylvicultural operations, orchards, as well as hazards to people present in nature parks are the main aspects (Harder, 1970; Bullard *et al.*, 1978; Katsma and Rush, 1980; Allan *et al.*, 1984; Byers and Scanlon, 1987; DeYoe and Schaap, 1987; Phillips *et al.*, 1987; Swihart and Conover, 1988; 1990; Conover and Decker, 1991; Swihart *et al.*, 1991; Andelt *et al.*, 1994; Conover, 1994; Wywialowski, 1994; Fisher, 1995).

Damage inflicted by wild ungulates on vegetation is not only exercised by feeding. After antler growth stops in late summer or early fall, males rub their antlers against trees, especially saplings, to remove the protective covering known as velvet. They often rub trees hard enough to remove the bark, break branches, or knock the tree over. Thus, white-tailed bucks rubbed 1,145 nursery trees with a wholesale value of at least $30,000 during 1978 and 1979 in a nursery in Carroll County, Ohio (Nielsen *et al.*, 1982).

Besides depredation to vegetation caused by wild ungulates, the problems created by nuisance black bears is well known in Northern Ontario (Landriault, 1998). Keeping

bears away from residential areas can be considered as one more necessity for chemical repellent application.

Target species in previous repellent research included birds, microtine rodents, lagomorphs, and deer. The efficiency of repellents in agricultural or sylvicultural settings has been the subject of extensive research (Dietz and Tigner, 1968; Conover, 1984; Melchiors and Leslie, 1985; Swihart and Conover, 1990), but the use of repellents to deter wildlife from roadways or railroads has not been widely reported.

Brown and Ross (1994) identified 6 commercially available and 12 non-commercially available wildlife repellents (Table 1). Both these categories comprised olfactory and taste repellents.

Chemical messages have long been known to play an important part in the lives of most mammals, and it is becoming apparent that the information transmitted may not only describe the social and reproductive status of the producer but also its genotype. An interesting experiment by Brisbin and Austad (1991) demonstrated that dogs were able to distinguish scents of individual humans left on metal or leather articles only held in the closed palm for 30 seconds. This and the study of Sommerville *et al.*, (1990) are examples of the astonishing mammalian scent abilities about which humans only have a vague idea. It is well known that the sense of smell plays an important role in the life history of wild ungulates.

Many methods have been used to control deer damage to crops and trees, including herd reduction, fencing, and repellents (Harris et al., 1983). To avoid the difficulties, material cost, and other limitations associated with mechanical barriers, attention has turned to chemical deterrents. These chemical contact repellents are simply

sprayed on seedlings in conjunction with an adhesive, and due to either their taste or their odor, reduce browse damage (Bullard et al., 1978). Contact repellents have a major deficiency, however, in that they protect only the particular foliage to which they adhere (Stockdale, 1981). New growth, which appears after application is not protected (Allan et al., 1984). The basis for commercial wildlife repellents consists of an interaction between the smell and taste properties of the products. Manufacturers' claims vary as to which mode is most effective. It is known that ungulates avoid putrescence (Brown and Ross, 1994), so it is likely that repellents based on strong, foul odors would be effective. Other commercial repellents have been developed that produce a strong ammonia odor. Repellents based on taste are typically represented by hot spices or extreme bitterness (due to their formulation including capsacin, a concentrated hot pepper extract).

Especially in areas where other forms of control are impractical, chemical repellents are often used (Scott and Townsend, 1985). However, the majority of chemical repellents are either ineffective or reduce crop/tree damage only slightly (Palmer et al., 1983; Conover, 1984; Swihart and Conover, 1990). Thus, the identification of effective repellents with biological basis is needed for use against white-tailed deer and other ungulates (Swihart et al., 1991).

McIvor and Conover (1991) concluded that repellents may reduce deer damage, but they rarely eliminate the problem. In most controlled tests, repellents have reduced deer damage by 50% or less.

According to an extensive survey conducted in the USA by Scott and Townsend (1985), many growers complained that recommended repellents and scaring devices did not work, or worked only temporarily. However, some growers reported that several

repellents provided protection from damage. Several chemicals are sold as deer repellents, and home-made remedies abound. Unfortunately, little information is available about their effectiveness (Swihart and Conover, 1988).

Table 1. Summary of possible repellents and their effectiveness identified by Brown and Ross (1994).

Commercial repellents*	# of tests	low effect	medium effect	high effect
Deer Away (BGR)®	7	1	3	3
Hinder®**	7	1	4	2
Wolfin®	0	0	0	0
Hot Sauce®**	4	2	0	2
Ropel®**	3	3	0	0
Thiram®**	4	3	1	0
Non-commercial repellents				
powdered egg solids	4	1	0	3
blood meal	1	1	0	0
feather meal	2	2	0	0
meat meal	1	1	0	0
bone tar oil	3	3	0	0
human hair	2	2	0	0
creosote	1	1	0	0
naphthalene	1	1	0	0
soap bars	2	1	1	0
predator feces and urine	4	0	3	1
predator gland secretion	1	0	0	1
lithium chloride	1	0	0	1
*Deer Away=putrescent egg solids; Hinder=ammonium soaps; Wolfin=synthetic wolf urine; Hot Sauce= capsacin (hot pepper derivative); Ropel=benzyldiethyl (2,6 xylylcarbamyl) methyl ammonium saccharide; Thiram=tetramethylthiuram disulfide. **Taste based contact repellents with no consequence for this study.				

However, contact repellents are of little importance for preventing wild ungulates from entering transportation corridors. Taste repellents imply that the animals consume a quantity of the repellent-sprayed vegetation before learning to avoid it. Actually, the animals are not prevented from entering the area but only from consuming vegetation on the treated site. Non-contact repellents (also known as area repellents) could prevent

vehicle-ungulate collisions. In this category, we may consider potential barriers acting through olfactory or visual deterrent properties. Although very few, compared to the multitude of studies that have tried to solve the problem of wildlife depredation of crops, there are some publications dealing with animal-vehicle collisions and the efforts to mitigate them. Flashing lights, noise, odors, visual signals and various combinations of these have been tested in an attempt to keep moose from entering vehicle and rail corridors. Initial results were favourable; however, once the animals had habituated to the stimuli, they returned to the transportation corridors (Brown and Ross, 1994). Unfortunately, there are no known solutions to the recurrent mortality of moose induced by train collisions, but there are several studies that have examined the problem and tried to find solutions (Andersen et al., 1991; Becker and Grauvogel, 1991; Child et al., 1991; Del Frate and Spraker, 1991; Jaren et al., 1991; Lavsund and Sandegren, 1991; McDonald, 1991; Modafferi, 1991; Oosenbrug et al., 1991; Schwartz and Bartley, 1991; Brown and Ross, 1994). Mitigative measures that have been proposed to date are largely academic, since the associated costs and logistics appear too prohibitive for field testing or practical use (Child, 1983).

Deer-automobile collisions have long been recognized as a serious problem (Jaren et al., 1991) and as summarized by Feldhamer et al., (1986), a variety of methods have been attempted to reduce deer accidents on roadways: repellents (Dietz and Tigner, 1968), reflectors and mirrors (Gordon, 1969), fences and gates (Reed et al., 1974), warning signs (Pojar et al., 1975), fencing (Falk et al., 1978), underpasses and overpasses (Reed, 1981) and highway lighting (Reed, 1981).

1.2.1. Predators as potential repellents:

As illustrated by Stoddart (1980), animals need to defend themselves against predators and other individuals of the same species. In most of the vertebrates, recognition of predators depends on a combination of different senses. There is nevertheless a great number of vertebrate species in which the olfactory sense is clearly dominant over vision and hearing. Several laboratory studies have shown that the odor of a predator affects normal prey behavior. The presence of a cat (*Felis domestica*) in or near a colony of rats (*Rattus* spp.) induces a "freezing" behavior which may last half an hour or more (Stoddart, 1980). Recognition of a predator through the perception of odor clues is a widespread phenomenon for the vertebrates. However, the differences between visual and olfactory senses as perceptual systems are not clearly understood. It is well known that young birds possess an innate fear of raptor silhouettes. Whether mammals possess a similar innate fear to predator odor, remains to be answered (Stoddart, 1980).

Studies in olfactory biology have progressed to the point where results can be applied to the field and achieve the goal of keeping crops free from debilitating pest infestations, primarily by invertebrates. Since about 1964, when insect sex pheromones were first identified and synthesised (Stoddart, 1980), olfactory biology has played an escalating role in the formulation of pest control programmes. Sex pheromone traps are now used in control measures against many insect pests world-wide with encouraging results. Part of the reason for this phenomenal success is that insects respond blindly to the messages carried in sex pheromones. For vertebrates, this is not so, and factors such as dominance status, amount of previous exposure to the signal, age, nutritional status,

and ability to communicate visually and acoustically at the same time as olfactorily, contribute to frustrate simple olfactory attempts at controlling behavior. Because of the complexity of vertebrate behavior and its mesh of releasers, application of odors has not been so successful (Stoddart, 1980).

According to Abbott et al., (1990) some species of ungulates respond with equal aversion to predator odors as to the actual sighting of predators. This effect of predator odor on ungulates has been employed in attempts to repel game from agricultural, horticultural, and sylvicultural areas, but has met with limited success (Abbott et al., 1990). Mammalian carnivores frequently mark their home-ranges or territories with faeces, urine and the odorous secretions of specialised skin-glands (Calder and Gorman, 1991). It can be assumed that such scent-marking confers benefits to the carnivore in its interactions with other members of its species. However, the predator's pungent odor may give an early warning of its presence to potential prey, inducing evasive action.

Sullivan et al., (1985) tested the effectiveness of predator odors (faecal and urine) in suppressing feeding by black-tailed deer (Odocoileus hemionus columbianus). Cougar (Felis concolor), coyote (Canis latrans), and wolf (Canis lupus) faeces as well as wolf, fox (Vulpes spp.), wolverine (Gulo gulo), lynx (Lynx lynx), and bobcat (Lynx rufus) urine provided the most effective suppression of deer feeding. Novel odors of ammonia and human urine did not reduce feeding.

White-tailed deer avoid areas of maximum wolf activity. This avoidance could be in response to faecal, urine, or scent gland odors. In a more controlled environment, predator faecal odors have resulted in significant suppression of feeding activity of black-tailed deer (Müller-Schwarze, 1972; Sullivan et al., 1985). Cougar, coyote, and wolf are

all natural sympatric predators of deer, so it is not surprising that their odors were most effective.

Experiments were also conducted by Melchiors and Leslie (1985) to evaluate the effectiveness of predator faecal odors as black-tailed deer repellents. Aqueous extracts of predator faeces were more effective than Big Game Repellent® (4.9% egg solids) and as effective as Big Game Repellent-Powder® (36% egg solids). Faecal odors of predators significantly suppressed feeding activities of black-tailed deer, however, additional laboratory and fieldwork is needed before predator odors can be used operationally. The repellency of predator faecal extracts is assumed to be due to the malodorous compounds of putrescent materials in the scats. It is possible that anal sac secretions contributed to the repellency of the extracts, functioning as kairomones.

Residents of suburbs sometimes try to protect their gardens, fruit trees, and other vegetation against browsing deer by placing droppings of predators near the endangered plants. Müller-Schwarze (1972) experimented with the effect of droppings from African lion (*Panthera leo*), Bengal tiger (*Panthera tigris tigris*), snow leopard (*Panthera uncia*), coyote, and mountain lion on the feeding behavior of black-tailed deer. The most consistent avoidance response was elicited by the odors of coyote and mountain lion, both of which occur sympatrically with black-tailed deer. The animals were extremely unlikely to have had any experience with either coyotes or mountain lions during their primarily sedentary first days of life, prior to being brought into captivity. They would not have survived such an experience. It is likely, therefore, that black-tailed deer and perhaps other ungulates possess a largely innate, negative response to odors of predators.

Suppressed feeding was observed in sheep (*Ovis domestica*) in response to the odor of dog (*Canis familiaris*) faeces as reported by Arnould and Signoret (1993). Another product, Formulation F'® (sic), based on the synthetic odor of lion faeces (Imperial Chemical Industries Public Health, UK) was tested on sheep by the same authors. It had little effect on sheep, even though, it was effective on red deer (*Cervus elaphus*) according to Abbott et al., (1990).

Sullivan *et al.*, (1985) also found that predator odors (faecal, urine, and anal gland) suppressed feeding by snowshoe hare on willow and coniferous seedlings. Lynx and bobcat faeces, weasel anal gland secretions, and lynx, bobcat, wolf, coyote, fox, and wolverine urine caused the most effective suppression of hare feeding damage. This suppression was not due to the novelty of a given odor, because hares did not respond to domestic dog urine, 2-methylbutyric acid, or isoamyl methyl sulphide. Thus, it seems plausible that the hypothesis of predator odors eliciting a "fear response" in snowshoe hares, and thereby suppressing their feeding on a given food source, might be valid.

The available data justify the generalisation that consistent effects of predator odors on prey species have been demonstrated, but that most of these are not sufficiently convincing to be of interest for large-scale field applications. Either the response is not very strong, or not durable enough.

