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POISONING MAMMALIAN PESTS CAN HAVE UNINTENDED CONSEQUENCES FOR FUTURE CONTROL: TWO CASE STUDIES

Summary: Vertebrate pest control operations using toxic baits can have unintended consequences for non-target species, some of which may themselves be pests. Learned avoidance behaviour (termed 'aversion') can be induced by sublethal dosing, which can arise when species with high and low susceptibilities to a toxin co-exist in the same area. In such cases the less-susceptible species (e.g., possums *Trichosurus vulpecula*) may be sublethally poisoned by control work targeting the more-susceptible species (e.g., rabbits *Oryctolagus cuniculus*). A case study of rabbit control on North Canterbury farmland is presented to demonstrate this effect. When control is being repeated at frequent intervals, it is prudent to vary the control methods used. Nevertheless, aversion induced by the use of one toxic bait (e.g., cyanide paste) can in some situations 'generalise' so that the efficacy of control using other toxins (e.g., 1080 and cholecalciferol in cereal baits) is also compromised. A case study of initial and follow-up possum control in four discrete areas of Canterbury forest provides an example of this problem. The implications of these findings for future pest management in New Zealand are discussed.

Keywords: Rabbits; brushtail possums; toxins; bait shyness; conditioned taste aversion.

Introduction

The potential for development of learned and innate behavioural resistance to toxins and baits is an important consideration for managers aiming for sustained control of vertebrate pests (Hickling, 1994). Learned avoidance behaviour (termed 'aversion') typically arises when an animal associates the sensory aspects of the toxic bait (e.g., taste or smell) with ill-effects of a sub-lethal dose of the toxin (Gustavson, 1977). Sublethal dosing arising from poor baiting practices or other operational problems can be minimised through good planning and management (Morgan, 1994). Managers are increasingly aware that over-reliance on a single control technique is unwise and that strategies such as 'bait switching' and use of alternative toxins need to be considered (Morgan, Morriss and Hickling, 1996; Ross, Hickling and Morgan, 1997). This paper reinforces these concerns by documenting two additional unintended consequences of toxin-based control – one involving cross-species impacts and the other involving cross-toxin effects.

Cross-species impacts

This type of problem arises when several pest species with differing susceptibilities to a toxin co-exist in an area where poisoning is done. During an operation that targets a susceptible species, another, less susceptible species can be poisoned at a sublethal level. The presence on New Zealand farmland of rabbits (*Oryctolagus cuniculus* L.) as agricultural pests, and possums (*Trichosurus vulpecula* Kerr) as conservation pests and disease reservoirs, provides an example of this 'cross-species' problem. Both species are typically targeted by control operations using sodium monofluoroacetate (1080) baits. Possums' LD_{50} to this toxin (1.5 mg kg^{-1} body weight; Morgan, *et al.,* 1986), however, is at least three times higher than that of rabbits (0.4 mg kg^{-1}; McIlroy, 1982). Moreover, possums are larger than rabbits (averaging 2.5 and 1.5 kg, respectively) so there is a 5- to 6-fold difference in the amount of toxin needed for a lethal dose for the two species.

Rabbit control in New Zealand is usually done with carrot baits containing 0.02% or 0.04% 1080, whereas possum control operations use baits containing 0.08% or 0.15% of that toxin. Low-strength baits are a known cause of poor possum kills (Morgan *et al.,* 1986) so we predicted that (i) many possums in rabbit control areas survive such operations, and (ii) surviving possums may subsequently develop aversion to 1080 baits and become difficult to control through typical 1080-based control operations. In winter 1996 we monitored a rabbit control operation in North Canterbury to test these predictions.

Cross-toxin impacts

Considerable recent research has focussed on the consequences of possums eating sublethal amounts of cereal bait containing 1080 (Morgan *et al*., 1996; O'Connor and Matthews, 1996; Ogilvie *et al.,* 1996; Ross *et al*., 1997; Henderson, Morriss and Morgan, 1997; Moss, O'Connor and Hickling, 1998). In contrast, the consequences of possums being sublethally poisoned by cyanide are less well known. Some possums avoid eating baits that emit cyanide gas and may be innately averse to the smell of this toxin (Warburton and Drew, 1994). Captive possums can also develop dose-dependent aversions to cyanide baits after ingesting sublethal amounts (O'Connor and Matthews, 1995).

