Anticoagulant Rodenticide Scientific Review
Final Report

Prepared for:

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October 2025

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1 Executive Summary

This report was prepared at the request of the Massachusetts Pesticide Board Subcommittee to evaluate scientific evidence on the use, risks, and potential alternatives to anticoagulant rodenticides (ARs), with emphasis on information most relevant to Massachusetts. The Subcommittee requested this review in the context of a changing regulatory landscape for ARs. Over time, EPA has developed progressively stricter risk mitigation measures to limit exposure risks of ARs to both humans and non-target wildlife. These measures address how ARs are packaged, sold, and used, though they remain federally classified as "general-use" pesticides. More recently, several states have adopted their own restrictions on ARs, reflecting growing concerns about unintended environmental consequences. While early regulations primarily focused on protecting human health, particularly preventing accidental poisonings in children, regulatory and public attention has increasingly shifted toward ecological effects, especially secondary and tertiary poisoning of wildlife predators and scavengers.

Background. ARs are used to control rodent populations by disrupting normal blood clotting mechanisms leading to internal bleeding and death over a period of days to weeks. This delayed action increases the likelihood of exposure to predators and scavengers that consume poisoned rodents. ARs are classified into two categories: first-generation anticoagulant rodenticides (FGARs) and second-generation anticoagulant rodenticides (SGARs). SGARs are generally more toxic and persistent than FGARs. In Massachusetts, product-use data indicate that SGARs are applied more widely by weight than FGARs, with products containing bromadiolone and brodifacoum among the most frequently used (Figure 1 and Figure 2). These data also indicate that most AR use occurs in structural pest control settings.

Human health effects. FGARs and SGARs are unequivocally toxic to humans, as they are specifically designed to disrupt normal blood clotting in mammals. The question then turns to whether these compounds are posing a risk to people when used as intended. Earlier decades saw large numbers of exposure incidents (e.g., unintentional poisonings), particularly among children. Multiple waves of risk mitigation measures appear to have substantially reduced reported incidents, as reflected in trends shown in Table 5 and Table 6. Maintaining effective control of rodent populations is important for public health more broadly because rodents can carry pathogens and host ectoparasites that cause disease in humans. These disease risks stem from exposure to infected rodents, which may be mitigated through use of ARs or alternative control strategies, which are described in Section 6.

Environmental effects. SGARs are consistently recognized as more toxic and persistent than FGARs. Acute toxicity assessments demonstrate significantly lower lowest-observed-adverse-effect concentrations (LOAECs) and median lethal doses (LD50s) for SGARs (see Table 7, Table 9, and Table 17). Residues can persist in animal tissues from days to months (Table 17), increasing the likelihood of secondary and tertiary exposure. A wide body of research—spanning global, national, and Massachusetts-specific studies—shows widespread SGAR exposure among non-target birds and mammals. Further, residues have been detected in species that do not primarily consume small mammals, which strongly suggests that tertiary exposures occur.

Several datasets also indicate that both the prevalence and geographic extent of wildlife exposure have increased over time; however, the presence of residues alone does not prove causation of health effects. Interpretation of tissue data must consider important limitations, including that carcasses obtained through rehabilitation/stranding programs may not represent the exposure situation within the underlying population and the possibility of underestimating exposure if affected animals die before they can be sampled. Despite these caveats, laboratory studies consistently document that secondary exposure can cause both sublethal effects and lethal toxicosis. Some studies have explicitly documented AR toxicosis in

wildlife based on necropsies that reveal internal hemorrhaging. The extent to which these effects contribute to population-level declines remains uncertain and would vary by species.

Emerging research also suggests that aquatic systems may be impacted by the transport and bioaccumulation of rodenticides, though further research is needed to better characterize the extent to which this occurs and its significance. Available studies indicate that ARs can accumulate through aquatic food webs, potentially exposing piscivorous species to these compounds. However, the concentrations detected in aquatic organisms are typically much lower than those found in baited rodents. As a result, while tertiary exposure through aquatic pathways is plausible, the risk of exposure is likely much lower than that associated with secondary exposure to rodent prey. Further, the literature to date on documented toxic effects in aquatic organisms is sparse.

This report further reviewed the potential for exposure to threatened and endangered species in Massachusetts. Exposure potential varies by species and setting. Consistent with EPA exposure assessment considerations (e.g., diet and foraging behavior, likelihood of primary bait access, and potential for secondary consumption of poisoned prey), most state-listed species likely have limited exposure potential. However, individuals of several listed predatory bird species, such as the Barn Owl, Short-eared Owl, Long-eared Owl, Bald Eagle, Peregrine Falcon, Northern Harrier, and American Bittern, could be at risk under some exposure scenarios.

Alternatives. This review describes a wide range of chemical and non-chemical options, each of which involves trade-offs in terms of feasibility, effectiveness, and risk. Integrated Pest Management (IPM) approaches were widely recommended by interested parties as a first-line strategy to reduce reliance on ARs. However, some interested parties acknowledged that chemical control remains an important “tool in the toolbox” and continues to be used by licensed applicators in many settings.

Data gaps. Limitations in available data constrain the ability to fully understand the risks and trends of ARs in Massachusetts. One such limitation is the lack of reliable data on rodenticide use by non-licensed applicators and consumers. In addition, the licensed applicator-use data reviewed in this report were limited to 2022 and 2023, which precluded analysis of longer-term trends over time. Substantial gaps remain in understanding the long-term ecological impacts of ARs, especially with respect to the cumulative effects of sublethal exposures over time.

2 Introduction

2.1 Purpose and Scope

In 2024, the Harvard Law School Animal Law and Policy Clinic petitioned the Massachusetts Pesticide Board Subcommittee, requesting the immediate suspension of all anticoagulant rodenticide (AR) registrations in the Commonwealth. The request stated that these rodenticides pose an unreasonable risk to non-target wildlife species, including raptors and other predators, which suffer secondary poisoning from consuming affected rodents. The petition also raised concerns about potential risks to domestic animals and human health, arguing that existing mitigation measures have not been sufficient to prevent exposure.

In response to this petition, the Massachusetts Pesticide Board Subcommittee reviewed the available evidence and determined that additional scientific evaluation was necessary to inform any registration decisions. To support this effort, the Massachusetts Department of Agricultural Resources (MDAR) issued a Request for Quotes (RFQ) to commission an independent scientific review of the human health and ecological effects of ARs and their potential chemical and non-chemical alternatives. MDAR awarded a contract to Eastern Research Group, Inc. (ERG) to conduct this scientific review.

MDAR structured the scientific review of ARs into three phases. In Phase One, MDAR tasked ERG with identifying all resources to consider for the scientific review culminating in a Phase 1 report. ERG then reviewed and summarized those resources in a draft Phase Two report which was presented to the Massachusetts Pesticide Board Subcommittee. During Phase Three, ERG finalized this scientific review report following a comment period from the subcommittee and public.

In June 2025, ERG submitted the final Phase One report, which addressed public comments on the draft report submitted in April 2025 (ERG, 2025). During this second phase, ERG evaluated key resources, interviewed identified representatives of state pesticide agencies, conducted a survey among identified interested parties, and synthesized findings into this comprehensive scientific review. In October 2025, ERG finalized this report by addressing Phase Two comments. A summary of the major public comments and how ERG addressed them can be found in Appendix A.

The scope for the AR scientific review project is documented in ERG's contract with MDAR, and the structure of this report reflects the scope. This final report is organized into the following sections:

- **Section 1** presents this report's overall findings.
- The remainder of **Section** 2 describes the information sources considered by the ERG team, public input opportunities, and the review process for this report.
- **Section 3** summarizes background information on these rodenticides, identifies AR uses in Massachusetts, summarizes information on AR usage quantities, and reviews federal and state restrictions and requirements to minimize impacts.
- **Section 4** reviews evidence for human health impacts.
- **Section 5** reviews evidence for environmental impacts.
- **Section 6** summarizes alternatives to ARs, considering chemical, mechanical, physical, and biological methods.
- **Section 7** lists the references cited throughout this report.
- **Appendix A** summarizes the major public comments and how ERG addressed them

2.2 Publications and Information Resources Considered

The ERG team was tasked with reviewing published information on AR human health and environmental impacts, primarily considering assessments issued by recognized authorities supplemented with peer-reviewed publications. ERG reviewed all assessments and key resources identified in the Phase One report, including documents from United States and international regulatory agencies, published literature, and stakeholder-identified materials. While the Phase One report described ERG's general approach for identifying and selecting peer-reviewed literature for this review, it did not provide the specific search terms, databases, or filtering criteria. Details of the literature search process are provided in Section 4.4 (for human health impacts) and Section 5.3 (for environmental impacts).

In addition to the literature review, ERG gathered information through interviews with state regulatory agencies, a survey of interested parties, and public input opportunities, as described below.

State Interviews

As part of Phase Two, ERG interviewed state agency representatives identified during Phase One. The goal of these interviews was to collect information on AR use patterns, state-specific regulations, alternatives, and other rodent management requirements.

ERG sought input from program leads in Massachusetts state agencies and senior pesticide officials from other New England states and states that were identified as relevant due to recent activity related to AR regulation or ecological concerns. Ultimately, ERG interviewed pesticide officials from California, Connecticut, Georgia, Maine, Nevada, New Hampshire, New York, North Carolina, Rhode Island, Vermont, and Washington. Information from these interviews is incorporated throughout this report, where relevant.

Survey of Interested Parties

ERG also prepared and circulated an online survey to 85 interested parties identified during Phase One, including non-governmental organizations, academic experts, industry representatives, and advocacy groups. The survey requested information on concerns related to ARs, data sources on non-licensed applicator use, publications and resources on human health and ecological effects, and information on chemical and non-chemical alternatives. Each participant was sent a unique survey link, and ERG followed up with nonrespondents, sending up to three reminders to encourage participation. The survey period ran from May 14 to May 30, 2025, and 36 of the 85 individuals responded. Responses were synthesized and incorporated into relevant sections of this report.

Public Input

The public was given multiple opportunities to submit input for this AR scientific review. Prior to initiation of Phase One, the Massachusetts Pesticide Board Subcommittee held a public meeting on March 18, 2025 during which the scope of Phase One was discussed. The Draft Phase One report was presented to the Massachusetts Pesticide Board Subcommittee during the April 15, 2025 meeting. All meetings of the Massachusetts Pesticide Board Subcommittee follow the Open Meeting Law where the public is allowed to attend. Following the April 2025 meeting, the public was invited to comment on the draft Phase One report. Those comments were considered by ERG when finalizing the Phase One report and when drafting this Phase Two report. The final Phase One report includes a brief summary of the public comments from Phase One and how ERG addressed them.

A draft of the Phase Two report was also made available for public comment. The Phase Two comment period ended on October 1, 2025. ERG addressed those comments in this final report and prepared a summary of the comments based on themes by multiple commenters (see Appendix A). In cases where public comments identified errors in the draft report, ERG corrected them.

3 Background Information on Anticoagulant Rodenticides

This section provides background information on anticoagulant rodenticides (ARs), including their mechanisms of action, chemical grouping, formulation practices, and pathways of exposure (Section 3.1). It also describes the federal and state regulatory frameworks that govern the use of ARs (Section 3.2 and Section 3.4) and presents available data on how these products are used in Massachusetts (Section 3.3), including the types of sites treated and quantities applied by licensed applicators. The information presented in this section is based on ERG's review of published resources, interviews with representatives of state agencies, product registration databases, and usage data collected by MDAR.

3.1 Overview of Anticoagulant Rodenticides

ARs are a class of chemicals used to control rodent populations by disrupting normal blood clotting mechanisms. Specifically, these compounds interfere with the vitamin K cycle, which plays a crucial role in blood clotting in mammals and birds (Hadler and Buckle, 1992; Watt et al., 2005). Following exposure, animals internally bleed and die over a period of days to weeks. The delay in death is intentional, allowing rodents to continue consuming bait and leaving toxic bait accessible to other individuals. Because symptoms develop gradually, affected rodents often maintain normal activity for some time, during which they may return to shared feeding sites, share bait locations, or feed in social groups. The timing of death depends on a combination of chemical-specific factors, such as the potency and bioaccumulation potential of the specific rodenticide used, and the dosage, metabolism, and susceptibility of the animal. Some rodents have developed resistance to certain ARs (McGee et al., 2020).

The delayed time to death caused by these rodenticides also increases the risk of secondary poisoning in non-target species (EPA, 2020b). Because poisoned rodents can live for days or weeks following exposure, they can be caught and consumed by predators and scavengers, such as hawks, owls, foxes, bobcats, and domestic pets. These secondary consumers can accumulate ARs in their systems, leading to unintended poisoning (EPA, 2020b). The bioaccumulation and biological persistence of the rodenticide chemicals can also lead to toxic effects in tertiary consumers (animals that eat secondary consumers) (EPA, 2020b). In addition, non-target species may be exposed to ARs directly if they consume bait intended for rodent control (EPA, 2020b).

First-Generation and Second-Generation Anticoagulant Rodenticides

ARs were first discovered in the 1940s, leading to the development of what are commonly known as first-generation anticoagulant rodenticides (FGARs) (Hadler and Buckle, 1992). The first of these compounds to be widely used for rodent control is warfarin, which had been used as a therapeutic treatment in humans for thrombosis. It became the first AR to be widely used for rodent control, followed by others, such as chlorophacinone and dopaquinones. FGARs typically require multiple feedings over several days to accumulate a lethal dose, making them effective but also allowing some rodents to develop resistance over time.

By the 1970s, as rodents had developed resistance to FGARs, manufacturers developed what are commonly known as second-generation anticoagulant rodenticides (SGARs) (Hadler and Buckle, 1992). These are more potent, requiring only a single feeding to deliver a lethal dose, with death occurring days later. These newer compounds, which include brodifacoum, bromadiolone, difenacoum, and difethialone, also have longer biological half-lives, meaning they persist in the tissues of poisoned rodents for longer periods of time (Vandenbroucke et al., 2008). While this increased potency and persistence make SGARs more effective for rodent control, it also heightens the risk of bioaccumulation in non-target species, leading to secondary poisoning in predators and scavengers that consume exposed rodents and raising concerns about their

long-term ecological impacts. Like with FGARs, resistance to some SGARs has been documented in the most common rodent pests (e.g., brown rat, black rat, house mouse) (McGee et al., 2020).

Product Formulation and Inert Ingredients

To create AR products, manufacturers blend active ingredients (i.e., FGARs and SGARs) with other components such as food-based materials and binding agents to enhance effectiveness. These mixtures are typically formed into small solid blocks or pastes designed for placement in bait stations. While manufacturers must disclose the identities and concentrations of active ingredients on product labels, there is no such requirement for "inert," ingredients. However, the Environmental Protection Agency (EPA) evaluates the potential impacts of both active and inert ingredients during the pesticide registration process. In ARs, the primary concern is the active ingredients; inert ingredients are not further discussed here because they have not been identified as contributors to risk.

Tamper-Resistant Bait Stations

Most AR products are packaged for use in tamper-resistant bait stations. These stations are intended to protect bait from moisture and spillage and to prevent access by children, pets, and non-target wildlife. Product labels specify instructions on application methods, rates, and safety precautions, and these directions are legally enforceable under state and federal pesticide laws.

EPA now requires that AR bait products be applied in tamper-resistant bait stations whenever bait is used outdoors, above ground, or in any indoor or outdoor location where children under six years of age, pets, or non-target wildlife have access (EPA, 2024d). The term "tamper-resistant" is defined by EPA as, among other things, capable of being locked or sealed and "strong enough to prohibit entry or destruction by dogs and by children under six years of age using their hands, their feet, or objects commonly found in the use environment" (EPA, 1994). The term "tamper-resistant" replaced the previously used term "tamper-proof" to clarify that these bait stations are not indestructible. EPA also notes that label requirements apply to pesticide applicators, not to bait station manufacturers, as the agency does not regulate the production or sale of empty bait stations unless they are sold together with rodenticide baits.

Additionally, Massachusetts regulations (333 CMR 13.08) require that any rodenticide bait that is applied indoors in generally accessible areas must be placed in a tamper-resistant bait station and secured to prevent lifting or removal. The Massachusetts regulation also requires applicators to place their name, phone number and application date on bait stations; and it requires active ingredients and EPA pesticide registration numbers to be listed on bait stations.

Additional details on federal and state regulatory requirements are provided in the following sections.

3.2 Federal Regulatory Context

This section describes the federal regulatory context for ARs, including EPA's processes for pesticide registration, re-evaluation, and risk mitigation. It summarizes major federal actions that have shaped the labeling, use restrictions, and classification of these products in the United States.

EPA Registration and Classification under FIFRA

EPA is the federal agency responsible for registering rodenticides (and other pesticides) and regulating their use in the United States (EPA, 2024e; 2024f). In the initial registration process, the company that intends to produce a rodenticide must first get approval from EPA. The company's application must specify the product's ingredients and their composition, information on the product's risks to human health and the environment, proposed labels, warnings, instructions for use, and other details.

As required by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), EPA conducts a registration review process for every pesticide at least every 15 years to ensure that the pesticide continues to meet FIFRA's standards and does not cause unreasonable adverse effects to human health and the environment. EPA makes risk management and regulatory decisions, where EPA considers the results of the risk assessments and benefit assessments, and determines if the proposed uses of the pesticide generally cause unreasonable risks under the FIFRA mandate. The FIFRA registration review process involves a preliminary work plan, a final work plan, focus meetings, an issue data call-in, a draft risk assessment, benefit assessment, ESA-related mitigation measures, a proposed interim decision (PID), and interim and final decisions (EPA, 2024e; 2024f). EPA may also publish risk mitigation decisions alongside proposed interim and final decisions.

When registering rodenticides, EPA classifies them as either "restricted-use" or "general-use" (40 CFR § 152.160-152.176). Restricted-use pesticides cannot be sold to the public and can only be sold to and used by appropriately licensed applicators. General-use pesticides, on the other hand, may be sold to anyone and (with few exceptions) used by anyone. All EPA-registered pesticides (including general-use pesticides) have labels with requirements that users must follow, and state and federal agencies have the authority to enforce label requirements. States also have the authority to restrict the use of general-use pesticides in their jurisdictions. The FGARs and SGARs registered with EPA and the Massachusetts Pesticide Board Subcommittee fall under both categories of use.

1998 Registration Eligibility Decision (RED)

In 1998, EPA issued a *Registration Eligibility Decision (RED)* covering rodenticides, including anticoagulant compounds. The 1998 RED reclassified many field-use products as restricted-use pesticides and introduced requirements for adding indicator dyes and bittering agents to reduce risks to children (EPA, 1998a, 1998b). However, EPA later determined that bittering agents could reduce efficacy and that there was insufficient evidence to require indicator dyes. In 2001, the agency removed these requirements. Although this decision was challenged in court, EPA's actions regarding indicator dyes were upheld, and the issue of bittering agents was remanded for further review (EPA, 2008).

2008 Risk Mitigation Decision (RMD)

As EPA's final action in response to the 2004 remand order, the agency published the *Risk Mitigation Decision (RMD) for Ten Rodenticides* in 2008, which covered seven ARs and three non-ARs (EPA, 2008). As part of this action, EPA established separate requirements for products intended for general consumers versus those marketed for agricultural and professional use. These requirements prohibit the sale of SGARs and loose bait products to general consumers, mandate tamper-resistant bait stations in many scenarios, and limit package sizes for consumer products. Although SGARs remain classified as general-use pesticides rather than restricted-use, EPA specifies that:

> "*Registrants will control distribution of the products so that they shall only be distributed to or sold in agricultural, farm, and tractor stores or directly to pest control operators and other professional applicators, and that registrants will not sell or distribute SGAR products in channels of trade likely to result in retail sale in hardware and home improvement stores, grocery stores, convenience stores, drug stores, club stores, big box stores, and other general retailers*" (EPA, 2022d).

Even so, because SGARs are not formally classified as restricted-use, they remain available to individuals without a pesticide license.

In the RMD, EPA explained that the aforementioned control measures were intended both to minimize children's exposure to rodenticides in the home environment and to reduce ecological risks to wildlife from

primary and secondary poisoning. The RMD did not prohibit professional application of SGARs outdoors, above ground; however, the use of tamper-resistant bait stations was required in these and other scenarios (EPA, 2008).

The list below summarizes key restrictions from the 2008 RMD, many of which are described in the preceding narrative. EPA grouped these restrictions according to the intended users of each rodenticide product. They are reproduced below for reference:

- Products intended for consumers (FGARs and non-ARs only):
    - "Consumer size" products are defined as "products containing less than or equal to one pound of bait and are available for sale in typical retail outlets (e.g., hardware and home improvement stores, grocery stores, convenience stores, drug stores, club stores, big box stores)."
    - SGARs are not allowed to be sold in consumer size products (only FGAR and non-AR rodenticides).
    - Bait blocks and paste forms are the only forms of bait approved for use. Meal, treated whole-grain, pelleted, and liquid forms of bait are prohibited.
    - All consumer size products must be sold packaged together with a ready-to-use (pre-baited) bait station. Bait stations must be tamper-resistant when placed in areas accessible to children or domestic animals.
- FGAR and non-AR products intended for agricultural use and professional applicators
    - Products must contain at least 4 pounds of bait. Any form of bait is acceptable.
    - Bait need not be sold in or with bait stations, but labels must require use of bait stations where children, domesticated animals, or non-target wildlife may be exposed (this is not a new requirement).
- SGAR products intended for agricultural use
    - SGAR products intended for use in agricultural settings must be sold in packages that contain more than 8 pounds of bait. Any form of bait is acceptable.
    - Product labels must require use of bait stations for all outdoor, above ground placements.
    - Labeled for use only inside of and within 50 feet of agricultural buildings and not for use in and around homes.
    - Bait need not be sold in bait stations, but labels must require use of bait stations for indoor applications where children, domesticated animals, or non-target wildlife may be exposed.
    - Registrants must agree to terms and conditions of registration specifying that the registrants will control distribution of the products so that they only be distributed to or sold in agricultural, farm and tractor stores or directly to professional applicators.
- SGAR products for professional applicators
    - SGAR products intended for use by professional applicators must be sold in packages that contain more than 16 pounds of bait. Any form of bait except liquid is acceptable.
    - Product labels must require use of bait stations for all outdoor, above ground placements.
    - Labeled for use only inside of and within 50 feet of buildings.

- Bait need not be sold in bait stations, but labels must require use of bait stations for indoor applications where children, domesticated animals, or non-target wildlife may be exposed.
- Registrants must agree to terms and conditions of registration specifying that the registrants will control distribution of the products so that they only be distributed to or sold in agricultural, farm and tractor stores or directly to professional applicators.

2022 Proposed Interim Registration Review Decision

In 2022, as part of its periodic FIFRA registration review process, EPA issued a *Proposed Interim Registration Review Decision* for all seven ARs. This proposed decision re-evaluated the human health and ecological risks of these compounds using updated scientific information and recommended additional measures intended to further reduce exposure to children, pets, and wildlife. The proposed risk mitigation measures included (EPA, 2022d):

- Classify all SGAR products as restricted-use pesticides.
- Classify all FGAR products ≥ 4 pounds as restricted-use pesticides.
- All consumer-sized FGAR products must be applied in ready-to-use disposable bait stations. All other methods of FGAR product application are prohibited.
- Require occupational handlers to wear respirators and gloves when using products that are loose formulations (e.g., meal baits, tracking powders, grain meals, waxy or paraffinized and non-paraffinized pellets).
- For outdoor above ground applications of loose formulations of chlorophacinone and diphacinone, prohibit the direct application of these products to food or feed crops, restrict application of these products to the dormant period of the target crop, and restrict application of these products to buffer strips, fence lines, and border areas adjacent to target crops.
- Prohibit broadcast applications (spreading of bait across a wide area) of FGARs in turfgrass and recreation areas, which would limit site managers to using bait stations and below ground rodenticides, or non-chemical rodent control methods such as mechanical traps.
- Require additional mitigation measures for broadcast, spot/scatter, and below ground applications of chlorophacinone and diphacinone products in cropped areas, rangeland, and pastures.
- Update the Terms and Conditions for Registration for all rodenticides to require registrants to develop, implement, and maintain rodenticide stewardship plans, including education and outreach materials for product users; registrants are also required to make these materials available on their websites.

This proposed interim decision is not a binding regulation, and EPA is expected to issue either a final interim decision or a full registration review decision in 2025 (EPA, 2024a). As of June 2025, EPA has not yet published a final interim decision or final decision for the 2022 proposed mitigation measures. Later sections of this report describe in detail the scientific reviews underpinning these proposed regulatory actions.

Section 3.4 summarizes additional restrictions and requirements implemented by individual states that go beyond the federal measures described above.

3.3 Use of Anticoagulant Rodenticides in Massachusetts

MDAR is the Massachusetts agency that registers pesticides for use in the state. Information on MDAR-registered products is available through the Massachusetts Pesticide Product Registration Information website (Kelly Registration Systems, Inc., 2025). This section provides an overview of the registration and use of ARs in Massachusetts. ERG compiled and analyzed data from two primary sources:

- The first is the Massachusetts Pesticide Product Registration Information website (Kelly Registration Systems, Inc, 2025), along with a corresponding Excel database provided by MDAR of the data underlying the website. The data from these two resources provide the latest information on registered products in Massachusetts as of March 2025.
- The second is the Commonwealth of Massachusetts' Annual Pesticide Use Information website (MDAR, 2025), which provides details on the reported use of each rodenticide as required by 333 CMR 10.14. Under this regulation, licensed applicators are required to annually report the amounts of rodenticides (and other pesticides) used within the Commonwealth. The most recently available usage data are for 2022 and 2023.

Together, these resources provide insight into which products are registered, the quantities used by licensed applicators, and the types of sites treated.

Registration and Availability of Anticoagulant Rodenticides

The seven ARs registered by EPA are:

- FGARs: Chlorophacinone, diphacinone (and its sodium salt), and warfarin (and its sodium salt)
- SGARs: Brodifacoum, bromadiolone, difenacoum, and difethialone

To assess which ARs are registered and used in Massachusetts, ERG searched the Massachusetts Pesticide Product Registration Information website for details on rodenticides containing the EPA-registered active ingredients above. As of March 5, 2025, all seven ARs registered by EPA were also registered for use in Massachusetts. The database included records for 96 unique EPA registration numbers corresponding to these active ingredients.

ERG also searched the Commonwealth of Massachusetts' Annual Pesticide Use Information website to determine the number of products used in 2023, the most recent year with available data (MDAR, 2025). According to these data, all seven active ingredients were used by licensed applicators in Massachusetts; and in 2023, licensed applicators used 58 different products containing these active ingredients. Table 1 summarizes the number of products registered, the range of concentrations of active ingredient(s) in each product, and the number of products used in 2023, by active ingredient. The accuracy of these data is not known and entirely depends on applicators' self-reporting practices.

