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User behaviour, best practice and the risks of non-target exposure associated with anticoagulant rodenticide use

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ABSTRACT

Usage of anticoagulant rodenticides (ARs) is an integral component of modern agriculture and is essential for the control of commensal rodent populations. However, the extensive deployment of ARs has led to widespread exposure of a range of non-target predatory birds and mammals to some compounds, in particular the second-generation anticoagulant rodenticides (SGARs). As a result, there has been considerable effort placed into devising voluntary best practice guidelines that increase the efficacy of rodent control and reduce the risk of non-target exposure. Currently, there is limited published information on actual practice amongst users or implementation of best practice. We assessed the behaviour of a typical group of users using an on-farm questionnaire survey. Most baited for rodents every year using SGARs. Most respondents were apparently aware of the risks of non-target exposure and adhered to some of the best practice recommendations but total compliance was rare. Our questionnaire revealed that users of first generation anticoagulant rodenticides rarely protected or checked bait stations, and so took little effort to prevent primary exposure of non-targets. Users almost never searched for and removed poisoned carcasses and many baited for prolonged periods or permanently. These factors are all likely to enhance the likelihood of primary and secondary exposure of non-target species.

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1. Introduction

Commensal rodents contaminate and consume crops (Daniels et al., 2003; Stenseth et al., 2003), damage property through gnawing wires and cables (Leung and Clark, 2005) and act as vectors of human and animal diseases such as leptospirosis, trichinosis and salmonellosis (Daniels et al., 2003; Meerburg et al., 2009; Webster and Macdonald, 1995). The control of rodent populations is therefore common and widespread. It is a critical component of modern agricultural practice as farmers seek to prevent rodents spoiling and consuming animal feed and stored grain, damaging buildings and transmitting disease. In the developed world, the primary means of controlling rodent populations, and their impacts, is with anticoagulant rodenticides (ARs)(Stenseth et al., 2003). There are two generic groups of ARs, so called first and second-generation anticoagulant rodenticides (FGARs and SGARs). The latter are more acutely toxic and persistent than FGARs and were developed during the 1970s and 1980s to combat the emerging problem of resistance to FGARs (Rowe et al., 1981; Lund, 1988,). SGARs are now the primary means of controlling rodents in Great Britain (Dawson et al., 2001; Dawson and Garthwaite, 2003) and in many other regions (e.g. Eason et al., 2002).

SGARs can be a highly effective means of controlling rodent populations. Nonetheless, their use can also lead to the unintended exposure of non-target species (Berny et al., 1997; Stone et al., 2000; Fournier-Chambrillon et al., 2004). Exposure occurs either directly via consumption of bait (primary exposure) or indirectly when predators or scavengers consume an animal that has already been exposed (secondary exposure). In Britain, secondary exposure has been identified in a variety of non-target mammals and birds. Polecat (*Mustela putorius*), stoat (*M. erminea*), weasel (*M. nivalis*), red fox (*Vulpes vulpes*), hedgehog (*Erinaceous europeaus*), barn owl (*Tyto alba*), tawny owl (*Strix aluco*), kestrel (*Falco tinnunculus*), buzzard

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(*Buteo buteo*) and red kite (*Milvus milvus*) populations have all been found to be exposed to varying extents (Dowding et al., 2010; McDonald et al., 1998; Newton et al., 1999; Shore et al., 1996, 2003a,b, 2006a,b; Walker et al., 2007, 2008a,b). However, the effect of exposure on species at both the individual and population level remain poorly understood (Burn et al., 2002; Knopper et al., 2007).

The relationship between AR usage and secondary exposure of predatory birds and mammals is complex (Eason et al., 2002; Shore et al., 2006a). Factors that are likely to contribute to the risk of non-target exposure include the persistence and toxicity of the rodenticides, level of usage, and how and where they are used (Shore et al., 2003a,b, 2006a). In the United Kingdom (UK), voluntary and regulatory measures relating to AR usage have been introduced to reduce the level of risk to non-target wildlife. The measures include the promotion of voluntary best practice guidelines and the confinement of the more toxic and persistent SGARs, flocoumafen and brodifacoum, to use indoors. A number of guidelines are promoted by government and industry (Anonymous, 1999, 2001; Think Wildlife, 2005), and are designed to increase awareness of the risks associated with AR use and increase the efficiency of rodent control. Examples of best practice include bait protection, fixed duration of baiting campaigns followed by bait removal, and searches for and removal of poisoned carcasses (Anonymous, 1999, 2002). While overall levels of AR usage in Great Britain have been monitored in the past (for example, Dawson and Garthwaite, 2003) there are limited published data on end user behaviour (McDonald and Harris, 2000). The extent to which best practice guidelines are adhered to is unknown.

