Chapter 9
CARNIVORES
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INTRODUCTION

Carnivores historically had an impact on man by preying upon domestic livestock. This predation caused more problems and controversy for man than any other conflicts with wildlife. Gray wolves *(Canis lupus)* and bears *(Ursus* spp.) were the major carnivores that preyed upon domestic livestock in Europe and Asia. During early settlement of North America, gray wolves, red wolves *(Canis rufus),* grizzly bears *(Ursus arctos),* black bears *(Ursus americanus),* and mountain lions *(Felis concolor)* were the major predators of domestic livestock. Today, with the removal of large predators from extensive areas, coyotes (*Canis latrans)* are the major predator of livestock in North America. Dogs and red foxes *(Vulpes vulpes),* mountain lions, black bears, grizzly bears, gray wolves, and bobcats *(Lynx rufus)* also prey on domestic livestock, but their predation is secondary to that of coyotes. All of the above carnivores have been controlled extensively because of their predation on livestock.

I discuss the extent of carnivore predation on domestic livestock, review past and current control methods, examine the impact of control on predator populations, behavior, and ecology, review public attitudes toward predator control, discuss when and how control should be implemented, and speculate on the future of techniques for prevention and control of predation on livestock. Coyote predation on livestock is emphasized because it causes the majority of conflicts (National Agricultural Statistics Service 1991) and has been researched most intensively. The effect of predation on the population dynamics of ungulates, lagomorphs, and rodents has been reviewed by other authors (Keith 1974, Connolly 1978, Mech 1984, Newsome 1990) and is not discussed here.

EXTENT OF LIVESTOCK LOSSES TO PREDATORS

Numerous studies have been conducted since 1970 to determine the magnitude of livestock losses to predators, particularly coyotes, because the extent of losses was unknown and disputed. The United States Fish and Wildlife Service (1978) and Pearson (1986) summarized several published studies of livestock losses to predators in the 17 western United States, where 88% of the country's sheep (Gee and Magleby 1976) are raised. Pearson (1986) indicated that 2.5% of adult sheep and 9.0% of lambs were lost to all predators, with coyotes taking 74% of the adult sheep and 77.7% of the lambs lost annually to predators. The National Agricultural Statistics Service (1991) reported that coyotes killed 63.7% of the sheep and lambs killed by predators in the United States during 1990. The United States Fish and Wildlife Service (1978) estimated an average annual loss to coyotes of 1-2.5% for ewes and 4-8% for lambs during 1972-78 in the western states. They also reported that livestock losses estimated from biological field studies and questionnaire surveys were similar. Predators were responsible for 25.8% of the adult sheep and 47% of the lambs lost to all causes (Pearson 1986). Pearson (1986) cautioned that many of the published studies in his summary could be considered atypical because many of the biological studies were conducted where predators were a problem and mail surveys might have been biased by greater response rates from producers suffering larger losses. Nass (1977) and O'Gara et al. (1983) reported that coyotes did not feed on 25 and 23% of the domestic sheep that they killed. Most of the above studies summarized by United States Fish and Wildlife Service (1978) and Pearson (1986) were conducted where various types and intensities of predator control were used.

Coyotes have expanded their ranges into the eastern United States where low losses of livestock and fowl recently have been reported (Jones 1987, Slate 1987). Dorrance and Roy (1976) reported that 1.6% of ewes and 2.8% of lambs were lost to predators in Alberta during 1974; coyotes were responsible for 88% of those losses. These mortalities occurred despite assistance from predator control specialists, who used unrestricted controls, including strychnine drop and 1080 baits.

Gee (1978) reported a 5.5% beef-calf loss to all causes in a nationwide United States survey, with predators deemed responsible for 11% of the losses. The United States Fish and Wildlife Service (1978) reported calf losses between birth and weaning to coyotes across the United States at 0.4%, with predation decreasing to nearly zero by weaning time. Dorrance (1982) reported that coyotes, black bears, and wolves were responsible for 35, 31 and 16%, respectively, of the 1,520 confirmed predation losses of cattle in Alberta during 1974-78.

Predators cause substantial losses of domestic goats also. In Texas, where an estimated 1.1 million goats (about 90% of the goats in the United States) are raised (Scrivner et al. 1985), predators were reported to take 18.1% of the adults and 33.9% of the kids in 3 studies (Pearson 1986).

Pearson (1986) stated that predators, particularly coyotes, accounted for losses of hundreds of chickens and turkeys in 14 western states. Andelt and Gipson (1979*a*) reported that a mated pair of coyotes killed 268 domestic turkeys worth $938 (US) between 4 June and 31 August 1976 on 1 farm in Nebraska. Production for the farm was about 130,000 turkeys.

Domestic dogs can be significant predators of livestock and poultry (Denny 1974). Dogs ranked second to coyotes and accounted for 13.6% of the sheep and lambs killed by all predators in the United States during 1990 (National Agricultural Statistics Service 1991). Walton (1990) reported that dogs ranked second behind coyotes in frequency of predation on sheep and goats in his study area in Texas. Schaefer et al. (1981) reported that in Iowa 3% of the sheep owned by questionnaire respondents were allegedly killed by coyotes and 1%

were killed by dogs. McAninch and Fargione (1987) reported that 88% of the sheep producers surveyed in New York indicated that dogs were the most harmful predator. Producers in Sonoma and Marin counties, California, reported that dogs were responsible for the majority of predation on sheep (Larson and Salmon 1988).

Livestock losses to mountain lions are not nearly as severe as are losses to coyotes. They accounted for 3.4% of the sheep and lambs killed by all predators in the United States during 1990 (National Agricultural Statistics Service 1991). However, significant impacts on individual operations can occur when a large number of animals are killed by a lion in >1 days (Weaver and Sitton 1978). Suminski (1982) estimated that lions kill 0.29% of the sheep annually in Nevada, and reported 59 sheep killed on 1 occasion. Suminski (1982) indicated that lion predation on domestic sheep appears to be more serious in Nevada than in any other western state. Cattle losses to lions appear greatest in Arizona, New Mexico, and Texas with losses generally decreasing northwards within the lion's range (Shaw 1983). Shaw (1977) reported that 6 of 12 mountain lions on a study area in Arizona killed cattle, with calves selected over other prey. Sheep are killed wherever they graze in areas occupied by mountain lions (Lindzey and Wilbert 1989) with most kills occurring during summer.

Bears accounted for 1.6% of the sheep and lambs killed by all predators in the United States during 1990 (National Agricultural Statistics Service 1991). Black bears and grizzly bears killed 1.3 and 0.5% of the sheep grazed on sheep allotments adjacent to Yellowstone National Park during 1976 and 1977 (Johnson and Griffel 1982). Both species killed sheep on the majority of allotments. Davenport (1953) reported that domestic sheep were the primary livestock killed by black bears in Virginia, and that the average annual value of sheep killed from 1941 to 1950 was only 0.09% of the value of sheep sold during 1950. Horstman and Gunson (1982) reported that cattle represented 81% and sheep and swine each represented 9% of the compensation claims submitted for black bear predation on livestock in Alberta; these losses represented 0.02% of the cattle, 0.11% of the sheep, and 0.02% of the swine in the area. Most predation on livestock apparently is by mature and old males (Davenport 1953, Horstman and Gunson 1982, Coolahan 1990).

Gray wolves, in North America, are primarily present in Canada, Alaska, and Minnesota. A few wolves are present in Wisconsin, Michigan, Montana, Idaho, and Washington (Peek et al. 1991). About 1,000 to 1,200 wolves inhabit northern Minnesota (Bailey 1978), where about 12,230 farms were located in 1978 (Fritts 1982). Over 90% of the farms had some livestock, with sheep and cattle present on >80% of the farms (Fritts 1982). Paul (1989) reported that 9 to 38 of 7,200 farms in Minnesota had verified losses to wolves each year from 1976 through 1988. The highest cattle losses to wolves were 0.045% during 1979, and the highest sheep losses were 0.27% during 1981, indicating that wolf predation on livestock in Minnesota is not a large problem except for a few farmers. Tompa (1983) reported that verified losses of all livestock classes to wolves in British Columbia were <0.1% of the respective populations and that the problems are localized. Bjorge and Gunson (1983) and Dorrance (1982) reported that wolves killed calves and yearlings at greater rates than adults and recommended placing only healthy animals on grazing leases in Alberta. The United States Fish and Wildlife Service (1987) reported that only a small fraction of ranchers and permittees in remote wolf country suffered verified livestock losses to wolves, and wolves may live near farms or grazing leases without killing livestock.

Bobcats kill some adult sheep, lambs, and goats (Young 1958, Nass 1977, Coolahan 1990). Bobcats accounted for only 2.8% of the sheep and lambs lost to all predators in the United States during 1990, whereas foxes and eagles accounted for 2.6 and 3.6%, respectively (National Agricultural Statistics Service 1991).

Economic Impacts of Predation on Livestock

Sheep numbers in the United States declined about 80% from 1942 to 1976 (Gee et al. 1977*b*), but stabilized between 1978 and 1989 (Markham 1990). Former sheep producers reported that the principal reasons for leaving the sheep industry included high predation losses, low lamb and wool prices, shortage of good hired labor, and retirement (Gee et al. 1977*b*).

The United States Fish and Wildlife Service (1978) estimated the economic impacts of coyote predation on producers with predator problems, producers without predator problems, and on consumers during 1977. They used an average lamb-loss rate of 4% (267,000 lambs) and a ewe-loss rate of 1.5% (125,000 ewes) to coyotes to estimate an economic loss of $19 million to producers from coyote predation in the 17 western states. The reduced number of sheep and lambs marketed due to coyote predation resulted in a higher market price, which benefited producers by $6 million. The net impact of coyote predation on sheep producers was a loss of $13 million, and the impact on consumers was $4 million in additional costs. The economic impact of coyote predation on calves was estimated at a $20 million loss to producers. However, due to the greater price flexibility of beef compared to sheep, the reduction in beef calves marketed (estimated at 0.4%, 115,000 fewer calves) resulted in a higher price, which benefited beef producers by $81 million. The net impact of the reduced supply of beef due to coyote predation was a gain of $61 million to beef producers, but it cost consumers an additional $98 million, resulting in an overall loss of $37 million.

Although the average value of livestock losses to predators reflects overall impact on producers, it does not reflect the severity of losses to some individuals. Coyote (Balser 1964, Gee et al. 1977*a*) and bear (Davenport 1953) predation is more serious for some producers than others. Most sheep producers suffer no or minor predator losses, whereas 20-25% of the producers who suffer losses have significantly higher losses than average (United States Fish and Wildlife Service 1978); these losses can drive producers out of business because of low profit margins. Nonfatal injuries and harassment of livestock by predators also can result in reduced weight gain and subsequent reductions in profit.

CHARACTERISTICS OF CARNIVORE PREDATION ON LIVESTOCK

Livestock killed by predators usually can be distinguished from those dying from other causes by the presence of external hemorrhaging; subcutaneous hemorrhaging and tooth punctures; damage to the skin, other soft tissues, and skull; blood on the soil and vegetation; and carnivore tracks, scats, or territorial marks near dead animals. Urgent calling and alert, defensive, and frightened behavior of livestock also suggest that predators may have killed livestock.

