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A California without rodenticides: challenges for commensal rodent management in the future

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Abstract: Rodenticides are an essential tool in the integrated pest management of infestations of commensal rodents *(Rattus norvegicus*, *R. rattus*, and *Mus musculus*). With the introduction of Assembly Bill 1788, the California Ecosystems Protection Act of 2019, California is potentially facing a future with new restrictions on the use of anticoagulant rodenticides to manage commensal rodents in urban areas. Assembly Bill 1788 has been proposed specifically to protect predators from anticoagulant rodenticide poisoning and seeks to restrict the application of second-generation anticoagulant rodenticides (SGARs) for use in many urban and non-urban areas of California, USA. Exclusion and cultural practices, such as landscape management and sanitation (i.e., cleaning of property including but not limited to trash containment and removal, and drain sanitation), remain important and successful tools for managing rodent populations. However, increased exposure of wildlife to anticoagulant rodenticides has been detected California. Several animal species have been documented as having succumbed to rodenticide toxicosis. When rodents are killed by SGARs and consumed by predators, SGAR residues have been detected in the livers of predatory species. However, the effects of chronic, sublethal exposure to predators are not well understood. We discuss the current and proposed changes to rodenticide legislation in California, impacts of rodenticide to wildlife, and the potential effects of restrictions on wildlife. We discuss limitations to rodent management programs that have historically replied on the use of SGARs and the potential impacts of the proposed legislation on communities across California. We also identify research gaps that are impeding the adoption of evidence-based best management strategies for rodent control. To improve the success of commensal rodent control programs in California, more research is needed to develop effective strategies for rodent management.

Key words: anticoagulant, California, commensal rodent, legislation, management, mouse, *Mus musculus*, Norway rat, *Rattus norvegicus*, *R. rattus*, rodenticides, roof rat

Commensal rodents, rats and mice, are considered some of the most economically significant pests in the world (Pimentel et al. 2005, Himsworth et al. 2013). Three species of commensal rodents are known to persist in almost all cities across California, USA (Marsh 1994). These are Norway rats (*Rattus norvegicus*), roof rats (*R. rattus*; Figure 1), and house mice (*Mus musculus*). These rodents exist in close proximity to human populations and are regularly found in homes, schools, restaurants, and other commercial settings as well as food processing plants, storage areas, and warehouses.

As human populations increase, coupled with uncertainty about climate change, so will the need for rodent-focused integrated pest management (IPM) strategies (Singleton et al. 1999, Baldwin 2017, Krijger et al. 2017). Studies have shown that climate change has the ability to affect fecundity, litter sizes, and the survivability of adults in some mammalian species (Post et al. 1997, Forchhammer et al. 2001, Walther et al. 2002). Climate change may also affect the free living, intermediate, or vector stages of pathogens, such as those that infect commensal rodents (Harvell et al. 2002).

The presence of commensal rodents around homes, food facilities, schools, and agricultural areas is associated with human risks of exposure to allergens that can trigger asthma (Mus m 1 and Rat n 1) and increase exposure to potentially infectious organisms (i.e., *Salmonella*) and parasites like tropical rat mites (*Ornithonyssus bacoti*) and fleas *(Ctenocephalides felis*, *Xenopsylla cheopis*) that may transmit other diseases (Easterbrook et al. 2007, Frye et al. 2015, Sheehan at al. 2017). However, little is

Figure 1. Roof rats (*Rattus rattus*) are among the most prolific rodent pests in cities in the western United States. They can often be found indoors, particularly in favorable conditions where sanitation is an issue.

Figure 2. Harborage in alleyways can provide shelter and food for rodents. It is often not the responsibility of the pest management professional to remove harborage, and therefore it can be difficult for them to integrate sanitation into a management program.

known about the ecology of wild commensal rodents and the pathogens they can vector in urban, residential communities.

Recent studies of urban commensal rodents in Vancouver, Canada, and New York City, USA report the presence of pathogens like *Leptospira* and *Bartonella* in commensal rodent populations (Frye et al. 2015, Himsworth et al. 2015, McVea et al. 2018). The Vancouver rat study found evidence of *Escherichia coli* in 62.7% of urban rats tested (Himsworth et al. 2015). More research is necessary to better elucidate the ecology and life history of rodent populations living in close proximity to humans.

The goal of commensal rodent management is to quickly reduce the population of rodents and sustain their reduction so that no further damage or exposure to allergens and pathogens occurs (Sheehan et al. 2010). To achieve this goal, rodent management needs to be quick and efficient, and the effects of this management should be sustained. In urban and residential infestations, this type of management is often referred to as population knockdown, most commonly achieved using a combination of trapping, habitat manipulation, and rodenticide placement. However, habitat manipulation and trapping can be costly and require additional hours of labor to be effective.

Pest control operators are tasked with the control of rodent populations through trapping and rodenticide bait use, but sanitation, exclusion, and the removal of harborage are the responsibility of the property owners (Figure 2). However, these services can be 2–5 times more costly due to labor and material costs (D. Van Steenwyk, Structural Pest Control Board, California Department of Consumer Affairs, personal communication). This may limit adoption of non-toxic service because property owners, the consumers of pest control services, would likely lean toward a more economical service.

Additional services such as rodent proofing (pest exclusion), habitat modifications, and sanitation must be approved by property owners, and these services are more costly than a pest management strategy based on rodenticide applications. A rodent management program based on rodenticide continues to be the most economically feasible service provided. Because of the strong likelihood of reinvasion, the use of rodenticides as a rodent management option is likely also a reason for its popularity.

The use of rodenticides to manage commensal rodents, whether by pest control operators or homeowners, is considered the easiest, cheapest, and quickest method to knock down rodent populations. Second-generation anticoagulant rodenticides (SGARs) have been recognized as being very effective because they typically take days before lethal effects occur (Fisher 2005). The SGARs inhibit the synthesis of vitamin K and subsequently clotting factors leading to internal bleeding and death after the ingestion of lethal amounts. This means that there is little opportunity for bait shyness to develop. Other reasons for their popularity include, but are not limited to, high oral toxicity, toxic effects after a single feeding, and high palatability.

