New Zealand Journal of Zoology, 2004, Vol. 31: 271–282

0301–4223/04/3104–0271

Enhancing maintenance control of possum populations using long-life baits

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Abstract Possum populations must be maintained at very low density if the aims of Tb eradication and conservation of particularly vulnerable native species are to be met. The present tactic of initial "knockdown" followed by annual maintenance control allows for reinfestation in between annual operations. Development of toxic baiting methods for "continuous" control of possum populations is therefore desirable. Six bait-type/presentation-methods designed for prolonged field life were exposed to field conditions at a forest edge site in Westland. Samples of baits were collected at 2-monthly intervals for up to 26 months, and assessed for palatability to possums and toxicant concentration. Regression analysis was used to predict the time at which reductions in palatability and toxicity would make the bait ineffective. Field life varied between 2 and >26 months. The most durable option tested was a solid gel bait containing cholecalciferol and presented in a purpose-designed bait station. This option was selected for assessment in continuous control of possums in forest-edge habitat in Westland. Baits were placed up trees beyond the reach of livestock and left in place for 10 months. Trap-catch monitoring showed these baits did reduce the number of possums, but only after improving the visibility, attractiveness, and accessibility of bait stations. As the study predicted that cholecalciferol gel bait should remain effective for >2 years in the field, there appears to be considerable potential for improving the efficiency (and probably environmental safety) of long-term control using this new tool.

Keywords possum; *Trichosurus vulpecula*; pest control; baits; bait palatability; 1080; cholecalciferol; brodifacoum; cyanide

Z03042; Online publication date 24 November 2004
Received 10 December 2003; accepted 12 July 2004

INTRODUCTION

Populations of the introduced brushtail possum (*Trichosurus vulpecula*) are presently managed to reduce their transmission of bovine Tb (Coleman & Caley 2000), damage to native flora (Payton 2000) and fauna (Sadleir 2000), and impacts on primary production (Butcher 2000). While the direct cost of production losses has been estimated at around $40 million per annum (Hackwell & Bertram 1999), even greater concern is focused on the potential losses to beef, dairy, and venison exports valued at $9.6 billion in 2001 (Game Industry Board 2002; Meat New Zealand 2002). These are estimated to be at 20% risk of suffering an annual reduction by $1.3 billion if New Zealand is unable to attain and then sustain a prevalence of <0.2% Tb infection in the national herds (Animal Health Board 2001). These threats have placed the possum among the most serious of vertebrate pests faced by any country, justifying present expenditure of $89 million per annum in control and associated research (National Science Strategy Committee 2002).

The most common strategy currently used for reducing possum impacts entails initial "knockdown" control of possum populations followed by maintenance control at intervals of about 12 months for Tb, or at longer intervals in conservation estate (Morgan & Hickling 2000). As populations in many areas are brought under control, maintenance control is becoming an increasing proportion of control work. Maintenance control typically uses baiting techniques that were developed primarily for initial control, i.e., baits with a short field life delivered either at high application rates or following periods of prefeeding, so that most possums find and eat them soon after delivery. Baits delivered aerially remain palatable for a few days, while those placed in bait stations may remain palatable for a few weeks depending on climatic conditions. Such "pulsed" baiting cannot control possums that disperse into the targeted area after baits have become unpalatable or insufficiently toxic. (This also leads to sublethal poisoning and resultant bait-shyness (Morgan et al. 2002)).

Consequently, most areas under maintenance control actually have no control for most of the time. This is a strategic weakness, especially where possums surviving in, or dispersing into, an area after control may continue to infect cattle with Tb. Reinforcing the need for maintaining possum populations at much lower levels than was previously believed necessary is the finding that disease transmission is non-linearly related to density (i.e., "convex up"), in contrast with the earlier assumption of linearity (Caley et al. 1999).

The forest edge is a particularly important habitat in which to carry out maintenance control, as transmission of Tb is most likely to be transmitted between possums, occupying or moving through this habitat, and cattle on adjacent farmland. Clearly, there is a need for a continuous baiting strategy, particularly for forest-edge habitat that possums are known to favour (Green & Coleman 1986). Where control is conducted for conservation purposes, it is also preferable that it is maintained continuously where rare and or slow-breeding species are being managed. For example, protection would be of more benefit if it were continuous rather than intermittent when conservation of populations of weta (Insecta, Orthoptera) (Innes & Barker 1999), mistletoe (*Peraxilla* sp.), and snail (*Powelliphanta* sp.) is at stake, because their populations are at densities so low that predation of a single or few individuals could jeopardise the survival and recovery of the population (G. Napp pers. comm.).

Recent developments in bait technology have focused on extending the field life of baits so that the probability of encounter by possums is increased. A study was designed to compare the field life of six combinations of bait type and presentation method, and to select the most promising option for experimentally maintaining low numbers of possums at a farm-forest interface after normal maintenance control. Deployment of toxic baits for prolonged periods has yet to be fully considered by the appropriate authorities, but the lack of native mammals, separation of possum populations from human settlements, and effective regulation of pest control suggest that this approach may be appropriate in New Zealand.

