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Managing Wildlife Damage: Secondary Toxicity of Anticoagulant Rodenticides - Effect on Predators

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INTRODUCTION

The rodent family, including rats, mice, and voles, thrive off urban and agricultural expansion. These areas supply ample food and shelter, facilitating population expansion. In Georgia, nuisance rodent species include non-native species such as the Norway (or brown) rat (*Rattus norvegicus*; Figure 1), roof rat (*R. rattus*; Figure 2), house mouse (*Mus musculus*), and native species such as pine vole (*Microtus pinetorum*), meadow vole (*M. pennsylvanicus*), and eastern chipmunk (*Tamias striatus*). Other rodents include such native Georgia animals as squirrels (4 species) and beaver (*Castor canadensis*). These species can cause considerable damage in some situations, but management of squirrels and beaver does not normally include toxic rodenticides. Their management is discussed in other publications. This paper will confine discussion to commensal rodents (frequently associated with humans; Norway rat, roof rat, house mouse), two species of vole, and chipmunk. Commensal means "sharing the table" from the Latin word, *mensa* – a table.

Many native and non-native rodents cause damage to property, such as chewing electrical wires or structures, fecal and urine contamination in homes and commercial establishments, grain contamination, insulation damage from nest construction, damage to landscape plants, and other damage. According to the International Food Safety & Quality Network, rodents (primarily commensal rodents) may contaminate as much as 20% of the world's food supply annually. Public attitudes are negative toward many rodent species and humans perceive them as nuisance pests. Human-wildlife conflicts led to management actions to reduce damages and curtail pest population growth.

Non-chemical and non-lethal methods for dealing with nuisance rodent problems include habitat modification and exclusion. Repellents, a non-lethal method, are not generally effective against most nuisance rodents. A common but lethal form of pest management is the use of toxic rodenticides. Lethal control may also include shooting (for larger species) or lethal trapping. This paper deals specifically with the consequences of anticoagulant toxicants (rodenticides) used to manage the 6 rodent species introduced in the opening paragraph. While non-anticoagulant rodenticides exist, this paper will focus on anticoagulant products. We recommend an integrated pest management (IPM) approach to solving nuisance rodent issues. IPM is defined as "a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tools in a way that minimizes economic, health, and environmental risks." End users should identify the species most likely responsible for the damage and formulate an integrated plan with non-lethal and lethal control measures. While there are multiple lethal options such as trapping, the focus of this paper is on rodenticide use and safety concerns associated with their use.

The primary use of a toxicant is to kill the offending rodent. A sub-lethal dose of toxicant can make the target sick but it may still be vulnerable to predation. Likewise, rodents that die from consumption of certain rodenticides can be scavenged as well. Predators that consume prey that has succumbed from lethal exposure or ingested a sub-lethal dose of certain rodenticides may develop symptoms characteristic of poisoning. This is known as "secondary toxicity". These predators, such as some mammals and birds of prey, may die or be found by the public. They may end up in veterinary hospitals or rehabilitation centers. They are the focus of this paper.

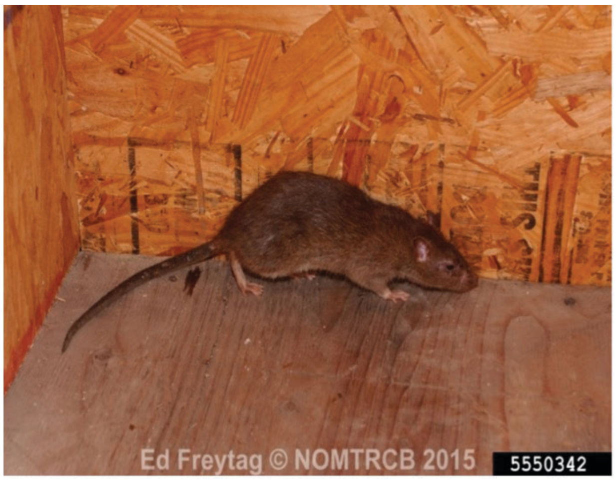

Figure 1: Norway rat *(Rattus norvegicus)*

Figure 2: Roof rat *(Rattus rattus)*

TAXONOMY

Class Mammalia – Mammals
Order Rodentia – Rodents
Family Muridae – Mice, Rats, Gerbils
Genus – *Rattus*
Norway rat – *Rattus norvegicus*
Roof rat – *Rattus rattus*

