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Deer Mice (*Peromyscus* spp.) Biology, Damage and Management: A Review

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ABSTRACT: The deer mouse is the most widely distributed and abundant small mammal in North America. They use a wide array of habitats, are very adaptable, and have a high reproductive potential. They play a number of roles in ecosystems, but can cause damage to orchards, forests, agriculture crops, and rangelands primarily through seed and newly-emerged seedling consumption. They also cause damage similar to house mice when they occupy buildings or other structures. Deer mice are important components in disease transmission especially of hantaviruses and Lyme disease. Damage reduction methods generally involve lethal control to reduce numbers using rodenticides and traps. Improvements in control methods are needed, especially in some agricultural crop types.

KEY WORDS: damage, deer mouse, management, *Peromyscus*, rodent, white-footed mouse

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INTRODUCTION

The rodent genus *Peromyscus* comprises a large number of species and subspecies in North America. There is disagreement on species classification within the genus; however, the number of distinct species ranges between 40 and 53 (Nowak 1999). The most widespread species is the deer mouse (*Peromyscus maniculatus*), but the white-footed mouse (*P. leucopus*) is also very widespread. Collectively, the genus is often referred to as deer mice or white-footed mice (Salmon 2009). In this review, we will refer to them as deer mice and will mainly include information on the two most widespread species, as they have been the most-studied species of deer mice.

Deer mice are quite variable in size, but generally are in the range of 15-30 g in mass with a total length of about 130-200 mm. They have larger eyes and ears compared to the house mouse (*Mus musculus*), and a relatively long tail (60-100 mm). The deer mouse acquired its common name from its bi-colored coat resembling the coat of a white-tailed deer, *Odocoileus virginianus* (Banfield 1974, Ramos 2008). The dorsal side is generally grey-brown to buffy in color while the undersides are white. The tail is also bi-colored. It is unknown how many species of *Peromyscus* there are because some are thought to be distinct species of this genus while others are thought of as subspecies. Deer mice are used quite often in physiological and genetic studies because they are clean, live well in the laboratory, can be easily fed, and have a high reproductive rate (Nowak 1999). Also, they do not have the same "mousy odor" that is prevalent in house mice (*Mus musculus*) (Timm and Howard 1994).

People have relatively little interaction with deer mice except when mice enter homes or structures. It has been noted, however, that human land use activities and practices can inadvertently and significantly affect deer mice populations and distribution, especially the less-widely-occurring species and ones with more specific habitat requirements (Nowak 1999). New information is always being released about various aspects of deer mice behavior, ecology, damage, and management. Hence, we believe that a new review of the species group is warranted. Previ-

ous reviews were presented by Banfield (1974), Lackey et al. (1985), Timm and Howard (1994), and Nowak (1999), and we have drawn heavily from those sources as well as more recent scientific literature.

BIOLOGY, BEHAVIOR, AND HABITATS

Because of their diverse diet and ability to adapt quickly, deer mice are able to prevail in a variety of habitats, including coastal areas, alpine tundra, boreal forests, woodlands, grasslands, brushlands, deserts, and arid tropical areas (Fitzgerald et al. 1994, Nowak 1999, Sullivan and Sullivan 2006). They can occur at high elevations above tree-line and in low-elevation deserts. This small mammal occupies nearly every type of ecotype within its wide distributional range, which spans from the Mexican Plateau northwards to the vicinity of the tree-line in the Labrador, Hudson Bay, and Yukon Territory in Canada (Banfield 1974). This mouse can survive practically anywhere that provides adequate cover such as burrows of other animals, cracks and crevices in rocks, surface debris and litter, and various human structures (Fitzgerald et al. 1994). Deer mice are also quite tolerant of human-altered landscapes, i.e., early successional landscapes, intensively managed forestlands, and agricultural and rural settings (e.g., Fantz and Renken 2005, Greenberg et al. 2006, Sullivan and Sullivan 2006, 2009, Kaminski et al. 2007).