METHODS

Assessment of the field life of baits

The key specifications for a long-life bait suitable for use in semi-permanent bait stations were perceived as:

(1) palatable and toxic to possums for at least 12 months (i.e., typical period between maintenance control operations) in areas of high rainfall (i.e., >3000 mm/yr);
(2) unattractive or unavailable to other vertebrate pests;
(3) low hazard to non-target species and humans during continuous presentation.

Six bait treatments and appropriate presentation methods (Table 1) were identified as being potentially capable of meeting these specifications.

The field life of both toxic (containing either 1080, cholecalciferol or brodifacoum) and non-toxic forms of baits was assessed by exposing baits in the field at sites at Taramakau Settlement, Central Westland (located at 42°42′S, 171°17′E). Samples of each non-toxic and toxic bait type (identical except for the presence of toxicant) were presented under forest canopy at the boundary of a farm property and Department of Conservation land. The site was selected because the local weather (rainfall 3000–5000 mm per annum spread over 200 rain-days, 80–90% humidity) presented a rigorous test of bait durability. Baits were presented in appropriate bait stations attached to wooden poles, and possums were prevented from feeding on the baits by attaching the poles to a solid steel post at about 1.5 m above ground level and by fitting galvanised iron "baffles" around the posts (Fig. 1). A small hole was created alongside the centre of the baffles to permit access to baits by rodents (which was later verified by the appearance of rodent droppings on the baffle), as bait removal by rodents was considered to be an important element of the field life of baits. Livestock and feral ungulates were excluded from feeding on baits by enclosing the test sites within deer fencing. Two enclosures were constructed to encompass variation in microclimate: one was located at a very sunny site, while the other was located at a shady site that received no direct sunlight.

Fig. 1 Bait stations containing gel baits and pellet baits mounted on "possum-proof" poles in the "shaded" bait-weathering enclosure.

Table 1 The bait types and toxicants selected for field-life evaluation, and the methods by which they were presented in the field.

Bait/toxicant type and manufacturer	Toxicant treatment—nominal concentration	Presentation method
Feratox® cyanide capsules (Feral Control*, Auckland) embedded in Ferafeed® paste (Feral Control)	80 mg/capsule	In biodegradable bags suspended on nylon fishing line threaded through the base of an inverted lower half of a 1.25-litre soft-drink bottle (i.e., a shroud). Method designed to be rodent-proof.
Feracol® paste (Feral Control) containing cholecalciferol	0.1% wt:wt	As above.
PestOff® 1080 pellets (Animal Control Products, Wanganui) with double wax-coating	0.15% wt:wt	In Philproof bait stations (Pest Management Services, Waikanae, Wellington).
PestOff® brodifacoum pellets (Animal Control Products) with double wax-coating	0.002% wt:wt	In Philproof bait stations (Pest Management Services).
No Possums® 1080 gel bait (Kiwicare Corporation, Christchurch)	0.15% wt:wt	In purpose-designed bait stations supplied by bait manufacturer.
No Possums® cholecalciferol gel bait (Kiwicare Corporation, Christchurch)	0.8% wt:wt	In purpose-designed bait stations supplied by bait manufacturer.

*Feral Control now trades as Connovation Limited.

Baits were placed in the enclosures in August 1999 and samples were collected at 2-monthly intervals thereafter for 12 months. The field life of some bait treatments exceeded expectations and so further samples were collected after 16, 19, and 26 months. At each visit, baits were first checked for signs of rodent feeding. A 1-kg sample of each non-toxic and toxic bait type was collected from each enclosure. Pellet bait samples comprised pellets collected from throughout the bait stations. Samples collected from sunny and shady sites were tested separately for palatability and toxin concentration.

Palatability of each non-toxic bait type was assessed as follows. Ten individually caged, acclimatised possums, of approximately equal sex ratio, were each presented with 200 g of bait from the field and 200 g of "fresh" (no older than 1 month) RS5 pellets (Animal Control Products, Waimate). RS5 pellets have previously been shown to remain stable during storage for 1 month, after which palatability slowly declines (Henderson & Frampton 1999). Normal diet (i.e., apple, carrot, and dietary feed pellets) was withheld during each test but fresh water was continually available. Where groups of possums were used for more than one trial, they were returned to normal diet for at least 1 night between palatability trials. Baits were presented at 1500 h and uneaten baits weighed at 0900 h on the following day. Two samples of each bait type (including the RS5 control) were placed adjacent to the possum cages and the mean weight change recorded over the test period was used to correct the weights of bait remaining before estimating the amounts consumed by each possum. Palatability was estimated as the total consumption of each test bait (from the field) expressed as a percentage of total bait consumption (test bait + RS5 control). A value of 50% would therefore indicate equal palatability of the two materials.

