Rodent baits and delivery systems for island protection

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CONTENTS

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ABSTRACT

There are five toxicants (brodifacoum, bromadialone, coumatetralyl, diphacinone, and flocoumafen) registered for rodent control in New Zealand. They are all anticoagulants and are available in water-resistant bait formulations (i.e. wax coating, wax block, or egg). Several new rodenticide products, which are currently in the process of being developed or registered, including a new anticoagulant difethialone, have also been identified. There are no published data on the relative effectiveness, palatability, or durability of the existing rodenticides for field use under New Zealand conditions. However, relevant published information on laboratory and wild rodents is reviewed. It is concluded that the highest priority should be to assess the four weather-resistant, second-generation anticoagulant products (Pestoff® Rodent block, Talon® 50WB, Contrac®, and Baraki®) for palatability, durability, and effectiveness for an island protection situation. Improvements could then be made to the existing products if required with additives to improve palatability or durability, lures to attract rodents, and repellents for non-target insect, lizard and bird species. Trials of an alternative (e.g. cholecalciferol) to the persistent anticoagulants should also be considered for island protection. The most rodent-attractive bait station which also eliminates bird access needs to be determined for the complete island protection system.

Keywords: Rodent control, baits, toxicants, lures, delivery systems, island protection.

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1. Introduction

Once rodents have been eradicated from an island, a system of long-term protection against reinvasion needs to be implemented. For this, sustained control requires placement of discrete amounts of toxic bait in targeted areas rather than the total coverage required for eradication. This requires a basic understanding of the different rodent species. In particular, knowledge of any species differences in movement patterns will assist in determining appropriate bait station placement, and knowledge of feeding behaviour is essential in designing the most palatable bait. The diet and ecological impact of rats arriving onto a pristine island environment may also be quite different from those of established populations on the mainland (Innes 1990).

To prevent reinvasions, the Department of Conservation (DOC) currently uses cereal baits (i.e. Pestoff® Rodent bait or Talon® 50WB) housed in permanent bait stations (D. Towns pers. comm.). However, these baits tend to degrade in the humid environments and are eaten by insects. There are also growing concerns over the environmental safety and non-target impacts of the current toxins used in baits and their delivery system. Initially, existing products need to be assessed to determine if they meet the required palatability, durability and efficacy standards. Those specifications are:

Palatability:	Greater than 95% of individuals of all four rodent species consume a lethal dose of bait on first exposure.
Durability:	The bait does not break down for a minimum of 6 months in a warm and humid environment.
Target specificity:	No birds either eat or can gain access to the bait, and lizard and invertebrate interference is minimised.

The objective of this report was to review the effectiveness and environmental safety of currently available rodent baits, lures, toxicants, and delivery systems, and identify the most promising options for development of an efficient bait-lure-toxin-dispensing system suitable for maintenance use in humid island environments.

2. Background

2.1 RODENTS IN NEW ZEALAND

The four species of rodents in New Zealand are all from the family Muridae: kiore (*Rattus exulans*), Norway rat (*Rattus norvegicus*), ship rat (*Rattus rattus*) and house mouse (*Mus musculus*). Kiore, which is the smallest of the *Rattus* species in New Zealand, has been here the longest (Atkinson & Moller 1990). Norway rats, which are the largest rats, are often found near water (Moors 1990). They colonised from ships and remain a potential source of new island invasions via this route, for example, a pregnant female was trapped in

1984 on a fishing boat off Stewart Island (Moors 1990). Ship rats are the most widespread mammal on the New Zealand mainland, but are not often seen as they are nocturnal, arboreal and shy (Innes 1990). It is important to note that the established New Zealand ship rats are all of the Oceania form, which differ in karyotype and possibly behaviour from the Asian form, which has recently reached New Zealand on Asian fishing boats (Innes 1990). The house mouse is one of the most widespread mammals of the world.

All four species are generally nocturnal and have excellent senses of smell, touch, hearing, and taste. Although rodents readily explore new surroundings, they are generally neophobic, i.e. wary of any new objects in a familiar environment. This can substantially reduce initial trapping success or bait acceptance (Shorten 1954, Cowan and Barnett 1975).