The objective of the current study was to use a questionnaire to determine how end-users applied ARs and whether they followed best practice guidelines designed to maximise efficacy and reduce the risk of non-target exposure. By gathering this information, we aimed to identify current usage practices that contribute to the risk of non-target exposure but which could be modified to mitigate such risks.

2. Methods

We conducted a survey of farmers in Northern Ireland (NI) in conjunction with a statutory biennial survey of pesticide use on farms. Farms were considered for survey if they reported in the Northern Ireland Agricultural Census, June 2005 (Anonymous, 2006) that they grew one of the following: barley, wheat, oats, oilseed rape, peas and beans, lupins or potatoes. The process of selecting the farms to be surveyed is detailed by Withers et al. (2006) and is described briefly here. Farms were first stratified into six size classes according to the total area of arable crops grown. Holdings were then selected at random within each of the size classes with the number of holdings being proportional to the total area of arable crops grown. A total of 273 farms were notified by letter that they had been selected to take part in the compulsory survey. Letters were followed up by personal interviews between November 2006 and April 2007. Farmers are obliged to take part in the statutory pesticide usage survey, but the additional questions on rodenticide usage were non-compulsory.

Prior to the main survey, a pilot study of ten farmers was used to improve the relevance and design of the questionnaire. This process resulted in a thirty-four question, closed format questionnaire, with contingency questions (Supplementary Information, Appendix I). This format of questionnaire was chosen as it provides a greater uniformity of responses and is easily processed (Babbie, 1990). Questions asked related to behaviours identified by best practice guidelines that reduce the risk of non-target exposure and increasing the efficiency of control (Anonymous, 1999, 2002; Think Wildlife, 2005). The main points were: maintenance of records (number of baiting points and quantity of bait used), protection of bait from non-target species, removal of bait at the end of treatment and searching for dead rodents at the end of treatment periods. In addition, we asked questions relating to usage (product used, period used). All responses are given as a percentage of the total number of questionnaires returned unless otherwise stated.

A multiple correspondence analysis (MCA) was used to analyse patterns in behaviour of respondents using ARs. An MCA was chosen due to its ability to analyse patterns of relationships for several categorical variables. The factors included in the model were: type of AR used (first or second-generation), period of use (periodic or permanent), location used (indoor or outdoor), protection of bait (yes or no), bait removed (yes or no), periodicity of bait checks (frequency), records kept of location used (yes or no), records of amount of bait used (yes or no), bait replenished (yes or no), training (level) and searches for dead rodents (yes or no). Strata size was initially included in the exploratory analysis for the MCA but did not help differentiate the responses and so was not included in the main analysis. Records with missing responses for the factors analysed were removed from the analysis. The number of dimensions was chosen based on examination of the contributory factors to each dimension. All statistical analyses were conducted using SPSS 17.0.0 (August 23rd, 2008).

3. Results

A total of 162 (59%) of the 273 farmers approached agreed to participate in the rodenticide survey. Information provided by 158 (57.9%) respondents was analysed as four forms were completed incorrectly. Of the 111 (41%) non-participating farms, 36 were asked to answer a reduced number of questions over the telephone but only two did so.

Most respondents ($n = 127$, 80%) undertook rodent control themselves but a few ($n = 10$, 6%) employed contractors. Only 21 (13%) did not use any chemical to control rodents. SGARs were most commonly used ($n = 117$, 74%) but a few respondents used FGARs ($n = 8$, 5%) or other rodenticides ($n = 3$, 2%). Seven (4%) respondents did not know what type of rodenticide they used. Rodent control was usually undertaken using one product but 9 (6%) respondents used two or three products together. The SGARs licensed for outdoor use, difenacoum and bromadiolone, were used by 54.5% of respondents and indoor products (flocoumafen and brodifacoum) by 19.6% (Table 1). The FGARs used were chlorophacinone and coumatetralyl (Table 1).

