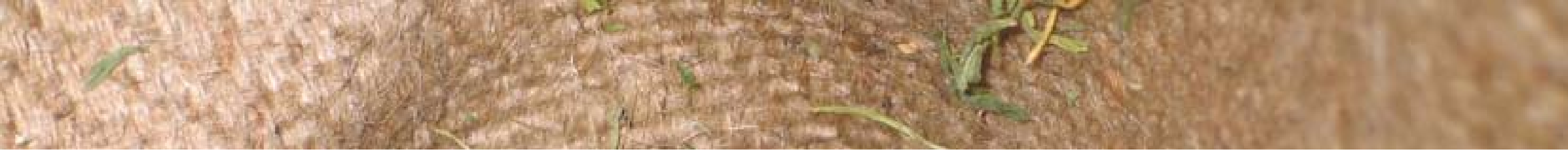

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SCIENCE FOR CONSERVATION 282

Department of Conservation
Te Papa Atawhai

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SCIENCE FOR CONSERVATION 282

Published by
Science & Technical Publishing
Department of Conservation
PO Box 10420, The Terrace
Wellington 6143, New Zealand

Cover: House mouse (*Mus musculus*). *Photo: G.A. Morriss*.

Science for Conservation is a scientific monograph series presenting research funded by New Zealand Department of Conservation (DOC). Manuscripts are internally and externally peer-reviewed; resulting publications are considered part of the formal international scientific literature.
Individual copies are printed, and are also available from the departmental website in pdf form. Titles are listed in our catalogue on the website, refer www.doc.govt.nz under *Publications*, then *Science & technical*.

ISSN 1173-2946 (hardcopy)
ISSN 1177-9241 (web PDF)
ISBN 978-0-478-14359-1 (hardcopy)
ISBN 978-0-478-14360-7 (web PDF)

This report was prepared for publication by Science & Technical Publishing; editing by Helen O'Leary and layout by Lynette Clelland. Publication was approved by the Chief Scientist (Research, Development & Improvement Division), Department of Conservation, Wellington, New Zealand.

In the interest of forest conservation, we support paperless electronic publishing. When printing, recycled paper is used wherever possible.

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Factors influencing palatability and efficacy of toxic baits in ship rats, Norway rats and house mice

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ABSTRACT

This study investigated factors affecting the amount eaten and effectiveness of commercially available toxic bait types designed for use in 'island sentinel' bait stations to prevent rodent reinvasion of islands. In laboratory trials, 20 individual ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*) and house mice (*Mus musculus*) were presented with one of six bait types and a non-toxic food in a free-choice test for 10 days. All three species preferred Pestoff® 20R rodent bait. Most of the baits tested were long-life baits, and of these, Contrac® All Weather Blox and Pestoff® Rodent Blocks were the most preferred and effective. These two bait types were then used to test the amount eaten and effectiveness of weathered bait. Ten individuals of each species were presented over 3 or 10 days with a choice of non-toxic food and a bait type weathered for 1, 3, 5, 8 or 12 months. The amount of bait eaten by mice and ship rats remained high, despite weathering. In another trial, mice were presented with one of 32 bait type/weathering combinations and a choice of non-toxic food for 10 days. Toxin was the only significant factor influencing bait preference: all brodifacoum baits were eaten, resulting in a 100% death rate, but 1080 (sodium fluoroacetate) baits were avoided, resulting in a death rate of only 8%. Either Contrac® All Weather Blox or Pestoff® Rodent Blocks would be suitable for use in 'island sentinel' bait stations against ship rats and mice. For Norway rats, frequent replacement of bait or development of a long-life formulation that they would find more attractive is recommended.

Keywords: bait characteristics, bait longevity, bait palatability, long-life baits, mortality, rodents, rodenticide, New Zealand

Morriss, G.A.; O'Connor, C.E.; Airey, A.T.; Fisher, P. 2008: Factors influencing palatability and efficacy of toxic baits in ship rats, Norway rats and house mice. *Science for Conservation 282*. Department of Conservation, Wellington. 26 p.

1. Introduction

Introduced rodents are being eradicated from increasing numbers of offshore islands around New Zealand, by means of toxic baits either applied aerially or distributed in systemic grids of bait stations (Towns & Broome 2003). Protection of the resulting improved biodiversity requires ongoing risk management strategies incorporating cost-effective means of detecting and preventing rodent re-establishment (Dilks & Towns 2002). As many rodent-free islands are remote and frequent servicing of devices or bait stations is not practical, 'sentinel' systems for detection and/or prevention of reinvasion are needed, and these must remain effective over relatively long periods of time. A review of rodent control methods that could be used to protect offshore islands (O'Connor & Eason 2000) identified a need to assess available weather-resistant ('long-life') second-generation anticoagulant bait formulations for durability, palatability to and efficacy against rodents. This report describes a series of trials conducted to determine the long-life bait most palatable to rats and mice, to test if weathering of bait formulations affects their palatability to rats and mice, and to investigate how various characteristics of bait affect palatability to mice.

2. Background

Pest rodent species tend to have generalist diets, but rats lack a protective emetic reflex (Hatcher & Weiss 1923). Rats have adaptive behavioural responses for selecting palatable and nutritious food, while rejecting palatable but harmful food. In rats, behavioural responses include neophobia and learned food aversions (e.g. Berdoy 1994). 'Tricking' rats and mice into accepting lethal amounts of toxic food remains a common tactic for managers seeking to control pest rodent populations. Relatively high palatability of toxic bait to a rodent species is critical to achieving effective control through application of bait. Most current rodenticide bait formulations contain an anticoagulant poison (such as brodifacoum), and have been developed for the control of commensal rodents, i.e. those that live in close association with human habitation. In New Zealand, such formulations are also used to control 'wild' populations of pest rodents, often on a large scale. Managers need to ensure a high acceptance of bait by a high proportion of the rodent population in situations where population densities and distributions, abundance of natural food, and presence of other (non-target) species are highly variable.

Ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*) and house mice (*Mus musculus*) are considered to be the rodents most likely to reinvade islands around New Zealand (Russell & Clout 2005). Efforts to control introduced rodents on the New Zealand mainland and on islands using various toxic bait formulations and application methods are often complicated by a paucity of information on bait palatability to and efficacy against different rodent species. For example, 1080 (sodium fluoroacetate) poisoning operations in mainland New Zealand that target brushtail possums (*Trichosurus vulpecula*) and rats are generally thought to cause little reduction of mouse populations in the operational area (Sweetapple & Nugent 2005), although field-based data to support this are scarce. Mice are generally less susceptible to anticoagulants than rats (Fisher 2005), suggesting that specific baiting methods or toxic formulations may be needed for the control of 'wild' populations of mice. The palatability and efficacy of two long-life bait formulations, presented in two different ways to Norway rats, have been investigated (Airey & O'Connor 2002). Results indicated that use of certain bait types and presentation methods could result in lower efficacy in control of this species. Given the range of bait formulations available to field managers for control of at least three species of (often sympatric) pest rodents, some baseline information on their relative palatability, and the factors affecting this, was considered important to assist optimisation of future field control operations.

