Ecotoxicology (2017) 26:90–96
DOI 10.1007/s10646-016-1744-5

Use of anticoagulant rodenticides by pest management professionals in Massachusetts, USA

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Accepted: 28 October 2016 / Published online: 8 December 2016

Abstract Secondary exposure to chemical rodenticides, specifically second-generation anticoagulant rodenticides (SGARs), poses a threat to non-target wildlife including birds of prey. Federal regulations in the United States currently limit homeowner access to SGARs as a way of minimizing this threat. With legal access to SGARs, pest management professionals (PMPs) represent a potential linkage to non-target exposure. There is limited research focused on rodent control practices, chemical rodenticide preferences, level of concern and awareness, or opinions on rodenticide regulations as they relate to PMPs. An online survey was sent to PMP companies across Massachusetts, USA, between October and November 2015. Thirty-five responses were obtained, a 20 % response rate. The preferred rodent control method among responding PMP companies was chemical rodenticides, specifically the SGAR bromadiolone. Respondents varied in their level of concern regarding the impact of chemical rodenticides on non-target species and showed a low level of awareness regarding SGAR potency and half-life. All responding companies reported using integrated pest management (IPM) strategies, with nearly all utilizing chemical rodenticides at some point. Enhanced education focused on SGAR potency, bioaccumulation potential, exposure routes, and negative impacts on non-target wildlife may improve efforts made by PMPs to minimize risk to wildlife and decrease dependence on chemical rodenticide use. Future studies evaluating use of anticoagulant rodenticide (ARs) by PMPs and the association with AR residues found in non-target wildlife is necessary to determine if current EPA regulations need to be modified to effectively reduce the risk of SGARs to non-target wildlife.

Keywords Rodent control · Anticoagulant rodenticide · Birds of prey · Secondary poisoning · Bromadiolone · Pest management professionals

Electronic supplementary material The online version of this article (doi:10.1007/s10646-016-1744-5) contains supplementary material, which is available to authorized users.

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Introduction

Anticoagulant rodenticides (ARs) are used worldwide to reduce rodent populations because of the detrimental impact of rodents on food production, spread of disease, and damage to property (Stenseth et al. 2003; Leung and Clark 2005). For decades, rodenticides have been used in both agricultural and urban settings (Watt et al. 2005). The use of first generation anticoagulant rodenticides (FGARs) including warfarin, chlorophacinone, and diphacinone, began in the 1940s and extensive use eventually resulted in acquisition of resistance in some rodent populations (Boyle 1960; Lund 1972; Watt et al. 2005).

The resistance to FGARs prompted the production of the second-generation anticoagulant rodenticides (SGARs), including brodifacoum, difethialone, bromadiolone, and difenacoum (Watt et al. 2005), which have increased potency, prolonged biological half-lives, and hepatic accumulation abilities (Stone et al. 2003; Watt et al. 2005). The higher single-dose efficacy of SGARs (Tosh et al. 2011), has resulted in greater frequency of use by pest management professionals (PMPs). Both groups of ARs antagonize vitamin-K epoxide reductase, inhibiting production of blood clotting factors, resulting in clinical symptoms often presenting as severe or lethal hemorrhaging (Eason et al. 2002). Bioaccumulation of SGARs is documented across many species from earthworms (*Eisenia fetida*) (Liu et al. 2015) to bobcats (*Lynx rufus)* (Serieys et al. 2015).

Due to dietary dependence on rodents, the impacts of SGARs on birds of prey consuming poisoned prey items has received extensive attention with numerous studies in multiple countries finding high rates of SGAR exposure among birds of prey (Table 1). Both SGARs and FGARs, which share the same mechanism of action, have been associated with secondary toxicosis—lethal or sublethal hemorrhaging—in birds of prey in clinical, field, or laboratory observations (Savarie et al. 1979; Mendenhall and Pank 1980; Radvanyi et al. 1988; Stone et al. 2003; Murray and Tseng 2008; Murray 2011; Salim et al. 2014; Rattner et al. 2015).