Newborn livestock killed by predators and partially consumed can be distinguished from stillborn livestock by characteristics not found in stillborn animals: a blood clot present at the closed end of the navel, pink lungs that float in water, fat around the heart and kidneys, milk in the stomach and intestines, milk fat and lymph in the lymphatic vessels that drain the intestinal tract, a worn soft membrane on the bottom of the hooves, and possibly soil on the bottom of the hooves (Wade and Bowns 1984).

Individual species of predators follow a general pattern of killing and feeding on livestock, but some variation occurs among individuals and some overlap occurs among species. The carnivore species responsible for killing livestock often can be differentiated by the type and location of wounds (e.g., wounds made by teeth, talons, or claws), size and distance between canine punctures, extent of injuries, location of feeding, amount of prey consumed, and if the prey was partly skinned, dragged, or covered. In general, a predator is relatively large compared to its prey if broken bones are common (Wade and Bowns 1984). Bears, coyotes, and foxes scavenge on carcasses, whereas mountain lions and bobcats usually kill their own food and usually do not scavenge on old or spoiled carcasses.

Coyotes generally kill adult sheep and goats by biting the throat just behind the jaw and below the ear (Fig. 1) (Wade and Bowns 1984, Acorn and Dorrance 1990); sheep suffocate an average of 13 minutes after capture (Connolly et al. 1976). The attacks usually leave tooth-puncture marks, subcutaneous hemorrhaging, and external bleeding in the neck region (Davenport et al. 1973, Bowns 1976, Tigner and Larson 1977, Wade and Bowns 1984). The spacing between upper-canine punctures is 2.9-3.5 cm, and the lower canines is 2.5-3.2 cm (Wade and Bowns 1984).

Connolly et al. (1976) found that food deprivation did not have an apparent effect on the prey-killing behavior of coyotes but did influence feeding on kills, suggesting that hunger is not the primary motivation for killing prey. Fox (1969) and Lehner (1976) reported that coyote predatory behaviors, which include identifying, capturing, killing, and consuming prey, are shaped through experience; but Connolly et al. (1976) reported that prey-naive coyotes possessed the inclination and ability to kill sheep. In a pen study, paired males killed more sheep than their mates, whereas 2-year-old males and their mates killed more sheep than yearling males, and unmated females did not attack (Connolly et al. 1976). However, in the wild, all coyotes do not kill sheep (Beasom and Gober 1975, Connolly et al. 1976, United States Fish and Wildlife Service 1978).

Lamb losses to coyotes generally are highest in spring (Wade 1973, Till and Knowlton 1983), which often coincides with lambing and coyote denning season when adults are feeding pups. Another major predation period has been noted during late summer and early fall (Klebenow and McAdoo 1976). Coyotes killed more lambs than ewes (Nesse et al. 1976, Nass 1977, Tigner and Larson 1977, Gluesing et al. 1980), with the most active lambs and those found on the periphery of bed grounds being selected (Gluesing et al. 1980). Coyotes usually begin feeding on the flank, just behind the ribs, or on the liver, heart, lungs, and mesenteric fat (Wade and Bowns 1984).

Coyotes often attack newborn calves in the flank whereas older calves are attacked in the flank and hindquarters (Acorn and Dorrance 1990). The abdomen of calves usually is opened and the internal organs eaten.

Domestic dogs usually do not attack livestock for food (Wade and Bowns 1984). Their attacks often result in indiscriminate mutilation of prey, with frequent injuries to the hindquarters, shoulders, and nose. Some dogs attack prey in a fashion similar to coyotes, and some coyotes attack prey in an indiscriminate fashion similar to dogs. Dog attacks often result in many dead and wounded animals (Acorn and Dorrance 1990).

Mountain lions usually kill ewes and other large prey by biting them in the back of the neck, although they may also suffocate the animal by biting it in the throat (Shaw 1983, Bruscino 1989). Killed animals often display massive hemorrhaging on the back of the neck and near the base of the skull, and claw marks and rakes along the shoulders and on the back. The upper canine punctures from mature lions range from 4.5 to 5.0 cm apart and lower canine punctures range from 3.0 to 4.0 cm apart (Shaw 1983).

Lions occasionally cover their kills (Shaw 1983, Bruscino 1989). When mass kills occur, such as on sheep bed grounds, most carcasses are not covered (Shaw 1983). If kills are made in open habitat, lions usually drag their prey under a low-hanging tree or bush. The presence of drag marks or large tracks (about the size of a large dog) with 3 distinct lobes on the back of the pad and a lack of toenail marks suggests that the kill was made by a lion.

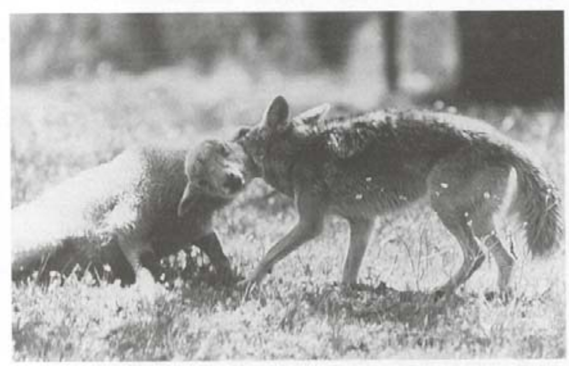

FIGURE 1. Coyotes usually kill domestic sheep by clamping their jaws on the victim's throat and waiting until they die. Photo by G. E. Connolly; courtesy of the U.S. Fish and Wildl. Serv.; published with permission of the *Rangeman's Journal*.

Mountain lions appear to prefer lambs to ewes (Bruscino 1989, Lindzey and Wilbert 1989). They may return for several nights to feed on the carcasses and often kill additional sheep (Shaw 1983). Lions seldom kill calves larger than 136-181 kg (Shaw 1983).

Lions usually enter the carcass at or just behind the rib cage (Shaw 1983, Bruscino 1989). They usually eviscerate the carcass and feed on the lungs, heart, and liver followed by the larger leg muscles and the underside of the legs.

All black bears do not kill cattle or domestic sheep (Murie 1948, Jorgensen 1983); however, grizzly bears appear prone to killing cattle and sheep (Murie 1948, Johnson and Griffel 1982). Black bears and grizzly bears typically kill domestic sheep by biting them on the dorsal side of the neck and less frequently on the frontal or jugal bones of the skull (Griffel and Basile 1981). Grizzly bears typically kill calves and yearling cattle by biting them on the dorsal side of the neck, occasionally on the lumbar region of the spine, and less frequently on the head (Murie 1948). Black bears and grizzly bears apparently do not attack by striking with the paws, but instead seize and hold their victims with their front paws before biting and killing their prey (Murie 1948, Griffel and Basile 1981). Black bears dragged 60% of the sheep carcasses approximately 23-46 m and the remainder <20 m from the kill site. Black and grizzly bear predation can be differentiated by the size of their tracks (Johnson and Griffel 1982).

Black bears and grizzly bears seem to show little preference for killing either lambs or ewes (Griffel and Basile 1981). Black bears and grizzly bears usually return to the kill to finish eating the carcass (Murie 1948, Griffel and Basile 1981). Most sheep and swine predation incidents by black bears were multiple kills (Horstman and Gunson 1982). Johnson and Griffel (1982) reported that grizzly bear predation on sheep occurred only on the bed grounds during the night or early morning.

Calves were selected over yearlings and adults by black bears (Dorrance 1982, Horstman and Gunson 1982), whereas grizzly bears prefer calves and yearlings to adult cattle (Murie 1948, Acorn and Dorrance 1990).

Most black bears first consume the udder (74%) or the flank (26%) of domestic sheep (Griffel and Basile 1981). Black bears and grizzly bears usually remove the paunch and intestines intact from the body cavity of sheep and cattle (Murie 1948, Griffel and Basile 1981). If additional feeding occurs, black bears usually split the hide over the rib cage and peel it off the more fleshy parts of the carcass; the hide is left intact, which generally distinguishes bear predation. Black bears next eat the costal arch and sternum of sheep, then the front shoulder, and lastly the hindquarters (Griffel and Basile 1981). Sheep that died of causes other than predation, but that were fed upon by bears, lack canine puncture marks on the neck, shoulder, facial area, lack hemorrhaging, and lack lacerations over the back (Griffel and Basile 1981).

Red foxes usually attack the throat of young lambs and kids (Wade and Bowns 1984). They usually begin feeding just behind the ribs and consume the viscera first. Red foxes often carry small carcasses to the den to feed their pups.

Bobcats usually kill small lambs by biting them on the head or back of the neck (Wade and Bowns 1984). The paired upper and lower canine punctures are 1.9-2.5 cm apart. Hemorrhaging from claw punctures often can be found below the skin on the neck, back, sides, and shoulders. Bobcats usually do not attack adult sheep or goats. Bobcats often begin feeding on the viscera after entering behind the ribs. They occasionally cache and cover some kills.

Bjorge and Gunson (1983) reported that wolves primarily attacked cattle on the hindquarters including tail, vulva, lower thigh, and occasionally on the face, behind the front legs, in front of the rear legs, and on the belly. Wolves apparently prey on young, inexperienced, or disabled cattle more frequently than healthy adult cattle (Acorn and Dorrance 1990). Wolves seem to prefer to feed on the viscera and hind legs of large domestic prey (Acorn and Dorrance 1990).

PREVENTION AND CONTROL METHODS

During the past century, predator control methods and philosophies have evolved from an approach of general population reduction to the removal of individual offending animals or the use of nonlethal control techniques. The methods employed for preventing or controlling predation generally depend on the intensity of the problems and the circumstances under which they occur. Most methods fall within nonlethal and lethal controls. Nonlethal methods prevent or control predation without killing predators, whereas lethal controls remove offending animals or suppress predator populations. Advantages of most nonlethal techniques include a minimal level of producer expertise, less reliance on Federal Animal Damage Control field agents, better acceptance by the public, and some techniques (e.g., a good fence) being more permanent solutions than continual population reduction. Disadvantages of nonlethal control techniques include labor and material expenses, maintenance, and occasional lack of success. However, most lethal controls also suffer these disadvantages.

Nonlethal Control Methods

Nonlethal methods used to prevent or control predation on domestic livestock include: various livestock husbandry methods, fencing, guarding dogs, guarding donkeys, and llamas; bonding sheep and goats to cattle; and frightening devices. Other techniques that provide questionable or inconsistent control of livestock depredations include aversive conditioning, repellents, antifertility agents, and electro-magnetic and ultra-sonic devices. Livestock husbandry practices that can be implemented to reduce sheep losses to predators include confinement, carcass disposal, size of livestock placed on pasture, lambing in confinement, use of herders, and regular surveillance.

Confinement. Confining sheep at night, particularly in predator-proof enclosures, is an effective husbandry practice. Most losses of sheep to coyotes occur at night (Bowns et al. 1973, Henne 1975) when coyotes are most active (Gipson and Sealander 1972, Andelt and Gipson *1979b,* Andelt *1985a).* Higher sheep losses in Kansas were incurred by producers that grazed sheep in pastures day and night whereas intermediate losses occurred when sheep were grazed only during daytime and the lowest losses occurred when sheep were confined day and night (Robel et al. 1981). Although cost-benefit ratios on day and night confinement are needed, confining sheep to corrals during daytime and night likely would be impractical for many producers. Suminski (1982) recommended bedding sheep close to camp or confining them at night to reduce mountain lion predation.