3. Objectives

The objective of this study was to identify factors likely to influence the efficacy of toxic baits against pest rodents from wild populations in New Zealand, using laboratory trials to determine:

- The relative palatability and efficacy of six types of commercially available rodent baits for wild-caught house mice, Norway rats and ship rats
- The effect of weathering on the relative palatability and efficacy of two rodent baits for wild-caught house mice, Norway rats, and ship rats
- The characteristics of bait which most influence the palatability of bait to wild-caught house mice

4. Methods

The procedures involving animals in this study were approved by the Landcare Research Animal Ethics Committee (3 October 2002). Experimental endpoints for euthanasia were defined: any rodent that had lost more than 25% of its body weight during the acclimatisation or trial period and, during the trial period, any rodents that were rendered prostrate by the effects of the poison baits for longer than 2 hours. Initially, any rodents surviving after 21 days in Trials 1 and 2 were euthanased, but this was extended to 30 days for mice after the 1-month weathering time point in Trial 2. In Trial 3, surviving mice were euthanased at 21 days.

4.1 HUSBANDRY OF WILD-CAUGHT RODENTS

Wild Norway rats were caught on farms near Lincoln, South Island, New Zealand by means of cage traps baited with cooked bacon. House mice were caught by hand in oat stacks on farms, also near Lincoln. Ship rats were caught in cage traps baited with soft liquorice smeared with peanut butter. Some ship rats were obtained from native forest at Prices Valley, Banks Peninsula, some from near Murchison, and some from commensal populations living on farms near Lincoln and within urban Christchurch. All rodents were housed at the Landcare Research animal facility, Lincoln. Pregnant rats and mice were not tested in these trials, as any rodents that were captured pregnant and subsequently gave birth during the acclimatisation period had their young euthanased. Rodents from island populations were not used because of the logistical difficulty and cost of capturing and transporting enough animals for the trials.

In all trials, Norway and ship rats were individually housed in solid metal cages (30 × 30 × 20 cm) with slatted tops and detachable nest-boxes (15 × 30 × 20 cm). Cage floors were lined with sawdust, and shredded paper was placed in the nest-box. House mice were individually housed in polycarbonate cages (40 × 20 × 15 cm) with a wire lids and the floors lined with sawdust and shredded paper. After capture, the animals had an acclimatisation period. During this period, they had free access to water, rat and mouse pellets (hereafter referred to as 'rodent pellets'; supplied by Weston Animal Nutrition, Rangiora), and supplementary food (e.g. a piece of fruit, sunflower seeds or cat biscuits). Rats and mice were acclimatised for a minimum of 30 and 21 days, respectively. All rodents were weighed weekly and only those of stable or increasing bodyweight were selected for use at the start of each trial.

4.2 TRIAL 1: RODENT BAIT PREFERENCES

This trial ran from December 2003 to April 2005. Six commercially available rodent bait formulations (Table 1) were selected for testing, including those perceived as being most effective by DOC field staff, plus one new product (Kiwicare® possum gel) that had been shown to have extended field life (Morgan 2004). Most were long-life formulations that contained agents to slow field degradation, but a short-life formulation—Pestoff® 20R cereal bait (Animal Control Products, Wanganui)—was also included. This formulation is registered

TABLE 1. RODENT BAITS USED IN THE RODENT BAIT PERFORMANCE TRIAL.

BAIT NAME	MANUFACTURER, COUNTRY	BAIT SIZE (g)	TOXIN	NOMINAL TOXIN CONCENTRATION (ppm)
Pestoff® 20R cereal pellet	Animal Control Products, New Zealand	2	Brodifacoum	20
Pestoff® rodent block	Animal Control Products, New Zealand	30	Brodifacoum	20
Contrac® All-Weather Blox	Bell Laboratories Inc., USA	30	Bromadiolone	50
Talon® wax blocks	Syngenta Crop Protection, Australia	20	Brodifacoum	50
Ridrat® Super Wax Bait	Rentokil, New Zealand	30	Bromadiolone	50
Kiwicare® possum gel	Kiwicare®, New Zealand	50[a]	Brodifacoum	50

[a] Bait was cut to size from a large slab of gel.

for aerial application and has been successfully used for rodent eradications on offshore islands. It is also sometimes applied for rodent control in New Zealand 'mainland islands' (Animal Control Products 2006). Fresh baits (< 3 months since manufacture) were used for each treatment group, and samples from each batch of bait were assayed for concentration of the toxicant by the Landcare Research toxicology laboratory, Lincoln.

The limited number of individual cages available for use in the trials, and seasonal difficulties in catching wild rodents, especially ship rats, meant that the different bait types were tested at times when suitable numbers of rodents could be obtained to allow all six bait types to be tested at once. Twenty animals of each species were randomly allocated to one of the six treatment (bait type) groups (total $n = 120$), with equal sex ratios in each group. In a two-choice test, the rats were offered approximately 30–60 g of toxic bait (mice were offered 20–30 g) and an equal volume of their normal food (rodent pellets), each placed in separate receptacles. These were glasses (6.8 cm diameter × 7.5 cm depth) for rats and stainless steel bowls (7.0 cm diameter × 4.5 cm depth) for mice. These receptacles were positioned at the end of the cage farthest from the nest area and spaced 10 cm apart. When baits and rodent pellets were weighed and replenished each morning, the position of each receptacle was swapped. Consumption of each food type by rats and mice was measured by collecting and weighing the food remaining of each type offered on the following morning, including any that had been removed from the receptacles and placed elsewhere in the cage (cached) by the rodents. The mean palatability of each toxic bait type was calculated daily using the amount of each toxic bait eaten by an individual rodent, divided by the combined amount of food (toxic bait + rodent pellets) eaten by the individual. A mean palatability figure greater than 50% indicated that the toxic baits were more acceptable than the rodent pellets. Three 'environmental controls' of each toxic bait type and the rodent pellets were randomly located in the room containing the rodent cages and weighed daily to correct for any weight changes due to moisture gain or loss by the baits or pellets during the trial period.

After 10 consecutive days of a two-choice treatment, surviving rodents were returned to their normal diet. All were observed twice daily for signs of poisoning, such as lethargy, bleeding, pallor and pilo-erect coat, which were recorded (along with day of death, if applicable). The efficacy was measured as the percentage mortality for each bait type over 21 days. A previous study (Fisher et al. 2004) found the mean time to death of rats that had eaten brodifacoum baits was approximately eight days. On this basis, the end-point for this trial was set at 21 days from the start of the trial to allow sufficient time for rodents that had eaten a lethal dose to die. The proportion of rodents dying between treatments was compared using logistic regression (Crawley 2002). ANOVA was used to test for differences between treatments in the survival time of those animals that died.

4.3 TRIAL 2: EFFECT OF BAIT WEATHERING ON ACCEPTABILITY AND EFFICACY

The two bait types with the highest average efficacy across all species in Trial 1 (Contrac® and Pestoff® rodent blocks, see Table 1 for details) were selected for further testing of the effect of weathering on bait efficacy in the three rodent species. These trials were conducted from June 2005 to July 2006.