Genus – *Mus*
House mouse – *Mus musculus*

Family Sciuridae – Squirrel
Genus – Tamias
Eastern Chipmunk – *Tamius striatus*

Family Cricetidae – Voles and hamsters
Genus – *Microtus*
Pine vole – *Microtus pinetorum*
Meadow vole – *Microtus pennsylvanicus*

NATURAL HISTORY

Norway rat. The Norway rat (Figures 1 & 3) is native to China but is a widespread invasive species throughout the globe. They are found throughout the United States. Preferred habitat for the Norway rat includes forested areas, open fields, or anywhere within proximity to urbanized areas. The Norway rat can be identified based on the dark back and grey underbelly along with small ears, blunt nose and short, 6 to 8-inch, hairless tail (Figure 3). The average lifespan of the rat is about 2 years in the wild, with a gestation period of 22 to 24 days and 2 to 14 offspring per litter. The Norway rat's omnivorous opportunistic diet typically contains meat, vegetables, seeds, fruits, and insects. While they are good climbers, they typically prefer to burrow in embankments and around or under structures.

Roof rat. The roof rat, sometimes called black or ship rat (Figures 2 & 3), is a widespread invasive species worldwide, believed to be native to India. The roof rat can be uniquely identified based on the dark brown back and light brown underbelly along with the large hairless ears and a tail longer than the length of its body (Figure 3). The average lifespan of this rat is about 2 years in the wild, with gestation period of 21 to 29 days and 6 to 12 offspring per litter. The rat's omnivorous generalist diet typically contains insects, fruits, snails, and songbird eggs. This generalist diet and high fecundity poses great threats to native species. Roof rats are good climbers and frequently found in attics or using trees and rafters in buildings.