Disposal of Livestock Carcasses. Predators may discover livestock as a source of food by being attracted to and feeding on carcasses (Lehner 1976, Fritts 1982). Todd and Keith (1976) reported higher coyote densities in areas containing carrion than in areas where carrion was removed. Producers in Kansas and Illinois that buried or hauled away dead sheep and swine sustained lower rates of coyote predation than producers that left the carcasses in the pasture or attempted to burn them (Robel et al. 1981, Jones and Woolf 1983). Although attracting predators to the area may be the major reason why the presence of carrion increased predation rates, scavenging on sheep carrion may assist predators to identify sheep as prey (Lehner 1976) and result in increased predation rates.

Size of Livestock Placed on Range. Producers in Kansas that lambed sheep during January to March had higher rates of losses to coyotes than producers that lambed from October to December or throughout the year (Robel et al. 1981). Lambs produced during January to March are more susceptible to predation than those born from October to December because they are smaller when placed on pastures during late spring and early summer, when losses to coyotes are typically highest (Robel et al. 1981). However, it may be important to Iamb when forage is abundant to promote better lactation and fast lamb growth.

Shaw (1977) suggested keeping calves out of lion country until they reach 140 kg or converting from a cow-calf operation to a weaner steer operation to reduce lion depredations. However, these practices may not be economically feasible.

Lambing in Confinement. Lambing in sheds or small lots can reduce predator and nonpredator losses (Wade 1973, Boggess et al. 1980). However, this practice requires extra labor, facilities, and feed for the confined sheep. Data are needed on the cost-effectiveness of this technique.

Herders. Herders routinely are employed to attend sheep on open range. Producers using herders generally have lower predation losses than producers without herders (Davenport et al. 1973, Tigner and Larson 1977, Nass et al. 1984). Sheep maintained in tight bands were less susceptible to black bear and grizzly bear predation than were bands allowed to wander freely (Jorgensen 1983). Some producers do not use herders because of difficulties in obtaining adequate numbers of capable herders and increased labor costs.

Record Keeping and Surveillance. By regularly counting sheep and surveying pastures, the onset of livestock losses to predators can be determined. As soon as losses are identified, corrective measures can be implemented. Retaining good records of livestock losses will help to identify loss patterns and problem areas that may require corrective action.

Other Husbandry Practices. Practices that provided inconsistent effectiveness or that may be difficult to manipulate to reduce losses include flock size and various characteristics of pastures. Robel et al. (1981) and Nass et al. (1984) reported that larger sheep operations had lower loss-rates than smaller operations whereas Dorrance and Roy (1976) reported the opposite relationship and Nielson and Curle (1970) reported no relationship. These conflicting results indicate that no conclusions can be drawn between flock size and predation rates.

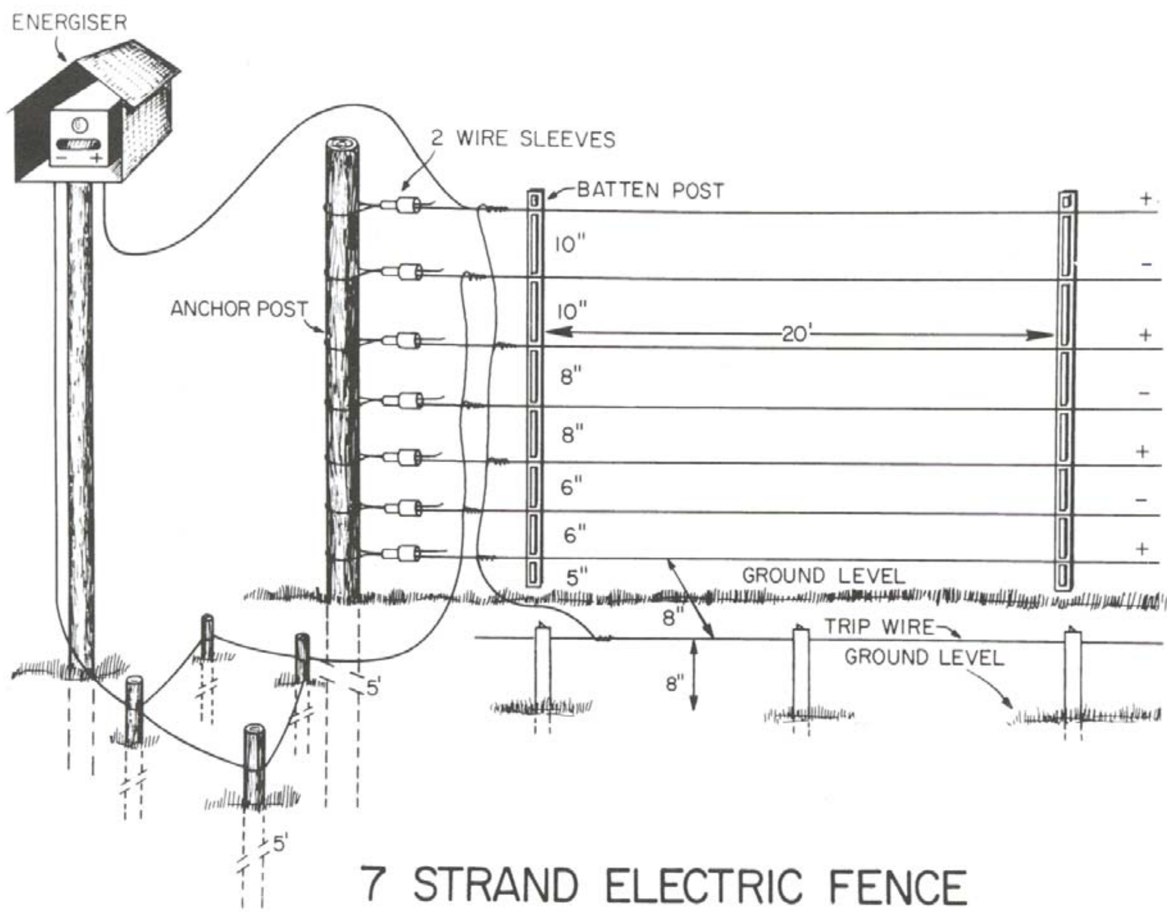

FIGURE 2. A 7-strand electric fence can effectively exclude coyotes from pens and pastures containing livestock. Provided by D. S. deCalesta.

Robel et al. (1981) reported that producers located > 8 km from towns or settlements in Kansas had higher sheep losses to coyotes than producers located <1.6 km from towns, but the opposite trend was observed for sheep losses to dogs. These loss relationships probably reflect higher densities of dogs and lower densities of coyotes near towns (Robel et al. 1981).

Habitat. Robel et al. (1981) reported that coyote predation rates on domestic sheep were higher in larger than smaller pastures, in pastures with taller grass, and in pastures with streams than without streams, but rates were not related to the distance of pastures from residences. These loss relationships may reflect habitat preferences of coyotes. Robel et al. (1981) also reported higher loss-rates in flat versus rough and rolling pastures, but Nass et al. (1984) reported lower predation rates in open pastures. Although the reason for the differences between these 2 studies is unknown, it seems likely that predation rates would be highest in those areas most attractive to coyotes.

Fritts (1982) indicated that calving in forested or brushy pastures was responsible for many instances of wolf predation on livestock in Minnesota. Keeping sheep out of berry patches may reduce predation on sheep by bears (Jorgensen 1983).

Fencing. Properly constructed conventional netwire and electric fences (Fig. 2) can effectively exclude coyotes from pastures containing domestic livestock (deCalesta and Cropsey 1978, Gates et al. 1978, Thompson 1979, Dorrance and Bourne 1980, Linhart et al. 1982, Wade 1982, deCalesta 1983, Shelton 1984, Shelton and Gates 1987). DeCalesta and Cropsey (1978), Dorrance and Bourne (1980), and Linhart et al. (1982) reported that fences were a cost-effective method of preventing predation. Costs of materials for coyote-deterring electric fences were estimated at $713-$1,125/km (Gates et al. 1978, Dorrance and Bourne 1980, Linhart et al. 1982) and at $1,543/km for coyote-deterring conventional fences (deCalesta and Cropsey 1978). One to 3 electrified wires placed outside an existing netwire fence also can reduce entry to pastures by coyotes (deCalesta 1983, Shelton 1984).

Electric fences were reported to complement (Linhart et al. 1982) and reduce demand (Dorrance and Bourne 1980) for lethal control. Other advantages of fencing include elimination of herding, greater control over intensity of grazing, less trampling of vegetation, and reduced parasite infestations due to reduced contact and mixing with adjacent herds (Jones 1938, cited by Wade 1982). Disadvantages of fencing include construction costs; fence maintenance, particularly in washout areas; control of vegetation under electric fences; and obstruction of wildlife (particularly pronghorn antelope *(Antilocapra americana)* and mule deer *[Odocoileus hemionus)* movements. Howard (1991) reported that a 1.5-m-high electric fence was a barrier to mule deer movements and should not be used in major deer movement/migration corridors. A 1.2-m-high netwire fence restricted fewer mule deer than the 1.5-m-high fence. Predators also may gain access through damaged fences, malfunctioning electric fences, or by digging under or jumping over some fences.

Livestock Guarding Dogs. Livestock guarding dogs (Fig. 3) have been used in the United States to protect sheep from predators since the early 1970s. They have been used to protect small and large flocks of sheep and goats in fenced pastures and large bands of sheep and goats on open range (Green and Woodruff 1988) primarily from coyote predation. Most guarding dogs are members of breeds that have been selectively developed in Europe and Asia to protect livestock from bears and wolves. The most common breeds used in the United States are the Great Pyrenees and Komondor, whereas the Akbash, Anatolian, Kuvasz, Maremma, Shar Planinetz, and mixed breeds are less common (Black and Green 1985, Green and Woodruff 1988). The Akbash was the most common breed used to protect sheep from predators on open range in Colorado (Andelt 1992). Most guarding dogs are large and imposing, weighing 34-45 kg and standing 64 cm or taller at the shoulders. Successful guarding dogs are trustworthy (i.e., will not harm sheep), attentive to sheep, and aggressive toward predators (Coppinger et al. 1983).

Guarding dogs are an effective method of deterring coyote predation of domestic sheep (Linhart et al. 1979; McGrew and Blakesley 1982; Pfeifer and Goos 1982; Coppinger et al. 1983, 1988; Green and Woodruff 1983, 1988; Green et al. 1984; Andelt 1985*b,* 1992; Black and Green 1985). Pfeifer and Goos (1982) surveyed 36 guarding dog owners in North Dakota and reported that dogs reduced predation by 93%. In a survey of 40 owners, Green et al. (1984) reported that guarding dogs saved an average of 68 head of sheep/owner, valued at an average of $3,836 annually. Andelt (1985*b*) reported that 12 producers with their 24 guarding dogs saved $27,000 worth of sheep/year from predators in Kansas. On 1 study site in Montana, guarding dogs, traps, snares, M-44s, and aerial gunning were used to deter coyote predation, but only the dogs successfully stopped predation (O'Gara and Rightmire 1987).

FIGURE 3. Akbash guarding dogs can effectively protect sheep in fenced pastures or on open range. Photo by W. F. Andelt.