Mattina *et al.*, (1991) suggested that aversive responses by herbivores to predator odors may not indicate recognition of the predator as a species. Instead the target species may be responding to a common carnivore "signal," such as sulphur-containing odorants produced during the digestion of meat. This theory has initiated the development and testing of synthetic predator odors. Once the effective constituents have been isolated

from genuine predator excretions, synthetic analogues could be generated, usually using sulphides. When compared to natural predator odors, some of these synthetics have proven equally effective (Mattina et al., 1991). However, the process of developing and testing repellents based on synthetic predator odors is still at a preliminary stage.

The paper published by Abbott et al., in 1990, described for the first time a multi-disciplinary approach, combining chemical and behavioral techniques, to develop a viable, odor-based deer repellent from lion scats. A comprehensive chemical analysis of lion scats was performed. Many of the identified compounds were similar to those present in the anal sac secretions of the lion and other carnivores. The deer repellent properties of lion scats previously demonstrated by other authors were also confirmed. In addition, solvent extracts of lion scats and synthetic formulations based on it were found to be as effective as the natural lion faeces in repelling deer. However, repellency of lion scats may be due to a general carnivore odor signal. This hypothesis would be in keeping with other observations of various predator odor repellences and may help to explain why European red deer react to the smell of African lion. Interestingly, faeces from the African lion were equally as effective as those of native predators in deterring North American black-tailed deer from feeding. This would support the theory that ungulates respond to a common carnivore signal (Abbott et al., 1990).

A new product based on synthetic wolf urine was recently developed in Sweden under the name of "Wolfin®" (Brown and Ross, 1994). This product is provided in an unique capsule form, and is designed to be applied in a different manner than spray-on repellents. The capsules are attached to posts spaced at intervals to create an "olfactory fence" of offensive odor. Wolfin® is the only repellent developed specifically to reduce

ungulate road-kills. The manufacturer claims dramatically successful results in reducing road-kills of moose and deer. However, testing in North America has been less conclusive, and the product application is still in the experimental stage. The Warden Service in Banff National Park conducted trials with Wolfin® (Brown and Ross, 1994). Also the Newfoundland-Labrador Wildlife Division and Parks Canada conducted trials on captive animals and field trials to repel moose from highways in Terra Nova National Park during winter 1993-94. The results of these experiments were negative, or at best inconclusive (J. Hamr, pers. comm.). Because of its design, Wolfin® is the only repellent for which it is possible to estimate costs of application along a line (e.g., roadside). The supplier suggests that effective coverage of both sides of a roadway would cost $1,090/km/year (1993 costs). Even though, as advertised, the product may have some deterring properties, we considered its price prohibitive, even for testing, in view of the inconclusive results of past applications.

Bobcats, coyotes, and humans occur sympatrically with white-tailed deer throughout much of the herbivore's range. Bobcats and coyotes share a long (≈ 1-2 million years) association with white-tailed deer, although coyotes have expanded their range into the southern and extreme eastern portions of the USA only in recent years, following wolf decline (Swihart et al., 1991). Although the relative importance of bobcats and coyotes as predators of deer is uncertain, coyotes are more likely to prey upon fawns, whereas bobcats also prey upon older deer (Swihart et al., 1991). In Connecticut, humans currently are the most significant predators of deer, whereas bobcats and coyotes occur in low numbers. However, interactions between white-tailed deer and humans have occurred in the eastern United States only for about 10,000 years. Moreover, learned reactions to

human odors presumably are altered in Connecticut because of the high frequency of encounters with human scent in suburban areas, that prove to be either innocuous or beneficial (e.g., availability of food around houses). Based on these factors, Swihart *et al.*, (1991) hypothesised that the order of repellency of odors of these three predators to white-tailed deer would be: bobcat > coyote > human. In general, this hypothesis was confirmed by their experiments.

An interesting paper was published by Mattina *et al.*, (1991). In order to identify the chemicals responsible for ungulate behavioral modifications, a dichloromethane extract of bobcat urine was analysed by gas chromatography and mass spectrometry. Among the compounds identified in the extract were phenol, indole, dimethyl sulfone, and 3-mercapto-3-methylbutanol. Compounds for which spectroscopic data were presented for the first time included one sulphide, two disulphides, and two trisulfides. The sulphur compounds are derived from an amino acid, S-(1,1-dimethyl-3-hydroxypropyl) cysteine ("felinine"), which was identified several years ago in the urine of the domestic cat. Although, a search of *Chemical Abstracts* uncovered no reports detailing the chemical composition of felid urine or faeces, three volatile sulphur compounds, which may function as pheromones, have been identified in the urine of the red fox: Δ^3-isopentenyl methyl sulphide, 2-phenylethyl methyl sulphide, and 3-methylbutyl methyl sulphide. Since volatility is an important property of compounds identified as semiochemicals, the authors attempted to identify the volatile compounds in bobcat urine as the first step in the characterisation of the semiochemicals in the urine, responsible for the suppression of agricultural damage caused by woodchuck (*Marmota monax*) and deer. 3-Methyl-3-buten-1-ol, pyrazine, methylpyrazine, 2,6-dimethylpyrazine,

phenol, trimethylpyrazine, dimethyl sulfone, δ-valerolactam, indole, 1-methylhydantoin, and phenylacetamide were positively identified in the urine extract. Fatty acids, bis-(2-ethylhexyl)-phthalate, and cholesterol were also identified. A synthetic deer repellent based on felinine and the acidic component of lion feces has been patented. The report does not discuss the presence of sulphur compounds other than felinine in the composition. The repellent is formulated with phenol, indole, δ-valerolactam, and palmitic acid, all of which have been identified as constituents of bobcat urine. It has been reported to be effective on white-tailed deer (Mattina *et al.*, 1991).

1.2.2. Putrescent eggs and Big Game Repellent®:

To reduce damage caused by deer, orchardists and nursery owners frequently have relied upon chemical repellents placed on or near the vulnerable plant. Although numerous repellents have been tested, a 37% solution of putrescent whole egg solids (Big Game Repellent®=Deer Away®, McLaughlin-Gormley-King Company, Minneapolis, MN.) has surpassed other compounds in reducing deer damage to nursery stock (Palmer *et al.*, 1983; Allan *et al.*, 1984; DeYoe and Schaap, 1987; Byers *et al.*, 1990; Swihart and Conover, 1990; Osko *et al.*, 1993; Milunas *et al.*, 1994). Big Game Repellent® (BGR) is a strongly odored concoction which supposedly deters by both taste and odor.

Nolte *et al.*, (1995) evaluated the effectiveness of Big Game Repellent-Powder® (BGR-P) in inhibiting black-tailed deer browsing on western red cedar. BGR-P virtually eliminated damage for 2 weeks after treatment, and the deer inflicted substantially less damage to BGR-P-treated trees than to control trees during the first 8 weeks of the study. Fraser and Hristienko (1982) found BGR to be effective in deterring moose from using

salt water pools adjacent to Highway 17 in Ontario. Another study by Andelt *et al.*, (1991) tested the repellency of chicken eggs, Big Game Repellent® (BGR), coyote urine, Thiram®, Hinder®, bars of soap, and Ropel® on tame mule deer in Colorado. Chicken eggs, BGR, and coyote urine performed better than the other repellents for deterring deer from feeding on pelleted rations.

Reported cost/acre for BGR in US dollars was found to be $180-400 for a recorded browsing reduction of 46% (Conover, 1984; Conover, 1987; Swihart and Conover, 1988). BGR has consistently performed well in controlled studies, however, its cost may deter more nurserymen than deer (Swihart and Conover, 1988; 1990).

Probably owing to the demonstrated efficiency of Deer Away®, derivatives of whole or powdered eggs are the most commonly used non-commercial repellents. Andelt *et al.*, (1991; 1992) tested whole, fresh, chicken eggs in feeding trials with mule deer and elk. Eggs were constituted at a ratio of 1-part egg to 4-parts water, by volume. The egg repellent was among the most effective of the deer repellents. In another study, a whole egg slurry was field tested on white-tailed deer and was found to be effective for periods of up to 6 days (Johnson, 1986). The same author also created a paste of 10% albumin powder and 90% water, and found it to be highly effective in deterring deer from eating treated cob corn. In each of these trials, however, untreated corn was available for consumption, so the deer could not be described as "hungry." Johnson (1986) speculated that the deterrence value of Deer Away® actually may be related to its albumin content rather than to its putrescence.

The volatile components of fermented egg products (FEP) repellent to deer, have been shown to be simultaneously attractive to coyotes (Bullard *et al.*, 1978). Some of

these same components also are found in anal-gland secretions of canids (Bullard *et al.*, 1978), suggesting that 2 functions may be involved in their repellency to ungulates: putrescence and predator odor. On this principle, Bullard *et al.*, (1978) developed a synthetic, fermented-egg coyote-attractant/deer-repellent and concluded it was effective in feeding trials.

Mulla and Hwang (1974) were the first to report on FEP chemical composition. They identified acetic, propionic, butyric, isovaleric, and isocaproic acid, and trimethylamine. There is some evidence about the mechanism by which the volatile compounds are formed. Whole fresh eggs contain about 11.5% protein and 10.2% fat. Both of these sources could be considered about equally in any degradation scheme. The aroma of FEP is composed of four distinct fragrances: cheesy volatile fatty acids; ammoniacal amines; fruity esters; and sulphurous organosulfur compounds (Bullard *et al.*, 1978).

The biological significance of fermented egg compounds may be complex indeed. The attractancy of smelly decomposed proteinaceous matter for canids is well known. However, in this case, there is perhaps an added dimension. Trimethylamine and all of the volatile fatty acids found in anal sac secretions of red foxes, dogs and coyotes are also present in FEP. Although biological functions of anal gland secretions have not been definitely established, most authors suggested some form of pheromonal activity (Albone and Fox, 1971). Other authors (Bullard and Shumake, 1977; Bullard *et al.*, 1978) believed that much of the effectiveness of FEP was attributable to the high responsiveness of animals to familiar predator odors in their environment. To date, FEP has not been tested as a deterrent to wild ungulates on road/railroad corridors.

1.2.3. Humans as potential repellents:

It is universally known that human presence elicits the most powerful fear and flight behavior in wild ungulates. While a combination of visual, auditory and olfactory stimuli undoubtedly constitutes the human presence image in the animal consciousness, the sense of smell appears to be the most reliable in wild ungulates. Unfortunately, no research has been done on this subject and no information could be found in literature to date. Paradoxically, everybody knows that human smell causes a deer or a moose to run away, but nobody knows what component of the human odor is responsible for eliciting avoidance behavior in wild animals. However, although very few, there are some publications of interest, that could be presented in two categories: (1) publications in human dermatology journals, mostly related to the attempts of the cosmetic industry to find a procedure to mitigate human skin odor emanations; and (2) publications related to the search for chemical compounds (including human odor components) that exercise an attractant effect on blood-sucking and biting insects. Korting *et al.*, (1988) recognized that very little was known about the sources of odor produced by the human skin. Also, the authors underlined the role of bacterial synthesis and transformation of primary compounds in causing body odor. Stoddart (1990) concluded that between 300-400 compounds are constantly released as by-products of human metabolism through the dermal glands, some 200 of these being carboxylic acids. These acids are apparently modified by bacteria into the equivalent alcohols, α-hydroxiacids and diols (Nicolaides, 1974).

Zeng *et al.*, (1992) demonstrated that characteristic human male axillary odors consist of C_6 to C_{11} normal, branched, and unsaturated aliphatic acids, with (E)-3methyl-2-hexenoic acid being the most abundant.

Roesseler (1961) observed strong attraction of host-seeking parasitic flies to "artificial sweat" composed of formic, acetic, propinic, butanoic, hexanoic, octanoic, lactic, citric, uric acid and amino acids. Leyden *et al.*, (1981) working on human odor chemicals and their biosynthesis reported the presence of two steroids, dehydroepiandrosterone sulphate and androsterone sulphate. Also cholesterol, which could serve as the building material for steroid synthesis is of interest. These authors stated that there were individual differences in the amount and quality of body odor produced. This could be an explanation for the ability of some humans to approach and handle wild animals more successfully than others.

A human-related stimulus widely used as wildlife repellent is human hair. Obtained from barber shops, human hair supposedly acts as an odor deterrent (McIvor and Conover, 1991). The authors recommended distributing handfuls of hair into mesh bags, and hanging the bags from individual trees, no more than three feet apart. Reported cost/acre for this procedure in US dollars was $10.00 for a browsing reduction of 34% (Conover, 1984). The Arboretum of the University of Wisconsin - Madison used bags of human hair to protect valuable plant specimens (Fisher, 1995). Harris *et al.*, (1983), Scott and Townsend (1985) also reported using human hair as wild ungulate deterrents with variable success.

The response of free-ranging moose fitted with heart-rate transmitters to monitor military disturbance, were analysed by Andersen *et al.*, (1996). In the disturbance trials,

the moose showed much shorter flush distances (the distance from the disturber at which flight began) with heart-rate returning to normal sooner after being disturbed by mechanical stimuli as compared to human stimuli. These results for moose are consistent with other studies on bighorn sheep (*Ovis canadensis*) and mule deer, which have demonstrated greater fear responses to people than to aircraft and snowmobiles. Except for human hair, no other human odors or related stimuli have been tested as ungulate deterrents to date (MacArthur *et al.*, 1982).