Two (1%) farmers had attended a training course on AR use, and 25 (15%) received instruction through a leaflet (Table 2). The majority ($n = 90$, 57%), though, relied on guidelines on the manufacturers' packaging.

Few respondents selectively applied ARs in years when rodents were considered to be a problem; the majority applied baits every year (Table 2). Most ($n = 91$, 58%) respondents applied baits over short periods, typically four months or less (Fig. 1a) with few

Table 1
Percentage of respondents ($n = 158$) using different anticoagulant rodenticide products. Nine farmers used more than one AR (seven used two ARs and two used three ARs in combination). No Warfarin use was recorded.

Anticoagulant	N	% of total respondents
Difenacoum	52	33.0
Bromadiolone	34	21.5
Flocoumafen	25	15.8
Brodifacoum	6	3.8
Chlorophacinone	5	3.2
Coumatetralyl	4	2.5

Table 2
Proportion of adherence to best practice guidelines among survey respondents who answered the key questions relating to best practice. Single responses (yes or no) were only possible to these questions.

Question	Total responses	Yes	No
Has the farmer received instruction on how to use rodenticides?	123	118 (95.9%)	5 (4.1%)
Is the number of bait points and amount of bait laid recorded?	126	14 (11.1%)	112 (88.9%)
Are bait points checked?	125	118 (94.4%)	7 (5.6%)
Is bait protected from being eaten by other animals?	123	114 (92.7%)	9 (7.3%)
Is bait removed once an infestation has declined?	120	36 (30.0%)	84 (70.0%)
Is a search for dead rodents made following baiting?	120	1 (0.8%)	119 (99.2%)

baiting the entire year (Fig. 1a and b). Use varied seasonally, and peak usage was during autumn and winter (Fig. 1b).

Baits were applied within buildings by 68% of respondents and outside buildings by 48%. When used outside, baits were used mainly around buildings i.e. within the vicinity of the farm, although 10% ($n = 16$) applied bait away from buildings in fields or hedges. Products that were licensed for indoor use only (flocoumafen, brodifacoum) were also used around the outside of buildings by 12% of farmers and away from buildings in fields or hedges by 3% of respondents. Most respondents did not keep records of where baits were used and those that did were most likely to bait permanently (Table 2), and some ($n = 26$, 16%) did not know how much bait they used in a year.