In some situations, aversion to one toxin or bait material can 'generalise' to others (e.g., Robbins, 1980). It is therefore possible that aversion to toxic bait used for initial control (e.g., cyanide paste) could trigger aversion to another toxin used subsequently (e.g., cereal pellets containing 1080). Conflicting anecdotal reports exist on whether sublethal cyanide poisoning has any adverse impact on subsequent possum control work. No effect has been reported in some regions, but in others (e.g., Taranaki and Otago) kills with cereal baits have been poor in areas where cyanide was used previously (G. Gallop and R. Allen, *pers. comm.*). We therefore undertook a pilot trial to assess the short-term effects of sub-lethal exposure to cyanide on the efficacy of subsequent control using cereal baits containing 1080 or cholecalciferol.

Methods

Cross-species impacts: rabbit control and farmland possums

In June 1996 the Canterbury Regional Council (CRC) undertook aerial control of rabbits on a 360 ha block of hilly farmland in North Canterbury. A fixed-wing aircraft was used to spread plain carrot bait over the area on two occasions to prefeed the rabbits and then to spread 5-10 kg ha^{-1} of toxic carrot bait to poison them. The toxic bait contained 0.02% 1080 toxin, was dyed green and contained no lure additive. Weather conditions were favorable throughout the operation.

The impact of the poisoning on possum numbers in the area was assessed in two ways: using trap-catch indices and by monitoring the survival of radio-tagged possums. Before the poison drop, eight trap-lines of 15 'Softcatch' leg-hold traps were placed in the 'poison' block in a range of habitats and operated for three nights with favourable weather. All possums caught were tagged and released without significant injury. Five additional trap-lines were monitored in similar habitat in a 'non-treatment' block 3 km away. Two weeks after the poison drop the 13 lines were reopened for a further 3 nights. In addition, 18 possums in the poison block and 8 in the non-treatment block were fitted with radiotransmitters. Radiotracking was undertaken for one week before and for a further week one month after the rabbit control. Live possums and carcasses were located by ground search using a combination of triangulation and close-approach methods (Samuel and Fuller, 1994). Pre- and post-control trap catch rates (adjusted for sprung traps and non-target captures) and mortality of the radio-collared possums were compared for the two areas.

The level of bait aversion among surviving possums was assessed in the field by comparing the consumption of plain maize and green-dyed (Bayer V200 dye at 100 ml kg^{-1}) carrot baits from 9 pairs of bait feeders placed in the poison and non-treatment areas 6 months after the control operation. Pairs of stations were attached to trees at a minimum 100 m spacing, and the amount of each bait type consumed was measured (±2 g) after one week and then daily for three consecutive days. Mean daily consumption of each bait type in the two areas was then compared.

At the same time, direct nocturnal observations were made of possums feeding on toxic carrot, non-toxic carrot and non-toxic cereal bait in the two areas. Possums were attracted to various potential observation sites (all >500 m from the paired stations described above) in each area using plain maize in bait stations. The 10 sites with greatest possum activity where selected for observation. On the afternoon before each observation session, the maize station was replaced with six short wooden stakes spaced 60 cm apart. Each stake supported 3 g of one of three bait treatments in random order: (i) non-lured, green-dyed 0.02% carrot pieces; (ii) non-lured, green-dyed non-toxic carrot pieces; and (iii) undyed non-toxic RS5 cereal pellets containing 1.0% cinnamon oil as a lure.

Direct observation of the stakes from a distance of 30 m, using a infrared scope and spotlight, began 30 min after sunset and continued until midnight. The behaviour of each possum when it first encountered the stakes, and the amount of each bait that it consumed (±0.1 g), were recorded. Size and fur colour were used to distinguish newly-arriving possums. When we were unsure that a possum was making its first visit the data gathered on it were omitted from the analysis. The relative numbers of possums that fed on the various bait types were compared between poison and non-treatment areas. This trial is described in more detail in Thomas (1997).