Toxin concentration of all bait treatments used was determined in the Landcare Research toxicology laboratory using standard, accredited methods.

Bait palatability data were analysed by analysis of covariance (ANCOVA) using the statistical package S-Plus. Data were analysed using bait type (three types) and location (i.e., sunny and shaded) as factors, and time (measured in months) as a covariate. Because toxicant concentration was measured using differing units, data were analysed separately for each bait treatment by analysis of covariance using location, time, and their interaction as the terms in the model fitted. For all data analyses, non-significant terms were dropped from the models by backward elimination (Crawley 1993) and the models refitted without these terms. The process was repeated until all terms in models were significant.

The maximum field life of the bait types was based on the regression-predicted decline in palatability and toxicant concentration. A reduction in either parameter is likely to lead to sublethal poisoning of many possums (Henderson & Morriss 1996; Henderson & Frampton 1999), and consequent development of bait shyness among most survivors (except those consuming the slow-acting anticoagulant toxicant brodifacoum) (Morgan et al. 2002). Thresholds were set that would be expected to result in approximately 20% reduced mortality. This would be expected if a decline in palatability of 20% was observed in a bait type with an initial palatability of >30% (Henderson & Frampton 1999). A 30% decline in toxicant concentration was used because the relationship between dose (which is directly related to toxicant concentration) and mortality for most toxicants is linear over most of the mortality-rate range (i.e., 16–84%), but sigmoid overall (Klaassen et al. 1986). Hence, assuming that a maximum of 95% of possums are vulnerable to each bait type, the decline in palatability required to reduce mortality from 95 to 85% is proportionally greater than a reduction from 85 to 75%. Accordingly, a palatability decline of 20% (i.e., double) has been assumed for the former and 10% for the latter (which is within the linear part of the dose-response relationship).

Field effectiveness of gel baits in maintaining low possum numbers

Gel bait containing cholecalciferol was identified as the most promising option for a field trial to determine effectiveness in maintaining low possum numbers on the forest edge. Three sites were selected in the Kokatahi Valley, Westland (centred at 42°53′S, 171°02′E), an area of intensive cattle farming close to native forest favoured by possums. Annual maintenance control was completed around the entire forest-edge perimeter of the valley in July–August 2000. After prefeeding, contractors used cyanide paste and 0.15% 1080 pellets (Animal Control Products, Wanganui) and traps, and subsequent monitoring in early September indicated a "residual trap catch" (National Possum Control Agencies 2001) of 4.0% of traps containing possums along the forest edge (D. Rowling pers. comm.).

At each of the three selected sites, a pair of forest-edge segments, each 1.5 km long and separated by 200–300 m, was randomly allocated to treatment or no treatment. In late September 2000, gel baits were distributed at approximately 20-m intervals along treated segments of forest edge with the aim, in time, of exposing possums crossing the forest edge to gel baits. Baits were placed up trees at a height of approximately 2 m to prevent access by livestock.

The impact of the bait stations was monitored at both treated and non-treated sites, using the change in numbers of possums caught in Victor "soft-catch" traps (National Possum Control Agencies 2001). The method includes correction for escapes and non-target captures. Trap-catch monitoring was conducted before baits were established in the field, after 5 months (late February 2001), and after baits were removed at 10 months (late July 2001). In each treated and non-treated area, 50 traps were placed at a distance of 0–5 m from the forest edge at the base of trees at a spacing of at least 20 m apart along a marked line, and they were set for 3 nights. Traps were set no closer than 200 m from the ends of each treated segment to reduce the likelihood of capturing possums that may have moved between treated and non-treated areas. The change in total numbers of possums trapped at 5 and 10 months relative to those trapped at time 0 was calculated and compared with equivalent data from the control lines. Statistical comparisons were made using the *t*-test for samples with unequal variances.

About 1 month after the 5-month monitoring, bait station visibility and accessibility to possums were improved, as the trap-catch data suggested that adequate control was not being achieved. Bait stations were made more conspicuous by removing surrounding branches and foliage, and access to the stations was improved by firmly leaning logs against some smaller trees. A mixture of flour and icing sugar (4:1 ratio) containing approximately 0.5% wt:wt "Jaffa" orange oil (Forest Boake Allen, Auckland), a flavour favoured by possums (Morgan 1990), was placed at the base of trees and inclined logs as a lure. The lower corners of bait containers (i.e., the plastic "margarine" containers in which gel baits are moulded and supplied) were punctured to allow drainage of water that had collected in some that were in a slightly backward-leaning alignment.

Captured possums were ear-tagged before being released to permit identification of recaptured animals. Survival was estimated at 5 months, as a second measure of effectiveness, from the number known to have been originally tagged. For this estimation the recapture component of the Jolly-Seber model (Pollock et al. 1990) was used in a mark-recapture computer package (MARK 2001). (The method did not permit estimation of survival at 10 months as that requires subsequent trap-catch data.)