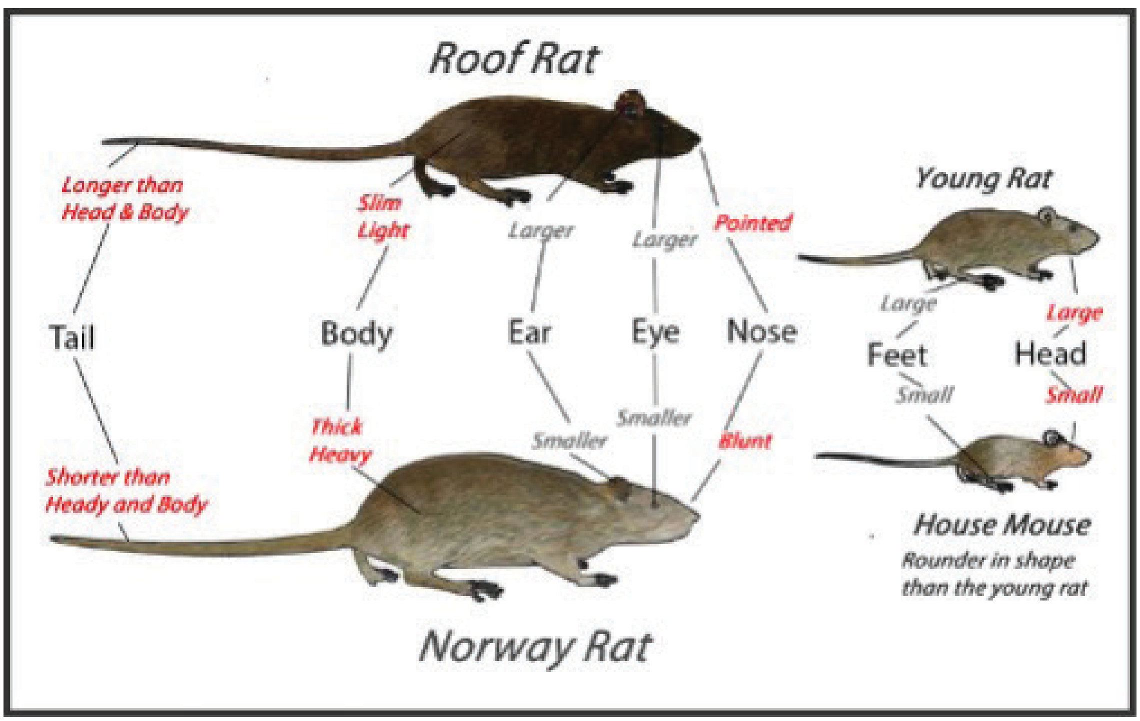

Figure 3: *Comparison of roof rat and Norway rat.*

House mouse. The house mouse (Figure 4), is a widely distributed invasive species, originating from the Mediterranean and China. Preferred habitat for the house mouse is within urban areas including homes, barns, and fields. The house mouse can have light brown to black fur with a lighter underbelly and a tail length ranging from 2 to 4 inches in length. The diet of this species includes plants, seeds, insects, and any human food or livestock feed that is easily accessible.

Figure 4: House mouse *(Mus musculus)*

Pine vole. The pine vole, or woodland vole (Figure 5), has a native range in the United States extending from the Midwest (Texas to Wisconsin), to the east coast (excluding Florida), and found primarily in deciduous forests. This vole's fur is typically light or dark brown with a white or silver underbelly. They can be uniquely identified by their large frontal claws and small eyes, ears, and tail. This species is a "surface burrower" and will tunnel in surface soils or thatch, including mulch or pine straw debris. The pine vole has an herbivorous diet of grass, forbs, seeds, and tubers but will, on occasion, consume insects. It can be a significant pest in fruit orchards, pecans, and landscape plantings.

Figure 5: Pine vole *(Microtus pinetorum)*

Meadow vole. The meadow vole (Figure 6) has a native range that extends across much of northern North America, and in the United States is primarily found in the Midwest and along the east coast with a limited distribution in Georgia. Preferred habitat of the meadow vole includes early successional forests and grassy fields. The meadow vole can be uniquely identified based on its light grey fur with white tips near the head and dark grey or orange fur near the tail. The diet of the meadow vole is like the pine vole, consisting of grass, forbs, seeds, tubers, and occasionally insects. Additionally, this vole is an agricultural pest and can destroy some crops through tunneling and direct feeding on the plant.

Figure 6: Meadow vole *(Microtus pennsylvanicus)*

Eastern chipmunk. The eastern chipmunk (Figure 7) is widespread across the eastern United States but is rarely found in the coastal plain region from the Florida peninsula to North Carolina. Chipmunks favor forested areas, specifically deciduous forests that provide shelter via downed trees or stumps but are widespread and common in residential areas as well. They can be identified by the five dark stripes along their sides and back, with white between the stripes on their side. Dark stripes are also located on their faces around their eyes. The diet of the chipmunk is typically herbivorous, mainly fruits, nuts, and seeds. Chipmunks will occasionally consume insects, small bird eggs, slugs, and mushrooms.

Figure 7: Eastern chipmunk *(Tamias striatus)*

Each of these rodents can serve as a vector or host for diseases, viruses, and bacterial infections. As a vector, they transmit the disease through bites or transfer of bodily fluid like blood. As a host they are the reservoir of the disease. Rodents may serve as hosts for Lyme disease (primarily transmitted by ticks) or murine typhus (primarily transmitted by fleas). As a host, rodents can potentially transmit toxoplasmosis, *Escherichia coli*, leptospirosis, and Hantavirus. These small rodents do not transmit rabies.