Producers in Colorado using guarding dogs lost an average of 0.4% of their ewes and 1.2% of their lambs to coyote predation whereas producers without guarding dogs lost 0.8-1.5% of their ewes and 4.7 -9.6% of their lambs (Andelt 1992). Producers in Colorado estimated that each guarding dog saved an average of $3,216 of sheep from predators annually (Andelt 1992).

Green and Woodruff (1988) reported that the rate of success in protecting livestock from predators did not vary among Great Pyrenees, Komondor, Akbash, Anatolians, Maremma, and hybrids, nor was the rate of success different among males and females or intact and neutered dogs. However, dogs that were reared with livestock from ≤ 2 months old had a significantly higher rate of success than dogs that were >2 months old when placed with livestock.

Green and Woodruff (1988) and Andelt (1992) reported that Komondors were more aggressive toward people than were Akbash, Great Pyrenees, and Anatolians. These differences in aggressiveness should be considered before purchasing guarding dogs. In areas where encounters between guarding dogs and humans are likely, such as on public lands, less aggressive breeds should be considered. Akbash, Anatolian Shepherds, and Komondors are more aggressive than Great Pyrenees and thus might be selected where bears, mountain lions, and wolves are frequent predators (Green and Woodruff 1990).

Purchase prices of guarding dog pups averaged $240 in Kansas (Andelt 1985*b*) and $331 and $458 (depending on breed) in the western United States (Green et al. 1984). Annual maintenance fees (food, veterinary care, miscellaneous costs) averaged $235-$250 (Green et al. 1984, Andelt 1985*b*). The major advantages of using guarding dogs include a decrease or elimination of predation, reduced labor to confine sheep at night, more efficient use of pastures for grazing, and reduced reliance on other predator control techniques. Major disadvantages of guarding dogs include some dogs not staying with or harassing sheep, some dogs being overly aggressive toward people, and the dogs can be subject to injury and premature death.

Additional costs and benefits of using guarding dogs are provided in Green et al. (1984) and McGrew and Andelt (1988). Overall, guarding dogs are a cost-effective means of reducing predation (Green et al. 1984).

The effectiveness of guarding dogs for deterring bear, mountain lion, and wolf predation on sheep has not been rigorously evaluated. Green and Woodruff (1989) reported that 15 of 20 encounters between livestock guarding dogs and black bears (17 encounters) and grizzly bears (3 encounters) resulted in bears being chased away without preying on sheep or in bears being shot by shepherds. Guarding dogs apparently were successful in protecting cattle from wolf predation (Coppinger et al. 1988), and were fairly effective in keeping wolves and black bears from carrion feeding sites in Minnesota (Coppinger et al. 1987).

Livestock guarding dogs are not compatible with the use of toxicants to control predators. Some producers have trained guarding dogs to avoid M-44s by allowing them to set off M-44s loaded with pepper; however, any mistakes by the dog likely will be fatal. Guarding dogs that have been tied probably will not be killed if captured in a snare. Most guarding dogs probably will not be injured in traps if removed in reasonable time.

Donkeys. Donkeys *(Equus assinus)* have recently been used with sheep and goats in an attempt to deter predation by coyotes and dogs. Walton and Feild (1989) estimated that 1,000 to 1,800 of 11,000 Texas sheep and goat producers used guarding donkeys in 1989. Green (1989) reported that several ranchers in Virginia and Montana also used guarding donkeys. Donkeys apparently have an inherent dislike for dogs and other canids. They will bray, bear their teeth, run and chase, and attempt to bite and kick an intruder (Green 1989).

Walton and Feild (1989) reported that 40 and 59% of Texas producers rated the effectiveness of donkeys as good or fair for deterring predation by coyotes. The effectiveness of guarding dogs is higher (Green et al. 1984; Green and Woodruff 1988; Andelt *1985b,* 1992). The effectiveness of donkeys for deterring bear and mountain lion predation of sheep and goats has not been determined. Green (1989) cited 1 donkey raiser who indicated donkeys will flee when bears or mountain lions are in the area.

Donkeys, although apparently less effective than guarding dogs, appear to have some advantages over guarding dogs. Donkeys are relatively cheap (<$250), less prone to accidental death, long-lived, do not require special feeds, stay in the same pasture as sheep, and are not very susceptible to traps, snares, M-44s, and toxic collars.

Green (1989) and Walton and Feild (1989) recommended using only 1 jenny or gelded jack/pasture; intact jacks are too aggressive and >2 donkeys might stay together instead of being with the sheep. They also recommended allowing about 4-6 weeks for the donkey to bond with the sheep. Donkeys should be removed during lambing because they might trample lambs or disrupt the ewe-lamb bond. Green (1990) recommended challenging a new donkey with a dog to test its response to canids; donkeys that are not aggressive should not be used. Donkeys are apparently most effective in small open pastures or where sheep are cohesive and graze together. Feeds containing anabolic agents such as monensin (Rumensin) and lasalacid (Bovatec) apparently are poisonous to donkeys.

Donkeys can be obtained from the Bureau of Land Management or United States Forest Service under the Wild Free-Roaming Horse and Burro Act for $75 each. They also can be obtained at stockyard auctions and from breeders for $20 to $250 (Green 1989, 1990; Walton and Feild 1989).

Llamas. During 1990, Franklin and Powell (1993) surveyed 145 producers, primarily in Montana, Wyoming, Colorado, California, and Oregon, to determine the effectiveness of llamas *(Llama glama)* for reducing coyote and dog predation on sheep. These producers reported that they lost an average of 21% of their ewes and lambs annually before acquiring a llama and 7% afterwards. The losses after using a llama were similar to estimated losses for producers without guarding animals in the 17 western states. An average annual savings of $1,253, due to using llamas, was reported by 87 of the producers. Eighty percent of the producers rated their guard llamas as effective or very effective. Markham (1990) also reported that llamas are effective in reducing coyote and dog predation of domestic sheep.

Llamas are naturally aggressive toward coyotes and dogs. Typical responses of llamas to coyotes and dogs are alertness, alarm calling, walking to or running toward the predator, chasing, kicking, or pawing the predator, herding the sheep, or positioning themselves between the sheep and predator. Testimonial accounts indicate that llamas are afraid of mountain lions, and their effectiveness in deterring bear predation is unknown.

Franklin and Powell (1993) reported that the average producer used 1 gelded male llama with 250 to 300 sheep in 101- to 121-ha pastures. One guard llama was more effective than multiple llamas. The effectiveness of gelded males, intact males, and females for deterring predators was similar. However, producers reported more problems with intact (25% of 61 intact males) than gelded males (5% of 135 gelded males) attempting to breed ewes. Producers also reported that aggressiveness by some llamas toward sheep was a problem.

Franklin and Powell (1993) reported that nearly all llamas in their survey were not raised with sheep and were not trained to guard sheep. The initial adjustment period for the llamas and sheep lasted only a few hours for half the llamas, and nearly 80% were adjusted within a week. Sheep that were introduced to llamas in corrals initially sustained lower losses than those introduced in pastures. Otherwise, Franklin and Powell (1993) reported that the success of llamas was not related to age when the llama was introduced, age of llama (after 1 or 2 years old) when guarding, if lambs were present or absent when the llama was introduced, or between open and covered (forested, shrublands, gullies, ravines, etc.) habitat. In contrast, Markham (1990) recommended introducing llamas to sheep just before or at lambing, purportedly because they readily bond to newborn lambs.

Franklin and Powell (1993) reported that gelded male llamas cost \$700 to \$800, whereas intact males were about \$100 less. Most producers reported that daily care for llamas was the same as for sheep and that no special feeds were provided. Average annual expense was \$90 for feed (not including pasture) and veterinary costs were about \$15. A 73.5-kg gelded llama consumes 3.0 to 4.5 kg of good grass hay/day. Depending on the area, llamas need to be dewormed 2 to 4 times/year. If food is provided for llamas, it should be placed in a feeder high enough to be out of reach of sheep. Llamas offer some of the same advantages as donkeys over livestock guarding dogs for protecting sheep; however, more data are needed on their effectiveness.

For information on llamas or sources of breeders, contact the International Llama Association, P.O. Box 370505, Denver, Colo. 80237, (303) 756-9004 or the Rocky Mountain Llama and Alpaca Association, 593 19-3/4 Road, Grand Junction, Colo. 81503, (303) 241-7921.

FIGURE 4. A siren-strobe device, developed by the Denver Wildlife Research Center, can effectively frighten coyotes away from sheep on bed grounds.

Bonding Sheep and Goats to Cattle. Bonding young sheep to cattle (Anderson et al. 1987, Hulet et al. 1987) and goats to sheep and cattle (Hulet et. al 1989) reduced coyote predation. No data are available on the optimum ratio of cattle to sheep or size of bonded herds that are practical for reducing predation. This technique has not been readily adopted by sheep producers, possibly because of the additional labor and expense involved with bonding sheep and goats to cattle.

Frightening Devices. Several frightening devices (Fig. 4) have been used successfully to reduce or prevent coyote predation on domestic livestock. The Denver Wildlife Research Center within the United States Department of Agriculture has developed and tested portable, battery-operated strobe light and siren devices to reduce coyote predation on pastured sheep. The devices consist of an electric timer wired to a strobe light, a warbling-type siren, and a battery. These devices, by emitting a varying and irregular sequence of light and sound stimuli from different locations, should minimize habituation by coyotes and prolong the period of repellency (Linhart 1983, 1984). The original prototype devices provided an average of 53 nights of protection in 10 trials, and a newer device protected pastured sheep for an average of 91 nights in 5 trials (Linhart 1983, Linhart et al. 1984). The siren-strobe devices did not frighten sheep, even when located on the bed grounds (Linhart 1983). These devices were placed near bed grounds on open range and reduced sheep losses to coyotes an average of 73% in 10 of 12 trials (Phillips and Fall 1990).

Gas exploders have been used to deter coyotes temporarily from preying on domestic livestock. Gas exploders produce large explosions (similar to rifle or shotgun blasts) that frighten coyotes. Gas exploders are portable, easy to operate, cost around \$200, and have relatively low operating costs. Gas exploders deterred coyotes from killing sheep for an average of 31 days on 30 ranches in North Dakota (Pfeifer and Goos 1982) and for 6 weeks on 1 ranch in Saskatchewan (Rock 1978, cited by Linhart 1984). The delay in predation enabled more time to locate offending coyotes that increased the effectiveness of ground-control techniques and aerial hunting (Pfeifer and Goos 1982). The temporary effectiveness of gas exploders should be especially useful around calving operations because calves are most susceptible to predation for a short period after birth. Habituation by coyotes to gas exploders can be delayed by moving the device to various locations in the pasture, by changing the firing rate, or by using rotating guns called Double Johns.

Other methods of frightening coyotes and deterring predation include parking vehicles or playing a radio near areas where predation occurs (Boggess et al. 1980). Robel et al. (1981) reported that producers placing lights over corrals or bells on $\geq$ 1 sheep in each corral sustained lower losses than producers that did not use either technique; however, the presence of bells on sheep in pastures did not deter predation.

Aversive Conditioning. Conditioned taste aversion has been proposed and tested as a nonlethal method of preventing coyotes from killing sheep. One method involves placing mutton baits laced with a strong emetic (e.g., lithium chloride) or placing sheep carcasses injected with lithium chloride on the range. Coyotes supposedly ingest the baits, become ill, and develop an avoidance of sheep because they associate sheep with sickness (Gustavson et al. 1974, 1976; Ellins et al. 1977). Gustavson et al. (1974,1976, 1982), Ellins et al. (1977), and Ellins and Catalano (1980) reported the suppression of attacks upon live prey in pens or reductions in predation in the field after consumption of baits laced with lithium chloride. The experimental designs and conclusions of some of these studies have been questioned (Griffiths et al. 1978, Horn 1983).