Deer mice build their nests in underground cavities under roots of trees or shrubs, under a log or board, or in a burrow made by another rodent. Although some species of *Peromyscus* have good burrowing capabilities, *P. maniculatus* and *P. leucopus* are not very good burrowers (Weber and Hoekstra 2009). Deer mice also nest in aboveground sites such as a hollowed log or fencepost, or in cupboards and furniture of unoccupied buildings (Timm and Howard 1994). The nests are made with various materials such as down from plants or shredded materials (Nowak 1999), stems, twigs, leaves, and roots or grasses. Nests can also be lined with fur, feathers, or shredded cloth (Timm and Howard 1994). This species is known to breed year round if conditions are favorable. In colder climates, they breed anytime between March and October. Females are poly-

estrous producing on average of 3-4 litters per year with a litter size ranging from 1-9 pups (Nowak 1999). The deer mouse has a tremendous breeding potential. Theoretically, 4 generations could be produced in one year, and if litters achieved maximum survival, the offspring of one pair could number 10,000 in one year. Specimens usually don't live from one year to the next, but some individuals live up to 32 months (Banfield 1974).

Deer mice are known as social rodents, being tolerant of conspecifics regardless of age and sex, especially during the winter, when up to 13 mice can be found huddled together to conserve heat (Banfield 1974, Nowak 1999). However, it has been observed that a female during estrus will actively defend her territory and nest containing her young. Home ranges span from 0.1 ha to 1.0 ha with males having larger home range sizes than females. Deer mice can move considerable distances; Virchow and Hygnstrom (1991) reported daily movements of over 100 m in sugarbeet fields. There are natural annual cycles in deer mice populations, with smaller populations occurring in spring and larger populations occurring in late autumn. The normal population fluctuation ranges from about 1-22 per ha (Banfield 1974). However, densities of these rodents depend on season, habitat, food availability, and pressure from predators and competing rodents. For example, several researchers have noted high population densities following heavy mast crop years (Yunger 2002, Falls et al. 2007, Vessey and Vessey 2007, Krebs et al. 2010). The importance of food supply to deer mouse populations was also noted by Ortega et al. (2004) who reported, interestingly, increased densities of deer mice when biological control agents (insects) were introduced to help control invasive spotted knapweed (*Centaurea stoebe*). They suggested that the insect larvae provided a critical overwinter food supply to the mice.

Deer mice are generally nocturnal and seldom seen during daylight hours. They climb well, walk deliberately, or hop on all four feet, leaving four tiny footprints in the snow and an occasional tail side-swipe (Dewsbury et al. 1980, Timm and Howard 1994). They may use tiny beaten paths under logs in forest-type areas or runways through the grass in prairie ecosystems. At times they have been seen tunneling under the snow in the winter (Fitzgerald et al. 1994) and other times they are seen scrambling on the top of the snow, which causes these mice to become particularly vulnerable to predation (Banfield 1974). Many species of deer mice have good climbing abilities (Dewsbury et al. 1980). Additionally, deer mice also have relatively good swimming abilities even though they tend to occupy drier upland areas (Evans et al. 1978). Deer mice, like house mice, have excellent stowaway capabilities; Baker (1994) estimated that live stowaway mice could arrive at the final destination in over 50% of transported truckloads of infested hay or grain.

Deer mice are an important prey species in the food chain. Some of the predators that prey on this small rodent include: snakes, owls, hawks, coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), badgers (*Taxidea taxus*), grasshopper mice (*Onychomys* spp.), weasels (*Mustela* spp.) (Fitzgerald et al. 1994), large fish, short-tailed shrews (*Blarina brevicauda*), ground squirrels, tree squirrels, striped skunks (*Mephitis mephitis*), American mink (*Mus-*

tela vison), raccoons (*Procyon lotor*), bears (*Ursus* spp.), and gray wolves (*Canis lupus*) (Banfield 1974). Owls, weasels, and foxes are known to eat the most deer mice (Banfield 1974).

Deer mice are omnivorous, eating a broad array of foods such as nuts, berries, fruits, invertebrates, carrion, fungi, bone, eggs, various plant parts, and seeds. Seeds are the staple in the diet of deer mice. They have been known to cache an assortment of seeds for a winter food supply. They transplant seeds via their cheek pouches to a chamber near their nests. The total volume of seeds collected can equal as much as 3 liters (Banfield 1974). Some of the seed species that are cached include ragweed (*Ambrosia artemisiifolia*), panic grass (*Panicum* spp.), sorrel (*Rumex acetosa*), tick trefoil (*Desmodium* spp.), apple (*Malus* spp.), cherry (*Prunus* spp.), Douglas fir (*Pseudotsuga menziesii*) and oak (*Quercus* spp.) acorns. By burying seeds in shallow pits, deer mice facilitate the dispersal and germination of some plant species such as Jeffery pine (*Pinus jefferyi*) (Briggs et al. 2009).