1.2.4. Soap as potential repellent:

McIvor and Conover (1991) suggested that regular bars of soap could act as an odor repellent for deer. The method of application was to pierce bars of soap so that they could be hung roughly 3 feet apart, high on plants to avoid being covered by snow. Small, 14-gram bars were more economical. Reported cost/acre in US dollars was $60.00 for a reported browsing reduction of 38% (Conover, 1984). Soap has been used to deter ungulates, and was found to provide good protection of trees in Ohio (Scott and Townsend, 1985a). Swihart and Conover (1990) tested 8 brands of soap on white-tailed deer in nurseries. They found no differences among brands, but overall, soap was a more effective repellent than Ropel®. However, it was less effective at protecting trees than Deer Away®. Other tests have confirmed that bar soaps could reduce deer damage in orchards. When comparing damage to trees with no protection to those with soap attached, 70% less damage was observed on branches within 1 yard of the soap. When deer pressure in an orchard was light to medium, bars of soap in the trees helped reduce browsing (Parkhurst, 1991).

In 1986, at the Virginia Polytechnic Institute and State University's Winchester Agricultural Experimental Station, Lifebuoy® soap bars were placed on 4-foot stakes at 15-foot intervals in the apple nursery rows. None of the trees close to Lifebuoy® soap had any damage, confirming the outstanding deer repellency of Lifebuoy® soap. Identification of the effective fragrances and the development of a sprayable product could lead to an effective repellent for use in orchards (Byers and Scanlon, 1987). However, soap has never been tested for preventing ungulate movement onto transportation corridors.

1.2.5. Visual and auditory stimuli:

Predator models were used in an effort to take advantage of naturally occurring predator-prey relationships. However, unless reinforced in a meaningful fashion, inanimate predator models were unlikely to be perceived as a real threat for very long (Koehler et al., 1990). Some animals fear new objects placed in their environment (neophobia) and may shy away from these for a few days. This phenomenon may be used to temporarily repel deer, rabbits (Sylvilagus spp.), and certain other pests by placing strange, unusual objects in a visible location (Koehler et al., 1990).

MacArthur et al., (1982) observed the greatest cardiac and behavioral responses from bighorn sheep when they were approached by a person with a leashed dog, presumably because of the resemblance of the dog to a coyote, the main predator of the sheep in the study area. The use of a dog (leashed or under adequate verbal control) could increase the effectiveness of direct harassment as a short-term (immediate and direct) measure to discourage caribou use of the right-of-way (Brown and Ross, 1994).

Many of the most serious mammalian pests are nocturnal, therefore, various types of continuous, flashing and/or revolving spot- or flood-lights, lanterns, strobe lights, and flares have been used to disrupt their use of an area. Such techniques have been used to move or deter pest mammals such as deer, bison (*Bison bison*), elephants (*Elephas maximum*), racoons, rabbits, rats, mice, and predators such as coyotes, foxes, and bears. Most authors considered lighting alone to be ineffective or only temporarily effective (several days), with only few reporting moderate success (Koehler *et al.*, 1990).

Several devices have been developed with the purpose of creating a visual barrier to ungulate movements. These devices typically are mounted on posts in a line parallel to the roadway, and angled to catch and reflect headlight beams (Brown and Ross, 1994). Stainless-steel "mirror" reflectors have been tested in North America and Europe. Although results have been inconsistent, these reflectors generally have been dismissed as ineffective at deterring ungulate highway crossings (Reed, 1981). The so called "Swareflex Wildlife Reflector®" incorporates a red prism which is said to reflect vehicle headlights parallel to the roadway thereby producing an "optical fence" of red light which deters ungulates from crossing the road until the vehicle has passed. A similar product, the "Strieter-Lite Wild Animal Highway System®," is an improved version of the Swareflex®-type system that employs 50% fewer reflectors. Purchase and installation of Swareflex® reflectors cost an estimated $5000/km in 1985 (Bradford, 1988). The cost of the Strieter-Lite® system was in excess of $6000/km in 1993 (Brown and Ross, 1994).

The effectiveness of Swareflex® reflectors has been tested in several jurisdictions. Three US states as well as Alberta reported reductions, while 7 states reported no change or no decrease in deer road-kills that could be attributed to the

reflectors (Schafer and Penland, 1985; Reeve and Anderson, 1993). In another study, the overt behavior of deer crossing roads was not altered by the presence of Swareflex® reflectors (Waring *et al.*, 1991).

In the mid-1980s, Alberta Transportation placed Swareflex® reflectors on portions of Highway 40 in an attempt to reduce caribou-vehicle collisions. Although no rigorous monitoring studies were conducted, the high number of caribou road-kills suggested the reflectors were of limited value (Brown and Ross, 1994). As a technique to reduce ungulate-vehicle collisions, roadside reflectors present several problems. There are no conclusive studies confirming their effectiveness. There is still uncertainty as to whether deer or other ungulates can, in fact, discriminate red light and, if they can, there is scepticism as to whether they avoid or otherwise react to it. Reflectors are functional only at night and, not in heavy precipitation. Their surfaces must be kept clean, requiring at least semi-annual maintenance. Snow accumulation on the reflectors also renders them nonfunctional for periods of time between maintenance in remote areas. Whether or not ungulates respond to reflector systems, their most important disadvantage is that they are designed to inhibit animals from crossing the road; they are not effective when ungulates are already on the road surface (Brown and Ross, 1994). In the 1960's a method was introduced in Sweden using a series of small mirrors placed on both sides of the road reflecting the head-lights of the cars into the area around the road (Lavsund and Sandegren, 1991). This was intended to frighten animals close to the road. Testing the method over a three-year period proved that mirrors had no effect on the number of accidents.

Highway lighting also has been investigated to reduce wildlife road-kills (Brown and Ross, 1994). Even sophisticated and expensive lighting systems on the roads did not prevent deer from being killed by vehicles (Reed, 1981).

Moving and/or reflective stimuli have been used particularly in efforts to prevent crop depredation by deer. Non-reflective stimuli that have been used included cloth strips or rags, flags, plastic jugs, wind propellers, tinsel, aluminium plates or pans, flashing, whirling strips or disks, and pieces of tin. All these methods were effective only for limited time and intensity (Koehler et al., 1990).

Gardeners and agriculturists have used various kinds of sound-producing techniques to repel mammalian pests from their fields or gardens. Everything from shouting, hand clapping, assorted noise-making devices (both home-made and commercially produced), and recorded animal sounds and communication signals (all in ranges that are audible to humans), to ultrasonics (above the hearing range of man), have been tried in efforts to prevent or alleviate damage (Koehler et al., 1990). Commercially produced ultrasonic whistles have been available for several years. They are designed to be mounted on vehicles and activated by the air-stream. The sound produced is in the 16-20 kHz range, alerting animals to the presence of oncoming traffic while remaining inaudible to humans (Brown and Ross, 1994). Muzzi and Bisset (1990) evaluated the effectiveness of commercially available wildlife warning devices mounted on Canadian National Railway locomotives in north-western Ontario, where moose were the principal big game species. Although the voluntary nature of participation by train engineers limited data quality, results suggested that ultrasonic whistles on locomotives could lead to a significant reduction in wildlife-train encounters and thus result in fewer moose

fatalities. The warning device used in that study was the Hobi Ultrasonic Whistle®, manufactured in Austria.

Despite claims of success by the manufacturers, there is evidence that the sound produced by ultrasonic whistles is inaudible to ungulates as well as humans, and it may be of such low intensity as to be inaudible >10 m from the whistle (Brown and Ross, 1994). However, Nygren (1981) tested wildlife warning whistles in Finland and concluded that canids, bears, deer, and elk heard the devices because their ears moved. In a controlled study of whistles under field conditions, Romin and Dalton (1992) reported no differences in responses by mule deer to vehicles with and without two brands of whistles. Several other studies also have failed to indicate the effectiveness of whistles at reducing wildlife-vehicle collisions (Brown and Ross, 1994). Even if ungulates could hear the high-frequency, low intensity sounds produced by warning whistles, it seemed likely that they habituated to them fairly quickly. The whistles also become plugged up by snow and ice in winter, insects in summer, and necessitate frequent maintenance to stay operative (J. Hamr, pers. comm.).

Discharging firearms, cracker shells, and/or other explosives proved effective to repel deer (Scott and Townsend, 1985) and to direct bison movements (Meagher, 1989). Gas exploders and various pyrotechnics were used to repel foxes, coyotes, bears, tree squirrels (*Sciurus* spp.), and rabbits as well as troublesome big game species such as deer, elk, and pronghorn antelope (*Antilocapra americana*). Some sources indicated that such sound-producing devices were effective to various degrees and generally more effective than visual or other acoustical stimuli. However, such control efforts are more practical

for small acreages and generally impractical and too expensive for protecting large stretches of travel corridors (Koehler *et al.*, 1990).

Numerous other sound-generating repellents are available commercially. One of the most commonly promoted and used commercial devices is AV-ALARM®. While originally developed to repel birds, the manufacturer reports that it has been used effectively (either alone or in combination with strobe lights, etc.) against deer, elk, coyotes, wild boar (*Sus scrofa*), porcupines (*Erethizon dorsatum*), and racoons. However, many who have used such devices in mammalian pest control programs or research have generally found AV-ALARM® to be only temporarily effective, if at all (Koehler *et al.*, 1990).

Use of animal-produced sound or communication signals, often referred to as biosonics or bioacoustics, is another approach to repelling animals from an area. Work to date has primarily focused on the use of conspecific distress or alarm calls to repel birds. However, research examining the potential use of mammalian communication signals to alleviate pest problems has been limited. While initial experimentation with recorded rat distress calls showed some promise (Sprock *et al.*, 1967), the use of biosonics for rodent control in buildings was abandoned because the alarm and distress calls were too stressful to people. Recorded conspecific distress calls have been only temporarily effective against coyotes (Koehler *et al.*, 1990).

Tape recordings of barking dogs have been suggested for repelling deer, foxes, bears, mountain lions, bobcats, racoons, and rabbits. However, there is little indication as to whether this technique is effective (Koehler *et al.*, 1990). Auditory repellents (sound making devices) clearly present a restraint, as they require energy to operate. This would

make them practically impossible to apply and maintain on long stretches of transportation corridors, especially during winter.

Physical harassment has been used in several jurisdictions in an attempt to discourage ungulate use of roads or airport runways. Specific techniques employed included firing rubber bullets or buckshot at the animals, and pursuit on foot, from a vehicle, or by a dog (Bashore and Bellis, 1982; Brown and Ross, 1994). Each method was effective temporarily and locally. However, ungulates quickly habituated to repetitive physical harassment and returned to the area after harassment cessation.

During the winter 1992-93, and occasionally, during previous winters, Alberta Fish and Wildlife Service personnel attempted various means of harassment to displace caribou from Highway 40. These included chasing on foot, yelling, and firing gunshots. A typical response by the caribou was to trot off the right-of-way as long as the pursuer followed, but then stop and return to the road shortly after cessation of the disturbance (Brown and Ross, 1994).

Trained dogs were used in an experiment described by Beringer et al., (1994). These authors showed that use of dogs to control browsing was more cost-effective than treatment with Hinder® repellent or no action. Tethered dogs failed to keep deer away from agricultural crops because deer quickly became accustomed to dogs and their barking. Dogs kept in bounds by an electronic containment fence also became ineffective on deer in the second year of testing due to habituation (Fisher, 1995). Obviously, such deterrent methods are not applicable along travel corridors.

1.3. Study objective and hypotheses:

The objective of the present study was the identification of effective wildlife repellents and feasible methods of their application along travel corridors. Therefore, the hypotheses were:

1. That there would be differences in the frequency and extent of wild ungulate presence between areas treated with repellents and areas with no repellents.

2. That there would be differences among ungulate responses to various repellents tested.

2. MATERIALS AND METHODS

2.1. Materials:

Subsequent to an extensive literature review, 13 potential repellents were selected and tested from 1996 to 1998. The effects induced by most of these products in repelling ungulates, as reported by different authors, had been contradictory and may be labeled as inconclusive. However, some authors reported positive findings warranting further investigation. For this experiment, the products with the highest potential for success were selected on this basis. Both effectiveness and potential for easy application have been considered. In addition to the 13 reported potential repellents thus selected, I added 5 other presumably effective substances suggested by personal experiences or clues provided by sources other than scientific literature.

The 18 selected, potential repellents tested during this study are listed in Table 2. I decided to test predator related stimuli in the form of wolf urine, wolf urine in antifreeze, coyote urine, wolf and coyote skins, wolf and wolf head silhouettes. Fresh wolf urine was collected in December, 1996 at the Canadian Wildlife Experience Animal Park in Massey, Ontario, where three timber wolves and two arctic wolves were kept in captivity. Since urine in its natural form might loose its odor by freezing, it was also mixed with antifreeze before use. A commercial product (simply called "Coyote Urine®") prepared by Hawbaker & Sons (Fort Loudon, PA, USA) containing coyote urine in antifreeze was also tested. This compound was reported to be successfully used by trappers in attracting predators.