TABLE 1. COUNTS OF EPA-REGISTERED FGAR AND SGAR PRODUCTS USED IN MASSACHUSETTS

Generation	Active Ingredient	Number of Unique Products* Registered for Use in Massachusetts in 2025	Number of Unique Products* Used in Massachusetts in 2023	Range of % Active Ingredient in Products Registered for Use in Massachusetts in 2023
FGAR	Chlorophacinone	5	6	0.005-0.2%
FGAR	Diphacinone (and its sodium salt)	31	11	0.005-0.2%

Generation	Active Ingredient	Number of Unique Products* Registered for Use in Massachusetts in 2025	Number of Unique Products* Used in Massachusetts in 2023	Range of % Active Ingredient in Products Registered for Use in Massachusetts in 2023
FGAR	Warfarin (and its sodium salt)**	5	2	0.025%
SGAR	Brodifacoum	16	9	0.0025-0.005%
SGAR	Bromadiolone	31	23	0.005%
SGAR	Difenacoum	2	1	0.005%
SGAR	Difethialone	6	6	0.0025%

Source of data: Massachusetts Pesticide Product Registration Information website (Kelly Registration Systems, Inc., 2025) and Annual Pesticide Use Information website (MDAR, 2025).
** Determined by unique EPA Registration IDs; a single product can be sold under multiple brand names.*
*** Certain formulations of warfarin contain multiple active ingredients; the sodium salt of warfarin was not included in any registered products.*

In 2025, the FGAR found in the greatest number of registered products in Massachusetts was diphacinone (and its sodium salt). It was included in 31 unique products registered in 2025, and licensed applicators reported using 11 of those products in 2023. Among the SGARs, bromadiolone was the active ingredient found in the greatest number of products registered in 2025. It was contained in 31 unique products, and licensed applicators reported using 23 of these products in 2023. Two factors might explain the differences between the number of products registered and the number of products used. First, the data for these two numbers come from different years. Second, the data on the number of products used only reflects self-reported data by licensed applicators; it does not account for products used by consumers.

Label Information and Allowed Uses

ERG reviewed the Kelly Solutions database to obtain additional details on registered AR products. This review included examining, for each product, the webpages for "Pests Controlled by this Product," "Sites to which this Product may be Applied," and "EPA Stamped Labels" webpages. The specific pests controlled by these products varied, but most products targeted species of mice (e.g., the house mouse, harvest mouse), rats (e.g., the Norway rat, roof rat, cotton rat), and voles (e.g., meadow vole). Similarly, the approved application sites vary widely and often include more than a dozen types of locations, such as domestic dwellings, commercial, institutional, and industrial areas and buildings, and transportation vehicles.

The EPA-accepted product labels linked in the Kelly Solutions database provide extensive information about individual products, and most labels that ERG reviewed are at least five pages long. These labels have information on allowed application methods and rates, formulation details, precautionary statements, and other relevant topics. Application is generally recommended in areas where rodents frequently feed, such as along walls, in corners, or near burrow openings. The amount of bait to apply varies depending on the target species. Labels consistently warn users that the products are extremely toxic to mammals and birds; they also advise users to avoid contaminating local water resources when disposing of equipment rinsate.

Reported Use by Crop or Site Type

ERG also analyzed reported usage by crop or site type. Table 2 presents the breakdown of AR products by crop or site types for all products used in Massachusetts in 2023, as reported in the state usage database. Most products were applied at "structural pest" sites, accounting for 56% of all applied products with a documented "crop or site treated" field. "Turf and landscape" was the next most common application site,

accounting for 22%. The remaining products were split among other "crop or site treated" fields. Some database records did not include any information in the "crop or site treated" field; the reason for this is not known.

TABLE 2. NUMBER OF PRODUCTS USED IN MASSACHUSETTS IN 2023 BY CROP OR SITE TREATED

Crop or Site Treated	Number of Unique Products*
Structural Pest	49
Turf and Landscape	19
Tree Fruit	5
Greenhouse	4
Right-of-Way	3
Tree and Shrub	3
Non-Soil Fumigation	2
Agricultural Crops	1
Pastures, Hay, and Forage	1
Vegetable	1

Source of data: Annual Pesticide Use Information website (MDAR, 2025).
** Determined by unique EPA Registration IDs; a single product can be sold under multiple brand names.*

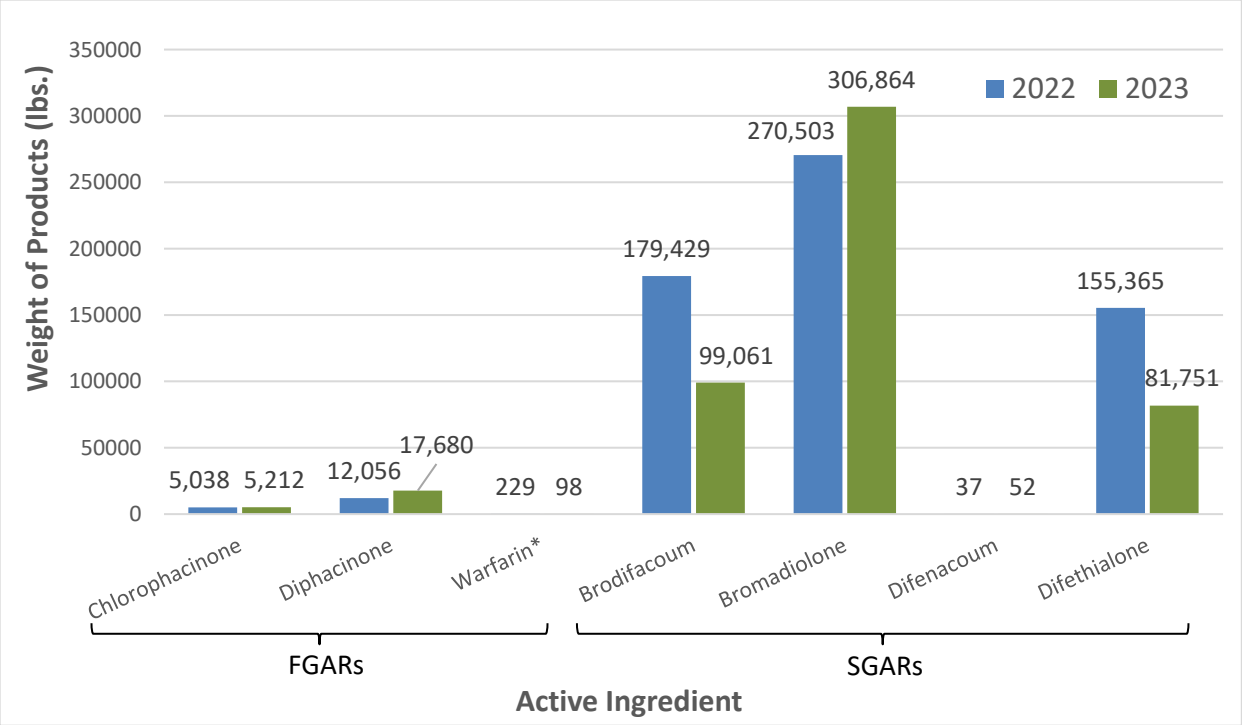
Quantities of FGARs and SGARs Applied by Licensed Applicators in 2022 and 2023

The quantities of ARs that licensed applicators applied in Massachusetts were obtained from the Commonwealth's Annual Pesticide Use Information website (MDAR, 2025). State regulation (333 CMR 10.14) requires licensed applicators to submit annual usage reports. The annual reports have fields such as "Product Name," "EPA Reg. No.," "Active Ingredients," "Total Amount," and "Crop or Site Treated." Most database records specified usage quantities in units of weight, but some records had other metrics (e.g., volumes, number of blocks). Reported usage amounts were standardized to pounds of active ingredients based on the specific product formulations from the Massachusetts Pesticide Product Registration Information website (Kelly Registration Systems, Inc., 2025). It is important to note that these figures reflect only self-reported data from licensed applicators; the data do not account for quantities purchased and applied by consumers.

Figure 1 shows weights of AR products applied by licensed applicators in Massachusetts in 2022 and 2023, broken down by active ingredient. The chart shows the total quantities of formulated products used, regardless of the concentration of active ingredients in each formulation. Across both years, SGAR products were used in far greater total amounts by weight than FGAR products—on average 27 times more. Overall, the total weight of products applied decreased by 111,939 pounds from 2022 to 2023, and the changes from year to year varied by active ingredient. For example, the use of bromadiolone, the active ingredient used in greatest quantities, increased by 36,000 pounds from 2022 to 2023, while brodifacoum and difethialone decreased by roughly 80,000 pounds and 74,000 pounds, respectively. Only two years of Massachusetts usage data are currently available electronically (previous years are available as hard copy), and additional years of data would need to be reviewed to understand licensed applicators' longer-term usage trends. That said, a 2015 survey of Massachusetts pest management professionals found that bromadiolone was the most commonly used AR active ingredient at the time, with 73% of respondents

reporting they had applied it since 2011, indicating that products containing bromadiolone likely have accounted for the greatest AR product use for more than a decade (Memmott et al., 2017).

FIGURE 1. WEIGHT OF PRODUCTS USED BY LICENSED APPLICATORS IN MASSACHUSETTS IN 2022 AND 2023



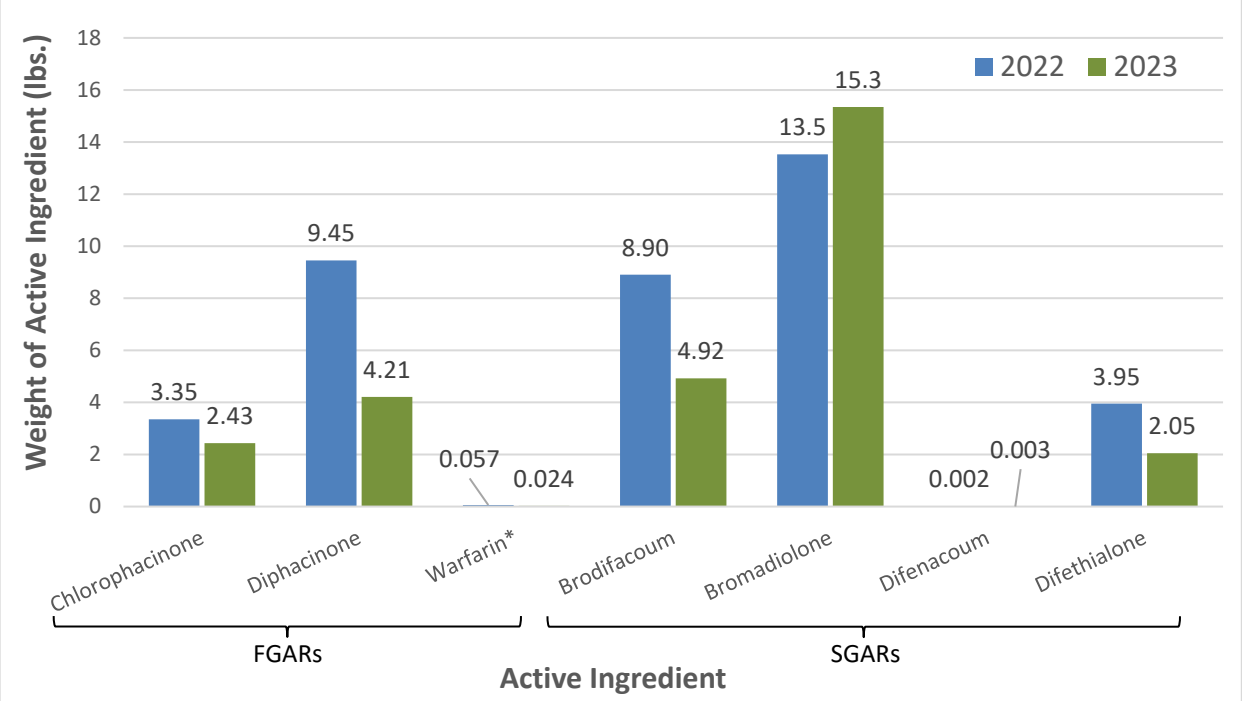
Source: MDAR, 2025
Notes: Usage data are self-reported by licensed applicators as required by 333 CMR 10.14.
**Certain formulations of warfarin have multiple active ingredients.*

The previous text summarized weights of FGAR and SGAR products used by licensed applicators in Massachusetts in 2022 and 2023. Data are also available on weights of FGAR and SGAR active ingredient usage, and Figure 2 summarizes those data for the same time frame. While the earlier data on product weight (Figure 1) show that SGARs were used in much larger total amounts than FGARs, this difference is less pronounced for the weight of active ingredients (Figure 2); and the relative quantities of active ingredient usage are more relevant for understanding total environmental exposures. The differences between the two figures likely reflect the different active ingredient concentrations in the AR products (Table 1). The distinction between product weight and active ingredient weight also highlights other differences. For example, Figure 1 suggests that diphacinone product use increased from 2022 to 2023; however, Figure 2 shows that the total weight of diphacinone active ingredient actually declined. This discrepancy indicates that the products used in 2023 were less concentrated than those applied in 2022. As shown in Table 1, registered diphacinone products vary widely in concentration, ranging from 0.005% to 0.2% active ingredient.

Overall, a total of 29 lbs of AR active ingredients were used by licensed applicators in Massachusetts in 2023. Among individual active ingredients, bromadiolone was the SGAR used in greatest quantities by weight in both 2022 and 2023, followed by the SGAR brodifacoum and the FGAR diphacinone. These three active ingredients were also present in the greatest number of unique products (Table 1). In contrast, warfarin and difenacoum accounted for the smallest quantities used (Figure 2) and were registered in the

fewest unique products (Table 1). As of 2025, only two products containing difenacoum were registered for use in Massachusetts, one of which was applied in 2023 (Table 1).

FIGURE 2. WEIGHT OF ACTIVE INGREDIENTS USED BY LICENSED APPLICATORS IN MASSACHUSETTS IN 2022 AND 2023



Source: MDAR, 2025
Notes: Usage data are user reported by licensed applicators as required by 333 CMR 10.14.
** Certain formulations of warfarin have multiple active ingredients.*

Quantities Applied by Site Type

For all seven AR active ingredients, structural pest control was the most common application category, accounting for 95% of total usage by licensed applicators in 2023 (Table 3). Specifically, structural pest applications accounted for more than 90% of the licensed applicators' total usage of chlorophacinone, brodifacoum, bromadiolone, and difenacoum. Turf and landscape treatments ranked second in terms of amounts of ARs used. Other use types, such as treatment of agricultural areas, right-of-way areas, trees and shrubs, and non-soil fumigation, collectively accounted for only a small fraction of total AR use. The data used to generate the following summary table has notable gaps. Most notably, of the 2023 diphacinone usage quantities in the statewide database, 23.5% had no entry for "crop or site treated," which complicates efforts to interpret usage quantities for this AR.

TABLE 3. WEIGHT OF ACTIVE INGREDIENT USED IN MASSACHUSETTS IN 2023, BY CROP OR SITE TREATED

Crop or Site Treated	Percent of Total Weight of Active Ingredient Used in 2023						
	FGARs			SGARs			
	Chlorophacinone	Diphacinone	Warfarin*	Brodifacoum	Bromadiolone	Difenacoum	Difethialone
Agricultural Crops	<0.1%	0%	0%	0%	0%	0%	0%
Greenhouse	0%	<0.1%	0%	<0.1%	<0.1%	0%	0%
Non-Soil Fumigation	0%	0.1%	0%	0%	0.1%	0%	0%

Crop or Site Treated	Percent of Total Weight of Active Ingredient Used in 2023						
	FGARs			SGARs			
	Chlorophacinone	Diphacinone	Warfarin*	Brodifacoum	Bromadiolone	Difenacoum	Difethialone
Pastures, Hay, and Forage	0%	0%	0%	<0.1%	0%	0%	0%
Right-of-Way	0%	0%	0%	<0.1%	<0.1%	0%%	2.2%
Structural Pest	92.2%	74.3%	60.8%	98.6%	98.7%	100	87.3%
Tree and Shrub	0%	0%	0%	0.2%	<0.1%	0%	<0.1%
Tree Fruit	1.5%	1.7%	0%	0%	0%	0%	0%
Turf and Landscape	6.5%	0%	39.1%	1.1%	1.3%	0%	6.9%
Vegetable	0%	<0.1%	0%	0%	0%	0%	0%
Blank Entry**	0%	23.5%	0%	<0.1%	0.4%	0%	3.7%
Total (pounds)	**2.43**	**4.21**	**0.0245**	**4.92**	**15.3**	**0.00261**	**2.05**

Source: MDAR, 2025.
Notes: 2023 usage data are user reported as required by 333 CMR 10.14. Under this regulation, licensed applicators are required to annually report the amounts of certain pesticides, including rodenticides, that they use within the Commonwealth.
** Certain formulations of warfarin have multiple active ingredients.*
*** Certain active ingredients did not have any information listed in the "Crop or Site Treated" field of the usage database. The reason for this is not known.*

Insights on Use by Non-Licensed Applicators

The survey that ERG distributed during Phase One included questions that sought data on amounts of ARs used by people other than licensed applicators. No respondents identified published information on this topic; and many respondents indicated they were not aware of any published data on AR quantities used by homeowners, businesses, or other unlicensed users. Several respondents pointed to the Annual Pesticide Use Information website (MDAR, 2025), but this resource only reports usage data for licensed applicators and is summarized above. Some respondents noted that SGARs remain widely available for online purchase, despite their intended use by licensed professionals based on EPA's Risk Mitigation Decision. Finally, a few respondents suggested exploring retail sales data from companies such as Amazon; however, the respondents did not provide further information on those data, which do not appear to be publicly available.

Interviews with state pesticide regulators similarly confirmed that while many states track AR usage by licensed applicators, none maintain records on quantities applied by consumers. The amounts of AR used in Massachusetts and other states by non-licensed applicators is evidently not known.

3.4 State-Level Restrictions

States also register pesticides and may impose additional limits on EPA-registered products that are used within their jurisdictions. States cannot, however, register pesticides that have not first been registered by EPA. ERG interviewed representatives from nine states other than Massachusetts (California, Connecticut, Georgia, Maine, New Hampshire, New York, Rhode Island, Vermont, and Washington) to identify state-level regulations or policies governing the use of FGARs and SGARs beyond federal requirements. Relevant insights from these interviews are summarized below.

Current Restrictions

The following examples highlight existing state-level measures that impose limits on ARs:

- **California**: In 2024, Assembly Bill 2552 expanded existing restrictions on ARs to prohibit the use and sale of all FGARs and SGARs, except when necessary to protect public health, water supplies, or agriculture. These are the most comprehensive statewide restrictions in the country and are described in more detail later in this section.
- **Washington:** State law (Washington Administrative Code (WAC) 16-228 § 1380) adds several requirements for outdoor, above ground use of rodenticides. These include mandatory use of locked or sealed tamper-resistant bait stations that are durable, resistant to overturning, and secured to prevent access by children, pets, and wildlife; prohibition of loose or tracking-powder baits in accessible locations and above-floor indoor placements; requirements to clearly label bait stations with applicator and active ingredient information; and cleanup of any spilled bait (WAC 16-228 § 1380, 2010).
- **Vermont:** In 2024, all SGARs were classified as restricted-use pesticides (6 VT Stats § 918(g)).
- **Rhode Island:** Rhode Island statute 250-RICR-40-15-2 outlines additional requirements regarding bait boxes and labeling, including the use of signal words such as “Danger-Poison” and “Warning.”
- **Maine:** On May 27, 2025, a law was passed that directed the Maine Board of Pesticides Control to “prohibit the use of rodenticides, including rodenticidal baits, in outdoor residential settings,” exempting certified applicators (132nd Leg., LD 356, 2025).
- **Georgia**: Georgia restricts the location and timing of rodenticide applications at schools and licensed childcare centers (Ga. Comp. R. and Regs. R. 620-11-.01).

Legislation Under Consideration

Many different bills related to the regulation of FGARs and SGARs are introduced each year in state legislatures across the country. Below is a list of recent proposed bans and restrictions being considered in state legislatures that were identified through ERG’s review. This list does not address bans and restrictions being considered in other states.

- **Vermont:** On February 25, 2025, Bill H326 was introduced in the state’s General Assembly, aiming to prohibit the use and sale of all FGARs and SGARs with certain exceptions. As of October 2025, this Bill had not advanced out of committee. Separately, in 2024 Vermont enacted 6 V.S.A. § 918(g), which requires all SGARs to be registered as restricted use pesticides (Class A), limiting their purchase and use to certified applicators.
- **Connecticut:** On February 10, 2025, Bill HB6915 was introduced in the Connecticut House of Representatives that would ban SGARs with some exceptions. A different bill (Substitute Senate Bill No. 9) was signed into law on July 9, 2025, which classified SGARs as restricted use in the state, limiting access to professional, licensed applicators.
- **New York:** On April 22, 2025, Bill S7532 was introduced in the New York State Senate to ban SGAR sales online and in retail stores and would prohibit the application of FGARs and SGARs within 500 feet of a wildlife habitat area. As of October 2025, the bill had not been signed into law.
- **Rhode Island:** On June 3, 2025, a bill passed the Rhode Island State Senate (2025-S 0651A) that would prohibit the sale of FGARs to consumers beginning March 1, 2026, and prohibit the sale of SGARs beginning January 1, 2027. In addition, use of both FGARs and SGARs would be prohibited by January 1, 2028, with some exceptions. As of October 2025, the bill had not been signed into law.

During the interviews, ERG also sought information on the extent to which cities and towns within the interviewed states had adopted their own policies to restrict or prohibit the use of ARs. Many interviewees explained that municipalities in their states cannot preempt state authority for regulating pesticides and therefore cannot ban all uses within their jurisdictions. However, some noted that a municipality could choose to limit or prohibit the use of ARs on city- or town-owned property. While these local actions do not affect private use, they reflect growing concern about ecological risks on public land.

In Massachusetts, several towns (e.g., Arlington, Newbury) have approved policies in recent years prohibiting the use of SGARs on town-owned properties (Pooler, 2023; Town of Newbury, 2024). In addition, other towns (e.g., Concord, Lexington) are seeking statewide authorization via home-rule petitions to regulate or prohibit rodenticides more broadly (Town of Concord, 2025; Town of Lexington, 2025). Because these local actions are evolving and a comprehensive review of local actions was not included in this project's scope of work, this report does not present a definitive tally; instead, Appendix A summarizes commenter-submitted compilations and further examples. On February 27, 2025, a bill was introduced in a subcommittee of the Massachusetts state legislature to direct MDAR not to register or reregister ARs except "for the limited use of anticoagulant rodenticides by licensed applicators in public health emergencies" (Bill S644, 2025). The bill is scheduled for a hearing by the Joint Environment and Natural Resources Committee on October 27, 2025.

California-Specific Regulatory Actions

Over the past decade, California has adopted multiple laws that progressively strengthened AR restrictions. In 2015, AB 2657 prohibited the use of SGARs, without prior authorization, in wildlife habitat areas managed by the California Department of Fish and Wildlife. In 2020, AB 1788 established a statewide moratorium on most uses of SGARs, with exemptions for certain public health and agricultural purposes. Specifically, the 2020 California law exempts:

- Government employees using SGARs for public health activities or protecting water supply infrastructure.
- Use by a mosquito or vector control district to protect public health.
- Eradication of nonnative species on offshore islands.
- Applications in which a rodent infestation is deemed a public health threat by a local or state public health officer.
- Approved research purposes.
- Applications at medical waste generator sites and by manufacturers of pharmaceuticals or medical devices.
- Agricultural activities, including food storage facilities, food manufacturing facilities, breweries, wineries, and other agricultural production sites.

AB 1298 (2021) corrected a drafting error in AB 2567. The new regulation clarifies that an exemption to the SGAR ban applies when the Department of Fish and Wildlife determines that SGAR use is necessary to control or eradicate an invasive rodent population for the protection of threatened or endangered species or their habitats.

Following a ruling by California's First District Court of Appeal in 2022, the California Department of Pesticide Regulation (CDPR) conducted a new assessment of diphacinone, a FGAR. DPR found that potential impacts to wildlife have occurred or are likely to occur, but CDPR has not yet proposed any restrictions. This prompted the passage of AB 1322 in 2023, which restricted the use of diphacinone in a similar manner, and

with similar exceptions, as SGARs. The law also directed CDPR to further restrict SGARs as needed, with the goal of reducing wildlife exposures.

In 2024, the legislature went further by enacting AB 2552, which expanded restrictions to include all FGARs and SGARs and introduced civil penalties for violations. As of January 2025, the use of any FGAR or SGAR in California is prohibited unless one of the previously listed exemptions applies. According to conversations with CDPR, data on the frequency or types of exemptions invoked under this law has not yet been compiled. The above restrictions will remain in effect until CDPR completes its re-evaluations of each rodenticide and issues final determinations.

On September 24, 2025, the CDPR held an informal public workshop to present proposed mitigation measures for ARs and to gather stakeholder feedback. CDPR posted a deliberative draft of proposed regulatory text and related materials in connection with the workshop. The regulation would, among other provisions, add use-site limitations, set duration caps on baiting, and include requirements for training, recordkeeping, and developing Sustainable Rodent Management plans. The public comment period for this draft regulation is open until November 8, 2025.

4 Human Health Effects of Anticoagulant Rodenticides

This section summarizes the current state of knowledge on the human health effects of anticoagulant rodenticides (ARs). It draws on major assessments issued by authoritative bodies (Section 4.2; Section 4.3) and the most recent evidence from peer-reviewed literature (Section 4.4). The targeted literature searches were conducted to address specific topics of concern and to help identify potential data gaps. Additional details on the search strategy and results are provided in later subsections.

4.1 General Considerations for the Scientific Review of Human Health Effects

ARs interfere with normal blood clotting in the vitamin K cycle in mammals. This interference has therapeutic medical applications as some ARs (e.g., warfarin) have been used to treat thrombosis in humans. This section does not review the extensive published information about pharmaceutical applications of selected AR chemicals because therapeutic uses of chemicals in ARs to treat health conditions are not relevant to incidental environmental exposures to these chemicals. The section focuses on scientific findings regarding adverse human health effects associated with poisoning incidents and environmental and occupational exposures to ARs.

United States, European, and other international regulatory agencies have all approved the use of ARs in their jurisdictions. The assessments by authoritative bodies reviewed in this section primarily consider the exposures and risks resulting from the use of ARs in accordance with registered label instructions. However, some data also address unintentional misuse, intentional self-harm, and accidental ingestion, especially among children. These data are based on incident reporting systems and case studies published in peer-reviewed literature, but these incident reporting data have inherent limitations. For example, many poisoning cases are reported voluntarily, lack complete exposure verification, or are difficult to attribute definitively to a specific AR product or active ingredient.

4.2 EPA Assessments

EPA has published numerous documents addressing the human health effects of ARs as part of the ongoing pesticide registration process. Under FIFRA, these documents serve different purposes, such as evaluating toxicity, summarizing incident reports, assessing benefits and risks, and supporting regulatory decisions.