Gel baits were tested at the Landcare Research toxicology laboratory before use in the field to ensure that toxicant concentrations were appropriate. Bait samples were collected after 5 and 12 months (i.e., 2 months after the final survey) for further assay. Assessment of efficacy was determined from the proportion of groups of 20 captive possums killed when offered this bait together with their normal diet.

Animal Ethics Committee approval was obtained for efficacy studies involving captive possums, and for the use of the trap-catch protocol in population monitoring. A Pesticides Board Experimental Use Permit was obtained for the field application of cholecalciferol gel bait.

RESULTS

Assessment of the field life of baits

Changes in palatability over time differed between bait type, as shown by a significant interaction between bait palatability and length of exposure to field conditions ($F_{2,48} = 17.7$, $P < 0.001$). This is demonstrated by the separate regression lines for the three bait types (Fig. 2) which showed declining trends in palatability that differed from a slope of zero for paste (i.e., slope = –0.83 ± 0.44, $t_{48} = 6.4$, $P < 0.001$) and pellet bait (slope = –1.76 ± 0.52, $t_{48} = 3.4$, $P = 0.002$), while the palatability of gel did not show a significant decline (slope = –0.25 ± 0.26, $t_{48} = 0.9$, $P = 0.35$). There were no significant effects of location (i.e., samples from shady or sunny enclosures) on palatability.

Toxicant concentration of different bait treatments during exposure to field conditions also showed differing trends (Fig. 3). Statistical comparisons of slopes to a slope of zero are shown in Table 2. It is likely that some of the variability in data between locations and over time was due to loss or uptake of moisture by different bait types and individually sampled baits. No attempt was made to correct data for such variations as they represent the influence of environmental conditions on the field life of baits. Change in bait toxicity was not significantly influenced by the location of samples in any of the analyses done for the six bait options. Significant declines in toxicity over time were found for 1080 gel, Feratox, and PestOff 1080 while toxicant concentration remained stable for PestOff brodifacoum and cholecalciferol gel. A significant increase was found for Feracol, which is attributed to a single unexpectedly high value at 12 months; if this value is excluded, the significant relationship disappears and the resulting slope is indistinguishable from zero, suggesting that the suspect value may have been due to either irregular dispersion of cholecalciferol through the gel bait, or to an unidentified experimental error.

The field life predicted by regressions, using declines of 20% and 30% respectively in palatability and toxicant concentration, are given in Table 3. Gel bait clearly retained palatability for much longer than the paste and pellet baits. Linear extrapolation of the

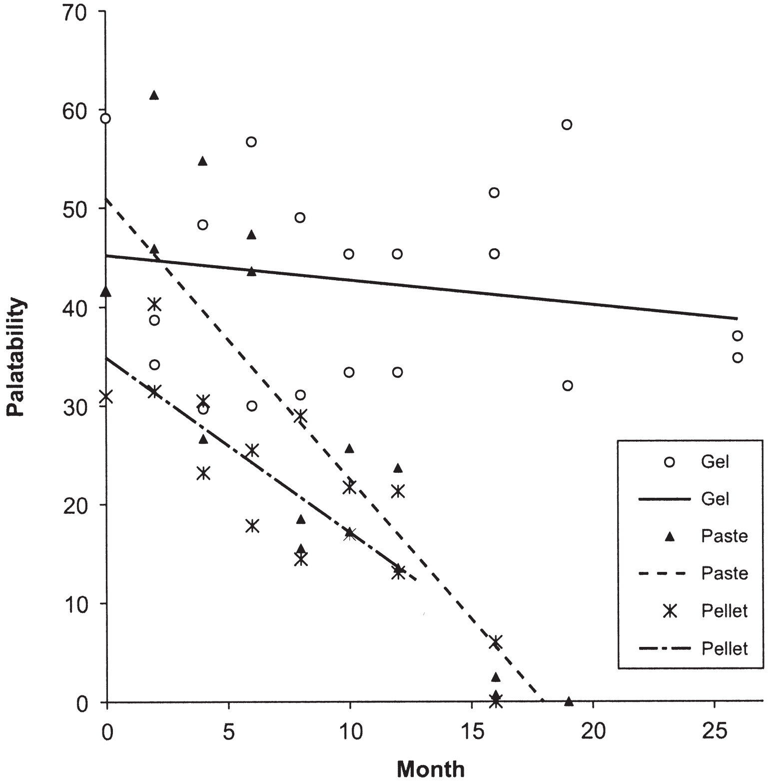

Fig. 2 Palatability to captive possums of the three types of non-toxic bait exposed to West Coast field conditions for up to 26 months. The dotted lines indicate the best linear fit to the data (r^2 = 0.09, 0.87, and 0.93 for gel, paste, and pellet bait, respectively). The slope for gel is not significantly different from zero, while the slopes for paste and pellet have significantly negative slopes (see text for statistics).

regression predicts that palatability would decline by 20% in 36.4 months. However, field data were collected only to 26 months, and it is unreasonable to assume that palatability would have continued to decline linearly.