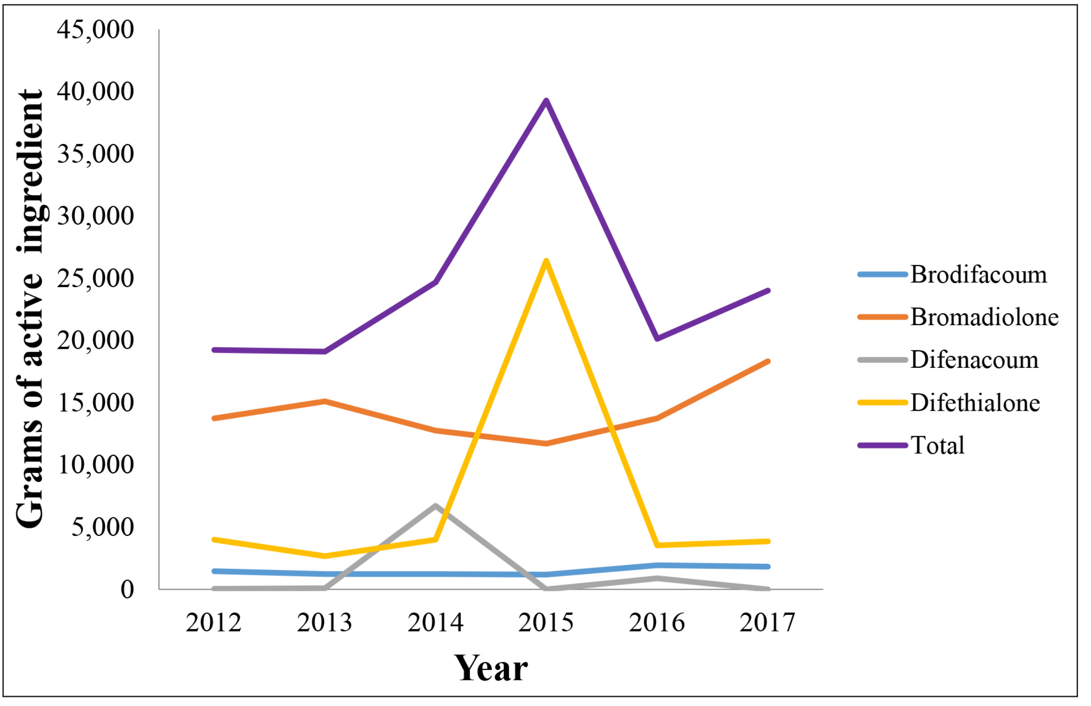

Figure 3. Amount in grams of 4 second-generation anticoagulant rodenticides (SGARs) applied between 2012 and 2017 in California, USA. The combined grams of SGARs applied are also displayed (purple).

New restrictions on the use of anticoagulant rodenticides have been proposed in several bills at the California Assembly. Due to lack of research in the effectiveness of nonlethal, nontoxic and/or integrated management programs, the impacts of this proposed legislation on rodent densities are unknown. The success of the restrictions on anticoagulant rodenticides in mitigating potential impacts to wildlife are unknown, nor is the potential impacts on both rodent populations and human health and safety.

Current and proposed changes to rodenticide legislation in California

Pesticides in California are applied under some of the strictest environmental regulations in the United States (London et al. 2008). The Federal Insecticide, Fungicide and Rodenticide Act, passed in 1972, provides for federal regulation of pesticide distribution, sale, and use. In 1996, the legislation was further amended by the Food Quality Protection Act, and again in 2012 by the Pesticide Registration and Improvement Extension Act of 2012. California has a separate regulatory system that requires additional review of pesticides by the U.S. Environmental Protection Agency (EPA), prior to the registration of products in California, thus further limiting or restricting the use of federally registered pesticides prior to being offered for sale in California. In 2008, the EPA revised a risk mitigation decision for 10 rodenticides that led to tightened safety standards that aimed to reduce risks to humans, pets, and nontarget wildlife. In response to evidence of wildlife weakened or killed by SGARs, the California Department of Pesticide Regulation (CDPR) further restricted the use and sale of SGARs (CDPR 2013). These restrictions came into effect in July 2014.

These recent risk mitigation measures for anticoagulant rodenticides in California include: (1) the classification of SGARs as restricted use so they are only permitted to be applied by professional, licensed applicators; (2) restriction on sale of SGARs to the public; (3) restriction of rodenticide placement to within 15.24 m of manmade structures, unless the placement limit on the label extends the bait placement distances (or there is a harborage present); and (4) determination that SGARs are not labeled for controlling ornamental, plant, or turf pests.

Information on applications of anticoagulant rodenticides by professional applicators in urban environments is lacking, as this information is generally protected under privacy laws (Rattner et al. 2014). However, in California, Pesticide Use Reporting (PUR) is reported in aggregate annually by CDPR. The restrictions on use and placement of SGARs appear not to have reduced the total amount of pounds of active ingredients used for structural pest control in California from 2012 to 2017 (Figure 3). At the time of publication, several inaccuracies were discovered in the CDPR's PUR database. However, even with these inaccuracies, it does not appear that the amount of applied SGAR has been significantly reduced. While the restrictions imposed in 2014 were intended to restrict the access of the homeowner to these products, the PURs suggested that the restrictions on sites, species and applicator for application of SGARs have not reduced the amount of these products placed around structures in California (https://www.cdpr.ca.gov/docs/pur/purmain.htm).

In 2016, the Food and Agricultural Code was further amended to restrict the placement of the 4 SGARs in any wildlife habitat area defined as a state park, state wildlife refuge, or state conservancy (CA Food and Ag Codes 12978.7). In February 2016, Assembly Bill (AB) 2596, Pesticides: Use of Anticoagulants, was introduced to the California Assembly by assembly member Bloom. A year later, AB 1687 replaced AB 2596 and was cited as the California Natural Predator Protection Act of 2017. This legislation prohibited the use of several active ingredients in California. Assembly Bill 1687 was amended to provide exemptions for use in agricultural production and in the event of public health emergencies. Assembly Bill 2422 was subsequently introduced with similar language. In 2019, AB 1788 was introduced as the California Ecosystems Protection Act of 2019 (https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200AB1788).