2.2 RODENT CONTROL IN NEW ZEALAND

The eradication of rodents (all four species) from islands has been achieved by both ground-based (e.g. Taylor & Thomas 1989, 1993; McFadden & Towns 1991; McFadden, 1992) and aerial techniques (e.g. McFadden & Greene 1994; Towns et al. 1993, 1994, 1995). The techniques developed in New Zealand to eradicate rodents from islands (Taylor & Thomas 1989, 1993) are now being successfully used internationally (e.g. Kaiser et al. 1997).

Once rodents have been eradicated from a particular island, the next stage is to ensure there are no reinvasions. These may be from any of the rodent species, not just the species originally eradicated. Because rodents have been removed, the island ecosystem has usually regenerated and threatened species of birds have often been reintroduced. Therefore, many protection programmes would have different constraints from the original eradication programme; in particular, the risks to non-target species would be of much higher priority. The lack of tools available to either detect or control very low rodent populations has also been a problem (Wace 1986).

Vertebrate pest managers have long recognised that the success of control programmes depends directly on an understanding of the animals' biology in any given situation. More recently, the importance of feeding behaviour (Berdoy & MacDonald 1991) and social behaviour (MacDonald et al. 1999) have been emphasised. Anecdotal evidence suggests that each species of rodent may exhibit different feeding preferences for the various commercial rodent baits, but no controlled studies to verify species preferences have been conducted.

3. Sources of information

Standard review procedures, including literature searches, on both published papers and unpublished reports, were undertaken. There is an extensive literature on rodents in general. Several reports focus on wild rodents, but few from the New Zealand perspective. Our review concentrates on species present in New Zealand and the relevance of some of the international research to island protection methods.

The report focuses on (i) palatability and longevity of currently available baits with some international data on general rodent palatability studies and methodology; (ii) toxicants currently registered in New Zealand, and their efficacy and environmental safety considerations; (iii) principles concerning the development of effective lures; and (iv) delivery systems.

4. Main findings

Five registered rodenticides (Pesticides Register 1998) are currently available in New Zealand (Table 1). They are all anticoagulants available as 15 different rodenticide products, including 11 water-resistant formulations (wax-coated pellets, wax blocks, or eggs). The different long-life formulations have not been assessed for durability or mould resistance. Liquatox® is registered for indoor use only, and the other formulations (cereal pellets and a tracking powder) are not suitable as long-life baits to prevent reinvasions.

TABLE 1. PRODUCTS CURRENTLY REGISTERED FOR RODENT CONTROL IN NEW ZEALAND.

TOXICANT	BAIT TYPE	PRODUCT NAME	DISTRIBUTOR
Brodifacoum	Pellets, wax pellets, and wax block Pellets and wax pellets Wax 'eggs'	Pestoff® Rodent bait Pestoff® Rodent block Talon® 20P Talon® 50WB	Animal Control Products Animal Control Products Crop Care Holdings Ltd. Crop Care Holdings Ltd.
Bromadiolone	Extruded block Wax pellets Wax pellets	Contrac® Ridrat® Supersqueak®	Pest Management Services Rentokil Rentokil
Coumatetralyl	Bait block Powder and wax block	No Rats & Mice® Racumin®	Kiwicare Corporation Bayer-AG
Diphacinone	Extruded block Liquid	Ditrac® Liquatox®	Pest Management Services Pest Management Services
Flocoumafen	Waxed wheat	Storm®	Cyanamid NZ Ltd

Our discussion with private companies and other researchers revealed that one of these and four other toxicants (Table 2), in eight baits, are either under development (cholecalciferol gel and zinc phosphide) or currently being considered for registration for rodenticide use (1080 rodent pellets, Racumin® paste, FeraCol®, and three Baraki® formulations).

TABLE 2. POTENTIAL PRODUCTS UNDER DEVELOPMENT FOR RODENT CONTROL IN NEW ZEALAND.