This section summarizes key EPA documents relevant to human health, including:

- **Risk mitigation and regulatory decision documents** that describe the rationale and actions taken to reduce human health risks (e.g., prohibitions, packaging requirements). These documents include the *Risk Mitigation Decision for Ten Rodenticides* (EPA, 2008), the *Updated Review of Rodenticide Incident Reports* (EPA, 2006), and the *2013 Statement of Reasons* to cancel certain registrations (EPA, 2013a).
- **Human health scoping documents** that define the scope of risk assessments, identify data gaps, and specify topics for further evaluation (EPA, 2015b, 2015e, 2015f, 2016e, 2016f, 2016g, 2016h).
- **Draft human health risk assessments** that summarize hazard, dose-response, exposure, and potential risks from using these rodenticides (EPA, 2020a) and the combined scoping and draft human health risk assessment for warfarin (EPA, 2015b).
- **Updated incident data reviews** that summarize reported poisoning incidents in humans, including their trends over time (e.g., declines in exposure following mitigation measures), notably the *2022 Revised Tier I Update Review of Human Incidents* (EPA, 2022a).

- **A use and benefits assessment** that evaluates the role of rodenticides in pest management, describes economic and practical considerations, and analyzes potential impacts and benefits of proposed risk mitigation (EPA, 2022b).
- **A review of residues of concern** that assesses whether degradation products of chlorophacinone or diphacinone in treated crops could pose human health risks through dietary and other exposures (EPA, 2022c).
- **The Integrated Risk Information System (IRIS) assessment for warfarin** that reviews scientific evidence of warfarin toxicity that was available in 1987 (EPA, 1987). Since then, EPA stopped evaluating pesticide toxicity in agency's IRIS program and instead did so as part of the pesticide registration and reregistration process.

This section summarizes these documents' findings on hazard identification, exposure incidents, and adverse health effects in humans. Section 5 summarizes ecological impacts described in these and other documents.

Risk Mitigation Decision Documents

In its 2008 Risk Mitigation Decision (RMD), which was part of the Agency's final decision on the reregistration eligibility of rodenticide products at that time, EPA cited data from the American Association of Poison Control Centers (AAPCC), which reported that since 1993, approximately 12,000 to 15,000 incidents of rodenticide exposure had been reported in children six years old or younger. Most exposed children experienced no symptoms or adverse effects. However, from 1999 through 2003, an average of 3,617 cases were treated per year in a health facility, 115 cases were symptomatic, and 17 cases required treatment in an Intensive Care Unit. EPA determined that the number of incidents leading to symptomatic diagnoses or requiring treatment was unacceptably high given the feasibility of risk reduction measures (EPA, 2008).

To support the 2008 RMD, EPA also published the *Updated Review of Rodenticide Incident Reports Primarily Concerning Children* (2006) (EPA, 2006). This report evaluated exposure incidents in children under six years old for all FGARs and SGARs except difenacoum (which was first registered for use in the United States in 2007, after EPA published its *Updated Review*). EPA analyzed data from its Incident Data System (IDS) from 1999 through 2005 and cases reported in the Poison Control Center Database from 1999 to 2003. According to IDS data, 63% of rodenticide incidents with young children involved brodifacoum (30 of 48 cases). Among all acute poisoning incidents reported to the Poison Control Center Database between 1999 and 2003, the percentage of children under six evaluated at a healthcare facility due to rodenticide exposure (27%) was greater than that of all pesticides combined (16%). However, the rodenticide exposure incidents were less severe than that of other pesticides overall, and the incidents were often treatable and rarely required hospitalization. According to the Poison Control Center Database, brodifacoum accounted for 78.8% of all rodenticide exposure incidents in children aged six and under during the five-year exposure period (1999-2003) (EPA, 2006).

By 2011, many rodenticide registrants had voluntarily amended or replaced their registrations to comply with the 2008 RMD. In 2013, EPA published a *Statement of Reasons and Factual Basis for Notice Intent to Cancel Registrations of, and Notice of Denial of Applications for Certain Rodenticide Bait Products* (EPA, 2013a). This document summarizes the risks to human health and the environment that served as the basis for EPA's intent to cancel all remaining non-compliant rodenticide registrations. One of EPA's primary concerns was the risk of acute exposure from a single ingestion event, such as when a child consumes rodenticide bait. Using an uncertainty factor of 1,000 and LD_{50} values from rat toxicity studies, EPA established the following surrogate exposure levels of concern: 0.003 mg/kg for warfarin, 0.00042 mg/kg

for brodifacoum, 0.00055 mg/kg for difethialone, and 0.0026 mg/kg for bromethalin. Registered AR bait products contain active ingredient concentrations ranging from 0.0025% to 0.025% (see Table 1). Based on this composition, EPA determined that a 5-gram bite of bait consumed by a 10-kilogram child would exceed the surrogate exposure levels of concern for each of these rodenticides (EPA, 2013a).

Human Health Scoping Documents

As part of the current registration review cycle, the EPA Health Effects Division (HED) published human health scoping documents outlining the scope of work necessary to support Registration Review for all seven ARs. These documents included an evaluation of previous risk assessments, updates to the toxicity, exposure, and usage databases, and updates to EPA science policy and risk assessment methodologies (EPA, 2015b, 2015e, 2015f, 2016e, 2016f, 2016g, 2016h). Because ARs are formulated exclusively as solids, EPA did not assess exposure to spray drift or volatilization; however, the agency reported that occupational handlers of ARs could have short- and intermediate-term dermal and inhalation exposure. Chronic dietary exposure and carcinogenicity studies were not required as part of the registration review process.

The EPA scoping documents assessed the toxicity profiles of all seven ARs. The most sensitive indicator of AR toxicity is prothrombin time (i.e., the time it takes for blood to clot), with signs of toxicity typically including hemorrhaging and death. HED evaluated available animal data (generally from studies of rats, rabbits, guinea pigs, and dogs) to characterize toxicity via oral, dermal, and inhalation (dust aerosols) exposure pathways (see Table 4). All seven anticoagulant active ingredients are toxicity Category I (highly toxic) for oral, dermal, and inhalation exposure. The AR active ingredients that were evaluated for dermal effects were found to cause mild to no irritation (Toxicity Category IV), except for warfarin, which caused moderate irritation (Toxicity Category III). Ocular effects ranged from moderate irritation (Toxicity Category II) to no irritation (Toxicity Category IV).

TABLE 4. ACUTE TOXICITY CATEGORIES OF ANTICOAGULANT RODENTICIDE ACTIVE INGREDIENTS

Rodenticide	Generation	Human Health Risk Assessment (Year)	Toxicity Category (I-IV)				
			Oral Exposure	Dermal Exposure	Inhalation Exposure	Dermal Effects	Ocular Effects
Warfarin	FGAR	2008	I	I	I	III	III
Chlorophacinone	FGAR	1997	I	I	I	IV	IV
Diphacinone	FGAR	1997	I	I	I	IV	III
Brodifacoum	SGAR	1997	I	I	I	N/A	III
Bromadiolone	SGAR	1995; 1996	I	I	I	N/A	III
Difenacoum	SGAR	2007	I	I	I	IV	IV
Difethialone	SGAR	2008	I	I	I	IV	II-III

Source: (EPA, 2015b, 2015e, 2015f, 2016e, 2016f, 2016g, 2016h).
The toxicity category of formulated AR products may differ from that of the active ingredient. AR product labels reflect the formulated end-use product, which often fall under Toxicity Category III with a signal word of "Caution."

As of March 31, 2015, distribution to retailers should have ceased for all rodenticide products non-compliant with the 2008 RMD. For insights into AR poisoning incidents for the period before this milestone, Table 5 aggregates exposure incident data from the IDS and Sentinel Event Notification System for Occupational Risk-Pesticides (SENSOR-Pesticides) from January 2010 through May 2015. The data in the

table were reported in the seven AR human health scoping documents. The IDS data document acute, non-occupational exposures, and the SENSOR-Pesticides data consider occupational incidents. Brodifacoum and bromadiolone accounted for the majority of reported incidents, consistent with their higher prevalence in rodenticide products and their historical usage patterns. In contrast, some active ingredients, such as diphacinone, had no reported IDS data during this period. A more recent EPA report, the *2022 Revised Tier I Update Review of Human Incidents*, presents updated IDS values, which are discussed later in this section and summarized in Table 6.

TABLE 5. ANTICOAGULANT RODENTICIDE HUMAN EXPOSURE INCIDENTS FROM 2010 TO 2015

Rodenticide	Generation	Severe Effects	Moderate Effects	Minor Effects	Unknown or No Effects	SENSOR-Pesticides
		January 1, 2010 – May 27, 2015				1998-2011
Warfarin (and its sodium salt)	FGAR	0	1	1	0	NA
Chlorophacinone	FGAR	0	1	0	1	12
Diphacinone (and its sodium salt)	FGAR	NA	NA	NA	NA	NA
Brodifacoum	SGAR	5	41	250	1	NA
Bromadiolone	SGAR	1	11	119	52	15
Difenacoum	SGAR	0	0	0	1	0
Difethialone	SGAR	0	1	12	9	4

NA – not applicable, because no data from the Main or Aggregate Incident Data System were reported for diphacinone or its sodium salt. Similarly, no SENSOR data were reported for warfarin or its sodium salt.
Source: (EPA, 2015b, 2015e, 2015f, 2016e, 2016f, 2016g, 2016h)

Human Health Risk Assessments

EPA's *Draft Human Health Risk Assessment for Registration Review of Anticoagulant Rodenticides* in 2020 (EPA, 2020a) and (EPA, 2020b) assess human health risks associated with exposures to all ARs except for warfarin. The multiple AR active ingredients were considered together due to their similar toxicity and use profiles, and warfarin was evaluated separately (see next paragraph). EPA concluded that the mode of action and toxicity profiles of FGARs and SGARs are well understood, and AR exposures have resulted in adverse effects at low dose levels (µg/kg) in repeat-dose studies across multiple mammalian species and exposure routes. Several of the human health scoping documents had previously identified a need for additional toxicity data, particularly for intermediate-term dermal and inhalation exposures. However, in its 2020 *Draft Human Health Risk Assessment for Registration Review of Anticoagulant Rodenticides* (EPA, 2020a), EPA determined that additional toxicity data were not needed, because it would not significantly further EPA's understanding of AR hazards nor change the agency's conclusion that AR use should be limited to reduce risk.

EPA published the *Draft Human Health Risk Assessment in Support of Registration Review for Warfarin* in 2015 as a joint document with the *Warfarin Human Health Assessment Scoping Document* (EPA, 2015b). In addition to its use as a rodenticide, warfarin is also used as a pharmaceutical, and its toxicity, mechanism of action, and methods of overdose treatment are well-established. Given the restrictions implemented by the 2008 RMD, EPA considered warfarin's potential for spray drift, occupational exposure, and residential exposure negligible. EPA found that dietary exposure to warfarin was not anticipated.

Historically, rodenticides have all been classified as having non-food use patterns—meaning, they are not reasonably expected to directly or indirectly contaminate food. However, EPA's Health Effects Division

(HED) has found evidence of chlorophacinone and diphacinone being used in "loose meal applications" (i.e., the ARs are present as granules or powders) in certain agricultural settings. As a result, EPA evaluated the risk of potential adverse human health effects associated with consuming crops that have chlorophacinone and diphacinone residues concern (EPA, 2022c). EPA determined that degradation products of chlorophacinone (o-phthalic acid, p-chlorophenyl acetic acid) and diphacinone (diphenylglycolic acid) are more mobile than their parent AR compounds; it also determined that these degradates are likely less toxic. The degradates' lower toxicity results from the fact that they do not have the anticoagulant moiety (known as inandione). Based on the degradates' lower toxicity and lower occurrence, EPA concluded that the degradates should not be considered potential residues of concern (EPA, 2022c).

2022 Revised Tier I Update Review of Human Incidents

In the *2022 Revised Tier I Update Review of Human Incidents*, EPA provided updated human incident numbers using IDS data (Table 6) (EPA, 2022a). Between the two time periods, 2010–2015 (Table 5) and 2015–2019 (Table 6), human exposure incidents declined for all ARs except for diphacinone and its sodium salt, which was not reported in the earlier IDS data. These updated data cover the period after March 31, 2015 when products that were non-compliant with the 2008 RMD should have no longer been available for distribution.

TABLE 6. ANTICOAGULANT RODENTICIDE HUMAN EXPOSURE INCIDENTS FROM 2015 TO 2019

Rodenticide	Generation	Severe Effects	Moderate Effects	Minor Effects	Unknown or No Effects
		January 1, 2015 – July 12, 2019			
Warfarin (and its sodium salt)	FGAR	0	0	0	0
Chlorophacinone	FGAR	0	1	0	0
Diphacinone (and its sodium salt)	FGAR	3	23	190	0
Brodifacoum	SGAR	1	12	85	0
Bromadiolone	SGAR	0	5	58	3
Difenacoum	SGAR	0	0	0	0
Difethialone	SGAR	0	0	3	4

Source: EPA, 2022a

In its 2022 evaluation, EPA evaluated longer-term trends in AR incidents. This evaluation was based on two data sources: 2009-2018 IDS data and 2004-2017 data from the American Association of Poison Control Centers (AAPCC). The evaluation found that SGAR incidents decreased over time, with the magnitude of the reduction different for the IDS data set (79% reduction between 2009 and 2018) and the AAPCC data set (70% reduction between 2004 and 2017). However, the evaluation had mixed findings for FGAR incidents: an 81% increase between 2009 and 2018 based on the IDS data and a 45% decrease between 2004 and 2017 based on the AAPCC data. The reason for the mixed FGAR findings is not known.

Although this section focuses on FGAR and SGAR toxicity, it should be noted that EPA also reported on increasing numbers of exposure incidents for non-anticoagulant rodenticides (i.e., alternatives to ARs, as described in Section 6) over the same time frame. This non-AR finding was consistent across the IDS data set (60% increase between 2005 and 2018) and AAPCC data (41% increase between 2004 and 2017). EPA suggested that this increase in non-AR incidents may have resulted from their increased use after EPA prohibited sale of SGARs in consumer size products.

EPA's review also presented rodenticide exposure incidents among workers, drawing from 2011-2015 occupational pesticide exposure incident data. However, this analysis could not evaluate post-mitigation trends, because rodenticide mitigation measures were not fully implemented until 2015. EPA summarized nationwide occupational exposure incident data for rodenticides, which included 21 cases between 2011 and 2015; however, 13 of these involved zinc phosphide, a non-AR.EPA also summarized occupational exposure incident data from three state-level databases. That analysis found that most occupational exposure incidents were of low severity, although 3 of the 15 incidents among the states evaluated were highly severe (EPA, 2022a).

Potential Impacts of 2022 Proposed Risk Mitigation Measures

EPA's Biological and Economic Analysis Division (BEAD) published the *Use and Benefits Assessment for 11 Rodenticides and Impacts of Potential Risk Mitigation* to summarize the potential impacts of the 2022 proposed risk mitigation measures (EPA, 2022b). The report discusses implications of adding restrictions to AR applications in residential, agricultural, and other settings; but the report does not present new data on toxicity and observed human health effects due to AR exposures. EPA did conclude that chemical rodenticides are the fastest and most reliable way to quickly control rodent infestations. Other methods of rodent control (discussed in Section 6), such as sanitation, exclusion, and mechanical traps, are often insufficient in the face of severe infestations or are impractical over large areas, which could have implications for public health. The potential impacts of the proposed mitigation measures vary depending on the rodenticide application method and what restrictions apply.

1987 IRIS Assessment for Warfarin

Of the seven ARs, only warfarin was evaluated by EPA's Integrated Risk Information System (IRIS) program (EPA, 1987). That is because, before that program evaluated other ARs, EPA made a policy decision that the agency would evaluate pesticide toxicity as part of the registration and reregistration process, instead of through the IRIS program.

The 1987 IRIS warfarin assessment noted several findings. In addition to its use as a rodenticide, warfarin is an oral medication used to treat various blood clotting conditions in humans. When administered therapeutically, the "maintenance dose" in humans ranges from 2–10 mg/day. EPA reported that the lowest maintenance dose, 2 mg/day, can be considered the Lowest Observed Adverse Effect Level (LOAEL) because that does was associated with increased clotting time; while that is the desired effect under controlled therapeutic conditions, the effect would be considered adverse to the general population.

EPA's evaluation found that women who take or who are exposed to warfarin during pregnancy may give birth to infants with birth defects, especially if exposure occurs during the first trimester. Reported birth defects include chondrodysplasia punctata, central nervous system effects, eye disorders, and developmental delays.

The 1987 IRIS report did not evaluate warfarin for carcinogenicity. Further details from the IRIS profile are not presented here because the literature reviewed in that assessment is all more than 35 years old.

4.3 Assessments Issued by Other Government Agencies and International Bodies

Outside the United States, several national and international bodies have conducted scientific assessments of the health effects of ARs. Most reports are risk assessments that examine specific exposure scenarios based on published (and sometimes unpublished) scientific studies. This section summarizes assessments issued by the European Union (EU), Canada, and the World Health Organization (WHO). The Australian Pesticides and Veterinary Medicines Authority is developing a scientific re-evaluation of ARs; however, this process was not complete yet at the time of this review.

The European Union

In the EU, the European Chemicals Agency (ECHA) regulates the use of pesticides. ECHA's Biocidal Products Committee (BPC) conducts scientific reviews and prepares opinions for ECHA related to active substance approval, renewal, substitution, and cancellation. In March 2021, the BPC received questions from the European Parliament regarding AR renewal applications (ECHA, 2024). Two questions pertained to human health:

- Do the alternative authorized biocidal products or non-chemical alternatives present a significantly lower overall risk for human health, animal health, and the environment?
- Would some anticoagulant active substances contained in rodenticides have a lower overall risk for human health, animal health, and the environment than others?

The BPC concluded that carbon dioxide, an alternative rodenticide, has a significantly lower risk profile for human health than ARs when used by trained professionals for controlling rodents through permanent baiting. The BPC also considers the rodenticides alphachloralose and cholecalciferol less risky to human health than ARs. Given this, the BPC could not conclude if alphachloralose and cholecalciferol had an overall lower risk profile than ARs. The BPC concluded that it was not possible to rank the overall risk of individual ARs, given that risk mitigation measures apply equally to all ARs (ECHA, 2024).

Health Canada

The Pest Management Regulatory Agency (PMRA) of Health Canada published AR re-evaluation decisions in 2006 and 2007. These included required label advisory statements for brodifacoum, bromadiolone, chlorophacinone, diphacinone, warfarin, and zinc phosphide to protect children, non-target animals, and pesticide handlers (PMRA, 2006, 2007). Commercial class end-use products were required to have additional content on labels, including information on increased PPE requirements and a statement that these products were for use only by certified pest control operators, farmers, and government-approved pest control programs. Additionally, PMRA required all AR baits be placed in tamper-resistant bait stations or in locations inaccessible to children, pets, or livestock.

Following the U.S. EPA's *Risk Mitigation Decision for Ten Rodenticides* (2008), PMRA re-evaluated risk mitigation measures for eight rodenticides (PMRA, 2009; 2010). Regarding human health risks, PMRA cited the same AAPCC data as reported by EPA. Given that increased risk mitigation measures in Canada took effect in 2007, PMRA considered the available information on human rodenticide exposures in Canada in 2009 and 2010 to be insufficient. PMRA also concluded that the EPA's conclusions were likely representative of what could be expected in Canada.

The World Health Organization (WHO)

The WHO Environmental Health Criteria Programme examines the relationship between environmental pollutant exposures and human health, promoting standardized toxicological and epidemiological methods for internationally comparable results. In 1995, the WHO concluded that exposure to ARs in the general population is unlikely, and residues of ARs are unlikely to be found in food; however, the use of dry baits to protect grain stores could result in contamination of the grain products (WHO, 1995). Occupational contact can be a significant source of exposure during AR manufacture, formulation, bait preparation, and application. Symptoms of poisoning range from minor (increased bleeding tendency) to severe (massive hemorrhage). Plasma prothrombin concentration is often used to assess the severity of poisoning. Treatment consists of vitamin K1 and co-administration of blood components in severe cases.

WHO's assessment cited 1988 data from the AAPCC, which reported 10,626 cases of human exposures to rodenticides, 89% of which involved children aged six and under. Rodenticide exposure accounted for 17%

of all pesticide exposures reported to AAPCC in 1988. WHO further reported that AR exposure—particularly warfarin exposure—during pregnancy can result in birth defects such as nasal hypoplasia (underdevelopment or absence of the nasal bone) and choanal stenosis (congenital narrowing of the nasal passages). Based on this information, WHO recommended several actions to reduce accidental ingestion: adding bittering agents to AR products, carefully selecting bait placements, training in the safe handling of rodenticides, and biomonitoring and health evaluation of exposed workers. WHO recommended further research on human exposure regarding teratogenic and embryotoxic effects, placental transfer of SGARs, tissue distribution of ARs after ingestion, and risk assessments related to occupational exposure. WHO classified warfarin as a Class Ib substance (highly hazardous) and all other FGARs and SGARs as Class Ia substances (extremely hazardous) (WHO, 1995).

4.4 Peer-Reviewed Publications on Human Health Risks

While the assessments conducted by EPA and other agencies are extensive and authoritative, this project also sought to identify and synthesize additional information on the human health effects of ARs. ERG conducted a literature review to complement and supplement the data summarized in regulatory assessments. When designing its literature search, ERG considered public comments, responses to the survey of interested parties, and themes and questions identified during broad literature searches.

Based on these factors, the literature search considered:

- AR poisoning in humans
- The relationship between rodents and zoonotic diseases
- Impacts of AR use on food safety
- Associations between AR exposure and other diseases
- Contamination of synthetic cannabinoids

ERG developed targeted search strategies to identify peer-reviewed studies addressing these topic areas. Each AR was included by name in the searches, except warfarin, due to the extensive literature on its pharmaceutical uses, which resulted in many irrelevant articles. The search was not limited by publication date, but it was restricted to studies available in English. For poisonings and zoonotic disease, results were later narrowed to studies conducted in the United States, as the context in other countries was often very different.

These searches yielded 636 peer-reviewed publications. After title and abstract screening, 72 articles were identified as potentially relevant. All were reviewed in full, and 31 are included in this summary. Articles were excluded if they focused primarily on disease or exposure data outside the United States or if they did not provide relevant insights on the selected topics.

ERG also reviewed studies recommended by stakeholders and public commenters on the Phase 1 report and incorporated them as appropriate.

Poisonings and Incidents (Child, Adult, and Case Studies)

The literature search yielded numerous publications with relevant AR poisoning information. This included a nationwide poison data report and 13 articles in the peer-reviewed literature, all of which are reviewed below.

The 2022 Annual Report of the National Poison Data System (NPDS) included 3,002 cases of single-chemical exposure involving “long-acting” ARs, of which 2,172 (72%) occurred in children under the age of six, and 2,864 (95%) were unintentional (Gummin et al., 2023). Among the 3,002 long-acting AR exposure incidents,

802 (27%) were treated in a healthcare facility. Most (97%) patients treated in a healthcare facility for long-acting AR exposure had no symptoms, and only four experienced major symptoms. No deaths were reported due to long-acting AR exposure. In 2022, there were 60 additional cases of single-chemical exposure, which mentioned warfarin-type ARs, of which 42 (70%) occurred in children under six years old. Of these exposure incidents, 16 cases were treated in a healthcare facility, none of which had symptoms more severe than moderate. Additionally, in 2022, there were 2,365 additional incidents involving unknown types of rodenticides (Gummin et al., 2023). Note: these data do not indicate whether incidents followed rodenticide use by professionals or homeowners, or whether the product was used according to label directions.

The 13 articles in the peer-reviewed literature addressed prevalence of rodenticide exposure in the United States, including case reports of such exposures. King and Tran (2015) analyzed annual reports to the AAPCC's National Poison Data System from 1987 through 2012. Of the 315,951 total reported AR exposures, 95.6% were unintentional, and 88.9% occurred in children under the age of six. The article provided further breakdown of these poisonings: 32% of cases received treatment in a healthcare facility; 2.3% of total cases had any reported health effects; and 0.6% of total cases had moderate or major effects, including 30 deaths (King and Tran, 2015).

Between 2000 and 2013, poison centers in Texas received over 60,000 reports of pesticide-related exposures in children and adolescents under the age of 20, 30% of which were due to rodenticides (Trueblood, Forrester, et al., 2016). From 2004 through 2013, 127 children and adolescents under the age of 20 were hospitalized in Texas for unintentional pesticide exposure, 25 (19.7%) of whom were hospitalized for accidental rodenticide poisoning. During this period, 31 hospitalizations occurred for intentional pesticide exposure, but none was associated with rodenticides. Based on 2010 U.S. Census data for children and teenagers, Trueblood, Shipp, et al. (2016) estimated that the prevalence of rodenticide-related hospitalizations per 100,000 children and adolescents was 0.3 (95% CI: 0.2, 0.5). In both Texas studies, no specifics were provided on the type of rodenticides associated with exposures, poisonings, or hospitalizations. Thus, it is possible that some of these incidents were not due to AR exposures.

Badakhsh et al. (2010) analyzed data from the Louisiana Hospital Inpatient Discharge Database from 1998 through 2007 and found 384 cases of pesticide-related hospitalizations, 20 (5.2%) of which were associated with accidental rodenticide exposure. Children under 18 years old had a statistically significantly higher rate of hospitalization due to rodenticide exposure than adults (OR = 8.55, 95% CI: 3.07, 23.78). Among pediatric hospitalizations for rodenticide exposure, very young children (ages 4 and younger) accounted for 64% of cases. As with the Texas study, details were not provided regarding the type of rodenticides involved in these cases from Louisiana (Badakhsh et al., 2010).

Watt et al. (2005) summarized AR exposure incidents reported to the AAPCC Toxic Exposure Surveillance System from 1993 through 2004. Of the 13,362 exposure incidents involving warfarin, 86.6% occurred in children under the age of six, and 95% of all incidents were unintentional. About one-third of all cases (32.7%; n = 4,372) were treated in a healthcare facility; 18 experienced major health outcomes; and three died. During the same period, 177,674 SGAR exposure incidents were reported, with 89.6% of these occurring in children under the age of six. Of all SGAR incidents, 96.2% were unintentional, 33.1% were treated in a healthcare facility, 282 experienced major health outcomes, and 17 resulted in fatalities.

Between 1993 and 1996, 10,762 cases of acute unintentional exposure to brodifacoum in children aged six and younger were reported to the AAPCC (Shepherd et al., 2002). Of these cases, 5,404 (50.2%) were managed outside of a healthcare facility. Of the 5,319 children seen in emergency departments, 118 (2.2%) were admitted for medical care. No major effects or deaths were reported in the study population (Shepherd et al., 2002).

Mullins et al. (2000) reviewed cases of SGAR exposure in children under six years old during two two-year exposure periods, 1993–1994 (n = 398), and 1996–1997 (n = 198). During the first two-year period, researchers evaluated prothrombin time at 24 and 48 hours after exposure, and only at 48 hours after exposure during the second two-year period. In neither two-year period did a child have a prothrombin time long enough to need vitamin K, and no children had any apparent bleeding complications. The researchers concluded that pre-school-aged children with unintentional acute SGAR exposure do not require routine laboratory follow-up or medical interventions (Mullins et al., 2000).