Considering that the same compounds simulating human sweat odors which attract parasitic Diptera might cause avoidance response in cervids was only a hypothesis leading to a totally new trail of experimentation. Therefore, in the winter of 1997 I tested m-cresol, 1-octen-3-ol, and the combination of acids named "Roesseler's artificial sweat" (see Introduction). The chemicals were supplied by Aldrich Chemical Company, Milwaukee, Wisc., USA. Related to the human sweat approach, I also tested whether clothing items would elicit avoidance behavior in wild ungulates. Human hair was another repellent that was tested. The recommended method for human hair application was followed by distributing handfuls of hair into mesh bags, and hanging the bags from trees (McIvor and Conover, 1991).

Table 2. Potential repellents used in the study.

#	repellent	period and method of testing	target species
1	wolf urine (natural)	winter 1997, pairs of trails in Loring	white-tailed deer
2	Mothballs®	"	"
3	"Deer away®" (putrescent egg solids).	"	"
4	wolf urine in antifreeze (natural)	"	"
5	"Coyote Urine®"	"	"
6	rotten eggs	"	"
7	soap bars	"	"
8	lemon fragrance	"	"
9	wolf and wolf head silhouettes	summer 1997, salt lick	elk, moose, deer
10	human silhouette	"	"
11	predator skins (wolf, coyote)	"	"
12	"Critter Ridder®" (irritant vegetable components)	"	"
13	clothing items	"	"
14	"Sanovan®" (dichlor benzene)	summer 1997, salt lick winter 1998, Loring	elk, moose, deer deer
15	human hair	winter 1998, pairs of trails in Loring	deer
16	m-cresol	"	"
17	1 octen 3 ol	"	"
18	Roesseler's sweat (see text, pg.36)	"	"

Deer Away®, formerly known as Big Game Repellent® (BGR), is the best known and widely tested commercial wildlife repellent. The product is available in both liquid and powdered form. The powdered form of this product supplied by Intagra Corp., Minneapolis, Minnesota, USA was selected for testing in the study. The effectiveness of BGR appears to depend upon the odor of volatile short-chain fatty acids and sulphur compounds (Bullard et al., 1978). As stated by Milunas et al. (1994), BGR is the only commercially available repellent that has consistently reduced damage to vegetation in controlled experiments.

In the patented process for preparing a fermented egg product (FEP) (Bullard et al., 1978), a mixture of powdered whole egg and water was held in open contact with the air at room temperature for 7-14 days. Micro-organisms from the air decompose the fat and protein. The egg-water mixture becomes a flowable slurry, which after ageing is complete, is converted to a yellow powder (FEP) by freeze-drying. Following this concept, I experimented with an egg slurry kept in open contact with air at room temperature for approximately 10 days. At the end of this interval, the compound acquired a strong putrescent odor.

Commercial naphthalene in the form of mothballs has been suggested as an effectively repulsive odor for moose and other wild ungulates (Harris et al., 1983; Scott and Townsend, 1985b). This was the reason for selecting mothballs among the repellents tested during this study.

Small regular bar soaps hung on plants spaced roughly 3 feet apart were found to give a good protection against deer damage (McIvor and Conover, 1991). Therefore, I tested this method by hanging soap bars in the experimental area as explained below.

Moreover, because different authors associated the odor of detergent products with human simulation as perceived by mammalian species, I also tested lemon fragrance in the form of commercial air freshener developed for use in cars and other small confined areas (Medo Industries, Inc., Tarrytown, NY).

"Critter Ridder®" (Chemfree Environment, Inc., Kirkland, Quebec) was a commercial chemical product advertised as 100% effective in repelling all species of wildlife. It has a powdered appearance and contains irritant vegetal compounds (probably capsacin) supposed to affect the respiratory sinuses and make the area around which the product was spread on the ground undesirable for wild animals.

Personal communications with individuals who had used it successfully for repelling bears, suggested the testing of a substance based on dichlorobenzene. This product, sold commercially as "Sanovan®," emanated a specific smell resembling the odor of chloride and/or naphthalene. Sanovan® is produced by Monarch Chemicals Ltd., Concord, Ontario, and is used as a toilet cleaner and deodorizer.

After the first winter of field work, I decided to extend the sphere of testing by introducing stimuli other than the traditional taste and olfactory deterrents investigated by other researchers. The tested visual deterrents included life size painted plywood silhouettes of a wolf, a human, and several wolf head silhouettes.

2.2. Methods:

Repellents are usually evaluated by avoidance or non-preference to treated materials by test animals. A major problem arises when trying to compare repellents tested in different studies because of differing combinations of repellents and dissimilar

procedures (Harris *et al.*, 1983). Most of the research that has been done on the subject, evaluated the effectiveness of repellents by comparing plots of treated and untreated (control) food resources in terms of percentage browsing damage induced by the studied species of wild ungulate.

Following different objectives, I considered an alternative approach and experimental set up. The experiment began in January 1997 with the collection of wolf urine from compounds at The Canadian Wildlife Experience in Massey, Ontario (Fig.4). This is an 1000-acre wildlife park that contained approximately 40 Rocky Mountain elk moving freely throughout the entire area. North American predators (timber and arctic wolves, cougars, black bears, lynx, and bobcats) were restrained in small (approx. 50× 50m) fenced enclosures. The fences were made of woven wire and assured a good visual and olfactory contact with the exterior. Elk moved freely around the entire area of the park but, especially in winter when deep snow conditions occur, they sought the proximity of plowed roads. Moreover the animals were supplementary fed during winter and the feeders were situated on the access road in a specially designated area. When the snow depth exceeded 50 cm, the animals moved around using clearly established trails. Wolf urine was tested for the first time in the park by spraying it on the vegetation at a distance ranging from a few cm up to ½ m from the trails used by elk. The sprayed area was about 30 cm above the snow level so as to mimic the natural urine deposition by a predator.

However, the animals kept in captivity at the park might have been habituated to the odors (and presence) of the predators as they were to humans. Actually, I had the opportunity to observe those animals for a long period of time prior to testing. Some of

the elk were observed on repeated occasions grazing a few meters away from the wolves' enclosure. Four barren ground caribou, also kept in the same conditions as the elk, were fed their supplementary diet only 3 meters away from the arctic wolves' enclosure. I never observed any kind of alert or fright behavior manifested by these ungulates, even in such proximity to their natural predators. Therefore this pilot experiment was considered inconclusive and I searched for an opportunity in which wild ungulates could be tested in more natural experimental conditions.

Loring, Ontario, is a very well known wintering yard for white-tailed deer (Fig. 4). Deer concentrate in this area every winter moving from as far away as 60-100 km. According to Broadfoot and Voigt (1996), deer concentrate into an area of 525 km^2 between the towns of Loring and Golden Valley, on both sides of Highway 522, as soon as the snow depth reaches about 20 cm. During 1983-1989, an average of 15,000 deer were present in the yard annually and they did not leave until the spring thaw when snow depth decreased to 5-15 cm. Deer also use very well defined trails which make their locomotion easier in deep snow. Telfer and Kelsall (1984) reported that North American ungulates show morphological and behavioral adaptations for survival in deep snow. Thus, deer habitually create familiar trail systems in their habitat whether snow is present or not to lessen the pressure of wolf predation, which may have been the principal driving force in the evolution of yarding behavior. In January 1997, the snow depth reached approximately 80-90 cm in Loring study area. After a few days of observation, I concluded that many deer were present in the area, and they were moving on the already created trails on a regular basis. The experimental area extended roughly 10 km north and 10 km south of the highway. Lateral gravel roads and snowmobile trails
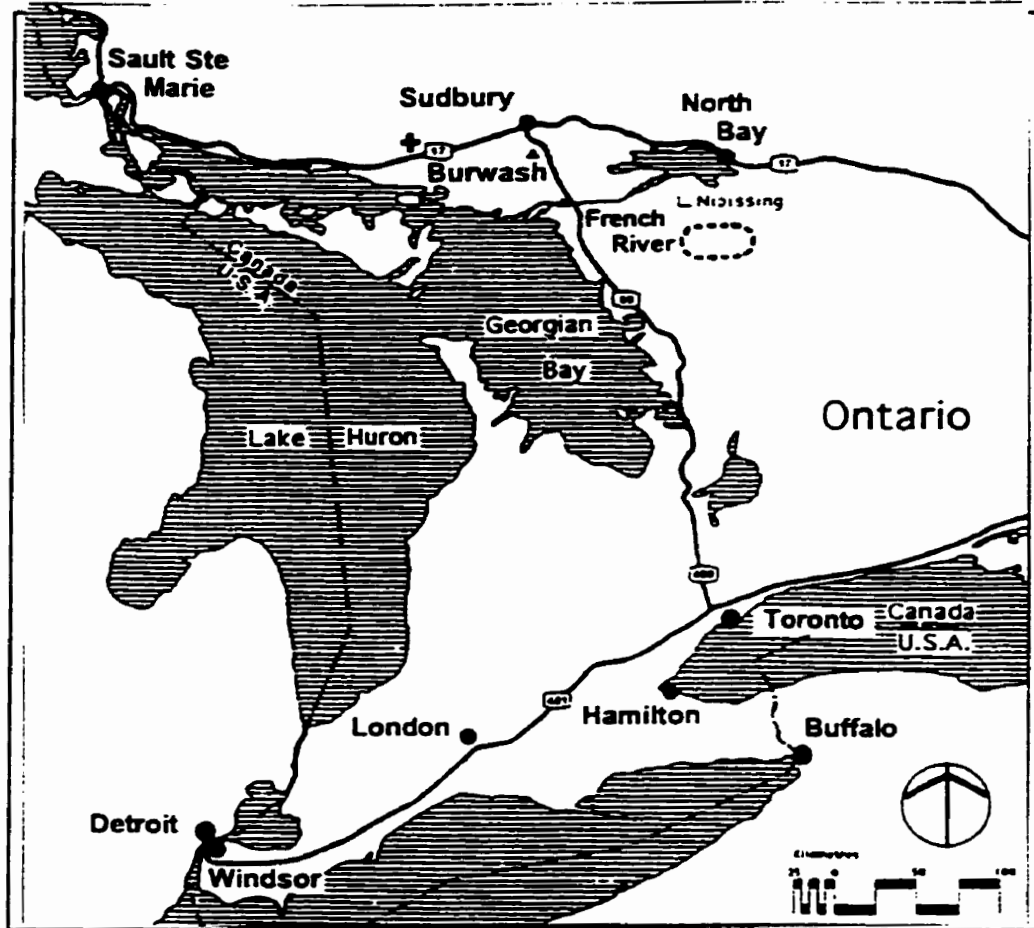
Figure 4. Location of study areas:

    ---- Loring deer yard

    ▲ salt lick

    ✚ Canadian Wildlife Experience park (Massey)

extended off the highway in different directions through the forest. Deer trails crossed these secondary transportation corridors very often, probably because these roads were not intensely used by humans. However, deer could be observed even in the proximity of the paved highway. Some of the local residents used to feed the deer in winter time, thus enhancing the attractiveness of the yards. Randomly marked and numbered pairs of deer trails crossing the lateral roads and snowmobile trails were selected. In each pair, one trail was designated as a control and the other as a treatment. At least 20 m separated the trails so that there would not be any interference of the repellents.

My goal was to identify as many intensely used deer trails as possible in order to have a large enough sample size for each of the repellents tested. Because the number of available trails was limited to a maximum of 30, the same trails were checked repeatedly and results were obtained for a particular repellent for several days before changing the repellent set up. Because I was actually interested in finding an effective and immediate way of deterring the animals from using the area, I processed all the results shortly after obtaining them. In order to acquire as many trials for statistical analysis as possible, some of the ineffective repellents (e.g., mothballs) were left in place even when additional products were introduced into the experiment. One of the basic assumptions in this situation was that we could expect additive effect (A=0, B=0, A+B=1) of repellents to occur, but exclusion effect (A or B=1, A+B=0) was considered very unlikely. In the situation when additive effects were suspected, the experiment was repeated with each of the used repellents separately in order to discover the true deterring stimulus. This might have been either a single product or a combination of more than one repellent.

In general terms, the same line of experimentation was followed during the second winter (January through April, 1998). Interestingly, many of the trails created by the deer in the second winter were situated in the same locations as in the previous year. However, the snow depth in the second winter only reached a maximum level of 40 cm.

Deer movement on the trails was monitored every 3-5 days and after each time new tracks were found on a trail, they were covered by sweeping fresh snow over the deer footprints, after applying the repellent (Fig. 5).

Wolf urine was applied by spraying it on tree trunks or other vegetation closest to the trail (< 40 cm). The mothballs, soap bars, and lemon fragrance pads were hung also as close as possible to the experimental trails. In the same manner, handfuls of human hair were attached to the vegetation with glue tape. All repellents were set up approximately at the level of a deer's head (60-70 cm above the trail, 30-40 cm above the snow surface). All other presumed repellents (Deer Away®, wolf urine in antifreeze, coyote urine, rotten eggs, Sanovan®, cresol, 1-octen-3-ol, and Roesseler's sweat) were solutions applied by soaking small sponges and suspending them from branches or twigs, as previously described.