Toxin concentration declined much more rapidly in some bait types than others. The field life of the 1080 gel bait was limited to 19 months by the decline in 1080 concentration. By contrast, there was no declining trend in cholecalciferol concentration suggesting that, sample variation notwithstanding, it remained stable over the 26 months. Field life of Feratox pellets was limited to 3.5 months by declining toxicant concentration but despite this relatively rapid decline, capsules retained some cyanide for up to 12 months. The field life of Feracol paste baits (3.6 months) was limited by declining palatability. Pest-Off pellets were limited to a field life of 4 months by declining palatability, even though 1080 and brodifacoum concentrations remained acceptable for longer. After 8 months, 1080 pellets showed considerable variability at each sampling interval, perhaps due to different rates of decay of individual pellets collected; those closest to the opening of bait stations appeared to deteriorate quickest. Brodifacoum showed no decline over the 26-month sampling period.

Rats interfered with two cholecalciferol gel baits during the first 2 months only, removing less than 1% of each bait block. Between the second and fourth month, two 1080 gel baits were also interfered with by rodents, which removed less than 0.2% of each block. No other signs of rodent interference with baits were recorded throughout the study.

Field effectiveness of cholecalciferol gel baits in maintaining low possum numbers

While a concentration of 0.8% wt:wt cholecalciferol was specified for gel bait used in the field trial, laboratory assay showed that the bait actually contained 0.9% wt:wt (SE = 0.02%).

Average possum-population trends in cholecalciferol-gel-treated and non-treated areas are summarised in Fig. 4. The possum population density at time 0 (i.e., 4.1% trap catch) was similar to the average recorded (4.0%) for the entire forest-edge perimeter of the Kokatahi Valley following the recently completed annual maintenance control.