A review of city ordinances in California found that 26 cities had also enacted ordinances that further restricted the sale and use of rodenticides. Of the 26 local ordinances identified (Table 1), 4 of the cities are below California's median household income (3–15%. The remaining 85% of cities range from 3–286% above California's median household income. The data indicated that communities with higher median household income are more likely to enact local ordinances discouraging the sale and use or rodenticides (Yates χ^2 = 11.12, $P < 0.001$).

The local communities restricting rodenticide sales may also advocate for changes in rodenticide policy at the state level (e.g., Poison Free Malibu). In this situation, the communities requesting restrictions on rodenticide use may be communities that are impacted the least by damage and diseases of rodents or have sufficient income to pay for higher-cost rodent management services such as trapping and rodent-proofing, which are more costly services. Pest infestations, including rodents, have been shown to be endemic in many low-income, urban neighborhoods in the United States (Phipantanakul et al. 2000, Chew et al. 2003, Matsui et al. 2005).

Rodenticide, wildlife, and potential impacts of proposed legislation

The secondary poisoning of predators is well documented in California and anticoagulant rodenticides have been shown to persist in many nontarget species (Elliott et al. 2016, Prat-Mairet et al. 2017, Sainsbury et al. 2018). Anticoagulant rodenticide has been detected in 70% of nontarget wildlife collected by the California Department of Fish and Wildlife (Hosea 2000). High levels of regional detection have also been reported from single-species populations (e.g., bobcats [*Lynx rufus*] and mountain lions [*Puma concolor*]) in Southern California (Riley et al. 2007), as well as multiple raptor species (e.g., barn owl [*Tyto alba*], great horned owl [*Bubo virginianus*], and Cooper's hawk [*Accipiter cooperii*]; Krueger et al. 2016).

Thus, it is possible that the exposure of wildlife to other pesticides is more widespread. However, because anticoagulant rodenticides are persistent, they have the potential to be detected at higher rates for longer periods of time than less persistent compounds (Thompson et al. 2014). One of the major issues with wildlife exposure to rodenticide is understanding how nontarget prey are being exposed to rodenticides. While some research exists on this issue, several researchers have identified wildlife exposure to rodenticides as a major research gap (Hoare and

Table 1. List of cities (with region and county) that have been identified as having local ordinances pertaining to the use and sale of rodenticides. The median household income (U.S. dollars) of cities has also been listed. The percentage above or below (-) the state median household income as identified from the U.S. Census Bureau is also listed.

Region	City	County	Median household income ($)	% above/below
Bay Area	Albany	Alameda	78,769	24
	Berkeley	Alameda	65,283	3
	Emeryville	Alameda	69,329	9
	El Cerrito	Contra Costa	88,380	39
	Richmond	Contra Costa	54,857	-14
	Fairfax	Marin	93,354	47
	San Anselmo	Marin	100,681	58
	San Francisco	San Francisco	78,378	23
	Belmont	San Mateo	106,287	67
	Brisbane	San Mateo	80,233	26
	Foster City	San Mateo	11,4651	80
	Menlo Park	San Mateo	115,650	82
	Portola Valley	San Mateo	182,381	187
	Santa Cruz	Santa Cruz	61,533	-3
Southern California	Agoura Hills	Los Angeles	107,268	69
	Calabasas	Los Angeles	117,176	84
	Hidden Hills	Los Angeles	245,694	286
	Malibu	Los Angeles	130,432	105
	Westlake Village	Los Angeles	115,550	82
	Whittier	Los Angeles	65,583	3
	Camarillo	Ventura	87,120	37
	Moorpark	Ventura	99,353	56
	Ojai	Ventura	60,714	-5
	Simi Valley	Ventura	89,595	41
	Thousand Oaks	Ventura	99,115	56
Other	Davis	Yolo	57,454	-10

Hare 2006, Elliott et al. 2014, Rattner et al. 2014).

Exposure of nontarget species is likely occurring from both legal and illegal applications of anticoagulant rodenticide. For example, exposure of wildlife to anticoagulant rodenticide from its illegal application has been frequently described from marijuana grows (Thompson et al. 2014, Franklin et al. 2018). Illegal applications of rodenticides in natural resource areas and the pathways of rodenticide to nontarget animals are better understood. For example, it is known that female fisher (*Martes pennanti*) survival is related to the numbers of marijuana cultivation sites they are likely to encounter (Thompson et al. 2014). If the process by which nontarget animals are exposed to rodenticides were better understood, the potential for applicators to mitigate for the exposure could be implemented so that exposure of nontarget species could be reduced.

In urban areas of Southern California, anticoagulant rodenticides not registered in the United Sates (Coumatetralyl) as well as active ingredients (Difenacoum) that are not readily

Figure 4. In California, USA, despite restrictions, rodenticide can still be readily acquired online. Examples above include restricted-use pesticides that require a license to purchase, products with active ingredients that are not registered in the United States, products that are not registered in the United States, repackaged products, and products sold without a label.

used (but registered) are being detected in urban coyotes (*Canis latrans*; N. Quinn, unpublished data). If urban residences are able to purchase rodenticides from outside the United States or on the internet (Figure 4), restrictions on purchasing these banned products may reduce nontarget exposure. However, in California there is currently no mechanism in existence to enforce pesticide applications on private property by individuals that are not licensed by CDPR or California's Structural Pest Control Board, and therefore illegal applications of restricted and unregistered products may go unnoticed. This is particularly true for unregistered rodenticides, which are not generally monitored for during wildlife investigations.

Perhaps a more important issue is the ability to better understand if there are any population-level effects on the exposure of nontarget species populations to rodenticides. Little is known about the sublethal effects of rodenticide exposure and if this translates to significant decreases in the population densities of nontarget species in urban environments. This knowledge gap has also been identified (Kramer et al. 2011, Rattner et al. 2014, Rattner and Mastrota 2018, Shore and Coeurdassier 2018, van den Brink et al. 2018). Quinn and Swift (2018) have suggested some solutions to this problem.