TOXICANT	BAIT TYPE	PRODUCT NAME	DISTRIBUTOR	CURRENT STATE
Cholecalciferol	Paste Gel	FeraCol® –	Feral Control Kiwicare Corporation	Limited sale permit Experimental
Coumatetralyl	Paste	Racumin®	Bayer-AG	Registration being considered
Difethialone	Grain, pellets, and wax block	Baraki®	AgrEvo	Registration being considered
1080	Cereal pellets	1080 Rodent pellets	Animal Control Products	Re-registration in 1999
Zinc phosphide	Micro encapsulated	–	–	Current research

4.1 BAITS

McFadden (1984) conducted preliminary bait preference trials with kiore on cereal types and artificial lures and Robertson et al. (1998) commented on the durability of three different bait types (Ridrat®, Talon® 50WB and Storm®) but, as previously noted by Eason (1991) and Innes (1995), there is little published research on the palatability or durability of these products under different environmental conditions. This is a significant deficiency. No information exists on the relative palatability of the current commercially available long-life baits and whether their palatability requires improvement. A bait palatable to all four rodent species is required, so that a lethal dose is consumed on first exposure. The bait must not break down over 6 months in a warm and humid environment, nor be eaten by insects (to avoid the poison entering the food chain).

In addition to palatability and durability, which are discussed in more detail later in this report, there are other influences on bait acceptance in the field. Two aspects of rodent biology are particularly helpful in understanding and improving bait acceptance: social behaviour and feeding behaviour. Social behaviour is important because it may affect access to baits. West et al. (1975) found that providing more, and smaller, bait stations increased bait consumption threefold in *Rattus rattus mindanensis*, because of the associated reduction in social disturbances. As regards feeding behaviour, Robards & Saunders (1998) found that *Mus domesticus* had quite distinct cereal bait preferences, with canary seed and ‘soft’ wheat varieties preferred. They also found that the use of these preferred whole grains in a pellet was acceptable to house mice and the only flavour or additive to improve bait consumption was fishmeal. This type of trial needs to be conducted with New Zealand rodent species to determine relative preferences of our current bait formulations with immediate follow-up with new formulations if one or more species do not find existing bait palatable. If improvements to the bait palatability are then required, knowledge of general rodent food preferences will assist in selecting the most appropriate additives to test.

Manipulation of feeding behaviour, as well as food preferences, is required to get rats to eat poisonous baits. A more complete description of 'the rodent as a food expert' (Reidinger & Mason 1983) emphasises three behavioural defences rats have against dietary poisoning: neophobia, primary or unlearned food avoidance, and learned food aversions. Although little is known about the development of food preferences in wild rodents, they usually select familiar foods (Jackson 1972). This highlights the importance of prefeeding (see Prakash 1988 for review), which not only overcomes neophobia, but also lessens the likelihood of aversions developing.

4.1.1 Palatability

Bait manufacturers claim high palatability for their bait. For example: Pestoff® rodent baits are claimed to be palatable because of the ingredients used; the overseas manufacturer (Bell Laboratories Inc.) which specialises in rodent baits considers Ditrac® and Contrac® (distributed by Pest Management Services) provide the best bait; and a new paste bait (Bayer-AG) includes fats to enhance palatability. However, there have been no independent scientific comparative evaluations of bait palatability nor comparative field trials of any of these products. Only one manufacturer (Bell Laboratories Inc.) states that they use knowledge of feeding behaviour to produce baits, their product being an extruded bait block with edges, because 'rats prefer edges to gnaw on'.

In an island protection system there will be alternative food available and hence the baits need to be at least as palatable as the alternative food sources. Hence comparative trials would need to include access to normal diet. Quy et al. (1996) found that the availability of alternative food and where baits were placed had the greatest influence on baiting effectiveness with farm populations of Norway rat. This highlights the need for two types of testing: (i) the relative palatability of the current products to determine the best bait, and (ii) bait consumption when plenty of natural foods are available to ensure consumption of a lethal dose on first exposure.

General food preferences and palatability have been studied in laboratory rats and these findings give a starting point for the type of additives that could be used if bait palatability tests on the existing baits showed that improvements were needed. As with many other animals, rats' preference for sugars has been well documented. Although they will drink a greater volume of 8% sucrose solution than any other concentration, food intake remains constant over a large range of concentrations of sucrose supplement. Addition of sucaryl significantly improved bait palatability to kiore on Little Barrier Island (Veitch 1995). Rats have also been shown to have an appetite for dietary fats (Elizalde & Sclafani 1990), and some bait manufacturers are starting to incorporate fats into their baits. However, there are some concerns that this also increases the palatability of the baits to non-target species (R. Henderson pers. comm.). The use of malted grains (soak until sprouting and then dry and toast) increases carbohydrate content by 100% and also greatly increases bait acceptance (Nolte 1999).