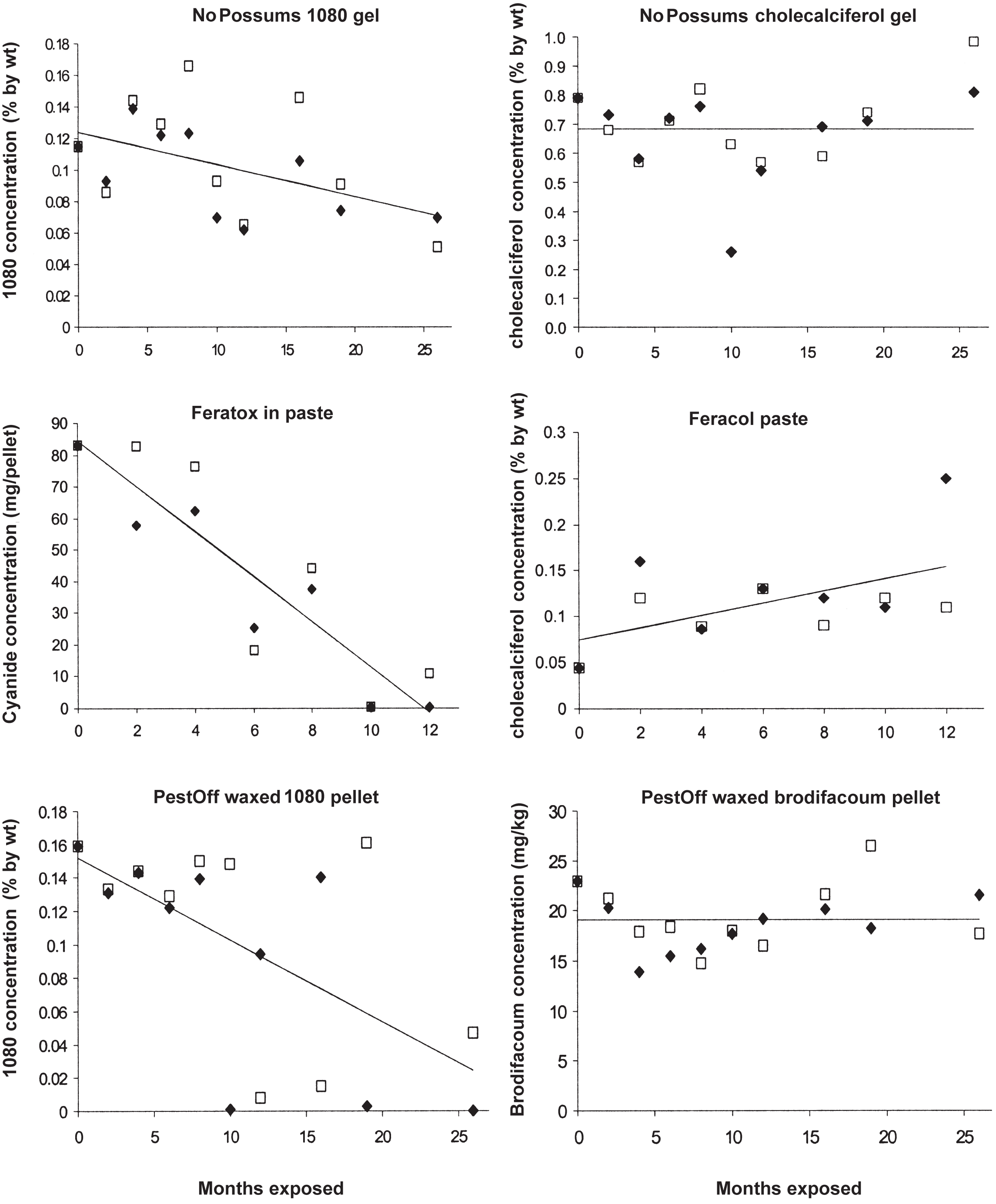

Fig. 3 Mean concentration (±SE) of toxicants in six bait types exposed to West Coast field conditions for up to 26 months. The line indicates the best linear fit to the combined data from sunny (squares) and shaded (diamonds) plots (see Table 2 for regression statistics).

Over the first 5 months, the populations in non-treated areas increased on average by 102% (t_2 = 5.3, P = 0.03) while those in the gel-bait-treated areas increased by 70% (t_2 = 3.2, P = 0.08). Improving the visibility, attractiveness, and accessibility of bait stations after the 5-month monitoring resulted in improved effectiveness of the gel baits. By 10 months, the populations in the non-treated areas had increased significantly (t_2 = 3.4, P = 0.07) by 181% of the average trap catch at time 0. By contrast, populations in the gel-bait-treated areas were only 23% higher than they were at the start, which was not a significant increase (t_2 = 1.1, P = 0.38). The difference between the overall increases in non-treated and gel-bait-treated areas from time 0 to 10 months was significant (t_2 = 1.9, P = 0.10).

The number of possums recaptured at 5 months indicated survival probabilities at this time of 86% (SE = 39%) in the non-treated areas and 46% (SE = 22%) in the gel-bait-treated areas. While the statistical precision of these estimates is low (due to few recaptures), the magnitude of the difference suggests a real effect on survival due to the gel bait treatment.

Samples of gel (n = 6) collected from the field site at 5 months contained a mean concentration of cholecalciferol of 0.77% (SE = 0.02%), while the mean concentration of samples (n = 3) collected after 12 months was 0.96% (SE = 0.05%). This variability was similar to that identified in sequential samples in the earlier assessment of bait field life and, again, suggests that cholecalciferol remains stable in gel exposed to field conditions.

Samples of baits collected after 5 months were divided into "firm" gel (i.e., unchanged in appearance from freshly made bait other than some loss of glossiness) and "loose" gel (i.e., gel from the lower part of containers that had become waterlogged due

Table 2 Significance tests of the slopes fitted to toxicant concentration for the different bait types exposed to field conditions.

Bait treatments	d.f.	Slope (SE)	r^2	t	P
1080 gel	18	−0.002 (0.0008)	0.25	2.45	0.025
Cholecalciferol gel	19	−0.004 (0.0042)	0.05	0.92	0.372
Feratox®	12	−7.15 (0.96)	0.82	7.48	<0.001
Feracol®	12	0.007 (0.003)	0.30	2.29	0.041
Feracol® (outlier removed)	11	0.003 (0.0023)	0.08	1.45	0.182
PestOff® brodifacoum	19	−0.049 (0.092)	0.02	0.53	0.604
PestOff® 1080	18	−0.005 (0.001)	0.39	3.39	0.003

Table 3 Initial palatability of the six bait treatments and the time until decline in palatability and toxicant concentration was estimated to reduce mortality by 20%. Since data were collected only up to a maximum of 26 months, caution is expressed with respect to greater (predicted) values, as decline may become non-linear beyond this period.

		Field life (months) predicted by linear regression	
Bait type	Initial palatability of non-toxic bait	Time to 20% decline in palatability	Time to 30% decline in toxicant concentration
1080 gel	59.1	36.4	18.6
Cholecalciferol gel	59.1	36.4	>26.0
Feratox® in paste	41.6	3.6	3.5
Feracol® paste	41.6	3.6	>12.0
PestOff® 1080 pellet	31.0	4.0	9.0
PestOff® brodifacoum pellet	31.0	4.0	>26

Fig. 4 Mean percentage trap catch in cholecalciferol-treated and non-treated areas at the start of the study and after 5 and 10 months. Vertical bars are standard errors of the means.