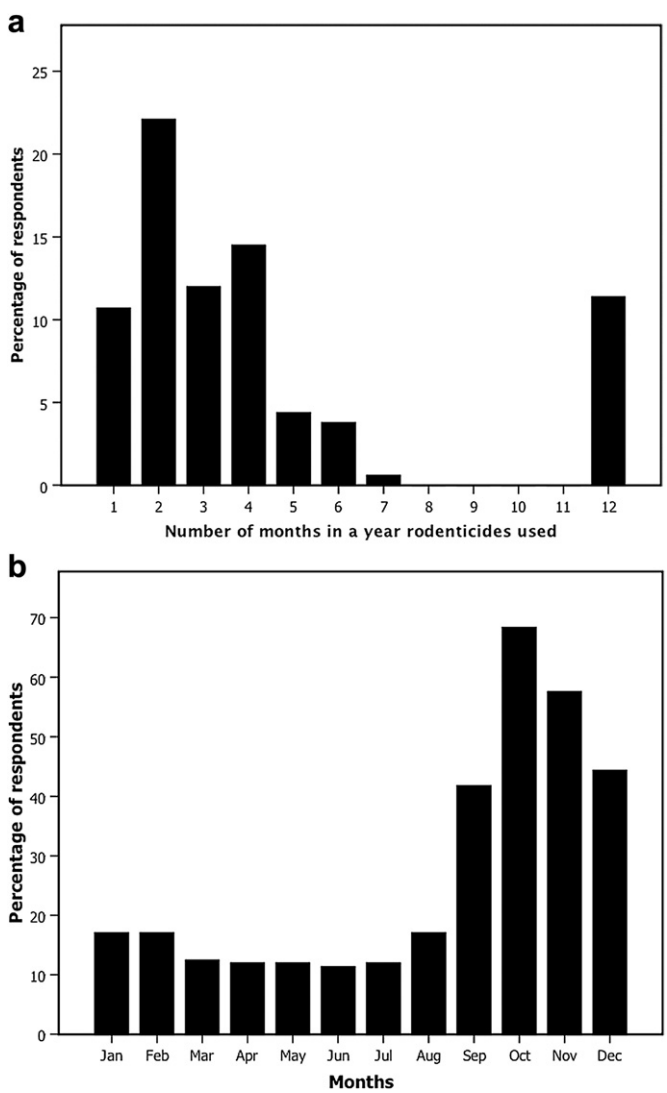

Fig. 1. Temporal variation in rodenticide usage among farmers. a) The typical number of months in a year that baits are applied by anticoagulant rodenticide users b) the percentage of anticoagulant rodenticide users ($n = 118$) that apply baits in each month of the year.

Despite the general lack of record keeping, baiting points were usually checked. Frequency of checks depended on the type of product used and the period over which baits were deployed (Table 2). FGAR users were less likely to check baits than SGAR users but the frequency of checks was highly variable. Half of respondents checked baits weekly but the frequency of checks varied on the duration of usage. Checks by permanent baiters were conducted either daily or fortnightly while periodic users (the bulk of respondents) checked baits weekly. Although bait was typically protected from non-target species (Table 2), this was less common amongst FGAR than SGAR users. Tubes or pipes ($n = 44$) were most commonly used to protect baits followed by bait boxes ($n = 30$) and a piece of wood/tile/glass ($n = 27$). Following treatment, bait was removed by over a third of respondents (Table 2), but baits were less likely to be removed by farmers that baited for prolonged periods. Only one user reported conducting a search for dead rodents following initiation of treatment but half of respondents ($n = 79$) reported finding dead animals without actively searching.

A total of 118 of the 127 respondents that used ARs answered all questions relating to best practice. Therefore, only responses from this group were included in the MCA. The factors, searching and training, were not included in the analysis as almost none of the respondents conducted searches and most had received no training other than the guidance on the product label (Table 2). In addition, replenishment of bait and records of amount of bait used were highly correlated (positively) with periodicity of checks and records of location of use respectively. Therefore, the latter were only included in the final analysis. Patterns in user behaviour were best explained by two dimensions in the MCA (Fig. 2a). The first dimension was most strongly characterised by the factors "Type of AR" (ie FGAR or SGAR), "bait protection" and "periodicity of checks", while the best discriminated responses in the second dimension were "periodicity of checks", "period used", "and "bait removed". The joint category plot (Fig. 2b) identified which categories were associated with each other (close together in the plot) and proximity to the origin was positively related to the number of respondents giving that response. It was evident from dimension 1 that most AR users apply SGAR baits (termed 2nd in the figure), protect them and check them weekly. In contrast, FGAR baits (1st) are used less often, are never checked and are not protected. Dimension 2 identified that the longer baits are used, the more variable checks become.

4. Discussion

By conducting an on-farm survey, we were able to obtain an outline pattern of rodenticide usage by a sample of farmers. Although our inability to engage non-respondents and determine their behaviour may have introduced some bias, as non-respondents can display different behaviours to respondents (White et al., 2005), our overall response rate was within acceptable limits for analysis (59%) (Babbie, 1990). Furthermore, the responses were credible with respect to the limited existing data on levels of rodenticide usage elsewhere in the UK (Dawson and Garthwaite, 2003; Dawson et al., 2001). Thus, this is the first published survey to document how the behaviour of end-users influences potential