To simulate weathering in field conditions, c. 9 kg of each bait type were placed in 1-m lengths of Novacoil (110 mm diameter) unpunched pipe (Iplex Pipelines, New Zealand). These 'bait stations' were laid on the ground and left outside the Landcare Research animal facility, Lincoln, where they were subject to natural climatic conditions. Individual baits were placed in stations so that maximum surface area was exposed for weathering (15 baits per 1-m length), i.e. as they would normally be placed for rodent control. Each length of pipe containing bait had stainless steel mesh (2–3-mm diameter) fixed over each end to exclude rodents or birds, while exposing the bait to changes in natural environmental moisture (humidity but not direct exposure to precipitation) and invertebrate activity. Sub-samples of each bait type were removed from the stations at 1, 3, 5, 8 and 12 months for presentation to rodent treatment groups.

Humidity, rainfall and temperature were recorded daily at the Landcare Research facility during this trial and cumulative rainfall calculated. Representative baits from each 'weathering interval' (except at 1 month) were also photographed to document their condition and assayed for toxin concentration (brodifacoum or bromadiolone) by the Landcare Research toxicology laboratory.

At each weathering interval (1, 3, 5, 8 or 12 months), ten of each rodent species were presented with either Contrac® or Pestoff® rodent blocks aged by these amounts of time in a two-choice bait-palatability and efficacy trial. Trial conditions were similar to those described above for Trial 1: rats were offered a choice between 30–60 g of toxic bait (mice 20–30 g) and 30–60 g (mice 20–30 g) of non-toxic cinnamon-lured RS5 pellet bait (Animal Control Products, Waimate). The latter bait type was selected as an industry standard bait commonly used in broad-scale baiting operations in New Zealand. Toxic bait and RS5 pellet consumption were measured by weighing the food remaining each morning. Relative palatability was expressed as the amount of each toxic bait eaten by an individual rodent over the 10 days, divided by the cumulative amount of food (toxic bait + RS5 pellets) eaten over 10 days. Six environmental controls of each bait type and RS5 pellets were placed in the trial room, and the mean daily weight changes in these used to correct the amounts of corresponding treatments eaten. Rodents were observed daily for signs of poisoning (as described in Trial 1) and the day of death was recorded. At 21 days, any surviving rodents were euthanased and classified as survivors. The efficacy of each bait was measured as the percentage mortality for each bait type over 21 days. As in Trial 1, an end-point of 21 days was used for rats (although this was 30 days for mice after the 1-month test, see below). In addition, the number of days to death was averaged for each bait type to determine any significant difference as baits weathered. ANOVA was used (as in Trial 1) to test for differences between bait types in the survival time of those animals that died.

For the 1-month-weathered baits, rodents were offered the two-choice test for 3 consecutive days. As a relatively low intake of toxic bait occurred, the duration of the two-choice test was extended to 10 consecutive days for subsequent weathering intervals to ensure adequate time to overcome possible neophobic responses. Also, in light of the 1-month test results, the end point of 21 days was extended to 30 days for mice to ensure none were euthanased before the onset of visible signs of poisoning and a true record of mortality was achieved. Logistical difficulties in obtaining sufficient mice meant that the 3-month test was split into two time points, with both rat species tested with baits weathered for 2.5 months and mice tested with baits weathered for 3.5 months.

4.4 TRIAL 3: RESPONSES OF MICE TO BAIT CHARACTERISTICS

In a factorial design, 96 mice were presented with a paired choice of 30 g of test bait and 30 g of non-toxic rodent pellets over 10 consecutive days. The 32 test bait types were manufactured and supplied by Animal Control Products (Wanganui and Waimate) to present combinations of the following variables:

- Toxicant—either 1080 (nominally 0.15%) or brodifacoum (nominally 0.002%)
- Bait medium—either No. 7 or RS5
- Presence or absence of green dye
- Presence or absence of 0.3% cinnamon
- Bait size—either 10- to 12-mm diameter (2 g) or 20-mm diameter (12 g)

As in previous trials, bait consumption was estimated daily by weighing the food remaining in each cage each morning. Three environmental controls for nine of the bait types (including the rodent pellets) were randomly located in the trial room to measure any weight changes due to moisture loss/gain, and the resulting bait intake corrected for these differences. Time to death was recorded, and at 21 days, any surviving mice were euthanased. The toxin concentration in eight of the bait types was assayed by the Landcare Research toxicology laboratory, Lincoln.

5. Results

5.1 TRIAL 1: RODENT BAIT PREFERENCES

All bait types had measured toxin concentrations within an acceptable range of the nominal concentration, except for Ridrat®, which was below the nominal concentration in the first two batches tested (Table 2).

For all three species, Pestoff® 20R cereal pellets had the highest efficacy, killing 100%, 100%, and 95% of Norway rats, ship rats, and house mice respectively by the end of the trial period (Table 3). Pestoff® rodent block was the next most effective bait type, but Contrac® All-Weather Blox had a similar overall efficacy. The effectiveness of Talon® wax blocks, Rentokil Ridrat® and Kiwicare® possum gel were, overall, lower. There were highly significant differences in mortality between bait types for both Norway and ship rats ($\chi^2 = 44.28$ and 21.49

TABLE 2. TOXIN CONCENTRATION ASSAYED IN SIX RODENT BAITS.

BAIT TYPE	TOXIN	NOMINAL TOXIN CONCENTRATION (ppm)	SAMPLE		
			1	2	3
Pestoff® 20R cereal pellet	Brodifacoum	20	15	23	23
Pestoff® rodent block	Brodifacoum	20	14	16	19
Contrac® All-Weather Blox	Bromadiolone	50	45	44	52
Talon® wax blocks	Brodifacoum	50	49	53	46
Rentokil Ridrat® Super Wax Bait	Bromadiolone	50	11	18	49
Kiwicare® possum gel	Brodifacoum	50	35[a]	42[a]	62

[a] These figures are likely to be lower than the actual concentration due to incomplete extraction from the gel material.

for Norway and ship rats respectively, df = 5, $P < 0.001$). However, there were no significant differences in mortality between the bait types for mice ($\chi^2 = 7.72$, df = 5, $P = 0.17$) (Table 3).

Mean consumption of palatable bait types peaked on day 3 of the trial for house mice and ship rats, and day 5 for Norway rats. The onset of signs of poisoning probably contributed to more variable and decreasing bait consumption beyond day 5 for all three species (Fig. 1). All bait types, except the Kiwicare® possum gel, had overall high palatability to mice (Fig. 1A).

While Pestoff® 20R showed some of the highest palatability scores, especially to rats, this formulation is likely to be less suitable for a sentinel role (i.e. detecting and combating reinvasion or invasion of rodent-free islands), because of its known shorter field life (Animal Control Products 2006).

There were no significant differences in the mean time (number of days from start of trial) taken for rodents to die (Table 4). For ship rats ($F = 0.66$, df = 5, 86, $P = 0.65$) this ranged from 9.59 ± 0.73 (mean ± SEM) days with the Pestoff® rodent block to 11.38 ± 0.89 days with Ridrat®. For Norway rats ($F = 0.59$, df = 5, 81, $P = 0.71$), the range was from 8.25 ± 0.81 days with Contrac® All-Weather Blox to 10.75 ± 2.66 days with the Kiwicare® possum gel. The time to death for mice ($F = 0.29$, df = 5, 103, $P = 0.92$) ranged from 8.80 ± 0.69 days with Ridrat® to 9.75 ± 0.96 days with the Kiwicare® possum gel.