At the end of March 1997, a life-size wolf silhouette of plywood was set up beside one of the most used trails. As the object seemed to produce the expected results of preventing the animals from using the trail, more wolf-head silhouettes were prepared for further experimentation. However, the wolf silhouette was not included in the statistical analysis of the first winter results because the weather did not permit the continuation of testing, as the snow melted and the deer left the area. One day after setting up the wolf silhouette, I observed the tracks of a deer that had approached it to within about 10

meters, stopped, hesitated, turned around and walked away. After another 5 days, deer were still not moving on that trail. Therefore, the wolf silhouette was included, along with the other similar visual stimuli, in the next summer (1997) experiment. The results were negative and this fact, in corroboration with similar negative results reported by other authors, prompted cessation of further winter testing of visual stimuli.

The field work for the summer of 1997 took place at a salt lick situated in an old field surrounded by a forested area, 30 km south of Sudbury, Ontario (Fig. 4). Over 50 observation days were recorded there. For most of the time, an automatic equipment was taking photographs of the animals that were using the mineral supplement. The equipment consisted of a Passive Infrared Trailer Monitor ("TrailMaster"), a common 35 mm camera, and a trigger device for the camera. The TrailMaster system is a passive infrared receiver which detects the combination of heat and motion and transmits an electric impulse to the trigger. Thus, it was known that at least four bull elk, four cow elk (one of them with a calf), one cow moose with a calf, two yearling moose (a female and a male), and two deer (a female and a male) were using the salt lick. Other animals were present at the site but were not photographed. Most of the animal visits at the salt lick took place at night (2300-0400) and the conditions for either making direct observations or photography were not favourable. However, a sand zone with a diameter of approximately 3 m was created around the salt lick to facilitate reading of the tracks (Fig. 6, a and b). Starting on May 8, 1997, the first observation period was characterized by a short interruption of animal visits. This could be explained by the fact that a tree stand for direct observation was being constructed, approximately 80 m away from the salt.
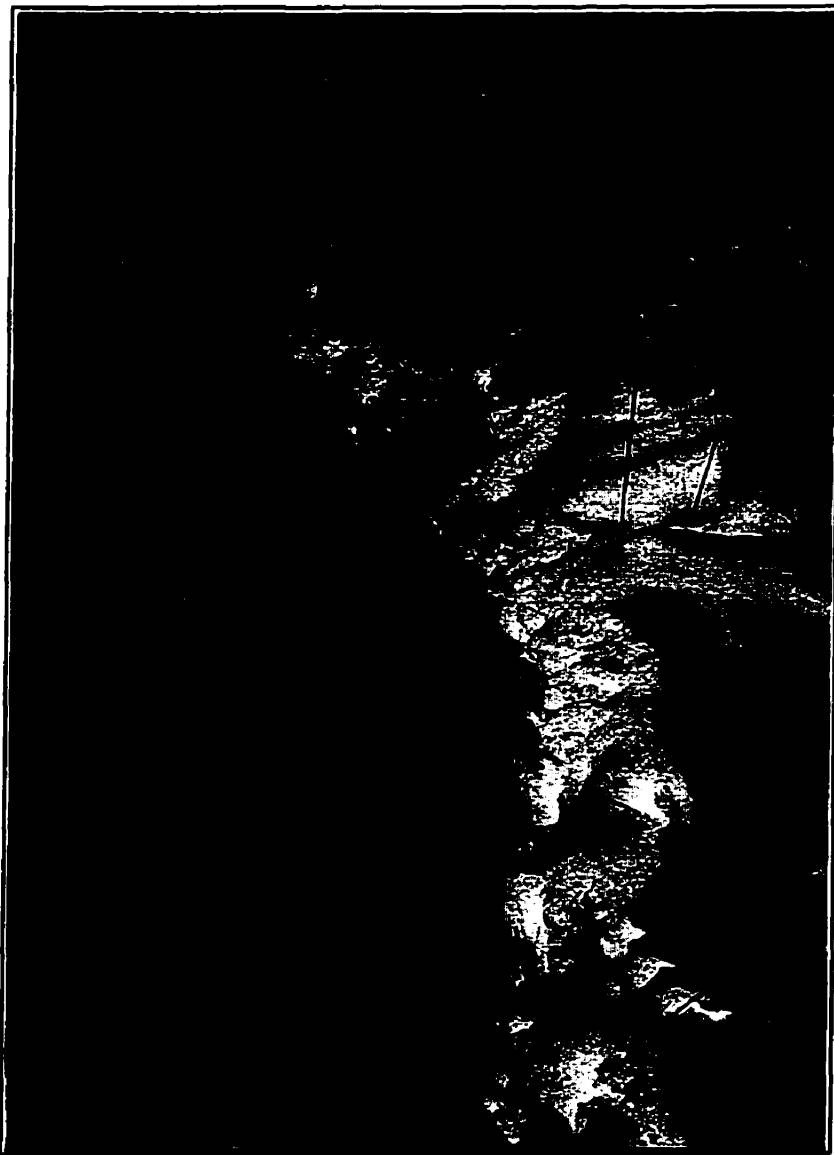
Figure 5. Trail used by deer in Loring (Ontario) winter yard.

From May 19th to June 10th the animals (elk and deer) reappeared and gradually increased their frequency of visits at the mineral lick. Therefore, on June 11, 1997, four wolf-head silhouettes made of plywood were introduced, followed after variable time intervals (Table 5) by clothing items, a life-size plywood wolf silhouette, and a life-size plywood human silhouette. The silhouettes were placed approximately 6 meters away from the salt in a standing position by sticking them into the soil (Fig. 7). Clothing items were suspended from a nearby tree, approximately 2 m away from the salt. On July 5th, a new commercial olfactory repellent called "Critter-Ridder®" (powder) was applied at the site by spreading it around the salt lick over the entire area covered by sand. One wolf and one coyote skin were suspended in the same manner and position as described for the clothing items. Some of the tested deterrents were actually removed as new products were introduced (Table 5). The same assumption for additive and exclusion effects as for the winter of 1996-1997 was considered. By July 29th, the predator skins, the human plywood silhouette and the "Critter-Ridder®" repellent were still in place. On this date, all except the predator skins were removed and a new product called "Sanovan®," a chemical compound based on dichlorobenzene was applied. Sanovan® was a liquid compound and it was applied in a small open plastic bottle set up just beside the salt block, so that its particular smell could emanate. Sanovan® was removed from the site on September 1st and until October 23rd there was a control period with no deterrents applied. October 23rd was the date Sanovan® was again applied until November 15th. As this product suggested some positive effect, it was further tested in the following winter.

Whereas in the two winters of experimentation, only deer were tested, in the summer of 1997, we tested potential repellents on a combination of wild ungulate

species. Sometimes, by analysing the photographs from the automatic camera in corroboration with the tracks left by the animals in the sand, we were able to determine what species of ungulates visited the salt supplement. However, in many instances, the tracks were confusing, as different species would use the supplement in a very fast succession. Because it was not possible to discriminate accurately between different species using the salt lick, the potential effect of repellents was tested on ungulates without species differentiation.

2.3. Statistical Analyses:

The nonparametric McNemar test was used to interpret the winter data. This test, also known as the test for significant changes, is applicable in the case of paired dichotomous data (Zar, 1996). The value of 1 was assigned for the situation in which animals were moving on the trail, and value 0 for the case in which no new tracks were present.

The winter data were arranged in a way that allowed calculation of the proportion of trails used by deer, compared to the total available trails for each checking day. For this data set, a Multivariate Analysis of Variance (MANOVA) was used, with the applied treatment as the "between groups" variable and the proportion of trails used of the total in both treatment and control categories, as "within subject" factors (Sokal and Rohlf, 1981; Norušis, 1990). As the differences in the numbers of trails used by deer on various days appeared also due to other factors which were not measured (e.g., temperature, precipitation, snow depth, etc.), we were only interested in our "within subject" results

that explained the possible variation between the numbers of treatment (with repellent) and control trails travelled by deer for each repellent tested.

A comparison for different treatments was made by One Way Analysis of Variance with a Tukey post hoc test (Norušis, 1990; Zar, 1996).

For the summer 1997 testing, the data were arranged in the form of a contingency table (Bailey, 1959) and a chi-square analysis was used to find if there were differences in animal visits at the salt lick between the days with and the days without repellents at the site. The probabilities of obtaining the observed results if the two variables were independent and the marginals fixed, were calculated by SPSS program, using Fisher's exact test, most useful when the total sample size and the expected values are small. This test is applied if any expected cell value in a contingency table is less than 5 (Norušis, 1990).

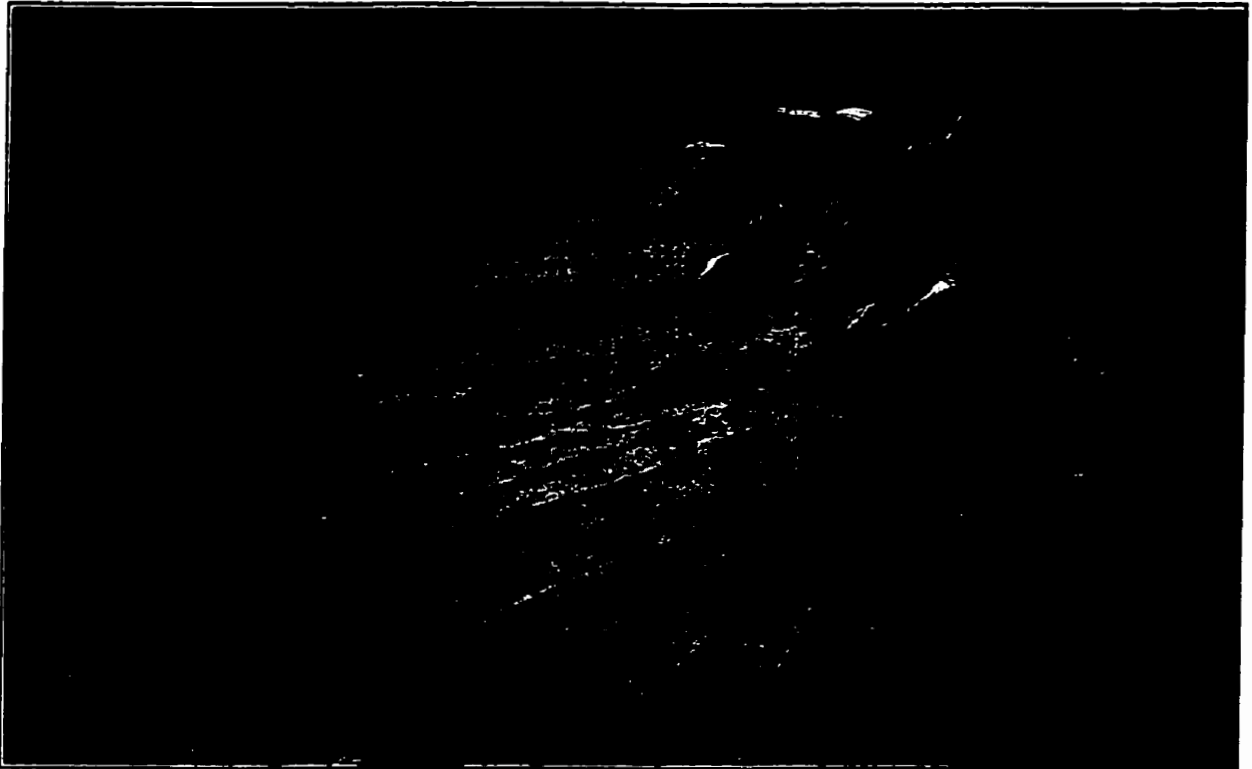Figure 6a). Sand around the salt lick with ungulate footprints.

Figure 6b). Sand at the salt lick after preparation for recording new tracks.

Figure 7. Human silhouette at the salt lick. Cow moose with calf nearby.

3. RESULTS

The initial application of wolf urine at The Canadian Wildlife Experience park in Massey, Ontario, did not produce encouraging results as the elk crossed most of the trails sprayed with the product within 10 hours.

Data collected on free-ranging white-tailed deer in Loring, Ontario in the winter 1996-1997 are summarized in Table 3. The only significant difference between treatment and control trails appeared in the case of mothballs in combination with other deterrents (wolf urine, Deer Away®, wolf urine in antifreeze, coyote urine, rotten eggs), (P<0.05).

Table 3. Summary of tested repellent effects on white-tailed deer in winter 1996-1997. McNemar test was used to determine statistical significance.

Repellent	pairs of trails checked (treat./contr.) n	trails walked by deer (treat./contr.)	statistical significance (P)
wolf urine*	55/55	30/29	1.00
mothballs + other*	210/210	160/173	0.04
mothballs only	42/42	34/34	1.00
"Deer Away®"	42/42	32/36	0.22
wolf urine in antifreeze	42/42	34/38	0.22
coyote urine	42/42	26/32	0.11
rotten eggs	42/42	34/33	1.00
soap bars**	49/49	41/42	1.00
lemon fragrance**	35/35	26/29	0.37
TOTAL	231/231	171/185	0.17
overall % trails walked by deer = 77			
* Because the mothballs were left in place until the end of the experiment, the total represents their reading plus the first time 21 pairs of trails had been treated with wolf urine. ** The soap bars and Lemon Fragrance were actually added onto different trails in combination with other previously ineffective repellents.			