The research gaps, combined with proposed restrictions, provide a challenge for managers. Without clear knowledge of the pathways of rodenticide exposure in wildlife, it is not possible to mitigate their potential impacts. Within the current proposed legislation, exemptions that allow for certain uses would mean that rodenticide exposure will continue. Therefore, without a clear understanding of the mechanisms of wildlife exposure, proposed restrictions will not have the intended consequence of eliminating wildlife exposure to SGARs or any other unrestricted active ingredient.

Managing rodents without SGARs or with further rodenticide restrictions

The management of rodents has been recognized as a "wicked problem" (Parsons et al. 2017). This term is used to describe problems that are often unique and have no definite solution. Among other things, wicked problems are considered to be a symptom of other problems (Head 2008). Additionally, pest control operators recognize that every rodent management job is unique, as infestation presents unique challenges for control. Currently, due to the additional labor needed to implement non-toxic rodent management, non-toxic programs may not be cost-effective alternatives to the use of rodenticide for home and business owners (D. Van Steenwyk, Structural Pest Control Board, California Department of Consumer Affairs, personal communication). Rodent-proofing, harborage removal, and trapping programs are more costly than rodenticide placement due to the time it takes to implement these programs.

Overreliance on 1 pesticide has led to resistance issues with many pest and pest management programs (Greaves and Ayres 1967, Marsh 1992, Busi et al. 2013, Sparks and Nauen 2015). This can be exacerbated by declining availability of active ingredients (Barzman et al. 2015). Restrictions on the use of SGARs are likely to cause pest management professionals to switch to other baits such as first-generation anticoagulant rodenticide (FGARs) or acute rodenticides (bromethalin, cholecalciferol, zinc phosphide). In rodent management, overreliance on FGARs prompted the development of the SGARs because of resistance issues and ineffective management of commensal rodents (Hadler and Buckle

1992). Currently, in parts of Europe, 50% of house mice carry mutations of the Vkorc1 gene (Marquez et al. 2019). These mutated genes lead to severe resistance to FGARs. There is also evidence of both bait shyness (Prescott et al. 1992) and palatability issues (Gill 1992) associated with acute rodenticide use in the management of rodents. The combination of resistance concerns coupled with bait shyness should lead to an increased integrated approach.

Integrated pest management is likely an important process in the management of urban commensal rodents. It incorporates multiple management options that could lead to more effective rodent management. It has been suggested for plant-based systems that a holistic IPM approach that includes all action levels (habitat modification, sanitation, non-toxic management, etc.) is probably unattainable (Stenberg 2017). Integrated pest management for commensal rodents is not well studied; therefore, it is unknown if this is also true for rodent-based systems. In the agricultural and food industry, the fact that growers are constrained by economic factors and other business realities has been linked to the inability to really have a choice in what pest management option they participate in (Hokkanen 2015). It is likely that this lack of choice, due to economic constraints and other business pressure, may also be experienced by private citizens and professional applicators who manage commensal rodents in urban settings.

The direct impact of area-wide (e.g., city-level) sanitation programs on managing rodents is not well understood in urban environments (Williams et al. 2015). Although frequently recognized as an important element in the success of rodent management programs (Corrigan 2001, Bonwitt et al. 2017), there appears to be little research on the effects of such programs in residential neighborhoods. Cities can invest considerable resources into sanitation practices such as the free garbage cart initiative in the city of Chicago, Illinois, USA, whereby the city provides free garbage carts in an effort to containerize their street waste. Research has shown that properties with drain blockages had higher levels of mice and rats inside properties and higher levels of rats outside (Langton et al. 2001). The Centers for Disease Control and Prevention (CDC) also places heavy emphasis on sanitation practices for Integrated Pest Management (CDC 2006), although publicly funded rodent abatement programs that could implement area-wide sanitation initiatives are in decline in most major urban centers. In 2018, The county of Los Angeles, California voted to disband the rodent abatement program (county-wide rodent management program), and other jurisdictions such as Orange County, California only provide service to individual property owners, not area-wide campaigns. Because restrictions on the use of SGARs could make it more expensive to manage rodents for individuals who choose to hire private pest control, management of rodents at the property level may decline. This may lead to a need for increased area-wide rodent management or even the creation of such programs in some cities.

While sanitation is an important part of an integrated management program, its adoption in urban environments is hard to attain due to dense aggregations of homes and the lack of government agencies providing targeted, area-wide residential rodent abatement. It is important to identify ways in which pest management professionals can encourage their customers to adopt sanitation practices as a way to permanently reduce rodent harborage and food sources.

The lack of cost-effective alternatives to rodenticide use, property owner resistance to make structural changes to their properties, and the pressure on the applicator to rapidly remediate the rodent infestation prove challenging for all involved in rodent management. Exclusion programs, while proven effective at excluding commensal rodents from the inside of structures, are often cost-prohibitive and do not impact the population of rodents surviving outside the property. Without scientifically proven management options that impact commensal rodent populations both inside and outside properties, it is difficult to provide evidence-based solutions to homeowners and pest control operators.

Modifications have been made to anti-coagulant rodenticide application procedures in different parts of the world. In Canada, as of

January 1, 2013, brodifacoum and difethialone are now restricted to indoor applications only. It is difficult to know if such restrictions would have any impact on nontarget exposure. House mice are known to make less frequent outdoor excursions (compared to rats), so their roles in vectoring anticoagulant rodenticide are probably limited at best. The fate of rodents exposed to anticoagulant rodenticides indoors is unknown. Since they frequent both indoors and outdoors, it is likely that they could still be involved in the pathway of anticoagulant rodenticide exposure to nontarget species despite these restrictions. It is unclear whether changing from the traditional continuous "preventative" baiting strategies (permanent placement of bait stations with rodenticide bait, checked and refilled at intervals ranging from once a week to once every 3 months) to evidence-driven rodenticide applications will have any impact on the rate of nontarget species exposures (Elliott et al. 2016). Others have shown that the way anticoagulant rodenticides are used can reduce the risks of secondary poisoning of nontargets (Shore et al. 2006, Jacquot et al. 2013), albeit outside of urban areas.