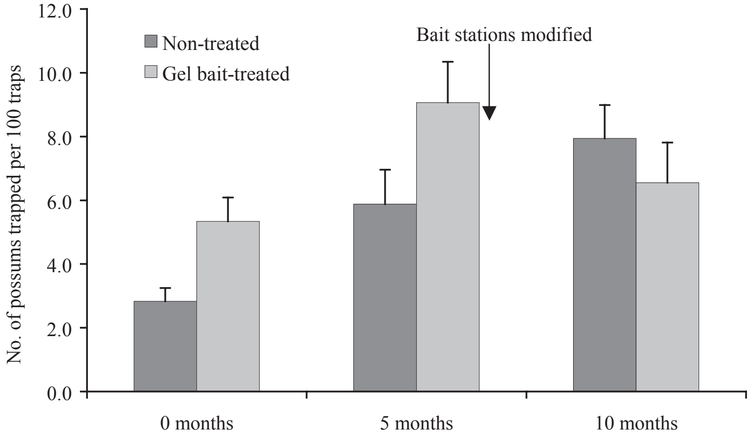

Table 4 Mean values of weight of gel bait eaten, mortality, time until death, and weight loss for possums offered gel bait exposed in the field for 5 or 12 months.

Duration (months) of field exposure of bait	Texture	No. of possums offered bait	Mean wt gel eaten (g) (and SE)	No. dead (%)	Mean time until death (days) (and SE)	Mean loss in body wt (%) (and SE)
5	Loose	10	76.7 (9.2)	10 (100)	7.0 (2.1)	8.7 (5.3)
	Firm	10	75.0 (11.0)	10 (100)	12.7 (5.6)	13.9 (7.5)
12	Firm*	20	40.1 (2.0)	20 (100)	7.3 (0.9)	14.5 (2.4)

*Loose baits were unavailable at 12 months as bait containers were punctured at 5 months to prevent collection of water.

to the slightly backward-leaning alignment of some bait stations). Firm gel samples ($n = 3$) contained 0.73% (SE = 0.03%) cholecalciferol on average and loose gel samples ($n = 3$) contained 0.80% (SE = 0.12%), demonstrating that there was no loss of toxicant due to the continual presence of water in the lower part of some containers.

Gel collected at both 5 and 12 months was palatable and lethal to captive possums (Table 4). While having access also to their normal diet, possums ate large amounts of the gel bait. For baits sampled at 5 months, there was no difference in mean consumption of firm and loose gel ($t_{17} = 0.2$, $P = 0.80$) demonstrating that palatability of the gel had been unaffected by the continual presence of water in some containers. Mean times until death and mean weight loss at death were similar to the ranges of values previously recorded for cholecalciferol baits (Morgan & Milne 2002).

DISCUSSION

Field life of baits and environmental risks

Of the bait types tested, gel baits offer the greatest potential for the development of cost-effective continuous baiting strategies for maintaining possum populations at very low density. Vertebrate pest control in New Zealand is less constrained by concerns over the risk of poisoning non-target species than in other countries. Populations of the main non-target species of concern, birds and invertebrates, suffer no long-term impacts from aerial-1080 baiting operations (Spurr 2000) and bird populations, at least, may benefit from the removal of possums (Veltman 2000). Nevertheless, the possibility of individual animals being unintentionally killed should be considered and avoided as far as practically possible by pest managers, especially if it is intended to deploy baits for prolonged periods. Of the options tested, the lowest environmental hazard is presented by the gel bait, which has been shown to be unattractive, unavailable, or inedible to a range of non-target species of concern (Morgan 1999). If used with cholecalciferol, risk is further reduced since this toxicant is less likely to lead to secondary poisoning problems than baits containing either 1080 or brodifacoum (Eason et al. 2000). Furthermore, the risk posed to humans is low compared with the other toxicants, particularly cyanide which, because of its rapid mode of action, carries a higher risk of causing death before treatment is available.

The long field life of gel bait with either 1080 or cholecalciferol has the additional advantage of reducing the likelihood of sublethal dosing and resultant bait shyness. Possums encountering weathered conventional (i.e., short field life) baits with reduced bait palatability and/or toxicity may consume sublethal doses (Henderson & Morriss 1996). Long-lived shyness to the bait is then likely to develop in most possums exposed to sublethal doses of 1080, cholecalciferol, or cyanide (but not brodifacoum, due to the slow mode of action of this toxicant) (Morgan et al. 2002). To avoid the problem of sublethal dosing and subsequent bait shyness where long-life baits are being used, it is essential that conservative field-life information is provided by manufacturers. The data presented here provide a guide to field life for the bait options tested. These data are conservative because they were collected in a mild, damp climate that would be expected to cause faster bait deterioration than cool, dry climates. Under these conditions the field life of the bait options tested, as determined by the 20% decline in either palatability (p) or toxicity (t), were as follows (with the limiting factor shown in brackets):