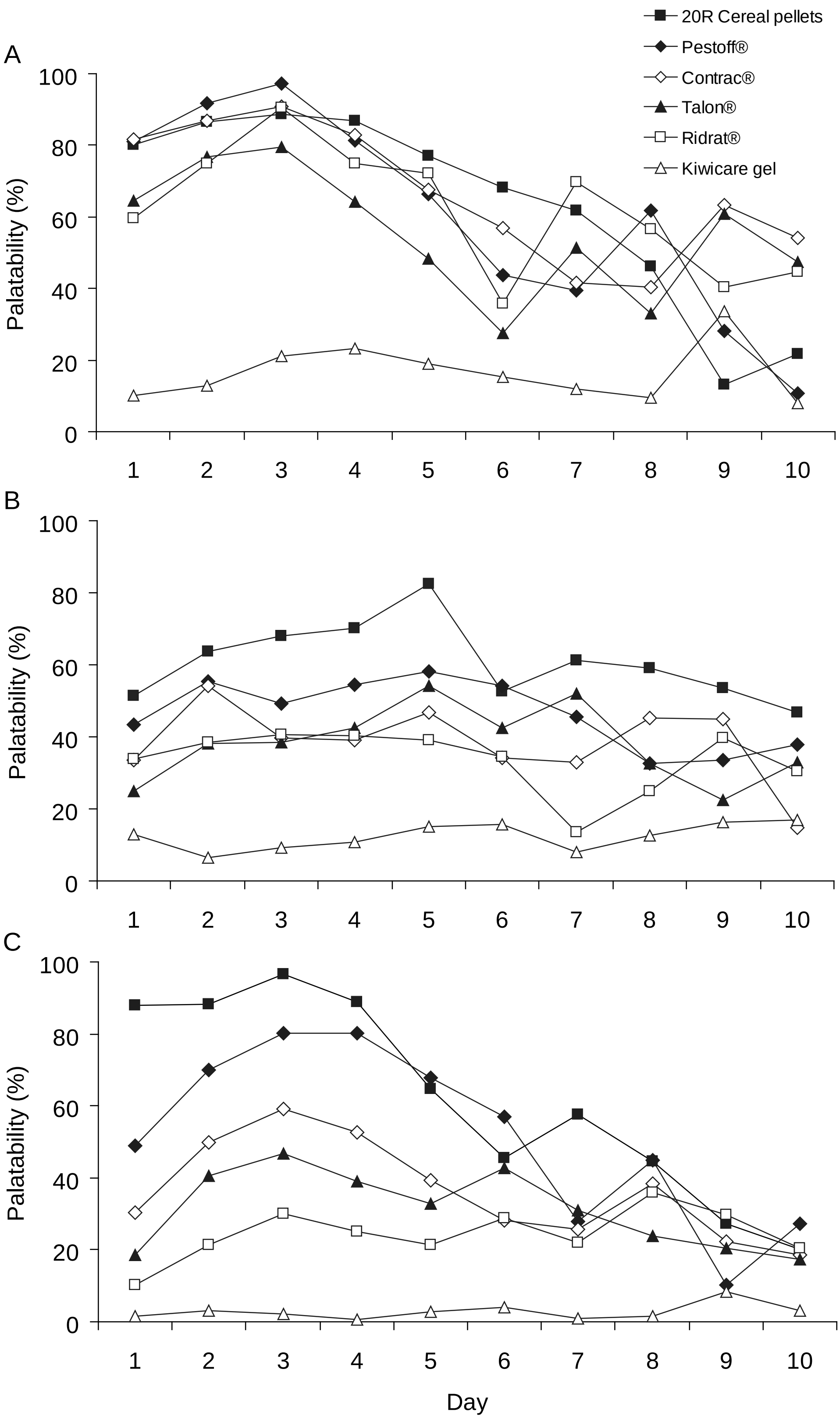
TABLE 3. PERCENTAGE MORTALITY OF RODENTS PRESENTED WITH SIX DIFFERENT RODENT BAITS IN A PAIRED CHOICE TEST (n = 20 OF EACH SPECIES FOR EACH BAIT TYPE).

	NORWAY RAT (%)	SHIP RAT (%)	HOUSE MOUSE (%)
Pestoff® 20R cereal pellet	100	100	95
Pestoff® rodent block	95	85	100
Contrac® All-Weather Blox	80	80	90
Talon® wax blocks	75	70	95
Rentokil Ridrat® Super Wax Bait	70	80	85
Kiwicare® possum gel	20	45	80

TABLE 4. TIME (DAYS) TO DEATH FOR RODENTS EATING A LETHAL DOSE OF SIX DIFFERENT RODENT BAITS (MEAN ± SEM). THE F AND P VALUES WERE DERIVED FROM ANALYSIS OF VARIANCE OF SURVIVAL TIMES FOR THOSE RODENTS THAT DIED AFTER EATING A LETHAL DOSE.

RODENT	BAIT TYPE						F VALUE	P VALUE
	PESTOFF® 20R CEREAL PELLET	PESTOFF® RODENT BLOCK	CONTRAC® ALL-WEATHER BLOX	TALON® WAX BLOCKS	RENTOKIL RIDRAT® SUPER WAX BAIT	KIWICARE® POSSUM GEL		
Ship rat	11.1 ± 0.7	9.6 ± 0.7	10.3 ± 0.7	10.9 ± 1.1	11.4 ± 0.9	10.7 ± 1.0	$F_{5,86} = 0.66$	0.65
Norway rat	8.3 ± 0.8	8.4 ± 0.6	8.3 ± 0.8	8.5 ± 0.8	9.5 ± 1.2	10.8 ± 2.7	$F_{5,81} = 0.59$	0.71
House mouse	8.9 ± 0.8	9.0 ± 0.7	8.8 ± 0.6	9.5 ± 0.7	8.9 ± 0.7	9.8 ± 1.0	$F_{5,103} = 0.29$	0.9

Figure 1. Palatability of six rodent baits presented to (A) mice, (B) ship rats, and (C) Norway rats for 10 consecutive days compared with consumption of normal feed (n = 20 for each species for each bait).



5.2 TRIAL 2: EFFECT OF BAIT WEATHERING ON PALATABILITY AND EFFICACY

The average monthly rainfall at the study site is shown in Appendix 1, and the cumulative rainfall over the 12-month bait weathering period was 683.8 mm. The mean monthly humidity ranged from 56.6% to 85.6% and the average monthly temperatures ranged from 6.8°C to 21.5°C (Appendix 1).

Both Contrac® and Pestoff® rodent blocks became mouldy over time (see Appendix 2). Mould had appeared on some Contrac® blocks (< 5% of the surface area) after 2.5 months' weathering (after 88 mm rain), but the bait blocks remained intact over the 12-month test, with mould growth confined to the surface and < 5 mm below the surface. The internal part of the bait block appeared similar to fresh bait at 12 months, even though > 90% of the outer surface was covered in mould (see Appendix 3). Pestoff® rodent blocks had darkened in colour after 1 month of weathering, but did not show external mould until 8 months (over 50% of the surface area), and by 12 months the bait blocks were covered in mould. The Pestoff® rodent blocks appeared to absorb moisture throughout, and after 1 month of weathering appeared expanded and darker in colour in compared with fresh baits. Although the Pestoff® rodent blocks were not friable when fresh, they became more so over time, this being demonstrated by some mice breaking them into small pieces at all time points tested (See Appendix 3). The toxin concentration in either bait type did not appear to decline until the 5-month time point (Table 5).