Both rats and the house mouse are damaging pests in poultry and stored grain. All three are common around urban settings and readily use urban trash, agricultural crops, stored grain, and native foods and habitat. Chipmunks and voles, in contrast, are more typically a nuisance in lawns and flowerbeds or foundation plantings around houses. They are rarely a pest in stored grains, warehouses, or poultry farms. However, the damage that commensal rodents, chipmunks, and voles inflict and the control methods used to manage these species share some similarities. Control methods can include a variety of options including exclusion and trapping. Lethal control with toxic bait is commonly used and this control option presents unique risks to humans, pets, and wildlife. Publications on control of commensal rodents (non-native rats and mice) are available on most Cooperative Extension websites as are publications on chipmunks and voles. The objective of this publication is to discuss the use of anticoagulant rodenticides (toxic bait) and the implications to non-target wildlife that may encounter the bait directly (primary toxicity) or rodents that have consumed the bait (secondary toxicity).

ANTICOAGULANT RODENTICIDES

In Georgia, rodenticides can be in bait blocks, pellets place-packs, soft baits and liquid forms. Powered baits are available only to licensed pest control operators. Loose pellets are no longer available but place-packs that contain pellets or loose meal treated with rodenticide may be available. Ready-to-use bait stations are readily available to the public and reduce risks of primary consumption to non-target species (Figure 8). Stations are categorized into four tiers depending on the risk to non-target species and resilience to withstand weather conditions. Ready-to-use bait stations are registered for both indoor and outdoor use and may be restricted to within a defined distance of structures such as barns or outdoor sheds. Readers should check with the Georgia Department of Agriculture – Pesticide Product and Registration website (https://agr.georgia.gov/pesticide-product-and-registration.aspx) for the most current products and restrictions. Consumers can use this website to research products, species (i.e., pest), restrictions, locations and other information. Consumers can contact the GA Department of Agriculture or local University of Georgia Cooperative Extension Agents for more information.

Figure 8: *Ready-to-use bait station.*

Lethal chemical rodenticides may have existed as far back as the time of early civilizations. Modern anticoagulant rodenticides (ARs) were developed to interfere with blood clot formation through vitamin K inhibition in the target species' liver. Species exposed to ARs can potentially exhibit bruising, internal or external bleeding, blood in urine or feces, cardiovascular shock, and death.

Anticoagulant rodenticide (AR). Anticoagulant rodenticides and non-anticoagulant rodenticides (NAR) are widely available in most states. Both classes of rodenticides are toxic and fatal to rodent species. Toxicity can be separated into two categories: acute and chronic. Acute toxicants are lethal after a single feeding event with sudden onset of symptoms after consumption. Chronic toxic substances may require multiple dosages to be fatal, are slower acting, with gradual onset of symptoms after consumption. The Environmental Protection Agency (EPA) uses signal words to characterize risk from a pesticide. Risk levels are "DANGER, WARNING, or CAUTION" (Table 1).

Table 1: EPA signal words for pesticide labels*.

Signal Word	EPA definition
CAUTION	Lower in toxicity. Slightly toxic if eaten; absorbed through skin, inhaled, or slight eye or skin irritation.
WARNING	Moderately toxic if eaten, absorbed through the skin, inhaled; causes moderate eye or skin irritation
DANGER	Highly toxic by at least one route or ingestion; may be corrosive; may cause irreversible damage to skin or eyes.

* Information in this table is accurate as of 15 October 2022. Reader should verify information at EPA website.

Mode of Action. Anticoagulant rodenticides work chronically – they act over short time periods in the body of the target species. The body normally has Vitamin K circulating in the blood stream. Vitamin K is critical to the formation of clotting factors in blood. ARs inhibit certain enzymes that work to form Vitamin K and block the recycling of Vitamin K. The animal's body is depleted of Vitamin K and only dietary Vitamin K is available. This dietary amount is insufficient to maintain clotting factor synthesis. Lack of sufficient clotting factor eventually leads to fatal hemorrhaging with the body. This process normally takes 4-10 days. The delay generally means that the animal does not associate feeding with the illness and therefore, does not stop feeding but, rather, continues to accumulate a lethal dose[1].