Cross-toxin impacts

Four field sites of 15 to 40 ha were established in discrete forestry plantations on the Canterbury plains (Boulder Park) and in remnant stands of native seral/ mixed hardwood forest on Banks Peninsula (Okuti and Kinloch 1 and 2). Between December 1996 and August 1997, 'pre-poison' possum abundance was assessed at each site by setting 100 Victor leg-hold traps that allowed possums to be caught, eartagged and released without significant injury. Traps were set at 20-30 m intervals at sites where they were likely to catch possums and spaced so that there were no more than 7 traps ha^{-1}. The percentage of traps catching possums over two fine nights was used as an index of relative possum abundance at each site (Warburton, 1996).

Initial control at each site was undertaken by prefeeding for 3 nights with a 10:1 mix of flour and icing sugar that contained 0.1% cinnamon oil, and then poisoning for a further 3 nights with cyanide paste (Trappers' Cyanide Co., Christchurch). The prefeed and toxic paste were spaced at approximately 5 m intervals along lines spaced 100 m apart. After poisoning the baits were destroyed by burying them and the surrounding area was searched thoroughly to locate possum carcasses. The original trapsites were then retrapped, using the same procedure as before, to estimate 'post-cyanide'possum abundance.

Follow-up control was undertaken using 'Sentry' bait stations attached to trees at 70-100 m intervals (i.e., 1-1.5 stations ha^{-1}) and filled with 200 g of toxic cereal bait. At two sites RS5 baits with a nominal concentration of 0.15% 1080 were presented 7-8 days after cyanide control. At the other two sites cholecalciferol baits (nominal concentration 0.8%) were presented 5 days or 25 days after cyanide control. The amount of cereal bait eaten was recorded weekly for 5 weeks and compared with previous bait consumption data for naive and shy possum populations baited in the same manner in similar habitats where there had been no recent use of cyanide (Henderson *et al*., 1997). The same sites were then retrapped for a third time to estimate 'post-cereal' possum abundance.

At two of the sites, we compared the proportions of ear-tagged possums caught before and after the follow-up cereal control to assess whether immigration of unmarked possums into the poison areas could have biased the kill estimates that we calculated from the change in bait take.

Results

Cross-species impacts

Spotlight counts before and after rabbit control indicated a high (>95%) kill of rabbits (unpublished CRC data). Pre-control catch rates of 13.2 and 13.4 possums per 100 trap-nights for the poison and non-treatment blocks fell to 9.8 and 11.3, respectively. This indicated that 12% (S.E. = 7%) of the possum population was killed.

Of the 18 radio-collared possums in the rabbit poison area, 10 (56%) were alive one month after control, whereas on the non-treatment area 7 of 8 (88%) had survived. This provided a kill estimate of 37% (S.E. = 8%). Five carcasses in the poison area were still relatively intact when found; all had large amounts of dyed carrot (range 25 – 47 g dry mass) in their gut.

Over a 3-night feeding period, 6 months later, similar amounts of maize (2.7 kg) and carrot (2.1 kg) were consumed by possums in the non-treatment area, compared with 2.5 kg of maize and only 0.5 kg of carrot in the poison area. When analysed on a per-station basis (Table 1) the relative consumption of the two bait types differed significantly between the two areas (two sample *t*-test; $t = 2.61$, d.f. = 16, $P = 0.019$) indicating that possums in the area subjected to poisoning avoided the carrot bait.

Observations made of 11 different possums feeding in the poison area and of 12 in the non-treatment area confirmed the existance of bait avoidance behaviour. Three and four possums, respectively, avoided eating any bait from the stakes and were scored as 'cautious' feeders. Six of the

Table 1: *Mean daily bait consumption* (±S.E.) *of two bait types from paired bait stations in the poison and non-treatment areas.*

Area	N	Consumption (g $station^{-1}$ day^{-1}) Maize	Carrot	Carrot:maize ratio
Poison	9	72.4 ± 22.5	13.3 ± 4.9	0.40 ± 0.16
Non-treatment	9	102.7 ± 13.5	90.6 ± 12.5	0.91 ± 0.10

remaining eight possums in the poison area avoided only the carrot baits, compared with only one of eight in the non-treatment area. This difference was statistically significant in a 1-tailed test Fisher Exact test ($P = 0.02$).