Similar high mortality was observed with Pestoff® rodent blocks for both mice and ship rats over the 12-month period (Table 6). There was a marginally significant increase in ship rat mortality ($\chi^2 = 10.26$, df = 4, $P = 0.04$) over the time points tested with Contrac® blocks due to the low mortality observed at the 1-month time point (Table 7). When the 1-month time point was excluded, there was no significant increase in mortality ($\chi^2 = 2.99$, df = 3, $P = 0.39$). All surviving mice (8 individuals) had apparently eaten large lethal doses (5.2–25.3 g) of Contrac® and appeared unaffected for the duration of the trial. There was a significant difference in Norway rat mortality ($\chi^2 = 23.62$, df = 4, $P < 0.001$) over the time points tested with Contrac® blocks due to the 0% mortality observed at the 1-month time point. When the 1-month time point was excluded, there was no significant difference ($\chi^2 = 7.23$, df = 3, $P = 0.07$). Overall, Norway rat mortality was low and variable throughout the 12-month test period. Consumption data indicated an initial neophobia to both the toxic bait and RS5 and then a preference for the RS5.

Mice found both types of weathered baits palatable (mean palatability at each time point ranging from 43.4% to73.5%) even after 12 months and ate similar amounts of the toxic bait as the non-toxic alternative (Fig. 2A), but there was a significant reduction in palatability of Pestoff® rodent blocks over time ($F = 11.29$, df = 1, 48, $P = 0.002$). Palatability of baits to ship rats remained relatively constant over 12 months (mean palatability at each time point 16.0% to 36.5%), and although its palatability to ship rats was lower than its palatability to mice, it was sufficient to achieve high mortality in ship rats (Fig. 2B). There was a marginal increase in palatability of Contrac® blocks over time ($F = 4.18$, df = 1, 48, $P = 0.05$) and no change in palatability with Pestoff® rodent blocks ($F = 0.003$, df = 1, 48, $P = 0.96$). Norway rats did not find the weathered baits as palatable (mean palatability at each time point 0.9% to 17.4%) as the other two species and showed generally

TABLE 5. TOXIN CONCENTRATION (ppm) OF LONG-LIFE BAITS TESTED DURING THE 12-MONTH WEATHERING TRIAL. AT EACH TIME POINT, ONE 30-g BAIT OF EACH TYPE WAS ANALYSED.

LONG-LIFE BAIT	TIME BAIT WEATHERED (MONTHS)						
	0	1	2.5	3.5	5	8	12
Contrac® (bromadiolone)	54	52	57	54	58	41	36
Pestoff® (brodifacoum)	16	15	13	14	15	11	12

TABLE 6. PERCENTAGE MORTALITY OF RODENTS (n = 10 AT EACH TIME POINT FOR EACH SPECIES) PRESENTED WITH WEATHERED PESTOFF® RODENT BLOCK IN A PAIRED CHOICE TEST WITH NON-TOXIC CINNAMON-LURED RS5. MORTALITY WAS ASSESSED 21 DAYS OR 30 DAYS FROM START OF BAITING. χ^2 FIGURES (WITH FOUR DEGREES OF FREEDOM) AND ASSOCIATED P VALUES WERE DERIVED FROM GENERALISED LINEAR MODELS ON THE PROPORTION OF RODENTS DYING.

RODENT	TIME BAIT WEATHERED (MONTHS)						χ^2_4	P
	1	2.5	3.5	5	8	12		
Ship rat	70	100		90	80	100	7.96	0.09
Norway rat	60	60		80	60	60	2.15	0.71
House mouse	80[a]		100	100	100	100	6.19	0.17

[a] Two mice alive and euthanased at trial end on day 21 may have died from poisoning after this time. The euthanasia time was subsequently extended to 30 days for mice in the following time points.

TABLE 7. PERCENTAGE MORTALITY OF RODENTS (n = 10 AT EACH TIME POINT FOR EACH SPECIES) PRESENTED WITH WEATHERED CONTRAC® ALL-WEATHER BLOX IN A PAIRED CHOICE TEST WITH NON-TOXIC CINNAMON-LURED RS5. MORTALITY WAS ASSESSED 21 DAYS FROM START OF BAITING (MOUSE MORTALITY ASSESSMENT WAS EXTENDED TO 30 DAYS AFTER THE 1-MONTH TIME POINT). χ^2 FIGURES (WITH FOUR DEGREES OF FREEDOM) AND ASSOCIATED P VALUES WERE DERIVED FROM GENERALISED LINEAR MODELS ON THE PROPORTION OF RODENTS DYING.

RODENT	TIME BAIT WEATHERED (MONTHS)						χ^2_4	P
	1	2.5	3.5	5	8	12		
Ship rat	50	80		90	90	100	10.26	0.04
Norway rat	0	80		80	30	50	23.62	<0.001
House mouse	80[a]		90	80	70	100	5.23	0.27

[a] Two mice alive and euthanased at trial end on day 21 may have died from poisoning after this time. The euthanasia time was subsequently extended to 30 days for mice in the following time points.

lower and more variable mortality (Fig. 2C). There was no significant difference in palatability to Norway rats over time of both bait types (Contrac® $F = 2.78$, df = 1, 48, $P = 0.10$; Pestoff® $F = 1.20$, df = 1, 48, $P = 0.28$).

There was no significant change in the mean (± SEM) time to death of rodents consuming a lethal dose of baits at any stage of weathering (Table 8). Times to death varied from 7.7 ± 0.8 days for mice eating the Pestoff® rodent blocks to 13.0 ± 2.0 days for Norway rats eating the Pestoff® rodent blocks (both after 12 months weathering).

Figure 2. Mean palatability acceptance (%) and resultant mortality (%) achieved by Contrac® and Pestoff® rodent blocks in a two-choice test with non-toxic RS5 pellets presented to (A) mice, (B) ship rats and (C) Norway rats (n = 10 per species per time point; group acceptance averaged over 10 days).