DAMAGE

Seeds and Seedlings

Deer mice consume various types of seeds and cause significant declines in plant populations such as silky lupine (*Lupinus sericeus*) and western stoneseed (*Lithospermum ruderales*) (Bricker et al. 2010), black spruce (*Picea mariana*) (Côté et al. 2003), Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*; Huggard and Arsenault 2009), lodgepole pine (*Pinus contorta*) (Lobo et al. 2009), and many more. They need to devour large amounts of seeds because of their high metabolic rates (Reichman 1979, Brown and Munger 1985, Hulme 1993, 1998). Mice are known to cause impacts to forest regeneration because of seed predation. In fact, foresters began relying on planting seedlings on regeneration sites to achieve adequate reforestation versus seeding the sites (Timm and Howard 1994). Zwolak et al. (2010) found that deer mice were almost twice as abundant in burned versus unburned stands. A possible reason for this is because after fire sweeps through a forest, foraging becomes easier and simpler for deer mice.

Studies have been done to find what mice select for in seeds. Animals may choose seeds based upon size, seed coat, digestibility, palatability, nutritional content, and secondary compounds (Janzen 1971, Kerley and Erasmus 1991, Vickery et al. 1994, Ramos 1996, Lewis et al. 2001, Lobo et al. 2009). Deer mice prefer ponderosa pine over Douglas fir seeds (Zwolak et al. 2010), bitterbrush (*Purshia tridentata*) and pinyon pine (*Pinus edulis*) over Utah juniper (*Juniperus osteosperma*) and smooth brome (*Bromus inermis*) (Everett et al. 1978), and lodgepole pine over white spruce (*Picea glauca*) and subalpine fir (*Abies lasiocarpa*) (Lobo et al. 2009). In general, deer mice seem to prefer variety in their diet (Everett et al. 1978).

Although most deer mice are seed predators rather than seed dispersers (Sullivan 1978, Zwolak et al. 2010), some mice do in fact cache seeds (Vander Wall 1992, Vander Wall et al. 2001). Occasionally, they will dig up and cache seeds that have recently been planted. In some cases, however, cached seeds result in plant recruitment when germination occurs. Large-seeded species have difficulty

germinating and establishing from seed on the soil surface and may require burial in seed caches for seedling establishment to occur (La Tourrette et al. 1981, Evans et al. 1983, Everett and Monsen 1990). In addition to hindering successful reforestation, seed consumption by rodents can also hinder rangeland rehabilitation (Everett and Stevens 1981, Everett and Monsen 1990, Bricker et al. 2010).

Although the main impact of deer mice on reforestation is seed consumption, they can also damage emerging seedlings (Coté et al. 2003). We also noted seedling damage by deer mice in a pen study, although house mice caused much more damage (G. Witmer, unpubl. data). In general, seedling damage by pocket gophers (*Thomomys* spp.) and voles (*Microtus* spp.) is much more prevalent in North America (Engeman and Witmer 2000, Witmer et al. 2009).

Agricultural Crops

Deer mice can also cause considerable damage to agricultural crops. Damage can occur to corn, almonds, avocados, citrus, pomegranate, and sugar beets. They also dig up and consume melon and alfalfa seeds. In cornfields, deer mice can dig up and consume corn seed, but can also feed on newly emerged corn seedlings. Hygnstrom et al. (1996) reported that the mean number of plants in unprotected corn populations was 20% less than wire-mesh protected corn populations; this percentage decrease in crop yield would be significant to most producers. Deer mice can also cause considerable damage to almond orchards, contributing to a net economic loss of \$19 to \$51/ha (Pearson et al. 2000). On the other hand, Villa et al. (1998) found little evidence of damage to sugarcane crops from deer mice. Stallman and Best (1996) also found little damage to crops in a strip-cropping system from deer mice. They speculated that the deer mice were providing more benefit to the agro-ecosystem by constructing burrows that increase the friability of the soil, depositing fecal material that increases soil fertility, and by consuming competing weed seed and insect pests.

Bird Predation

We know that introduced rats (*Rattus* spp.) and house mice can have serious impacts to native flora and fauna when introduced to islands. In fact, invasive house mice have been found to have a serious impact on Tristan albatross (*Diomedea dabbenena*) and Atlantic petrel (*Pterodroma incerta*) populations on Gough Island by feeding on chicks (Wanless et al. 2007). It has been shown that deer mice will also prey upon bird eggs and nestlings, both in nests in trees (Bradley and Marzluff 2003) and in ground nests (Blight and Bertram 1999, Schmidt et al. 2001).