Laboratory Wistar rats were found to repeatedly leave a warm home cage, where a notionally adequate diet (rat chow) was provided, to travel 16 m into extreme cold (–15°C) to seek more palatable foods. The preference was: shortcake, Coca-Cola, meat paté, peanut butter, and standard rat chow (Cabanac & Johnson 1983). It is not known why the foods were preferred in this order but it may well be sugar content. Such a marked behavioural response provides a basic study design for measuring relative palatability.

Generalisation of conditioned flavour avoidance was used by Mason et al. (1985, 1991) to investigate the different flavour qualities of rodenticides. Mason et al. (1985) showed that rats are capable of recognising flavour components of a complex substance. Conceivably, if the flavour preference of the rodent in a given pest situation was known, it might be possible to formulate a bait with taste qualities that closely matched the taste preferences of the pest. Further work (Mason et al. 1991) has shown that toxicants themselves can have complex flavours. They found warfarin generalised to the broadest number of flavours, including 'bitter', 'sweet' and 'salty' qualities, which contrasts with earlier statements about warfarin being 'tasteless'. The only other toxicant tested that is used in New Zealand was calciferol (assuming it is similar to cholecalciferol), which was found to have both 'bitter' and 'sweet' qualities. This technique could be further applied to develop flavour mimics for use in prebait formulations, and flavour-masking agents to increase consumption of less palatable baits. In fact, Mason et al. (1991) suggested that common salt reliably masks 'bitter' flavours and, furthermore, both sodium nitrate and glycine appear highly attractive to laboratory rats and might enhance bait palatability.

Preliminary work with laboratory rats on the addition of a possible 'addictive' substance in a food was inconclusive (Cook & Dean 1996). In theory, the inclusion of 'addictive' lures has possible application, but they might not be target-specific, which would have detrimental implications for non-target species.

4.1.2 Environmental longevity

Bait manufacturers also make claims about long-life baits; e.g. 'Pestoff® wax-coated baits lasted ages on Codfish Island'. These statements and the lack of published results emphasise the paucity of available robust or comparable data. To increase bait longevity manufacturers often produce wax-coated baits or wax blocks, but it is generally assumed that some loss of palatability is to be expected with these baits. However, in one farm situation in Britain, when there was abundant alternative food, wax blocks proved as effective as cereal baits containing the same toxicants (Buckle 1994). This highlights the need to know the relative palatability of baits before assuming there might be difficulty with the field use of these products. If deficiencies are identified, manufacturers might be willing to improve the baits of interest.

Although a wax coating may lengthen a particular bait type's field life by a few weeks (Thomas 1998), it may not make it a truly long-life bait (i.e. durability of at least 6 months). Recent work with possum baits has shown that although a thin wax coating may limit the moisture uptake, it does not completely eliminate it and it needs only a small amount of moisture (5–10%) for mould to grow and baits to degrade (Henderson & Frampton 1999). Wax blocks can be made by a number of different processes, and this also influences the bait properties (Buckle 1994). Extruded blocks (e.g. Contrac®) withstand exposure to moisture better than compressed blocks (e.g. Pestoff®), but the current bait formulations have not been tested. Any mould that grows could affect palatability, but this also has not been investigated. If these issues are found to be a problem, there are other possible additives that may extend bait life and could be investigated.

In order to prolong the life of baits they are usually used in specialised bait stations (see section 4.4) rather than left in the open. A more recent adaptation has been the successful use of baits, Talon 50WB® particularly, in plastic bags to increase field life (Taylor & Thomas 1993). Liquid bait in a bait station could reduce the risk of non-target poisoning, since there would be no danger of cereal bait being scattered outside (Prakash 1988). Although the longevity of a liquid formulation may be greater than cereal baits, this has not been evaluated and there are no field formulations available in New Zealand.

4.2 TOXICANTS

Details of the efficacy and environmental safety are given below for the currently registered toxicants and the potential products.