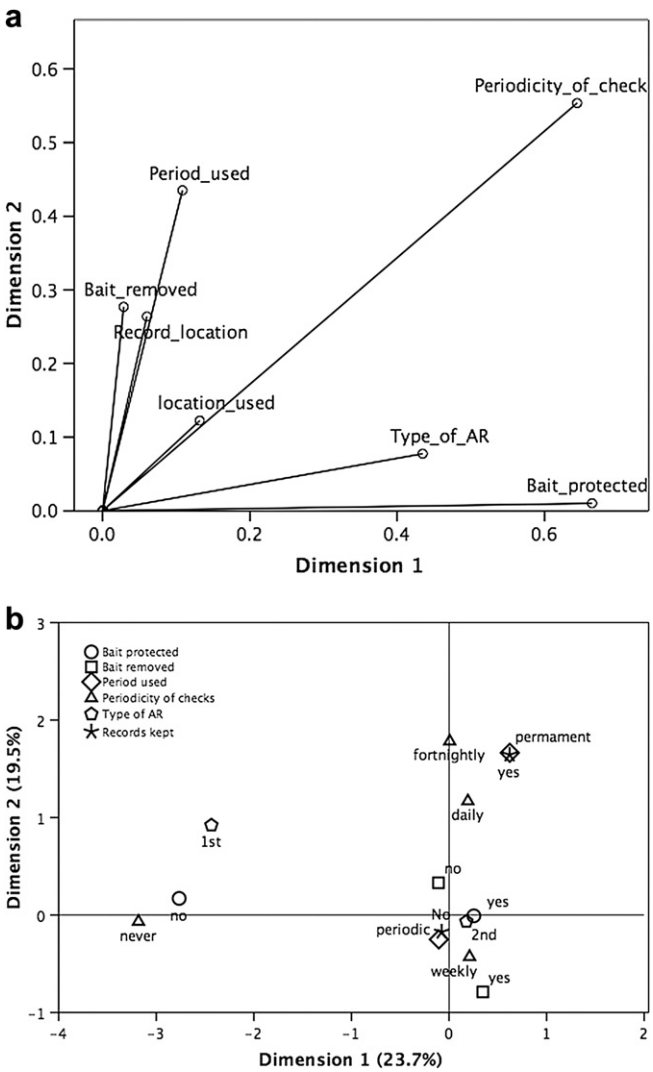

Fig. 2. a) Discrimination measure plot and b) joint category plot for a multiple correspondence analysis of behavioural traits amongst anticoagulant rodenticide users. *The amounts of variation explained by the two dimensions in the MCA are stated in the figure axes.*

risk to non-targets. It is also the first survey of rodenticide use in Northern Ireland; all previous surveys only covered Britain.

Most farmers used ARs every year as a means of preventing rodent infestations but a small proportion reported only using baits in years when rodents were perceived to be a problem. Farmers that bait every year appear to fall into two groups, permanent and periodic baiters. Periodic baiters use ARs for part of the year and are categorised by a high variation in the frequency with which they check bait stations, poor record keeping and baiting periods that extend beyond the 4–5 weeks recommended for controlling infestations (Anonymous, 1999, 2002). In contrast, permanent baiters apply ARs throughout the year, regularly check bait points and maintain records. The majority of permanent baiters do this apparently in response to the requirements of customers who specify that rodent control is practiced by suppliers. However, permanent baiting contravenes best practice recommendations, partly because it increases the risk of non-target exposure (Anonymous, 2001, 2002). Therefore, consumer requirements, combined with the failure of many periodic users to remove ARs following periods of treatment, extend the availability of baits to well beyond the autumn and winter period of peak rodenticide use. This may in part explain why ARs are detected in non-target wildlife at all times of the year and why exposure is not restricted to periods of peak AR use (Shore et al., 2003a).

If baits are not removed, or if baiting is permanent, the risk of primary non-target exposure can potentially be reduced by protecting baits. Most farmers protect bait from non-targets but FGAR users are less likely to do so than SGAR users. Although the risk of non-target primary exposure is likely to be low in NI because FGAR use is uncommon, this may not be the case in Great Britain where nearly a quarter of farmers use FGARs (Dawson et al., 2001). Although FGARS are less acutely toxic than SGARs, they are still toxic to most vertebrates and direct consumption can lead to death (Fisher et al., 2003; Mendenhall and Pank, 1980). It is unclear if FGAR users do not protect bait because of a lack of awareness of the hazards of these rodenticides, but our results suggest that promotion of best practice may need to highlight that FGARs, as well as SGARs, present a risk to non-target species.