First Generation. Anticoagulant rodenticides became commercially available in the 1950-1970's and these came to be called First Generation Anticoagulant Rodenticides (FGAR). As rodents developed resistance to early compounds, the need arose to develop newer compounds – these became known as Second Generation Anticoagulant Rodenticides (SGAR). FGAR's were widely available to the public and are chronically toxic (Figure 9). FGARs may cause anemia, ataxia, anorexia, limping, swollen appendages, coughing, and death. Chemical compounds currently registered for use in the US include chlorophacinone, diphacinone, and warfarin.

Second Generation. Second generation anticoagulant rodenticides (SGARs) were developed after 1970 to target rodent species that developed resistance to FGARs. These substances are acutely toxic and, though available to consumers, have more restrictions on use. Consumers must read and follow all label instructions when using FGAR's or SGAR's. SGARs currently registered for use in the U.S. include brodifacoum, bromadiolone, difenacoum and difelthialone.

Figure 9: ***First generation anti-coagulant rodenticide containing diphacinone.***

[1] Buckle, A. P. & C. T. Eason. 2015. Chapter 6: Control Methods: Chemical. Pp 123-154 *in* Buckle & Smith (editors). Rodent Pests and Their Control, 2nd Edition, CAB International Oxfordshire, England.

REGULATIONS

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) was first enacted in 1947 and monitors pesticide use, exchange, distribution, registration, and disposal in the US. A pesticide is "any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest, or intended for use as a plant regulator, defoliant, or desiccant, or any nitrogen stabilizer". Prior to sale on the market, pesticides were required to be registered with the United States Department of Agriculture (USDA) when first enacted, and the U.S. Environmental Protection Agency (EPA) after 1970. Registered pesticides must exhibit low to minimum risk to human health or the environment. Additional restrictions were added to FIFRA through the Pesticide Control Act of 1972 and the Pesticide Registration Improvement Act of 2003.

Consumers using any commercially available rodenticide must read and follow all label instructions and precautions. It is a violation of state and federal law to use pesticides in a manner inconsistent with the published label. Consumers can obtain additional information at the Georgia Department of Agriculture Pesticide Product and Registration website.

WILDLIFE IMPACTS

ARs may pose a poisoning risk in pets and wildlife. This risk can be through primary, direct consumption of the rodenticide, or secondary risk such as consumption of species that had rodenticides circulating in the body. SGARs are especially hazardous to non-target species due to higher toxicity and slow breakdown, or half-life, of the compounds. Concentrations of ARs have been found in non-target prey species (reptiles, insects, crustaceans, and shorebirds) increasing the probability of indirect AR consumption (Figure 10). From 1998 to 2015, ARs were detected in 58% (474 of 812) of individual animals tested in the US, including 31 different species, 13 of which were raptors[2]. Brodifacoum appeared in most reports and is the greatest threat to non-target species mortality.