At least three identified studies reported incidents of AR exposure before 2000 (Chua and Friedenberg, 1998; Gehlbach and Williams, 1977; Klein-Schwartz and Smith, 1997). While AR restrictions have dramatically increased since the 1990s, these studies provide more evidence of accidental exposure in children, especially children under the age of six; they also provide evidence of intentional, albeit rare, exposure among adults. Most children unintentionally exposed to ARs experienced mild to no symptoms (Chua and Friedenberg, 1998; Gehlbach and Williams, 1977; Klein-Schwartz and Smith, 1997).

Several other case reports from the last 45 years are available in the literature (Greef et al., 1987; Kruse and Carlson, 1992; Lu et al., 2021; Rauch et al., 1994; Schum and Lachman, 1982; Underwood et al., 2014). Reigart and Roberts (2001) evaluated reports of SGAR exposure incidents reported to Poison Control Centers between 1997 and 1999 and observed five deaths, all of which were associated with intentional suicidal ingestion. Zurawski and Kelly (1997) reported a case of a 19-year-old woman who was 22 weeks pregnant when she intentionally ingested brodifacoum in a suicide attempt eight days prior to admission. After receiving supportive care, including vitamin K therapy, the woman fully recovered, and no fetal hemorrhage or teratogenic effects were observed. The patient later had an uncomplicated delivery, and her infant was born healthy and remained so at one year of follow-up.

Zoonoses and Ectoparasites

Rodents are known reservoirs of several zoonotic diseases, including those caused by bacteria (e.g., leptospirosis, rat-bite fever, salmonellosis, and sylvatic typhus) and those caused by viruses (e.g., hantavirus, hemorrhagic fever with renal syndrome, and Lassa fever) (CDC, 2024a). Recent work in Boston further documents circulation of *Leptospira* spp. in urban *Rattus norvegicus* populations (Stone et al., 2025), underscoring that rodent-associated pathogens can be locally relevant. Rodents may also contribute to indirect disease transmission when people are bitten by ticks, mites, fleas, and mosquitoes that have fed on infected rodents. Indirectly transmitted diseases associated with rodents include anaplasmosis, borreliosis, murine typhus, Lyme disease, plague, scrub typhus, and Colorado tick fever. Tularemia may be transmitted through direct contact with infected rodents or indirectly through ticks and deer flies that have fed on infected rodents (CDC, 2024b).

ARs are widely used for rodent population control, but their use can have complex impacts on zoonotic disease dynamics. For example, suppression of rodent populations may temporarily increase the movement of fleas and ticks to new hosts, while sublethal exposure to rodenticides could potentially influence rodents' susceptibility to infection.

This section summarizes three peer-reviewed studies examining these interactions in the United States: one study on the association between rodenticide exposure and infection with zoonotic pathogens, and two studies evaluating the use of combined rodenticide and insecticide baits to reduce ectoparasite burdens and associated disease risk. Because zoonotic diseases are geographically specific, studies focused on rodent-borne zoonotic diseases outside the United States were not evaluated (CDC, 2024a).

Murray and Sánchez (2021) investigated whether rodents exposed to ARs were more likely to be infected with zoonotic pathogens, namely *Leptospira* spp. and *Escherichia coli*. The researchers trapped over 250 rats across 14 community areas in Chicago. A subset of 99 rats was screened for ARs. After controlling for

physiological predictors of disease, researchers observed that older rats (age greater than 65 days) and rats exposed to ARs (and survived to be trapped) were significantly more likely to be infected with *Leptospira* spp. than other rats. While the researchers did not study the mechanism by which AR-exposed rats might be more susceptible to *Leptospira* infection, they hypothesized this could be due to 1) the immunomodulatory effects of ARs or 2) infected rats potentially being more likely to consume AR bait due to decreased energy; however, the researchers note that this latter theory is unlikely because rats are considered asymptomatic chronic carriers of *Leptospira*. The researchers did not observe significant associations between AR exposure in rats and *E. coli.*

Hinds et al. (2021) evaluated whether combining brodifacoum with the systemic insecticide fipronil could improve control of ectoparasites on rodents prior to the rodents' death. In this study, Norway rats and house mice that were carrying fleas or ticks were offered bait containing both compounds. Nearly all fleas on treated rodents died within 1–2 days of exposure to the combination bait, before the rodents succumbed to the AR. Ticks were also effectively controlled with the combined bait, though their mortality was slower, occurring within 3–7 days. In contrast, ectoparasites remained viable on control animals. This finding demonstrates that incorporating an insecticide into rodenticide bait can prevent ectoparasites from abandoning dying rodents and seeking new hosts, which may reduce the risk of zoonotic pathogen transmission during rodent control operations.

Poché and Poché (2024) evaluated the effect of combined warfarin and fipronil (an insecticide) on white-footed mice and the blacklegged tick, a host and vector of Lyme disease in the United States. In laboratory tests, white-footed mice were manually infested with ticks and were fed combined rodent and tick bait for 4 days. The bait was palatable to mice and caused 100% mortality within 13 days, with an average time until death of 7 days. Critically, the latency of warfarin toxicity allowed time for low doses of fipronil to act systemically, killing all larval ticks before rodent death. The study demonstrated that combining an AR with an oral acaricide can effectively target both rodent hosts and their ectoparasites, reducing the risk of infected ticks dispersing to new hosts after rodent death. The authors concluded that this integrated pest control approach could support more comprehensive tick management strategies near residential areas.

Food Safety

Few studies are available in the peer-reviewed literature that evaluate how AR use affects food safety and dietary exposures. ERG identified two U.S.-based peer-reviewed studies focused on the potential risks of consuming AR-contaminated pig tissue and drinking water in Hawaii. The state considered these studies when assessing risks for the proposed application of diphacinone by aerial broadcast.

Researchers conducted a controlled study in Hawaii to measure diphacinone residues in feral pig tissues (Pitt et al., 2011). Pigs were fed low and high concentrations of diphacinone bait (3.5 and 7.4 mg/kg) and euthanized prior to showing symptoms. Researchers analyzed liver, fat, and muscle tissue in both raw and cooked forms; and the cooked forms were boiled or roasted to an internal temperature of 71.1 °C (160 °F). Residue levels increased proportionally with the amount consumed by the pigs, and concentrations were higher in liver than in fat or muscle. Cooking concentrated diphacinone due to moisture loss; however, the maximum detected level (3.65 ppm in roasted liver) was not high enough to pose a clinically significant risk to humans. Using conservative extrapolation from rodent data with a 1,000-fold uncertainty factor, the authors concluded that a 55-kg adult would need to consume approximately 3.1 kg of liver in a single day or 1.2 kg per day for 14 days to approach a potentially harmful dose.

Eisemann and Swift (2006), representatives of USDA and the U.S. Fish and Wildlife Service respectively, assessed human health risks from consuming meat or water contaminated with diphacinone after aerial rodenticide applications in native Hawaiian ecosystems. To estimate risk, they calculated the amount of contaminated food or water an adult or child would need to ingest to reach doses shown to produce

detectable effects on blood clotting; and those doses were derived from toxicological test data collected from laboratory rats. For drinking water, researchers used surface water models to approximate the concentration of diphacinone in stream waters after broadcast application in high-elevation rainforests. The authors reported that a 55-kg human would have to consume an impossible volume of water, 188 to 2,383 liters in a single day (or 57 to 733 liters of water over multiple days) to experience detectable changes in blood clotting. For pregnant women and infants, whose susceptibility is higher, the minimum volume of water needed to pose a risk was also greater than realistic consumption rates. Regarding game meat, the authors estimated that a 55-kg adult would need to consume more than 2.3 kg of pig liver or nearly 13 kg of game bird liver in a single day to ingest a dose sufficient to alter clotting time, concluding that this scenario is also highly unlikely. For pregnant women, lower amounts could potentially be of concern (e.g., as little as 0.45 kg of pig liver per day); however, the authors noted that the more likely scenario would involve ingestion of smaller quantities of muscle meat rather than large amounts of liver tissue.

General Human Health and Pesticide Exposure

ERG identified two epidemiological studies that investigated links between indicators of pesticide exposure (including exposure to ARs) and adverse health effects.

Mar et al. (2018) conducted a large, multicenter case-control study investigating the link between pediatric-onset multiple sclerosis (MS) and exposure to various household chemicals, including rodenticides. After adjusting for sociodemographic factors, the study found that children who had lived in homes where rat, mouse, gopher, or mole control products were used at any point during childhood had more than twice the odds of developing MS compared to unexposed children (adjusted OR = 2.10; 95% CI: 1.35–3.26). Similar findings were reported for household use of weed control agents and for plant or tree disease control products. The researchers did not differentiate between anticoagulant and non-anticoagulant rodenticides, and rodenticide uses were self-reported, thereby limiting the ability to draw conclusions about specific compounds or mechanisms.

Desai et al. (2025) investigated the association between residential pesticide exposure and survival in children diagnosed with acute lymphoblastic leukemia (ALL). Data on pesticide use, including rodenticides, from pre-conception to 12 months prior to diagnosis, were collected from parents of 837 children in California diagnosed with ALL between 1995 and 2008. Rodenticide use during pregnancy or in early childhood was significantly greater among children who died compared to those who survived (25% vs. 15.5%; p = 0.02). After adjusting for covariates, exposure to rodenticides was associated with an increased risk of death (HR 1.70; 95% confidence interval (CI) 1.08–2.64; p = 0.02), particularly for children exposed during pregnancy (HR 1.90; 95% CI 1.15–3.16; p = 0.01). Rodenticides in the study included both ARs and non-ARs. The authors noted, however, that d-Con, a brodifacoum-containing product banned for residential use in 2015, was the most commonly reported rodenticide among study participants.

Contamination of Synthetic Cannabinoids

ERG identified seven peer-reviewed studies describing coagulopathy (severe bleeding disorders) in humans that was reportedly linked to the consumption of synthetic cannabinoids contaminated with ARs in the United States.

In 2018, in Illinois, 174 suspected and confirmed coagulopathy cases, including five deaths, were linked to the use of synthetic cannabinoids contaminated with ARs (Fasih, 2019; Kelkar et al., 2018; Navon et al., 2019; Panigrahi et al., 2018). A case report further explored circumstances for 34 of the Illinois patients (Kelkar et al., 2018). Common symptoms included gross hematuria (i.e., blood in urine) (56%, n = 19) and abdominal pain (47%, n = 16). Most patients were exposed via inhalation, and the average time from inhalation to the onset of symptoms was one to three days (Kelkar et al., 2018). At least 15 patients in Illinois received confirmatory anticoagulant tests, all of which were positive for brodifacoum (100%, n = 15)

(Kelkar et al., 2018). Fewer patients were positive for difenacoum (33%, n = 5), bromadiolone (13%, n = 2), or warfarin (6%, n = 1) (Kelkar et al., 2018).

The cannabinoid-related coagulopathy cases in 2018 were not limited to Illinois, though Illinois saw the greatest number of cases. More than 300 people nationwide experienced the coagulopathy that was likely due to ingestion of contaminated cannabinoid products, and 7 of these people died (Arepally and Ortel, 2019). Between April and September 2018, the Johns Hopkins Health System based in Baltimore, MD reported 16 suspected and confirmed cases of bleeding and clinical toxicity associated with the consumption of contaminated synthetic cannabinoids (Bahouth et al., 2019). Brodifacoum exposure was confirmed in 12 of 13 tested patients (92%). A case report of a 29-year-old woman in Wisconsin poisons with brodifacoum linked to synthetic marijuana use was also described (Kircher and Perez, 2020). The source of contamination in the nationwide outbreak described throughout this paragraph remains unknown (Arepally and Ortel, 2019; Fasih, 2019; Kelkar et al., 2018).

5 Environmental Effects of Anticoagulant Rodenticides

This section summarizes the current state of knowledge on the environmental effects of anticoagulant rodenticides (ARs). It draws on major assessments issued by authoritative bodies, including EPA, other U.S. federal and state agencies, the European Union, and Canadian regulatory authorities. Additionally, it incorporates findings from peer-reviewed toxicological and ecological studies, case investigations related to secondary AR exposure, and potential AR-related population risks to non-target wildlife.

Other sources of information on environmental effects of ARs include necropsy or liver-panel case files that organizations submitted to MDAR, veterinary case records, media-reported events, or individual case investigations compiled by Massachusetts agencies (e.g., MassWildlife). These sources are not reviewed here because analysis of those data were not included in this project's scope of work. Appendix A provides further context on this matter and describes how these sources of information will be considered by the Pesticide Board Subcommittee, even though they are not reviewed in this document.

5.1 EPA Assessments

As part of the pesticide registration review process described earlier, EPA has conducted ecological risk assessments for ARs. These assessments include *problem formulation* documents, which provide detailed overviews of the toxicological properties, environmental fate, and ecological exposure pathways of these compounds. Further, EPA is also required by the Endangered Species Act to determine whether continued registration of ARs may affect threatened or endangered species or their designated critical habitats. To meet these obligations, EPA has issued a series of draft and final Biological Evaluations (BEs) that assess potential impacts and recommend mitigation strategies. Some documents summarized in this section were also discussed in the section on human health effects of ARs (Section 4). The focus here, however, is on their findings and determinations related specifically to ecological risks.

The following text summarizes the key EPA documents relevant to environmental effects, including:

- **Risk Mitigation Decision** (EPA, 2008) describes the regulatory measures to reduce ecological risks, including prohibitions and restrictions designed to minimize primary and secondary poisoning of non-target wildlife.
- **Problem Formulation Reviews for seven anticoagulant rodenticides** (EPA, 2015a, 2015c, 2015d, 2016b, 2016c, 2016d, 2016i) define the scope of ecological risk assessments, identify assessment endpoints (e.g., effects on birds and mammals), and outline the conceptual models and data needs for evaluating ecological risks.
- **Draft Ecological Risk Assessment for Registration Review** (EPA, 2020b) evaluates potential ecological risks to terrestrial and aquatic organisms, considering both primary poisoning (direct ingestion by non-target species) and secondary poisoning through the consumption of contaminated prey.
- **Proposed Interim Registration Review Decision** (EPA, 2022d) summarizes EPA's proposed mitigation measures to address identified ecological risks, such as new label requirements, application restrictions, and other risk reduction strategies.
- **Final Biological Evaluation** (EPA, 2024b) comprehensively assesses potential effects on federally listed threatened and endangered species and their designated critical habitats and proposes mitigation strategies to reduce adverse impacts.

When reviewing the aforementioned documents and other publications, this section focuses on hazard identification and exposure to non-target wildlife and ecosystems.

2008 Risk Mitigation Decision

The *2008 RMD* (EPA, 2008) documented EPA's final decision in the reregistration eligibility of rodenticide products, including the seven FGAR and SGARs (including diphacinone sodium salt and warfarin sodium salt) and zinc phosphide (refer to Section 3.2 for additional discussion of this publication). EPA's analysis in this report was largely based on an earlier comparative ecological risk assessment, *Potential Risks of Nine Rodenticides to Birds and Non-Target Mammals: A Comparative Approach* (EPA, 2004). EPA's 2008 RMD analysis determined that both FGARs and SGARs may pose significant risks to non-target wildlife through primary and secondary exposure pathways.

EPA determined that SGAR exposure in non-target wildlife was likely to be widespread anywhere that SGARs are used. EPA reviewed necropsy investigations of wildlife and observed that 48% of diurnal raptors and owls examined in a New York study showed detectable residues of SGARs. That finding was based on 15 different species of raptors and owls. Additionally, based on a similar review of necropsies of wildlife in California, EPA noted that 71%–84% of various predatory mammals (e.g., bobcats, mountain lions, kit foxes) showed detectable SGAR residues.

EPA also found that SGARs have greater potential to adversely affect non-target wildlife than FGARs. This determination was based on multiple lines of evidence, including laboratory and pen studies wherein predators and scavengers eat known quantities of poisoned prey. In its summary of relevant studies, EPA reported that rodenticide compounds can persist in the tissues of target organisms (i.e., rodents that have already consumed bait) at levels that can result in acute toxicity to predator species via secondary exposure.

As part of its evaluation of risk mitigation measures, EPA summarized the available information on the development of resistance to ARs in target animal populations. This consisted of a 1970s-era nationwide testing program for resistance to the FGAR warfarin in Norway rats, which identified some level of resistance in a large proportion of rats.

2015-2016 Problem Formulations

As part of the registration review process, EPA published problem formulation documents for the seven ARs (EPA, 2015a, 2015c, 2015d, 2016b, 2016c, 2016d, 2016i). These documents reviewed scientific information on the environmental fate, ecological hazards, and exposure pathways associated with each compound. They also outlined the preliminary analysis plan for evaluating risks to non-target organisms, including endangered and threatened species, and for identifying data gaps. These documents formed the scientific foundation for subsequent ecological risk assessments and described available toxicity data for primary and secondary exposure in birds and mammals. The problem formulations consistently identified direct consumption of bait (primary exposure) and consumption of contaminated prey (secondary exposure) as the principal pathways of concern for non-target birds and mammals.

Table 7 summarizes findings from acute oral and dietary toxicity studies for mammals and birds, as reported in the problem formulation documents. The table reviews findings only from primary exposure scenarios (i.e., birds and mammals ingesting bait). Table 8 summarizes secondary exposure findings. According to EPA's classification of these data, these compounds are often "highly" or "very highly" toxic to both mammals and birds, with low LD_{50} and LC_{50} values indicating lethal effects at low doses and low exposure concentrations, respectively. (Note: The footnotes to Table 7 define LD_{50} and LC_{50} as well as other measures of toxicity). In addition to mortality, some data show sublethal impacts (e.g., lethargy, impaired coordination, internal bleeding) that can reduce survival among predators.

TABLE 7. PRIMARY EXPOSURE TOXICITY ENDPOINTS FOR BIRDS AND MAMMALS

Anticoagulant Rodenticide	Taxonomic Group	Study Type	Test Species	Toxicity Endpoint*
Chlorophacinone (FGAR)	Birds	Acute oral	Northern Bobwhite quail (*Colinus virginianus*)	LD_{50} = 258 mg/kg-bw. Moderately toxic.
	Birds	Dietary	Northern Bobwhite quail (*Colinus virginianus*)	LC_{50} = 56 mg/kg-diet Highly toxic.
	Birds	Chronic	Mallard duck (*Anas platyrhynchos*)	NOAEC = 0.046 mg/kg diet, based on reduction in mean 14-day survivor weights.
	Mammals	Acute oral (single dose)	Black-tailed Prairie Dogs *(Cynomys ludovicianus)*	LD_{50} = 1.94 mg/kg-bw. Very highly toxic.
	Mammals	Acute oral (5-day exposure, multiple doses)	Laboratory Rat (*Rattus norvegicus*)	5-day LD_{50} = 0.8 mg/kg-bw. Multiple doses for 5 consecutive days, equal to the LD_{50} dose.
	Mammals	Dietary (5-day exposure)	Laboratory Rat (*Rattus norvegicus*)	LC_{50} = 1.14 mg/kg-diet. Mortalities occurred 4–9 days after test start; animals observed 9 days.
	Mammals	Chronic	Rabbit (*Oryctolagus cuniculus*)	Developmental NOAEL = 10 µg/kg-bw/day.
Diphacinone (FGAR)	Birds	Acute oral (primary bait consumer)	Northern Bobwhite quail (*Colinus virginianus*)	LD_{50} = 1,630 mg/kg-bw. Mortalities occurred ≤5 days after gavage; observed 30 days.
	Birds	Acute oral (secondary consumer)	American kestrel (*Falco sparverius*)	LD_{50} = 98.6 mg/kg-bw. Highly toxic. 7-day study; mortalities occurred 8–47 hrs after dosing.
	Birds	Dietary	Mallard duck (*Anas platyrhynchos*)	LC_{50} = 906 mg/kg-diet. Moderately toxic. 25-day test; most mortalities from 3–8 days, all mortalities less than 16 days.
	Mammals	Acute oral (single dose)	Laboratory Rat (male) (*Rattus norvegicus*)	LD_{50} = 1.9 mg/kg-bw. Very highly toxic. 14-day study; mortalities from days 2–9.
	Mammals	Dietary (5-day exposure)	Laboratory Rat (*Rattus norvegicus*)	LC_{50} = 2.08 mg/kg-diet. Very highly toxic. Observed 14 days; mortalities days 4–12.
	Birds	Acute oral (primary bait consumer)	Mallard duck (*Anas platyrhynchos*)	LD_{50} = 621 mg/kg-bw Slightly toxic.

Anticoagulant Rodenticide	Taxonomic Group	Study Type	Test Species	Toxicity Endpoint*
Warfarin (FGAR)	Birds	Dietary	Northern Bobwhite quail (*Colinus virginianus*)	LC_{50} = 625 mg/kg-diet. Moderately toxic. 15-day study, most deaths, days 3–7; one on day 10.
	Mammals	Acute oral (single dose)	Laboratory Rat (*Rattus norvegicus*)	LD_{50} = 3.0 mg/kg-bw. Very highly toxic.
	Mammals	Dietary (5-day exposure)	Laboratory Rat (*Rattus norvegicus*)	LC_{50} = 4.41 ppm. Very highly toxic. Observed 14 days; mortalities days 3–9.
Brodifacoum (SGAR)	Birds	Acute oral	Mallard duck (*Anas platyrhynchos*)	LD_{50} = 0.26 mg/kg bodyweight. Very highly toxic.
	Birds	Sub-acute oral	Northern Bobwhite quail *(Colinus virginianus)*	LC_{50} = 0.8 mg/kg diet. Very highly toxic. 40-day exposure period.
	Mammals	Acute Oral	Laboratory Rat (*Rattus norvegicus*)	LD_{50} = 0.42 mg/kg-bodyweight (females). Highly toxic.
	Mammals	Acute Dietary	Laboratory Rat (*Rattus norvegicus*)	LC_{50} = 0.55 mg/kg diet. Very highly toxic.
	Mammals	Acute dietary	Wild mammal Vole *Microtus sp*.	LC_{50} = 1.4 mg/Kg diet. Very highly toxic.
Bromadiolone (SGAR)	Birds	Acute – Avian Oral Dose	Northern Bobwhite quail (*Colinus virginianus*)	LD_{50} = 170 mg/kg-bw NOAEL = 50 mg/kg-bw. LOAEL = 100 mg/kg-bw based on mortality. Observed 30 days.
	Birds	Acute – Avian Dietary	Northern Bobwhite quail (*Colinus virginianus*)	LC_{50} = 37.6 mg/kg-diet; NOAEC < 10 mg/kg-diet; LOAEC ≤ 10 mg/kg-diet, based on mortality. Observed 25 days after the exposure period.
	Birds	Acute – Avian Dietary	Mallard duck (*Anas platyrhynchos*)	LC_{50} = 158 mg/kg-diet; NOAEC < 19 mg/kg-diet; LOAEC ≤ 19 mg/kg-diet, based on mortality, clinical signs of toxicity (reduced water consumption, lethargy, and mild anorexia) with recovery by day 15, and reduced food consumption with recovery by day 10. Other sublethal effects: bloody droppings, loss of coordination, and blood-filled cysts on bills. Observed 25 days.

Anticoagulant Rodenticide	Taxonomic Group	Study Type	Test Species	Toxicity Endpoint*
	Mammals	Acute – Mammalian Oral Dose	Laboratory Rat (Wistar albino; *Rattus norvegicus*)	LD_{50} = 0.6 mg/kg-bw. Sublethal effects were not reported. Observed 14 days.
	Mammals	Developmental – Mammalian 10-day Oral Dose	Laboratory rat (Sprague-Dawley; *Rattus norvegicus*)	NOAEL = 0.035 mg/kg-bw; LOAEL = 0.070 mg/kg-bw, based on vaginal bleeding, hypotonicity, pale eyes, and mortality
Difenacoum (SGAR)	Birds	Acute oral (primary bait consumer)	Northern Bobwhite quail (*Colinus virginianus*)	LD_{50} = 67 mg/kg-bw. Moderately Toxic.
	Birds	Dietary	Mallard duck (*Anas platyrhynchos*)	LC_{50} = 14.1 mg/kg-diet. Very highly toxic
	Mammals	Acute oral (single dose)	Laboratory Rat (*Rattus norvegicus*)	LD_{50} = 1.8 mg/kg-bw Very highly toxic.
Difethialone (SGAR)	Birds	Acute	Northern Bobwhite quail (*Colinus virginianus*)	LD_{50} = 0.26 mg/kg-bw. Very highly toxic.
	Birds	Sub-acute dietary	Northern Bobwhite quail (*Colinus virginianus*)	LC_{50} = 0.56 mg/kg-diet Very highly toxic. 30-day exposure period.
	Mammals	Acute Oral	Laboratory Rat (*Rattus norvegicus*)	LD_{50} = 0.55 mg/kg of bw.
	Mammals	Acute Oral Difethialone/ Fipronil	Laboratory Rat (*Rattus norvegicus*)	LD_{50} > 5,050 mg/kg-bw**.

LD_{50} = Lethal dose that kills 50% of population; LC_{50} = Lethal concentration that kills 50% of population; NOAEC = No Observed Adverse Effect Concentration; NOAEL = No Observed Adverse Effect Level; LOAEL = Lowest Observed Adverse Effect Level.

Source: EPA Problem Formulations for ARs (EPA, 2015a, 2015c, 2015d, 2016b, 2016c, 2016d, 2016i).

** This column presents LD_{50} values in units of mg active ingredient per kg body weight and LC_{50} values in units of mg active ingredient per kg of diet. Acute toxicity classifications are included where applicable, as are the most sensitive endpoints for reported NOAECs.*

*** Dose represents the mass of the AR product (not active ingredients), which contains two active ingredients.*

Table 8 summarizes laboratory studies evaluating secondary poisoning hazards of ARs to predators and scavengers. These studies assessed whether consuming prey that had ingested AR baits caused adverse effects or mortality in a range of avian and mammalian species. The table compiles details on test species, exposure scenarios, number of animals tested, and observed outcomes—including deaths and sublethal signs of toxicity (e.g., prolonged clotting times). Although the designs and endpoints of these studies vary, they collectively illustrate that secondary exposure to ARs have the potential to contribute to adverse effects in non-target organisms, particularly in species consuming multiple contaminated prey items over time.

Across studies summarized in Table 8, SGARs such as brodifacoum and difenacoum were generally associated with higher rates of mortality and severe coagulopathy in predators and scavengers compared to FGARs like chlorophacinone and diphacinone.