Structural Damage

While most of their time is spent in fields, occasionally, deer mice cause damage to structures, furniture, household items, stored materials, and wiring (Timm and Howard 1994, Corrigan 2001). Deer mice often move into buildings to seek shelter from winter conditions and food shortages. They will bring in food (e.g., seeds) to cache as a food supply, but they will also readily make use of stored pet food and bird seed. Hence, proper storage of foodstuffs is important to reduce the attractiveness of

buildings to mice. The damage they cause is similar to that caused by house mice, and both species may occur in buildings at the same time. At times, people may not even know that these mice inhabit their house until they see their droppings and holes in their upholstery or clothes, since mice use these items as nesting materials. Deer mice will often inhabit unoccupied cabins for shelter. When the owners of the cabin return and clean it, they find damage to their property.

Disease Pathogens

Deer mice are a potential source of numerous disease agents. For example, Padovan (2006) listed 24 viral, 16 bacterial, and 5 fungal pathogens that have been isolated from various species of deer mice. Some diseases can be transmitted directly by the mice (e.g., hantavirus, leptospirosis, plague, salmonellosis, tularemia), whereas other diseases (e.g., babesiosis, Colorado tick fever, human granulocytic anaplasmosis, Lyme disease, rickettsialpox, relapsing fever, Rocky Mountain spotted fever, western equine encephalitis) are transmitted indirectly, generally through an insect vector (e.g., tick, flea, mite, mosquito) (CDC 2010). Two diseases that can cause fatal illness in humans that are associated primarily with deer mice are Hantavirus Pulmonary Syndrome (HPS) and Lyme disease. The Sin Nombre hantavirus causes HPS in humans, and this disease has been endemic in the Americas for at least several decades (Hjelle and Glass 2000). The hazard from this hantavirus can be high when humans enter cabins or other structures that have been unoccupied for extended periods of time and contain substantial amounts of mouse urine and feces. Guidelines for avoiding hantavirus and Lyme disease infection are posted on the CDC website. Also, new guidelines for researchers working with wild rodents have been published (Kelt et al. 2010). Finally, it is worth noting that rodents have been implicated in food safety issues, as they can contribute to field crop contamination with *E. coli* and other disease pathogens (Salmon 2008, Li et al. 2012). Another human safety issue is the attraction of birds to airports to feed on rodents (mainly deer mice and voles), resulting in increased risk of bird-aircraft strikes (Witmer and Fantinato 2003).

MANAGEMENT AND CONTROL

A number of methods and materials are used to control deer mice and manage the damage that they cause, but the main tools have been traps and rodenticides. Management approaches in a commensal setting (in and around buildings and structures) are similar to those used for house mice control. Some habitat management approaches are available for agricultural and forestry/orchard settings.

A variety of traps can be used to control deer mice and house mice in and around buildings. These include snap traps, live traps, and multiple-capture traps (Timm and Howard 1994, VPCRAC 2009). Bait the traps as per house mice, using peanut butter, sunflower seed (*Helianthus* spp.), or breakfast cereal. A variety of live trap types (e.g., Sherman traps) are effective in capturing deer mice in forest or field settings (Dizney et al. 2008), but live-trapping of deer mice by the general public is discouraged because of the potential exposure to hantavirus (VPCRAC 2009, Quinn et al. 2012, but see Kelt et al. 2010).

A variety of rodenticides and formulations are used to control deer mice and house mice in commensal situations (Table 1). While many EPA-approved rodenticide labels do not specifically list deer mice or white-footed mice, many just use the term “mice” on the label. Rodenticides selected to control deer mice should specifically list deer mice on the label. First-generation anticoagulants, chlorophacinone and diphacinone, are commonly used and can be effective toxicants (Marsh et al. 1977). Zinc phosphide-treated grain is effective in controlling rodent populations, in general, and is used in some airport, orchard, agriculture, and rangeland settings to control voles, deer mice, and other small rodents. Presumably, deer mice populations are often reduced when rodenticides are used in field settings to control a different rodent pest species. For example, in a study to examine the effects of prairie dog (*Cynomys ludovicianus*) rodenticides on deer mice, Deisch et al. (1990) observed that zinc phosphide consistently lowered deer mouse densities. Also, since the diet of deer mice is mostly made up of seeds, they are more susceptible to grain-based rodenticide pellets or grain-coated rodenticide baits. Gorenzel and Salmon (2003) developed an above-ground bait station for placement of anticoagulant rodenticides in almond orchards in California to reduce nut damage by deer mice. They noted, however, that the rodenticide bait was not very effective once almonds, which the deer mice preferred as a food source, were available.