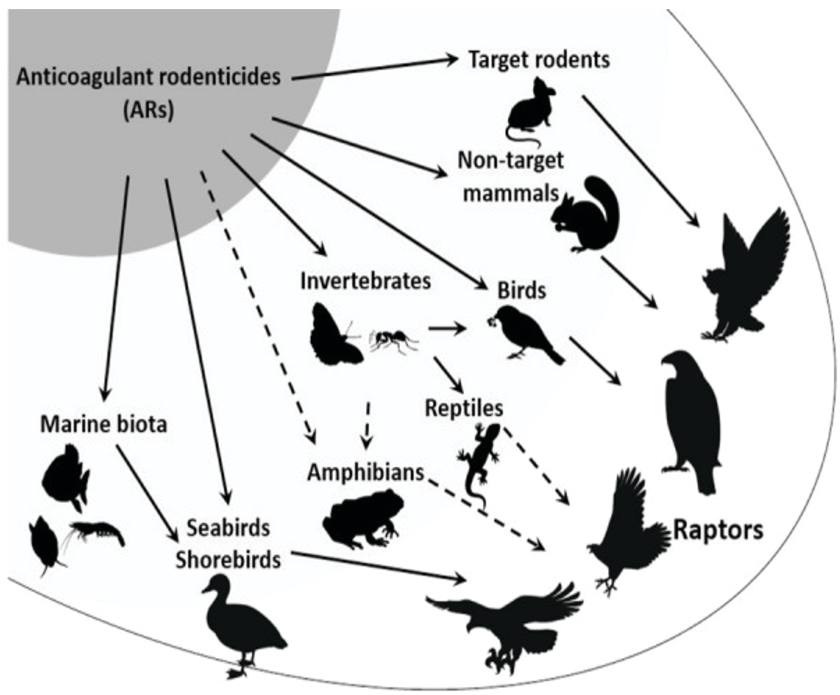

Figure 10: *Potential pathways of anticoagulant rodenticides (ARs) to raptors.*

Raptors. Lethal dosages of ARs for raptors are often lower than that of mammalian carnivores due to the lack of ability to metabolize compounds found in the rodenticides. Raptors are exposed to ARs through secondary pathways.

An example is a case in New York, where from 1971 to 1997, ARs were found in the livers of 51 deceased raptors, with confirmed causes of death in 13 great horned owls (*Bubo virginianus*) and 7 red-tailed hawks (*Buteo jamaicensis*). Brodifacoum presence was documented in 80% of the cases. In another example from New Jersey between 1998 to 2001, ARs were found in 45% of 265 tested raptors, including 12 different species. There was an 81% detection frequency in red-tailed hawks (n=85) and 82% in great horned owls (n=53). Brodifacoum was the most commonly found AR[3].

[2] Nakayama, S. M. M., A. Morita, Y. Ikenaka, H. Mizukawa and M. Ishizuka. 2019. A review: poisoning by anticoagulant rodenticides in non-target animals globally. Journal of Veterinary Medical Science 81(2):298–313.

[3] Stansley, W., M. Cummings, D. Vudathala, and L. A. Murphy. 2014. Anticoagulant rodenticides in red-tailed hawks, Buteo jamaicensis, and great horned owls, Bubo virginianus, from New Jersey, USA, 2008-2010. Bulletin of Environmental Contamination and Toxicology 92: 6-9.

Carnivores. Diets of these species suggest that toxicity from ARs rose through secondary or tertiary pathways, such as consumption of a smaller predator that had been exposed to prey with rodenticide present in the system (Figure 11). Secondary toxicity may make carnivores more susceptible to infections or diseases, with the potential of being fatal.

In the Santa Monica National Recreation Area in California, from 1996 to 2004, 83% of 24 dead coyotes (*Canis latrans*) tested positive for presence of ARs in the liver, with 12 deaths confirmed to have been caused by poisoning. From 1997 to 2004, 93% of 89 dead bobcats (*Lynx rufus*) tested positive for ARs in the liver. Seventy-seven percent of the bobcats had multiple rodenticide compounds circulating in the body at the time of death. During the same period, 11 of 12 mountain lions (*Puma concolor*) livers tested positive for the presence of ARs with two of confirmed deaths from the poisoning[4]. These two mountain lions were observed consuming a coyote prior to death. In Southern California, confirmed deaths of bobcats and mountain lions were found with circulating levels of brodifacoum, bromadiolone, difethialone and diphacinone[5].

Other Species. Additional species like reptiles and invertebrates can be affected from primary, secondary, or tertiary exposure to the rodenticides. Unfortunately, there are limited studies and resources observing the effects of these toxins on the species, especially within the United States.

In Australia, deceased reptiles, the dugite (*Pseudonaja affinis),* tiger snake (*Notechis scutatus*), and the bobtail (*Tiliqua rugosa*), were examined for rodenticide exposure. In total, 91% of dugites were exposed to one type of AR and 73% were exposed to more than one; 45% of tiger snakes were exposed to rodenticides; 60% of bobtails were exposed to one type of AR while 40% were exposed to more than one. The most detected rodenticide in their system was brodifacoum[6]. However, the mortality of each animal was not associated with the poisoning. A captive study of reptiles in California, including the giant ameiva (*Ameiva ameiva*), boa constrictor (*Boa constrictor*), Central American wood turtle (*Rhinoclemmys pulcherrima*), and the green iguana (*Iguana iguana*), displayed the effects of exposure to ARs. ARs were given to these species in high dosages, based on concentrations found in mammals that succumbed to the poisoning, and did not result in mortality. External and internal hemorrhaging, during necropsy, were the most observed symptoms after exposure.