Despite widespread protection of SGAR baits, the risk of secondary exposure resulting from the scavenging of poisoned rodent carcasses is likely to be significant. This is because the results from our survey suggest that farmers rarely search for and remove carcasses, but many often see dead rodents on their farms. Furthermore, the number of dead rodents that farmers note from their casual observations is likely to be a fraction of the true number as many carcasses will be scavenged quickly and not be seen. The widespread exposure to rodenticides of scavengers, such as the red kite (Walker et al., 2008a), is consistent with the idea that scavenged carcasses are likely to be a significant exposure pathway for scavenging birds and mammals. Searches for poisoned rodents and removal of their carcasses are essential if secondary poisoning via scavenging is to be minimised.

Due to the longer half-lives of SGARs compared with FGARs, extensive usage of more persistent ARs potentially enhances the risk of secondary poisoning (Eason et al., 2002; Wyllie, 1995). The unexpectedly high level of flocoumafen use in NI increases the risks to non-targets from AR use compared to other regions of the UK, especially as this compound is more toxic and persistent than any of the other SGARs available in the UK (Fisher et al., 2003; Parmar et al., 1987). We suggest that a greater availability or marketing of flocoumafen based ARs explains their greater level of use in NI rather than a general preference of farmers towards the most toxic ARs. Flocoumafen use elsewhere in the UK is relatively low (Dawson et al., 2001; Olney et al., 1991; Thomas and Wild, 1996) and it is rarely detected in predatory birds and mammals (Shore et al., 2003a,b; Walker et al., 2007, 2008a,b). Given the greater use of flocoumafen in NI, we would predict that there would be greater exposure to flocoumafen in predatory birds and mammals in NI than elsewhere in the UK though whether this would result in a greater occurrence of mortalities is unknown.

Despite apparent variable adherence to best practice amongst users in our survey, the extent of misuse appears to be low and is comparable to elsewhere in the UK. In NI, misuse in part may arise from the greater availability, and use of, flocoumafen in the Republic of Ireland (RoI) (Eadsforth et al., 1996; Dawson et al., 2001; McDonald and Harris, 2000). At present, there are no restrictions on flocoumafen and brodifacoum use in RoI and labelling does not carry the same restrictions as in the UK, where these compounds are restricted to indoor use only. As our survey suggests that most users obtain guidance on use from the manufacturers' guidelines, misuse amongst users who purchase ARs from the RoI may result from a lack of awareness of restrictions that apply to the UK. Addressing the labelling and sale of these products to farmers in Northern Ireland may therefore reduce such misuse.

Despite low awareness of best practice campaigns (CAIP, 2009), it is unlikely that low awareness alone explains the variable adherence recorded. Most farmers employ at least one element of

best practice that suggests farmers already recognise the need to bait efficiently and protect wildlife but other factors are preventing total adherence. The time required to bait correctly may be the largest obstacle as rodent control is labour intensive (Anonymous, 2009). Lack of time is already recognised as part of the many pressures of farm management and consequently rodent control may not be a priority for many (Parry et al., 2005). A preventative approach to baiting may also be a symptom of the inability of farmers to dedicate the time needed to control infestations, even though such practices may have poor efficacy, waste money and increase selection pressure for resistance (Cowan et al., 1995). Clearly, there is a need to improve awareness and uptake of usage practices amongst farmers to reduce both the risk to non-target species and enhance the efficacy of rodent control. However, any campaigns designed to achieve this may also need to focus on demonstrating how best practice can be achieved in a timely manner and the financial benefits this will construe.

5. Conclusions

The results of our study suggest that, despite the availability of best practice guidelines for ARs, the uptake of such practice is heterogeneous amongst farmers. Many farmers in our survey carried out baiting in a manner that potentially increased the risk of exposure of non-target wildlife species. Low awareness of best practice may in part explain this, suggesting that there is a continuing need for promotion schemes, such as the Campaign for Responsible Rodenticide Use. However, it is also important that reasons for low adherence to best practice are clearly identified if such campaigns are to be successful.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jenvman.2010.12.014.

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