However, this statistical significance resulted from the very large sample size as the naphthalene balls were left in place until the termination of the experiment. Thus, we tested 210 pairs of trails with naphthalene plus other deterrents, out of which 160 were used by deer in spite of the presence of the substances. Compared to this, 173 control

trails out of 210 were used by the animals. Although the difference shows statistical significance, it was considered unimportant for practical purposes as the animals still used an unacceptably high number of trails with combined deterrents on them. Moreover, when considering the mothballs only (n=42), no differences were obtained between the number of treatment and control trails walked on by deer.

No other chemicals or materials, alone or in combinations, produced significant differences between control and treatment trails in terms of deer usage. This statement is also true for the repellents tested in the second winter, 1997-1998 (Table 4).

Table 4. Summary of repellents used in winter 1997-1998. McNemar test was used to check for significance.

Repellent	pairs of trails checked (exp./contr.) n	trails walked by deer (exp./contr.)	statistical significance (P)
Sanovan®	68/68*	48/44	0.42
human hair	240/240*	147/151	0.68
m-cresol	60/60	45/46	1.00
1-octen-3-ol	60/60	34/35	1.00
Roesseler's sweat	60/60	27/31	0.29
TOTAL	300/300*	187/189	0.83
Overall % trails walked by deer = 63			
* The first 8 Sanovan® applications were not included in the overall calculation. Also, the human hair was included in the next three experimental application types because the hair was not removed until the end of the experiment.			

The results of the tests performed during summer of 1997 were analyzed by Fisher's exact test and cross-tabulation. Table 5 is a summary of the potential deterrents tested and the time periods in which they were applied at the salt lick.

The data in the column "animals visiting the site" should be regarded with caution. Even though there was sand covering a radius of about 3 m around the mineral lick, reading the tracks of the animals in these conditions did not yield precise results.

Table 5. Repellents tested in summer 1997.

time period	repellent on site	animals visiting the site	# of checking days	# of days with new tracks found
May 19 – May 25	none	elk cow + calf four elk two deer	5	5
May 25 – May 29	none	four elk two deer	4	4
May 23 – June 10	none	four – five elk two deer	3	3
June 11	four wolf heads (plywood)	one deer three elk	1	1
June 12 – June 20	four wolf heads clothing items	elk and deer	5	5
June 21 – June 25	wolf silhouette	five elk one deer	3	3
June 25 – June 27	human silhouette	none	1	0
June 17 – July 4	human silhouette	three bull elk cow elk with calf moose cow, calf, deer	2	2
July 5 – July 9	human silhouette "Critter-Ridder" predator skins	four-five elk two-three moose two deer	2	2
July 9 –July 29	predator skins human silhouette "Critter-Ridder"	four-six elk two-three moose two deer	3	3
July 29 – August 1	dichlor-benzene predator skins	none	1	0
August 1–August 9	dichlor-benzene predator skins	cow elk with calf	3	1
August 9-August 15	dichlor-benzene	none	3	0
August15-August26	dichlor-benzene	cow elk with calf	3	1
August26-August30	dichlor-benzene	none	1	0
Sept. 1 – Oct. 3	none	one elk	8	1
Oct. 3 – Oct 13	none	cow elk with calf probably a deer	2	2
Oct. 13 – Oct. 23	none	two adult elk + calf one moose	3	3
Oct. 23 – Nov. 5	dichlor- benzene	few elk tracks	3	1
Nov.5 – Nov. 15	dichlor –benzene	one moose	3	1

Because the methods used for data collecting did not record the presence of every single ungulate appearing at the site, no attempt was made to analyze the data for differences among species of wild ungulates. As shown in Table 6, the wolf and wolf head silhouettes, clothing items and Critter-Ridder® did not produce any modifications in

ungulate behavior. In the case of the three other products, differences between the number of checking days and the number of days with new animal visits at the site were recorded. A cross-tabulation including the analysis of these three products (human silhouette, predator skins, Sanovan®), as well as the control days (days with no deterrent at the site) showed a highly significant difference between these four situations (P<0.005), and a Phi value (equivalent of a correlation coefficient) of 0.48. Sanovan® was responsible for this difference, since removing this product from the analysis eliminated significant results. Through cross-tabulation, we found no significance (P=0.59), and the presence at the site of human silhouettes, predator skins, or no deterrents showed a Phi value of only 0.16. Following these encouraging findings, we further tested Sanovan® in the winter 1997-1998, but obtained no other significant results for this product (Table 4).

As for the winter experiment, we have to take into account the impact of numerous variables related to weather conditions, deer physiology and behavior over a relatively long period of time. These variables were not measured, but undoubtedly, they played a role in the variability of our data. In order to account for these unknown variables, the winter data were also subjected to a two-way Analysis of Variance. Thus, the ratio of trails used by deer to the total number available for each situation was calculated (# trails used by deer/# trails available for each case), (Table 8). The "within subject" factors (coded "track" in Table 7) represented the differences between treatment and control trails for each separate case. As expected, a significant difference between treatments existed, (P=0.001), explaining 54% of the variance present. No differences were obtained in any of the repellent tests between treatment and control trails used by

deer, (P>0.05), with only 9% of the variance explained by repellent presence (Table 7 and

Table 8).

Table 6. Repellents used in summer 1997. Fisher's exact test interpretation.

Repellents	# of checking days	# days with new animal tracks	Fisher's exact test significance (P)
none	25	18	
wolf and wolf heads silhouettes	9	9*	
clothing items	5	5	
human silhouette	8	7	0.64
"Critter-Ridder®"	5	5	
predator skins	9	6	0.54
"Sanovan®"	17	4	< 0.01

* Where the number of days checked and the number of days with new animal tracks were the same. no statistics were calculated.

Table 7. Summary table for MANOVA analysis. All winter data.

Source of variability	SS	DF	MS	F	Signif F
within cells	.33	41	.01		
track	.03	1	.03	4.00	.052
treatment by track	.07	13	.01	.70	.752

Assumptions of homogeneity of variance and homogeneity of variance-covariance matrices were satisfied. There was no significant interaction between the repellents and the "within subject" effects. Furthermore, group #7 (putrescent eggs) and group #10 (Sanovan®), which were showing the least and the most variability, respectively (Table 8), were removed from the analysis. In order to check for possible hidden effects, the MANOVA procedure was repeated on this modified data. The results did not change the significance, as the Phi value increased to only 0.13, demonstrating that neither of the presumptive deterrents tested in our winter experiments were suitable for practical large

scale application. Even though not statistically significant, the 9% to 13% variance explained by "within subject" factors means that deer were sensitive to disturbances in their environment. Out of 14 different presumptive deterrents applied in winter, 10 caused reduced usage of treatment compared to control trails (Fig. 8). Deer showed reluctance for using trails with new objects on them, whatever the object was, but this effect was too weak to be of practical use along travel corridors.

The winter of 1996-1997 differed from the winter of 1997-1998 in snow depth, resulting in different intensities of deer usage of the trails. Thus, in the first winter, characterized by an average snow depth of over 70 cm, the deer used the trails in 77% of cases. In the second winter, with average snow cover of only about 40 cm, the deer were less dependent on the trails and moved around in a more random pattern (63% of trails used). However, this situation occurred equally on both treatment and control trails. The Multivariate Analysis of Variance was performed in order to accommodate for such disturbing variables and to uncover the real effect of the repellents, if any. Even though statistically significant effects for neither tested objects nor chemicals were found, One Way Analysis of Variance was performed for the ratios of deer usage of the treated trails. This procedure showed a statistically significant difference among the repellents(P=0.009) and a post hoc Tukey test pointed out a difference between group 9 (soap bars, 83% trails walked by deer) and group 14 (Roesseler's sweat, 38% trails used). This result should be interpreted, however, in view of % control trails used by the animals during the same testing period (83% for soap bars and 51% for Roesseler's sweat). Thus, the overall effect of these products was not significant, as proven by the MANOVA procedure.

Table 8. Means and standard deviations for winter data. Ratios of trails used by deer and the total available for each repellent tested.

Repellent treatment	Trails			
	treatment		control	
	x	SD	x	SD
wolf urine	.55	.09	.50	.07
mothballs+others	.76	.09	.82	.10
mothballs	.80	.07	.81	.20
Deer Away®	.76	.07	.85	.01
wolf urine in antifreeze	.80	.13	.90	.13
coyote urine	.61	.07	.76	.06
eggs	.80	.01	.78	.03
lemon fragrance	.77	.18	.85	.15
soap bars	.83	.15	.83	.12
Sanovan®	.53	.35	.49	.28
human hair	.59	.17	.63	.14
m-cresol	.75	.07	.76	.09
1-octen-3-ol	.56	.09	.58	.26
Roesseler's sweat	.38	.02	.51	.02
TOTAL	.70	.18	.73	.18

Figure 8 has been included in order to visually compare the effects of each tested repellent in treatment and control situations.

One interesting side discovery was made when testing the m-cresol and 1-octen-3-ol. Clusters of snow fleas were observed underneath the sponges in which the chemicals had been soaked (Fig. 9). The insects were identified as *Achorutes nivicolus* (Fam. Entomobryidae), and were obviously attracted by these chemicals.

Lights and sounds are another category of scaring devices that can be included in the group of common human-related stimuli. Although we did not test such stimuli in experimental settings a few incidental observations are in order at this point. As the tested animals frequented the mineral supplement mostly at night, the automatic camera would usually flash while taking pictures. At the same time, clicking noises were produced by

the equipment both at night and during daylight. On a few occasions, the animals recorded on photographs exhibited sudden jumping postures (Fig. 10a) in response to these strange stimuli. However, although most of the photographed animals showed awareness of the camera, they did not reveal alarm in their postures. Regularly taken photographs at two mineral supplements in the summer of 1998 have confirmed these findings. Thus, every time a new animal appeared at the site for the first time, it was reluctant to use the mineral block. Very quickly, though, the animals became habituated to the situation and on repeated occasions, they would move close in to investigate, even pushing the camera out of place with their muzzle (Fig. 10b).

In relation to the hypotheses stated, we conclude that:

1. The present study did not reveal any statistical differences in the intensity or the extent of wild ungulate presence between areas treated with repellents and those with no repellents.

2. There appeared to be a statistically significant difference among the effects of only a few of the presumptive repellents tested, but this difference proved to be largely due to confounding environmental factors. Thus, the apparent effects of such "repellents" proved to be of no practical value in this study.
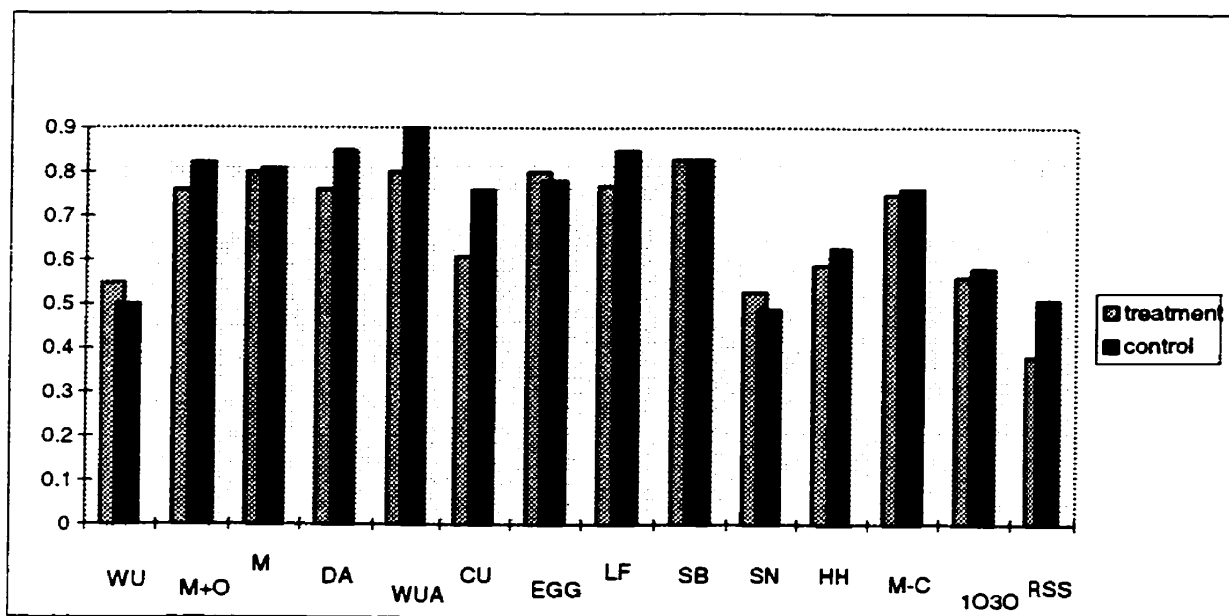
Figure 8. Ratios of trail usage by deer in winter.

(Legend: WU-wolf urine; M+O-mothballs+others; M-mothballs; DA-Deer Away; WUA-wolf urine in antifreeze; CU-coyote urine; EGG-putrescent eggs; LF-lemon fragrance; SB-soap bars; SN-Sanovan; HH-human hair; M-C-m-cresol; 1O3O-1-octen-3-ol; RSS-Roesseler's sweat)

Figure 9. Cluster of snow fleas attracted by m-cresol and 1-octen-3-ol.

Figure 10a). Elk alarmed by sudden flash of camera at the salt lick.

Figure 10b). Elk at the salt lick, investigating the automatic camera.