4.2.1 Registered anticoagulant rodenticides

Anticoagulant toxicants act by interfering with the normal synthesis of vitamin-K-dependent clotting factors in the liver of animals (Hadler & Shadbolt 1975). This results in an increase in blood clotting time to the point where no clotting occurs.

Two first-generation anticoagulants (diphacinone and coumatetralyl) are currently registered for use in New Zealand. At least two to three feedings of bait are needed to kill rodents with these toxicants. Four second-generation rodenticides have been developed in the last 20 years: brodifacoum, bromadiolone, flocoumafen, and difethalione. Three of these are already registered in New Zealand and the fourth, difethialone, is under review by the Pesticides Board at present. These all differ from earlier anticoagulant rodenticides in that only a single feeding is needed to induce death.

The main advantage of the second-generation rodenticides is their potency, which makes them highly effective. In comparison, the first-generation anticoagulants are more rapidly metabolised and excreted, and there is less risk to non-target species. For a full review of the persistence of different anticoagulant compounds see Eason (1999).

We have not discussed the fate of the toxicants in soil or water in the following sections, since the risk of serious pollution or contamination would be low after the use of these anticoagulant baits in bait stations. The second-generation anticoagulants generally have low solubility in water and the chances of significant contamination of water by any of the toxicants is low, unless bait material was directly tipped into streams.

Brodifacoum

Brodifacoum is formulated as ready-to-use baits of low concentrations (20 and 50 ppm). It is marketed worldwide to control a wide range of commensal and field rodents and in New Zealand is available in four long-life field products: wax-coated pellets (Pestoff® Rodent bait and Talon® 20P at 20 ppm), wax block (Pestoff® Rodent block at 20 ppm), and 'eggs' (Talon® 50WB at 50 ppm).

Efficacy: Brodifacoum is undoubtedly one of the most potent rodenticides available. The LD_{50} for Norway rats is 0.27 mg/kg (Hone & Mulligan 1992), 0.32 mg/kg for kiore (L. Booth & M, Wickstrom unpubl. data), 0.4 mg/kg for mice (Hone & Mulligan 1992), and for wild ship rats 0.69 mg/kg (Dubock & Kaukeinen 1978).

Brodifacoum has been the toxicant most used in New Zealand for rodent control, with 28 of 33 rodent eradications on New Zealand islands in the last decade using it (Innes & Barker 1999). It has also been the predominant toxicant used for island protection.

Environmental safety: Brodifacoum is also extremely toxic to a number of other animal species. In most mammals LD_{50} values are ≤1 mg/kg, while most birds tested to date had an LD_{50} of between 3 and 20 mg/kg. The risk to individual bird species depends on their susceptibility, size, and their eating habits, and some species are highly susceptible with LD_{50} value ≤1 mg/kg (e.g. pukeko, Eason & Spurr 1995).

Brodifacoum has the potential to cause both primary and secondary poisoning of non-target species. Baits in bait stations, however, are likely to be less accessible to non-target species than baits on the ground. A wide range of birds has been found dead from either primary or secondary poisoning after field use of brodifacoum in New Zealand, primarily after aerial operations (See Eason & Spurr 1995 for review).

In summary, animals most at risk from feeding directly on cereal-based baits containing brodifacoum are those species that have a granivorous, herbivorous, or omnivorous diet (e.g. weka). The risk of secondary poisoning is probably greatest for predatory and scavenging birds (e.g. morepork) that may feed on live or dead rats. It has also been noted that rodents become more susceptible to predation after eating brodifacoum baits, and some die in the open (Cox & Smith 1992).

Bromadiolone

The New Zealand rodent wax block Contrac® contains bromadiolone at a concentration of 50 ppm. The wax pellet formulations (Rid-rat® and Supersqueak®) also contain bromadiolone at 50 ppm. Even at higher concentrations it is considered more palatable than most other anticoagulants (Prakash 1988), though the New Zealand bait formulations have not been tested.

Efficacy: A complete kill can be obtained in Norway rats after 24-hour feeding, whereas 5 days are needed for ship rats and a longer period for mice.