Cross-toxin impacts

Pre-poisoning catches were 22 - 45 possums per 100 trap nights, which was adequate for application of the 2-night catch index technique (Warburton, 1996). Cyanide paste was moderately effective (60 - 84% kill) in reducing possum abundance at the four sites. However, five weeks of follow-up control with toxic cereal baits was completely ineffective, as no additional kill was apparent at any site (Table 2).

This pilot trial did not directly incorporate 'non-treatment' sites where cereal control was assessed in areas where cyanide had not been used. Nevertheless, these data are in marked contrast to the outcomes of numerous cereal-baiting trials undertaken recently in similar Canterbury habitats (e.g., 82% mean kill for five cholecalciferol trials and 87% mean kill for five 1080 trials; Henderson *et al.,* 1997).

At Okuti and Boulder Park, 40 percent of 43 possums trapped after the initial cyanide control had eartags, which did not differ significantly from 31 percent of 52 possums having tags when trapped after the subsequent cereal poisoning ($\chi^2 = 0.8$, d.f. = 1, $P = 0.37$). This indicated that the kill estimates were not being confounded by any substantial immigration of possums into the study sites during the 5 weeks of cereal baiting.

During the 5 weeks of follow-up control, modest amounts of cereal bait (18g ha^{-1} of 1080 bait and 33g ha^{-1} of cholecalciferol bait) were consumed at the bait stations. These rates were similar to those recorded previously for bait-shy populations (35 g ha^{-1} for cholecalciferol bait in Henderson *et al.,* 1997) and lower than rates for naive populations (39 g ha^{-1} for 1080 bait and 88 g ha^{-1} for cholecalciferol bait in Henderson *et al.,* 1997). Since no significant mortality was recorded, it appears that small sublethal amounts of bait were consumed by many possums, rather than large amounts by a few.

Discussion

Cross-species impacts

The North Canterbury study confirms prior speculation (Hickling, 1994) that a 0.02% 1080 carrot-based control operation can be highly successful in controlling rabbits and yet leave the resident possum population largely intact. The two kill estimates we obtained for possums in the present study were both low (and consequently imprecise). They did not differ statistically so we suggest that their average (25%) is a reasonable estimate for the incidental possum kill that occurred during this rabbit control operation.

Morgan *et al.* (1996) demonstrated a relationship between sublethal dose level and the proportion of possums becoming averse. Their work predicts that a control operation providing, on average, an LD_{25} dose for possums should be very effective in generating aversion among survivors. Our field trial confirmed this; 6 months after the control work, most of the possums in the poisoned area refused carrot bait even when it was not toxic. This effect may prove to be persistent as individual possums can retain aversions for several years (O'Connor and Matthews, 1997). The main

Table 2: *Change in possum trap-catch, mean percentage kills, and measured toxin concentrations at four field sites after 3 nights of initial control with sodium cyanide paste and 5 weeks of follow-up control with toxic cereal pellets. The follow-up work began 5-25 days after the cyanide baits were destroyed; toxin concentrations were measured by the Landcare Research toxicology laboratory.*

Site	Catch per 100 trap-nights				
	Pre-cyanide	Post-cyanide[1]	Post-cereal	Toxin	Concentration (%)
Kinloch 1	45	12	12	1080	0.19
Kinloch 2	22	4	4	1080	0.19
Okuti	24	5	9	Cholecalciferol	0.70
Boulder Park	42	17	18	Cholecalciferol	0.83
Mean % kill (± S.E.)			75 ± 6		-20 ± 20[2]
Significance of change[3]			$P < 0.001$		$P = 0.35$

[1]the measured cyanide concentration of the baits used in the the four areas was 45-52%
[2]this negative value indicates that the trap-catch index increased after control
[3]assessed using a Student's one-sample *t*-test

mechanisms for loss of aversion in the population are likely to be natural mortality and recruitment (both of which are slower processes for long-lived possums than for rabbits or rodents).

There are at least two possible strategies for combating the kind of aversion problem evident at the North Canterbury poison site. Moss *et al*. (1998) suggested that shyness can be largely avoided if a pest population is prefed with bait that very closely mimics the intended toxic bait. Doing this apparently inhibits aversion because it reduces the *novel* cues with which possums associate their toxin-induced ill effects. It might, therefore, be useful to add green dye to the non-toxic carrot used to prefeed rabbits in areas where possums are also a problem species.