Between 1998 and 2001, researchers in New York, USA, analyzed 265 liver samples from 12 different raptor species and found that 49 % of the samples contained anticoagulant residues; 84 % of the positive cases were positive for brodifacoum and 22 % of cases were positive for bromadiolone, both SGARs (Stone et al. 2003). A 2011 study analyzed liver samples from 161 raptors admitted to a wildlife clinic in Massachusetts, USA, between 2006 and 2010 and found that 86 % had AR residues present; the SGAR brodifacoum was found in 99 % of the positive cases (Murray 2011). In these studies, AR toxicosis was determined to be the cause of death in 15 and 6 % of positive cases, respectively. Literature highlighting SGARs' impact on non-target wildlife supported the US Environmental Protection Agency's (EPA) decision to finalize and implement the 'Risk Mitigation Decision for Ten Rodenticides', which ended the retail sale of SGAR products to general consumers (e.g., homeowners) in order to minimize risk to non-target species (US EPA 2008). However, the decision allows continued use of SGARs by PMPs and agricultural users, with regulations pertaining to bait box use and purchasing amounts (US EPA 2008).

Research into the knowledge, awareness, and use of rodenticides by individual consumers and PMPs is extremely limited but is vital to better understand how to minimize the risks posed by SGARs to non-target wildlife (Mcdonald and Harris 2000; Morzillo and Mertig 2011; Tosh et al. 2011; Bartos et al. 2012). A 2012 study surveyed individual consumers and PMPs about their knowledge and use of ARs. Only five "Pest Control Operators" (PCOs) responded; of the four PCO respondents that used chemical rodenticides, 3 used SGARs and two used FGARs. The researchers found that homeowners frequently used products containing SGARs, ignored labels, and were inconsistent in their awareness of impact on wildlife (Bartos et al. 2012).

This conclusion is echoed in a 2000 study that analyzed AR use by employees of game estates in Great Britain (Mcdonald and Harris 2000), a 2010 survey of knowledge and AR purchasing behaviors by urban homeowners in California (Morzillo and Mertig 2011), and a 2011 study that gathered behavioral information on farmers in Northern Ireland (Tosh et al. 2011). These studies uncovered useful information about the need to enhance customer awareness regarding the potential risks associated with rodenticides, ensure effective labeling, and limit access to high-risk products (e.g., SGARs) in order to improve standards of application and limit the impact to non-target wildlife (Mcdonald and Harris 2000; Morzillo and Mertig 2011; Tosh et al. 2011; Bartos et al. 2012).

Table 1 Select studies reporting AR exposure in various species of birds of prey measured in liver tissue

Number of species	Sample size	Percent positive for ARs	Location	Time interval of data collection	Reference
12	265	49[a]	New York, USA	1998–2001	Stone et al. 2003
4	30	73[a]	Loire Atlantique, France	2003	Lambert et al. 2007
3	164	70[a]	British Columbia, Canada	1988–2003	Albert et al. 2010
4	161	86[b]	Massachusetts, USA	2006–2010	Murray 2011
7	773	47[a]	Scotland, United Kingdom	2000–2010	Hughes et al. 2013
5	30	53[b]	Norway	2009–2011	Langford et al. 2013
6	104	61[b]	Canary Islands, Spain	2009–2012	Ruiz-Suárez et al. 2014
2	127	81[b]	New Jersey, USA	2008–2010	Stansley et al. 2014

[a] predominantly SGARs

[b] solely SGARs

Although informative, the literature addressing the knowledge base and practices related to rodenticides has focused on individual consumers and not PMPs, who in the US have access to the more potent SGARs and are therefore a potential source of exposure to non-target species. The role played by PMPs must be understood to establish how effective the current EPA regulations may be at reducing the impacts of SGARs on wildlife. Access to this information will also highlight where improvements in regulation and education can be made (Mcdonald and Harris 2000; Bartos et al. 2012).

The aim of this paper is to report results from a statewide rodent control and rodenticide use survey of PMPs and their respective companies in Massachusetts. The data collected are meant to highlight current PMP practices, preferences, and knowledge surrounding rodenticide use in order to better understand potential linkages to rodenticide exposure in non-target species.