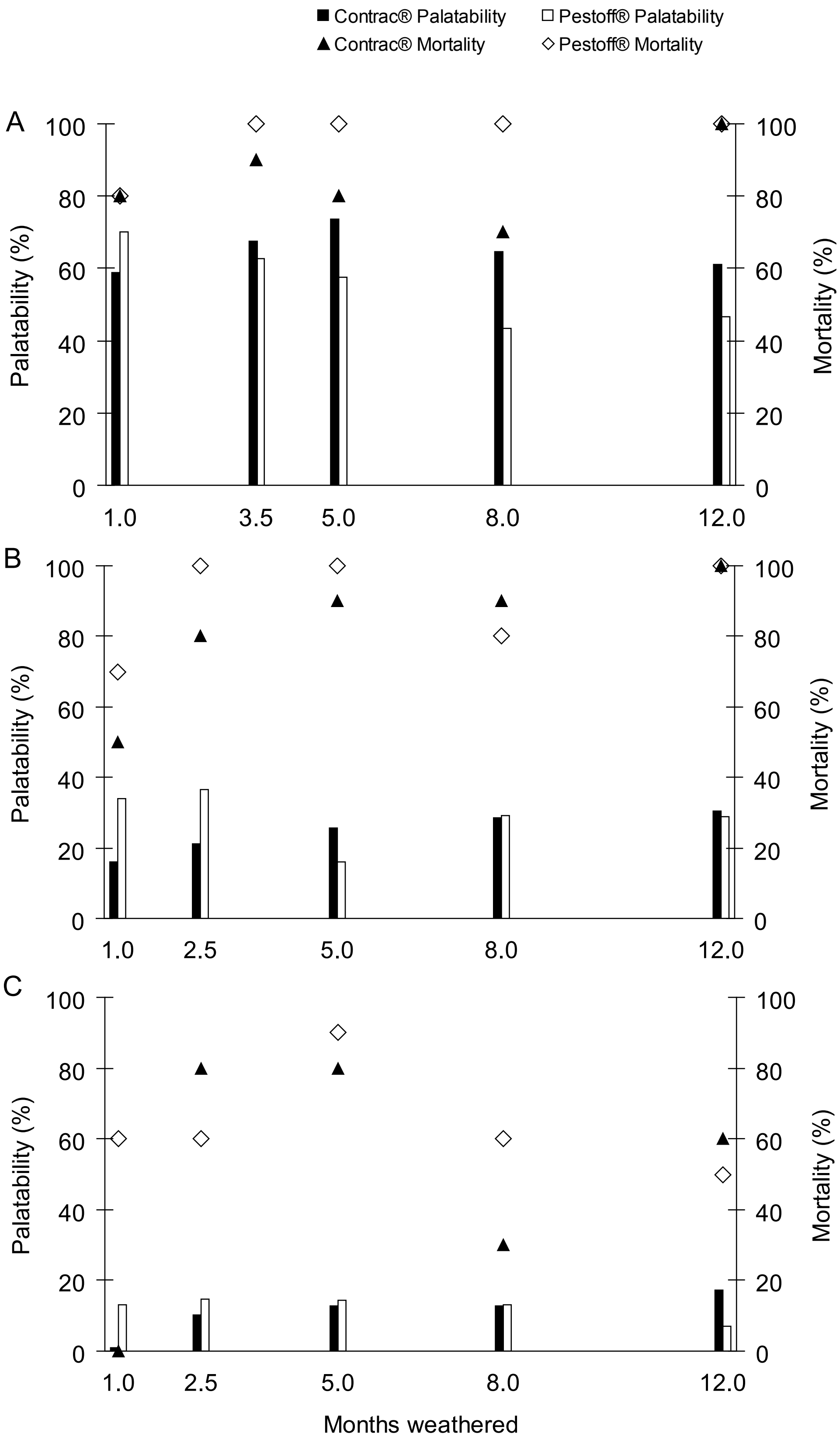


TABLE 8. TIME (DAYS) TO DEATH FOR RODENTS EATING A LETHAL DOSE OF CONTRAC® OR PESTOFF® RODENT BLOCKS (MEAN ± SEM). THE *F* AND *P* VALUES WERE DERIVED FROM ANALYSIS OF VARIANCE OF SURVIVAL TIMES FOR THOSE RODENTS THAT DIED AFTER EATING A LETHAL DOSE.

BAIT	RODENT	TIME BAIT WEATHERED (MONTHS)						*F* VALUE	*P* VALUE
		1	2.5	3.5	5	8	12		
Contrac®	Ship rat	11.8 ± 1.8	10.9 ± 0.)		9.3 ± 0.9	12.0 ± 1.0	12.7 ± 0.9	$F_{4,36} = 1.70$	0.17
	Norway rat		12.9 ± 1.1		12.4 ± 1.8	9.7 ± 1.8	9.2 ± 0.9	$F_{3,21} = 1.61$	0.22
	Mice	11.3 ± 1.4		10.3 ± 1.2	12.5 ± 1.8	11.0 ± 1.3	8.1 ± 0.8	$F_{4,37} = 1.06$	0.39
Pestoff®	Ship rat	11.9 ± 1.4	12.2 ± 1.5		10.1 ± 1.0	11.3 ± 1.0	12.9 ± 0.9	$F_{4,37} = 0.81$	0.53
	Norway rat	9.7 ± 2.4	8.3 ± 0.8		9.4 ± 1.4	10.0 ± 0.9	13.0 ± 2.0	$F_{4,26} = 1.04$	0.40
	Mice	12.3 ± 1.9		11.0 ± 1.5	10.8 ± 1.5	12.5 (± 1.4	7.7 ± 0.8	$F_{4,42} = 2.20$	0.0

5.3 TRIAL 3: RESPONSES OF MICE TO BAIT CHARACTERISTICS

Of all the variables tested by presenting mice with choices of different bait types, the only significant effect was toxin type ($\chi^2 = 104.9$, df = 1, $P < 0.0001$), with less 1080 bait being eaten by mice. The raw mean (± SEM) consumption of the non-toxic rodent pellets by mice, averaged over all treatments, was 16 ± 0.15 g over 10 days. All brodifacoum baits were eaten, with a mean consumption of 13.2 ± 0.5 g over the 10 days, while a mean of only 0.52 ± 0.04 g of baits with 1080 were eaten over the 10 days. This resulted in 100% mortality in mice from brodifacoum baits but only 8 ± 0.03% mortality from 1080 baits.

Laboratory assays of the toxic bait treatments showed mean concentrations of 19 ppm brodifacoum (v. 20 ppm nominal concentration) and 170 ppm (0.17%) 1080 (v. 150 ppm (0.15%) nominal concentration).

6. Discussion

6.1 TRIAL 1: RODENT BAIT PREFERENCES

The short-life bait Pestoff® 20R was highly acceptable to all three rodent species, as were the remaining four long-life baits (Pestoff® rodent block, Contrac® All-Weather Blox, Talon® wax block, and Ridrat®). All three rodent species tested preferred the five cereal-based bait types over the Kiwicare® gel bait. Logistical and cost constraints were the major reason for not using island-sourced rodents in these trials, and it remains unknown whether there would be any significant differences in bait palatability and efficacy between mainland-sourced rodents (as used) and island populations. However, rodents that invade islands are most likely to originate from mainland populations, including commensal rodents living on boats or around ports. Hence, the bait preferences and susceptibilities found in rodents used in these trials are likely to represent those of invaders of islands. It is also unknown whether pregnant or lactating females would respond differently to the baits tested, but other research with wild Norway rats has found that breeding females tend to eat more (Shepherd & Inglis 1987).

6.2 TRIAL 2: EFFECT OF BAIT WEATHERING ON PALATABILITY AND EFFICACY

Both Pestoff® and Contrac® rodent baits remained highly effective for 12 months, despite obvious changes in appearance due to weathering. The Contrac® block is a hard, extruded formulation, which is perhaps why degradation due to weathering did not penetrate far into the surface of the bait (< 5 mm). The Pestoff® block is a compressed wax bait and slightly softer—moisture absorption in the internal part of the blocks was observed from as early as 2 months. The climatic conditions the trial baits were exposed to could be described as moderate to dry, so that baits used on islands with extreme climates may need to be monitored to ensure that degradation does not occur more quickly than is documented here. The photos in Appendix 2 could help managers gauge how often weathered baits should be replaced in different island scenarios. Our assay results suggest that brodifacoum or bromadiolone concentration declined slightly as the integrity of the outer surface of the bait decreased, but even in the 12-month test, the baits retained sufficient toxin to remain highly effective against ship rats and mice. However, there was an apparent downward trend in the concentration of toxins in the baits from 5 months onwards, so that baits older than this would become less likely to deliver an effective lethal dose to rodents in a single feed.