Environmental safety: A wide range of species are susceptible to bromadiolone. There are reports that hazards to wildlife do exist when using bromadiolone against field rodents even if the secondary poisoning risk to carnivores and raptors seems to be less pronounced than with brodifacoum and flocoumafen. While less potent than brodifacoum or flocoumafen, bromadiolone is also persistent in the liver (Kamil 1987).

Coumatetralyl

Coumatetralyl is an effective anticoagulant rodenticide, which is more potent than the original first-generation anticoagulants such as warfarin or pindone, but less persistent than the second-generation anticoagulants. The only bait block (which does contain some wax) available in New Zealand is 'No Rats & Mice®'. Racumin® baits contain 375 ppm coumatetralyl in the powder, wax block and new paste formulations. Although registered, the wax block is not currently sold in New Zealand.

Efficacy: The efficacy and palatability of coumatetralyl bait is well proven overseas for the ship rat and Norway rat but it is unknown for kiore.

Environmental safety: Secondary poisoning risks for predatory birds or mammals after eating rodents poisoned with coumatetralyl are currently being investigated, as it is thought that the hepatic persistence of coumatetralyl is likely to be limited when compared with second-generation anticoagulants such as brodifacoum. Also, the acute toxicity of coumatetralyl in one bird species (Cape sparrow *Passer melanurus*) is low when compared with its acute toxicity in rats (Heyl 1986) and the toxicity of brodifacoum to birds (Godfrey 1985).

Diphacinone

The rodenticidal activity of diphacinone was first described in 1952. It is available for field use in New Zealand as a wax block (Ditrac®) at 50 ppm. A liquid formulation (Liquatox®) is also available but is for indoor use only.

Efficacy: Diphacinone is more toxic than pindone or warfarin to most rats and mice. House mouse populations may be effectively controlled, but prolonged baiting periods are necessary. Diphacinone is not effective against warfarin-resistant rodents (Prakash 1988). The acute oral LD_{50} ranges from 3 mg/kg in the Norway rat to 141–340 mg/kg in mice (Hone & Mulligan 1982; Note: the two values shown are those reported from two different acute toxicity studies).

Environmental safety: The LD_{50} ranges from 7.5 mg/kg in dogs, 14.7 mg/kg for cats, 35 mg/kg in rabbits, 150 mg/kg for pigs, and 3158 mg/kg for mallard ducks. There are few published data on the secondary poisoning risks from diphacinone, but birds have been shown to be affected by eating poisoned carcasses. In laboratory trials (Hone & Mulligan 1982) both great-horned owls and saw-wheat owls were affected, but not barn owls. In the USA, golden eagles showed signs of haemorrhages after eating meat from animals poisoned with diphacinone (Savarie et al. 1979). New Zealand pen trials have shown 71% mortality in stoats fed diphacinone-poisoned rats (Spurr & O'Connor 1998).

Flocoumafen

Flocoumafen is a second-generation anticoagulant developed by Shell Research Ltd and still registered through them as a rodenticide in New Zealand in a wheat-based bait (Storm®) at 50 ppm.

Efficacy: Flocoumafen is similar to brodifacoum, but most rodent species have higher LD_{50} values for flocoumafen than for brodifacoum (Haydock & Eason 1997).

Environmental safety: Flocoumafen is also extremely persistent in the liver and has the potential to cause both primary and secondary poisoning of non-target species. There is very little detailed information on the non-target impacts of flocoumafen, but as this toxicant is very similar to brodifacoum the impacts are also likely to be similar.

4.2.2 Potential rodenticides

Cholecalciferol

Cholecalciferol was developed in the 1980s as a rodenticide (Marshall 1984). Although there are no cholecalciferol rodenticides currently registered in New Zealand, two new cholecalciferol baits are currently being developed, so we have included it in this review. Feral Control has a new cholecalciferol paste FeraCol®, for possums and rodents, which currently has a limited sale permit. There will be two bait types: a peanut paste and an oil-based citrus paste. In addition, they will be marketing biodegradable 'paper' bags which will hold the paste for at least 3 months if not broken (J. Kerr pers. comm.), but will degrade if the bag is damaged, allowing paste to be exposed to the weather. Secondly, a new cholecalciferol gel bait is currently being developed for possums by Kiwicare Corporation Ltd (see Table 2). Because of the long-life formulation of this bait and the known toxicity of cholecalciferol to rodents, there is a potential to develop this bait type further, specifically as a rodenticide.