Methods

Participant recruitment

A list of 256 pest control companies was generated referencing the list of licensed commercial pesticide applicators ($n = 7385$ licenses), which was assembled and provided by officials from the Massachusetts Pesticide Board for the purpose of this study. The licenses encompass a wide range of pesticide uses; to ensure appropriate targeting, participation was restricted to companies that (1) employ commercial pesticide applicators who are licensed through the Massachusetts Pesticide Board (2) are located and provide services within Massachusetts and (3) offer rodent control services.

Contact information was obtained through publicly accessible websites, which provided telephone numbers and/or email addresses. Companies without listed email addresses were contacted via telephone in order to acquire an email address. In total, e-mail addresses were obtained for 162 pest control companies meeting the set criteria. These companies were subsequently sent emails containing an invitation to participate in the survey along with a link to the online survey.

Survey design

A primarily closed-ended questionnaire, consisting of approximately 34 questions, and two 'tracks' was generated using Qualtrics (www.qualtrics.com) (Qualtrics LLC 2015), an online survey platform. This platform was selected because of its accessibility, user-friendly interface, secure network, and low cost advantage. The questions were developed to collect information pertaining to a company's rodent control practices, rodenticide preferences, secondary exposure concerns, and opinions regarding EPA regulations.

Two 'yes or no' filter questions were included to distill the targeted population. The first asked whether the company provided rodent control services; if no was selected, the respondent was sent to the end of the survey. The second asked if the company ever used chemical rodenticides; two tracks of questions were created to accommodate the two response options (Supplementary.Appendix 1).

Demographic questions pertaining to respondent's position within his/her company, company type (e.g., independently owned, chain, franchise, or county owned), Massachusetts counties serviced, and number of licensed employees were asked to gauge size of company and respondent's likelihood of being well-versed in company policies. For questions pertaining to chemical preferences, product trade names were provided alongside the chemical name to provide reference and avoid potential uncertainty.

The survey was made available for a 3-week period between October and November of 2015. An invitation to participate in the study was sent via email, along with a link to the confidential online survey. A reminder email was sent to those who had not completed the survey after two weeks' time. Prior to contacting companies, this study and the survey questionnaire were reviewed and authorized by the Tufts Institutional Review Board (IRB Excluded Status: 1509027).

Statistical analysis

The survey responses and associated figures were compiled and generated using Microsoft Excel. Descriptive statistics were used to analyze the data.

Results

Forty-six individuals started the survey, of which there were 29 full responses and 6 partial. The remaining 11 participants were not considered for analysis due to insufficient data.

All of the included responses ($n = 35$) represented PMP companies that provided rodent control services; 97 % used chemical rodenticides ($n = 34$). One respondent represented a PMP company that does not use any chemical rodenticides; responses from that survey were not included in the following analysis.

The majority of companies using chemical rodenticides were described as "independent; privately owned and operated" (85 %, $n = 29$ of 34), with "chain; one parent company operating business locations" and "franchise; independent owner operating individual store associated with larger parent corporation" each represented by 6 % of the survey participants ($n = 2$ of 34).

Sixty-five percent employ “1 to 5 licensed individuals” (65 %, $n = 22$ of 34), with more than half primarily servicing suburban areas (56 %, $n = 19$ of 34).

To gauge the individual participant’s familiarity with rodent control and company preferences, respondents were asked “how many years have you worked for the company where you are currently employed,” with the average response being 17 years (SD = 11.93). All respondents reported participating in ‘continuing education’ related to rodenticide, with 59 % attending within the last year ($n = 19$ of 34). Seventy percent of the respondents identified themselves as their respective company’s ‘founder, president, or owner’ ($n = 23$ of 33) and 21 % were managers ($n = 7$ of 33).

Chemical use and rodent control preferences

The SGAR bromadiolone was reported to be the most frequently used chemical rodenticide at that current time (2015) (57 %, $n = 17$ of 30). Second generation anticoagulant rodenticides accounted for 80 % of the current preferred chemicals (Fig. 1). Bromadiolone was consistently favored among chemicals that have been used from 2011 to 2015 (Fig. 2).

