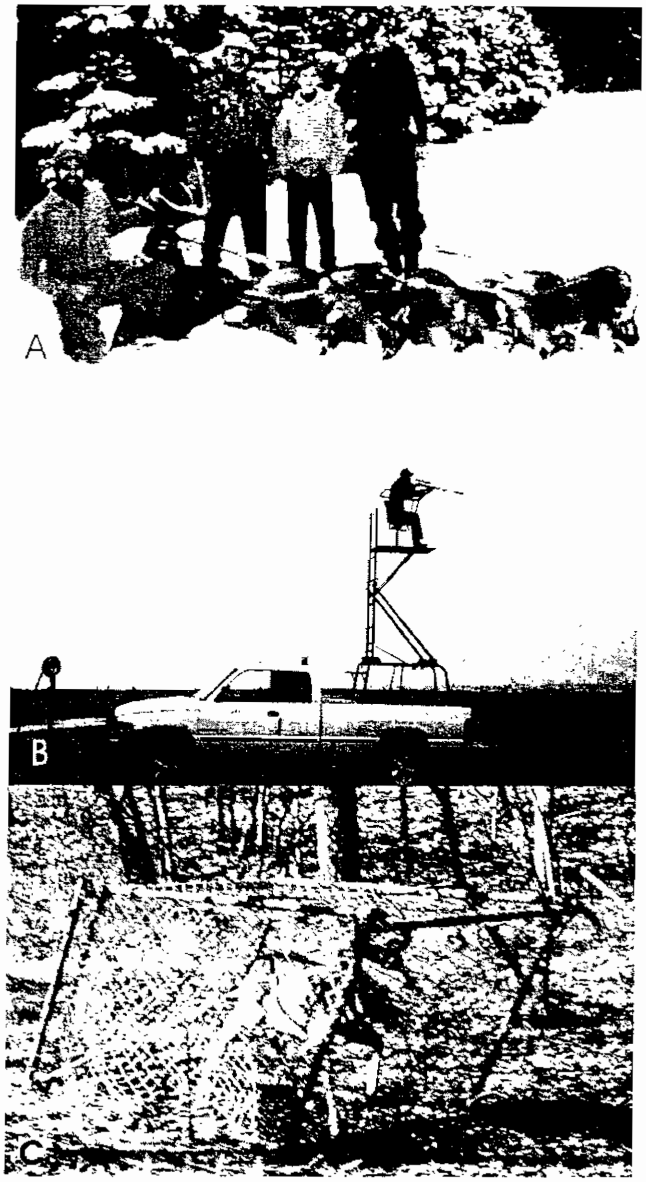

Fig. 8. Population control methods for deer include: A. well-managed hunting, B. sharp-shooting, and C. trapping (for euthanasia or translocation).

Hunting, Shooting, and Trapping

Regulated, managed hunting in rural settings is the most practical and effective method of managing overabundanr deer populations and controlling damage (Fig. 8A). It is also the most ecologically, socially, and fiscally responsible method. Some states have special depredation permits that can be issued to a landowner to remove a specific number of deer at a problem site outside the normal hunting season, if sufficient control cannot be achieved during the hunting season. Well-managed hunting can also be effective for reducing burgeoning deer numbers in urban settings. Several case studies have outlined strategies to ensure the success of deer hunts in areas that are also populated with humans (McAninch 1995, VerCauteren and Hygnstrom 2002, Warren 2002). Professional sharpshooters have also been employed effectively to reduce deer numbers in areas where hunting was not considered safe (DeNicola et al. 2000) (Fig. 8B).

Deer can be captured with drop-door traps (Fig. 8C), rocket nets, drop nets, or tranquilizer guns, and then relocated or euthanized. However, these methods of deer removal are usually at least twice as expensive as shooting. In addition, there are problems with holding deer humanely in captivity until they can be transported somewhere for release, and with finding suitable release sites. In areas such as arboretums, where shooting is normally prohibited, the use of a skilled marksman under permit is probably preferable to live capture (Ishmael and Rongstad 1984). Live capture/transplanting is generally the control option of last resort, mandated by safety considerations or sensitive public relations issues.

RODENTS AND OTHER SMALL MAMMALS

Damage Assessment

Rodents and other small mammals are often not readily observed causing damage, and their damage is frequently difficult to measure and quantify. Likewise, accurate estimates of monetary losses of much of this damage are difficult to ascertain. Damage assessments indicate rodents and nonpredatory small mammals cause tremendous annual losses of food and fiber. Conover (2002) estimated the value of rodent damage to agriculture in the United States could be as high as $7 billion annually. In the timber industry, American beaver (*Castor canadensis*) and pocket gophers (Family Geomyidae) cause the most damage. Miller (1987) surveyed forest managers and natural resource agencies in 16 southeastern states and estimated annual wildlife-caused losses, primarily attributed to beaver, to be $11.2 million on 28.4 million ha. Comparatively, in 1998 Louisiana expended $2 million to control nutria (*Myocastor coypus*) (Bounds and Carowan 2000). Other types of damage include losses of sugarcane to rats (*Rattus* spp.), orchard damage by voles (*Microtus* spp.), and decreased forage quantity on rangelands caused by rodents, rabbits, and hares (Fig. 9). In households, house mice (*Mus musculus*) are the primary species conflicting with humans.

Quantifying losses to evaluate efficacy of techniques can be challenging. Most research compares plots where the resource was protected to those with no protection, or production in areas with no rodents to areas with rodents. However, loss estimates must be converted to accurate assessments of dollar losses to compare cost/benefit evaluation of control programs (VerCauteren et al. 2002*b*). Conversion to dollars is often difficult, given the vast areas involved and variability in rodent populations. Given these considerations and the complexity of damage situations, it is easy to realize the need for better monitoring techniques, damage assessment methods, and control effort evaluation.

Species Damage Identification

Most wild mammals are secretive and not easily observed; many are nocturnal. Often the investigator must rely on sign, such as tracks, trails, tooth marks, feces, or burrows to identify the species responsible for damage. Trapping may be necessary to make a positive identification of damage-causing small rodents; frequently, more than one species is involved.