Conover et al. (1977), Burns (1980, 1983*a*), Burns and Connolly (1980), and Horn (1983) found that coyotes did not develop an avoidance of live prey after feeding on prey baits or carcasses treated with lithium chloride, and Bourne and Dorrance (1982) reported that distribution of lithium chloride-treated baits on farms did not reduce coyote predation on sheep. Gustavson (1982) attempted to avert wolves from preying on cattle by placing lithium chloride-laced baits on the range, but the effectiveness of the baits could not be determined. Lithium chloride in honey baits did not reduce black bear damage to beeyards (Dorrance and Roy 1978).

Conditioned taste aversion may be difficult to develop in coyotes because coyotes apparently rely more on vision than their other senses during predation (Wells and Lehner 1978) and because only a small proportion of coyotes may ingest the baits (Linhart et al. 1968). Burns et al. (1984) reported that 20 of 21 coyotes that received sublethal doses of toxicants from sheep neck collars subsequently were killed by another toxic collar indicating little potential for the use of repellents or aversive conditioning agents in collars to repel coyotes.

Aversive conditioning currently does not appear to be a viable technique for reducing coyote predation on livestock. However, if coyotes could be trained not to kill sheep, then these coyotes could become valuable assets and should be protected because they would likely prevent other coyotes (that may kill sheep) from entering their territories (Burns 1983b).

Repellents. Numerous chemicals that might provide olfactory repellency or that might cause gustatory or taste avoidance in coyotes have been tested (Lehner et al. 1976, Botkin 1977, Lehner 1987). No chemicals consistently repel coyotes while not harming sheep nor do they provide significant efficacy while being practical for producer use (Lehner et al. 1976, Botkin 1977, Linhart 1983). The lack of success with repellents may be related to coyote emphasis on visual cues to locate and attack prey (Wells and Lehner 1978), thus, providing little deterrent effect on the prey-killing behavior of coyotes (Linhart 1983).

Antifertility Agents. The use of antifertility agents for inhibiting coyote (Balser 1964; Linhart et al. 1968; Stellflug et al. 1978, 1984) and red fox (Allen 1982) reproduction has been investigated, but these agents have not been consistent in limiting reproduction in the field because of limited consumption of baits by coyotes and foxes and fairly high consumption by non-target animals (Linhart et al. 1968). Dogs, crows *(Corvus brachyrhynchos),* and gray foxes *(Urocyon cinereoargenteus)* also consumed baits intended for red foxes (Linhart 1964). Improved attractants and bait delivery systems may increase the success of antifertility agents.

Antifertility agents have been viewed as a method of reducing coyote populations (Balser 1964). However, these agents also may reduce livestock losses because non-reproductive coyotes would not require as much food as reproductive coyotes caring for pups. Use of antifertility agents may provide an acceptable method of reducing coyote densities, providing the delivery system is host specific and that it is used prudently.

Relocation. Capture and relocation of animals has been used to solve some conflicts with wildlife. Weaver and Sitton (1978) reported 5 depredating lions were tagged, removed from the vicinity of livestock losses, and released. None of the relocated lions were retaken on subsequent depredation permits, suggesting that relocation was successful. However, Shaw (1983) reported that 2 relocated lions again killed livestock.

Problems with relocation include high cost, difficulty in finding relocation sites, financial responsibility for moved animals, occasionally lower survival for relocated animals, return of some animals to the capture site, possible introduction of diseases to the relocation site, and the possibility of the animals becoming a problem at the new site. Fritts et al. (1985) found that the annual survival rate of relocated wolves introduced where other wolves were present was 60%, which was similar to nonrelocated wolves. Eight of 104 relocated wolves returned to the capture site from 50 to 65 km, but others that did not return were relocated farther away (Fritts et al. 1984). Fritts et al. (1984) noted that translocation of wolves from areas of livestock depredation was largely unsuccessful in keeping wolves out of livestock production areas.

McArthur (1981) reported that several translocated black bears returned to the capture site and others became a nuisance in another area. A female was likely to return to the capture site if all the cubs were not translocated. Transplants were more successful if they occurred over greater distances, over more ridges, required a greater gain in elevation, and if a physiographic barrier was present.

Compensation. Minnesota and Alberta compensate livestock owners for livestock killed by wolves. Colorado and Wyoming reimburse livestock owners for animals killed by mountain lions and bears. Of the visitors to Yellowstone National Park, 48% felt that the government should pay compensation for livestock lost to wolves, whereas 29% felt conservation groups should pay and only 18% felt that it was the ranchers' burden (McNaught 1987).

Lethal Control Methods

Traditional lethal control techniques include use of steel traps, snares, sodium cyanide ejectors, den hunting, shooting from the air or ground, hunting with dogs, livestock protection collars, and toxic baits. The effectiveness of each method varies with geographic location, and each has advantages and disadvantages. Control methods have been used to stop predation by specific coyotes or to stop recurrences of perennial problems through local population reduction. More than 73,000 coyotes have been killed by various methods used by the Federal Animal Damage Control Program in 15 western states during 1986 (Table 1).

Trapping. Properly set traps can effectively capture offending predators and usually permit release of nontarget animals. Gipson (1975) reported that 33% of the coyotes trapped in response to damage complaints had fed on the items reported damaged. Andelt and Gipson (1979*a*) reported that 6 of 12 coyotes captured near sites of domestic turkey losses showed evidence of having killed turkeys.

Opponents of trapping primarily base their opposition on trapping's perceived or demonstrated lack of selectivity for target species, on foot injuries sustained by captured animals in some types of traps, and on the trauma of restraint (Linhart et al. 1981). Trap selectivity depends upon the type of trap and where and how the trap is set. Trap selectivity can be increased significantly by attaching pan tension devices, which increase the weight required to spring the trap; thus, small animals such as kit foxes *(Vulpes macrotis),* swift foxes *(V. velox),* gray foxes, striped skunks *(Mephitis mephitis),* opossums *(Didelphis marsupialis),* and jackrabbits *(Lepus californicus)* are excluded, but large animals such as coyotes are captured (Linhart et al. 1981, Linhart 1983, Turkowski et al. 1984). Traps modified with pan tension devices excluded 92-100% of the small nontarget animals whereas unmodified traps excluded 6%. Other methods of reducing capture of nontarget animals include setting traps >8 m from carcasses (Hein 1992), covering baits in dirt-hole sets, and setting traps away from residences.

Padded-jaw traps (Fig. 5) have significantly reduced injuries to the feet of captured coyotes (Linhart 1983; Olsen et al. 1986, 1988; Onderka et al. 1990), gray foxes, red foxes, raccoons *(Procyon lotor),* and bobcats (Olsen et al. 1988), and caused less trauma than unpadded traps for red foxes (Kreeger et al. 1990). Onderka et al. (1990) reported that the limbs of coyotes caught in unpadded traps, compared to padded traps, had a greater tendency to freeze in cold weather.

An earlier version of the padded-jaw trap had lower rates of capturing coyotes (Linhart et al. 1986, 1988; Linscombe and Wright 1988), bobcats, and red foxes (Linscombe and Wright 1988) than standard traps. However, Skinner and Todd (1990) and Linhart and Dasch (1992) reported that newer and improved padded-jaw traps, when properly set, were as efficient as unpadded traps for capturing coyotes. Tullar (1984) reported similar capture rates of red foxes with padded and unpadded traps and Skinner and Todd (1990) reported that the efficiency of padded traps compared to unpadded traps, for capturing coyotes, improved as trappers became more familiar with padded traps. Leghold traps were 3 times as efficient as leg snares for capturing coyotes (Skinner and Todd 1990). Padded 1eghold traps and Fremont foot snares were superior to standard leghold traps and the Novak snare for holding terrestrial forbearers with minimal injury (Onderka et al. 1990).

Pan-tension devices and padded-jaw traps were devised to meet objectionable aspects of leghold traps. Use of smaller traps and daily, early-morning trap checks have reduced injuries to trapped animals (Novak 1987). Drawbacks of these trap modifications include added costs, reduced trap speed, and missed captures (Linhart et al. 1986, Olsen et al 1986). Tranquilizer tabs (Balser 1965) attached to traps reduced injury to the restrained feet of coyotes by 61% (Linhart et al. 1981).

Lindzey (1987) reported that traps set around livestock killed by mountain lions can be effective in removing lions if they return to the kill. Trapping primarily was used to remove depredating wolves in Minnesota (Fritts 1982). Fritts (1982) reported that setting traps near the area of losses and limiting the duration of trapping increased chances that the captured wolf was an offender, however, the extent of trapping necessary to reduce losses was not obvious.

Culvert traps are used extensively in parks and developed areas to capture bears. Culvert traps are expensive and restricted to areas accessible by roads.

Snaring. Snaring (Fig. 6) is an effective method of capturing coyotes in natural runways and in holes under or through woven-wire fences (Young and Jackson 1951). A loop is placed in the snare to encircle the coyote's neck as it passes through, and a locking device holds the loop closed on the neck.

TABLE 1. Number of coyotes taken by method in 15 animal damage control programs, FY 1986 (Connolly 1988).

State	Shot from aircraft	Trap	M-44	Snare	Den	Called and shot	Other[a]	All methods
Ariz.	752	977	150	22	7	36	77	2,021
Calif.	274	3,776	747	521	499	616	1,054	7,487
Colo.	1,161	126	322	106	461	280	109	2,565
Id.	2,115	737	74	71	136	352	76	3,561
Mont.	2,242	633	542	337	86	0	382	4,222
Nebr.	88	313	491	56	74	96	31	1,149
Nev.	2,378	1,114	58	29	133	82	264	4,058
N.M.	1,172	1,387	1,472	780	95	382	151	5,439
N.D.	977	259	0	41	95	20	29	1,421
Okla.	913	682[c]	720	196	111	557	104	3,283
Oreg.	2,134	2,152	208	551	374	280	257	5,956
S.D.	1,810[b]	187	372	152	28	152	185	2,886
Tex.	2,900	3,478	7,359	3,912	237	854	428	19,168
Ut.	2,120	474	384	71	656	271	140	4,116
Wyo.	3,394	233	58	71	1,103	699	474	6,032
Totals	24,430[b]	16,528[c]	12,957	6,916	4,095	4,677	3,761[a]	73,364
% Total	33.3	22.5	17.7	9.4	5.6	6.4	5.1	100.0

[a]Includes 3,505 shot, 222 taken with dogs, 33 by spotlight, and 1 not specified.
[b]Includes 617 taken by private aircraft under ADC supervision.
[c]Includes 1 taken in live trap.

Guthery and Beasom (1978) reported that snares set under fences were easy to deploy and more effective than M-44s but less effective than leghold traps. They also reported that snares were 10 to 12 times more selective than traps; snares could be made even more selective by attaching a stop that would prevent the device from closing below about 5 cm in diameter, thus allowing many small nontarget animals to escape. Phillips et al. (1990) evaluated the tension loads that coyotes, mule deer, domestic calves, and lambs applied to snares so that better breakaway snares could be developed that would allow the release of large mammals. Andelt (1988) recommended that snares should not be set within 50 m of animal carcasses, inside big game wintering yards, on trails traveled by big game, or under fences where deer, antelope, or dogs crawl to avoid capturing nontarget animals.