Researchers in France collected 25 slugs (*Deroceras reticulatum*) over 15 days from a brodifacoum bait station[7]. The slugs accumulated SGAR in the digestive system, with peak concentration three days after consumption. The SGAR was observed to be filtered out of the system, on average, within 2.5 days. While no mortality was recorded for the species, the concentrations stored within the species can pose a risk to insectivores, such as the European starling (*Sturnus vulgaris*) and the common shrew (*Sorex araneus*).

RECOMMENDATIONS

Recommended use. Use of rodenticides are often used to control nuisance rodents as they are fast-acting and can assist in mitigating disease spread and controlling other damages. Always read the label of the desired rodenticide for proper use. Wear gloves when handling to minimize direct contact with the product. Clear the identified location of items that can be moved like watering cans, child or pet toys, or food storage items. When inside, turn off heating or cooling systems to avoid aerosol spread of the rodenticide. Be sure to keep children and pets away from the area while rodenticide is actively used. When no longer in use, be sure to clean the area thoroughly.

[4] Moriarty, J. G., S. P. Riley, L. E. Serieys, J. A. Sikich, C. M. Schoonmaker, and R. H. Poppenga. 2012. Exposure of wildlife to anticoagulant rodenticides at Santa Monica Mountains National Recreation area: from mountain lions to rodents. Proceedings of the Vertebrate Pest Conference, 25:144-148.

[5] Riley, S. P. D., C. Bromley, R. H. Poppenga, F. A. Uzal, L. Whited, and R. M. Sauvajot. 2010. Anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban southern California. The Journal of Wildlife Management 71(6): 1874-1884.

[6] Lettoof, D. C., M. T. Lohr, F. Busetti, P. W. Bateman, and R. A. Davis. 2020. Toxic time bombs: Frequent detection of anticoagulant rodenticides in urban retiles at multiple trophic levels. Science of the Total Environment 724: 138218. https://doi.org/10.1016/j.scitotenv.2020.138218.

[7] Alomar, H., A. Chabert, M. Coeurdassier, D. Vey and P. Berny. 2018. Accumulation of anticoagulant rodenticides (chlorophacinone, bromadiolone and brodifacoum) in a non-target invertebrate, the slug, Deroceras reticulatum. Science of the Total Environment 610-611: 576-582.

Minimizing Risks. The use of rodenticides is not the only solution when working to remove or eradicate rodents from the area. To prevent initial infestation and damage, waste bins can be secured, and food stored appropriately. In addition, keep areas clean and free of clutter or loose materials and reduce pathways or connections to water sources. General information on nuisance wildlife control is available on university cooperative extension websites.