Characteristics of the damage may provide clues to the species involved. In orchards, for example, major strip-

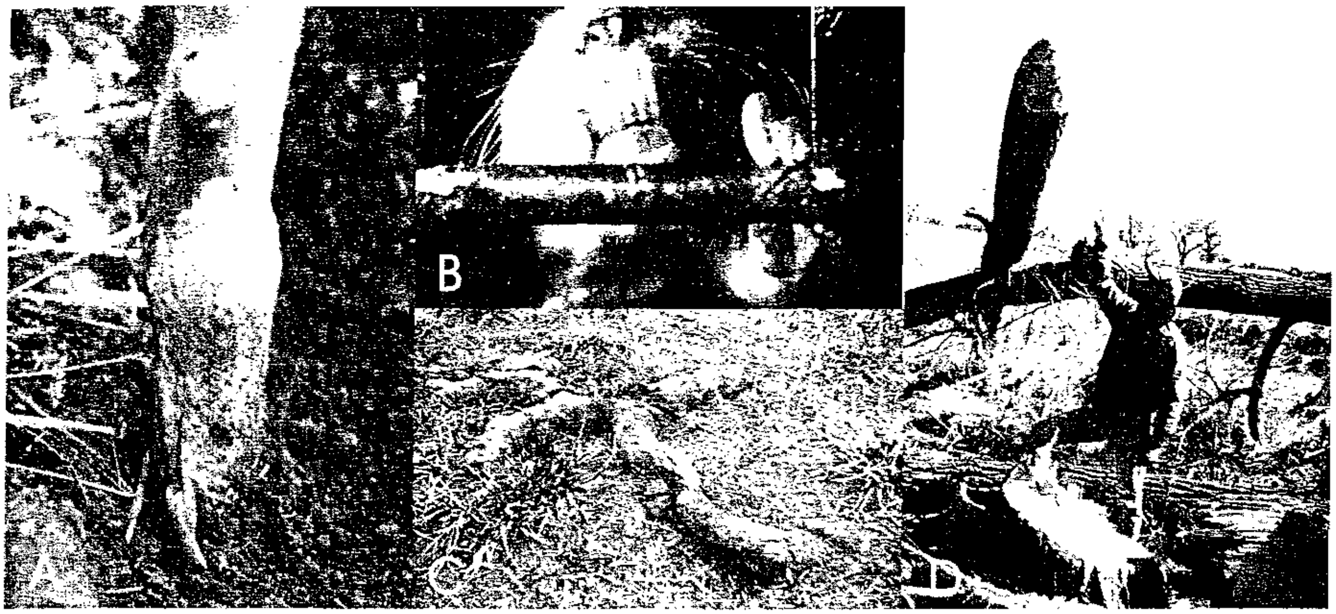

Fig. 9. Examples of rodent damage: A. tree damage in orchards by voles, B. damage to underground cables by pocket gophers, C. soil cast left by pocket gophers, and D. beaver damage to trees.

ping of roots is usually caused by pine voles (*Microtus pinetorum*), whereas damage at the root collar or on the trunk up to the extent of snow depth is most often caused by meadow voles (*Microtus pennsylvanicus*). Rats gnaw stalks of sugarcane until they are hollowed out between the internodes but usually not completely severed. Rabbits, in contrast, usually gnaw through the stalks, leaving only the ring-shaped nodes. Damage to plants can generally be grouped as: 1) root damage—pocket gophers and pine voles; 2) trunk debarking—meadow voles, squirrels (Family Sciuridae), porcupines (*Erethizon dorsatum*), woodrats (*Neotoma* spp.), rabbits, and mountain beavers (*Aplodontia rufa*); 3) stem and branch cutting—beavers, rabbits, meadow voles, mountain beavers, pocket gophers, woodrats, squirrels, and porcupines; 4) needle clipping—mice, squirrels, mountain beavers, porcupines, and rabbits; debudding—red squirrels (*Tamiasciurus hudsonicus* and *T. douglasii*) and chipmunks (*Tamias striatus* and *Eutamias* spp). These characteristics can aid in identification of rhe species responsible, but positive identification should be made either by species-specific sign (e.g., tracks, feces) or by capture of iudividuals.

Bats

Bats, the only mammals capable of true flight, eat vast quantities of insects. Only a few of the 190 species of bats in North America cause problems; primarily when they form roosrs or maternity colonies in human dwellings or structures. Bars are susceptible to many pesticides (Fitzgerald et al. 1994). Those most commonly encountered in pest situations are: little brown bat (*Myotis lucifugus*), big brown bat (*Epresicus fuscus*), Mexican free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*) in the Southwest, and the Yuma myotis (*Myotis yumanensis*) in the West (Greenhall 1982, Frantz 1986). Species identification may be difficult, but is imporrant because several bat species are threatened or endangered and protected by state and federal laws.

The presence of bats in a building is usually evideuced by noise (squeaking, scratching) and by presence and distinctive pungent odor of accumulated feces and urine. Bat feces are readily identified from those of rodents by odor, insect content, and ease with which they are crushed. Many people are fearful of bats and panic in their presence. Bats can carry and transmit rabies, although <0.05% of bats are thought to be rabid (Fitzgerald et al. 1994). However, because infected bats may exhibit weakness or paralysis, they are often unable to fly or roost and therefore pose a greater risk of contact with humans aud domestic animals. Where bat colonies are allowed to persist, fecal deposits accumulate, and the fungus that causes histoplasmosis can develop. Damage management techniques involve education to overcome phobias, habitat modifications (one-way valve devices on structures after young reach flight stage and construction of artificial roosts), repellents (naphthalene), and traps.

Beaver, Muskrat, and Nutria

Burrowing aquatic rodents, as agents of disturbance, can alter habitats in positive and negative ways. American beaver, muskrat (*Ondatra zibethicus*), and nutria are aquatic rodents that can cause damage in and arouud natural and human-created wetlands. Due to their burrowing habits, they cause damage to man-made dams, levees, and irrigation canals. The presence of these species is evidenced by the damage they cause and by their tracks, droppings, and trails. Beaver and muskrat are native to North America and nutria were introduced from South America. The regulations regarding control of these species vary from state to state.

Beaver damage is easily identified by the distinctive, cone-shaped tree stumps that result from their gnawing (Fig. 9D). Other beaver sign includes dams, lodges, bank burrows, and green sticks with the bark freshly peeled off. Muskrat and nutria are smaller than beaver and do not build dams or plug culverts. Nutria scat has distinctive parallel lines runuing along its length (LeBlanc 1994).

Beaver ear a wide variety of plant species, but are usually locally selective, which can result in overexploitation of preferred species (Fitzgerald et al. 1994). Damage caused by beaver results from feeding behavior (tree cutting) and their efforts to control water levels (dam building) (Miller and Yarrow 1994). Beaver also fell and girdle large-diameter trees to access the branches, contributing to losses in timber value (Fitzgerald et al. 1994). They also cause flooding of roads, dwellings, and other human property.

The most serious damage caused by muskrats is washouts and cave-ins of pond dams, levees, and irrigation canals. They can also cause severe damage to grain, such as rice, and to garden crops growing near water. Their cone-shaped huts of aquatic material projecting 0.5–1 m above the water surface, feeding platforms of aquatic vegetation, and burrow entrances indicate muskrat presence. Their burrow entrances, 13–17 cm in diameter, are much smaller than those of nutria.

Nutria can cause significant damage to rice and sugarcane, especially in fields adjacent to Gulf Coast marshes (LeBlanc 1994). They may severely impede cypress (*Taxodium distichum*) regeneration (Conner and Toliver 1987) and damage wooden structures and floating marinas. Nutria have been implicated as a threat to the persistence of coastal marshes (Ford and Grace 1998).

Beaver, muskrat, and nutria can be infected with several pathogens, and internal and external parasites that can be transmitted to humans (Perry 1982, Thorne et al. 1982, Davidson and Nettles 1997). Proper water treatment measures should be taken before drinking water in regions where these species occur. Damage management techniques include habitat modification (explosives for dams, drain devices in dams or culverts), exclusion, traps (live traps accompanied by translocation, Conibears, footholds), snares, and shooting.

Deer and White-footed Mice

Deer and white-footed mice (*Peromyscus maniculatus* and *P. leucopus*) are common and widely distributed throughout North America (Timm and Howard 1994). Species of *Peromyscus* are the primary reservoirs of the Sin Nombre hantavirus (Corrigan 2001), which was recently found to be the cause of an often-fatal pulmonary syndrome in humans. These mice are nocturnal, active year round, and their populations may show large fluctuations. Their cheek pouches give them the capacity to carry 3–5 times more food than other species of mice and may increase their efficiency in exploiting small, particulate food items that are patchily distributed (Vander Wall and Longland 1999). *Peromyscus* can be significant seed predators (Sullivan 1978), and in some areas direct seeding for reforestation has failed as a result of their foraging activities. Their effects on reforestation have caused a shift to the use of hand-planted seedlings in many areas. *Peromyscus* also can cause significant losses to corn seedlings in conservation tillage systems, but this damage may be offset by their consumption of harmful insects and weed seeds (Clark and Young 1986, Johnson 1986). *Peromyscus* invade homes where they eat stored food and damage upholstered furniture or other materials shredded for use in nest building. Trapping with snap or live traps is the best method to identify the species present. Damage management techniques for *Peromyscus* include habitat and food modifications, exclusion, traps (snap traps and live traps), repellents, and toxicants.

Ground Squirrels

Ground squirrels, genus *Spermophilus*, are important pest species in north-central and western North America, causing serious economic losses to agricultural and range resources. Belding's (*S. beldingi*), California (*S. beechyi*), and rock (*S. variegatus*) ground squirrels are all considered pests in at least part of their range (Marsh 1994*a*). They can inflict serious damage to pastures, rangelands, vegetable gardens, and grain, fruit, or nut crops. A careful search of an area showing damage will reveal opened seed hulls and caches. They often live in colonies or concentrate in localized areas (Marsh 1994*b*). As a group, ground squirrels are widely recognized for their ability to achieve high population levels in suitable habitats (Giusti et al. 1996). Ground squirrel burrows can collapse irrigation levees, increase erosion, damage farm machinery, and cause injury to livestock and humans. Ground squirrels also predate nests of ground-nesting birds, including those of waterfowl (Sargeant and Arnold 1984, Marsh 1994*a*).

Ground squirrels are diurnal and easily observed (Marsh 1985*a*). They hibernate and estivate and show major dietary shifts during the year (Marsh 1985*a*, 1986). Effective control strategies must consider these factors. Ground squirrels are extremely adaptable, so indirect control through habitat modification, exclusion, or use of chemical and visual repellents has limited, if any, benefit in most situations (Whisson et al. 2000). Ground squirrels carry several zoonotic diseases, including plague; in plague-endemic areas, ground squirrel control should be combined with ectoparasite control (Marsh and Howard 1982). Damage management techniques include habitat modification (exclusion, burrow ripping, and flooding), toxicants, fumigants, traps (live traps, size #0–1½ foothold traps, snap traps), and shooting.

Marmots

Marmots (*Marmota* spp.), also known as woodchucks, can cause damage to a variety of crops; forage production may be markedly reduced by marmot feeding and trampling (Marsh 1985*a*). Damage to crops such as alfalfa, soybeans, beans, squash, and peas can be costly and extensive. They damage fruit trees and ornamental shrubs by gnawing or scratching woody vegetation. Damage often occurs on farms, in home gardens, orchards, nurseries, around buildings, and occasionally on dikes (Bollengier 1994). Their burrows, often positioned along field edges, can cause damage to farm machinery and injure livestock; burrows can compromise the structural integrity of irrigation ditches, resulting in loss of water. In suburban areas, burrows under buildings or in landscaped areas cause problems (Marsh and Howard 1982). The presence of marmots is easily ascertained by direct observation of animals and burrows. During periods of forage growth, vegetation around burrows is noticeably shorter than in surrounding areas. Occupied burrows can be identified in spring by the presence of dirt pellets ranging from marble to fist size. Damage management techniques include frightening devices, fumigants, traps (Conibear traps, foothold traps, live traps) and shooting.

Voles

Voles, also called meadow mice, field mice, and pine mice, cause extensive damage to forests, orchards, and ornamentals by gnawing bark and roots (Sullivan et al. 1987, O'Brien 1994). In North America, there are 19 species of voles, 4 of which are of pest significance. They are the most prolific of all rodent species and probably the most important item in the food chain among secondary consumers (Corrigan 2001). Tree or shrub damage usually occurs under snow or dense vegetation; the bark is gnawed from small trees near the root collar and up the trunk to the snow surface (Fig. 9A). Voles gnaw through small trees or shoots up to about 6 mm in diameter. Some species also cause extensive damage to root systems; this damage may not be detected until spring when it is reflected in condition of new foliage. Voles can damage field and garden crops as well; when vole populations are high, losses can be severe (Clark 1984, Marsh 1985*a*). They are also carriers of bubouic plague and tularemia.

Vole populations are characterized by 3 levels: low, high, and irruptive (Johnson and Johnson 1982). In North America, population peaks occur about every 4 years, although not in explosive numbers and not predictably (Johnson and Johnson 1982). Voles are active throughout the year. Their presence is most easily ascertained by searching for their runways and burrow systems. In orchards, these can be found by pulling the grass and other debris from the bases of trees. Gnawing on trunks and roots of trees is usually less uniform than that of other rodents. Tooth marks can be at all angles, even on small branches, and may vary from light scratches to channels 3 mm wide, 2 mm deep, and 10 mm long. In hay crops, runways with numerous burrow openings, clipped vegetation, and feces can be detected in dense vegetation. Damage management techniques for voles include habitat modification (provision of alternative foods), exclusion, toxicants, and traps (snap traps).

Moles

There are 7 species of moles (representing 5 genera) in North America; 4 of these species have distributions restricted to the Pacific Northwest and West Coast of the United States (Yates and Pedersen 1982). Moles feed primarily on soil invertebrates, especially earthworms and grubs (insect larvae). Vegetation can comprise up to 20% of the diet of some species of moles; although they cause some damage to crops and ornamentals, they are most detrimental to turf areas (Marsh 1996). They are active year round. Voles and mice also use burrows of moles and can be responsible for some damage attributed to moles (Henderson 1994*a*).

The presence of moles usually can be detected by the mounds of soil brought up from extensive tunnels dug in search of food and by the raised soil of surface burrows. Shallow tunnels of moles can be confused with rhose of pocket gophers but moles typically leave volcano-shaped mounds composed of clods of soil and their burrow plugs are at the peaks of the hills; gophers leave fan-shaped mounds, with the burrow plug near the base of the mound (Henderson 1994*a*). Generally, gophers produce larger mounds than moles, but the Townsend's mole (*Scapanus townsendii*) can produce up to 4 mounds per day (Yates and Pedersen 1982).

The burrowing activity of moles may reduce production of forage crops by undermining and smothering vegetation and by exposing root systems to drying. Forage production in pastures can be reduced by 10–50% by burrowing activity (Yates and Pedersen 1982). Their surface burrows can also plug harvesting machinery and contaminate hay and silage. The burrowing activity of moles can extensively damage lawns and golf greens. Damage management techniques include habitat modification (soil compaction, flooding), exclusion, chemical repellents, insecticides (to reduce the mole's primary food source), fumigants, toxicants, and traps.

Pocket Gophers

Thirteen species of pocket gophers (*Geomys* spp., *Pappogeomys castanops, Thomomys* spp.) occur in the United States. They can cause substantial damage to agricultural crops, lawns, rangeland, and tree plantings. Gophers feed primarily on underground portions of plants and trees. Root crops such as potatoes, sweet potatoes, beets, parsnips, turnips, and carrots are favorite foods, as are field crops such as alfalfa and clover (Marsh 1998). Damage is often undetected until a tree shows aboveground signs of stress, by which time the damage may be lethal. Pocket gophers may also damage plastic irrigation lines in agricultural settings as well as underground pipes and cables (Fig. 9B). In rangeland, soil disturbance and mound building by pocket gophers results in increased plant diversity, favoring annual and invasive species. They can also reduce the carrying capacity of rangeland for livestock. Gopher mounds can cause equipment breakage and increase wear of haying machinery. Furthermore, their burrows can cause substantial losses of irrigation water, especially in flood-irrigated crops (Marsh 1998).

Pocket gophers are a major impediment to reforestation in the western United States (Crouch 1986). They damage trees by stem girdling and cutting, root clipping, and exposing roots to drying (Case and Jasch 1994). In winter, pocket gophers often forage above ground by tunneling through snow. Extensive aboveground girdling is fairly easy to detect. Damage to roots, however, may go unnoticed until seedlings become discolored and tip over (Nolte et al. 2000).

Fan-shaped soil mounds in contrast to the conical mounds of moles easily identify pocket gopher presence. Burrow entrances are typically plugged. Above ground debarking damage caused by pocket gophers shows small tooth marks, differing from the distinct broader grooves left by porcupines and the finely gnawed surface caused by meadow voles. Gophers sometimes pull saplings and vegetation into their burrows. Gophers also fill some of their snow tunnels with soil, forming long, tubular "soil snakes" that remain after the snow melts (Fig. 9C). Damage management techniques include habitat modification (flood irrigation, crop rotation), cultural practices (plastic mesh cylinders to protect seedlings, protective coverings for pipes and cables), fumigants, toxicants, and traps.

Prairie Dogs

There are 5 species of prairie dogs (*Cynomys* spp.) in North America; the Mexican (*C. mexicanus*) (endangered) and Utah (*C. utahensis*) (threatened) prairie dogs are federally listed. Prairie dogs live in colonies that are easily identified by conical mounds around burrow entrances and by the presence of these highly visible rodents. Populations were reduced greatly by intensive control and conversion of habitat to agriculture in the early- to mid-1900s. In recent years populations have been expanding, commensurate with reduced control efforts.

Prairie dogs damage rangelands and pastures by clipping vegetation for food and nesting material and by clearing cover from the vicinity of burrows (Hygnstrom and Virchow 1994). Their activity not only reduces available forage but also can alter species composition of vegetative communities in favor of forbs. Competition with cattle is minimal and, in some situations, beneficial effects of prairie dogs may offset competition. Thus, each conflict situation should be evaluated individually (Fagerstone 1981). Crops planted near prairie dog colonies can receive serious damage from feeding and trampling. Also, damage to irrigation systems is common, and American badgers (*Taxidea taxus*) digging for these rodents cause even greater damage. The burrows and mounds created by prairie dogs can increase soil erosion and drainage of irrigation water, and cause damage to farm machinery. Prairie dogs also serve as a reservoir for bubonic plague (Hygnstrom and Virchow 1994).

In recent years, prairie dogs have thrived in urban areas that were historically prairie dog habitat. Damage in these environments includes degradation of community open space, clipping of landscape vegetation, and encroachment into residential yards. Populations in urban areas can increase the probability of bubonic plague transmission to pets.

Prairie dog colonies provide habitat for other species such as the endangered black-footed ferret (*Mustela nigripes*). It is a violation of federal law to poison a prairie dog town where ferrets are present (Hygnstrom and Virchow 1994). Damage management techniques include habitat modification (e.g., deferred grazing), exclusion, fumigants, toxicants, traps (foothold and Conibear), and shooting.

Rabbits and Hares

Rabbits (*Sylvilagus* spp.) and hares (*Lepus* spp.) (Family Leporidae) can damage or completely destroy landscape plantings, gardens, agricultural crops, and rehabilitated rangeland. In winter, leporids may strip bark from and debud fruit trees, conifers, and other trees and shrubs (Craven 1994). Populations of hares show large fluctuations and, during peak densities, hares can severely damage vegetation and compete with livestock for forage (Fig. 10).

Stems clipped by rabbits and hares have a clean, oblique, knife-like cut. Rabbits and hares usually clip stems 6 mm in diameter or less at a height not more than 50 cm above the ground. Repeated clipping will deform seedlings. Leporids can often be observed at damage sites along with their tracks, trails, and droppings.

Rabbits are known vectors of tularemia, a zoonotic disease, and they may carry larvae of several ascarid roundworms that can produce disease if uncooked, infected meat is ingested by humans (Davidson and Nettles 1997). Damage management techniques include rabbit "drives" or "roundups," use of ferrets, habitat modification, exclusion, chemical repellents, traps, snares, and shooting.

Fig. 10. High jackrabbit densities negatively impact vegetation.

Tree Squirrels

Tree squirrels can be grouped into 3 categories: large tree squirrels (gray [*Sciurus carolinensis*], fox [*S. niger*], and tassel-eared [*S. aberti*]), pine squirrels (red and Douglas), and flying squirrels (northern [*Glaucomys sabrinus*] and southern [*G. volans*]) (Jackson 1994*b*). Squirrels eat plants and fruits, dig up newly planted bulbs and seeds, strip bark and leaves from trees and shrubs, invade homes, and consume bird eggs (Hadidian et al. 1987, Jackson 1994*b*). Squirrels can also cause problems by traversing power lines, gnawing on them, and shorting out transformers.

Squirrels often can be observed at the damage site. Damage to conifers is indicated by green, unopened cones scattered on the ground under mature trees aud by accumulated cone scales and "cores" at feeding stations. Bark stripping can be observed in trees, and bark fragments are often found on the ground, as are the tips of twigs and small branches. These activities may interfere with natural reseeding of trees that are important to forestry, particularly in ponderosa pine (*Pinus ponderosa*) forests where pine squirrels may remove 60–80% of the cones in poor to fair seed years (Jackson 1994*b*). Damage management techniques include cultural practices (trimming limbs near buildings and transformers), exclusion, frightening devices, chemical repellents, toxicants, traps (Conibear, foothold, and live traps), and shooting.

Woodrats

Woodrats, also called pack rats, brush rats, or trade rats, are attracted to human food supplies in buildings and will remove small objects such as utensils and other items, sometimes leaving sticks or other objects "in trade." There are 9 species of woodrats in the United States; several have become significant pests in suburban and semi-rural developments in the Southwest (Corrigan 2001). They often construct conspicuous stick houses in cabins, unused vehicles, rocky outcroppings, or in the upper branches of trees (Marsh and Howard 1982, Salmon and Gorenzel 1994). They will shred mattresses and upholstery for nesting material.

Woodrats are agile climbers and consume fruits, seeds, and green foliage of herbaceous and woody plants. They clip small branches and strip and finely shred patches of bark for their nests. Their damage may be confused with that of tree squirrels and porcupines; however, woodrats leave a relatively smooth surface with a few scattered tooth marks and tend to litter the ground beneath the tree less than tree squirrels. Woodrats have been involved in epizootics of plague and have been infected with tularemia. At least 6 species of woodrats have been ideutified as reservoirs of trypanosomes (parasitic blood-infesting protozoans) that cause Chagas disease (Corrigan 2001). Because some subspecies of woodrats are endangered, one should check local regulations before undertaking control efforts. Damage management techniques include exclusion, chemical repellents, toxicants, traps (snap and live traps), and shooting.

Commensal Rodents

The 3 species of commensal rodents (those that live primarily around human habitation) are Norway rats (*Rattus norvegicus*), roof or black rats (*R. rattus*), and house mice. These omnivorous rodents consume millions of bushels of grain each year: in the field, on the farm, in the elevator, mill, store, home, and in transit. They also waste many more millions of bushels by contamination. One rat can eat approximately 9–18 kg of feed per year and probably contaminates 10 times that amount with its urine and droppings (Timm 1994*a*,*b*).

Besides consuming plant products, commensal rodents will feed on poultry chicks and occasionally will attack adult poultry, wild birds, newborn pigs, lambs, and calves. In buildings and vehicles, rodents gnaw electrical wires, creating a serious risk to human safety (Corrigan 2001) and sometimes starting fires. Their gnawing also causes considerable property damage. Extensive damage to foundations and concrete slabs sometimes results when rats burrow under buildings; and burrowing into dikes and outdoor embankments causes erosion. Health departments annually report hundreds of human babies bitten by rats. Many viral and bacterial diseases are transmitted to humans by rodent feces and urine-contaminated food and water. Among the diseases rats may transmit to humans or livestock are plague, murine typhus, leptospirosis, trichinosis, salmonellosis, and ratbite fever.

Signs of commensal rodents include gnawing, droppings, tracks, burrows, and darkened or smeared areas along walls where they travel. Reviews of problems caused by these species and methods of control are provided by Timm (1994*a*,*b*), Hygnstrom and VerCauteren (1995), and Corrigan (2001). Damage management techniques include tracking powder, habitat modification, cultural practices (sanitation), exclusion, fumigants, toxicants, and traps (snap and multiple-catch traps).

Control Techniques

There are 2 general categories of control related to rodents and other small mammals: nonlethal and lethal. Many traditional methods of wildlife damage management are lethal; however, these methods are increasingly being questioned by society on the basis of humaneness and target specificity. Presently, we lack ability to alleviate many wildlife damage problems in effective and economical ways using only nonlethal techniques (Conover 2002). Wildlife researchers specializing in wildlife damage management are expending considerable effort to develop nonlethal means to reduce damage. The following section briefly reviews control techniques commonly used to manage populations of rodents and small mammals. An Integrated Pest Management (IPM) approach is recommended for the control of rodents and other small mammals. The IPM concept favors timely and strategic incorporation of a combination of cost-effective control techniques to reduce the impact of species on valuable resources.

Habitat Modification and Cultural Practices

All animals are dependent on food and shelter; therefore, elimination of one or both of these requirements will force them to move from the immediate area. This method of control, where practical, is the most desirable and usually has the most permanent effect in reducing small mammal damage. However, other species often are dependent upon the same habitat. Modifications of the habitat can result in greater adverse impacts to desirable nontarget species and natural communities than careful use of a registered toxicant or other control tool. Modifications can also create situations that contribute to other species becoming pests.

Many rodents and small mammal pests can be discouraged from using areas by removal of brush and woodpiles, weeds, and other debris. Commensal rodent control can be greatly facilitated by removal of harborage, garbage, and refuse. Squirrel interference with power transformers may be reduced if vegetation near power poles is managed (Hamilton et al. 1987). Mountain beaver populations in silvicultural areas may be decreased by removing surface shelter such as stumps, logs, and brush piles (Cafferata 1992). High populations of muskrats in sugarcane are associated with debris remaining in fields after harvest (Steffen et al. 1981).

Control of pine voles with anticoagulant baits was enhanced in apple orchards cultivated 2 or 3 times a year (Byers 1976). Davis (1976) reported that pine vole damage in an apple orchard was reduced by mowing 3 times a year, clearing vegetation from under the trees, removing pruned branches, restricting distribution of fertilizer and, after harvest, inspecting and cleaning vulnerable parts of the orchard. Byers (1984), however, found that cultural controls (combinations of mowing, cultivation, and herbicide application) were much more expensive than application of toxic baits and offered no advantages in vole control.

Water levels behind beaver dams can be manipulated by installing a perforated pipe or a 3-log drain (Miller and Yarrow 1994) through the dam. Various mechanical methods have been developed to prevent beaver from stopping water flow through culverts (Roblee 1987). Muskrat damage to farm pond dams can be reduced by maintaining a 3:1 slope on the water side of the dam, a 2:1 slope on the outer face, and a top width of 2.4 m (Miller 1994).

Provision of alternative foods can reduce conifer seed loss to mice in forest regeneration projects (Sullivan and Sullivan 1982) and may be useful in reducing loss of agricultural crop seedlings in no-tillage fields (Hygnstrom et al. 2000) and orchards (Sullivan and Sullivan 1988). Pocket gopher infestations in logged areas can be reduced by prompt regeneration and minimal site preparation. Selective cutting, when feasible, can be used in areas with high potential for gopher infestations (Crouch 1986). Use of insecticides to reduce numbers of soil invertebrates can protect turf from nine-banded armadillos (*Dasypus novemcinctus*) and moles, but damage may initially increase due to increased food searching by animals already present (Henderson 1994*a*).

Exclusion

Exclusion involves installation of barriers that prevent access by pest species into structures or areas, or elimination of their physical contact with specific objects. Rodent proofing of structures is achieved most economically if incorporated into construction plans. Corrigan (2001) provides detailed suggestions on how to accomplish rodent-proof construcion. Basically, all openings or sites where rodents might create openings are protected with wire mesh, sheet metal, or concrete, providing long-term protection.

Exclusion is a necessary part of an effective program to remove bats from structures. Final closure of entrances to the structure should not be made until all young have reached the flight stage. At that time these openings can be closed with a one-way door that permits bats to leave the structure but prohibits re-entry.

In small orchards, rodent and rabbit damage can be eliminated by wrapping trees with hardware cloth or burlap that is buried about 5 cm deep around the tree base. Fences made of 1.2- to 2.5-cm mesh net wire 0.7–1 m high can protect small areas against nonclimbing rodents and small mammals. Lower edges of fences should be buried with an "L" shape on the outside of the fence to prohibit burrowing under the fence.

A 0.6-m-wide expandable metal band placed around tree trunks 2 m above the ground will keep squirrels out of individual trees. Branches should be trimmed within 2 m of the ground or buildings.

Steel-sheathed wire may be used on undergronnd power and telephone lines to prevent pocket gopher gnawing. Plastic seedling protectors will protect conifer seedlings from rodents and rabbits. These plastic net-tubes are placed over seedlings at planting. Some allow branches to grow through the netting and provide protection for the terminal bud for 3–5 years as the terminal leader grows through the tube.

Frightening Devices

Frightening devices may deter rodents and small mammals from localized areas for short periods of time. These devices are designed to frighten animals by targeting their visual or auditory senses. Visual repellents (e.g., eye spots, predator effigies, mylar) were designed to repel birds, although some of these visual devices may also affect mammals (Mason 1998). Sonic devices include distress calls, pyrotechnics (e.g., live ammunition, shell crackers, fire crackers), propane cannons, and sirens. Ultrasonic devices are no more effective at frightening animals than sonic devices. Although readily available and commonly used, most frighrening devices are ineffective. Limited research with frightening devices has been conducted on rodents and small mammals.

Chemical Repellents

Several compounds have been registered for use as small-mammal repellents (Jacobs 1994); however, definitive efficacy data for most are lacking (Mason 1998), as is information on why some chemicals repel offending animals. Repellents are most effective when applied directly to foods with the intent of reducing consumption (Mason 1998). Chemical repellents are grouped into 3 categories: sensory irritants, semiochemical odors (e.g., predator urines), and those that produce conditioned taste avoidance behavior (Clark 1998, Mason 1998). They function by producing smell or taste aversions, or gastrointestinal malaise. Sensory irritants are usually more effective than semiochemicals. Use of some area repellents, such as naphthalene or para-dichlorobenzene, in structures is often limited because the vapors cannot be prevented from permeating areas occupied by people. The efficacy of repellents applied to plants or seeds is affected by availability of natural foods and ability to withstand weathering. "Bitter" chemicals (e.g., thiram, denatonium benzoate, denatonium saccharide, sucrose octaacetate), are not necessarily perceived by animals as such, and are not inherently repellent to herbivores. Repellents claiming to work because they are perceived as bitter by humans probably are either ineffective or are paired with some other compounds that cause illness or distress (Mason 1998, Nolte 1999). Some repellents create a burning sensation (e.g., capsaicin). Various taste sensations (bitter, sour, sweet, etc.) affect animals differently, or may have no effects. Thiram, the most widely used taste repellent, can be applied to trees, tree seeds, seedlings, bulbs, and shrubs to protect them from rodents and moles. Thiram should not be used on plant parts eaten by humans or domestic animals. Fruit trees must be sprayed only in the dormant season.

Fumigants

Fumigants registered for rodent control include smoke-producing gas cartridges, aluminum phosphide, chloropicrin, and methyl bromide (Corrigan 2001). Fumigants are lethal when inhaled and are used to kill burrowing mammals. When fumigants are used, all burrow openings should be closed after introduction of the pesticide. The active ingredients in gas cartridges are a combination of sulfur, nitrate, charcoals, or phosphorous compounds which, when ignited, produce carbon monoxide and other gases; these gases asphyxiate rodents in their burrows (Corrigan 2001).

Aluminum phosphide is a fumigant available in tablets or pellets that produces toxic phosphine gas when exposed to atmospheric moisture; this gas is flammable or explosive at some concentrations. Chloropicrin is typically used as an additive to fumigants to provide an exposure warning (like sulfur is added to natural gas). Its only other registered rodent uses are in empty grain and potato storage bins to control rats and mice. Methyl bromide, because it has been docnmented to deplete atmospheric ozone, will nor have its registration renewed. Hygnstrom and VerCauteren (2000) evaluated effectiveness of 5 fumigants (aluminum phosphide, gas cartridge, methyl bromide, chloropicrin, and a methyl bromide–chloropicrin mixture) for managing prairie dogs; all reduced burrow activity by 95–98%. Jacobs (1994) provides information on specific fumigants.

Toxicants

Toxicants are the most common method used to control damage-causing populations of rodents and other small mammals. Toxicants require little labor and can be used to kill large numbers of animals, even in remote areas. Damage reduction is the goal of any control program, and must be the final measure of efficacy. Efficacy of a control program may be increased by using several toxicants in combination or by periodically alternating those used; this strategy aids in avoiding development of resistance to the primary toxicant (Marsh 1988).

One disadvantage of toxicants is that they usually are not species specific (Conover 2002). Potential hazards to nontarget species must be considered when toxicants are used. Hazards associated with use of a toxicant are not necessarily related to toxicity of the compound, but are more often associated with how they are applied. Hazards to nontarget wildlife can be reduced by properly selecting toxicants, bait composition and formulation techniques (including bait color, size, shape, texture, and hardness), and bait delivery systems (Marsh 1985*b*). Some toxicants may be absorbed by plants and pose a risk to herbivores (Conover 2002). To reduce environmental hazards, the U.S. EPA closely regulates registration of toxicants, approving only those that decompose rapidly and do not pose a significant threat to other species. Above- and below-ground carcass searches can be conducted to evaluate efficacy and nontarget mortalities of the management effort (Witmer et al. 1995, VerCauteren et al. 2002*a*).

Toxicants are classed as either anticoagulants or non-anticoagulants. Historically, anticoagulants were considered multidose or chronic toxicants and non-anticoagulants as single-dose or acute toxicants. New-generation anticoagulants, however, can be effective in a single feeding and some new non-anticoagulants need to be ingested by individuals of the target species over a period of several days (Marsh 1988). Baits come in a variety of forms including food, block, pellets, loose meal, seeds, packets, liquids, tracking powder, and nontoxic monitoring blocks.

Numerous toxicant formulations are registered for use in commensal rodent control, around farm buildings, and in noncrop areas; fewer are available for use in crops. Development of registrations for in-crop use of toxicants, particularly anticoagulants, is a high priority research area. However, use of toxicants is expected to decline as alternative methods of reducing damage are developed (Fagerstone and Schafer 1998).

Anticoagulants are chemicals that disrupt the normal clotting process of blood. Death in poisoned rodents results from internal hemorrhaging and damage to capillaries (Corrigan 2001). There are 2 classes of anticoagulants, first-generation (multiple-dose) and second generation (single-dose). First-generation anticoagulants typically require several consecutive doses to kill, while second-generation anticoagulants cause death after a single dose. First-generation anticoagulants generally require ingestion for 3–14 consecutive days to be effective. Bait shyness is generally not a problem because animals do not associate ill effecrs with bait consumption. However, bair delivery procedures must consider the need for making toxicants available over several consecutive days. Warfarin was the first, most widely used, of the "rat poisons" for many years (Corrigan 2001). Despite a popular misconception that warfarin is no longer used because mice and rats have developed a physiological resistance to it, in actuality, its patent has expired and newer pesticides more profitable for manufacturers have displaced the older pesticides. Physiological resistance to warfarin and other first-generation anticoagulants is actually a minor problem; such resistance usually only occurs after continuous use at the same site for several years, and can be overridden by switching temporarily to another rodenticide, such as zinc phosphide. Nevertheless, manufacturers and marketers of the second-generation anticoagulants, which are effective against rodents resistant to the first-generation compounds, have touted this effectiveness against resistant rodents in their sales pitch. Chlorophacinone and diphacinone are other first-generation anticoagulants still widely used, but neither is effective against rars resistant to warfarin. Vitamin K is an antidote for first-generation anticoagulants.

The acrive ingredients brodifacoum, bromadiolone, and difethialone comprise the most popular second-generatiou anticoagulants used in the United States (Corrigan 2001).

These anticoagulants are highly toxic to rodents and a single feeding on baits with an active ingredient concentration as low as 0.005% can produce death (Marsh 1988). Currently, all second-generation anticoagulants are effective against warfarin-resistant rodents.

Anticoagulants can be obtained in prepared baits or purchased as concentrates for mixing with fresh bait. Baits should be placed where rodents feed, drink, or travel. For anticoagulants that require multiple ingestions, bait stations, purchased from pesticide supply houses or constructed from wood or metal, are particularly useful in protecting the bait from weather and nontarget species (Fig. 11). Some baits come in packets that are gnawed open by rodents, others are available in moisture-resistant paraffin blocks. Several anticoagulants are registered for use in tracking powders, which are dusted into burrows and along runways where house mice or Norway rats travel. Rodents ingest the anticoagulant by licking the toxic dust from their feet and fur.

Toxicants with different modes of action provide an obvious answer to anticoagulant resistance. The 3 most common non-anticoagulant baits used in the structural pest management industry are zinc phosphide, cholecalciferol, and bromethalin. Zinc phosphide is an effective, acute toxicant that has been in use for over 50 years with minimal nontarget hazards (to humans and other nontarget species). A key to success with zinc phosphide is prebaiting to establish a feeding routine. For some species of field rodents, such as prairie dogs, it is the only pesticide currently registered for use (Fagerstone and Schafer 1998). Hygnstrom et al. (2000) found that zinc phosphide pellets applied in-furrow at planting reduced corn yield loss; zinc phosphide has since been registered for this use. Hygnstrom et al. (1994) provide species-specific baiting strategies using zinc phosphide. Cholecalciferol (vitamin D_3) is both a single- and multiple-feeding toxicant effective on commensal rodents (Marshall 1984). No secondary hazards have been associated with its use (Marsh 1988). Bromethalin is also effective on rats, including those resistant to warfarin.

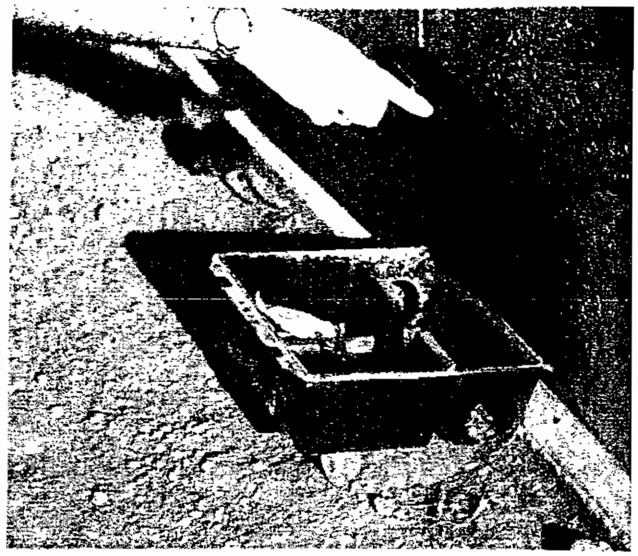

Fig. 11. Bait station and packet of anticoagulant bait used for rodent control.

Strychnine is another non-anticoagulant acute rodenticide used to control pocket gophers and some species of ground squirrels to reduce damage to forest seedlings, agricultural crops, and home landscaping (Fagerstone and Schafer 1998). As a result of regulatory and court actions, its former widespread use has now been restricted to underground applications (in pocket gopher and ground squirrel burrows).

Traps

Live traps are often used to capture mammals of all sizes without harming them (Fig. 12). They are an excel-