Snares that capture coyotes by the leg occasionally have been used in the United States and Canada. Coyotes captured in the Fremont foot snare sustained fewer foot injuries than those captured in the Novak foot snare (Onderka et al. 1990). The Fremont foot snare cable is attached to the spring arm and is thicker in diameter than the Novak foot snare cable, which may have reduced foot injuries. Coyotes captured in Novak foot snares sustained less foot injuries when the snares were attached to drags as opposed to stationary objects. Onderka et al. (1990) reported that more ungulates might be captured, held, and injured in foot snares equipped with a spring arm, that throws the snare loop above the hoof, than in traps. Lindzey (1987) reported that foot snares set around livestock killed by mountain lions can be effective in removing lions if they return to the kill.

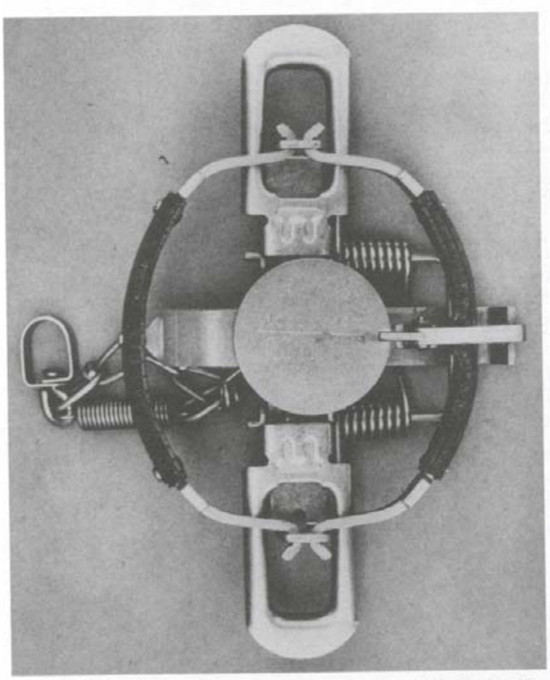

FIGURE 5. The padded-jaw trap can reduce injuries to the restrained feet of captured coyotes. Photo by S. B. Linhart; courtesy of U.S. Fish and Wildl. Service.

The Aldrich foot snare and culvert traps have replaced the leghold trap for capturing bears. The Aldrich foot snare is inexpensive, portable, easily hidden, and can be used in a variety of sets (Johnson and Pelton 1980). Prebaiting can be used to locate areas of black bear activity and to eliminate unproductive trap sites (Johnson and Pelton 1980). An automobile hood spring, which acts as a shock absorber, can be attached to snare cables to eliminate virtually all major injuries to bears (Johnson and Pelton 1980). Foot snares do not present a danger to nontarget species (Kolenosky and Strathearn 1987), whereas the leghold trap can cause serious injuries to bears (Stickley 1961, cited by Johnson and Pelton 1980).

Because many black bears and grizzly bears quickly return to the kill to finish eating the carcass (Murie 1948, Griffel and Basile 1981, Johnson and Griffel 1982), depredating bears can be most selectively captured if snares are set only at fresh kills.

Sodium Cyanide Ejectors. Sodium cyanide ejectors (i.e., the Coyote Getter, a 38-cartridge activated device, or the M-44, a spring activated device) have been used by the Federal Animal Damage Control Program in the United States from about 1940 to present, except from 1972 to 1974 (Connolly and Simmons 1984). Coyote Getters have been used in Manitoba and Alberta, but use of the M-44 and Coyote Getter has not been encouraged in Saskatchewan (United States Fish and Wildlife Service 1978).

Sodium cyanide ejectors consist of a hollow metal tube crimped closed at the bottom, a firing mechanism, a sodium cyanide cartridge or capsule holder, and a sodium cyanide capsule or cartridge. The metal tube is driven: into the ground and the capsule holder is wrapped with wool or rabbit fur smeared with a lure attractive to canids. A lethal dose of sodium cyanide is ejected into an animal's mouth when the device is pulled. Death occurs within seconds.

M-44 capsules are registered to control coyotes, red and gray foxes, and wild dogs that depredate livestock and poultry (Connolly 1988). Sodium cyanide ejectors were more selective for capturing coyotes (Robinson 1943, Beasom 1974) and more efficient (Robinson 1943) than steel leghold traps, which were not modified with pan-tension devices. Sodium cyanide ejectors are primarily selective for canids (United States Fish and Wildlife Service 1978), with target species comprising 95% of the animals taken (Dorrance 1980, Connolly 1988).

Denning. Denning, the practice of locating dens of depredating coyotes and destroying the pups and/or adults, has been reported (but not supported with biological data) as a method for coyote population reduction (Young and Dobyns 1945, Gier 1968) and as a method of stopping predation on livestock (Young and Dobyns 1945, Lemm 1973) primarily where the increased food demands of pups cause serious losses. Denning has been criticized as an unselective method of removing offending animals (Defenders Wildlife 1978, Sierra Club 1978, Humane Soc. 1978, cited by Till and Knowlton 1983). However, Till and Knowlton (1983) reported that predation incidents declined 98.2% when pups and adults were removed and 87.7% when only the pups were removed from dens of offending coyotes. Their analysis indicated that denning can be highly selective and cost-effective over a short period of time.

Aerial Hunting. Aerial hunting of coyotes apparently began as early as 1923 and was first officially adopted by the Federal Animal Damage Control Program as an operational control method in 1942 (Wade 1976). Aerial hunting with fixed-wing aircraft and helicopters has been conducted primarily for the protection of livestock and secondarily for the value of furs and bounty payments (Wade 1976). Aerial hunting achieved major importance (concurrent with curtailed use of toxicants in 1972) in the Federal Animal Damage Control Program by 1975, when it accounted for 42% of the coyotes killed (Connolly 1982). Aircraft also can assist in locating den sites (Miner and Quiroz 1974, Wade 1976). Aerial hunting is an expensive although effective method of controlling problem coyotes, especially in open terrain and when control of predation is urgent. Aerial hunting also has been used to control wolf populations (Keith 1983).

Aerial hunting is completely selective for the target species and can be highly selective for offending coyotes (Connolly 1982, Connolly and O'Gara 1987). Connolly and O'Gara (1987) reported that 6 of 11 coyotes taken from a helicopter had recently attacked or fed on collared sheep. Because most coyotes are territorial and usually have home ranges <15 km^2 in size (Camenzind 1978, Andelt 1985*a*), selectivity for offending coyotes can be increased by applying aerial and ground controls near sites of predation.

Ground Shooting. Attracting coyotes within shooting range with predator calls that imitate the sound of an animal in distress is a very selective method of removing individual coyotes (Beasom 1974, Henderson 1986). Producers also have solved many of their own problems by lying in wait and shooting coyotes as they entered sheep corrals and pastures.

Hunting with Decoy and Other Dogs. Some Federal Animal Damage Control Program field agents use decoy dogs to assist in removing coyotes. The agents frequently imitate the howl of a coyote. If coyotes respond, they move to a position that is fairly close to the coyotes and howl again. When coyotes respond, they release 1 or 2 small dogs that run toward the approaching coyote(s). The coyote(s), in an attempt to protect their pups, usually chases the dog(s) back to the field agent who shoots the coyote. This technique is effective from the start of denning until late summer (Rowley and Rowley 1987). Weaver and Sitton (1978) and Suminski (1982) indicated that hunters with dogs were the most frequently used method of removing depredating lions.

Livestock Protection Collars. These devices were developed during the 1970s and 1980s for control of coyote predation on sheep and goats. They were registered by the United States Environmental Protection Agency (EPA) in 1985, and Montana, New Mexico, South Dakota, Texas, and Wyoming have established EPA-approved programs to allow collar use by state-certified applicators as of March 1990 (Connolly and Burns 1990). The collar, consisting of 2 toxicant-filled reservoirs, is positioned on the neck of young and adult sheep and goats to exploit the neck-attacking behavior of coyotes. Coyotes that attack collared livestock usually bite the collars and receive an oral dose of the toxicant, Compound 1080 (sodium fluoroacetate). Generally, 20-50 collared lambs or kids were placed in pastures where predation was occurring and other livestock were removed.

The efficacy of the collars for livestock protection has been studied by the Denver Wildlife Research Center (Connolly 1980, Connolly and Burns 1990), the New Mexico Department of Agriculture (Littauer 1983), the Texas Agricultural Experiment Station (Scrivner 1983, Texas Agricultural Experiment Station 1983), and the Texas Department of Agriculture (Walton 1990). Thirty-eight to 71% of the collars on livestock attacked by predators were punctured in the 4 studies. In 17 of 28 field tests in Texas, Idaho, Montana, and Alberta, predation stopped or declined following use of collars (Connolly 1980). The greatest advantage of the toxic collar is selectivity for livestock-killing coyotes.

Disadvantages include the cost of collars, the labor involved in collaring and managing livestock, the fact that livestock must be sacrificed, and the potential hazards of lost or punctured collars (Connolly 1982). Burns et al. (1988, 1991) concluded that the amount of 1080 residue found on collared sheep killed by coyotes or within coyotes killed by the collars presented minimal primary and secondary hazards to nontarget species.

Scrivner (1983) estimated that the costs of using toxic collars (including collared animals killed or missing, collars punctured or missing, transportation, labor, feed, and miscellaneous) averaged $1,828.78/rancher for a 52-week period in Texas. In New Mexico (Littauer 1983), the cost of collars (excluding labor and transportation) used by ranchers averaged $443/coyote killed when prorating the initial investment in collars over 4 seasons of use and accounting for lost and punctured collars (W. F Andelt, unpubl. data).

Techniques for using toxic collars are still evolving as experience in their use accumulates. Research on the differential vulnerability of lambs to coyote predation may increase the effectiveness of toxic collars. Lambs with reduced mobility, or lambs from ewes with reduced mobility increased the probability of a lamb being on the periphery of the bed ground and thus increased the probability that the lamb would be noticed and attacked by a coyote (Gluesing et al. 1980). Lambs that were most active (Gluesing et al. 1980), orphaned, or recently introduced to a flock (Blakesley and McGrew 1984) were most vulnerable to coyote predation. Placing toxic collars on the most vulnerable lambs should increase the probability of exposing offending coyotes to toxic collars.

Walton (1990) indicated that EPA restrictions resulted in low use of livestock-protection collars. Use of these collars for deterring predation on sheep by bears and mountain lions does not seem feasible because these predators often bite sheep in the back of the neck or through the skull.

Single Lethal-dose Baits. The use of toxic chemicals for predator control in the United States began as early as 1847, when strychnine was introduced (United States Fish and Wildlife Service 1978). Small bite-sized baits containing strychnine were used in the United States until toxic baits were withdrawn from use in 1972 by Presidential Executive Order 11643 and the cancellation of all registrations of predacides by the EPA. Use of strychnine baits by the Federal Animal Damage Control Program increased from 632,187 baits in 1960 to 822,043 baits in 1970, and 1080 baits also were used by an unknown number of governmental hunters (Connolly 1982). Strychnine baits also were used extensively in Alberta in 1974 (Dorrance and Roy 1976). Bjorge and Gunson (1985) reported that the use of bite-sized portions of strychnine-poisoned meat baits were effective in reducing the number of wolves and subsequent mortality of cattle on 1 study area in Alberta.