Rodent-proofing of buildings is important to reduce invasion by mice (Timm and Howard 1994, VPCRCAC 2009, Quinn et al. 2012). However, excluding mice entirely is not easy because of their ability to climb, jump, and squeeze through very small openings (Baker et al. 1994). Guidelines for rodent-proofing were provided by Baker et al. (1994). Good sanitation, such as not leaving food materials out and available, using rodent-proof food storage and trash containers, and not providing materials that can be readily used for bedding, can help prevent serious mouse infestations.

Habitat modification can also help reduce an area’s carrying capacity for deer mice. Practices can include mowing, clearing the overgrowth of plants especially near buildings, and removing brush and debris piles (VPCRCAC 2009). Modifying habitats to increase the use of the area by predators and raptors can help increase predation pressure on rodents. This could involve placement of nest boxes and perches for raptors (e.g., Witmer et al. 2008). In reforestation efforts, the consumption of conifer seeds can be reduced by supplying supplemental foods such as sunflower seeds (Sullivan 1979, Sullivan and Sullivan 1982) or by removing natural food sources and cover such as blackberry (*Rubus fruticosus*) bushes (Schreiner et al. 2000).

Repellents have not been found to be very effective with deer mice (VPCRCAC 2009) with the exception of some seed treatments (e.g., Nolte and Barnett 2000). Some people use naphthalene (moth balls) in confined places to repel mice, but that material is not registered for that purpose (Timm and Howard 1994). An organic mouse repellent designed to repel mice from agricultural equipment and structures has been registered and is commercially available (EarthKind, Inc., Bismarck, ND). Predator

Table 1. Rodenticide active ingredients and number of products used in the United States to control mice, including deer mice. (compiled by J. O’Hare, USDA National Wildlife Research Center, from the National Pesticide Information Retrieval System, Purdue University, using the search words: mice, deer mice, white-footed mice) **Rodenticides selected to control deer mice should specifically list deer mice on the label. Some of the product registrations may have been cancelled.**

Active Ingredient	Number of Products
Bromethalin	19
Diphacinone	18
Zinc phosphide (Zn3P2)	15
Brodifacoum	14
Methyl bromide	12
Bromadiolone	11
Difethialone	11
Aluminum phosphide	9
Chlorophacinone	5
Sulfuryl fluoride	4
Warfarin	4
Cholecalciferol	3
Chloropicrin	2
Difenacoum	2
Magnesium phosphide	2
Thymol	1

odors (urine and feces) have not been found to be effective in repelling deer mice from field areas (Zimmerling and Sullivan 1994, Fanson 2010). Researchers have reported some effective repellency to some compounds such as bitter-tasting cardenolides (Glendinning 1992) and 10% pine oil (Wager-Pagé et al. 1997).

MANAGEMENT AND RESEARCH NEEDS

Additional management methods need to be developed for a number of reasons. Timm and Howard (1994) noted that new efficacious and cost-effective methods to reduce seed predation are needed. Additionally, some tools are continually being restricted or removed from use by governmental agencies (e.g., bans on traps or cancelation of rodenticide registrations (Fall and Jackson 2002, Eason et al. 2010)). Also, methods that have been effective in the past may no longer be as effective. For example, first-generation anticoagulants used in California for deer mouse control have recently been found to no longer be effective (T. Salmon, unpubl. report). In some situations, methods to remove deer mice from homes and other buildings are limited because of concerns with lethal control (traps) and the use of toxicants. Methods that are effective at one time of year or in a specific setting may not be effective at other times or in other settings. In general, a multiple-method approach (i.e., an IPM approach) will be needed to resolve problems (Witmer 2007). Better methods are needed to protect emerging crops, planted seeds, and tree nut crops.

More efficacious and palatable rodenticide baits are needed, but at the same time we need selective chemical delivery systems and ways to reduce risk to non-target animals. For example, research is being conducted to add a bird repellent to rodenticide baits to reduce the poisoning of birds (S. Werner, USDA National Wildlife Research Center, pers. commun.). We also need more non-lethal methods developed which could include multiple capture traps, barriers, repellents, and fertility control materials. Effective methods to reduce the risk of hantavirus infection and to improve treatment would be very helpful as well.

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