Development of best management practices may lead to a reduction of nontarget species exposure to anticoagulant rodenticides in agricultural areas (Tosh et al. 2011). Adherence to best management practices for rodenticide placement by a government rat control program in Southern California has been shown to reduce rodenticide placement (Orange County Mosquito and Vector Control District [OCMVCD] 2010, Krueger et al. 2015). In this example, OCMVCD developed a best management policy for rat control (OCMVCD 2010) that outlines specific situations where rodenticide bait may be placed, only if ≥1 of the following conditions exist: (1) pre-construction habitat removal (e.g., California Department of Transport work, development projects, etc.); (2) residential hoarding cases, pre-cleanup; (3) large-scale landscape projects; (4) extreme circumstances observed by a public health professional; and (5) confirmed presence of a rodent-borne disease.

Adhering to this rodenticide placement policy led to an approximate 9,000 pound per year reduction in the annual amount of rodenticide placed by OCMVCD staff from 2012 to 2017 (Krueger et al. 2015). The effects of these best management practices on rodent densities and any potential reduction in exposure of nontarget species to rodenticide are unknown.

The modification of rodenticide label language, without the elimination of the rodenticide product, has led to success in the past for eliminating deaths of certain species by primary and secondary exposure to anticoagulant rodenticide (McMillin and Finlayson 2010). McMillin and Finlayson (2010) worked with stakeholders, regulators, and pesticide registrants to modify the label of the rodenticide product that caused mortality in geese (*Branta canadensis*) after its application in artichoke fields. The label was changed to limit the application when conditions favor goose presence in artichoke fields. No deaths have occurred since the label modification.

Impacts to California

It is difficult to predict how California residents will be impacted by the new proposed restrictions on rodenticide use. Impacts of increased restrictions on rodenticide could include, but are not limited to, increased expenses incurred for private pest management or contributions to public pest management, increased contact with rodents, and increased likelihood of exposure to disease.

Research suggests that human exposure to rats is common in areas with high population density, such as inner-city, economically challenged neighborhoods (Davis 1953, Childs et al. 1998, Langton et al. 2001, Battersby et al. 2002, Reis et al. 2008, Walsh 2014, Ayral et al. 2015). The effects of rodent management (with or without rodenticide) on the reduction of zoonoses are not well understood. Studies have found that lethal, urban rat management is associated with an increased chance that surviving rats would carry *Leptospira interrogans* (Lee et al. 2018). It is difficult to know if there is a threshold level or population density at which the risk of exposure to rodent-borne zoonoses or allergens is significant.

It is very likely that high densities of commensal rodents and people in urban areas can provide opportunities for increased contact between humans and rodents. This could increase the risk of rodent-borne pathogen transmission. However, the prevalence and variation of pathogens between urban and rural rodents is not consistent. Research has shown a lower prevalence of pathogens in urban rodents compared to rural rodents (Inoue et al. 2008, Hsieh et al. 2010), while other studies have noted the opposite (Halliday et al. 2015). A study from an urban center in Southern California shows that the population of fleas on rodents and backyard wildlife has increased significantly since 1967 (Krueger et al. 2016). A study of rat ectoparasites in New York City found the number of fleas on Norway rats to be higher than previously recorded (Frye et al. 2015). Further restrictions on rodenticide use in California could have serious implications for rodent densities in highly developed areas and thus increase the risk of pathogen spill-over to humans.

There are many unknowns when predicting the implications of further rodenticide restrictions to Californians. A partial list of these unknowns include: (1) whether rodenticide restrictions will increase rodent damage and vector-borne disease transmission to people; (2) the psychosocial effect (interrelation of social factors and individual thought and behavior) of interactions between humans and rats in areas with high rodent populations (German and Latkin 2016); (3) effects of rodent damage on infrastructure such as flood control channels and airports; (4) additional economic costs associated with rodent control that will be passed along to consumers and property owners; and (5) how options and effectiveness of area-wide sanitation and harborage removal considering local jurisdictions are reducing publicly funded rodent control and abatement programs.

Conclusions

The need to identify best management practices for urban commensal rodents is long overdue. The management of commensal rodents in urban and suburban areas is not well understood, and neither is their role in the exposure of wildlife to anticoagulant rodenticides. Although there continues to be more and more restrictions for rodenticide applications, according to CDPR's PUR, the use of rodenticides in California continues to increase. Without evidence-driven research or industry-driven best management practices that promote effective rodent management strategies that are both practical and economical, the use of rodenticides will likely remain a popular choice among pest management professionals for urban-based commensal rodent management programs in California. Because of these, the intended outcomes from proposed legislation (AB 1788) will not be achieved.

In California, there is also a need for increased enforcement of rodenticide applications. There is no mechanism in existence in California to enforce pesticide applications by homeowners. It is known that unregistered rodenticide products are making their way into the California market. Inspections of professionals applying rodenticides are also limited. Focusing on promoting improved enforcement for both professional and unlicenced professionals could have an impact on exposure to nontarget species.

The research gaps on the pathways of anticoagulant exposure of nontarget species are rather large, particularly in urban systems. It is unknown if legal rodenticide applications have the ability to even have population-level impacts on nontarget species. The role of illegal applications of rodenticide and its impacts on nontarget wildlife are also not known and require further research. Without filling these research gaps, any proposed legislation is likely to fail in its efforts to eliminate SGAR exposure to wildlife.

The proposed restrictions on rodenticide in California are not necessary and have the potential to have serious repercussions for the public health of Californians. Research is needed to increase the efficacy of rodent management while limiting potential environmental impacts before any major restrictions are implemented. Without data-driven efforts to aid in the development of mitigation measures, exposure of wildlife to anticoagulant rodenticides will continue to occur.

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Literature cited

Ayral, F., J. Artois, A. L. Zilber, F. Widén, K. C. Pounder, D. Aubert, D. J. Bicout, and M. Artois.

2015. The relationship between socioeconomic indices and potentially zoonotic pathogens carried by wild Norway rats: a survey in Rhône, France (2010–2012). Epidemiology & Infection 143:586–599.