Data on the hazards and benefits of toxic baits are scarce. Kilgore (1969) and Nunley (1977) reported that increases in small carnivore numbers seemed to coincide with reduced use of strychnine drop baits. Bortolotti (1984) reviewed the causes of deaths of 143 golden eagles *(Aquila chrysaetos)* and 172 bald eagles *(Haliaeetus leucocephalus)* preserved as study skins in museums and reported that 71% *(n* = 27) of the golden eagles and 2 of 7 bald eagles, where cause of death was known, were killed by poisons (mostly strychnine) or traps. Robinson (1948) indicated that the effectiveness of strychnine baits declined as coyotes learned to detect the toxicant.

Tigner et al. (1981, cited by Connolly 1982) reported that only 9-27% of nontoxic small lard baits placed 10-50 m from animal carcasses ("draw stations") were taken by coyotes; many baits were removed by nontarget animals. Similarly, Linhart et al. (1968) reported that most baits containing chemosterilants were taken by nontarget species. Guthery et al. (1984) indicated that nontoxic baits were taken slightly more frequently by coyotes than by nontarget animals in Texas. Forty-two and 14% of the producers using strychnine baits in Alberta during November-March and April-October 1977 reported that nontarget species (primarily black-billed magpies *[Pica pica],* ravens *[Corvus corax],* and dogs) were killed. Beasom (1974) reported that strychnine meat-baits and strychnine egg-baits were less selective than the M-44 or shooting because they incidentally killed a variety of game animals, raptors, rodents, songbirds, and reptiles.

Selectivity of baits was increased in Texas when employed (1) in December and January, when coyote consumption rates were highest, (2) in dense vegetation to reduce consumption by crows, and (3) on clear nights with a full moon to decrease rodent consumption (Guthery et al. 1984). In Alberta, the uptake of baits by birds was reduced significantly when the baits were covered (M. J. Dorrance, Alberta Agric. Prot. Branch, Edmonton, pers. commun.). Connolly (1982) stated: "It remains to be documented that small, toxic baits can be delivered effectively to coyotes without adverse impact on nontarget species."

Toxic Bait Stations. This method, now banned in the United States, generally consisted of 23-45 kg of livestock meat injected with thallium sulfate or 1 mg of 1080/28.4 g of bait. Thallium sulfate in toxic bait stations was first used for control of coyotes in 1937 and was gradually replaced with compound 1080, starting in 1944 (Robinson 1948), because 1080 was more selective for canid species and safer to apply. The Federal Animal Damage Control Program used 1080 bait stations for coyote control most frequently in the early 1960s when 15,000-16,000 stations were placed each winter in the western United States (Connolly 1982). The use of this technique by the Federal Animal Damage Control Program declined annually after 1964 to 7,289 stations in 1971 (Connolly 1982), and the technique was banned in 1972. Compound 1080 was used extensively in Alberta, British Columbia, Manitoba, and Saskatchewan but its use has significantly decreased recently due to supposed lack of public acceptance (McKay 1975, Dorrance and Roy 1976, United States Fish and Wildlife Service 1978).

Data on the effectiveness and hazards of 1080 bait stations are scarce. Robinson (1948) reported 75-100% reductions in predator losses following early use of toxic bait stations. Lynch and Nass (1981) reported an inverse relationship between the number of toxic bait stations used in the western states and the number of livestock lost to predators on the national forests from 1960 to 1972. Connolly (1982) reported that coyotes fed on 41% of nontoxic (simulated) bait stations and that about 33% of the meat was consumed by coyotes and nontarget species in Wyoming, Idaho, and New Mexico during 1981. Coyotes fed on 94% of the baits in New Mexico but on only 30% in Idaho and 27% in Wyoming; these data suggest that 70% of the bait stations used in Idaho and Wyoming would have had no effect on coyotes (Connolly 1982). Robinson (1948) concluded that although some primary and secondary poisoning of birds and mammals would occur, the selectivity of 1080 was much higher for canids than for other wildlife species.

Toxic bait stations usually were placed at a density not exceeding 1/88.9 km^2 (Robinson 1953*a,b).* Considerations of coyote home ranges and territorial behavior may help explain why bait stations did not appear to suppress coyote populations in the southern United States (Wagner 1972). Andelt (1985*a)* found that the home ranges of resident coyotes (87% of the population) in South Texas averaged 4.5 km^2 whereas transient (13% of the population) home ranges averaged >36.7 km^2. Because resident coyotes were territorial and occupied small home ranges (Andelt 1985*a),* 1 bait station/88.9 km^2 probably would be used by only a small proportion of the coyote population. The lower dependence on scavenging in southern areas compared with northern areas likely contributed to the lower effectiveness of treated baits in southern areas (Linhart 1981).

PUBLIC ATTITUDES TOWARD CONTROL OF PREDATORS

Various attitudes toward coyotes and wolves and their control exist. Some ranchers have stated that coyotes are a major threat to the sheep-raising industry (Wagner 1975, Nesse et al. 1976, Gee et al. *1977a,* Tigner and Larson 1977), whereas animal protectionists have maintained predator losses claimed by sheepmen are exaggerated, control practices pose environmental hazards, and that coyotes are a valuable part of the wildlife resources and need protection. Buys (1975) reported that approximately 92% of sheepmen and 76% of cattlemen believed that predator control is necessary for the survival of their industries. Ranchers and animal protectionists often find it difficult to discuss rationally the issue of coyote control because individuals on both sides are often emotionally charged. Thus, their opinions are often formulated without data on, or knowledge of the effectiveness, hazards, humaneness, and effects of control techniques on individual animals or on the population dynamics of target and nontarget species. Some trapping and sport hunting enthusiasts also do not concur with organized animal damage control activities because they feel these activities compete with their harvest of animals.

Because laws and policy decisions are based upon pressures from special-interest groups, technical and economic information (Arthur et al. 1977), and knowledge of public attitudes, scientific research data are of the utmost importance for educating special-interest groups and the public and for shaping rational policy decisions. Scientific research data should be presented by representatives of recognized nonadvocacy institutions to special-interest groups, with emphasis on fostering mutual understanding and a spirit of compromise between opposing groups (Dorrance 1983).

Public perceptions toward predators, primarily wolves and coyotes, and control measures have been surveyed (Arthur et al. 1977, Stuby et al. 1979, Arthur 1981, Kellert 1985). Approximately one-third of the respondents had not heard of the rancher-environmentalist controversy over the killing of coyotes, and knowledge of coyote habits and population trends was limited. A majority of the public felt that ranchers should have the right to kill those animals that were killing their livestock, but only a minority of the public approved of killing as many coyotes as possible to prevent future problems. The respondents were just about equally concerned over the killing of coyotes and the predatory killing of sheep by coyotes. As sheep and lamb losses to coyotes were hypothetically increased, respondents were more willing to approve of killing coyotes. In general, public attitudes toward wildlife are changing. Kellert (1976) reported that Americans 18-29 years of age were far more interested in wildlife, more concerned about animal welfare issues, and more likely to oppose hunting than those over 65. Kellert (1976) also found that a humanistic orientation toward animals was shared by about 70% of the public.

A majority of hunters and residents near Glacier National Park, where wolves are recolonizing, visitors to Yellowstone National Park, and residents of Wyoming supported restoration of wolves (McNaught 1987, Bath and Buchanan 1989, Tucker and Pletscher 1989). Kellert (1986) reported that most respondents supported the right of farmers to protect their stock from wolf predation. Most respondents favored control of only the depredating animal and use of nonlethal methods such as relocation, guarding dogs, and improved husbandry.

The public has rated nonlethal control methods (e.g., guarding dogs, repellent chemicals, and birth control) as more accept- able than current lethal control methods, but rancher subsidies and indemnity payments are considered less acceptable than some lethal control methods (Fig. 7) (Arthur et al. 1977, Stuby et al. 1979, Arthur 1981). The public is more concerned about the humaneness (lack of pain and suffering to the animal) and specificity (extent that only offending animals were subject to control) of control methods than about their cost-effectiveness. Trapping and slow-acting poisons were believed to cause more suffering than other lethal control methods and were judged least acceptable, whereas shooting with guns and using fast-acting poisons were regarded as causing the least amount of suffering and were judged most acceptable. Kellert (1985) reported that over 90% of the public objected to the use of poisons.

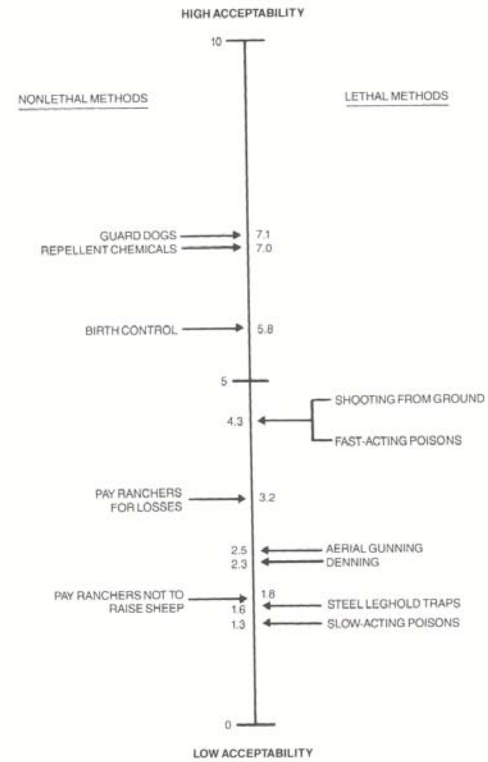

FIGURE 7. Public acceptability of various coyote damage control techniques (modified from U.S. Fish and Wildl. Serv. 1978 and Arthur 1981).

IMPACTS OF PREDATOR CONTROL

The impact of predator control on predator population densities, behavior, and ecology are to a great extent unknown. Few evaluative studies have been conducted, and to assess some of these parameters would require research extending over years, if not decades. Recent control efforts by the Federal Animal Damage Control Program have no significant impacts on target populations at the national level, but target populations may be significantly impacted in localized areas where they are reduced to minimize damage (United States Department of Agriculture 1990). The program removed 76,050 coyotes, 1,226 bobcats, 207 mountain lions, 4,667 red foxes, and 291 black bears during 1988 (United States Department of Agriculture 1990). The control, by approximately 450 Federal Animal Damage Control agents, was conducted on about 11% of the land in 17 western states and the number of coyotes removed annually in 1974 (70,000 to 85,000) represented about 24% of the total harvest and only about 4% of the coyote population (Pearson 1978, United States Fish and Wildlife Service 1978). However, extensive control efforts by the Federal Animal Damage Control Program using thallium sulfate and 1080 bait stations during the 1940s may have temporarily depressed coyote densities around 1950 in some of the western states (Robinson *1953b,* 1961; Linhart and Robinson 1972; Nunley 1978). Robinson (1948) reported that control of coyotes with toxic bait stations sometimes reached local extirpation in areas where natural foods were scarce during winter. Apparently, coyote densities returned from the 1950 lows to the 1940-41 precontrol levels in Colorado and New Mexico during 1960 and 1970, respectively, but they probably remained depressed in Wyoming over the same period (Linhart and Robinson 1972). However, a large increase in coyote densities after the ban on toxicants in 1972 was not apparent (Roughton 1977). Concurrent with the presumed decrease in coyote densities in Wyoming was an apparent increase in the densities of small nontarget carnivores, particularly the red fox, thus supporting the concept that a decrease in 1 carnivore species leads to an increase in other sympatric carnivores (Linhart and Robinson 1972). Red foxes apparently avoid coyotes with their home ranges abutting or only overlapping the perimeter of coyote home ranges (Voigt and Earle 1983, Major and Sherburne 1987, Sargeant et al. 1987). Similarly, coyotes have been reported to occupy areas between wolf ranges.