Chemical rodenticides (ARs, neurotoxins, zinc), preventative management (eliminating entry points, water and food sources), and trapping (live or snap traps) were equally reported to be active rodent control methods. When asked, “which of these method were used most frequently,” Fifty-two percent of participants reported chemical rodenticides ($n = 16$ of 31) (Fig. 3).

Integrated Pest Management (IPM) is used by 100 % of the participating companies, with 97 % of respondents integrating chemical rodenticides into an IPM strategy about half or more than half of the time.

Seventy-six percent of companies rotate the use of a predominant chemical, with “effectiveness at eliminating rodents” (76 %, $n = 19$ of 25) and “palatability of the products to rodents” (60 %, $n = 15$ of 25) being the primary reasons for rotation. Respondents provided seasonal changes, weather restrictions, and rodent control maintenance vs. initial control as “other factors”.

Removal of bait and rodent carcass removal

Ninety-seven percent of respondents reported finding bait from previous pesticide management work. Sixty-six percent of companies return to site to remove bait they have placed, about half or more than half of the time (Fig. 4). Rodent carcasses are found about half or much less than half of the time (84 %, $n = 28$ of 33) and when found the carcasses are removed 89 % of the time ($n = 24$ of 27).

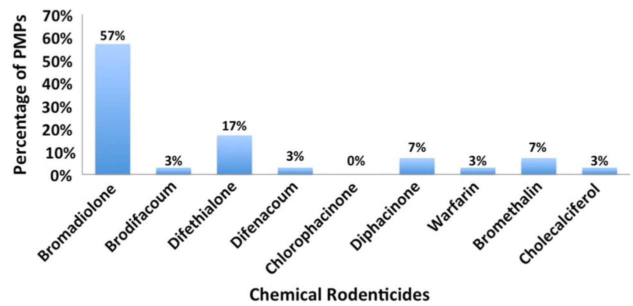

Fig. 1 Frequency of responses from Pest Management Professionals in Massachusetts when asked, “Which chemical rodenticide does your company currently use most frequently to control for rodents?” ($n = 30$)

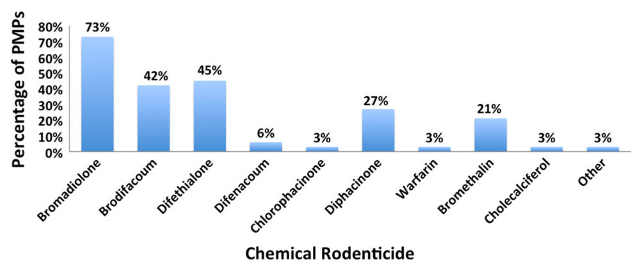

Fig. 2 Frequency of responses from Pest Management Professionals in Massachusetts when asked, “Which chemicals has your company used between 2011 and present?” ($n = 33$)

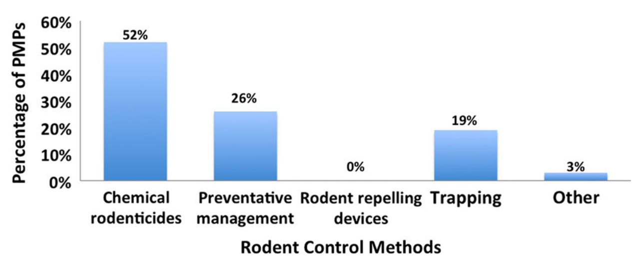

Fig. 3 Frequency of responses from Pest Management Professionals in Massachusetts when asked, “Which method of rodent control does your company use most frequently?” ($n = 31$)

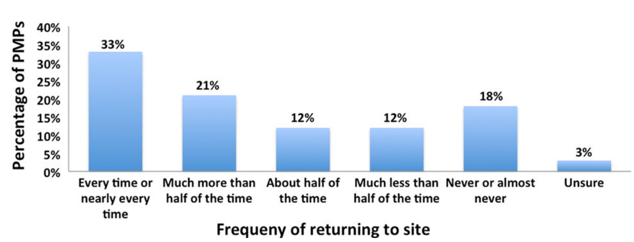

Fig. 4 Frequency of responses from Pest Management Professionals in Massachusetts when asked, “How often does your company return to a site to remove chemical rodenticide bait placed by your company?” ($n = 33$)