4. DISCUSSION

Even though several authors have placed strong emphasis on predator-related stimuli as wild ungulate deterrents, the results of this study did not support that theory. Predator-related stimuli tested during our study were either odor based (wolf urine, coyote urine, human sweat simulants), visual scaring devices (wolf and human silhouettes), or a combination of the two (wolf and coyote skins). None of these presumptive repellents proved to have strong effect upon wild ungulate behavior. These findings are consistent with the conclusions of several other authors.

Andelt et al., (1991;1992) tested the repellency of coyote urine on tame elk and mule deer in Colorado. At the concentrations used, coyote urine and BGR® performed better than other repellents in deterring elk from feeding on cubed alfalfa hay. However, consumption of rations treated with odor repellents (BGR®, chicken eggs, coyote urine, and Hinder®) increased from day 1 through day 5 of the trial. Consumption of diets treated with Thiram® (taste repellent) gradually decreased. Most of the deterrents failed to prevent feeding by hungry elk, compared to elk fed ad libitum. If elk were even moderately hungry, all the repellents tested, with the exception of the 6.2% concentration of Hot Sauce® (taste repellent), did not deter browsing.

One of the few studies dealing with ungulate-train collisions (Brown and Ross, 1994) reported that predator urine was found to be ineffective in deterring ungulates from using a railway right of way in Jasper National Park.

The effectiveness of predator faecal odors in modifying feeding selection by sheep and cattle was investigated by Pfister *et al.*, (1990). The results suggested that faecal odors may not prevent livestock from entering a treated area but may reduce the time spent grazing in such an area.

Swihart *et al.*, (1991) found that the effectiveness of bobcat and coyote urine on white-tailed deer declined over time, suggesting that deer either habituated to the scents or that the repellent components of the odors were lost via evaporation or degradation. Similar reductions in efficiency of predator urine placed in tubes or vials were reported by Sullivan *et al.*, (1985) and Sullivan (1986). Innate responses to fear-provoking olfactory stimuli should not be subject to habituation (Müller-Schwarze, 1990), although habituation in response to learned avoidance responses seems possible in the absence of occasional reinforcement. Experiments with naïve mule deer suggested that aversive responses to predator odors may have a genetic component (Müller-Schwarze, 1972). Whether the mechanism of predator-based repellents is innate or learned is thus unclear and the phenomenon is too complex to set clear demarcation between the two response mechanisms.

The presence of predators has been suggested as an important factor influencing the foraging behavior of prey species (Schoener, 1971; Pyke *et al.*, 1977). However, field evidence is rare, and although some foraging models account for predation, most assume that predators are unimportant. In his study of feeding behavior of moose on Isle Royale, Michigan, Edwards (1983) showed that only cows with calves, the age class most susceptible to predation, expressed distribution and diet modified by the presence of

wolves. Other moose did not seem to be affected by the presence of predators in their home range.

After his long term observations on predation by wolves, Mech (1970) concluded that the behavior of animals upon the approach of wolves is well adapted to countering the sudden-rush type of attack. If prey sense wolves soon enough, they will hurry right out of the area. But if they can see the wolves, they may stand and watch until it is apparent that the wolves are after them. The author described incidents in which caribou did not flee nearby wolves unless suddenly pursued. The result of this behavior is that the strength of the prey is saved until the encounter when it is really needed. This energy saving behavior seems to be so well developed in caribou that they have learned to distinguish a hunting wolf from a wolf not interested in hunting. At certain times, wolves move among herds of caribou without alarming them, whereas on other occasions, the predators greatly disturb the caribou (Mech, 1970).

Müller-Schwarze (1990) concluded that the available results of several studies justify the generalization that consistent effects of predator-related deterrents have been demonstrated, but that most of these are not sufficiently unequivocal to be of interest for serious large-scale field applications. So far, the response has been neither strong, nor durable enough.

Although some users have reported the effectiveness of naphthalene (Scott and Towsnend, 1985), further testing has not supported those claims. Our findings are in concordance with those of Harris *et al.*, (1983), and Conover (1984) who tested the effect of mothballs and found them inefficient in repelling wild ungulates. As explained in the

results section, the apparent effect observed for mothballs in winter 1996-1997 was only an artefact of the very large sample size and was not sustained by further experimentation.

Putrescent eggs and their commercial derivatives (e.g., Deer Away® -BGR) are most often cited in literature as successful ungulate repellents. Many references reported astonishingly positive results in preventing wild ungulate browsing damage. However, Palmer et al., (1983) concluded that even though only Big Game Repellent® was consistent in reducing deer feeding, the product still required further investigation. Although BGR produced statistical difference compared to no treatment, it did not totally prevent deer feeding.

Andelt et al., (1991) tested the repellent effects of Big Game Repellent® on tame mule deer in Colorado and found that the effectiveness of the product was reduced when apple twigs were sprayed with 7 cm of water to simulate heavy rainfall. When deer were even moderately hungry, BGR® also failed to deter browsing.

Swihart and Conover (1990) examined the effectiveness of BGR® in reducing damage by deer to Japanese yews in Connecticut nurseries during winter. Although BGR® was the most effective of the tested repellents (76.0% reduced damage relative to untreated plants), it did not completely eliminate damage. Further, the cost of applying BGR ($444 per ha) seriously limited its use to small ornamental plantings.

Deer Away® was the only repellent of 15 tested that kept moose from roadside saltwater pools (Fraser and Hristienko, 1982). This repellency was most pronounced for the first 10-day period following application. Deer Away® was effective in pool water at all concentrations from 2 to 0.05%, but less effective at a concentration of 0.02%. Mean sodium concentration of the pools tested in that study was 336 ppm, considerably less

than that expected in the brine solution on a freshly salted road. However, it seems that in the above cited experiment, the repellent acted more through its taste properties than through its odor. In Jasper National Park, Deer Away® did not persist on trees and shrubs after light rain (Brown and Ross, 1994).

A study published by Conover (1987) concluded that despite the 50% reduction in deer-induced damage, the levels of browsing in the BGR sprayed plots were still unacceptably high.

Andelt *et al.*, (1991; 1992) tested whole, fresh, chicken eggs in feeding trials with mule deer and elk. The egg repellent was among the most effective of the deer repellents, but was only intermediate in performance for elk. It was not successful in deterring hungry individuals of either species.

In another study, a whole egg slurry was field tested on white-tailed deer and was found to be effective at repelling them for periods of up to 6 days (Johnson, 1986). The same author also created a paste of 10% albumin powder and 90% water, and found it to be highly effective in deterring deer from eating treated cob corn. In each of these trials, however, untreated corn was available for consumption, so the deer could not be described as "hungry." Similar results were found in the present study showing that putrescent eggs and commercial derivatives were not able to deter wild ungulates.

In some situations, wild ungulates manifest a high level of avoidance to human activity. This was the basis for introducing the testing of some human related stimuli in our study. In other areas and conditions, wild ungulates react in a totally unexpected way, showing adaptability and astonishing tolerance of close human presence. The present study failed to show that human-related stimuli (olfactory and visual) had any effect as

area repellents for wild ungulates. Therefore we conclude that wild ungulate perception of the human image is variable and dependent on the given set of conditions. Both innate reactions and learning play an important role in triggering behavioral responses of cervids when approached by humans. Where the conditions so dictate (e.g., areas with extensive hunting activity) animals learn quickly to avoid humans, become elusive and secretive, usually move around only during night time and are rarely, if ever, seen by humans. Totally opposite to this, in areas like natural parks where protective measures extend over long periods of time, humans are not perceived as a threat and wild ungulates spend their lives in close proximity to humans to the extent of becoming a nuisance. In between these two extreme situations, it seems that animals process the information about human presence in their surroundings not only through their senses, but also through some kind of integrative mechanism. Recognition of human-related danger would not be simply determined by human smell or sight, but rather, as in the case of natural predators, the animals try to asses the level and imminence of potential danger before taking to flight. Thus, for example, white-tailed deer in our study area were easily approached during winter time, when no real threat was present to them. The same animals showed a different behavior in late fall during the legal hunting season, when they could be rarely seen.

Other authors have likewise found that human related stimuli did not have a strong enough repellent effect. Human hair and creosote were tested and did not prove effective (Harris *et al.*, 1983; Conover, 1984). Fisher (1995) reported that bags of human hair were used to protect valuable plant specimens at the Arboretum of the University of Wisconsin - Madison, but were only effective where deer were not used to the presence of

humans. In Banff National Park, Alberta, elk and black-tailed deer do not seem to exhibit any avoidance behavior regarding human activity (Krakauer, 1995). A great number of fatalities occur due to animal-vehicle collisions in the area. The animals not only feed in very close proximity to humans, but even "beg" for a free meal and sometimes become a hazard to humans. Thus, females become particularly dangerous during the spring calving season and bulls (or bucks) became aggressive during the autumn rut. As reported by Scott and Townsend (1985a), human hair was the most commonly used repellent by fruit growers in Ohio. Hair was rated as providing "complete" to "a little" protection from damage by 83% of growers using it, but 16% of growers thought hair did not work as a deer repellent. The fatty acid 3-methyl-2-hexanoic acid is the principal odorous component in human sebaceous gland secretion and, hence, of human hair (Zeng et al., 1992). Anecdotal reports suggested that human hair may repel deer, although studies have failed to reveal repellency (Conover and Kania, 1988). Contrary to anecdotal claims, the results reported by Milunas et al., (1994) are consistent with other investigations (Conover, 1984) that failed to reveal any effect of human odor on deer browsing. This was true both when 3-methyl-2-hexanoic acid was used in the concentration present in human sweat, and when it was presented in ten times that concentration.

The odors of soap bars and lemon fragrance may be included in the category of indirect human-related stimuli, since normally these fragrances are not present in the natural environment. Fisher (1995) found that bars of soap acted as deer repellents as long as the animals were not habituated to human presence. Our study revealed no repellent effects of these products on deer. This is consistent with the findings of other authors. Parkhurst (1991) mentioned that when deer pressure in orchards was light to medium,

hanging bars of soap in the trees could help reduce browsing. But when deer pressure was heavy, about the only effective control was fencing. Similar findings were published by Byers and Scanlon (1987) following their study at Virginia Polytechnic Institute and State University's Winchester Agricultural Experimental Station and also by Swihart and Conover (1990).

Sanovan®, the commercial product based on dichlorobenzene produced highly significant results in summer tests at the salt lick. Unfortunately, these results were not confirmed by subsequent testing during winter 1997-1998. Therefore it was suspected that seasonal physiological shifts in mineral requirements, rather than the repellent, influenced the tested ungulates. During three summers of field work on moose, Fraser (1979) noted that these animals were particularly attracted to springs which were rich in sodium in May and early June, and to aquatic vegetation containing sodium between mid-June and mid-July. The author often saw moose on roads and drinking from roadside puddles during the same period that the springs and aquatic vegetation were being used and felt that behavior and presence of moose on the roads between May and July deserved special study because this activity coincided with the peak time of collisions between moose and vehicles in Ontario.

The exact nature of apparent sodium dependency of ungulates is not completely understood. The potassium-water-sodium imbalance theory, described by Weeks and Kirkpatrick (1976), suggests that the drive to consume sodium is highest in spring due to a high intake of potassium and water from green forage, producing a temporary negative sodium balance. Alternatively, Geist (1981) suggested that mountain sheep use licks to replace skeletal minerals catabolized during the previous winter. Neither theory explains

all incidences of salt-licking by ungulates, nor the strong attraction of caribou to salt in fall and early winter. Irrespective of the explanation, sodium dependency has been described as the most "hard-wired" need in the life history of some ungulates (Brown and Ross, 1994). In our case, the animals used the salt supplement in spring and early summer, which may coincide with their high mineral requirements determined by gestation, lactation, and antler growth. Once these critical periods ended, the animals did not frequent the salt lick with equal intensity. Therefore, the results obtained after Sanovan® application at the salt lick were considered an artefact of mineral requirement shifts in ungulates. However, in view of the highly significant results obtained, the use of Sanovan® as a summer ungulate repellent should be further investigated.

4.1. Animal habituation:

Researchers who have documented an apparent decline in ungulate repellence of predator odors over time have been unable to ascertain whether the decline occurred due to habituation or evaporative loss of the active, volatile components (Swihart et al., 1991). The longevity of the effective constituents in predator odors can be enhanced by the addition of slow-release compounds (Sullivan et al., 1988). It is also possible that predator urine might gain some of their efficiency by functioning as taste repellents (Swihart et al., 1991).

Child (1983) stated that flashing lights, noise, odors, visual signals and combinations of several of those have been tested in an attempt to keep moose from entering vehicular and rail corridors. Initial results were favorable. Once the animals had

habituated to the stimuli, however, they began to frequent the transportation corridors once again.

Harassment can lead to avoidance or abandonment of areas, to reduction in population range and, ultimately, to reduction of the population due to loss of access to resources, increased predation or increased energy costs. Using theoretical understanding of animal behavior, biologist have predicted that animals associate unpleasant experiences with the localities and times in which they experienced the unpleasantness and avoid the places thereafter. This hypothesis was applied successfully for control of red deer and chamois in New Zealand. In areas where deer found the best habitat and caused damage, heavy hunting and harassment were instituted purposefully (Geist, 1981). However, animals also can adjust to some disturbances or link them to some positive aspects.