Baldwin, R. A. 2017. Challenges and opportunities for the wildlife damage management profession in the face of expanding wildlife populations: an extension perspective. Proceedings of the Wildlife Damage Management Conference 17:1–8.

Battersby, S. A., R. Parsons, and J. P. Webster. 2002. Urban rat infestations and the risk to public health. Journal of Environmental Health Research 1:57–65.

Barzman, M., P. Bàrberi, A. N. E. Birch, P. Boonekamp, S. Dachbrodt-Saaydeh, B. Graf, B. Hommel, J. E. Jensen, J. Kiss, P. Kudsk, and J. R. Lamichhane. 2015. Eight principles of integrated pest management. Agronomy for Sustainable Development 35:1199–1215.

Bonwitt, J., A. M. Sáez, J. Lamin, R. Ansumana, M. Dawson, J. Buanie, J. Lamin, D. Sondufu, M. Borchert, F. Sahr, E. Fichet-Calvet, and H. Brown. 2017. At home with *Mastomys* and *Rattus*: human–rodent interactions and potential for primary transmission of lassa virus in domestic spaces. American Journal of Tropical Medicine and Hygiene 96:935–943.

Busi, R., M. M. Vila-Aiub, H. J. Beckie, T. A. Gaines, D. E. Goggin, S. S. Kaundun, M. Lacoste, P. Neve, S. J. Nissen, J. K. Norsworthy, M. Renton, D. L. Shaner, P. J. Tranel, T. Wright, Q. Yu, and S. B. Powles. 2013. Herbicide resistant weeds: from research and knowledge to future needs. Evolutionary Applications 6:1218–1221.

California Department of Pesticide Regulation. 2013. Initial statement of reasons and public report: designating second generation anticoagulant rodenticides as restricted materials. California Department of Pesticide Regulation, Sacramento, California, USA.

Centers for Disease Control and Prevention (CDC). 2006. Integrated pest management: conducting urban rodent surveys. U.S. Department of Health and Human Services, Atlanta, Georgia, USA.

Chew, G. L., M. S. Perzanowski, R. L. Miller, J. C. Correa, L. A. Hoepner, C. M. Jusino, M. G. Becker, and P. L. Kinney. 2003. Distribution and determinants of mouse allergen exposure in low-income New York City apartments. Environmental Health Perspectives 111:1348–1351.

Childs, J. E., S. L. McLafferty, R. Sadek, G. L. Miller, A. S. Khan, E. R. DuPree, R. Advani, and G. E. Glass. 1998. Epidemiology of rodent bites and prediction of rat infestation in New York City. American Journal of Epidemiology 148:78–87.

Corrigan, R. M. 2001. Rodent control: a practical guide for pest management professionals. GIE Media, Cleveland, Ohio, USA.

Davis, D. E. 1953. The characteristics of rat populations. Quarterly Review of Biology 28:373–401.

Easterbrook, J. D., J. B. Kaplan, N. B. Vanasco, W. K. Reeves, R. H. Purcell, M. Y. Kosoy, G. E. Glass, J. Watson, and S. L. Klein. 2007. A survey of zoonotic pathogens carried by Norway rats in Baltimore, Maryland, USA. Epidemiology and Infection 135:1192–1199.

Elliott, J. E., S. Hindmarch, C. A. Albert, J. Emery, P. Mineau, and F. Maisonneuve. 2014. Exposure pathways of anticoagulant rodenticides to nontarget wildlife. Environmental Monitoring and Assessment 186:895–906.

Elliott, J. E., B. A. Rattner, R. F. Shore, and N. W. van den Brink. 2016. Paying the pipers: mitigating the impact of anticoagulant rodenticides on predators and scavengers. Bioscience 66:401–407.

Fisher, P. 2005. Review of house mouse (*Mus musculus*) susceptibility to anticoagulant poisons. Department of Conservation Science Internal Series 198, Department of Conservation, Wellington, New Zealand.

Franklin, A. B., P. C. Carlson, A. Rex, J. T. Rockweit, D. Garza, E. Culhane, S. F. Volker, R. J. Dusek, V. I. Shearn-Bochsler, M. W. Gabriel, and K. E. Horak. 2018. Grass is not always greener: rodenticide exposure of a threatened species near marijuana growing operations. BMC Research Notes 11:94.

Forchhammer, M. C., T. H. Clutton-Brock, J. Lindström, and S. D. Albon. 2001. Climate and population density induce long-term cohort variation in a northern ungulate. Journal of Animal Ecology 70:721–729.

Frye, M. J., C. Firth, M. Bhat, M. A. Firth, X. Che, D. Lee, S. Williams, and W. I. Lipkin. 2015. Preliminary survey of ectoparasites and associated pathogens from Norway rats in New York City. Journal of Medical Entomology 52:253–259.

German, D., and C. A. Latkin. 2016. Exposure to urban rats as a community stressor among low-income urban residents. Journal of Community Psychology 44:249–262.

Gill, J. E. 1992. A review of the results from laboratory tests of some rodenticides against eight rodent species. Proceedings of the Vertebrate Pest Conference 15:182–191.

Greaves, J. H., and P. Ayres. 1967. Heritable resistance to warfarin in rats. Nature 215:877.

Hadler, M. R., and A. P Buckle. 1992. Forty-five years of anticoagulant rodenticides—past, present and future trends. Proceedings of the Vertebrate Pest Conference 15:149–155.

Halliday, J. E., D. L. Knobel, B. Agwanda, Y. Bai, R. F. Breiman, S. Cleaveland, M. K. Njenga, and M. Kosoy. 2015. Prevalence and diversity of small mammal-associated *Bartonella* species in rural and urban Kenya. PLOS Neglected Tropical Diseases 9:1–14.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D. Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. Science 296:2158–2162.

Head, B. W. 2008. Wicked problems in public policy. Public Policy 3:101.

Himsworth, C. G., A. Y. Feng, K. Parsons, T. Kerr, and D. M. Patrick. 2013. Using experiential knowledge to understand urban rat ecology: a survey of Canadian pest control professionals. Urban Ecosystems 16:341–350.