Awareness and concern for impacts on non-target species

When asked, "How long a mouse may live after ingesting a lethal dose of SGARs," 79 % accurately reported 1–7 days ($n = 26$ of 33) (US EPA 2008; Smith et al. 1990). When asked, "How long SGARs may remain toxic in the system of a mouse," 34 % of respondents were "unsure" ($n = 11$ of 32), 28 % selected '1–3 days.' ($n = 9$ of 32), and 19 % selected "1 week" ($n = 6$ of 32). A single participant reported 1 year, which was considered to be the only answer within the accurate time frame for the half-life of SGARs, which is approximated to be 113.5–350 days (Huckle et al. 1988; Prichard 2013).

Participants were asked to identify their level of concern regarding the potential negative impacts of anticoagulant rodenticides on both "non-target wildlife (e.g., bird of prey, coyote, raccoon)" and more specifically, "birds of prey (falcons, hawks, owls)." In general, the distribution of concern was similar and half of the participants had a neutral or low level of concern across both groups (Fig. 5).

Opinions on current rodenticide regulations

More than half of the respondents (55 %) believed that the EPA regulations limiting access of SGARs to homeowners have been successful in reducing secondary exposure and negative impacts on non-targets. When asked if they would support a comprehensive ban on the use of SGARs, limiting both homeowner and professional access to these chemicals, 68 % were somewhat or strongly opposed to such a ban, with 26 % remaining neutral. If a comprehensive ban on SGARs were to be put into place, IPM was selected as the most favored control method to serve as a substitute.

Discussion

This study shows that chemical rodenticides, specifically SGARs, are the preferred method of rodent control among the Massachusetts PMP companies that responded to this survey. The SGAR bromadiolone was the most preferred AR between 2011 and 2015, with 73 % of survey respondents acknowledging use during that time. Fifty-three percent stated that bromadiolone is currently (in 2015) their most frequently used chemical rodenticide. Difethialone, also an SGAR, was reported as being the most frequently used chemical rodenticide by 17 % of participating PMP companies in 2015, with only 3 % reporting brodifacoum as being most frequently used.

Current US EPA regulations, which took partial effect in 2011, assume that PMP use of SGARs results in lower risk to non-target species due to professional proficiency (US

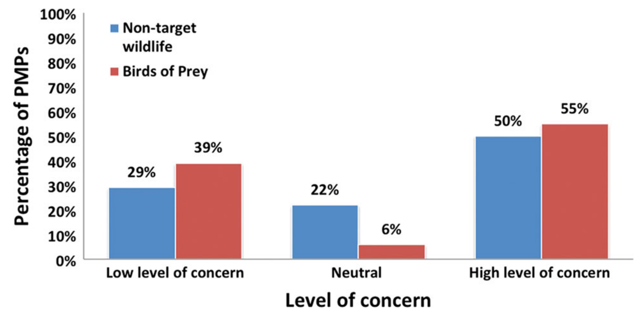

Fig. 5 Comparison between the level of concern held by Pest Management Professionals in Massachusetts for "non- target wildlife (e.g. bird of prey, coyote, raccoon)" on a whole and "birds of prey (e.g. falcon, hawk, owl)" more specifically. ($n = 32$ for non-target wildlife responses, $n = 31$ for birds of prey responses)

EPA 2008). However, a recent study analyzing AR exposure in birds of prey in Massachusetts from 2012–2016, found 96 % of the 94 birds analyzed to be positive for SGARs in liver tissue. Of the positive birds, 68 % had residues of bromadiolone and/or difethialone (Murray unpublished data). As 74 % of PMPs surveyed here reported bromadiolone and/or difethialone to be their most frequently employed chemical rodenticides in 2015, there is a need to investigate this potential overlap and evaluate the effectiveness of current regulations as they relate to SGAR use by PMPs and non-target wildlife exposure.