(1) No Possums® cholecalciferol gel bait in purpose-designed bait stations .... >26 months (p)
(2) No Possums® 1080 gel bait in purpose-designed bait stations .... 15 months (t)
(3) PESTOFF® 1080 waxed pellets in Philproof bait stations .... 4 months (p/t)
(4) PESTOFF® brodifacoum waxed pellets in Philproof bait stations .... 4 months (p)
(5) Feracol® paste in waxed paper bags in bait stations .... 4 months (p)
(6) Feratox® pellets embedded in paste in waxed paper bags in bait stations .... 2 months (t)

The field life demonstrated for the paste and pellet baits tested at the Taramakau Settlement enclosures suggest that, for continuous control, it may be possible to use these options more sparsely than is normally required for initial knockdown control or conventional annual maintenance control. This could lower the cost of control appreciably by reducing both the intensity of applying baits and the frequency with which areas are revisited to assess the need for further action. While not as long-lived as gel baits, the paste and pellet baits tested may be quite adequate where an intermediate extension of field life is all that is required.

Field effectiveness of gel baits in maintaining low possum numbers

Cholecalciferol gel baits were effective in preventing the expected two-fold increase in trap catches observed in untreated areas of forest-edge habitat, provided the visibility, attractiveness, and accessibility of bait stations were improved (though only the combined effect of these "improvements" was assessed). Elevated (i.e., 1.5–2.0 m) bait stations containing 1080 baits have previously been shown to be less effective (average mortality of 52% during a 5-week control operation) than bait stations at ground level (average mortality of 84%) (Henderson et al. 1999). The poor efficacy of elevated gel baits during the first 5 months of this study shows that prolonged use of elevated bait stations is unlikely to help all possums moving across the forest edge to discover the bait stations. However, after making the elevated bait stations easier to find, efficacy was improved so that, at 10 months, the trap catches were reduced to a level similar to that recorded at the outset (i.e., shortly after annual maintenance control). This suggests that more prolonged use of conspicuous gel baits could have eventually produced further declines in the forest edge possum populations, but this idea remains as yet untested. If cholecalciferol gel bait really can remain effective for at least 2 years in the field, there is considerable potential for improving the efficiency (and probably environmental safety) of maintenance control using this new tool. Where livestock are present, a bait location height of 2 m is necessary, but in areas where livestock are excluded, the bait station can be 0.35 m above ground at the base. This height is convenient for possums at ground level to feed at, and should reduce interference by ground-dwelling non-target species such as weka (*Gallirallus australis*).

It is possible that the population reduction was achieved as an "episodic" event shortly after bait stations were modified, rather than as a result of continuous control. However, the gel was shown to remain potentially continuously-effective by the initial Taramakau Settlement field-life trials, and by the assessments of palatability and toxicity of gel bait collected from the field trial site at 12 months.

Although the presence of water in gel bait containers did not influence bait toxicity or palatability under the field conditions of this trial, it is still worth perforating the lower corners of gel bait containers to enable drainage of rainwater.

The 20-m spacing of baits along the forest edge was considered to be adequate in this study. However, poor kills from the use of cholecalciferol gel baits (and 1080 pellets) in another recently completed study (Morgan & Milne 2001) was in part attributed to a spacing that may have been too sparse (i.e., 1/ha and 2/ha). While both 1080 and cholecalciferol gel baits have consistently produced high mortality in trials with captive possums (Morgan & Milne 2001; this study), the optimal ways of using gel baits in the field are yet to be identified. Prefeeding may, for example, improve initial discovery of bait stations (G. Hickling et al. 1990, unpubl.), albeit with increased cost.

Further research to exploit the promising potential of gel baits for efficient, sustained possum control could include:

(1) Confirmation of the efficacy of conspicuous gel baits in achieving continuous control in forest-edge habitat.
(2) Development of a livestock-proof shroud to enable use of gel baits at ground level.
(3) Optimising the spacing of gel baits for sustained control in different habitats.
(4) Design of efficient best-practice control strategies using gel baits, including the use of non-toxic gel as a prefeed to maximise initial uptake of toxic gel bait.
(5) Use of non-toxic gel baits to aid identification of pockets of surviving possums (since tooth marks in gel are readily identifiable and stable).

ACKNOWLEDGMENTS

I thank the Animal Health Board for funding the study; the landowners of Taramakau Settlement and the Kokatahi Valley on whose properties the fieldwork was conducted; Dale Rowling of the West Coast Regional Council for assistance in organising the fieldwork; Steve Hough, Nick Poutu, Keven Drew, Torsten Heidecke, and Grant Morriss for carrying out fieldwork; Geoff Wright and the staff of the Landcare Research toxicology laboratory for conducting toxicant assays; Julie Turner and the staff of the Landcare Research animal facility for conducting bait tests with captive possums; Ray Webster and Guy Forrester for statistical advice; and Cheryl O'Connor, Graham Nugent, Penny Fisher, Christine Bezar, Phil Cowan, and two anonymous referees for constructive comments on earlier drafts.

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