Himsworth, C. G., E. Zabek, A. Desruisseau, E. J. Parmley, R. Reid-Smith, C. M. Jardine, P. Tang, and D. M. Patrick. 2015. Prevalence and characteristics of *Escherichia coli* and *Salmonella* spp. in the feces of wild urban Norway and black rats (*Rattus norvegicus* and *Rattus rattus*) from an inner-city neighborhood of Vancouver, Canada. Journal of Wildlife Diseases 51:589–600.

Hoare, J. M., and K. M. Hare. 2006. The impact of brodifacoum on non-target wildlife: gaps in knowledge. New Zealand Journal of Ecology 30:157–167.

Hokkanen, H. M. T. 2015. Integrated pest management at the crossroads: science, politics, or business (as usual)? Arthropod–Plant Interactions 9:543–545.

Hosea, R. C. 2000. Exposure of non-target wildlife to anticoagulant rodenticides in California. Proceedings of the Vertebrate Pest Conference 19:236–244.

Hsieh, J. W., K. C. Tung, W. C. Chen, J. W. Lin, L. J. Chien, Y. M. Hsu, H. C. Wang, B. B. Chomel, and C. C. Chang. 2010. Epidemiology of *Bartonella* infection in rodents and shrews in Taiwan. Zoonoses and Public Health 57:439–446.

Inoue, K., S. Maruyama, H. Kabeya, N. Yamada, N. Ohashi, Y. Sato, M. Yukawa, T. Masuzawa, F. Kawamori, T. Kadosaka, and N. Takada. 2008. Prevalence and genetic diversity of *Bartonella* species isolated from wild rodents in Japan. Applied and Environmental Microbiology 74:5086–5092.

Jacquot, M., M. Coeurdassier, G. Couval, R. Renaude, D. Pleydell, D. Truchetet, F. Raoul, and P. Giraudoux. 2013. Using long-term monitoring of red fox populations to assess changes in rodent control practices. Journal of Applied Ecology 50:1406–1414.

Kramer, V. J., M. A. Etterson, M. Hecker, C. A. Murphy, G. Roesijadi, D. J. Spade, J. A. Spromberg, M. Wang, and G. T. Ankley. 2011. Adverse outcome pathways and ecological risk assessment: bridging to population-level effects. Environmental Toxicology and Chemistry 30:64–76.

Krijger, I. M., S. R. Belmain, G. R. Singleton, P. W. Groot Koerkamp, and B. G. Meerburg. 2017. The need to implement the landscape of fear within rodent pest management strategies. Pest Management Science 73:2397–2402.

Krueger, L., J. Newton, A. Semrow, L. Levy, K. Nguyen, T. Morgan, S. Sun, J. Sims, S. Koenig, L. Shaw, and R. Cummings. 2015. An analysis of the largest publically funded rodent control program in California: Orange County Mosquito and Vector Control District's rodent control program, 2004–2014. Proceedings and Papers of the Mosquito and Vector Control Association of California 83:52–56.

Krueger, L., Y. Bai, S. Bennett, C. Fogarty, S. Sun, M. Kosoy, A. Maina, K. Nelson, E. Platzer, L. Osikowicz, A. L. Richards, S. Shariar, A. Trinidad, and R. Cummings. 2016. Identification of zoonotic and vector-borne infectious agents associated with opossums (*Didelphis virginiana*) in residential neighborhoods of Orange County, California. Proceedings of the Vertebrate Pest Conference 27:268–279.

Langton, S., D. Cowan, and A. Meyer. 2001. The occurrence of commensal rodents in dwellings as revealed by the 1996 English House Condition Survey. Journal of Applied Ecology 38:699–709.

Lee, M. J., K. A. Byers, C. M. Donovan, J. J. Bidulka, C. Stephen, D. M. Patrick, and C. G. Himsworth. 2018. Effects of culling on *Leptospira interrogans* carriage by rats. Emerging Infectious Diseases 24:356.

London, J. K., J. Sze, and R. S. Lievanos. 2008. Problems, promise, progress, and perils: critical reflections on environmental justice policy implementation in California. UCLA Journal of Environmental Law and Policy 26:255–289.

Marsh, R. E. 1992. Reflections on current (1992) pocket gopher control in California. Proceedings of the Fifteenth Vertebrate Pest Conference. 15:289–295.

Marsh, R. E. 1994. Roof rats. Pages B125–B132 *in* S. E. Hygnstrom, R. M. Timm, and G. E. Larson, editors. The handbook: prevention and control of wildlife damage. Cooperative Extension Division, University of Nebraska - Lincoln, Nebraska, USA.

Marquez, A., T. Ulivieri, E. Benoit, A. Kodjo, and V. Lattard. 2019. House mice as a real sanitary threat of human and animal leptospirosis: proposal for integrated management. BioMed Research International 2019:1–9.

Matsui, E. C., E. Simons, C. Rand, A. Butz, T. J. Buckley, P. Breysse, and P. A. Eggleston. 2005. Airborne mouse allergen in the homes of inner-city children with asthma. Journal of Allergy and Clinical Immunology 115:358–363.

McMillin, S. C., and B. F. Finlayson. Investigation of chlorophacinone-related goose deaths in Monterey County, California. 2010. Proceedings of the Vertebrate Pest Conference 24:178–180.

McVea, D. A., C. G. Himsworth, D. M. Patrick, L. R. Lindsay, M. Kosoy, and T. Kerr. 2018. Exposure to rats and rat-associated *leptospira* and *bartonella* species among people who use drugs in an impoverished, inner-city neighborhood of Vancouver, Canada. Vector-Borne and Zoonotic Diseases 18:82–88.

Orange County Mosquito and Vector Control District (OCMVCD). 2010. Vector reduction manual: procedures and guidelines. Orange County Mosquito and Vector Control District, Garden Grove, California, USA.

Parsons, M. H., P. B. Banks, M. A. Deutsch, R. F. Corrigan, and J. Munshi-South. 2017. Trends in urban rat ecology: a framework to define the prevailing knowledge gaps and incentives for academia, pest management professionals (PMPs) and public health agencies to participate. Journal of Urban Ecology 3:1–8.