While it is likely that the rodents that died in these trials consumed quantities of bait far in excess of a single effective lethal dose (approximated as twice the oral LD_{50}), in an island reinvasion situation it will be important to use bait types that are sufficiently palatable to rodents to enable them to consume an effective lethal dose in a single feed. Based on a LD_{50} value of 0.4 mg/kg for brodifacoum in mice (Godfrey 1985) and an average bodyweight of 18 g, a mouse would need to consume 0.7 g of Pestoff® rodent block to ingest an effective lethal dose. Ninety percent of all mice at the different time points in the trials consumed more than this at first exposure. Ship rats, using an LD_{50} of 0.9 mg/kg (Sridhara & Krishnamurthy 1992) and an average bodyweight of 143 g, would need to eat 5.1 g of Pestoff® rodent block. Fourteen percent of ship rats at the different time points consumed more than this at first exposure. Norway rats, using an LD_{50} of 0.27 mg/kg (Godfrey 1985) and an average bodyweight of 246 g, would need to eat 6.6 g of Pestoff® rodent block. Sixteen percent of the Norway rats at the different time points consumed more than this at first exposure. The fact that ship rats had greater mortality than Norway rats would suggest that that the former species overcame initial avoidance behaviour quickly and ate a lethal dose at subsequent exposure to the bait. Higher proportions of all three species consumed an effective lethal dose on their first night's encounter with fresh Pestoff® rodent block (Mice 100%, ship rats 35%, Norway rats 50%) compared with weathered bait at all time points.

Based on an LD_{50} value of 0.99 mg/kg for bromadiolone in mice (Meehan 1978) and an average bodyweight of 18 g, a mouse would need to consume 0.7 g of Contrac® to ingest an effective lethal dose. Eighty-eight percent of the mice at the different time points combined consumed more than this at first exposure. Ship rats, using an LD_{50} of 2.2 mg/kg (Sridhara & Krishnamurthy 1992) and an average bodyweight of 143 g, would need to eat 12.6 g of Contrac®. Four percent of ship rats at the different time points consumed more than this at first exposure. Norway rats, using an LD_{50} of 0.65 mg/kg (Meehan 1978) and an average bodyweight of 246 g, would need to eat 6.4 g of Contrac®. Six percent of the Norway rats at the different time points consumed more than this at first exposure. As with Pestoff®, the fact that greater mortality with ship rats occurred compared with Norway rats would suggest that ship rats overcame initial avoidance behaviour and ate a lethal dose at subsequent exposure to the bait. Similarly, higher proportions of all three species consumed an effective lethal dose on the first night's encounter with fresh Contrac® (mice 95%, ship rats 10%, Norway rats 40%) compared with weathered bait at all time points. The high proportion of mice consuming a lethal dose may be indicative of neophilic behaviour, i.e. they are attracted to new objects in their familiar environment (Clapperton 2006), but continuing high palatability percentages of the toxic baits through the various weathering time points show that even though the toxic baits were weathered they still were preferred or equally preferred to the fresh (< 3 month old) RS5 baits.

In field situations, the amount of bait eaten by an invading rodent on first encounter is a critical factor in successful control, as they may not encounter bait more than once. Our results indicate that rats, in particular, will not always eat a lethal amount of either Pestoff® or Contrac® on first encounter when alternative food is present. Successful prevention of island invasion using 'sentinel' baits must therefore rely on baits retaining high palatability and efficacy over time, and also being applied in such a way that rodents are likely to have multiple encounters with bait over a short period of time.

The 0% mortality of Norway rats with Contrac® after 1 month is most probably indicative of an initial neophobic response, with the rats not consuming a lethal dose in the 3 days they were exposed to the bait. In fact, the lower and more variable efficacy of both bait types (Pestoff® or Contrac®) at all time points against Norway rats may be related to neophobia, food preference, or a combination of both. The Norway rats caught for this trial were commensal, and neophobia has been described as common behaviour in commensal but not non-commensal Norway rats (Clapperton 2006). Protection against Norway rat invasion could be enhanced by using Pestoff® and Contrac® in the types of bait stations shown to be favoured by that species (Spurr et al. 2006), thereby increasing the liklihood of uptake of bait by invading rats. Another option would be to improve palatability of Pestoff® or Contrac® rodent blocks to Norway rats by altering the bait composition with additives or lures. These could include food-based lures, which may increase the attractiveness of the bait as well as enhancing its palatability; or lures based on the physiology or biochemistry of the target rodent species (O'Connor & Eason 2000).

Some mice appeared to have eaten substantial quantities of Contrac® over 10 days without showing any effects of poisoning. A possible explanation for this is measurement error, but we consider this unlikely, as many of the individuals that died ate similar or smaller measured quantities of bait (as little as 1.1 g) as survivors (who ate 5.2–25.3 g). There is also evidence from the UK of low levels of natural resistance to bromadiolone in mice (Rowe et al. 1981), which may have been the case here. All eight surviving mice that ate Contrac® at each time period (2 at 1 month, 1 at 3.5 months, 2 at 5 months, and 3 at 8 months) were females. This may be an indication of the lower susceptibility of female mice to bromadiolone (Meehan 1978), suggesting that brodifacoum may be the most suitable toxin for mouse control.

6.3 TRIAL 3: RESPONSES OF MICE TO BAIT CHARACTERISTICS

Mice avoided bait containing 150 ppm 1080, but there was no effect of any other bait characteristic (i.e. bait medium, size, dye, or lure) on bait palatability. Mice, because of their small bodyweight, are generally considered to be relatively susceptible to 1080, although it is less toxic to mice than to most other rodents (oral LD_{50} 8.33 mg/kg; McIlroy 1982).

There was no avoidance by mice of bait containing brodifacoum. The oral LD_{50} estimates for brodifacoum in mice range from 0.4 to 0.52 mg/kg (Fisher 2005). As is often found with anticoagulant baits, mice in this trial ate up to 20 times more bait than was required for a lethal dose (i.e. 0.43–0.65 g; Fisher 2005). Because of brodifacoum's environmental persistence (Eason et al. 2001), carcasses of poisoned mice are likely to contain brodifacoum residues. Despite the efficacy of the brodifacoum baits, this over-eating behaviour is likely to increase the residual concentrations of brodifacoum available to predators or scavengers of poisoned rodents.

Our result was consistent with the findings of O'Connor & Booth (2001) who investigated the acceptance and efficacy of four rodenticide bait formulations in wild mice and found Pestoff® had high acceptance and efficacy.

7. Conclusions and recommendations

Our results indicate that the Pestoff® 20R cereal pellet bait was highly acceptable to ship rats, Norway rats and house mice, confirming its suitability for island eradication or broad-scale baiting operations. Of the long-life baits, Pestoff® rodent blocks, Contrac® All-Weather Blox, Talon wax blocks, and Rentokil Ridrat® all had adequate palatability and efficacy to all species but, overall, the Pestoff® rodent block and Contrac® All-Weather Blox performed best in terms of palatability and resultant mortality.