Classical learning theory explains some interesting phenomena concerning responses of big game to motor noises. The animals may take flight, remain indifferent or even be attracted to such noises, as has been observed for caribou and deer (Geist, 1981). Naïve animals initially may run from an unusual sound, but subsequent behavior depends on experiences associated with that sound. If the sound persists and remains localized, and the animals can approach or withdraw freely, it can be expected that they soon will ignore it. If the sound becomes associated with alarming events - such as being pursued by a snowmobile - the animals subsequently will respond to the sound with excitation and flight. If the sound becomes associated with something favourable, such as abundance of food, the individuals will approach and try to benefit. Thus, big game animals become conditioned to and accept noisy highways and airports, crowds of harmless tourists, and

the presence of loud, dusty, smelly, industrial activities - all of which tend to be localized and therefore, highly predictable activities. The astonishingly high degree to which large mammals are willing to associate with humans can be seen primarily in national parks, but not only there. A number of authors have pointed out that large mammals will habituate to what appears to be, at first glance, noxious stimuli (Geist, 1981; Krakauer, 1995). Moreover, large mammals also will search out human activities in order to benefit from them. The most impressive of these examples is caribou following the sound of chainsaws of logging operations in order to feed on the lichens of downed trees. This has been observed in Newfoundland, Scandinavia, and British Columbia. The same response was reported for white-tailed deer in Wisconsin (Geist, 1981).

Not all species adapt uniformly to the same stimuli. While mule deer may accept humans and their activities very readily, as is well-illustrated in Waterton Lakes, Banff and Jasper National Parks, Alberta, white-tailed deer in the very same areas remain shy and flighty (Krakauer, 1995).

As long as people and grizzlies meet, and such meetings are not reinforced negatively for bears, then bears will not only learn to ignore people, but they will go to the next behavioral stage of investigation and aggression. Examples abound through all western home ranges of grizzlies invaded by humans. Also bighorn sheep initiate exploration of a human by sniffing, licking, chewing and pulling on various parts of the person (Geist, 1981). Bashore and Bellis (1982) reported a case where white-tailed deer continued to feed undisturbed by military jet aircraft taking off a few meters away. Ohio crop growers felt that "exploders" provided little protection from white-tailed deer damage (Scott and Townsend, 1985a). Reports of the ability of caribou to readily adapt to

noise disturbances have been variable, but in many instances caribou have demonstrated the same capacity as other ungulates to habituate to disturbance (Geist, 1981).

Andelt *et al.*, (1991; 1992) found that the relative efficiency of Thiram® (taste repellent) increased over time, in contrast to the decreasing efficiency of the odor-based repellents tested. They speculated that mule deer habituated more readily to odor-based repellents than to taste-based repellents. Habituation may have allowed a reduction in the fear-evoking response inherent in odor-based repellents (Sullivan *et al.*, 1985; Williams *et al.*, 1990). An offensive-tasting repellent, on the other hand, may remain somewhat repulsive even if animals are exposed repeatedly (Andelt *et al.*, 1991).

Even though the experimental set up of the present study was not designed to monitor and document animal habituation, some conclusions can be drawn in relation to this phenomenon: (i) the animals showed clear habituation to the visual and auditory stimuli produced during operation of the photographic equipment; (ii) as presented in the conclusions of the authors cited above, habituation is an important adaptive characteristic of wild animals. Previous life experience determines the speed through which habituation will occur. In both experimental settings of the present study the tested animals were aware of human existence and presence in the area. Therefore, rapid habituation to human related stimuli should be considered in interpreting the results of the study.

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APPENDIX

ALTERNATIVE METHODS FOR UNGULATE MORTALITY MITIGATION ON TRAVEL CORRIDORS

The results of this study, supported by the long line of publications that were researched, indicated that chemical repellents were unlikely to be effective in preventing ungulate-vehicle collisions. Research continues in different parts of the globe as human encroachment into wild ungulates' habitats generates increasing concerns. Some alternative methods have been recommended by various authors. Even though most of them could be highly effective, the cost and logistics of application restrict their usefulness only to very limited stretches of transportation corridors.

Intercept salt baiting and alternative de-icers:

Considering the importance of salt in attracting wild ungulates onto roadways, intercept salt baiting was already recognized as a good method by Aldo Leopold in 1933. Because ungulate attraction to winter road surfaces is frequently presumed to be a response to a dietary need to consume salt or other elements, provision of those supplemental minerals in some safe locations away from the road could lead to a reduction in road-kills (Wiles and Weeks, 1986). Intercept salt licks established along the Sallmo-Creston Highway, in BC, have been successful in reducing caribou use of the right-of-way (Brown and Ross, 1994). In the Crowsnest Pass of southern Alberta, bighorn sheep road-kills were reduced following construction of artificial salt licks away from highways (Bradford, 1988).

In light of the known detrimental effects of salt applied to roadways, much testing has been, and continues to be conducted to identify effective road de-icers that lack the negative characteristics of salt (Brown and Ross, 1994). However, none of this research

appears to have been driven by the need to reduce wildlife road-kills. Damas and Smith (1982), Fraser and Thomas (1982), and Poll (1989) were the only authors to recommend use of an alternate de-icer (calcium chloride) to reduce road-kills of ungulates.

Many substances have been identified as potential alternatives to rock salt as a road de-icer. The 5 most-common include calcium chloride, magnesium chloride, calcium-magnesium acetate (CMA), sodium formate, and urea (Kelsall and Simpson, 1991). To date, apparently no de-icer has proven as effective as salt without being prohibitively expensive.

Intercept feeding and vegetation manipulation:

Wood and Wolfe (1988) investigated intercept feeding to divert mule deer away from highways and reduce the frequency of deer-vehicle collisions. Potential benefits projected as a result of reducing collisions exceeded feeding costs. The technique demonstrated usefulness in a short time-frame at locations where large numbers of deer presented a risk to vehicles. However, this study suggested that intercept feeding might be expected to reduce deer-vehicle collisions by < 50%, requiring the application of additional or alternate methods (e.g., fencing) to further lower the collision rate.

Removal of forage vegetation in the areas immediately adjacent to roadways has the potential to reduce wildlife roadkills by reducing the attractiveness of those areas as wildlife habitat. The best potential for success with vegetation manipulation involves rendering the roadside relatively undesirable, while enhancing habitat away from the corridor (Brown and Ross, 1994). However, these authors stated that studies evaluating the effectiveness of vegetation manipulation in reducing roadkills have been inconclusive. If the main attraction is not roadside habitat but the road surface itself (as along Highway

40, Alberta) adjustment of habitat quality in the vicinity is unlikely to succeed in significantly reducing roadkills (Brown and Ross, 1994).

On the other side, Andersen *et al.*, (1991) cited clearing the forest around the railways in Norway as being the most promising measure for moose-train collision reduction. Removal of available moose browse and cover was expected to reduce the time spent by moose close to the railway line and increase the locomotive driver's chance of seeing moose on or close to the railway in time to stop the train. Field experimentation showed that this method reduced the number of train-killed moose by 56% (Jaren *et al.*, 1991).

Driver Awareness. Public education campaigns:

Several techniques have been employed to alter driver behavior with the intent of reducing wildlife-vehicle collisions. Theoretically, increasing the awareness of drivers to the likelihood of such collisions should improve their responsiveness to the sudden appearance of an animal on the road, allowing more time for evasive action and resulting in fewer road-kills (Bown and Ross, 1994).

The most widely used driver-awareness technique is the installation of roadside warning signs. The most common structure is a 76×76 -cm yellow diamond with a black silhouette of a leaping deer. These signs probably are not effective at increasing driver awareness or reducing driver speed or ungulate road-kills, largely because they are left in place year-round and motorists habituate to them. A key to the effectiveness of any technique designed to enhance driver awareness is to avoid driver habituation to the warning. Removing or covering the signs during seasons or times when wildlife normally would not be expected on the road could partially alleviate this effect (Williams, 1964).

Brown and Ross (1994) reviewed data on the effectiveness of game-crossing signs. They reported that research in Sweden indicated that signs had no effect on driving speed, and went unnoticed by 60% of motorists. Pojar *et al.*, (1975) designed and tested a

dramatic, animated deer-crossing sign in Colorado. The sign was large (1.83×1.83 m) and consisted of 4, neon, deer silhouettes lighted in sequence to portray a deer leaping. When the sign was activated, the mean speed of vehicles decreased less than 4.9 km/h (speed limit=96.6 km/h), and the ratio of deer crossings to deer killed did not change. Vehicle speeds decreased much more when deer carcasses were placed in view on the roadway. The authors concluded that, although drivers apparently saw the animated sign, the reduction in speed was insufficient to reduce the number of deer killed. This prototype sign cost $2000 (US) in 1971 (Pojar et al,. 1975), and required 110V electrical power. Large, dramatic signs consisting of larger-than-life outlines of elk or moose, with or without a reflective "eye," have been used in some areas, including Highway 40 (Alberta). Although their effectiveness has not been quantified, Poll (1989) felt such signs were relatively effectual in increasing driver awareness.

An alternative that shows some promise is a dramatic, illuminated sign which is activated only when animals trigger a microwave detection beam located in the right-of-way. Such a sign was effective in reducing traffic speeds up to 24 km/h when activated (Brown and Ross, 1994). It has an important advantage over conventional signs in avoiding the "cry-wolf" syndrome when ungulates are not on the road. Unfortunately, this system is not appropriate for large scale application because it covers a stretch of only 400 m, and was estimated to cost $10,000 (Bradford, 1988). An additional drawback to its use in remote areas is its dependence on electrical current to operate.

Oosenbrug et al., (1986) considered that a public education program to alert drivers to times and locations of greatest risk may for now be the best overall approach to the problem. Public information campaigns have been implemented in a number of jurisdictions in an attempt to increase awareness of road-kill hazards. Despite the lack of quantitative information, there is reason to believe that awareness campaigns directed at specific, localized problems, can be effective (Brown and Ross, 1994).

Speed limits:

According to Brown and Ross (1994), reduction of highway speed limits has the potential to reduce wildlife road-kills. If vehicles are operated at lower speeds, drivers have more time to react, presumably increasing their ability to avoid collisions. Damas and Smith (1982) suggested that imposition of speed limits of 60 km/h or less would help reduce road-kills. However, the correlation between vehicle speed and ungulate mortality rates is unquantified (Brown and Ross, 1994). Reduced train speed was identified as one of the most feasible options for moose-train collision prevention in Alaska (Becker and Grauvogel, 1991).

Fences:

Current efforts at reducing collisions of vehicles with deer and other large game species rely heavily on the construction of deer-proof fences at highway property boundaries (Bellis and Graves, 1971). To date, fencing has been the only dependable method for eliminating deer damage under high animal pressure, but this method can be very expensive (Dietz and Tigner, 1968; Byers and Scanlon, 1987).

Scott and Townsend (1985) concluded that fencing may be the only viable control method for agricultural growers with hunting restrictions, high value crops, or severe damage.

Fences are so effective at controlling ungulate movement that, if access to the other side of the right-of-way is desirable, structures such as overpasses or underpasses must be incorporated into the design to allow animals to cross. This is of particular importance in dealing with migratory species or species with localized habitat requirements when that habitat is bisected by the fence (Brown and Ross, 1994). Bergerud et al., (1984) felt that caribou, in particular, appeared to be susceptible to potential negative effects of fencing without crossing structures. The most effective crossing structures used in Banff National Park are underpasses, which apparently were

accepted readily by elk, bighorn sheep, mule deer, white-tailed deer, moose, and various carnivore species (Bertch, 1991).

According to Lavsund and Sandegren (1991), fences along the roads have proven to be effective measures for reducing the number of moose collisions. In Sweden, about 1300 km of highway were fenced in 1991. This protected a small percentage of all roads (1-2%), but a high percentage of the main roads, especially those with four lanes, intensive traffic and a high speed limit (110 km/h). The number of moose accidents along a fenced road decreased 80-100%. Fences were build according to an economic model which took into account the expected number of accidents, the cost of an individual accident and the cost to build and maintain the fence.

The Glenn Highway (Anchorage, Alaska) fence consisted of 2.4 m of wire mesh placed 25 cm above the ground. In combination with lighting, a total reduction of 70% in moose/vehicle accidents was recorded. For the fenced only length of the highway, the reduction was 95%, for the lit, unfenced portion 65% (McDonald, 1991).

Unfortunately, fencing may be too costly to be considered for application on the entire network of highways and railroads in North America. However, it can be useful on specific stretches of transportation corridors that have been identified as high risk areas.

Rubber bullets:

To displace elk and bears from populated areas, wardens in Banff National Park have experimented with the use of riot guns that fire rubber bullets (Brown and Ross, 1994). Rubber bullets did not work well as a negative physical stimulus for several reasons: 1) they elicited little reaction from the animals (there is speculation that elk may have been unaffected because in social situations they frequently experience rough physical contact, such as antler jabs and kicks; 2) they were considered inhumane because bullets caused severe bruising and, in some cases, penetrated the skin and became lodged

in muscle tissue; and 3) all members of a group of elk could not be treated, making groups difficult to move. However, rubber projectiles larger than bullet-size could be considered as an alternative method for future testing by firing from the locomotives.