Despite considerable man-induced mortality, coyote populations are self-maintaining through behavioral adaptations and biological compensatory mechanisms such as increased rates of reproduction, survival, and immigration

(Knowlton 1972, Connolly and Longhurst 1975). Reduced population densities likely result in less competition for limited resources such as food, den sites, and mates and may reduce transmission of diseases and parasites. As coyote populations are reduced, pregnancy rates (Gier 1968), especially for yearling females, and litter sizes (Knowlton 1972) increase, whereas natural mortality rates decrease (Connolly and Longhurst 1975). Connolly and Longhurst's (1975) model suggested that coyotes, through compensatory reproduction, can withstand a 70% annual control level and that 3 coyotes would need to be killed for every animal present at breeding time to hold the density below 50% of the precontrol level. In most areas, coyote numbers likely are controlled by competition for limited resources such as food and by social stress, diseases, and parasites (Connolly and Longhurst 1975).

Connolly and Longhurst's (1975) model indicated that the number of breeding females changed only slightly with increased control intensity but that litter sizes increased. Because livestock losses are relatively serious during spring and summer due to the increased food demand of pups (Wade 1973), control of <75% of the coyotes may actually increase predation due to a greater demand for food by larger litters (Connolly and Longhurst 1975).

The effects of control, sport hunting, and general trapping on coyote behavior and ecology are not well known. However, comparisons of the ecology and behavior of exploited and unexploited coyote populations, in addition to some reported changes in behavior, have suggested that coyotes may be adapting to exploitation either through learning or heredity. Robinson (1948) reported that some coyotes learned to detect strychnine in drop baits or became wary of traps and that others refused to feed on lethal bait stations. Wagner (1975) reported that coyote responses to Coyote Getters dropped off markedly after a few years of use. Andelt et al. (1985) reported that coyotes captured in steel leghold traps and released subsequently avoided scent stations used to determine their relative abundance. Gustavson et al. (1974) and Olsen (1975) reported that lithium chloride-produced aversions in coyotes lasted 2-7 months, and Linhart et al. (1976) reported that electric shock-produced aversions lasted 3-9 months.

Exploitation also may have an effect on the social organization and activity patterns of coyotes. In unexploited areas, most coyotes existed in relatively large groups (Bowen 1978, 1981; Camenzind 1978; Andelt 1985*a),* whereas coyotes in exploited areas generally have been considered to exist in smaller groups (Hibler 1977, Althoff and Gipson 1981). Coyotes have been reported as more active during the daytime in unexploited (Gipson and Sealander 1972, Andelt 1985*a)* areas (Andelt and Gipson 1979*b).* Roy and Dorrance (1985) reported that coyotes avoided open areas near roads during daylight hours in areas where they were hunted. Exploitation likely removed some individuals, causing smaller groups, and also likely selected against diurnally active coyotes that were more visible and thus more susceptible to hunters. Adaptation and selection appear to be occurring.

Red foxes are a major predator of nesting waterfowl. Thus, controlling coyotes to reduce livestock losses may allow an increase in red foxes, which may increase predation on waterfowl.

PREDATOR CONTROL IN PRACTICE

When To Use Prevention And Control Methods

Determining when predator control should be undertaken for livestock protection varies with the type of control methods employed. Nonlethal control methods (i.e., livestock husbandry, fencing, livestock guarding dogs, frightening devices, and herders) are socially acceptable and should be used when they achieve a reduction in predation losses that exceeds the cost of control. The need for lethal control should be based upon aesthetic, social, economic, ecological, political, and administrative considerations (Berryman 1972). Costs of lethal control techniques should be related to the value of livestock saved and equated to social and aesthetic values. Control decisions should be developed cooperatively with other concerned agencies, related to other resource decisions, and based on accurate data. The objective of control programs should be to alleviate the problem, not to destroy offending animals.

The optimal time of year for employing control methods varies with the type of controls used. Nonlethal control techniques, such as frightening devices, should be employed shortly before predation begins (if it is predictable) or immediately after it begins to avoid the establishment of a problem or pattern that may be difficult to disrupt. Frightening devices should be removed as soon as they are not needed because predators are more likely to habituate to them with time. Approved lethal controls for removing specific offending animals should be employed as soon as possible after predation begins to minimize livestock losses. If local populations of predators are removed before predation begins, control efforts should be implemented immediately before predators become a problem because predators quickly move into areas vacated by other predators. Windberg and Knowlton (1988) described the large number of coyotes using small areas and the presence of transient animals available to fill vacant territories. Control applied too long before damage starts likely will be relatively ineffective.

If population suppression over large areas is warranted, control techniques should be employed just prior to whelping, when the population is at a normal low and dispersal has subsided (Knowlton 1972). It does not seem prudent to suppress coyote numbers in the fall, when dispersal is occurring and before the population normally undergoes a large natural reduction within a brief period (Knowlton 1972). Dorrance (1980) suggested that dispersal by coyotes, primarily from mid-February through April, probably negates the effect of preventive control on local coyote populations prior to mid-February in central Alberta.

How To Implement Predator Control

Choosing how to implement predator control involves consideration of who will conduct the control and what methods should be applied. Control measures can be conducted by the general public, sport hunters and trappers, the producer who is suffering damage, private industry, or governmental agencies. The question of who conducts the control requires consideration of the status of the target species, hazards of the control techniques, and the ownership and legal responsibilities for the land where the control measures are to be performed (Berryman 1972). Control should be limited to or supervised by professionals when it might affect sensitive species, requires techniques that threaten human life and nontarget species, or that has permanent adverse environmental effects, and is conducted on public lands (Berryman 1972, Dorrance 1983).

Two governmental approaches to prevention and control of livestock predation involve extension education and governmental animal damage control assistance. The extension approach uses a relatively small number of wildlife specialists who train producers and the general public in nonlethal and lethal methods of controlling predation. After the training period, the producers or volunteers conduct the control themselves. Extension education is successful and is the primary means of animal damage control in the eastern states, Kansas, Missouri, and Alberta, Canada.

The Federal Animal Damage Control Program employs about 450 animal damage control agents who conduct control operations and provide extension education for producers in the western states. The relatively large livestock operations, open-range husbandry practices, and the use of public lands for grazing in the West suggest that using professional animal damage control agents to control predation is more suitable there than it might be in the East (United States Fish and Wildlife Service 1978). The Federal Animal Damage Control Program emphasizes the protection of livestock through nonlethal techniques, the removal of offending animals, and the management of local depredating populations (Fall 1984), replacing earlier attempts at population reduction (Fall 1984).

Future Prevention And Control Techniques

The types of control techniques that will be used in the future likely will be determined by considerations of predator population dynamics, public sentiment, costs, effectiveness, and environmental hazards of techniques. Based upon public sentiment, nonlethal techniques likely will continue to be preferred over lethal techniques directed at offending animals and both approaches will be preferred over lethal methods directed at population reduction. When lethal techniques are used, emphasis will be placed upon using those techniques that are most humane (e.g., using padded instead of conventional leghold traps) and selective (e.g., using pan-tension devices on traps) for the target animals. Livestock producers cannot afford to use illegal techniques (e.g., poisons), especially on public lands, because their use may encourage the public to remove livestock from public lands.

Reducing predator populations over small and large areas is difficult and likely will become less popular. Connolly and Longhurst (1975) indicated that coyote populations probably cannot be substantially reduced over large areas without the use of toxicants. Although toxic drop baits and bait stations are the most economical methods of reducing coyote numbers, they have been relatively unselective for coyotes and may select against carrion-eating coyotes in favor of coyotes that are more prone to kill live prey, including livestock.

The effectiveness of reducing predator populations with some of the current lethal techniques (e.g., trapping, M-44s, shooting from the ground and air) probably decreases in proportion to the decline in the breeding population as control measures increase (Connolly and Longhurst 1975).

Killing coyotes at rates of <75% of the population may stimulate reproduction and aggravate losses by increasing the food demand of larger litters (Connolly and Longhurst 1975). Young and Jackson (1951), Henderson (1972), Lehner (1976), and Windberg and Knowlton (1988) described the difficulty of trying to reduce coyote numbers. Young and Jackson (1951:156) equated reducing coyote populations to "digging a hole in the ocean."

Livestock guarding dogs likely will become the most effective and most popular technique for deterring predation on livestock, particularly sheep and goats. However, lethal techniques will be necessary to remove predators in areas where livestock guarding dogs and other nonlethal techniques may not work. Predators that adapt to guarding dogs and remain a problem will need to be averted from livestock or killed by other techniques.

Antifertility agents likely will be accepted by the public and may become popular if techniques such as the Coyote Lure Operative Device (Marsh et al. 1982, Stolzenburg and Howard 1989) or species-specific contraceptives can be developed so that only the target animals will be affected. Antifertility agents might prevent the compensatory increase in reproduction associated with the killing of coyotes and thus might reduce predation associated with the need to feed pups (Connolly and Longhurst 1975).

Den hunting (Till and Knowlton 1983) may remain an effective control technique even at high rates of control, because the number of females with litters decreases only slightly with increased removal of coyotes (Connolly and Longhurst 1975). However, this technique may not remain viable because of public concern over the removal of pups.

Use of nonlethal and lethal control techniques (particularly those directed at offending animals) that do not affect overall predator numbers may best serve the interests of both ranchers and animal protectionists.

SUMMARY

Predators have been estimated to kill 2.5% of the adult sheep and 9.0% of lambs annually in the western United States. Coyotes kill about 74% of the adult sheep and 77.7% of the lambs lost annually to predators. Dogs, red foxes, mountain lions, black bears, grizzly bears, gray wolves, and bobcats also prey on domestic livestock, but their predation is secondary to that of coyotes.

Nonlethal and lethal control techniques are used to prevent or control predation. The more successful nonlethal methods include various livestock husbandry practices such as confinement, disposal of livestock carcasses, and use of herders; fencing; guarding dogs; and various frightening devices. Lethal methods of deterring predation include trapping, snaring, denning, shooting from the air and ground, and livestock protection collars.

Predators will continue to prey on domestic livestock throughout the foreseeable future. This problem likely will be minimized through effective public education programs, the adoption of nonlethal and more humane lethal control techniques, and the development of new and improved techniques. The trend away from predator population reduction methods is likely to continue, especially when considering current public sentiment, predator population dynamics, costs, and environmental hazards of control techniques. The public controversy over methods of resolving wildlife-human conflicts probably will not diminish until safe, effective, selective, economical, nonlethal methods are developed for preventing predation. Hopefully, innovative research will provide new methods of

reducing livestock losses to predators while enabling humans to pursue the recreational and aesthetic opportunities that predators offer.

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