If this strategy is considered overly costly, or otherwise inconvenient, an alternative would be to accept that shyness will arise among possums that survive rabbit control operations and undertake follow-up work to target these individuals using alternative slow-acting toxins in new bait formulations (Henderson *et al,*. 1997, Ross *et al.,* 1997). The relative merits of these two approaches, and the most cost-effective means by which each can be applied, are the subject of ongoing experiments. Meanwhile, pest managers need to consider the bait shyness problem identified in the present study when planning new poison operations on farmland.

Cross-toxin impacts

Cyanide paste provided moderately effective possum control in our replicate trial areas, but the possums that survived the cyanide control survived subsequent exposure to cereal-based 1080 (an acute-acting toxicant) or cholecalciferol (a sub-acute toxicant) for at least 2 months thereafter. Since possums' aversions can be very persistent (see above) such control may continue to be unsuccessful for a considerable, although as yet undefined, period.

Behavioural resistance to eating toxic bait can arise from either innate or learned mechanisms (Hickling, 1994). Warburton and Drew (1994) concluded that 12-54 % of possums in Canterbury forests had innate avoidance to the odour of cyanide that led them to survive poisoning with cyanide paste baits. To date no studies have detected more than 10 % innate avoidance when possums are first exposed to cereal baits containing 1080 or cholecalciferol (Morgan 1990). Furthermore, Henderson *et al*. (1997) achieved high kill percentages with these baits when they were in habitat that was similar to our study areas but which had not been recently poisoned with cyanide. Therefore, while it is possible that sporadic poisoning within our four areas in previous years could have selected for possums with high levels of innate toxin aversion, we do not consider this likely.

Possums can develop learned aversions after injesting sublethal doses of cyanide paste. In two-choice feeding trials with captive possums, 44-66% of individuals developed such aversion (O'Connor and Matthews, 1995). Learned aversion to 1080 cereal baits affects similar proportions of possum populations (34 - 82% depending on dose; Morgan *et al.,* 1996). Consequently, we suggest that our follow-up control failed because many of the survivors of the initial control work received a sublethal dose of cyanide, which not only induced a learned aversion to the cyanide paste but also caused possums to exhibit 'enhanced neophobia' (*sensu* O'Connor and Matthews, 1996). This led them to feed cautiously on the cereal bait (note the lower-then-expected take of cereal bait that we recorded) so that they consumed a sublethal dose for a *second* time, this time of toxic cereal bait.

This hypothesis requires confirmation – for example by monitoring bait consumption of individual possums. If it proves correct, it implies that the surviving possums (which would have been dosed with two toxins and two baits) would be exceedingly resistant to further toxin-based control. We predict that 'bait-switching', which can overcome possums' learned aversion to 1080 (Morgan *et al.,* 1996, Ross *et al.,* 1997), would be ineffective on such possums and that different methods, for example trapping, would have to be employed. Slow-acting anticoagulant toxins (e.g., brodifacoum) may also remain effective on such possums (Henderson *et al*., 1997, Ross *et al*., 1997).

The management implications of cyanide-induced aversion to other toxic baits will depend on the persistence of this form of 'bait shyness' and whether the problem affects other possum populations. Cyanide paste is a useful toxic bait for possum control because it can achieve moderate to high kills, is relatively target-specific, inexpensive and simple to use, and permits the recovery of fur and carcasses for post-mortem. The new Feratox® formulation of cyanide is also weather-resistant and has reduced cyanide odour. Given that sub-lethal cyanide poisoning may promote generalized aversion to other bait types, it is important that the observations and hypotheses presented here be investigated further so that sound strategies for the use of cyanide-based products can be developed.

Conclusion

The past decade has seen major increases in the extent and frequency of possum control operations in many parts of New Zealand (Parliamentary

Commissioner for the Environment, 1994). Despite the recent intoduction and spread of rabbit calicivirus disease, it seems inevitable that rabbit poisoning campaigns will continue. The two case studies reported here highlight the importance of developing medium- and long-term strategies for the application of toxins for vertebrate pest control. Pest control managers need to maintain records of their control work and to share these with other managers working on the same or adjacent land. A centralised database that maintained records of the geographic boundaries, timing and baiting strategies employed in all pest control operations could be a worthwhile national initiative towards achieving this goal.

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