The marked avoidance of 1080 baits shown by mice in these trials indicates that avoidance is probably a contributing factor to the current low mouse mortality achieved by many 1080 baiting operations.

Based on the findings of this study, the authors make the following recommendations:

- Pestoff® rodent blocks and Contrac® All-Weather Blox are suitable for offshore island 'sentinel' protection against invading ship rats and mice, where long-life baits are required.
- The acceptance and efficacy of long-life baits for Norway rats needs improvement. This might be achieved by reformulation of baits to include highly palatable or familiar food items and/or effective lures.

- Long-life baits should not be left for more than 12 months in ‘sentinel’ bait stations, or should be replaced once they appear completely mouldy and/or start to fragment.
- Effective 1080 baiting strategies for mice require further investigation. If field populations of mice show significant avoidance of 1080 baits, consideration should be given to reformulation of baits and/or the use of alternative toxins.

8. Acknowledgements

This work was funded by the Department of Conservation (Science Investigation No. 3738). Julie Turner, Karen Washborne and Ryan Moffat provided technical support in animal maintenance and data collection and Mike Wehner trapped wild rodents for use in the trials. Thanks to Guy Forrester for statistical advice, Eric Spurr and Bruce Warburton for helpful comments on drafts of this report, Christine Bezar for editing, and Wendy Weller for final word processing.

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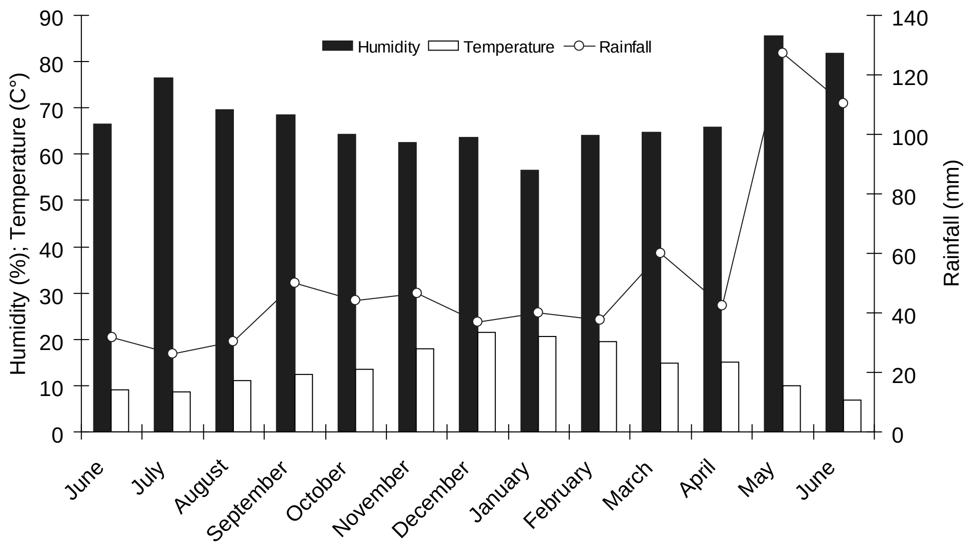
Appendix 1

LOCAL CLIMATE IN TEST AREA, JUNE 2005 TO JUNE 2006



Appendix 2

PHYSICAL APPEARANCE OF WEATHERED BAIT IN TRIAL 2

Figure A2.1A. Contrac® weathered for 2 months (on left). A small amount of brown mould was visible on the upper surface. Unweathered block on right for comparison.

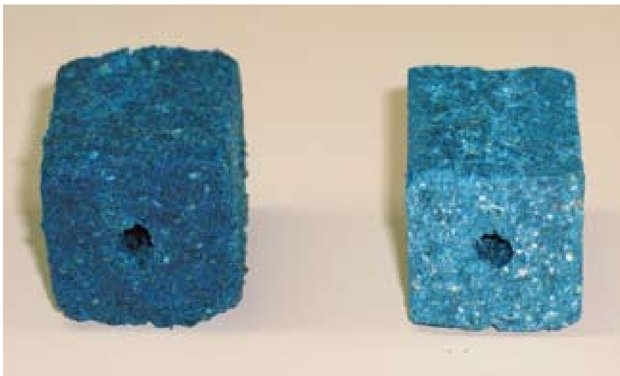


Figure A2.1B. Pestoff® bait weathered for 2 months (on left). The bait was slightly expanded and darker from water absorption. Unweathered block on right for comparison.

Figure A2.2A. Contrac® weathered for 3.5 months (on left). Approximately 50% of the bait's surface was covered with brown mould. Unweathered block on right for comparison.

Figure A2.2B. Pestoff® bait weathered for 3.5 months (on left). The appearance of the bait was similar to bait weathered for 2 months. Unweathered block on right for comparison.

Figure A2.3A. Contrac® weathered for 5 months (on left). Most of the bait's surface was covered with brown mould. Some baits were covered with wispy white and/or powdery greed mould. Unweathered block on right for comparison.

Figure A2.3B. Pestoff® bait weathered for 5 months (on left). The appearance of the bait was similar to bait weathered for 2 and 3.5 months. Unweathered block on right for comparison.

Figure A2.4A. Contrac® weathered for 8 months (on left). Most of the bait's outer surface was covered with brown mould. Other baits were covered with wispy white and powdery green mould. Unweathered block on right for comparison.

Figure A2.4B. Pestoff® bait weathered for 8 months (on left). Half the bait's surface was covered with brown and white mould. Some baits were slightly fragmented. Unweathered block on right for comparison.

Figure A2.5A. Contrac® weathered for 12 months (on left). Most of the bait's outer surface was covered with brown mould, wispy white and powdery greed mould. Unweathered block on right for comparison.

Figure A2.5B. Pestoff® bait weathered for 12 months (on left). Most of the bait's surface was covered with brown and white mould. Unweathered block on right for comparison.

Appendix 3

WEATHERED BAIT EATEN BY RODENTS

Figure A3.1A. Contrac® bait weathered for 12 months (on left) and after one night presented to a ship rat (on right). This photo demonstrates that the bait was only weathered on the surface and appeared similar in colour and density to fresh bait once the weathered surface was removed.

Figure A3.1B. Pestoff® bait weathered for 12 months after one night presented to a mouse. This photo demonstrates the friability of the weathered Pestoff® bait.

What baits do rodents prefer and are they effective?

Introduced rodents are being eradicated from increasing numbers of offshore islands around New Zealand. As many of these now rodent-free islands are remote and frequent servicing of trapping devices or bait stations is not practical, 'sentinel' systems for detection and/or prevention of reinvasion are needed, and these must remain effective over relatively long periods of time. This report describes trials conducted to determine the long-life bait most palatable to rats and mice; to see if weathering of baits affects their palatability to rats and mice; and to investigate how various characteristics of baits affect their palatability to mice.

Morriss, G.A.; O'Connor, C.E.; Airey, A.T.; Fisher, P. 2008: Factors influencing palatability and efficacy of toxic baits in ship rats, Norway rats and house mice. *Science for Conservation 282.* 26 p.