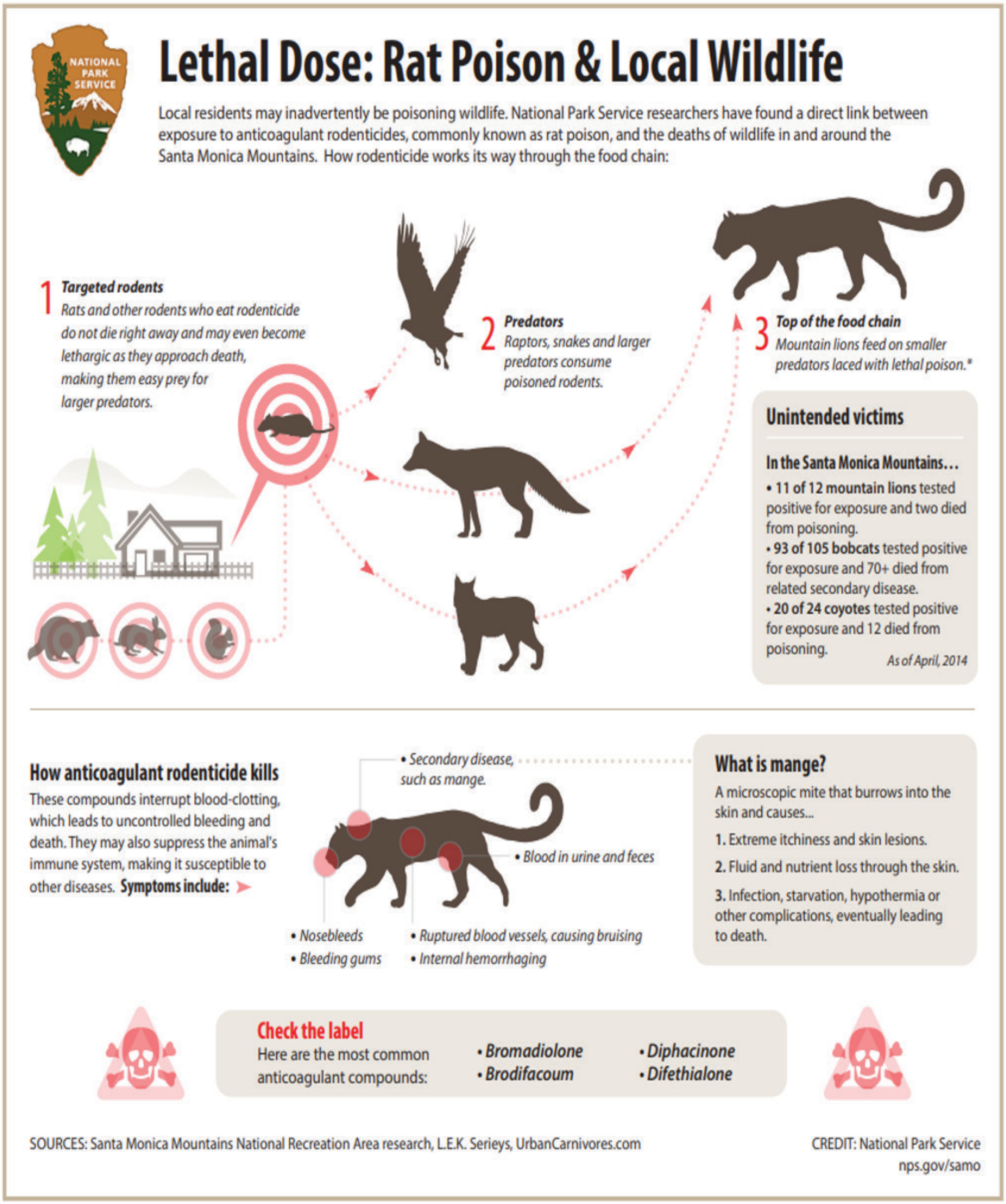

Figure 11: *Potential pathways of anticoagulant rodenticides (ARs) to carnivores.*

When habitat manipulation or exclusion methods are not applicable, rodents may be trapped using snap traps with multiple entrances or more expensive alternatives such as CO_2 piston traps. If the use of rodenticide is necessary, deceased rodents should be removed from the area as soon as possible to minimize secondary exposure to predators. Check with local health departments to determine proper and legal disposal methods.

In general, the best approach to managing rodents is utilizing an integrated pest management (IPM) system. This system involves learning the target species' behaviors and activity patterns. From these observed behaviors, homeowners can determine the best approach to removal and when to implement it. Homeowners can continue to monitor the species and adapt by exploring different methodologies over time as removal efforts are explored. We recommend an integrated pest management (IPM) approach to solving nuisance rodent issues. End users should identify the species most likely responsible for the damage and formulate an integrated plan with non-lethal and lethal control measures.

FURTHER READING

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FIGURE CREDITS – ACCESSED ON 14 OCTOBER 2022

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Figure 11. https://www.nps.gov/samo/learn/management/rodenticides.htm

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