Efficacy: Our experience with cholecalciferol in rabbits (Eason 1993) and possums (Henderson et al. 1994), and the conflicting reports of the efficacy of cholecalciferol in rodents (Marshall 1984, Twigg 1992, Tobin et al.1993) strongly suggest that the use of highly palatable bait, taste 'masks', and pre-feeding are important for consistent efficacy.

The single dose LD_{50} for cholecalciferol in Norway rats and house mice is similar (between 40 and 45 mg/kg). No LD_{50} data are available for ship rat*s* or kiore.

Environmental safety: There is considerable species variation in susceptibility to cholecalciferol amongst other mammals and birds. The risk of secondary poisoning is low, and multiple exposures over several days would be required to cause toxicosis.

Cholecalciferol is less toxic to birds than the other rodenticides (Haydock & Eason 1997). However, the lower toxicity to birds does not mean that they could not be poisoned, and the appropriate use of bait stations would still be important. There have been few studies assessing the toxicity of cholecalciferol to invertebrates, but it appears to be low, based on one study which showed no deaths in weta (Ogilvie & Eason 1996).

Difethialone

Difethialone is a second-generation anticoagulant from a different chemical family than brodifacoum. A commercial rodenticide Baraki® is available overseas and AgrEvo have an application for registration currently before the New Zealand Pesticides Board. Three formulations are being registered; one is a wax block (Baraki®), which should be evaluated alongside the other second-generation anticoagulant blocks for its relative palatability and durability.

Efficacy: Difethialone is considered palatable and efficacious in both laboratory (Nahas et al. 1989) and field tests (Marshall 1992, Saxena et al. 1992) against Norway rats and mice. The LD_{50} ranges from 0.38 mg/kg for ship rats to 0.51 mg/kg for Norway rats (Lechevin & Poche 1988), and is unknown for kiore.

Environmental safety: Despite being considered as potent as brodifacoum, difethalione is believed to pose less of a threat to non-targets because of the low level of the poison in baits (Lechevin & Poche 1988). Nevertheless, there is a prolonged half-life of difethalione in the liver, which is likely to pose secondary poisoning residue threats similar to those of brodifacoum to some non-target species, and it is known to be toxic to birds (Lechevin & Poche 1988).

Sodium monofluoroacetate (1080)

Sodium monofluoroacetate (1080) has not been used in rodent eradications, but is used to control both possums and rodents in many mainland control operations. Animal Control Products is currently renewing the registration to include both 0.08% and 0.15% for both rodents and possums (B. Simmons pers. comm.).

Efficacy: 1080 can be highly effective at killing rats, and over 90% of ship rats have been killed after aerially sowing of 1080 baits in New Zealand (Innes et al. 1995). It is generally effective against all rodents, but is less toxic to mice (LD_{50} 4.0–8.0 mg/kg (Eisler 1995)). The LD_{50} value for laboratory strains of Norway rats has been reported as 2.5 mg/kg and less at 0.1 mg/kg for wild ship rats. However, as symptoms of poisoning occur within 30 minutes to 1.5 hours, bait shyness may be induced when 1080 is repeatedly used for sustained rodent control (Sinclair & Bird 1984). There has been one report of kiore avoiding 1080 at 0.8% (Atkinson & Moller 1990).

Environmental safety: Non-target effects of 1080 control have been studied extensively over the last 50 years. Sodium monofluoroacetate is highly toxic to invertebrates, mammals, and birds, and should be used with care so that non-target species likely to eat baits do not come into contact with them. Dogs are extremely susceptible, and most other carnivores are highly sensitive to poisoning. Herbivores are less sensitive, and birds and reptiles are the least sensitive (Atzert 1971). However, individuals of a wide range of mammal and bird species have been found dead after 1080 use (Spurr 1991, 1994), and endangered species with limited numbers could be placed at risk of primary or secondary poisoning by use of 1080. Poisoned rodents should be considered a hazard to other animals that may prey on or scavenge them.

The environmental fate of 1080 has been more extensively studied than any other vertebrate pesticide. It can be metabolised by some soil micro-organisms, such as *Pseudomonas* species (Walker & