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Chapter 2

INVASIVE RODENTS IN THE UNITED STATES: ECOLOGY, IMPACTS, AND MANAGEMENT

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ABSTRACT

Many invasive rodents have become established in the United States and its territories. The species include several species of *Rattus*, house mice (*Mus musculus*), Gambian giant pouched rats (*Cricetomys gambianus*), ground squirrels (*Spermophilus parryii*), nutria (*Myocastor coypus*) and marmots (*Marmota caligata*). While most were introduced accidently, some were introduced for food or fur. Additionally, some native species of rodents have been placed on islands, at least on a temporary basis, to study rodent species interactions. These rodents have caused serious impacts to native flora and fauna, agriculture, and other resources. They have caused the extinction or many species of birds on insular ecosystems. Although many methods are used to control or eradicate introduced rodents, rodenticides and traps are the main tools. Since the early 1990s, agencies have been eradicating rodents from various islands, primarily for conservation purposes. Of about 27 eradication attempts, 22 (81%) appear to have succeeded with only about 5 failures. For several islands, however, it is too early to determine if the attempted eradication has been successful or not. In the case of failed eradications, rapid re-invasion by rodents from nearby islands may be the reason. Numerous additional eradications are planned. We review the introduced rodent species, their impacts, and eradications, both successful and unsuccessful, that have occurred in the United States. Most eradications involved the use of the anticoagulant rodenticides diphacinone and brodifacoum. Rodenticides have been applied by hand-broadcast, bait station deployment, and aerial broadcast. We briefly review the strategies and methods used in eradication projects and the efforts to mitigate potential non-target and environmental impacts. Finally, we consider some of the remaining challenges in invasive rodent management and eradication in the United States, including the use of toxicants, land access, public attitudes, resource availability and monitoring difficulties.

Introduction

Many species of plants, microbes, and animals have been introduced around the world. Species are considered "alien" or "invasive" when they are not native to an area, but become established and cause, or are likely to cause, economic or environmental harm or harm to human health (NISC, 2008). Pimentel (2011) compiled information on the economic and environmental costs of introduced species around the world. Some vertebrate species were introduced purposefully, while others were introduced inadvertently or by escaping captivity. Purposeful introductions include animals used for food, fur, as work animals, or as companion animals. In some cases, they were introduced as a means of biological control (e.g., mongoose introduced to control rats). Game animals (including birds, mammals, and fish) have been widely introduced outside their native ranges to provide sporting opportunities and a source of game meat. Larger mammals, such as pigs and goats, were often introduced to islands by early explorers so that a supply of meat would be available to ships stopping on their long voyages. Those same ships were infested with rats and mice which, as a result, have colonized much of the world (Drake and Hunt, 2009).

Many species of terrestrial vertebrates have been introduced into parts of the United States and its territories (Witmer and Fuller, 2011). This includes all taxa of vertebrates:

- Mammals: 86 species
- Birds: 127 species
- Reptiles: 126 species
- Amphibians: 53 species
- Fish: 673 species

While many of these species were non-native to North America, many others were native, but had been moved from one region to another. An example is bullfrogs (*Rana catesbeiana*) native to eastern North America being moved to western North America where they have become an invasive species causing severe ecosystem disruption and even native species extinctions (Snow and Witmer, 2010).

The most common introductions are the commensal rodents, which have been widely introduced around the world (Long, 2003). However, it should be noted that many native rodent species occur worldwide. Approximately 40% of all mammalian species are rodents; this amounts to about 2,277 species (Wilson and Reeder, 2005). Native rodents have ecological, scientific, social, and economic values (Witmer et al., 1995). Rodents are important in seed and spore dispersal, pollination, seed predation, energy and nutrient cycling, the modification of plant succession and species composition, and as a food source for many predators. Additionally, some species provide food and fur for human uses. Rodents are also used extensively in medical research.

As invasive species, however, rodents are particularly problematic because they have many characteristics that make them very effective invaders. Rodent species have adapted to all life-styles: terrestrial, aquatic, arboreal, and fossorial (underground living). Most rodent species are small, secretive, nocturnal, adaptable, and have keen senses of touch, taste, and smell. In contrast to the normally small-sized body rodent, the capybara (*Hydrochaeris hydrochaeris*) of South America can reach 70 kg in mass. Rodents have excellent abilities to jump, climb, swim, and squeeze through small openings (Timm 1994a; Pitt et al., 2011a). For most species of rodents, the incisors continually grow throughout their lifespan, requiring constant gnawing to keep the incisors sharp and at an appropriate length. Additionally, rodents are known for their high reproductive potential. Many species have multiple litters per year with as many as 8-10 young per litter (Corrigan, 2001). Many species of rodents are omnivorous and can survive on a wide array of food types. Rodents can survive long periods of inclement weather or food shortages by storing foods for later use and by summer estivation and winter hibernation.

Numerous invasive rodents have become established in parts of the United States and its territories (Figure 1). The species include several species of *Rattus*, house mice (*Mus musculus*), Gambian giant pouched rats (*Cricetomys gambianus*), ground squirrels (*Spermophilus parryii*), nutria (*Myocastor coypus*), hoary marmots (*Marmota caligata*), and arctic ground squirrels (*Spermophilus parryii*). While most were introduced accidently, some were introduced for food or fur. Additionally, some native species of rodents (voles, *Microtus* spp. and deer mice, *Peromyscus* spp.) have been placed on islands, at least on a temporary basis, to study rodent species interactions (e.g., Crowell, 1983; Crowell and Pimm, 1976). Introduced rodents have caused serious impacts to native flora and fauna, agriculture, property, and other resources. Long (2003) reviewed the many rodent introductions around the world.

Figure 1. Introduced rodents, such as this roof rat, can cause extensive damage to island flora and fauna.

Several types of damage have been caused by rodent introductions to the United States (Hygnstrom et al., 1994; Witmer and Singleton, 2010). The substantial and world-wide loss of human food, both crops in field and stored foodstuffs, has been documented in several reviews (Meerburg et al., 2009a; Witmer and Singleton, 2010). In addition to consuming human foodstuffs, rodents also contaminate much more stored food through high levels of defecation and urination. Rodents also transmit many diseases to humans, companion animals, and livestock (Meerburg et al., 2009b). For example, the plague bacteria, *Yersinia pestis*---clausal agent of the Black Death which killed millions of humans worldwide in several pandemics---reached North America in the late 1800s via infected rats on ships arriving in California ports (Witmer, 2004).

Rodents can be prolific on islands where they have few or no predators. Their omnivorous foraging has led to the endangerment or extinction of numerous island species, especially bird species (Moors and Atkinson, 1984; Witmer et al., 1998; Veitch and Clout, 2002; Engeman et al., 2006; Towns et al., 2011). While their impacts to seabirds have been long known, invasive rodents also impact seeds and seedlings, invertebrates, sea turtle eggs and hatchings, and other resources (Witmer et al., 2007a; Caut et al., 2008; Angel et al., 2009; Towns et al., 2009; St. Clair, 2011; Drake et al., 2011). Most seabirds that nest on islands have not evolved to deal with mammalian predators and are very vulnerable to introduced rodents and other species introductions. In addition to direct effects, rodents can have many indirect effects on island resources through competition and trophic cascade effects (Russell, 2011). Invasive rodents have reached over 80% of the world's island groups where they have caused the demise of many endemic species (Atkinson, 1985). As a result, there has been a concerted worldwide effort to eradicate introduced rodents from islands with numerous successes (Howald et al., 2007; Witmer et al., 2011). These efforts have relied heavily on the use of rodenticides (Howald et al., 2007; Witmer et al., 2007b). In this chapter, we review the rodent introductions, impacts, and management strategies and methods used to reduce invasive rodent impacts and populations. We also review the invasive rodent eradication projects and methods used in the United States.

Biology and Ecology of Introduced Rodents: Species Accounts

Nutria or coypu *(Myocastor coypus)*, semi-aquatic rodents native to southern South America, are an invasive species having detrimental impacts mainly in the southern and eastern United States, but also in the Pacific Northwest. Nutria were introduced into the U.S. in 1899 for fur farming in California and later to several other states (Carter and Leonard, 2002). Nutria dispersals resulted primarily from releases by fur farmers, escapes during hurricanes or rising floodwaters, or as translocations in an attempt to control nuisance aquatic vegetation. Some states, such as Louisiana, continue to recognize nutria as a beneficial natural resource for fur and food, and manage populations for low densities – below presumed marsh vegetation damage thresholds. In other situations, such as at the Blackwater National Wildlife Refuge in Chesapeake Bay, Maryland, where nutria have caused excessive marsh damage, government agencies have implemented an eradication strategy (Kendrot and Sullivan, 2009). Nutria and the damage they cause to crops, canals, and wetlands have been well-described (Bounds et al., 2003; LeBlanc, 1994).

Generally, nutria have dark brown fur and weigh about 5-9 kg. At first glance at a nutria swimming, they can be mistaken for a beaver or a muskrat, both rodents native to North America. Female nutria are polyestrous and are sexually mature in approximately 5 months (LeBlanc, 1994). They are non-seasonal breeders capable of producing 3 to 4 litters a year with an average of 4 to 5 kits per litter. Nutria are voracious consumers of vegetation and are known to completely denude vegetation from areas where they feed before moving on. Their ease of mobility on land and in water makes them effective dispersers, posing significant challenges for resource managers.

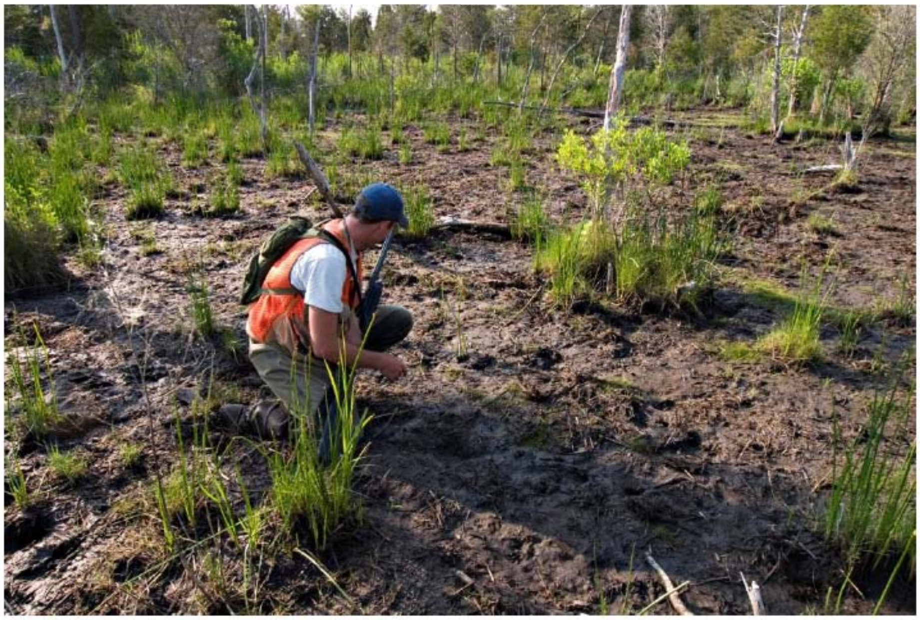

Figure 2. Nutria damage to marsh vegetation in Maryland.

The ravenous appetite of these herbivores can cause damage to agricultural crops and aquatic vegetation, and can alter aquatic ecosystems (Figure 2). Crops damaged the most in the southeastern United States are rice and sugarcane, but other crops can be damaged as well: cereal grains, beets, peanuts, melons, and alfalfa (LeBlanc, 1994). In Louisiana, tens of thousands of acres of damaged marsh vegetation have been documented (Marx et al., 2004). Extensive marsh damage has also occurred in Maryland's Delmarva Peninsula (Kendrot and Sullivan, 2009). The areas damaged by nutria become permanent, open water ponds. Tidal and flooding impacts become more severe. The loss of marshland also removes habitat for native wildlife species such as waterfowl, wading birds, and muskrats (Bounds and Carowan, 2000; Southwick Associates, 2004). Finally, nutria burrowing habits can weaken irrigation structures and levees and they are a host for some diseases (LeBlanc, 1994).

Nutria populations and damage have been controlled mainly by private hunters and trappers. When nutria fur prices declined in the 1980s, damage in many areas became a great concern. In Louisiana, a method was devised to manage nutria damage and to supplement fur values with incentive payments to registered trappers and hunters of $4.00-5.00 per nutria tail. Unlike classic bounty systems, the program is intensively managed to target specific areas for population reduction; in 2003-2004, 332,596 nutria tails were collected in designated harvest areas by 346 participants (Marx et al., 2004). Traps, snares, shooting, and dogs have been used to remove nutria from the Delmarva Peninsula in Maryland (Kendrot and Sullivan, 2009). Rodenticides are rarely used for nutria control because of the potential hazards to non-target animals and water quality. Research continues to develop new methods to control nutria populations, such as multiple-capture live traps (Witmer et al., 2008) and improved attractants (Jojola et al., 2009).

Gambian giant pouched rats *(Cricetomys gambianus)* are native to a large area of central and southern Africa. They had become popular in the pet industry in some countries and became established on Grassy Key in the Florida Keys in 1999, following an escape or release by a pet breeder (Engeman et al., 2006; Perry et al., 2006). Despite a prolonged eradication effort, a free-ranging and breeding population remained on the island (Engeman et al., 2006; Engeman et al., 2007). There is a concern that if this rodent reaches the mainland, there could be damage to the Florida fruit industry because Gambian rats are known to damage numerous types of agricultural crops in Africa (Fiedler, 1994). Imported Gambian rats may also pose risks as reservoirs of monkey pox and other diseases. An outbreak of monkeypox occurred in the Midwestern United States in 2003 as a result of infected Gambian rats imported from Africa for the pet industry (Enserink, 2003). A climate-habitat modeling study suggested that their new range in North America could expand substantially were they to become established on the United States mainland (Peterson et al., 2006).

Figure 3. Gambian giant pouched rat captured in a cage trap on Grassy Key, Florida.

Gambian rats are gray brown in color and can reach a considerable size: about 2.8 kg in weight and about 1 m in length (Kingdon, 1974). Females produce 4 young per litter and can bear 8 or more litters per year (Ajayi, 1975). Because of their reproductive potential and their large size, they have been raised in captivity as a source of protein in Africa (Ajayi, 1975). Since free-ranging Gambian rats are new-comers to North America, relatively little is known about their biology, habitat use, impacts, and interactions with native species or about the most effective means to capture or control these rodents. Hence, current efforts are concentrating on use of traditional live trap capture methods (Figure 3) and rodenticides in bait stations (Engeman et al. 2007). Eradicating Gambian rats from Grassy Key has proven problematic because of the large number of private properties on the island, some of whose owners will not allow government employees on their property or will not allow the use of rodenticides on their property (Witmer and Hall 2011). It will be important to develop additional tools to manage or eradicate this species and other rodent invaders in the United States (Witmer et al., 2010; Witmer and Hall, 2011).

Norway rats *(Rattus norvegicus)* are native to a large part of Asia, but now occur worldwide with the exception of the polar regions (Long 2003). They were introduced to North America about 1775 in trans-Atlantic shipping (Brooks, 1973; Meehan, 1984). They are now completely established in both rural and urban areas throughout the United States, including Alaska and Hawaii. This species is one of the oldest and best known invasive vertebrates in the United States and is responsible for a variety of types of damage to crops and stored commodities (Jackson, 1977; Timm, 1994a). These rats spread rapidly and continuously across the country in shipped commodities, initially following wagon, riverboat, and rail routes. Areas with the least human traffic were the last to be reached.

The fur color of this rat is typically brown above and lighter brown gray below. The tail is sparsely haired and scaly and typically about the same length as the head and body. Norway rats generally weight about 500 g. One of the three common commensal rodent species on the North American continent, the Norway rat is closely tied to human settlements. Breeding may occur throughout the year. Females produce litters of 6-12 young and can bear 4-6 litters per year (Timm, 1994a). Gestation is about three weeks and animals reach sexual maturity in about three weeks (Timm, 1994a). Populations can expand rapidly when food, water, and habitat are available.

In farm settings, damage to stored food and grains, damage to garden crops, and predation on eggs and baby chickens is common. Grain consumption and fecal contamination is a common problem in commercial grain storage facilities (Jackson, 1977). Damage to roads, bridges, railroad track beds, and hydraulic structures may result from the burrowing activities and the associated soil loosening or flooding (Timm, 1994a). Structural damage in buildings results from gnawing and burrowing and may include damage to doors, window sills, and walls as well as to pipes and wiring. Insulation may be damaged or removed in the course of nest building. In urban areas, Norway rat populations are commonly associated with poor sanitation or accumulation of trash and food refuse in inner-city areas, although outdoor feeding of pets and wildlife often support suburban populations as well. Norway rats serve as reservoirs of a number of diseases that may affect humans and domestic animals, most commonly salmonellosis, leptospirosis, and trichinosis (Meehan, 1984). In areas with high rat populations in close association with humans, rat bites may occur, particularly to babies or young children.

Davis (1953) believed outdoor populations could be completely managed by environmental control and sanitation and demonstrated this repeatedly with experiments in Baltimore and New York City. However, Fall and Jackson (1998) contended that the political impossibility of maintaining diligence by urban residents and sustained support by public and private sectors has allowed Norway rat problems to continue unabated. Numerous products are available commercially to property owners for Norway rat control and extensive professional rodent control services are available through the structural pest control industry (Timm, 1994a; Corrigan, 2001).

Roof rats *(Rattus rattus)*, known also as black rats or ship rats, are native to a large portion of the Orient, probably throughout the Indo-Malayan region and through southern

China (Long, 2003). They also are now widespread worldwide, especially on tropical islands. In the United States, they occur along port and shore areas in southeastern and western North America and throughout Hawaii and tropical Atlantic and Pacific Ocean islands. Although known most commonly as a commensal species closely tied to man, this species, particularly in warmer areas, readily establishes in undeveloped areas, including native forests in Hawaii and on oceanic islands. According to Brooks (1973), roof rats were well established in Virginia in the early 1600s. They were well-established in North America's east coasts areas by the 1800s. They occur sporadically in warmer inland areas but rarely persist. However, a recent infestation discovered in urban Phoenix, Arizona raised concerns that the species could permanently establish in "islands" of suitable habitat and subsequently threaten crops and orchards (Nolte et al., 2003). In more temperate areas, they compete poorly with the larger and more aggressive Norway rat and occur mostly in port areas and generally indoors (Meehan, 1984).

The fur color is reddish-brown, brown or black, with the belly area being lighter or white. The tail is generally longer than the head and body. Adult roof rats weigh in the range of 150 to 250 g. As in Norway rats, breeding may occur throughout the year if resources are available and the pattern of breeding and the reproductive potential are similar between species. Roof rat females bear 3 or more litters with 5-8 young per litter each year (Marsh, 1994). Recently a variant of *Rattus rattus*, the Asian house rat, has been separated taxonomically as *Rattus tanezumi* (Musser and Carleton, 2005). Animals of both species are generally similar in appearance; however, *Rattus tanezumi* appears more variable and has a somewhat shorter tail. A chief distinguishing feature is a differing number of chromosomes between the two species, but this is of course not evident without use of special laboratory techniques and some authorities have not accepted the name change. *Rattus tanezumi* has recently been reported as a new invasive species in North America based on collections in California (James, 2006).

Like the Norway rat, the roof rat invades homes and structures, causing damage and contamination of stored food and commodities (Marsh, 1994). However, it readily adapts to field and forest habitats in tropical and semi-tropical areas causing damage to orchard, grain, and sugarcane crops. Because of their arboreal nature, roof rat can prey on adult birds, nestlings, and eggs under some circumstances and are recognized worldwide as the likely cause of rare bird extinctions in many island areas, including Hawaii (Munro, 1945; Atkinson, 1977; Pitt and Witmer, 2007). Black rats also eat snails and in Hawaii, they depredate the introduced predatory snail, *Euglandina rosea*, which has complicated management strategies to protect native tree snails (Meyer and Shiels, 2009). Roof rats also pose substantial threats to native plants through seed predation, as well as potentially aiding in the spread of non-native seeds via dispersal (Shiels, 2011; Shiels and Drake, 2011).

This species is also a reservoir for a number of diseases of humans and animals, but is most notorious for its role in bringing bubonic plague, the "Black Death," to 14th century Europe. The occurrence of bubonic plague in Hawaii during the period 1899 to 1958 was associated with this species (Tomich, 1986) as were the initial outbreaks in California in the early 1900s (Witmer, 2004).

Figure 4. Rat-proof bird nest box designed to protect endangered Hawaiian birds.

Control methods and materials are the same or similar to those used for Norway rat control. However, this species has been a particular target of recent efforts, both in the United States and in many other countries, to eradicate them from islands where seabirds or other desirable species are threatened by rat predation (Howald et al., 2007; Witmer et al., 2007a). Pitt et al. (2011b) recently developed and tested a nest box for endangered Hawaiian birds that prevents access by roof rats (Figure 4).

Polynesian rats (*Rattus exulans*), also known as Kiore or Pacific rats in Australasia, are a small tropical rat native to the Southeast Asia mainland that has spread throughout islands in the Pacific in conjunction with human settlement of the region (Matisoo-Smith and Robins, 2004). Although they do not occur on the United States mainland, they are well established on most tropical and semitropical islands (less than about 30° latitude) throughout the Pacific, including the Hawaiian Islands (Roberts, 1991). Polynesian rats are the smallest species (110-150 mm body length) in the genus *Rattus* and are slender (40-100 g) with relatively small feet and large ears. Like many rodents species, they are primarily nocturnal. Their fur is reddish brown on the dorsal surface and light gray on the belly. Polynesian rats may breed throughout the year and have up to 4 litters annually with 3-6 young in each (Jackson, 1965). They are sexually mature at 2 months and may have a life expectancy of around 1 year.

Polynesian rats have adapted to a wide range of habitats from forests to grasslands to agricultural crops, such as sugar cane. They are good climbers but do not swim so their dispersal to new islands is limited by human movement via ships and cargo (McCartney, 1970; Spenneman, 1997; Matisoo-Smith and Robins, 2004). They are opportunistic omnivores and their diets vary greatly by what is available by season and location so as to exploit locally abundant food sources (Kami, 1966; Kepler, 1967; Fall et al., 1971; Crook, 1973; Tobin and Sugihara, 1992; Sugihara, 1997; Rufaut and Gibbs, 2003). Predators of Polynesian rats include mongooses, cats, other larger rodents, and birds (Marshall, 1962). In addition, many Polynesian cultures consider rats to be a valuable food resource and rodents may have been introduced into new areas intentionally for food (Spenneman, 1997).

Polynesian rats are a significant agricultural pest throughout the Pacific region and they damage a variety of crops including rice, corn, macadamia nuts, sugarcane, coconut, cacao, pineapple, soybeans and root crops (Strecker, 1962; Tobin and Sugihara, 1992; Sugihara, 1997). Previous research documented the extensive effects of rat damage on sugarcane, but sugarcane production has largely been replaced by diversified agriculture in Hawaii (Pitt and Witmer, 2007). Rat damage has now shifted to high value seed crops (corn, soybean), and tropical fruits. Because Polynesian rats were spread through the Pacific Basin several thousand years ago, the impacts to the native flora and fauna are not readily apparent (Kepler, 1967; Crook, 1973; Rufaut and Gibbs, 2003; Meyer and Butaud, 2009). Polynesian rats are effective predators on sea birds, lizards, insects, and sensitive plant species that did not evolve with predation. Recent eradication efforts of Polynesian rats on islands have revealed these impacts as species recovery has occurred (Gibbs, 2009).

A variety of methods have been employed to reduce the effects of Polynesian rats on agriculture and the environment (Jackson, 1994). The primary successful methods have integrated rodenticides, alteration of cultural practices, and trapping (Sugihara, 1997). Rodenticides have been effectively used to reduce agricultural damage, protect forest birds, and protect seabird colonies. Previous attempts to control rat damage biologically have been unsuccessful and deleterious for other species. The most frequently cited failure is the introduction of mongoose to Hawaii in 1883 (Pitt and Witmer, 2007).

House mice *(Mus musculus* and *M. domesticus)* are native to southern Europe, northern Africa and Asia (Long, 2003). They now occur worldwide, including Antarctica, and are probably the most numerous and widespread mammalian species in the world next to humans (Witmer and Jojola, 2006). While house mice originated in the grasslands of Central Asia, they have followed humans around the world as stowaways on ships. They are very good invaders and probably reached to most parts of the world as stowaways on ships and cargo. House mice have remarkable abilities that have allowed them to be highly successful in many habitats around the world (Figure 5). Chief among these are their reproductive potential and their adaptability in different environments (Timm, 1994b; Witmer and Jojola, 2006).

House mice are small, slender rodents with fur that is grayish brown above and gray to buff underneath. This small (maximum mass of about 20 g for adults) and highly prolific animal is a continuous breeder in many situations; a female can produce 5-10 litters, each with 5-6 young, per year (Timm, 1994b). The young mature within about 3 weeks and soon become reproductively active. House mice are short-lived (generally less than one year) and have high population turn-over. In one study, 20 mice placed in an outdoor enclosure with abundant food, water, and cover, became a population of 2,000 in eight months (Corrigan, 2001).

Figure 5. House mice have amazing abilities which allow them to access almost any available areas or resources.

House mice cause many types of damage (Timm, 1994b; Witmer and Jojola, 2006). A major concern is the consumption and contamination of stored foods; it has been estimated that substantial amounts of stored foods are lost each year in this manner. Mice also consume and contaminate large amounts of livestock feed at animal production facilities. While mice generally live in close proximity to humans (Corrigan, 2001), sometimes feral populations occur. In these cases, the mice may damage many types of crops in the field, especially corn, cereal grains, and legumes. Australia has mouse "plagues" periodically resulting in enormous losses to stored crops and crops in the field (Brown et al., 2004). In buildings, a mouse infestation can be a considerable nuisance because of the noise, odors, and droppings. More importantly, they damage insulation and wiring (Hygnstrom, 1995). House fires have been caused by mice gnawing electrical wires; likewise, communication systems have been shut down for periods of time resulting in economic losses. Additionally, house mice are susceptible to a large number of disease agents and endo-parasites. Consequently, they serve as reservoirs and vectors of disease transmission to humans, pets, and livestock (Grantz, 1994). Important among these diseases are leptospirosis, plague, salmonella, lymphocytic choriomeningitis, and toxoplasmosis. Finally, when introduced to islands, mice can cause significant damage to natural resources, including both flora and fauna. For example, on Gough Island, mice fed on nestling albatross chicks (Cuthbert and Hilton, 2004). Additionally, Witmer (unpubl. data) documented seedling damage by house mice in a pen study. However, mice are subordinate to introduced rats so the impacts of mice not noticed when rats are also present on the island (Angel et al., 2009). This phenomenon was demonstrated by the large increase in mice abundance on Buck Island, USVI, after invasive roof rats were eradicated (Witmer et al., 2007a

A large number of methods and materials have been developed to help solve house mouse problems. In general, the use of multiple approaches and materials – integrated pest management – is more likely to reduce a mouse problem to a tolerable level (Witmer, 2007). The tools available and their proper use have been extensively reviewed (Brooks, 1973; Prakash, 1988; Timm, 1994b; Corrigan, 2001).

Hoary marmots (*Marmota caligata*) are native to parts of the mainland of North America, including portions of Alaska, USA, and the Yukon and Northwest Territories of Canada and southward through British Columbia, Canada, with fingers of their range extending along mountain ranges down into the states of Washington, Montana, and Idaho. The biology, ecology, and management of marmots were thoroughly reviewed by Armitage (2003). Of the several North American species of the *Marmota* genus, hoary marmots are the largest, weighing up to 7 kg. The fur is a grizzled-grey and more brownish towards the rear parts of the body and tail. The belly is whitish and the feet are all black. Hoary marmots live in loose colonies. These burrowing rodents are known for their sharp whistle warning of potential danger (such as a predator) given before scurrying to the safety of their burrow. The colony uses several burrow systems. The principle predators include badgers, wolverines, bears, wolves, and eagles.

The habitats used by hoary marmots are general high elevation, rocky areas and include alpine meadows, rocky talus slopes, and cliffs. These diurnal rodents are herbivores consuming a wide array of grasses and herbaceous vegetation; they will, however, consume some animal matter (Armitage, 2003). They put on significant body fat before entering winter hibernation. Often the entire colony will hibernate together in one burrow. Mating occurs soon after emergence from hibernation. There are 3-5 young per litter and only one litter per female per year (Armitage, 2003). Hence, marmots do not have the reproductive potential that rats and mice have.

Hoary marmots were introduced to Sud Island, Alaska, in about 1930 (Bailey, 1993), presumably to provide a source of food and/or fur for native and non-native people. While predatory, aquatic mammals (such as otters and seals) use the shoreline of the island, the marmots are the only terrestrial mammal occurring on the island. Additionally, this purposeful introduction has made marmots the only herbivore occurring on the island. The island is also home to about 23 species of birds, including seabirds, shorebirds, waterfowl, raptors, and passerines. Many of these bird species nest on the ground or in naturally-occurring burrows (e.g., rock crevasses).

The vegetation of Sud Island is comprised mainly of grasses, sedges, and several species of herbaceous plants (USDI, 2010). Hoary marmots consume large amounts of foliage, but also feed on flowers, seeds, berries, mosses, lichens, and roots (USDI, 2010). Marmots are known to impact plant communities in a number of ways, including species composition, species richness, and plant biomass (Del Moral, 1984; Semenov et al., 2001; Stallman and

Holmes, 2002; Armitage, 2003). On mainland areas, marmots are also known to damage trees (Anthony and Fisher, 1977; Swihart and Picone, 1994) and some of that damage may be related to scent-marking (Swihart, 1991a). Marmots can also cause significant damage to a variety of crops and hayfields (Swihart, 1991b; Bollengier, 1994). Their burrowing can also lead to increased soil erosion and can weaken dikes and building foundations (Bollengier, 1994). Marmots prefer southern to eastern slopes (Armitage, 2003), and on Sud Island, the most damage occurs on the eastern slopes (USDI, 2010). Marmots seemed less abundant on the steep western slopes, and hence, less damage is apparent (USDI, 2010). Marmots on Sud Island may also be competing with burrow-nesting birds for nest sites (USDI, 2010). Because marmots are known to consume some animal matter, it is possible that they are also doing some feeding on bird eggs and nestlings, but this has not been documented on Sud Island.

Marmot populations and damage can be managed in a number of ways, including exclusion, live-trapping and relocation, or killing with toxicants, shooting, or kill-traps (Dolbeer et al., 1991; Bollengier, 1994; Armitage, 2003). In general, research on repellents has not identified highly effective materials (Armitage, 2003) and laws and regulations affect which methods can be used in any given situation. An effort to eradicate the introduced hoary marmot population on Sud Island (see USDI, 2010) has been underway for the last year or two, but a number of factors have hindered success, including the steepness and rockiness of the slopes occupied by the marmots as well as the relatively low effectiveness of shooting and trapping which are the primary methods being used.

Arctic ground squirrels (*Spermophilus parryii*) are one of numerous species of ground squirrels that occur in North America. Arctic ground squirrels occur in Alaska, the Yukon and Northwest Territories of Canada and somewhat down into British Columbia, Canada. The biology, ecology, and management of ground squirrels were thoroughly reviewed by Yensen and Sherman (2003) and Banfield (1974). The arctic ground squirrel is the largest species of ground squirrel in North America with a weight of about 700 g. While much of the squirrel is tawny colored, the back is greyish to buffy-brown with white spots. Ground squirrels live in colonies and build extensive burrows, although permafrost often limits burrowing abilities. These ground squirrels are diurnal and their main predators include weasels, canids, and raptors.

Arctic ground squirrels occur on open tundra areas north of the treeline, but also within clearings in the northern forests. Arctic ground squirrels are mainly herbivores, but like most species of ground squirrels, will also each some animal matter, including insects and small vertebrates (Yensen and Sherman, 2003). They consume green foliage as well as seeds and berries. They also store large amounts of food to feed on after the long (often 7 months) hibernation period. There are 3-6 young per litter with only one litter per year (Yensen and Sherman, 2003) which is similar to the reproductive potential of marmots. Food resources seem to regulate population sizes, but additionally, winter survival can be low (Hubbs and Boonstra, 1997; Hubbs and Boonstra, 1998). Predation can also play a role in population dynamics (Hubbs and Boonstra, 1997; Karels et al., 2000).

While arctic ground squirrels occur widely across Alaska and on some islands near the mainland, they were introduced to a number of islands (Big Koniuji, Kavalga, Kodiak, Afognak, Unalaska, Amaknak Islands, and probably many others; Bailey, 1993) as early as 1895 as a source of food for introduced foxes and as a source of fur for people (Ebbert and Byrd, 2002). The foxes were introduced in the 1700s for the growing fur industry. Ironically, the squirrels were introduced as a new source of food for introduced foxes after the foxes had decimated the native seabird populations.

Arctic ground squirrels can have substantial effects on vegetation composition and biomass, especially in their high activity areas (Mallory and Heffernan, 1987; Frid and Turkington, 2001). Ground squirrel species occurring further to the south in North America, are known to cause substantial damage to crops, orchard trees, and rangeland forage (Askham, 1994). Their burrowing can weaken levees and undermine foundations and roadbeds (Askham, 1994). Additionally, some ground squirrels prey upon eggs and nestlings of ground-nesting birds (Askham, 1994). Hence, along with effects on island vegetation, arctic ground squirrels introduced to islands in Alaska could impact seabird populations (Ebbert and Byrd, 2002). The main methods of control of ground squirrel populations are through the use of traps, shooting, rodenticides, and burrow fumigants (Askham, 1994). Rodenticides have been proposed for use in control and/or eradication of arctic ground squirrels from some Alaskan islands, although care will be needed to reduce non-target animal losses (Ebbert and Byrd, 2002).

Other mainland rodent introductions have occurred as well. However, because many of these introductions were with rodent species native to North America, it is problematic at times to sort out which were actually introductions versus native species occurrences or natural range expansion. For example, the large aquatic rodent, North American beaver (*Castor canadensis*) was extirpated from much of North America as a result of trapping for the growing fur industry in the 1700s and 1800s (Baker and Hill, 2003). During the mid-1900s, they were re-introduced to many parts of their former range, but also to some new areas where they never occurred historically (Baker and Hill, 2003). Soon many of these populations were causing damage to commercial forest lands and other resources by tree girdling and cutting for food and to build dams (Miller and Yarrow, 1994; Baker and Hill, 2003). Extensive flooding often occurs after dams are built or when road culverts are blocked, damaging roadbeds and other resources. While beaver have a relatively low reproductive potential (one litter of 3-4 young per year), they are long-lived, reaching ages of 20 years in some cases (Miller and Yarrow, 1994). Populations are controlled by trapping, shooting, and by the use of pond levellers and culvert protective devices (Miller and Yarrow, 1994). Beaver were also introduced to some islands of the US and Canada (Long, 2003). Additionally, they have been introduced to Europe, Scandinavia, Russia, and Argentina (Long, 2003; Baker and Hill, 2003). Their range has greatly expanded in Chile and Argentina and extensive forest damage is occurring (Jaksic et al., 2002).

Fox and gray squirrels (*Sciurus niger* and *Sciurus carolensis*, respectively) are native to eastern North America, but have been introduced to parts of the far western United States and Canada (Edwards et al., 2003; Long, 2003). As per their eastern counterparts, introduced squirrels can damage trees, crops, wiring, and buildings as well as reducing tree seed recruitment (Jackson, 1994; Long, 2003; Krause et al., 2010). Once introduced, they are also known to out-complete some native populations of the tree squirrels (Long, 2003; Krause et al., 2010). Fortunately, tree squirrels have a relatively low reproductive potential (1 litter of 3 young per year; Jackson, 1994). Population control, as with beaver, is by use of traps and shooting (Jackson, 1994). Because fox squirrels introduced to California occur in urban/suburban settings, management options can be constrained by social considerations (Krause et al., 2010). Gray squirrels have also been introduced to Great Britain, South Africa, and Australia. Numbers of native red squirrels in Great Britain have declined substantially in numbers and range after the introduction and expansion of gray squirrel populations from North America (Long, 2003).

Muskrats (*Odontra zibethicus*) are one of the most widespread native species of rodent in North America, but populations have been introduced to some non-native areas such as parts of California (Long, 2003; Erb and Perry, 2003). Muskrats cause substantial amounts of crop damage, especially in areas where irrigated agriculture is practiced (Long, 2003). Damage also occurs from their burrowing activity and heavy foraging on aquatic vegetation (Miller, 1994; Erb and Perry, 2003; Long, 2003). Muskrats have a high reproductive potential (as many as 6 litters per year, each with 4-8 young; Miller, 1994). Additionally, muskrat populations are cyclic with high population numbers every 5-10 years (Miller, 1994). Control of populations is achieved by trapping and shooting and in some states, rodenticides can be used (Miller, 1994; Erb and Perry, 2003). Muskrats have been widely introduced across Europe and Asia as a source of fur (Long, 2003). In these regions, extensive damage to aquatic vegetation, and in some cases crops, has occurred (Long, 2003).

Finally, a few small populations of black-tailed prairie dogs (*Cynomys ludovicianus*), native to the prairies of the midwestern United States, were introduced to parts of Florida. Little has been reported on those populations or any damage that may be occurring. Additionally, a small population of **c**apybara (*Hydrochaeris hydrochaeris*), native to South America, has become established in Florida. As with the prairie dog introductions, little is known about this population or any damage that may be occurring.

RODENT MANAGEMENT AND RESEARCH NEEDS

Many methods and tools have been developed and used to control rodent populations or to reduce the damage they cause (Table 1). Which methods are commonly used varies greatly from region to region around the world as well as between developed and undeveloped countries. Methods used also vary with regard to the type of management. With long-term management of rodent populations (such as in agricultural and urban/suburban settings) a greater variety of approaches are used, generally through an Integrated Pest Management (IPM) strategy (Witmer, 2007). So while traps and rodenticides are the mainstays of rodent population management, IPM also employs habitat management, exclusion and sanitation (Hygnstrom et al., 1994). On the other hand, if eradication of the invasive rodent species is the management goal, rodenticides are heavily relied upon, although traps may be used to some extent with the rodenticides. Some of the methods are highly regulated and regulations vary across political jurisdictions. The many methods used to manage rodent populations and damage have been described at length by Prakash (1988), Buckle and Smith (1994), Hygnsgtrom et al. (1994), and Caughley et al. (1998). In this chapter, we will only address traps and rodenticides in more detail.

A wide array of traps have been developed and used to manage rodents and many types are commercially available (Hygnstrom et al., 1994; Winn, 1986; Proulx, 1999). Trap types are subdivided into live traps and kill traps. With live traps the rodent becomes contained in a box or cage trap after tripping a treadle. Another type of live trap is the leg-hold trap which when tripped by the rodents paw springs the jaws of the trap to close tightly around the leg and hold the animal until the trapper arrives. Leg-hold traps are generally only used for larger rodent species such as nutria, muskrats, and beaver. Live traps often can be purchased at hardware or garden stores as well as through catalogues or websites. Leg-hold traps are generally obtained through websites or catalogues. Animals captured in live traps can be relocated (where regulations allow) to other locations or euthanized. An advantage of live traps is that non-target animals captured can often be released unharmed (Figure 6).

Table 1. Methods and techniques for rodent control that have been suggested, tested, or used to reduce rodent populations and damage around the world (from Witmer and Singleton, 2010)

Physical	Chemical	Biological	Other
Rodent proof construction	Baits/baiting systems	Fertility control	Appeasement
Passive barriers	Glues	Immunogens	Insurance
Electric barriers	Poison sprays	Habitat modification	Bounties
Drift fences	Poison moats	Cultural practices	Harvest
Trapping	Tracking powder	Crop timing	Compensation
Flooding burrows	Tracking greases, gel	Crop diversification, and species selection	
Drives	Repellents	Buffer crops	
Hunting	Attractants	Parasites	
Clubbing	Aversive agents	Diseases	
Frightening devices	Plant systematics	Predators	
Flame throwers	Sterilants	Ultrasonics	
Burrow destruction	Fumigation	Biosonics	
Habitat destruction	Psychotropic drugs	Resistant plants	
Harborage removal	Herbicides	Lethal genes	
Supplemental feeding	Poisons mixed with vehicle oil applied to flooded rice	Endophytic grasses	
Digging		Unpalatable plants	
Dogs together with flooding or digging			

Figure 6. Nutria in an experimental multiple capture live trap in Louisiana.

Kill traps cause the rapid death of the rodent by body constriction when the rodent trips the trap's trigger mechanism. The most common type of rodent kill trap is the snap trap. These are commonly sold at hardware and garden stores. Another type of kill trap is the Conibear trap used for larger rodent species. They can be purchased through websites or catalogues. Hygnstrom et al. (1994) provided good illustrations of various types of traps and directions for their proper and effective use. Effective trapping requires skill and practice. Using the proper type of trap for the situation, proper placement, and appropriate bait is very important to achieve a high level of trap success (i.e., a high capture rate). A disadvantage of kill traps is they can injure or kill non-target animals, including birds. Various types of traps are also used to monitor rodent populations. Rodent population monitoring is essential so that necessary management action can be taken before populations get very large at which point extensive damage to resources cannot be avoided.

Table 2. The main rodenticides used in the United States by category and percent active ingredient (from Witmer and Eisemann, 2007)

Acute Rodenticides
• Cholecalciferol (0.075%)
• Strychnine (0.5%)
• Zinc phosphide (2%)
• Bromethalin (0.01%)
Fumigants
• Aluminum phosphide (56%)
• Magnesium phosphide (56%)
• Acrolein (95%)
• Gas cartridges (variable)
1st Generation Anticoagulants
• Chlorophacinone (0.005%)
• Diphacinone (0.005%)
• Warfarin (0.025%)
• Pindone (0.025%)
2nd Generation Anticoagulants
• Bromadiolone (0.005%)
• Brodifacoum (0.005%)
• Difethialone (0.0025%)

Rodenticides are widely used in the United States as well other parts of the world. Because of their toxic nature and potential harm to people, pets, and livestock, rodenticides are carefully regulated by the United States Environmental Protection Agency (EPA) as well as by state agencies. There are many types of rodenticides and these vary by active ingredient as well as formulation (Table 2). These materials vary widely in their mode of action and in toxicity. The types and uses of rodenticides in the United States were reviewed by Witmer and Eisemann (2007). Their specific use for conservation purposes (i.e., the eradication of invasive rodents) was reviewed by Witmer et al. (2007b).

Proper training and careful use is required to safely use rodenticides so that they are effective in reducing rodent populations while minimizing the hazard to non-target animals. An EPA-approved product label provides considerable information on the product and its use, including: the registrant and EPA registration number(s), active ingredient and concentration, target species and settings in which it can be used, directions for use, storage and disposal requirements, precautionary statements, safety and environmental hazards, and threatened and endangered species considerations.

Both primary (direct consumption) and secondary hazards (consuming a poisoned rodent or poisoned non-target animal) can occur to non-target animals when rodenticides are used. Rodenticides such as brodifacoum (a second generation anticoagulant) are highly toxic, but also result in persistent residues in body tissues of animals that consume poisoned rodents (Witmer and Eisemann, 2007). There is a growing concern about the secondary effects of these residues in predatory animals (e.g., Thomas et al., 2011). The main safeguard for the safe use of rodenticides in the United States is carefully following the EPA label instructions for the product. Other considerations include the product used; when, where, and how it is applied; cleaning up spills promptly; and not using rodenticides where highly valued or protected wildlife occur (determined by scouting the area before use).

Additional research is needed to improve existing methods and to develop new methods for invasive rodent detection and control. More research is needed in both lethal and nonlethal means of resolving rodent damage situations (Witmer et al., 1995; Witmer and Singleton 2010). The research should include, but not be limited to, detection methods, new rodenticides, effective repellents, barrier development and improvement; biological control; fertility control; and habitat manipulation. Researchers also need to identify effective commercially-available rodenticide formulations for the various invasive rodents in each region of the country as Pitt et al. (2011c) has done for rats and mice in Hawaii. Another important research need is greater evaluation of the effectiveness of combinations of techniques, given that combinations could potentially be much more effective in the reduction of damage and may be more acceptable to the public.

Invasive Rodent Eradication

Since the early 1990s, federal and state agencies, along with conservation organizations, have been eradicating rodents from various islands in the United States, primarily for conservation purposes. Witmer et al. (2011) documented the attempted eradications of introduced rodents in the United States and its territories. Of about 27 eradication attempts, 22 (81%) appear to have succeeded with only about 5 failures. For several islands, however, it is too early to determine if the attempted eradication has been successful or not. Additionally, experimental rat eradication trials on 12 small islands in The Bay of Islands, Adak, Alaska, failed or rapid re-invasion occurred and those are not included in the list of more concerted eradication efforts as eradication methods were being investigated. In some cases, what appeared to be failed eradications may have resulted from rapid re-invasion by rats from nearby islands, suggesting the need to eradicate rats from groups of islands as an eradication unit. Genetic analyses of DNA from rats before and after eradications is helping sort out the issue of re-invasion versus failed eradication. Numerous additional eradications are underway or being planned. Most rodent eradications around the world have used the second-generation anticoagulant brodifacoum (Howald et al., 2007). In the United States, however, most eradications have used the first generation anticoagulant diphacinone. Initial rodent eradications used hand-broadcast and bait stations containing rodenticides, but in recent years, aerial broadcast via helicopter has become common. This allows rodent eradications on much larger and more rugged islands such as Rat Island, Alaska (2,700 ha; Witmer et al, 2011). Currently, the USDA Animal and Plant Health Inspection Service (APHIS) has two rodenticides registered with the EPA for island conservation purposes: one formulation of diphacinone pellets and two formulations of brodifacoum pellets (Witmer et al., 2007b; Figure 7).

A variety of mitigation measures are employed to reduce non-target hazards and environmental impacts. Examples include the rodenticide type, formulation, method and timing of baiting; placement of some non-target wildlife species in captivity until after the baiting operation; removal of rodent carcasses; and avoidance of bait placement in aquatic systems (Witmer et al., 2007b). In general, impacts to non-target species during invasive rodent eradications should be considered in terms of population-level effects, rather than the effects to individuals, and in terms of the "greater good' that is achieved from a successful eradication. While there will probably always be some losses of non-target animals, proper precautions should minimise such risk and allow for the rapid recovery of affected populations (Howald et al. 2005). Those involved with successful invasive rodent eradications on islands are often surprised at how rapidly the island's flora and fauna recover after rodents are removed (Witmer et al., 2007a).

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

Keep away from humans, domestic animals and pets. If swallowed, this material may reduce the clotting ability of the blood and cause bleeding. Wear protective gloves when applying or loading bait. With detergent and hot water, wash all implements used for applying bait. Do not use these implements for mixing, holding, or transferring food or feed.

ENVIRONMENTAL HAZARDS

This pesticide is toxic to birds, mammals and aquatic organisms. Predatory and scavenging mammals and birds might be poisoned if they feed upon animals that have eaten bait.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Applicators and other handlers must wear:
-long sleeved shirt and long pants
-gloves
-shoes plus socks

For aerial application, in addition to the above PPE, loaders must wear protective eyewear or a face shield and a dust/mist filtering respirator (MSHA/NIOSH TC-21C).

USE RESTRICTIONS

It is a violation of Federal law to use this product in a manner inconsistent with its labeling. A copy of this label must be in the possession of the user at the time that the product is applied.

READ THIS LABEL: Read this entire label and follow all use directions and precautions.

IMPORTANT: Do not expose children, pets or other non-target animals to rodenticides. To help prevent accidents:
1) Keep children out of areas where this product is used or deny them access to bait by use of tamper resistant bait stations.
2) Store this product in locations out of reach of children, pets, and other nontarget animals.
3) Apply bait only according to the directions authorized.
4) Dispose of product container and unused, spoiled, or unconsumed bait as specified in the "**STORAGE AND DISPOSAL**" section.