TABLE 8. SUMMARY OF SECONDARY EXPOSURE HAZARDS TO BIRDS AND MAMMALS FROM LABORATORY STUDIES

Anticoagulant Rodenticide	Predator/ Scavenger Species	Prey Offered	Number of Prey Offered Daily per Predator/ Scavenger	Number of Predators per Exposure Duration	Number of Dead Predators/ Scavengers	Signs of Toxicity in Survivors
Chlorophacinone (FGAR)	Barn owl	Rats fed choice of 0.005% bait or untreated bait for 5 days	1–2	2 for 10 days	0	None
	Black-billed magpie	Rats fed 0.005% bait for 5 days	Unrestricted	20 for 5 days	0	None
	American kestrel	Voles fed 0.01% bait until dead	1 1 every 3 days	10 for 21 days 10 for 61 days	0 0	10 10 External bleeding/internal hemorrhaging
	Red-tailed hawk	Voles fed 10 g 0.0005% bait daily up to 9 days	2	5 for 6 days	0	None
	Great horned owl	Voles fed 10 g 0.005% bait daily up to 9 days	2	1 for 6 days	0	None
	Tawny owl	Mice fed 0.0075% bait	4	4 for 10 days	0	Increased blood coagulation time
	Eurasian buzzard	Mice fed 0.0075% bait	Unrestricted	4 for 7 days 6 for 10 days 3 for 5-5-5 days (separated by 3 days) 3 for 40 days	4 6 3 3	Increased blood coagulation time
	Carrion crow	Mice fed 0.0075% bait	Unrestricted	4 for 10 days	0	Increased blood coagulation time
	Eurasian buzzard	Mice fed 0.0075% bait	4	4 for 7 days	0	None
	Carrion crow	Mice fed 0.0075% bait	3-4	12 for 3 days 12 for 5 days	0 0	None None

Anticoagulant Rodenticide	Predator/ Scavenger Species	Prey Offered	Number of Prey Offered Daily per Predator/ Scavenger	Number of Predators per Exposure Duration	Number of Dead Predators/ Scavengers	Signs of Toxicity in Survivors
	White stork	Mice fed 0.0075% bait	Unrestricted	3 for 3 days 3 for 14 days	0 0	1 or 2 1 or 2 (Increased blood coagulation time)
	Mongoose	Rats fed 0.005% bait for 5 days	1	1 for 1 day 1 for 3 days 2 for 5 days 1 for 6 days 1 for 7 days 1 for 9 days 1 for 10 days	1 1 2 1 1 1 1	No survivors
	Coyote	Ground squirrels fed 15 g of 0.01% bait for 6 days	1	7 for 5 days	3	None
	European ferret	Rats fed 0.005% bait for 5 days	Unrestricted	20 for 5 days	11	Not reported
	European ferret	Prairie dogs fed 25 g of 0.0025% bait daily for 6 days	4 (1 every other day)	6 for 8 days	5	Not reported
	European ferret	Voles/mice fed 0.0075% bait	5 total	2 for 4 days	1	Increased blood coagulation time
	Red fox	Mice fed 0.0075% bai	20 total	1 for 4 days	1	No survivors
	European ferret	Muskrats fed 0.0075% bait	Unrestricted	2 for 4 days 1 for 8 days	1 1	1 bleeding No survivors
	European ferret	Voles fed 0.0075% bait	Unrestricted	4 for 3 days	0	Increased blood coagulation time
	Weasel	Mice fed 0.005% bait	Unrestricted	4 for 90 days	3	None
Diphacinone (FGAR)	Great horned owl	Mice fed choice of 0.01% bait or untreated food for 10 days	2	3 for 5 days	2	1 increased blood coagulation time

Anticoagulant Rodenticide	Predator/ Scavenger Species	Prey Offered	Number of Prey Offered Daily per Predator/ Scavenger	Number of Predators per Exposure Duration	Number of Dead Predators/ Scavengers	Signs of Toxicity in Survivors
	Saw-whet owl	Mice fed choice of 0.01% bait or untreated food for 10 days	2	1 for 5 days	1	No survivors
	Barn owl	Mice fed choice of 0.01% bait or untreated food for 10 days	Unrestricted	2 for 10 days	0	None
	American crow	Rats fed 0.005% bait until death	1-2	10 for 1 day 11 for 6 days	0 0	None 5 (external bleeding / increased blood coagulation time)
	Golden eagle	Meat laced at 2.7 mg a.i./kg	454 g	4 for 5 days 3 for 10 days	0 0	4 (external bleeding / increased blood coagulation time) 3(external bleeding / increased blood coagulation time)
	Mink	Nutria fed 0.01% carrot bait for up to 10 days	Unrestricted	3 for 5–18 days	3	No survivors
	Mongoose	Rats fed 0.005% bait for 5 days	1	1 for 1 day 1 for 3 days 2 for 5 days 1 for 6 days 1 for 7 days 1 for 8 days 1 for 10 days	0 1 2 1 1 1 1	Not reported No survivors No survivors No survivors No survivors No survivors No survivors
	Ermine	Deer mice fed 0.01% bait for 10 days	2	2 for 5 days	1	Not reported
	Striped skunk	Deer mice fed 0.01% bait for 10 days	2	5 for 5 days	0	Not reported

Anticoagulant Rodenticide	Predator/ Scavenger Species	Prey Offered	Number of Prey Offered Daily per Predator/ Scavenger	Number of Predators per Exposure Duration	Number of Dead Predators/ Scavengers	Signs of Toxicity in Survivors
	Deer mouse	Liver from diphacinone poisoned owls	1 g daily	4 for 7 days	1	3 increased blood coagulation time
	Rat	Meat containing 0.5 mg/kg	Unrestricted	8 for 6 days	4	Not reported
	Dog (domestic)	Nutria fed 0.01% carrot bait for up to 10 days	Unrestricted	3 for 6-10 days	3	No survivors
Warafin (FGAR)	Tawny owl	Mice fed bait for 3 days	1 every other day	4 for 90 days 2 for 28 days	0 0	None
	Black-billed magpie	Rats fed 0.05% bait for 4–7 days	Unrestricted	14 for 5 days	0	None
	Barn owl	Rats fed 0.005% bait	4 total	4 for 5–7 days	2	Not reported
	Eurasian buzzard	Rat/mouse	Unrestricted	1 for 18 days	0	Not reported
	Mink	Nutria fed 0.025% bait for at least 7 days	Unrestricted	3 for 8–15 days	3	No survivors
	Mink	Rabbits fed 25 or 67 mg/kg bait for 5 weeks	Unrestricted	50 for 28 days	0	None
	Least weasel	Mice fed 0.001% bait, 0.005% bait, or 0.02% bait for 3 days	Unrestricted	2 for 9 days 2 for 29–90 days 2 for 12–57 days	0 1 2	Increased blood coagulation time
	European ferret	Prairie dogs fed 0.05% bait for 15 days	1	10 for 7 days	0	None
	European ferret	Prairie dogs fed 0.05% bait for 15 days	Unrestricted	10 for 5 days	0	None
	Racoon	Rats fed 0.025% bait for 5 days	1 3	8 for 5 days 10 for 5 days	0 0	None
	Dog (domestic)	Nutria fed 0.025% bait for at least 7 days	Unrestricted	3 for 8–16 days	1	External bleeding / increased blood coagulation time

Anticoagulant Rodenticide	Predator/ Scavenger Species	Prey Offered	Number of Prey Offered Daily per Predator/ Scavenger	Number of Predators per Exposure Duration	Number of Dead Predators/ Scavengers	Signs of Toxicity in Survivors
	Dog (domestic)	Mice fed 0.025% bait, 0.05% bait. Mice dosed with 2.5 mg, 10 mg, 40 mg	4–10 10 1 1 1	4 for 56 days 1 for 56 days 1 for 56 days 1 for 25 days 1 for 17 days	0 0 0 1 1	None
Brodifacoum (SGAR)	Owls	"Rodents"	Not reported	6 Barn owls fed rodents for 10 days	5	Not reported
	Raptors-Golden eagle (*Aquila chrysaetos)*, Redtailed hawk, (*Buteo jamaicensis),* Red shouldered hawk (*Buteo lineatus)*	"Rodents"	Not reported	4 for 7–9 days 4 for 7–9 days 2 for 7–9 days	0 4 1	Not reported
	Vole and American Kestral (*Falco sparverius)*	Vole treated with 1.4 ppm for 3 days	Not reported	10 for 6 days	4	Not reported
	Gray and Red foxes	"Poisoned rat meat"	Not report	5 for 1–4 days	2	Not reported
Bromadiolone (SGAR)	Barn owl (*Tyto alba*)	Rats fed choice of 0.005% bait or untreated bait for 5 days.	1–2	1 for 1 day 2 for 3 days 1 for 6 days 2 for 10 days All observed for 20 days.	0 0 0 1	None

Anticoagulant Rodenticide	Predator/ Scavenger Species	Prey Offered	Number of Prey Offered Daily per Predator/ Scavenger	Number of Predators per Exposure Duration	Number of Dead Predators/ Scavengers	Signs of Toxicity in Survivors
	Barn owl (*Tyto alba*)	Mice were fed commercial bait (% was not reported) and allowed to die.	2–3	6 for 1 day 6 for 3 days 6 for 6 days	0 0 0	Increased blood coagulation time, returning to normal after 10 days.
	Stone marten (*Martes foina*)	Yellow-necked field mice fed 0.005% bait in excess to feed for 4 days.	4–8	2 for 1 day 2 for 4 days All observed for 3 weeks.	0 0	Increased fragility of small blood vessels of the muscles on top of the skull for individuals exposed for 4 days.
	Mongoose (*Herpestes auropunctatus*)	Black or Norway rats fed 0.005% bait for 5 days.	1	2 for 1 day 2 for 3 days 2 for 5 days 2 for 6 days	0 1 2 2	Not reported
	Coyote (*Canis latrans*)	Ground squirrels fed 15 g of 0.01% bait for 3 days.	1	4 adults for 5 days, 3 sub-adults for 5 days All followed until death or 30 days post-treatment.	0 2	2 coyotes stopped feeding for 8 and 16 days but resumed feeding and survived until the end of the study.
Difenacoum (SGAR)	Barn owls	Rats fed with 50 ppm bait	Not reported	1 for 1 day 2 for 3 days 1 for 6 days 2 for 10 days	0 0 0 0	The 3 owls offered rats for 6 or 10 days survived but all hemorrhaged
	Barn owls	Mice fed with bait	3 6 12	6 for 1 day, then 3 days, then 6 days	0 0 0	Increased blood coagulation time, external bleeding
	Barn owls	Mice fed 50 ppm bait	Not reported	4 for 15 days	1	Not reported

Note: Secondary poisoning data was not presented in the problem formulation for the SGAR difethialone.
Source: EPA Problem Formulations for ARs (EPA, 2015a, 2015c, 2015d, 2016b, 2016c, 2016d, 2016i).

The problem formulations also present reviews of ecological incident databases that document hundreds of confirmed or probable wildlife poisoning cases attributed to ARs. These incidents often involve raptors and other predatory birds, consistent with known secondary exposure pathways. However, the EPA notes that incident reports likely underrepresent the true frequency of poisonings because carcasses can be difficult to find.

For most ARs, EPA identified gaps in avian reproduction studies, passerine toxicity studies, and terrestrial invertebrate toxicity data. Although aquatic exposure is generally assumed to be minimal due to use patterns, EPA identified potential effects on aquatic organisms due to runoff carrying ARs from baits to surface waters as a data gap. The problem formulation documents also stress that many federally listed endangered and threatened species could be exposed through consumption of contaminated prey, triggering the need for Endangered Species Act evaluations.

2020 Draft Ecological Risk Assessment for Registration Review

In 2020, EPA published the *Seven Anticoagulant Rodenticides: Draft Ecological Risk Assessment for Registration Review*, which evaluated ecological risks associated with the use of FGARs and SGARs (EPA, 2020b). The scope of the assessment focused on risks to birds and mammals from primary and secondary exposure and on potential chronic effects on growth and reproduction.

EPA confirmed that SGARs generally have higher acute toxicity to wildlife than FGARs and that SGAR residues persist in animal tissues longer, increasing the likelihood of secondary poisoning through predation. Among birds, the FGARs (warfarin, diphacinone, and chlorophacinone) are considered slightly to moderately toxic via acute oral exposure. Subacute dietary toxicity was classified as moderate (warfarin and diphacinone) to high (chlorophacinone). In contrast, SGARs are substantially more toxic to birds via dietary exposure and are classified as very highly toxic (brodifacoum, difethialone) or moderately toxic (difenacoum, bromadiolone).

Although relatively few chronic studies were available, EPA derived estimated Lowest Adverse Effect Concentrations (LOAECs) for each AR based on data from chlorophacinone in mallard ducks, using acute-to-chronic extrapolation for other compounds. Table 9 shows maximum bait concentrations measured in rodent carcasses, the derived LOAECs, and the calculated ratios of exposure (as gauged by bait concentrations in carcasses) to effect levels (as gauged by LOAECs). These ratios illustrate the degree to which observed AR residues in carcasses exceed the estimated toxicity thresholds; in other words, a high ratio indicates greater risks, because exposures exceed the LOAEC by greater margins. As Table 9 shows, bromadiolone and difethialone had the highest ratios (chronic risk quotients) of exposures to effect levels.

TABLE 9. AVIAN CHRONIC RISK QUOTIENTS BASED ON CONSUMPTION OF CONTAMINATED CARCASSES

Anticoagulant Rodenticide	Anticoagulant Rodenticide	Bait Concentration (mg/kg-carcass)	LOAEC (mg ai/kg-diet)	Ratio of Bait Concentration to LOAEC
FGAR	Chlorophacinone	4.1	0.096	43
FGAR	Diphacinone	3.4	0.5	7
FGAR	Warfarin	2.95	0.5	6
SGAR	Brodifacoum	1.83	0.09	20
SGAR	Bromadiolone	25.97	0.002	13,000
SGAR	Difenacoum	0.74	0.008	93
SGAR	Difethialone	2.67	0.001	2,700

Source: Adapted from Table 9-18 of EPA, 2020b

[1]Ratio of anticoagulant rodenticide residue mass in organism divided by the estimated avian chronic Lowest Observed Effect Exposure Concentration (LOAEC) for the toxicant.

EPA's Incident Data System (IDS) compiles ecological incident reports submitted to the agency. Each record may include details such as chemical residue analysis results, suspected or confirmed pesticides involved, the observed effects on wildlife, and information on the date and location of the incident. EPA's 2020 Draft Ecological Risk Assessment summarized 1,627 incidents involving ARs and classified each by the likelihood that the AR contributed to the observed effects (Table 10). The categories used for characterizing the likelihood of animal mortality resulting from exposure are highly probable, possible, probable, and unlikely. Among the data that EPA reviewed, SGARs (especially brodifacoum and bromadiolone) accounted for the majority of incidents in which the likelihood of animal death resulting from AR exposure was "highly probable," "possible," and "probable." Incidents were distributed across all certainty categories, with nearly 30% considered "highly probable" and additional cases classified as "probable" or "possible."

TABLE 10. THE NUMBER OF INCIDENTS PER CERTAINTY CATEGORY FOR EVALUATED RODENTICIDES AS OF 2019

Anticoagulant Rodenticide	Residue Only[1]	Highly probable[2]	Possible[3]	Probable[4]	Unlikely[5]	Un-related[6]	Un-specified[7]	Total
Chlorophacinone (FGAR)	8	21	11	14	8	8	4	**74**
Diphacinone (FGAR)	24	29	54	15	22	18	5	**167**
Warfarin (FGAR)	1	11	7	4	3	2	0	**28**
Brodifacoum (SGAR)	81	302	120	155	51	64	31	**804**
Bromadiolone (SGAR)	56	67	76	79	37	35	21	**371**
Difenacoum (SGAR)	1	2	6	3	4	0	0	**16**
Difethialone (SGAR)	14	41	38	31	13	12	18	**167**
Total (by involvement likelihood)	**185**	**473**	**312**	**301**	**138**	**139**	**79**	**1,627**

Source: Adapted from Table 6-8 of EPA, 2020b, which defined the incident classification categories as follows:
[1] Pesticide was detected in a live animal, and an incident report was submitted to document the exposure.
[2] Pesticide was confirmed as the cause of incident through residue analysis or other reliable evidence or circumstances, and the pesticide's toxicity or history of previous incidents gives strong support that the pesticide was the cause.
[3] Pesticide could have caused the incidents, but there are other plausible explanations.
[4] Circumstances of the incident and properties of the pesticide indicate that this pesticide was the cause, but confirming evidence is lacking.
[5] Evidence exists that a stressor other than exposure to this pesticide caused the incident, but that evidence is not conclusive.
[6] Conclusive evidence exists that a stressor other than exposure to this given pesticide is what caused the incident.
[7] No information on the certainty category was available for the incident.

2022 Proposed Interim Registration Review Decision

In 2022, EPA published its *Proposed Interim Registration Review Decision for Seven Anticoagulant Rodenticides* (EPA, 2022d). This document reiterated many findings of the 2020 Draft Ecological Risk Assessment and provided additional quantitative analysis of ecological risks. Specifically, EPA calculated acute dose-based and dietary-based Risk Quotients (RQs) for birds and mammals to characterize the likelihood of adverse effects from consuming treated bait.

Table 11 and Table 12 summarize the results of these acute risk calculations for mammals and birds, respectively. For each active ingredient, EPA calculated RQs for primary bait consumption over a single day and over multiple days (which was six days for mammals and unspecified durations for birds). The RQ represents the ratio between the calculated environmental exposure and the toxicity threshold established in laboratory testing. The calculated RQ values are an indicator of potential ecological risks. EPA set a level of concern (LOC) for non-listed mammals and birds for RQs as a value greater than 0.5. As RQs increase, the potential for ecological risks also increases.

Among mammals, some ARs had RQs less than the LOC for single-day consumption of primary bait under certain feeding strategies and class sizes of mammals; the multiple-day RQs of all ARs exceeded the LOC for all feeding strategies and mammal size classes (see Table 11). For birds, all ARs had RQs less than 0.5 for single-day consumption of primary bait; and for multi-day exposures, brodifacoum and difethialone produced the highest acute-risk estimates, with multiple-day RQs ranging up to 168 (see Table 12).

TABLE 11. SUMMARY OF ACUTE RISKS FROM ANTICOAGULANT RODENTICIDES TO MAMMALS

Active Ingredient	Primary Bait Consumption, Single-Day Risk Quotients	Primary Bait Consumption, Multiple-Day Risk Quotients
Chlorophacinone (FGAR)	0.80 – 1.73	5.11 – 11
Diphacinone (FGAR)	0.80 – 1.73	4.687 – 10.05
Warfarin (FGAR)	4.02 – 8.67	23.53 – 50.67
Brodifacoum (SGAR)	0.40 – 0.87	27 – 59
Bromadiolone (SGAR)	0.40 – 0.87	2.66 – 12.81
Difenacoum (SGAR)	0.80 – 1.73	4.74 – 10.25
Difethialone (SGAR)	0.40 – 0.87	11 – 24

Source: Adapted from Table 3 of EPA, 2022d

TABLE 12. SUMMARY OF ACUTE RISKS FROM ANTICOAGULANT RODENTICIDES TO BIRDS.

Active Ingredient	Primary Bait Consumption, Single-Day Risk Quotients	Primary Bait Consumption, Multiple-Day Risk Quotients
Chlorophacinone (FGAR)	0.02 – 0.07	0.13 – 0.43
Diphacinone (FGAR)	0.02 – 0.07	0.12 – 0.40
Warfarin (FGAR)	0.11 – 0.34	0.62 – 2.0
Brodifacoum (SGAR)	0.01 – 0.03	117 – 166
Bromadiolone (SGAR)	0.01 – 0.03	0.18 – 1.49
Difenacoum (SGAR)	0.02 – 0.07	0.12 – 0.40
Difethialone (SGAR)	0.01 – 0.03	52 – 168

Source: Adapted From Table 4 of EPA, 2022d

EPA noted that sublethal effects observed in mammals during toxicity testing included internal bleeding, lethargy, and other coagulopathy-related symptoms. For birds, observed effects included lethargy, impaired coordination, and hemorrhaging. EPA concluded that all ARs pose an acute risk to non-listed mammals and that brodifacoum and difethialone pose acute risks to birds. EPA did not make findings related to endangered species.

EPA also conducted chronic risk calculations, but they were based on a more limited toxicity threshold dataset. Those calculations indicated that ARs present a chronic risk to both mammals and birds, driven by the ARs' persistence in tissues and their potential for cumulative effects from repeated exposure.

2024 Biological Evaluation

In 2024, EPA published its final Biological Evaluation (EPA, 2024b), which assessed the potential effects of ARs on federally listed threatened and endangered species and designated critical habitats. EPA conducted a taxa-based assessment that evaluated both primary and secondary exposures for non-target animals. The analysis was conducted on both FGARs and SGARs with results organized by application method (e.g., bait station, burrow, and broadcast). Table 13 summarizes EPA's findings.

TABLE 13. POTENTIAL FOR EFFECTS ON PRIMARY AND SECONDARY CONSUMERS BY APPLICATION METHOD

Chemical	Bait Station		Burrow		Broadcast	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
FGARs	Yes	Yes	Yes	Yes	Yes	Yes
SGARs	Yes	Yes	Yes	Yes	NA	NA

NA = Not Applicable
Source: Adapted from Table 2-1 of EPA, 2024b

For primary exposure, EPA noted that in-burrow baiting is more likely to cause primary exposure to non-target animals than bait stations. That is because the bait is placed directly into burrows, which may be accessible to other species. In contrast, tamper-resistant bait stations are generally designed to limit access to non-target animals. On the other hand, broadcast applications were identified as presenting the greatest potential for non-target primary exposure, as baits are dispersed over larger areas where access is not controlled. SGARs are not typically allowed to be applied via broadcast methods, which explains the "not applicable" entries for SGARs in Table 13.

Additionally, EPA acknowledged that all application methods can result in secondary exposure to non-target animals. For example, when rodents ingest bait—however applied—and die above ground, their carcasses can be readily consumed by raptors, foxes, and other carnivores. In the case of burrow applications, the likelihood of secondary exposure depends partly on whether poisoned rodents die in burrows (reducing availability) or on the surface (increasing availability).

Although EPA recognized that terrestrial invertebrates (e.g., insects) can also accumulate rodenticides and be consumed by insectivorous wildlife, invertebrate-mediated exposure is generally considered a minor pathway relative to the consumption of target rodents. Overall, EPA determined that predators and scavengers of target species (as opposed to terrestrial invertebrates) remain at the greatest risk of secondary poisoning across all use patterns.

EPA found that the risks to wildlife associated with the use of ARs varied considerably across application methods. EPA's analysis of FGARs determined that broadcast applications was likely to adversely affect a larger number of threatened and endangered species compared to burrow or bait station uses Table 14). For example, broadcast application was estimated to likely adversely affect 54 mammal species and 42 bird species, compared to 45 mammal species and 16 bird species affected by bait station use. Amphibians and

reptiles were also more likely to be adversely affected by broadcast application than by burrow or bait station application. Among the species EPA found to be likely adversely affected by FGAR use, EPA also identified a subset that would likely be in future jeopardy when considering population-level exposure and potential effects. The number of species determined to be in jeopardy by application method is shown in parentheses in Table 14.

TABLE 14. NUMBER OF THREATENED AND ENDANGERED SPECIES NATIONWIDE LIKELY TO BE ADVERSELY AFFECTED BY FGARS BY APPLICATION METHOD

Taxon	No. of T and E Species	No. of T and E Species Likely to be Adversely Affected by Application Method (and likelihood of future jeopardy)		
		Bait Station	Burrow	Broadcast
Mammals	100	45 (27)	51 (34)	54 (40)
Birds	95	16 (7)	16 (1)	42 (18)
Amphibians	47	0 (0)	5 (0)	12 (0)
Reptiles	59	14 (4)	14 (0)	30 (5)

Source: Adapted from Table 3-6 of EPA, 2024b

When conducting a similar analysis for SGARs, EPA evaluated only bait station applications, as current product labels prohibit the use of these compounds for broadcast applications and generally restrict their use for in-burrow application with some exceptions. EPA found that SGAR use in bait stations was estimated to likely adversely affect the same number of species as FGARs: 45 mammal species, 16 (7) bird species, 0 amphibian species, and 14 reptile species.

EPA also found that FGAR and SGAR use has the potential to adversely affect or modify the critical habitats of five threatened and endangered species: California tiger salamander, Alameda whipsnake, Mexican spotted owl, Northern spotted owl, and Louisiana pinesnake. These results are not discussed further because all five species are endemic to the western or southeastern United States, and none have known ranges in Massachusetts.

These "likely to adversely affect" determinations are based on highly conservative analyses, and they do not mean that entire species are in jeopardy or that critical habitats are being adversely modified. Rather, these determinations are primarily intended to identify the subset of issues to be further evaluated by EPA in consultation with other agencies (e.g., the National Marine Fisheries Service, the National Forest Service) as part of developing a Biological Opinion to determine whether potential effects to individuals might negatively impact populations or species overall.

EPA developed 11 measures intended to mitigate the identified risks to threatened and endangered species and to critical habitats. These measures are part of a suite that EPA may select from when determining how best to reduce exposure to listed species and their habitats, and include: additional restrictions on bait station use and placement in certain areas, prohibitions on certain broadcast and below ground applications, bans on application in aquatic habitats, requirements for post-application follow-up activities, requirements for burrow hole treatment, updated registration terms and conditions, and requirements for reporting observations of dead or dying non-target animals to EPA (EPA, 2024b).

5.2 Assessments Issued by Other Government Agencies and International Bodies

Outside of the EPA, other national and international bodies have conducted scientific assessments of the ecological risks of ARs. Most reports are risk assessments or policy reviews that evaluate potential adverse effects on wildlife and ecosystems under specific use scenarios, drawing upon published literature, incident data, and field studies. This section summarizes assessments issued by the U.S. Department of Agriculture's (USDA's) Animal and Plant Health Inspection Service (APHIS), Health Canada's Pest Management

Regulatory Agency (PMRA), the European Chemicals Agency (ECHA), the World Health Organization (WHO), the Canadian Province of British Columbia, and the California Department of Pesticide Regulation (CDPR). Additional insights from a recent U.S. Geological Survey (USGS) investigation of eagle mortality are also included. Collectively, these assessments indicate areas of scientific consensus regarding the ecological impacts of ARs; they also point to important uncertainties in the understanding of these impacts.

U.S. Department of Agriculture

The USDA APHIS Wildlife Services (WS) conducts Methods Risk Assessments to evaluate the human health and ecological risks associated with wildlife damage management activities, including the use of ARs. This section reviews the peer-reviewed chapters that ATSDR published on risks of brodifacoum, chlorophacinone, and diphacinone (USDA, 2023a, 2023b, 2025). USDA has also published risk assessments on rodenticides other than ARs; those are not reviewed here.

The USDA AR assessments primarily focus on WS operational uses, such as the eradication of invasive rodents from islands to protect sensitive ecosystems and limited applications near non-residential structures. For example, brodifacoum is used under restricted conditions for island conservation projects, with label requirements and mitigation measures designed to reduce exposure to non-target wildlife and humans. Chlorophacinone and diphacinone are primaily used to control burrowing rodents, such as prairie dogs, ground squirrels, and mountain beavers, often through hand-baiting directly into their burrows to limit non-target exposure.

Overall, these assessments concluded that risks to sensitive terrestrial vertebrates (especially scavenging mammals and birds) are inherent to AR use. The assessments also noted that adhering to application restrictions and required mitigation measures generally keeps risks low or manageable. Examples of the restrictions and mitigation measures include carcass searches and bait placement protocols. Much of USDA's analysis draws on EPA risk assessments but tailors findings to WS's operational contexts, which often differ from typical urban or agricultural uses.