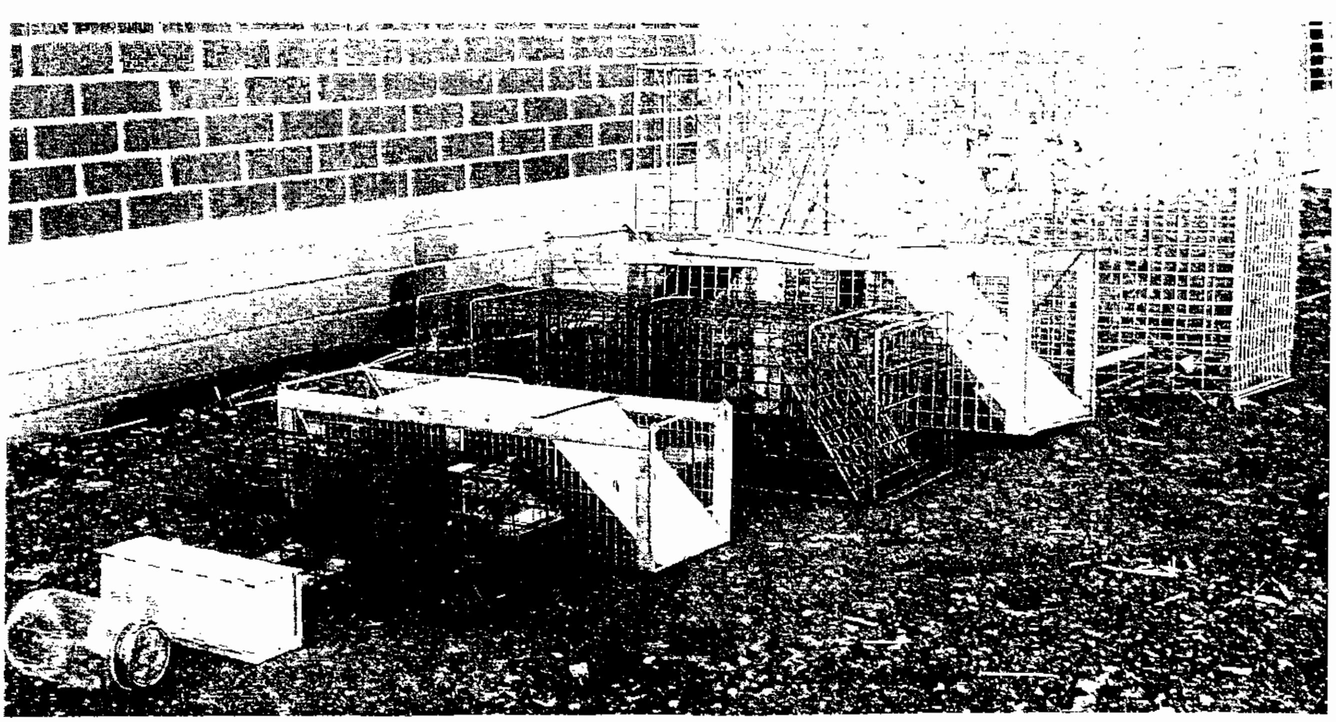

Fig. 12. Live traps come in a variety of sizes and styles for almost any mammalian species.

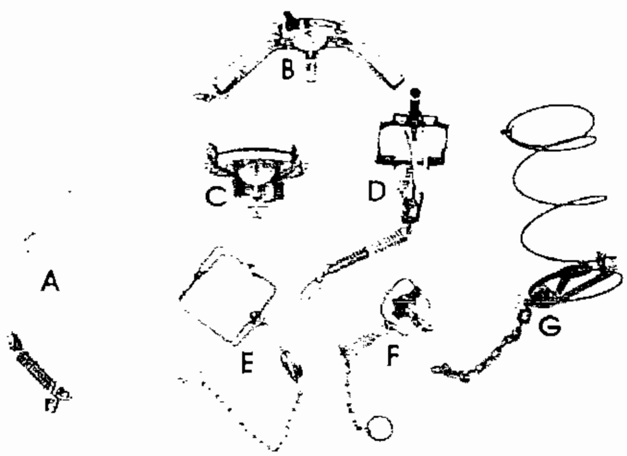

Fig. 13. Examples of several types of traps including: foothold (B, C, D, and F), snares (A and G), and body-gripping trap (E).

lent option for use in residential areas or in situations where rodents and other small mammals causing damage are to be relocated. Various homemade designs can be constructed of wire mesh or wood, or wire mesh and plastic models can be purchased commercially. Certain models can be used to capture a variety of species while others are species specific. Some designs have doors at both ends, permitting visibility through the trap, thereby reducing trap shyness. Suggested baits, which depend on the species being trapped, include apple slices, sunflower seeds, peanut butter, and rolled oats.

Foothold traps are manufactured in several sizes and designs. Traditional foothold traps are commonly used for beaver, muskrat, and nutria control, while smaller sizes are used to capture tree and ground squirrels, rats, and marmots. Use of foothold traps, body-gripping traps, and snares is controversial; however, properly used they are effective and valuable wildlife management tools. Some states prohibit their use, whereas others sanction only traps with padded or offset jaws. Like other types of traps, there is potential to capture nontarget species; this danger can be lessened by using proper trap sizes, pan tension devices, break-away mechanisms, species-specific baits, and selecting trap locations that target the habits of the species being trapped (Conover 2002).

Body-gripping traps, primarily Conibears® (Fig. 13E), are used in water sets for beaver, muskrat, and nutria. Manufactured in a variety of sizes, they have the humane feature of killing quickly. These traps have a pair of opposing, heavy-gauge rectangular rods that close like scissors when triggered, killing the animal with a quick body blow. Conibear® traps are lightweight and easy to use. They can be placed at entrances of burrows and lodges and in dams, runs, and slides. Care should be taken when large Conibear® traps are used due to the potential hazard to pets, children, and nontarget species. Some states prohibit the use of dry-land sets.

Somewhat similar body-gripping traps are available for moles and pocket gophers. For moles, the trap is placed over a section of the burrow that has been intentionally collapsed or compressed by the broad trap pan. The trap is activated when the mole traveling the runway pushes up on the compressed roof, trips the trigger pan, and is caught by the loops or scissor action of the jaws. The harpoon trap is set in a similar fashion, but a spring-loaded harpoon spears the mole. For gophers, traps are placed into the exposed laterals or main tunnels of the burrow system. The openings can then either be left exposed or covered.

Snap traps are most commonly used for controlling rats and mice, and are used regularly in houses and other buildings. Advantages to using snap traps include: reduced danger to children or pets compared to some chemicals, easy recovery of killed animals, and no contaminants. Obstacles such as boxes or boards can be used to direct rodents to traps. Preferred baits include a mix of peanut butter and rolled oats, a small piece of bacon or apple, or a raisin. Snap traps can be used outdoors to capture small field rodents when only a few animals are involved or to capture animals for identification or population ecology studies.

Snares

Beaver can be captured as effectively with snares as with Conibear® or foothold traps (Weaver et al. 1985). Snares cost and weigh less than traps. Depending on whether the snare has a stop lock device to restrict tightening, the behavior of the captured animal and the length of time it's been held, as well as the part of the anatomy that is being held, the animal may or may not die before it can be found and released. Snares are also effective in controlling small populations of rabbits. Animals must be traveling a well defined trail or using a specific entrance such as a hole in a fence. Snares are made of a loop of lightweight wire or cable incorporating a locking device to prevent the animal from backing off the tension in the cable. Snares can be set to kill the captured animal or to hold it by the leg or neck. Research is being conducted to make snares more species selective. State wildlife regulations should be checked to ascertain legality of usage.

Shooting

Shooting can be a selective method of eliminating individual pest mammals. Small-bore shotguns, rifles, and air guns are effective firearms. Some animals can be shot most effectively at night by using a spotlight with a red lens or night-vision equipment. Shooting is especially useful in controlling animals with low reproductive rates, such as porcupines. Local wildlife codes must be reviewed before shooting is used. Shooting at night, in particular with a spotlight, is not legal in some states.

CARNIVORES AND OTHER MAMMALIAN PREDATORS

Damage Assessment

Depredations of livestock by mammalian predators have been a concern to livestock producers for many centuries and continue to be an economic burden to some individuals. In the United States, 273,000 sheep and lambs were estimated to have been lost to predators in 1999 (U.S. Department of Agriculture 2000). Losses to predators represented 36.7% of total losses to all causes and were valued at $16.5 million to farmers and ranchers. The loss of goats to all predators was valued at $3.4 million. In 1999, depredations of sheep and lambs were principally caused by coyotes (60.7%), dogs (15.1%), mountain lions (*Puma concolor*) [5.7%], and bobcats (*Lynx rufus*) [4.7%]. Cattle and calf losses to predators in the United States totaled