As mentioned, the survey found that only 3 % of PMPs currently (2015) prefer the SGAR brodifacoum and that between 2011 and 2015 only 42 % of PMPs reported its use. Previous literature has documented a high rate of brodifacoum exposure. Between 2008 and 2010, Stansley et al. (2014), detected brodifacoum in 76 % of red-tailed hawks and 73 % of great horned owls in a New Jersey, USA, study. Likewise, Murray found brodifacoum residues in 99 % of the birds testing positive for ARs between 2006 and 2010 (2011) and again between 2012 and 2016 (Murray unpublished data) in Massachusetts, USA. The high percentage of brodifacoum exposure documented in the literature coupled with the lower frequency of use of brodifacoum among PMPs relative to other SGARs reported in this survey may suggest that much of the exposure to brodifacoum is a result of general consumer use. As EPA regulations take effect and SGARs become unavailable to general consumers (US EPA 2008), additional research analyzing rodenticide exposures will be necessary to better understand the avenues of exposure.

IPM was reported to be used by all PMP companies participating in this study, with the majority implementing chemical rodenticides into their IPM strategies. The state of Massachusetts states that the IPM approach, "… usually consists of monitoring pest problems, the use of non chemical pest control, and resorting to conventional pesticides only when it is absolutely necessary and the pest damage exceeds an aesthetic or economic threshold" (Commonwealth of Massachusetts 2015). Sarwar (2015) explains that IPM should "minimize[s] the reliance on chemical pesticides." Our survey results show that when implementing IPM strategies, 97 % of PMP companies use chemicals more than half of the time. Exploring the threshold that determines the decision made by PMPs to use chemical rodenticides could determine if there is excessive dependence on poisons that could be reduced through education or regulation.

An understanding of the factors that influence the reliance on chemical rodenticides is necessary to determine the most effective approach to decreasing their use. Study participants described cost, effectiveness, and clientele preferences as driving forces behind chemical rodenticide use. Respondents stated that prevention and exclusion are "more expensive and time consuming than chemical options" and that chemical bait boxes provide clients with the "long term warranties and minimum service costs" that they request. Understanding these influential factors is crucial to providing PMP companies with practical alternatives in the future. It also emphasizes the need to explore public education about the risks of SGARs to wildlife in order to reduce pressure put on PMPs by client expectations, which may be formed without an awareness of the risks of SGARS to wildlife (Morzillo and Mertig 2011; Tosh et al. 2011; Bartos et al. 2012).

This study discovered variation in the level of concern for non-target wildlife as well as a low level of awareness regarding the toxicity of SGARs. This highlights an opportunity for education of PMPs. A study on chemical rodenticide use by homeowners found that increased awareness of impacts on non-target wildlife translated to a higher likelihood of behavior changes that decreased exposure risk (Morzillo and Mertig 2011). Even when products are used in accordance with the law, enhancing overall awareness may increase the efforts made to minimize excess use of chemicals and reduce the risk posed to non-target wildlife (Mcdonald and Harris 2000).

All of the respondents reported participating in continuing education related to rodenticides. This creates an opportunity where enhanced education of SGARs could easily be integrated. A qualitative study investigating why there is variation in level of concern and awareness across PMPs would help in targeting education materials.

The researchers acknowledge that the results of this study are limited by small sample size. The sensitivity of the topic and specificity of the target population may have contributed to the low response rate, a restricting component acknowledged in a similar study by Bartos et al. (2012). Significant effort was put forth to ensure that the questionnaire was written without bias by substantiating the wording and flow of questions with a representative from the Massachusetts Pesticide Board and experts within the rodent control field, and evaluating pilot group response time and participation. The questionnaire was constructed to avoid the revelation of illegal or unethical practices. Additional consideration was paid to reassure participants of the confidentiality of their survey responses. However, the topic and purpose of the study may have created unavoidable assumption of risk or hesitation, limiting participation. Nonetheless, the 20 % response rate provides previously undocumented and valuable information about rodent control practices and rodenticide use by PMPs.

Given the limited literature on this topic, there is a need for continued research that explores chemical rodenticides use by PMPs and homeowners, in order to better understand how to minimize secondary exposure while maximizing rodent control (Mcdonald and Harris 2000; Bartos et al. 2012). This study focused on PMPs within the state of Massachusetts; similar studies across multiple states may highlight regional differences or similarities, suggesting where regulation changes or education may be most needed or valuable.