While WS does use diphacinone in Massachusetts for brown rat control, these uses are infrequent and small in scale—averaging about 16.7 pounds of product annually, which is 0.1% of the estimated statewide diphacinone usage of licensed applicators based on the data presented in Figure 1 (USDA, 2023a).

Health Canada's Pest Management Regulatory Agency (PMRA)

In 2009 and 2010, Health Canada's Pest Management Regulatory Agency (PMRA) published proposed and revised risk mitigation measures for FGARs, SGARs (excluding difenacoum), bromethalin, and zinc phosphide (PMRA, 2009, 2010). These efforts were driven by concerns about risks to children, pets, and non-target wildlife; and they considered data and analyses from EPA's risk assessments and risk mitigation decisions.

PMRA concluded that SGARs pose a particularly high risk of secondary poisoning to predators and scavengers due to the substances' high toxicity and persistence in animal tissues. To mitigate these risks, PMRA issued several regulatory actions. For domestic (consumer) products, these included prohibiting the sale of brodifacoum, bromadiolone, and difethialone, requiring all other baits to be sold pre-packaged with tamper-resistant bait stations, and banning loose bait formulations such as pellets and meals. For commercial products, the measures prohibited certain liquid formulations, restricted outdoor use to tamper-resistant bait stations, and required additional label amendments emphasizing precautions to protect children and wildlife.

These Canadian measures closely paralleled EPA restrictions but were adapted to Canadian use patterns. PMRA emphasized that, despite limited Canadian incident reporting data at the time, available evidence

from field monitoring and U.S. experience warranted precautionary mitigation measures to prevent unintended ecological impacts and protect public health.

European Chemicals Agency (ECHA)

In 2023, the European Chemicals Agency (ECHA) Biocidal Products Committee (BPC) published an opinion under Article 75(1)(g) of Regulation (EU) No 528/2012 evaluating the comparative environmental risks of ARs (ECHA, 2023). The assessment reviewed data from regulatory dossiers and scientific literature to compare the ecological hazards of FGARs and SGARs. The comparative assessment ultimately contributed to further restrictions on the sale, distribution, and authorized uses of ARs in the European Union.

BPC concluded that SGARs pose greater environmental concerns than FGARs, mainly due to SGARs' persistent, bioaccumulative, and toxic (PBT) properties. Specifically, the primary drivers of comparative risk were persistence in animal tissues, potential for secondary poisoning of predators and scavengers, and bioaccumulation in terrestrial ecosystems. Among all active ingredients assessed, warfarin was considered to have the least hazardous ecological profile, primarily because it is readily biodegradable and less persistent in the environment than other ARs.

BPC did not rank the ecological risk of all ARs, primarily due to uncertainties in some datasets. Nonetheless, the comparative assessment underscored that the environmental risks associated with SGARs are generally higher than those posed by FGARs. The BPC further discussed which ARs are most suitable for specific uses (e.g., rat versus mouse control) and discussed available alternatives to ARs. These alternatives include both lethal and non-lethal control measures intended to mitigate ARs' ecological impacts (see Section 6).

World Health Organization (WHO)

The World Health Organization (WHO) Environmental Health Criteria Programme published *Environmental Health Criteria 175: Anticoagulant Rodenticides*. This program's mission is "to identify new or potential pollutants; to identify gaps in knowledge concerning the health effects of pollutants; to promote the harmonization of toxicological and epidemiological methods to have internationally comparable results." This report, although three decades old, is the most recent WHO assessment on ARs and reviews their effects on humans, animals, and the environment (WHO, 1995).

WHO considered multiple lines of ecological evidence, including LD_{50} values (i.e., the dosage at which 50% of organisms are expected to die due to lethal toxic exposure), toxicity to rodents, toxicity to non-target mammals, and the impacts of short- and long-term exposure. WHO considered impacts of accidental, primary, and secondary AR poisoning in various non-target species, including domestic and farm animals. The assessment emphasized that both primary and secondary poisoning are well-documented causes of mortality among non-target birds and mammals. WHO noted that ARs can contaminate water sources, despite the compounds' low water solubility and soil affinity.

WHO made several recommendations aimed at decreasing non-target AR exposure, such as using bittering agents to reduce accidental ingestion, designing bait formulations less attractive to birds and domestic animals, careful bait placement to limit access by non-target species, and disposal of poisoned rodents by burial or incineration to reduce secondary poisoning hazards (WHO, 1995).

Canadian Province of British Columbia

In 2021, the Ministry of Environment and Climate Change Strategy in the Canadian Province of British Columbia published a *Review of Second-Generation Anticoagulant Rodenticides and Risks to Non-target Wildlife* (Ministry of Environmental and Climate Change Strategy, 2021). This report documented risks to wildlife from SGARs and patterns of their use in British Columbia. The Ministry used this information to inform policy decisions regarding SGAR sale and use under the province's Integrated Pest Management Act.

The report emphasized that SGARs are highly toxic, persistent, and bioaccumulative, and that residues from treated rodents pose a well-established risk of secondary poisoning for predatory and scavenging wildlife. A targeted literature review and stakeholder engagement process confirmed that SGARs (particularly bromadiolone and brodifacoum) were the most frequently detected rodenticides in non-target species. Small mammals were the most contaminated prey group, followed by birds. The authors noted that residues can persist in vertebrate tissues for prolonged periods, ranging from 15–55 days for FGARs and 108–307 days for SGARs.

Potential sublethal effects of exposure among predators included impaired body condition, greater susceptibility to disease and environmental stressors, and coagulopathy. Attributing wildlife deaths to rodenticide poisoning remains challenging, however, because residue detection alone does not establish the cause of death; and necropsies combined with residue analysis are generally needed for confirmation. The report highlighted that despite widespread evidence of exposure, population-level effects remain poorly understood due to data gaps and the opportunistic nature of carcass collection. The authors also noted that overreliance on SGARs, inadequate application of IPM practices, and use by untrained applicators have contributed to unnecessary environmental risks.

In 2023, British Columbia enacted regulations “prohibiting the sale and use of SGARs for all members of the public, and most commercial and industrial operations” (BC Gov News, 2022). This regulation only applies to brodifacoum, bromadiolone, and difethialone; the regulation does not apply to difenacoum because it has not been registered for use in Canada (Ministry of Environmental and Climate Change Strategy, 2021).

California Department of Pesticide Regulation

The California Department of Pesticide Regulation (CDPR) has conducted several investigations into the ecological impacts of ARs on non-target wildlife.

In a 2018 assessment, CDPR analyzed peer-reviewed publications, sales and use reporting data, and wildlife incident and mortality reports (CDPR, 2018). They concluded that FGARs were less persistent, less bioaccumulative, and generally less toxic to non-target wildlife than SGARs. At the time, CDPR concluded that FGAR use was “unlikely to have a significant adverse impact to non-target wildlife.” This decision was based on the aforementioned FGAR properties. In contrast, SGARs were found to pose higher risks due to their greater toxicity, longer persistence in tissues (with hepatic half-lives exceeding 100 days), and higher rates of exposure detected in predatory wildlife such as bobcats and mountain lions. Brodifacoum in particular was identified as having the highest risk profile among SGARs.

CDPR also noted that despite earlier restrictions on SGARs, exposure data in wild animals did not show clear decreases in detections or concentrations in some species. CDPR also documented evidence of adverse sublethal effects and mortality in selective predators. Examples of adverse impacts include coagulopathy and internal hemorrhage, increased disease susceptibility and severe notoedric mange in bobcats associated with AR exposure (linked to immune dysregulation and compromised skin barrier), and documented mortalities in selective predators (CDPR, 2018).

In 2023, CDPR issued a separate notice proposing to reevaluate the FGAR diphacinone, following updated wildlife incident data that showed an increasing percentage of toxicosis cases involving this pesticide (CDPR, 2023). Between 2019 and 2021, diphacinone was detected in up to 50% of animals with confirmed pesticide-related deaths; sales and use of diphacinone also increased over that period. This coincided with restrictions on SGARs (AB 1788, 2020), which could have contributed to a greater reliance on diphacinone in rodent control. CDPR emphasized that the available data did not conclusively attribute mortality to diphacinone alone because multiple rodenticides were often present in samples. However, the agency concluded that a “significant adverse impact to non-target wildlife has occurred or is likely to occur from

the use of diphacinone." As a result, CDPR proposed to reevaluate ecological risks and consider whether additional mitigation measures are warranted.

CDPR is currently reevaluating the registrations of both SGARs and FGARs, including diphacinone, to determine whether additional restrictions or mitigation measures are necessary to protect non-target wildlife. While this process is underway, statewide prohibitions on most uses of these rodenticides remain in effect under California law.

5.3 Peer-Reviewed Publications on Ecological Effects

ERG's scope for this project also included identifying and synthesizing information from the scientific literature on specific topics of interest related to ARs' ecological effects. This literature review is intended to complement and supplement the information summarized in scientific and regulatory assessments.

The topics covered here were selected based on several considerations:

- Specific questions about exposure and effects raised in stakeholder input and public comments.
- Themes that emerged during broad literature searches.
- Areas where the scientific and regulatory assessments indicated limited available data or uncertainty.

The topics of interest included:

- The extent of AR exposure in non-target, carnivorous avian and mammalian wildlife in Massachusetts and comparable settings.
- Recent evidence of lethal and sublethal toxic effects in non-target animals.
- The occurrence, transport, and fate of ARs in aquatic systems and the implication for piscivorous animals.

ERG focused the literature search on studies and review articles published since 2019. That cutoff year was selected because earlier publications were likely considered as part of EPA's most recent ecological risk assessment.

ERG considered two information sources as part of its literature review. First, ERG queried EPA's ECOTOX database for relevant insights. According to EPA, this database has an inventory of "chemical environmental toxicity data on aquatic and terrestrial species." The queries used the names of the seven active ingredients found in FGARs and SGARs, and publications that met the following criteria were retrieved:

- Laboratory or field studies that examined toxicological effects of a single AR active ingredient on live organisms under controlled experimental conditions.
- Studies of wild animals found dead in the environment, when such studies reported toxicological endpoints or residue concentrations.
- Studies on effects to non-target species (e.g., predators, scavengers) with plausible exposure pathways to ARs.
- Studies that report toxicological effects related to mortality, growth and development, reproduction, bioaccumulation, or impairment of blood clotting.
- Studies available in English.
- Studies published since 2019.

Second, ERG conducted keyword-based searches of the peer-reviewed literature using Google Scholar. The keyword-based searches used Boolean strings, combining the following terms: "anticoagulant rodenticide," "toxicity," "indirect effects," "mammal," "bird," and "risk." This supplemental search considered peer-reviewed journal articles and reports written in English (or already translated into English) and published between 2019 and 2025.

The following discussion, organized topically, summarizes the relevant studies identified through ERG's literature search.

Population-level Exposure in Raptor and Carnivorous Mammal Species

Since 2019, several researchers have published research on FGAR and SGAR exposure measured in wild populations of raptors and carnivorous mammal species that may be particularly susceptible to secondary exposure to ARs. Below are the most relevant recent articles on this topic.

Murray (2020) analyzed AR residues in red-tailed hawks (*Buteo jamaicensis*) that were admitted to the Tufts Wildlife Clinic in North Grafton, Massachusetts, between 2017 and 2019, and that subsequently died. Birds that were brought to the clinic displayed signs of illness or injury. After birds died or had to be euthanized, liver samples were taken. This research considered 43 hawks: 40 were found in Massachusetts, two in Connecticut, and one in Rhode Island. Fourteen of the birds were diagnosed with AR toxicosis. Liver samples from all 43 birds tested positive for ARs. SGARs were the most frequently detected: brodifacoum was present in 100% of birds, bromadiolone in 63%, and difethialone in 67%. FGARs were detected less frequently (7%). Most of the birds (91%) contained residues of two to four rodenticides in their livers.

The author compared these results to earlier studies of red-tailed hawks (M. Murray, 2011, 2017) that were presented at the same veterinary clinic between 2006 and 2010 and between 2012 and 2016 (Table 15). The most recent results had the highest percentage of detections across the three sampling periods compared (2006–2010, 2012–2016, and 2017–2019). The author noted that despite EPA's risk mitigation measures implemented in 2015, exposure in birds has remained high, suggesting that existing restrictions may not be sufficient to protect red-tailed hawks from secondary poisoning.

TABLE 15. PERCENT OF RED-TAILED HAWKS PRESENTED TO A CLINIC IN MA WITH LIVER SAMPLES POSITIVE FOR ANTICOAGULANT RODENTICIDES OVER THREE TIME PERIODS

Time Period	No. of Red Tailed Hawks[1]	Percent Positive for at Least 1 AR	Percent Positive for 2 to 4 ARs
2006 – 2010[2]	80	89%	1.3%
2012 – 2016[3]	37	97%	78%
2017 – 2019[4]	43	100%	91%

1. Birds presented at Tufts Wildlife Clinic in North Grafton, Massachusetts, USA.
2. Source: Murray (2011)
3. Source: Murray (2017)
4. Source: Murray (2020)

Murray (2011) and Murray (2017) also published on AR exposure in a broader range of raptor species admitted to the same Tufts Wildlife Clinic following injury or signs of AR toxicosis. These publications summarized data for three species of owls and for red-tailed hawks. Murray (2011) summarized data collected between 2006 and 2010, documenting that 86% of the collected birds across these species tested positive for at least one AR, with brodifacoum most frequently detected; however, only 1.3% of these birds from this time period had residues of more than one SGAR. FGARs were not detected. Building on this work, Murray (2017) evaluated residues in those same raptor species, but they were collected from 2012

and 2016. The research found that 94% of all birds tested were positive for at least one SGAR and 66% were positive for residues of more than one SGAR, indicating that more than one SGAR was likely commonly used in the areas where the birds were collected. Brodifacoum remained the most commonly detected compound, present in 95% of the sampled birds. FGARs were detected in only two birds.

In addition to the data on red-tailed hawks presented in Table 15, the two studies published by Murray documented AR residues in barred owls (*Strix varia*), great horned owls (*Bubo virginianus*), and eastern screech-owls (*Megascops asio*). As shown in Table 16, the increase in detections of ARs was consistent across species. Murray (2017) also examined pesticide use reports from pest management professionals, finding a strong correspondence between the SGARs most commonly applied and those most often detected in the birds.

TABLE 16. PERCENT OF THREE OWL SPECIES PRESENTED TO A CLINIC IN MA WITH LIVER SAMPLES POSITIVE FOR ANTICOAGULANT RODENTICIDES OVER TWO TIME PERIODS

Species		No. of Birds[1]	Percent Positive for at Least 1 AR	Percent Positive for >1 AR
Barred Owl	2006 – 2010[2]	40	75%	Not reported
	2012 – 2016[3]	24	88%	42%
Great Horned Owl	2006 – 2010[2]	18	100%	Not reported
	2012 – 2016[3]	17	100%	71%
Eastern Screech Owl	2006 – 2010[2]	23	87%	Not reported
	2012 – 2016[3]	16	100%	69%

1. Birds presented at Tufts Wildlife Clinic in North Grafton, Massachusetts, USA.
2. Source: Murray (2011)
3. Source: Murray (2017)

Keating et al. (2024) conducted a global literature review and meta-analysis to assess the extent of AR exposure in wild, non-domesticated carnivorous mammals. The authors searched for studies reporting exposure data on terrestrial carnivores, excluding laboratory animals and domestic animals. Most studies were from the United States and Europe, but records were compiled from across the globe. They found evidence of AR detections in eight taxonomic families within the order Carnivora, with species from the Mustelidae family (e.g., stoats, weasels, and fishers) the most frequently represented. Other well-represented families included Canidae (e.g., wolves, coyotes, and foxes) and Felidae (e.g., bobcats, cougars, and mountain lions). Overall, the review highlighted that a wide range of carnivorous mammals are subject to non-target exposure.

Among all compounds reported, the SGARs brodifacoum and bromadiolone were most commonly detected, present in 66% of published studies, 81% of study locations, and 80% of examined species. The authors attributed this predominance largely to the relatively long half-lives of these compounds in animal tissues with respect to other ARs. The review also noted that underlying studies linked AR exposure to morbidity or mortality in a substantial proportion of cases: authors of included studies reported that rodenticides contributed to mortality in at least one individual in about 34% of species. However, the studies considered as part of this review did not include LD_{50} values for brodifacoum or bromadiolone in wild terrestrial Carnivora species, highlighting a data gap regarding lethal dose thresholds for these taxa.

Nakayama et al. (2019) conducted a global literature review and meta-analysis of publications from 1998 to 2015 documenting incidents of primary and secondary AR poisoning in non-target animals. Of the 4,891

individual non-target animals included in their analysis, 55% had detectable levels of ARs in liver tissue. SGARs were most frequently detected: brodifacoum was found in 31% of all sampled animals, bromadiolone in 30%, and difenacoum in 26%. The authors attributed these findings to both higher usage rates and the relatively longer tissue half-lives of these compounds compared to FGARs. Detection rates greater than 50% were found across different animal groups, including Carnivora species, other mammal species, raptors, birds other than raptors, and reptiles. The review presented additional insights on raptors. For instance, 34 out of the 39 raptor species considered in the publication had detectable anticoagulant residues in liver tissue. Further, the authors observed that raptors that primarily prey on non-target species also exhibited evidence of exposure to ARs, suggesting that tertiary exposure could be an important and under-recognized pathway for exposure in these birds.

Buckley et al. (2023) tested the livers of 45 New England fishers (*Pekania penanti*) opportunistically trapped across Vermont and New Hampshire during 2018 to 2019 for ARs. All but one animal (98%) had detectable amounts of at least one rodenticide; 84% had residues of more than one compound; and two individuals tested positive for five different rodenticides. The FGAR diphacinone was the most frequently detected, present in the livers of 96% of fishers at concentrations up to 0.96 ppm, followed by the SGAR brodifacoum, detected in 80% of fishers. The authors did not observe differences in exposure patterns based on geography or animal age. All animals were trapped legally for their pelts; the animals were not submitted for analysis due to suspected poisoning. The authors emphasized that this near-universal exposure suggests ARs are widespread in the environment and could pose underappreciated health risks to wild fishers in the northeastern United States.

Carrera et al., (2024) analyzed liver samples from 30 wild carnivorous mammals collected in Alicante Province, southeastern Spain, during 2021–2022. These included 25 red foxes (*Vulpes vulpes*), 3 European badgers (*Meles meles*), and 2 common genets (*Genetta genetta*). SGARs were detected in red fox livers: difenacoum, bromadiolone, and brodifacoum were present in 100% of the foxes; flocoumafen (an SGAR not registered by EPA) was found in 96%; and difethialone in 60%. The FGARs warfarin, diphacinone, and chlorophacinone were detected at lower rates (12%, 8% and 20% respectively). 60% of red foxes had at least one SGAR at concentrations exceeding 200 ng/g liver, a threshold associated with adverse health effects. The study further observed that foxes diagnosed with infectious disease had significantly higher mean and median concentrations of several SGARs compared to those animals killed by trauma, suggesting that animals exposed to AR may be more susceptible to infectious diseases.

Cooke et al. (2023) evaluated the prevalence and potential impacts of ARs in four non-target nocturnal predatory bird species in Australia—eastern barn owl (*Tyto javanica*), southern boobook (*Ninox boobook*), tawny frogmouth (*Podargus strigoides*), and powerful owl (*Ninox strenua*). Liver samples from 60 birds collected opportunistically between 2003 and 2022 were tested for residues of eight ARs. SGARs were detected in 92% of all birds sampled, with brodifacoum found in 92% of individuals and bromadiolone in 32%. FGARs were detected in fewer samples; warfarin was not detected at all, and pindone was only found in powerful owls (42%) at low concentrations unlikely to cause toxicity. The study found that exposure to multiple SGARs increased the likelihood of potentially lethal liver concentrations. Specifically, 80% of eastern barn owls, 68% of tawny frogmouths, 42% of southern boobook owls, and 33% of powerful owls had SGAR concentrations at levels likely to result in toxic or lethal effects. Contrary to the authors' expectations, species that do not primarily prey on rodents, such as tawny frogmouths and powerful owls, exhibited similarly high contamination levels compared to rodent specialists. No significant association was detected between land-use type (urban, agricultural, forest) and SGAR concentration or the number of SGARs detected, suggesting widespread contamination across landscapes.

Silveira et al. (2024) tested liver samples from 597 fishers collected in the northeastern United States for 11 ARs, including all FGARs and SGARs considered in this report. Overall, 78.6% of fishers tested positive for at

least one rodenticide, and over half (55%) had residues of multiple compounds, suggesting repeated or chronic exposure. The FGAR diphacinone was the most frequently detected (64.3% of samples), followed by the SGARs brodifacoum (53.8%) and bromadiolone (28%). Using spatial interpolation (kriging), the authors identified a hotspot of exposure spanning southern New Hampshire, Vermont, and southeastern New York. Regression models indicated that the proportion of "wildland-urban intermix" landscapes described as "low density buildings within a largely forest-dominated landscape" was the strongest and most consistent predictor of exposure. By contrast, neither agricultural land use nor the presence of protected areas was a significant predictor. The authors concluded that the widespread residential use of ARs in these intermixed landscapes is likely a significant driver of exposure for forest carnivores in the region.

A report by the U.S. Geological Survey (USGS, 2023) evaluated exposure to ARs (and other contaminants) in bald eagle and golden eagle carcasses collected across eight western and midwestern U.S. states from 2014 to 2017. Among the seven EPA-registered FGARs and SGARs, brodifacoum was detected in the greatest number of samples, present in the livers of 114 bald eagles (70% of those tested) and 52 golden eagles (39%). The authors noted this high detection rate could be partly explained by the relatively low analytical detection limit for brodifacoum (<0.002 mg/kg wet weight, which is an order of magnitude less than others); it could also be explained by the chemical's high persistence in tissues and widespread use. Other SGARs were rarely detected, and FGARs were largely absent, except for a single detection of diphacinone in a golden eagle. The researchers conducted systematic necropsy and diagnostic testing to determine the cause of death for each eagle. They found that the leading causes of mortality were trauma, electrocution, and lead poisoning; AR toxicosis was not identified as the primary cause of death in any of the birds examined.

Lethal and Sublethal Toxic Effects on Non-Target Animals

Since 2019, several researchers have published on the FGAR and SGAR exposure doses and tissue concentrations that may induce or be associated with lethal and sublethal effects on non-target animal species.

Rattner et al. (2019) reported results from a series of controlled studies investigating the ecotoxicological effects of the SGAR brodifacoum in American kestrels (*Falco sparverius*). In one experiment, kestrels were fed brodifacoum-contaminated diets for 7 days at concentrations intended to reflect realistic exposures from consuming contaminated prey. This exposure caused dose-dependent sublethal toxic effects, including prolonged blood clotting times, bruising, anemia, and microscopic hemorrhaging. Although clotting times returned to baseline within about a week after exposure ended, brodifacoum residues persisted in liver and kidney tissues for several weeks, with estimated terminal half-lives exceeding 50 days. The authors also conducted an experiment evaluating the effects of sequential exposure, in which kestrels were first fed brodifacoum or the FGAR chlorophacinone for 7 days, followed by a recovery period and then a second exposure to chlorophacinone. Kestrels initially exposed to brodifacoum showed significantly prolonged blood clotting times after the second exposure compared to controls and to birds that had only been exposed to chlorophacinone. These findings suggest that repeated or sequential exposure to ARs in wild raptors could have lasting and cumulative effects on coagulation, even after apparent recovery from initial exposure.

Nakayama et al. (2019) is a global literature review and meta-analysis of publications from 1998 to 2015 that was previously summarized above in the context of exposures in non-target animals. This study also compiled published estimates of median lethal doses (LD_{50}) and elimination half-lives ($T_{1/2}$) for both FGARs and SGARs in various non-target wildlife species. These data illustrate the substantially greater toxicity (as indicated by lower LD_{50}s) and persistence of SGARs relative to FGARs, which are reasons why SGARs are

considered to pose higher ecological risks. For example, in mice, brodifacoum's LD_{50} is 0.4 mg/kg compared to 20.5 mg/kg for chlorophacinone, and brodifacoum's liver half-life exceeds 300 days. Table 17 below reproduces the authors' compilation of reported LD_{50} values and half-lives across species and ARs.

TABLE 17. NON-TARGET WILDLIFE LD50S AND ELIMINATION HALF-LIFE FOR FGARS AND SGARS

Animal	FGAR			SGAR			
	Chlorophacinone	Diphacinone	Warfarin	Brodifacoum	Bromadiolone	Difenacoum	Difethialone
Median Lethal Dose (LD_{50}; mg/kg) *(ranges represent estimates from multiple studies)*							
Mouse	20.5	141-340	374	0.4	1.75	0.8	1.29
Rat	11	30	14-323	0.35-0.5	0.56-0.84	-	0.55
Dog	-	0.88-15	20-50	0.25-1	8.1	-	-
Cat	-	5-15	2.5-20	<25	>25	-	-
Chicken	-	-	942	3.15	-	-	-
Northern Bobwhite	258	2,014	>2,150	--	138	--	0.26
Ring-necked Pheasant	>100	--	--	10	--	--	--
Mallard	--	3,158	620	4.6	--	--	--
American Kestrel	--	97	--	--	--	--	--
Australasian Harrier	--	--	--	10	--	--	--
Eliminated Half-Life ($t_{1/2}$; days)							
Mouse plasma	11.7	-	14.9	91.7	33.3	20.4	38.9
Mouse liver	35.4	-	66.8	307.4	28.1	61.8	28.5
Rat	-	3	-	-	-	-	-
Pig	-	5.43	-	-	-	-	-
Screech Owl	-	11.7	-	-	-	-	-

Source: Adapted from Nakayama et al., 2019

Elliott et al. (2024) has compiled a database of SGAR liver concentrations and postmortem assessments of 951 terrestrial raptor carcasses collected in North America from 1989 to 2021. Using generalized linear mixed-effects models, the authors estimated family-level SGAR concentrations associated with necropsy-based diagnoses of SGAR-induced mortality. SGAR poisoning was diagnosed when necropsy indicated hemorrhage, pallor, or bleed-out in the absence of other causes; and when the diagnosis was confirmed by liver residue measurements. Median (50% probability) expected toxicity thresholds, expressed as liver concentrations, for total SGAR concentrations were estimated as 78 ng/g for Accipitridae, 55 ng/g for Falconidae, 107 ng/g for Strigidae, and 39 ng/g for Tytonidae. Compound-specific thresholds for all families combined were 106 ng/g for bromadiolone, 62 ng/g for brodifacoum, and 50 ng/g for difethialone. The study also proposed Toxicity Equivalence Factors (TEFs) of 1 for difethialone, 0.8 for brodifacoum, and 0.5 for bromadiolone; these TEFs can be used to characterize cumulative risk for animals exposed to multiple ARs. The authors note that these thresholds are lower than earlier published benchmarks (e.g., 100–200 ng/g) and recommend caution in interpreting liver residues, as many factors—including exposure timing, repeated exposures, and interspecific variability—can influence the relationship between residue concentrations and clinical toxicosis.