(SEE RIGHT PANEL FOR ADDITIONAL USE RESTRICTIONS)

RESTRICTED USE PESTICIDE

DUE TO HAZARDS TO NON-TARGET SPECIES

For retail sale to and use only by Certified Applicators or persons under their direct supervision and only for those uses covered by the Certified Applicators certification.

For use by or in cooperation with government conservation agencies.

BRODIFACOUM-25D CONSERVATION

PELLETED RODENTICIDE BAIT FOR CONSERVATION PURPOSES

For control or eradication of invasive rodents in dry climates on islands or vessels for conservation purposes

ACTIVE INGREDIENT
Brodifacoum (CAS No. 56073-10-0) 0.0025%
INERT INGREDIENTS 99.9975%
TOTAL 100.0000%

KEEP OUT OF REACH OF CHILDREN

CAUTION

First Aid

If swallowed	-Call a physician or poison control center immediately for treatment advice. -Have person sip a glass of water if able to swallow. -Do not induce vomiting unless told to do so by a poison control center or doctor. -Do not give anything by mouth to an unconscious person.
If on skin or clothing	-Take off contaminated clothing. -Rinse skin immediately with plenty of water for 15-20 minutes. -Call a poison control center or doctor for treatment advice.
If inhaled	-Move person to fresh air. -If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably mouth-to-mouth if possible. -Call a poison control center or doctor for further treatment advice.
If in eyes	-Hold eye open and rinse slowly and gently with water for 15-20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. -Call a poison control center or doctor for treatment advice.

Have the product container or label with you when calling a poison control center or doctor, or when going for treatment.

For a medical emergency involving this product, call (877) 854-2494

NOTE TO PHYSICIAN: If swallowed, this material may reduce the clotting ability of blood and cause bleeding. If ingested, administer Vitamin K_1, intramuscularly or orally, as indicated in bishydroxycoumarin overdose. Repeat as necessary based on monitoring of prothrombin times.

USE RESTRICTIONS, (CONT)

This product may be used to control or eradicate Norway rats (*Rattus norvegicus*), roof rats (*Rattus rattus*), Polynesian rats (*Rattus exulans*), house mice (*Mus musculus*) or other types of invasive rodents on islands for conservation purposes, or on grounded vessels or vessels in peril of grounding.

This product may be applied using bait stations, burrow baiting, canopy baiting or by aerial and ground broadcast application techniques.

This product is to be used for the protection of State or Federally-listed Threatened or Endangered Species or other species determined to require special protection.

Do not apply this product to food or feed.

Treated areas must be posted with warning signs appropriate to the current rodent control project.

This product is for use in dry climates.

DIRECTIONS FOR USE

BAIT STATIONS: Tamper-resistant bait stations must be used when applying this product to grounded vessels or vessels in peril of grounding, or when used in areas of human habitation. Bait must be applied in locations out of reach of children, non-target wildlife, or domestic animals, or in tamper-resistant bait stations.
TO BAIT RATS: Apply 4 to 16 ounces (113 to 454 grams) of bait per placement. Space placements at intervals of 16 to 160 ft (about 5 to 50 meters). Placements should be made in a grid over the area for which rodent control is desired.
TO BAIT MICE: Apply 0.25 to 0.5 ounces (7 to 14 grams) of bait per placement. Space placements at intervals of 6 to 12 ft (about 2 to 4 meters). Larger placements, up to 2 ounces (57 grams) may be needed at points of very high mouse activity. Placements should be made in a grid over the area for which rodent control is desired.
FOR BOTH RAT AND MOUSE BAITING: Maintain an uninterrupted supply of fresh bait for at least 15 days or until signs of rodent activity cease. Where a continuous source of infestation is present, permanent bait stations may be established and bait replenished as needed.

Page 1 of 2
EPA Approved 03/18/08
EPA Reg. No. 56228-37

Figure 7. The EPA-approved label for a rodenticide designed for invasive rodent eradication on islands.

Planning and conducting a successful invasive rodent eradication from islands poses many challenges and should not be undertaken without a thorough commitment and adequate resources. The basic tenets of a successful eradication are: all individuals must be put at risk; animals must be removed faster than they can reproduce; and the risk of immigration must be zero (Parkes and Murphy, 2003). An eradication attempt that is 99% successful can ultimately result in 100% failure. Because of the large commitment of resources and public funds in eradication efforts, the potential for failure should be minimized. Planning and implementation components include:

- Preliminary monitoring and research,
- Feasibility of eradication,
- Regulatory compliance,
- Public information and communications media,
- Public support,
- Technical assistance and operations,
- Planning,
- Logistics,
- Procurement of equipment and other services,
- Monitoring and research,
- Staff recruitment and training,
- Implementation,
- Contingency planning,
- Follow up monitoring, and
- Implementation of a bio-security plan.

A number of challenges remain with invasive rodent management and eradication in the United States. Some of the challenges faced include the public and agency concerns about the use of toxicants and traps, land access (especially to private lands), public attitudes, resource availability, and detection and monitoring difficulties (Witmer and Hall, 2011; Witmer et al., 2011). Nonetheless, we will hopefully continue to relieve the burdens on insular and mainland ecosystems caused by rodent introductions. The flora and fauna of islands generally respond favorably and rapidly after invasive rodents are removed. Endemic, threatened, or endangered species can be, and have been, re-introduced after successful rodent eradications. For example, the endangered St. Croix ground lizard (*Ameiva polops*) was recently re-introduced to Buck Island in the U.S. Virgin Islands after the successful eradication of roof rats (*Rattus rattus*; Witmer et al. 2007a). The recent eradication of Polynesian rats and house mice from Cocos Island (a small island off of Guam) set the stage for the re-introduction of the endangered Guam rail, *Gallirallus owstonii* (Lujan et al., 2010).

Conclusion

Invasive rodents will continue to pose challenges to land and resource managers, commodity producers, and homeowners. Many tools are available to reduce rodent populations and associated damage. They should be used in a well thought out IPM approach.

Rodenticides will continue to be an important tool against rodents and their damage, but care must be exercised in their use. It is probably safe to assume that much of the public will continue to be leery of toxicant use. Hence, public education will be important to ensure continued availability of rodenticides. Continued technology development and transfer are essential to improve the effectiveness and safety of rodenticides and other methods used to control or eradicate invasive rodents.

Additionally, seabird populations, sea turtle populations and other island resources warrant protection from invasive rodents. The recovery of fauna and flora on uninhabited islands after a successful rodent eradication is particularly notable (Witmer et al., 2007a; Witmer et al., 2011). The significant impacts of introduced rodents on native flora and fauna have been repeatedly demonstrated. Invasive rodents are very adaptable, can exploit a wide array of resources as food and cover, and can increase reproduction very quickly when and where abundant resources exist (Macdonald et al., 1999). While invasive rodents will continue to pose challenges to land and resource managers, they can be controlled or even eradicated with a well-planned and adequately-supported effort using rodenticides and other tools. With proper planning, non-target losses will be minimal and these populations, along with other island resources, will often recover quickly after the invasive rodents have been removed.

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