Further research comparing survey results, pesticide use reports submitted to government agencies, and laboratory tissue samples of rodenticide residues would help in tracking the effectiveness of the current EPA regulations (Bartos et al. 2012).

Conclusions

This study has identified high dependence on SGARs, variations in levels of concern and awareness of risk to non-target species, inconsistencies in bait and rodent carcass removal, and in rationales driving chemical rodenticide use among PMPs in Massachusetts, USA. Enhanced education for individuals controlling for rodents and using ARs, as well as for the clientele who may influence PMP practices, will create greater awareness and may enhance efforts to minimize secondary exposure risks to wildlife. If use of ARs by PMPs and homeowners continues to result in non-target species exposure, regulation changes may be necessary despite some hesitation from the professionals.

Acknowledgments Special thanks to the Massachusetts Pesticide Board for providing feedback and access to public licensing records, Jef C. Taylor for valuable insight, and to all survey participants.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Tufts University Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of interest The authors declare that they have no competing interests.

References

Albert CA, Wilson LK, Mineau P, Trudeau S, Elliott JE (2010) Anticoagulant rodenticides in three owl species from western Canada, 1988–2003. Arch Environ Contam Toxicol 58:451–459

Bartos M, Dao S, Douk D, Falzone S, Gumerlock E, Hoekstra S, Longcore T (2012) Use of anticoagulant rodenticides in single-family neighborhoods along an urban-wildland interface in California. Cities Environ 4:12

Boyle CM (1960) Case of apparent resistance of Rattus norvegicus Berkenhout to anticoagulant poisons. Nature 188:517

Commonwealth of Massachusetts (2015) Integrated pest management. The official website of the executive office for administration and finance. http://www.mass.gov/anf/budget-taxes-and-procurement/procurement-info-and-res/procurement-prog-and-serv/epp-procurement-prog/green-products-and-serv/specific-epp-statewide-contracts/integrated-pest-management.html. Accessed 18 Feb 2016

Eason CT, Murphy EC, Wright GR, Spurr EB (2002) Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. Ecotoxicology 11:35–48

Huckle KR, Hutson DH, Warburton PA (1988) Elimination and accumulation of the rodenticide flocoumafen in rats following repeated oral administration. Xenobiotica 18:1465–1479

Hughes J, Sharp E, Taylor MJ, Melton L, Hartley G (2013) Monitoring agricultural rodenticide use and secondary exposure of raptors in Scotland. Ecotoxicology 22:974–984

Lambert O, Pouliquen H, Larhantec M, Thorin C, L'Hostis M (2007) Exposure of raptors and waterbirds to anticoagulant rodenticides (difenacoum, bromadiolone, coumatetralyl, coumafen, brodifacoum): epidemiological survey in Loire Atlantique (France). Bull Environ Contam Toxicol 79:91–94

Langford KH, Reid M, Thomas KV (2013) The occurrence of second generation anticoagulant rodenticides in non-target raptor species in Norway. Sci Total Environ 450:205–208

Leung LKP, Clark NM (2005) Bait avoidance and habitat use by the roof rat, Rattus rattus, in a piggery. Int Biodeterior Biodegradation 55:77–84

Liu J, Xiong K, Ye X, Zhang J, Yang Y, Ji L (2015) Toxicity and bioaccumulation of bromadiolone to earthworm Eisenia fetida. Chemosphere 135:250–256

Lund M (1972) Rodent resistance to the anticoagulant rodenticides, with particular reference to Denmark. Bull World Health Organ 47:611

Mcdonald RA, Harris S (2000) The use of fumigants and anticoagulant rodenticides on game estates in Great Britain. Mammal Rev 30:57–64

Mendenhall VM, Pank LF (1980) Secondary poisoning of owls by anticoagulant rodenticides. Wildl Soc Bull 8:311–315

Morzillo AT, Mertig AG (2011) Linking human behaviour to environmental effects using a case study of urban rodent control. Int J Environ Studies 68:107–123