Fate and Transport of Anticoagulant Rodenticides in Aquatic Systems

A growing body of literature indicates that ARs are transported through the aquatic food web. Research teams studying aquatic systems in Germany (Kotthoff et al., 2019; Regnery et al., 2020) have detected both FGARs and SGARs in fish tissues collected from geographically dispersed surface waters.

Kotthoff et al. (2019) reported the first evidence of ARs in freshwater fish and suspended particulate matter in Germany. Analyzing bream liver and particulate samples from the German Environmental Specimen Bank, they detected brodifacoum in 88% of fish livers sampled in 2015, sometimes at concentrations exceeding 10 µg/kg. Other SGARs (difenacoum, bromadiolone, difethialone, flocoumafen) were detected less frequently. No FGARs were identified. Their temporal analysis of bream liver over two decades showed significantly increasing brodifacoum concentrations at some sites, suggesting accumulation over time.

Regnery et al. (2020) hypothesized that rodenticides enter streams primarily through contamination of urban stormwater and wastewater originating from bait stations in or near combined sewer systems (i.e., sewer pipe networks that convey both residential wastewater and stormwater). Consistent with this hypothesis, the researchers detected brodifacoum in raw wastewater, treated wastewater, combined sewer overflow discharges (i.e., water released when sewer systems exceed capacity during storm events), and in fish liver samples. Other SGARs were detected in fish livers but not in water samples or sediments. Further, samples from stream networks without urban wastewater influence largely showed no rodenticide detections, supporting the hypothesis that urban sewer systems are a major introduction pathway.

Regnery et al. (2024) conducted a field sampling study to determine whether SGARs bioaccumulate through the aquatic food web, as they have been found to do in the terrestrial food web. They found that higher-trophic-level fish had SGAR detections in a higher portion of samples and higher mean liver concentrations, while low-trophic-level herbivorous fish (common nase) had no detectable residues. This pattern suggests SGARs can biomagnify in aquatic food webs, potentially exposing fish-eating birds and mammals. Similar to the 2020 study, SGARs were largely absent in streams without urban wastewater inputs.

Transmission of SGARs through the aquatic food web has also been observed in the eastern United States. Facka et al., (2024) tested the liver samples of fishers (*Pekania pennanti*), bobcats (*Lynx rufus*), and river otters (*Lontra canadensis*) collected between 2019 and 2022. The samples were tested for evidence of FGAR and SGAR accumulation. While ARs were common in fishers and bobcats (whose diets include rodents), the ARs were also found in approximately 16% of river otters, which was notable because these semi-aquatic animals primarily consume fish and aquatic invertebrates. The authors interpret this as confirmation of "the presence of [ARs] in aquatic systems in Pennsylvania and likely throughout the Northeastern United States."

Schmieg et al. (2025) exposed rainbow trout (*Oncorhynchus mykiss*) to brodifacoum and observed dose-dependent disruption of blood coagulation, internal hemorrhaging, anemia, and mortality. Adverse effects were associated with hepatic residues of 122.6 ng/g in liver, which is within the range reported from wild fish. The authors interpret these results as evidence that brodifacoum residues present in aquatic food webs may pose a risk to fish health.

5.4 Consideration of Threatened and Endangered Species in Massachusetts

According to MassWildlife's Natural Heritage and Endangered Species Program website, Massachusetts has a wide variety of plant and animal species, including some unique species that occur naturally within the state. Under the Massachusetts Endangered Species Act (MESA), 180 species of animals and 273 species of plants are currently listed as Endangered (E), Threatened (T), or of Special Concern (SC) (Table 18). Of these 453 species, 27 are also listed as federally endangered or threatened. These species are considered at risk

or potentially threatened with extinction. The primary criteria used to determine extinction risk include rarity within the state, observed population trends, and the overall level of threat.

TABLE 18. SUMMARY OF THE MASSACHUSETTS ENDANGERED SPECIES ACT (MESA) LIST

Taxonomic Group	Endangered	Threatened	Special Concern	Totals
Mammals (including 6 whales)	11 (7 FE)	0	6	17
Birds (breeding)	9 (1 FE)	7 (2 FT)	14	30
Reptiles (including 5 sea turtles)	8 (4 FE, 1 FT)	5 (2 FT)	3	16
Amphibians	0	3	2	4*
Fish	4 (2 FE)	2 (1 FT)	4	10*
Invertebrates (non-marine only)	33 (2 FE, 2 FT)	28	42	103
Plants (vascular)	159 (3 FE, 1 FT)	72	42	273
Totals	224 (18 FE, 5 FT)	117 (5 FT)	113 (0)	453* (27 FE or FT**)

Source: 321 CMR 10.00

**Blue-spotted Salamander (Ambystoma laterale) is Threatened in Bristol County and Plymouth County and is of Special Concern in other counties. To avoid double-counting in this table, this species is considered only once in the total. FE = species listed under the U.S. Endangered Species Act as Federally Endangered. FT = species listed under the U.S. Endangered Species Act as Federally Threatened.*

The remainder of this section provides additional context on the taxonomic groups of threatened and endangered species and species of special concern in Massachusetts, with particular attention to their potential vulnerabilities to ARs. Because ARs have been shown to be highly toxic in animals generally, the likelihood of adverse effects in each species is driven by whether or not the animal is likely to be exposed.

Mammals

In Massachusetts, 11 mammalian species are listed as endangered, six are listed as of special concern. Of these 17 species, six are whales, which are assumed to have little or no exposure to ARs according to EPA's biological evaluation (EPA 2024b). Eight of the listed species are bats that primarily feed on flying insects and are also unlikely to be meaningfully exposed.

The remaining three species are of special concern. Two are shrew species that primarily inhabit forests and bogs, away from urban and agricultural areas where ARs are typically deployed, and thus likely have a limited exposure risk except through incidental foraging where bait has been broadcast. The final listed species is the Southern Bog Lemming—a rodent that, although rarely sighted in Massachusetts, has the potential to establish burrows in urban areas, cornfields, forests, and bogs, where exposure is possible.

Birds

There are currently nine endangered bird species listed in Massachusetts, seven threatened species, and fourteen species of special concern. Bird species most at risk of AR exposure generally fall into two categories:

- Birds that forage for terrestrial insects and seeds along the ground that could incidentally ingest bait pellets mistaken for food.
- Birds that prey upon small mammals (particularly rodents) and that could then experience secondary exposure via ingestion of poisoned prey.

Six species listed in Massachusetts engage in ground foraging and could therefore be at risk of incidental exposure to broadcast bait: the Grasshopper Sparrow, Upland Sandpiper, Mourning Warbler, Vesper Sparrow, Northern Parula, and Eastern Meadowlark.

Seven listed bird species are predators that routinely or opportunistically prey on rodents and other small mammals, creating potential for secondary exposure. These species are the Barn Owl, Short-eared Owl, Long-eared Owl, Bald Eagle, Peregrine Falcon, Northern Harrier, and American Bittern.

The remaining listed species, including all federally listed bird species in Massachusetts, are unlikely to experience meaningful exposure because they feed primarily on aquatic prey, arboreal food sources, or flying insects. EPA (2024b) rated the three federally listed bird species occurring in Massachusetts as not subject to exposure for the above reasons.

Fish

There are currently 10 fish species listed as endangered (n = 4), threatened (n = 2), or of special concern (n = 4) in Massachusetts. Because ARs are applied terrestrially, obligate aquatic animals (i.e., animals that live their entire lives in water) are generally considered at low risk of exposure when compared to animals exposed primarily through ingesting bait or secondarily through ingesting baited rodents. Although researchers have detected the presence of ARs in the aquatic food chain, EPA (2024b) issued "no effect" determinations for all federally listed fish, presumably due to the limited amounts of exposure and the limited evidence for toxicity.

Reptiles

There are currently eight endangered reptile species listed in Massachusetts, five threatened species, and three species of special concern.

Five of these species are marine species (sea turtles). These species are not expected to have any primary exposures to ARs or secondary exposures due to ingesting baited rodents. Their exposures would most likely be only tertiary exposures, and the magnitude of those exposures is expected to be limited. In its Biological Evaluation (EPA, 2024b), EPA used the same rationale when determining that sea turtles are not at risk due to AR exposures.

Exposure risk for the six listed turtles varies depending on whether they forage terrestrially. Four species (the Wood Turtle, Bog Turtle, Eastern Box Turtle, and Blanding's Turtle) are opportunistic omnivores that feed on plants and animals, both on land and in water. The most likely route by which these species could experience AR exposure is by ingesting broadcast bait pellets or poisoned carrion. The other two listed turtles (the Northern Diamond-Backed Terrapin and the Northern Red-Bellied Cooter) feed exclusively on aquatic animals and are therefore at lower risk of exposure.

One MESA-listed species, the Eastern Wormsnake, primarily feeds on earthworms, snails, and insects and is therefore considered to have a low exposure risk. In contrast, the remaining four listed snake species (Timber Rattlesnake, Eastern Hog-nosed Snake, Eastern Ratsnake, Copperhead) are likely at risk of secondary dietary exposure because they prey on mice and other small mammals that could be directly exposed to rodenticides.

EPA (2024b) concluded that ARs were likely to adversely affect 29 out of 59 federally listed reptiles, including the MESA-listed Bog Turtle. Other federally listed species in Massachusetts were rated as "not affected or "not likely to be adversely affected."

Amphibians

There are no endangered amphibians currently listed in Massachusetts, but there are three threatened species and two species of special concern. Three of these species are salamanders (Jefferson Salamander, Blue-spotted Salamander, Marbled Salamander) and one is a toad (Eastern Spadefoot). (Note: the Blue-spotted Salamander is listed as threatened and a species of special concern in different areas). These species primarily eat insects but may be at risk from dietary exposure to consuming bait. In addition, EPA (2024b) notes that certain salamander species use the burrows of small mammals for shelter or other reasons, thereby increasing their potential chance of exposure.

Invertebrates and Insects

There are currently 33 endangered invertebrate or insect species listed in Massachusetts, 28 threatened species, and 42 species of special concern. According to EPA these species are considered at low or no risk of either direct ingestion or secondary dietary exposure to ARs. Consistent with this, EPA (2024b) made “no effect” determinations for all federally listed insects and invertebrates.

Plants

There are currently 159 endangered plant species listed in Massachusetts, 72 threatened species, and 42 species of special concern. With no evidence of ARs causing toxic effects to plants, EPA (2024b) made “no effect” determinations for all federally listed plants.

6 Findings on Anticoagulant Rodenticide Alternatives

This section summarizes the current state of knowledge on alternatives to anticoagulant rodenticides (ARs) considering both chemical and non-chemical methods for rodent control. ERG identified alternative methods from the following sources:

- Key EPA assessments described earlier in this report
- The Massachusetts Pesticide Product Registration Information website (Kelly Registration Systems, Inc, 2025)
- The Commonwealth of Massachusetts' Annual Pesticide Use Information website (MDAR, 2025)
- Peer-reviewed research on the efficacy of rodent traps and other control strategies (e.g., Motro et al., 2019)
- Feedback gathered through ERG's stakeholder interviews and surveys

These sources generally categorize AR alternatives into four groups. The list below describes these categories, without considering their viability in the Commonwealth. The feasibility of alternatives will depend on the application setting and other factors, such as desired effectiveness, environmental impact, and cost. In addition, the preferred alternative may vary between commercial applicators and homeowners. ERG was not charged with conducting a comprehensive comparative analysis of the AR alternatives or recommending adoption of any alternatives. Mention of alternatives in this section does not suggest that they have been demonstrated to be effective alternatives to ARs in Massachusetts or elsewhere.

ERG considered the following categories of alternatives and sought stakeholder input regarding experiences with each:

- Chemical methods involve the use of rodenticides that do not contain anticoagulants. These alternatives target rodents through various mechanisms, including the use of neurotoxins, disruption of calcium absorption, asphyxiation, contraceptives (e.g., ContraPest), or impairment of cellular function.
- Mechanical methods use devices like snap traps, glue traps, snare traps, cage traps, and drawstring bags to capture or kill rodents without relying on chemical agents.
- Physical methods alter the environment to remove rodents' sources of food, water, and shelter. These can include sealing possible entry points to buildings and practicing good sanitation methods, such as avoiding placing trash bags directly on the ground.
- Biological methods can include pathogens (e.g., Salmonella) and predatory animals (e.g., cats) to control rodent populations.

Finally, this section describes Integrated Pest Management (IPM) approaches, which combine multiple rodent control methods in a coordinated, sustainable, and environmentally responsible strategy.

6.1 Chemical Methods

ERG researched multiple chemical rodenticides that are not anticoagulants. These alternatives employ various mechanisms for rodent control, including the use of neurotoxins, metabolic disruptors, and contraceptives. Broadly, the chemical rodenticide alternatives fall into two groups:

- **EPA-registered rodenticides.** Table 19 lists the active ingredients for several chemical rodenticides. The FGARs and SGARs are included for reference and for comparison to other substances that ERG identified. The table identifies the rodenticides and presents EPA's acute toxicity ratings; it also identifies seven chemical alternatives. As the table shows, some chemical alternatives (e.g., bromethalin, triptolide) have acute toxicity ratings similar to those for the listed FGARs and SGARs. Although this indicator does not capture the full spectrum of potential human health and environmental impacts, it suggests that the active ingredients of certain alternatives may be less toxic to humans than the active ingredients in ARs on a per mass basis, while others carry similar toxicity profiles. Of these alternatives, aluminum phosphide and zinc phosphide are classified as restricted use pesticides (RUPs).
- **Minimum-risk rodenticides.** Additional AR chemical alternatives fall under the category of minimum-risk pesticides, which EPA does not register under FIFRA. To be eligible for this designation, the products must contain active ingredients and inert ingredients from EPA's list of approved substances (EPA, 2016a) and meet additional criteria for labeling, health claims, and other factors. Examples of active ingredients for minimum-risk pesticides include various plant-based oils, acids (e.g., acetic acid), and salts (EPA, 2024c, 2025).

TABLE 19. TOXICITY AND OTHER HAZARD RATINGS FOR ANTICOAGULANT RODENTICIDES AND SELECTED CHEMICAL ALTERNATIVES

Rodenticide Type	Rodenticide Active Ingredient	EPA Ratings				
		Acute Oral Toxicity Group	Acute Inhalation Toxicity Group	Acute Dermal Toxicity Group	Primary Eye Irritation Rating	Primary Skin Irritation Rating
FGAR	Chlorphacinone	I	I	I	IV	IV
FGAR	Diphacinone	I	I	I	II	IV
FGAR	Warfarin	I-II	IV	IV	N/A	N/A
SGAR	Brodifacoum	I	I	I	IV	III-IV
SGAR	Bromadiolone	I	I	I	III	IV
SGAR	Difenacoum	I	I	I	IV	IV
SGAR	Difethialone	I	I	I	III-IV	IV
Alternative	Aluminum Phosphide	IV	I	IV	II	II
Alternative	Bromethalin	I	I	II	IV	IV
Alternative	Carbon Dioxide	N/A	N/A	N/A	N/A	N/A
Alternative	Cholecalciferol	I	IV	III	N/A	N/A
Alternative	Triptolide	I	I	I	N/A	N/A
Alternative	4-vinylcyclohexene diepoxide (VCD)	III	IV	III	I	II
Alternative	Zinc Phosphide	I	I	III	IV	IV

N/A = Not Available

Source: EPA ratings are taken from pesticide registration eligibility decisions, EPA fact sheets, National Pesticide Information Center fact sheets, and other resources.

Notes: Toxicity category I is for the most toxic substances, and toxicity category IV is for substances that are not acutely toxic. Category I substances have a signal word of "Danger" on the label and may or may not also include the word "Poison" based on acute toxicity; category II is labelled "Warning"; category III, "Caution"; and category IV does not have a signal word on the label.

Usage Quantities of Chemical Alternatives

Table 20 indicates how many chemical rodenticide alternatives are currently registered for use in Massachusetts and the number of products that were used by licensed applicators in 2023 (Kelly Registration Systems, Inc, 2025; MDAR, 2025). Bromethalin has the greatest number of unique products registered (59) and the highest number of products used by licensed applicators (14). Zinc phosphide is also widely available, with 16 products registered and three reported in use.

TABLE 20. COUNTS OF EPA-REGISTERED ANTICOAGULANT RODENTICIDE ALTERNATIVES USED IN MASSACHUSETTS

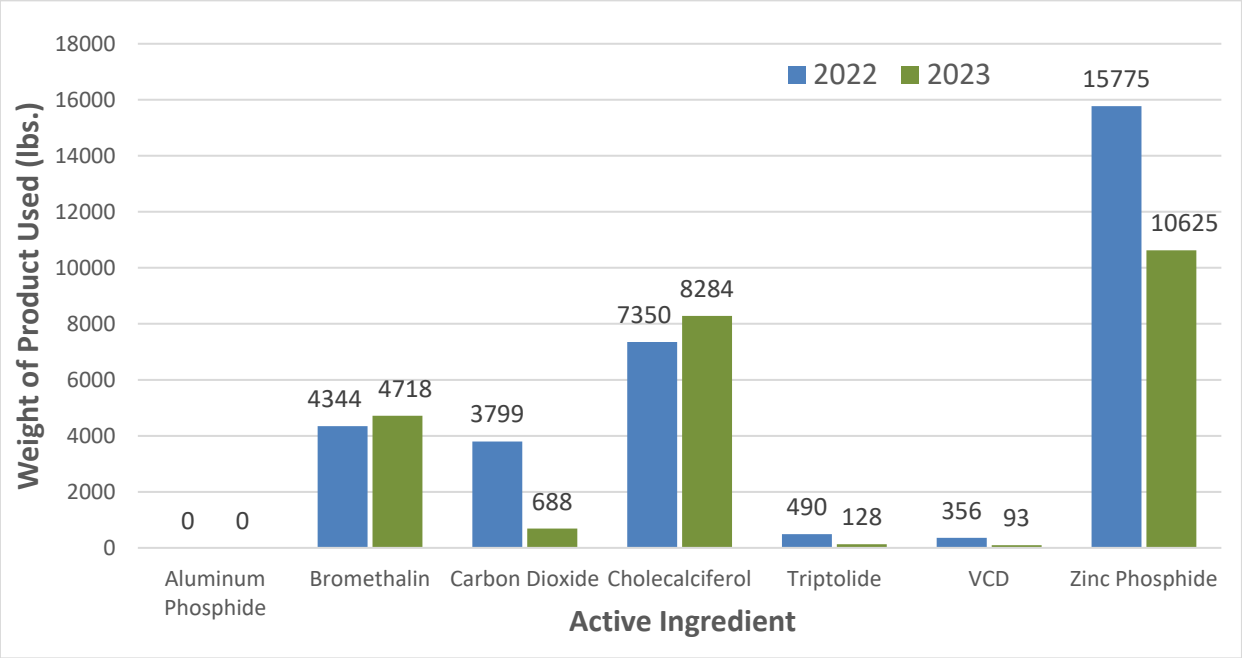
Active Ingredient	Range of % Active Ingredient in Products Registered for Use in Massachusetts in 2025**	Number of Unique Rodenticide Products* Registered for Use in Massachusetts in 2025	Number of Unique Rodenticide Products* Used in Massachusetts in 2023
4-Vinylcyclohexene diepoxide (VCD)	0.096%	1	1
Aluminum phosphide	55-77.5%	11	0
Bromethalin	0.01-0.025%	59	14
Carbon dioxide	99.9-100%	3	2
Cholecalciferol	0.075%	8	5
Triptolide	0.0011%	1	1
Zinc phosphide	2-63.2%	16	3

Data Sources: Kelly Registration Systems, Inc (2025) and MDAR (2025).
Notes: 4-vinylcyclohexene diepoxide and triptolide are used in the same product (ContraPest).
** Determined by unique EPA Registration IDs; a single product can be sold under multiple brand names.*
*** All compositions are reported as weight percentages.*

Figure 3 and Figure 4 present usage rates for the chemical alternatives noted above. The total amount of AR products applied by licensed applicators in 2023 (Figure 2) was 20 times higher than the total amount of chemical alternatives (Figure 3).

Figure 3 presents the total weight of formulated products used by licensed applicators in 2022 and 2023, and Figure 4 shows the weight of active ingredients only. Among alternatives, zinc phosphide was used in the greatest quantities in both years. Carbon dioxide usage also decreased considerably between 2022 and 2023. As with previous data summaries for rodenticide usage, the information shown in Figures 3 and 4 only account for self-reported uses by licensed applicators; they do not account for consumer use.

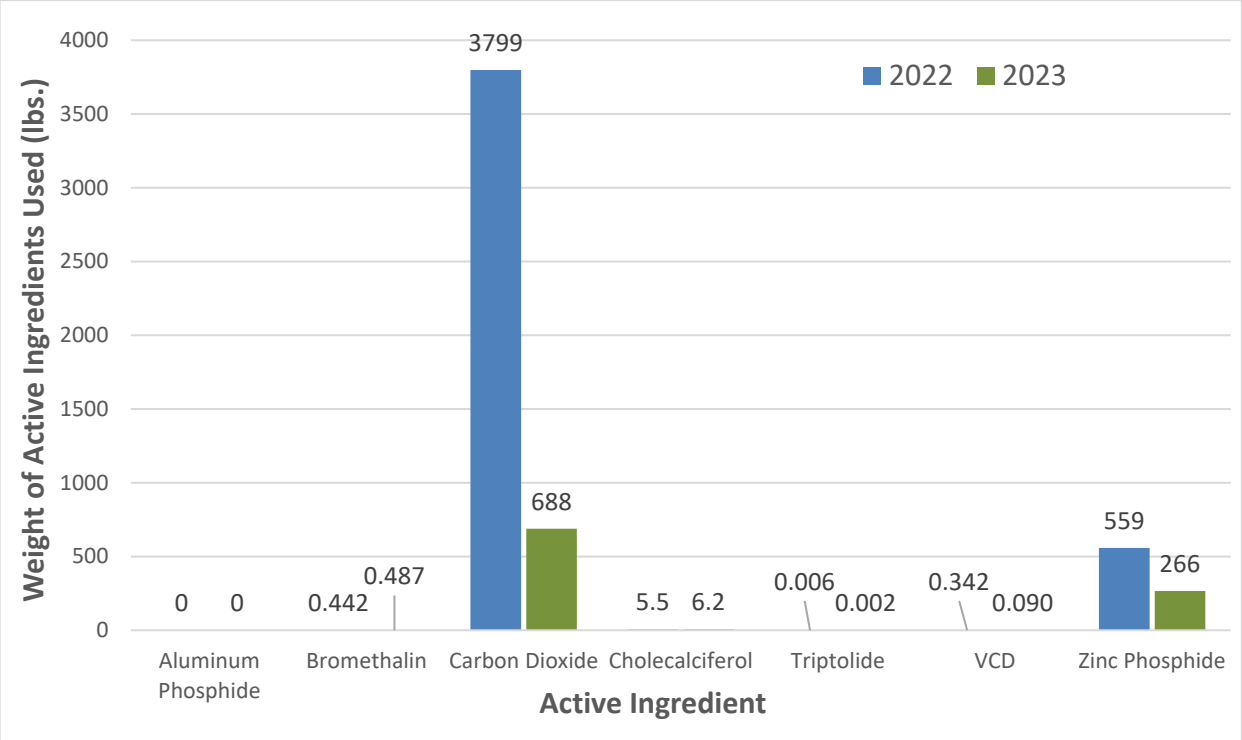
FIGURE 3. WEIGHT OF CHEMICAL ALTERNATIVE RODENTICIDE PRODUCTS USED IN MASSACHUSETTS IN 2022 AND 2023



Source: MDAR, 2025

Notes: Usage data are self-reported by licensed applicators, as required by 333 CMR 10.14.

FIGURE 4. WEIGHT OF CHEMICAL ALTERNATIVE RODENTICIDE ACTIVE INGREDIENTS USED IN MASSACHUSETTS IN 2022 AND 2023



Source: MDAR, 2025
Notes: Usage data are self-reported by licensed applicators, as required by 333 CMR 10.14.

The following paragraphs provide further information on the chemical alternatives, including their mechanism for rodent control, advantages and disadvantages of use, and any observations on usage. The chemical alternatives that are fatal to rodents are discussed first, followed by a discussion of contraceptives.

Aluminum Phosphide

Aluminum phosphide is a highly toxic fumigant rodenticide that was first registered in the United States in 1958. In the presence of moisture (which includes humidity and stomach acid), aluminum phosphide releases highly toxic phosphine gas. This gas impacts the respiratory system and impairs cellular respiration, leading to death. This rodenticide is typically used on burrowing rodents, often in agricultural settings. Tablets, pellets, or powder containing aluminum phosphide are placed in burrows, after which applicator block the burrow entrances.

Aluminum phosphide is currently registered for use in 11 products in the Commonwealth; however, all 11 products were not used by licensed applicators in 2022 or 2023 (Table 20).

The resources that ERG reviewed identify various advantages of aluminum phosphide as an AR alternative, including:

- Aluminum phosphide is highly effective, rapidly killing entire rodent burrow systems.
- Aluminum phosphide is a fumigant and it does not rely upon rodents ingesting bait. Therefore, even "bait shy" rodents will be controlled by this alternative. There is no evidence of rodents

developing resistance to aluminum phosphide, presumably due to its mechanism of rodenticidal action.

- Phosphine, the most toxic substance generated after aluminum phosphide applications, is not persistent or accumulative in the environment.

Disadvantages of aluminum phosphide include:

- Phosphine gas is highly toxic to humans and animals; therefore, applicators must exercise extreme caution when handling and using aluminum phosphide.
- It can be difficult for applicators to identify and block all entry points into burrows where aluminum phosphide is used; and blocking these access points is important for maximum effectiveness.
- This rodenticide cannot be used in residential settings or near buildings occupied by people or animals.

Bromethalin

Bromethalin was first registered as a rodenticide in 1984. Bromethalin acts as a neurotoxin in rats; upon consumption, it disrupts cell energy production in the central nervous system. Nerve cells swell, putting pressure on the brain and ultimately leading to paralysis and death (NPIC, 2016).

Bromethalin is fed to rodents in bait form (e.g., blocks, pellets, worms) in tamper-resistant bait stations and typically requires only a single dose due to its high toxicity (Table 19). Different species have varying capacities to metabolize bromethalin, resulting in significant differences in toxicity across species. Because it accumulates in baited rodents, bromethalin poses a risk of secondary exposure to rodent predators, including pets (Coppock, 2013) and birds of prey (M. Murray and Cox, 2023).

In 2025, bromethalin was registered for use in 59 different products in the Commonwealth of Massachusetts, the highest number of any of the chemical rodenticide alternatives; and 14 of these products were used by licensed applicators in 2023 (Table 20). Among the chemical alternative rodenticides reviewed, bromethalin products ranked third in statewide usage in 2022 and 2023 (Figure 3).