Phipatanakul, W., P. A. Eggleston, E. C. Wright, and R. A. Wood. 2000. The prevalence of mouse allergen in inner-city homes. Journal of Allergy and Clinical Immunology 106:1070–1074.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273–288.

Post, E., N. C. Stenseth, R. Langvatn, and J. M. Fromentin. 1997. Global climate change and phenotypic variation among red deer cohorts. Proceedings of the Royal Society of London B: Biological Sciences 264:1317–1324.

Prat-Mairet, Y., I. Fourel, J. Barrat, M. Sage, P. Giraudoux, and M. Coeurdassier. 2017. Non-invasive monitoring of red fox exposure to rodenticides from scats. Ecological Indicators 72:777–783.

Prescott, C. V., M. El-Amin, and R. H. Smith. 1992. Calciferols and bait shyness in the laboratory rat. Proceedings of the Vertebrate Pest Conference 15:218–223.

Quinn, N., and C. Swift. 2018. What do we need to know to assess individual and population-level effects on wildlife from rodenticides? Proceedings of the Vertebrate Pest Conference 28.

Rattner, B. A., R. S. Lazarus, J. E. Elliott, R. F. Shore, and N. van den Brink. 2014. Adverse outcome pathway and risks of anticoagulant rodenticides to predatory wildlife. Environmental Science and Technology 48:8433–8445.

Rattner, B. A., and F. N. Mastrota. 2018. Anticoagulant rodenticide toxicity to non-target wildlife under controlled exposure conditions. Pages 45–86 *in* V. N. van den Brink, J. E. Elliott, R. F. Shore, and B. A. Rattner, editors. Anticoagulant rodenticides and wildlife. Springer, Cham, Switzerland.

Reis, R. B., G. S. Ribeiro, R. D. Felzemburgh, F. S. Santana, S. Mohr, A. X. Melendez, A. Queiroz, A. C. Santos, R. R. Ravines, and W. S. Tassinari. 2008. Impact of environment and social gradient on *Leptospira* infection in urban slums. PLOS Neglected Tropical Diseases 2:1–10.

Riley, S. P., C. Bromley, R. H. Poppenga, F. A. Uzal, L. Whited, and R. M. Sauvajot. 2007. Anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban southern California. Journal of Wildlife Management 71:1874–1884.

Sainsbury, K. A., R. F. Shore, H. Schofield, E. Croose, M. G. Pereira, D. Sleep, A. C. Kitchener, G. Hantke, and R. A. McDonald. 2018. Long-term increase in secondary exposure to anticoagulant rodenticides in European polecats *Mustela putorius* in Great Britain. Environmental Pollution 236:689–698.

Sheehan, W. J., P. Permaul, C. R. Petty, B. A. Coull, S. N. Baxi, J. M. Gaffin, P. S. Lai, D. R. Gold, and W. Phipatanakul. 2017. Association between allergen exposure in inner-city schools and asthma morbidity among students. JAMA Pediatrics 171:31–38.

Sheehan, W. J., P. A. Rangsithienchai, R. A. Wood, D. Rivard, S. Chinratanapisit, M. S. Perzanowski, G. L. Chew, J. M. Seltzer, E. C. Matsui, and W. Phipatanakul. 2010. Pest and allergen exposure and abatement in inner-city asthma: a work group report of the American Academy of Allergy, Asthma & Immunology Indoor Allergy/Air Pollution Committee. Journal of Allergy and Clinical Immunology 125:575–581.

Shore, R. F., and M. Coeurdassier. 2018. Primary exposure and effects in non-target animals. Pages 135–157 *in* V. N. van den Brink, J. E. Elliott, R. F. Shore, and B. A. Rattner, editors. Anticoagulant rodenticides and wildlife. Springer, Cham, Switzerland.

Shore, R. F., H. M. Malcolm, D. McLennan, A. Turk, L. A. Walker, C. L. Wienburg, and A. J. Burn. 2006. Did foot-and-mouth disease-control operations affect rodenticide exposure in raptors? Journal of Wildlife Management 70:588–593.

Singleton, G. R., H. Leirs, L. A. Hinds, and Z. Zhang. 1999. Ecologically-based management of rodent pests—re-evaluating our approach to an old problem. Pages 17–29 *in* G. R. Singleton, H. Leirs, L. A. Hinds, and Z. Zhang, editors. Ecologically-based management of rodent pests. Australian Centre for International Agricultural Research, Canberra, Australia.

Sparks, T. C., and R. Nauen. 2015. IRAC: mode of action classification and insecticide resistance management. Pesticide Biochemistry and Physiology 121:122–128.

Stenberg, J. A. 2017. A conceptual framework for integrated pest management. Trends in Plant Science 22:759–769.

Thompson, C., R. Sweitzer, M. Gabriel, K. Purcell, R. Barrett, and R. Poppenga. 2014. Impacts of rodenticide and insecticide toxicants from marijuana cultivation sites on fisher survival rates in the Sierra National Forest, California. Conservation Letters 7:91–102.

Tosh, D. G., R. F. Shore, S. Jess, A. Withers, S. Bearhop, W. I. Montgomery, and R. A. McDonald. 2011. User behaviour, best practice and the risks of non-target exposure associated with anticoagulant rodenticide use. Journal of Environmental Management 92:1503–1508.

van den Brink, N. W., J. E. Elliott, R. F. Shore, and B. A. Rattner. 2018. Anticoagulant rodenticides and wildlife: concluding remarks. Pages 379–386 *in* V. N. van den Brink, J. E. Elliott, R. F. Shore, and B. A. Rattner, editors. Anticoagulant rodenticides and wildlife. Springer, Cham, Switzerland.

Walsh, M. G. 2014. Rat sightings in New York City are associated with neighborhood sociodemographics, housing characteristics, and proximity to open public space. PeerJ 2:1–14.

Walther, G. R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. Beebee, J. M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389.

Williams, S. B., C. E. Alexander, and L. J. Mason. 2015. Sanitation's impact on the effectiveness of the pest management programs of food processing facilities. Journal of Stored Products Research 60:48–53.

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