Murray M, Tseng F (2008) Diagnosis and treatment of secondary anticoagulant rodenticide toxicosis in a red-tailed hawk (Buteo jamaicensis). J Avian Med Surg 22:41–46

Murray M (2011) Anticoagulant rodenticide exposure and toxicosis in four species of birds of prey presented to a wildlife clinic in Massachusetts, 2006-2010. J Zoo Wildl Med 42:88–97

Prichard A (2013) Memorandum: second generation anticoagulant rodenticide assessment. Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/registration/reevaluation/chemicals/brodifacoum_final_assess.pdf. Accessed 18 Feb 2016

Qualtrics LLC (2015) Qualtrics. http://www.qualtrics.com/. Accessed 18 Feb 2016

Radvanyi A, Weaver P, Massari C, Bird D, Broughtont E (1988) Effects of chlorophacinone on captive kestrels. Bull Environ Contam Toxicol 41:441–448

Rattner BA, Horak KE, Lazarus RS, Schultz SL, Knowles S, Abbo BG, Volker SF (2015) Toxicity reference values for chlorophacinone and their application for assessing anticoagulant rodenticide risk to raptors. Ecotoxicology 24:720–734

Ruiz-Suárez N, Henríquez-Hernández LA, Valerón PF, Boada LD, Zumbado M, Camacho M, Almeido-González M, Luzardo OP (2014) Assessment of anticoagulant rodenticide exposure in six raptor species from the Canary Islands (Spain). Sci Total Environ 485:371–376

Salim H, Noor HM, Hamid NH, Omar D, Kasim A, Abidin CMRZ (2014) Secondary poisoning of captive barn owls, Tyto alba javanica, through feeding with rats poisoned with chlorophacinone and bromadiolone. J Oil Palm Res 26:62–72

Savarie PJ, Hayes DJ, McBride RT, Roberts JD (1979) Efficacy and safety of diphacinone as a predacide. In: Kenaga EE (ed) Avian and Mammalian Wildlife Toxicology. STP 693 American Society for Testing and Materials, Philadelphia, PA, pp 69–79

Sarwar M (2015) The rodents (mammalia: rodentia)–gnawing away on crops and options for the integrated pest management at field. Am J Mark Res 1:136–141

Serieys LE, Armenta TC, Moriarty JG, Boydston EE, Lyren LM, Poppenga RH, Crooks KR, Wayne RK, Riley SPD (2015) Anticoagulant rodenticides in urban bobcats: exposure, risk factors and potential effects based on a 16-year study. Ecotoxicology 24:844–862

Smith RH, Cox PR, Rampaud M (1990) Rodenticide ecotoxicology: systems analysis and simulation. Proc Fourteenth Vertebrate Pest Conf 14:47–45

Stansley W, Cummings M, Vudathala D, Murphy LA (2014) Anticoagulant rodenticides in red-tailed hawks, Buteo jamaicensis, and great horned owls, Bubo virginianus, from New Jersey, USA, 2008–2010. Bull Environ Contam Toxicol 92:6–9

Stenseth NC, Leirs H, Skonhoft A, Davis SA, Pech RP, Andreassen HP et al. (2003) Mice, rats, and people: the bio-economics of agricultural rodent pests. Front Ecol Environ 1:367–375

Stone WB, Okoniewski JC, Stedelin JR (2003) Anticoagulant rodenticides and raptors: recent findings from New York, 1998–2001. Bull Environ Contam Toxicol 70:0034–0040

Tosh DG, Shore RF, Jess S, Withers A, Bearhop S, Montgomery WI, McDonald RA (2011) User behaviour, best practice and the risks of non-target exposure associated with anticoagulant rodenticide use. J Environ Manage 92:1503–1508

US Environmental Protection Agency, EPA (2008) Risk mitigation decision for ten rodenticides. USEPA Office of Prevention, Pesticides and Toxic Substances. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2006-0955-0764. Accessed 18 Feb 2016

Watt BE, Proudfoot AT, Bradberry SM, Vale JA (2005) Anticoagulant rodenticides. Toxicol Rev 24:259–269