The resources that ERG reviewed identify various advantages of bromethalin. These include:

- Bromethalin acts quickly, with death occurring between several hours to a few days after ingestion.
- Bromethalin is effective against AR-resistant rodents.
- Secondary poisoning risk is lower for bromethalin compared to ARs.

Disadvantages include:

- Because bromethalin is highly toxic to pets, especially cats and dogs, some authorities have recommended risk mitigation measures when applying this chemical (PMRA, 2009, 2010).
- There is no antidote for bromethalin poisoning; once the lethal dose is administered, only supportive care can be provided.
- Secondary poisoning is possible and has been observed in non-target mammalian species (Cox et al., 2022) and raptors (Murray and Cox, 2023).

Carbon Dioxide

As of 2025, three rodenticide products registered for use in the Commonwealth have carbon dioxide as an active ingredient; and two of these three were used by licensed applicators in 2023 (Table 20). The uses in 2022 and 2023 were dominated by Rat Ice, which accounted for 99.5% of the statewide uses. The other and

less widely used product, IGI CARBON DIOXIDE, involves using canisters of carbon dioxide to asphyxiate rodents in their burrows (Kelly Registration Systems, Inc, 2025; MDAR, 2025)

EPA first registered Rat Ice for use in June 2017. The product uses dry ice (i.e., solid carbon dioxide), which then releases carbon dioxide gas. Rat Ice is applied in pellets that are less than an inch in diameter. Applicators locate rodent burrows and place the pellets inside, then block off the burrows. As the dry ice sublimates, the released carbon dioxide displaces oxygen in the burrow. The resulting carbon dioxide buildup eventually leads to asphyxiation, killing rats within a few hours of application (DC Health, 2018). Dry ice products such as Rat Ice are intended for outdoor applications. Applicators should avoid using dry ice when people or animals are in nearby buildings. Applicators should wear appropriate personal protective equipment (e.g., heavy insulated gloves, eye protection) to prevent burns from contacting the pellets. Additionally, the resulting carbon dioxide can be hazardous in confined spaces.

Among the chemical rodenticide alternatives considered in this report, carbon dioxide was used in the greatest quantities by licensed applicators in Massachusetts in 2022 and 2023 (Figure 4). The carbon dioxide usage self-reported by licensed applicators decreased by 82% between 2022 and 2023. The reason for that decreased usage is not known.

The resources that ERG reviewed identify various advantages associated with using dry ice products (with carbon dioxide as the active ingredient) for rodent control. These advantages include:

- When applied according to label instructions and not in enclosed spaces, dry ice products are generally safe for use around humans and pets.
- Dry ice does not leave toxic residues, nor is it of concern for soil or water contamination.
- Exposed rodents typically die within minutes to hours, making this an efficient alternative to ARs, which typically take longer to kill rodents.
- Because it is a gas, carbon dioxide from the alternative products readily spread to hard-to-reach areas in burrows, which is more challenging for baits.
- Unlike ARs, carbon dioxide products do not result in secondary poisoning.

The primary disadvantage of carbon dioxide products is that they are only viable when burrow locations are known.

Cholecalciferol

Cholecalciferol (Vitamin D_3) was first registered as a rodenticide in 1984. It is currently registered for use in eight different products in the Commonwealth, though recent self-reporting data indicate that licensed applicators used five of these products (Table 20). Cholecalciferol-based rodenticides are typically placed in tamper-resistant bait stations or secure dispensers. Upon ingestion, cholecalciferol causes rodent blood calcium levels to increase, which can lead to various sublethal and lethal effects (NPIC, 2016).

The resources that ERG reviewed identify multiple advantages of cholecalciferol as a rodenticide. These include:

- Cholecalciferol is a suitable option for rodents that have developed resistance to ARs.
- Due to minimal accumulation in rodent tissues, cholecalciferol poses a significantly lower risk of secondary poisoning to non-target species when compared to ARs; and cholecalciferol has been reported as being similarly effective (Noh et al., 2023).
- Rodents often receive a lethal dose of cholecalciferol after one rodenticide application, without needing repeated applications.

Disadvantages of cholecalciferol include:

- Concern has been raised about a high risk of primary poisoning in household pets.
- There may be secondary poisoning effects.
- There is no antidote for cholecalciferol poisoning. Once the lethal dose is administered, only supportive care can be provided.

Zinc Phosphide

Zinc phosphide has been registered for use in pesticide products since 1947. For rodent control, it can be applied in both bait and powder formulations. Upon consumption, zinc phosphide reacts with stomach acid, releasing toxic phosphine gas. The gas then enters the body's cells and disrupts their ability to produce energy, ultimately causing cell death. Zinc phosphide affects all cells, but particularly targets those in the heart, lungs, and liver (NPIC, 2016). As noted in Table 19, zinc phosphide is one of the more toxic chemical alternatives to ARs. EPA may further restrict zinc phosphide uses in the future according to the agency's 2022 Proposed Interim Decision.

Advantages of zinc phosphide as an AR alternative include:

- Zinc phosphide acts quickly. The time to death after ingestion depends on the exposure dose and can range from minutes to a few days.
- Phosphine, the most toxic substance generated after zinc phosphide applications, is not persistent or accumulative in the environment.
- Rodents often receive a lethal dose of zinc phosphide after one application, without needing repeated applications.

Disadvantages of zinc phosphide include:

- Zinc phosphide exposure is dangerous to humans and pets through inhalation or ingestion, emphasizing the importance of using baits that only attract rodents.
- Rodents may be deterred by zinc phosphide's strong odor and unpleasant taste.
- Some zinc phosphide products are available in powder formulations, which are generally restricted to enclosed or inaccessible spaces (e.g., wall voids, burrows) to reduce the risk of inhalation or non-target contact. This limits its use in some settings.

Contraceptives (VCD and Triptolide)

Contraceptives are designed to prevent the animals from reproducing. Currently, ContraPest is the only contraceptive product registered for use in Massachusetts. This product was first registered by EPA in 2016, and it contains two active ingredients, 4-vinylcyclohexene diepoxide and triptolide, supplied in bait form. The active ingredients target reproductive cells, ultimately rendering exposed rodents infertile but without killing them. Some have argued that use of contraceptives offers a humane approach to reducing rat populations (Pyzyna et al., 2018).

However, because the rodents remain alive, they continue to feed, cause property damage and potentially pose a public health threat as a disease vector. This has caused some to question use of contraceptives as a permanent solution for rodent control, unless used in conjunction with other methods. These concerns also might explain the relatively low use of the contraceptives in comparison to the other chemical alternatives (see Figure 3).

Advantages of contraceptives as an AR alternative include:

- Some stakeholders interviewed by ERG said, when compared to ARs, contraceptives are a humane, non-lethal form of rodent control.
- There is no need to locate and retrieve carcasses, given that the contraceptives do not kill rodents.

Disadvantages include:

- The contraceptives do not kill the infertile rodents, which means they will continue to potentially cause damage to property and pose public health risks.
- In comparison to the faster acting alternatives, contraceptives take much longer to achieve effective control as they require continuous feeding to be effective.

6.2 Mechanical Methods

Mechanical methods use devices (e.g., traps, snares) to control rodent populations without relying on chemical agents. These devices are generally categorized into two types: kill traps and live traps, which are discussed separately below. A third type of mechanical method is described at the end of this section.

Kill Traps

Kill traps are devices designed to catch and kill rodents. The following list identifies commonly used kill traps.

- **Snap Traps:** Snap traps use a spring-loaded bar that snaps down quickly onto a rodent when it attempts to take the trap's bait. These traps are inexpensive, reusable, and commonly available to both professional applicators and the public. When set and maintained properly, snap traps are considered among the more humane lethal control options because they generally kill rodents instantly. However, if placed incorrectly or if the bar does not strike properly, they can cause injury and prolonged suffering instead of immediate death.
- **Electric Traps:** Electric traps use high-voltage electric shocks to control rodent populations. Typically, bait is applied to attract rodents to the traps, and the rodents are shocked by metal plates when they make contact. Designs are typically escape-proof. Due to the quick nature of deaths, electric traps are generally considered to be a humane option. These traps sometimes have features that prevent non-target species and humans from being shocked.
- **Glue Traps:** Glue traps, sometimes referred to as sticky traps or glue boards, use a very strong adhesive on a flat surface to trap rodents that walk on them; and they can be used with or without bait. This method is considered by many to be cruel and inhumane because trapped rodents can suffer agonizing, prolonged deaths while struggling to escape. Additionally, non-target species can get stuck in these traps (e.g., birds, reptiles, pets).

Advantages of kill traps as AR alternatives include:

- Snap and electric traps provide quick, humane kills.
- Kill traps are reusable, inexpensive, and not harmful to the environment.
- Carcass removal is relatively easy, because the carcasses are where traps were placed—and not hidden.

Disadvantages of kill traps include:

- Most kill traps have a limited capacity, as they can only kill one or a few rodents at a time.
- When compared to chemical methods, kill traps are labor intensive to set up, monitor, and reset.

- If not placed properly, kill traps can pose a risk to non-target animals.
- "Trap shyness," especially among rats, can be a challenge.
- Rodents may learn to avoid kill traps if they detect human scent.
- Electric traps require power to use.
- Many consider glue traps to be inhumane.

Live Traps

Live traps are devices designed to capture rodents live, after which they can either be released elsewhere or killed humanely. Commonly used live traps include cage traps, box traps, pitfall traps, snare traps, and drawstring bags. The parties ERG interviewed for this project indicated that live traps require continued maintenance to be effective.

Advantages of live traps as an AR alternative include:

- Live traps are not lethal.
- Live traps allow for relocation of captured rodents, if relocation is legal and practical.

Disadvantages of live traps as an AR alternative include:

- Live rodents may spread disease and disrupt ecosystems.
- Live traps require ongoing monitoring and upkeep.
- Relocation is not always effective; if the release site is too close to the capture area, rodents may return to the original site or quickly occupy nearby structures, such as neighboring properties.

Electromagnetic and Ultrasonic Pest Repellent

A third category of mechanical methods is using electromagnetic and ultrasonic pest repellents to keep rodents away. These devices emit sound waves at high frequencies that are irritating to rodents—but they cannot be heard by humans. These devices are designed to deter rodents from entering the areas that the devices protect; they do not kill the rodents.

Advantages of these repellents as an AR alternative include:

- These products are generally easy to use.
- These products are non-toxic and humane.

Disadvantages of these repellents as an AR alternative include:

- The effectiveness of these products is disputed (Aflitto and Hofstetter, 2014).
- Rodents may become habituated to the irritating noise, therefore limiting the effectiveness of the devices.
- Multiple devices are required for large areas.

6.3 Physical Methods

During the interviews that ERG conducted and in survey responses, multiple parties identified physical methods as alternatives to ARs. These approaches include any strategy that makes it more difficult for rodents to survive in an area, thereby encouraging them to leave or slowing population growth. Common

physical methods include exclusion and sanitation practices, as further explained below. These strategies are most effective when used as part of an IPM approach, which Section 6.5 describes further.

Exclusion

Exclusion involves sealing entry points in structures to prevent rodents from entering indoor spaces. These entry points can include gaps around doors and windows, cracks and openings in foundations, utility pipe penetrations, and gaps in other structural components (e.g., siding, chimneys). Materials commonly used for sealing include caulk, wire mesh, expanding foam sealant, steel wool, and hardware cloth (Ministry of Environmental and Climate Change Strategy, 2021).

Exclusion reportedly can be an effective long-term solution, provided the strategy is implemented before a large infestation takes place; exclusions may be less effective if implemented to control an existing severe infestation. This approach can be labor- and time-intensive, as property owners must identify all entry points, purchase appropriate materials, and seal all gaps. Ongoing monitoring and maintenance are necessary to ensure entry points remain sealed over time. Certain buildings (e.g., older, larger structures) can be particularly challenging to seal all entry points.

Sanitation

Sanitation involves thoroughly cleaning surfaces to remove all food and water sources, making spaces less attractive to rodents. This method is especially important in areas where any food processing, storage, and preparation occurs. Good sanitation practices include regularly cleaning equipment, cleaning floors and other surfaces where food waste and accumulate, using trash cans and dumpsters that seal completely, and storing waste containers securely outdoors. Sanitation requires continuous upkeep of spaces, and it is particularly effective if implemented before infestations develop. It is also considered a humane method for controlling rodent populations (Ministry of Environmental and Climate Change Strategy, 2021).

6.4 Biological Methods

Biological methods for rodent population control include, but are not limited to, predator-based control.

This method involves using natural rodent predators to suppress populations. Examples of animals commonly used for rodent population control include owls, hawks, kestrels, snakes, foxes, feral/domestic cats, and certain breeds of trained dogs. Predator-based control can occur through use of domestic animals and wildlife (which can be attracted to rodent-infested properties by providing suitable habitats).

Barn owls are one of the most frequently cited species used for predator-based rodent control (Labuschagne et al., 2016). In the presence of barn owls, significantly less rodenticide may be required to control rodent populations (Bontzorlos et al., 2024). In agricultural settings, barn owl populations have also been shown to significantly improve crop yields by limiting rodent populations (Browning et al., 2016; Motro, 2011). To encourage the establishment of barn owl populations, property owners can install habitats, such as barn owl boxes.

A pilot study in California similarly demonstrated the effectiveness of birds of prey in controlling rodent populations in flood-control facilities to reduce the ground squirrel populations on levees and dams. (Ventura County Public Works, 2017). The study involved two sites: one control site where ARs were used to control rodent populations and one where hawks and owls were drawn to the site by setting up nest boxes and perches. Ultimately, the predator-based approach was almost 50% more effective at reducing rodent-caused burrowing damage compared to the ARs used at the control site.

A related predator-based control method is through use of predator cues—or signals to rodents that a predator is nearby. One such cue is cat urine, as its odor can result in aversions, genetic changes, and the

release of stress hormones among rodent populations (Mulungu and Martin, 2024; Mulungu et al., 2017). Strategically placing these cues in rodent habitats can offer some measure of control.

Advantages of predator-based control as an AR alternative include:

- Predator-based rodent control is a sustainable approach without the types of ecological damage caused by ARs and other rodent control methods.
- Some consider predator-based control to be a humane and natural method for controlling the rodent population.
- This alternative can be used in conjunction with other methods in a broader IPM strategy.

Disadvantages of predator-based control include:

- Predators alone may not be able to significantly reduce rodent populations during major infestations.
- Predators cannot control rodent populations as quickly as some of the chemical methods described above.
- Some predators may harm non-target wildlife species.
- Predators may need a suitable habitat, which is not always realistic.
- Many predators (e.g., raptors) cannot be used when controlling rodents in indoor or urban settings.

Historically, other biological-based methods have been used to control rodent populations (e.g., adding Salmonella to chemical rodenticides), but that specific practice does not appear to be used today in the United States.

6.5 Integrated Pest Management

IPM involves using multiple methods discussed above in combination to create a more effective, sustainable, and environmentally friendly approach. Through IPM, actions are taken to prevent pests from becoming an issue by assessing environmental factors that favor rodent activity and establishing conditions that discourage their presence. Effective IPM programs combine inspection, monitoring and reporting techniques and may enable property owners or applicators to limit the need for chemical methods for rodent control (EPA, 2025).

Key considerations for implementing IPM include:

- In any situation where rodent control may be an issue, monitoring and inspection should be conducted first to assess the rodent population.
- Action thresholds based on the pest population level that causes a nuisance, health hazard, or economic threat. Action threshold should be set to determine when additional measures should be taken to suppress rodent populations.
- Once action thresholds are exceeded, habitat management can be performed through physical methods, such as exclusion and sanitation, to make the environment less favorable for rodents. If necessary, mechanical methods, such as kill traps and live traps, can also be used.
- Use of chemical methods (i.e., application of chemical rodenticides) should be limited when non-chemical methods provide similar results.

Massachusetts law (Mass. Gen. Laws. ch. 132B, § 2) defines Integrated Pest Management as “a comprehensive strategy of pest control whose major objective is to achieve desired levels of pest control in

an environmentally responsible manner by combining multiple pest control measures to reduce the need for reliance on chemical pesticides; more specifically, a combination of pest controls which addresses conditions that support pests and may include, but is not limited to, the use of monitoring techniques to determine immediate and ongoing need for pest control, increased sanitation, physical barrier methods, the use of natural pest enemies and a judicious use of lowest risk pesticides when necessary." Under Chapter 132B (Massachusetts Pesticide Control Act) and 333 CMR 14.00 (Protection of Children and Families from Harmful Pesticides), IPM is expressly promoted in sensitive settings. In particular, 333 CMR 14.00 requires schools and child-care facilities to maintain and submit IPM plans to the Commonwealth.

When applied correctly, IPM can suppress rodent populations while preventing the need for rodenticide applications, thereby protecting both human and ecological health (EPA, 2025). Commercial pest management professionals in Massachusetts implement IPM elements (e.g., site inspection and monitoring, sanitation and exclusion, structural repairs, targeted trapping, and recordkeeping) to limit unnecessary rodenticide use and to minimize risks to non-target species. The effectiveness depends on site-specific implementation (e.g., building condition, sanitation, and monitoring).

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Appendix A: Summary of Public Comments on Draft Phase Two Report (dated August 2025)

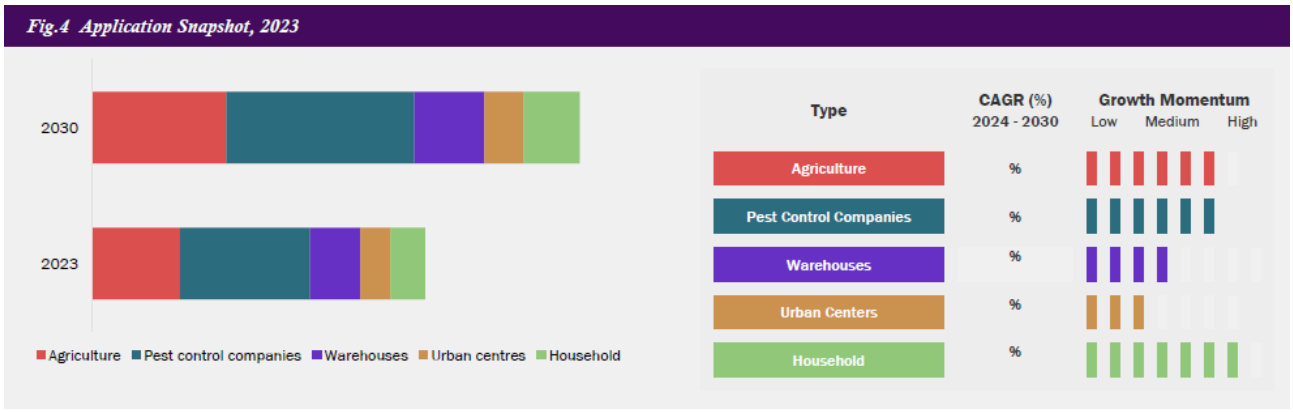
MDAR solicited public feedback on the draft Phase Two report during a public comment period that closed on October 1, 2025. Forty-eight comments were received. Approximately 40% primarily expressed views for or against restricting or banning anticoagulant rodenticides (ARs). The remainder commented on sections of the draft report that warranted response by ERG, including identification of factual errors, suggestions for additional data sources or topics, and recommendations for further analyses.

ERG incorporated edits and clarifications into this Final Report where comments identified factual inaccuracies; ERG also made changes to improve clarity and to add relevant sources. In some cases, comments were outside the scope of this report or would have required substantial new analyses beyond the current effort. This appendix summarizes the key themes raised in the public comments, describes how ERG addressed them, or explains why they were not addressed. All public comments received will be submitted to the Massachusetts Pesticide Board Subcommittee along with this final report.

Comments related to local necropsy and liver-panel datasets or case reports. Multiple comments requested inclusion of necropsy and liver-panel datasets collected by local organizations (e.g., Cape Ann Wildlife, Save Massachusetts Wildlife) and other agency case files. ERG acknowledges these data are relevant to understanding potential wildlife risks in Massachusetts. However, analyzing individual toxicology case files submitted to MDAR was not included in ERG's scope for this scientific review. While this Final Report does not independently review those data, the underlying necropsy and liver-panel reports and MDAR's analysis of those data will be considered in the deliberations of the Massachusetts Pesticide Board Subcommittee. In short, the data in question will be considered in the ongoing scientific review, despite not being reviewed in this report.

Similarly, multiple commenters referenced Massachusetts case reports (e.g., bald eagles, snapping turtles, coyotes) collected by the organizations noted above, by state agencies, or described in media reports. However, consistent with the scope described above, this Final Report does not independently review, verify, or adjudicate individual case files or media-reported events. Any such materials that have been submitted to MDAR will be transmitted to the Massachusetts Pesticide Board Subcommittee, together with this Final Report and other supporting documents, for the Subcommittee's consideration.

Comments related to the data gap on rodenticide use by non-licensed applicators and consumers. Multiple commenters noted that more detailed AR usage data are in a Grand View Research rodenticide market report linked here: https://www.grandviewresearch.com/industry-analysis/rodenticides-market. Some commenters include the following image from that report:



Commenters note that this figure suggests that "pest control companies" account for the largest share of rodenticide applications while "households" represent a smaller fraction. These data were not included in the final report for three reasons. First, this project only considered publicly available data in the open literature and not reports for purchase behind paywalls. Second, while a free version of the Grand View Research report is available, it only includes report excerpts that lack methodological detail or context on how usage data were derived. Third, the figure shown above appears to summarize the global rodenticide market rather than markets in Massachusetts or the United States. For these reasons, the report continues to state that reliable information on rodenticide use by non-licensed applicators/consumers is limited.

Comments related to economic impacts and cost-benefit analysis. Multiple comments requested that this report quantify economic impacts (e.g., costs of restrictions, product substitutions, enforcement) or conduct a cost-benefit analysis comparing ARs with alternatives. A review of these types of economic considerations—including monetization of costs or benefits, distributional/equity analyses, or market-impact—was outside the scope of this scientific review, which focused on human health and environmental impacts. Further, multiple commenters note that ARs are often the most economically efficient way of addressing certain pest infestations, but as noted above, estimating costs and benefits of AR and alternative usage was not included in this project's scope.

Comments related to evaluations of other states' regulatory impacts. Some commenters asked for an assessment of how recent AR statutes and regulations in other states, particularly California, have affected costs or effectiveness of rodent control, rodent populations/damage, rodent-borne diseases, and wildlife. While these are important policy questions, systematically collected datasets and completed evaluations on this matter have not been issued to date; and no public comments or survey of interested parties pointed to published information sources to consider. Therefore, no information was included in the report to address this comment.

Comments related to toxicity categories in Table 4. Some comments indicated that Table 4 in the draft report presented EPA acute toxicity categories for technical active ingredients in a way that could be read as reflecting formulated end-use products. Table 4 now explicitly reports technical active ingredient categories, and a footnote to the table explains that product signal words are assigned to the formulated products.

Comments related to public health benefits, food safety benefits, and risk-benefit framing. Many commenters urged greater emphasis on the potential adverse public health consequences of rodent infestations and cited materials linking rodents to disease and allergens (e.g., leptospirosis in urban rats; mouse allergens and childhood asthma). These comments correctly point out that effective rodent reduction can lower disease risks and protect food quality and sanitation, and the report notes this context. The report was not expanded to include a literature review of rodent-borne disease outbreaks, as requested by commenters, because this report focuses on direct toxicity of ARs and does not quantify benefits from their use.

Some commenters asked that the report include a citation to Stone et al. (2025), a study on leptospirosis in rats in Boston. This citation was added to the report; however, this study and similar publications do not specifically discuss rodenticides. Moreover, the public health benefits of rodent control noted in these publications are not specific to ARs; they could result from any effective rodent control strategy. This report continues to focus on summarizing research on the health and environmental impacts of ARs; and it acknowledges the public health benefits of effective rodent control, without comprehensively summarizing the literature on that topic.

Note that EPA's *Use and Benefits Assessment for 11 Rodenticides and Impacts of Potential Risk Mitigation* was summarized at a high-level to reflect federal risk-benefit considerations relevant to ARs. Conducting a

new, quantitative risk-benefits assessment or a comprehensive review of rodent-borne disease trends was not included in the scope of this scientific review.

Comments related to municipal actions in Massachusetts. Multiple commenters noted that many municipalities have adopted policies or practices to reduce or prohibit SGAR use on municipal property and that more than "several" have pursued home-rule petitions. Some commenters supplied a third-party compilation that lists "41 towns and cities who already have reduced the use of SGARs on municipal property and 19 towns and cities who have filed (or will soon file) home rule petition." The report has been updated to better reflect the extent of such local efforts, which are difficult to track because they are constantly evolving. The compilation of local actions is linked here for completeness, though ERG did not review or validate the list: Commenter-compiled municipal actions list.

Comments related to legislation under consideration. Commenters provided updated status for several state legislative actions. We have incorporated these updates into Section 3.4 of the report.

Comments noting an association between mange and AR exposure. Several commenters cited pre-2019 studies from Southern California reporting associations between AR exposure and severe notoedric mange in bobcats, including evidence of immune dysregulation and altered skin-barrier function (e.g., Serieys et al., 2018, *Urbanization and anticoagulant poisons promote immune dysfunction in bobcats*; Serieys et al., 2018, *Anticoagulant rodenticides in urban bobcats: exposure, risk factors and potential effects based on a 16-year study*). In response to these comments, we updated Section 5.2 to explicitly reflect the CDPR (2018) assessment's discussion of adverse effects linked to AR exposure, including increased disease susceptibility and severe notoedric mange in bobcats as described in the studies synthesized by CDPR (e.g., Serieys et al., 2018). The section now includes a standalone sentence citing CDPR (and the underlying Serieys papers) that lists examples of adverse impacts. While the primary Serieys studies predate our 2019–present literature window, they are acknowledged through CDPR's evaluation and cited for completeness.

Comments related to selection and relevance of human health studies. Several commenters questioned the choice of articles summarized in Section 4.4 of this report. Several changes were made in response to this input. First, text was revised to explain why research on therapeutic uses of chemicals found in AR products was not summarized in this report. Second, a study summarizing research in Slovakia was removed from the report because it did not meet this project's literature screening criteria. Finally, the report still briefly summarizes the research on synthetic cannabinoid adulteration because those articles met the literature screening criteria, but the report acknowledges that the research does not inform risks from use of regulated AR products.

Comments noting omitted study on brodifacoum and fish health. A comment recommended the report include information from a recently published laboratory study on rainbow trout coagulopathy following brodifacoum exposure (Schmieg et al., 2025). A brief summary of this publication has been added to Section 5.3 of this report.

Comments related to Integrated Pest Management (IPM). In response to multiple comments, Section 6.5 of the report was revised to include additional context on IPM. The changes added Massachusetts context under Chapter 132B and 333 CMR 14.00 (including the school/daycare IPM plan requirement) and acknowledged that commercial applicators already implement IPM elements to limit unnecessary rodenticide use and to reduce non-target risks.

Comments related to additional chemical alternatives. Several commenters identified alternative rodent control products not discussed in the report (e.g., active ingredients or formulations registered in other states or countries, products in development). Our review focused on pesticide products currently registered for use in Massachusetts, so chemicals that lack Massachusetts registrations were not discussed.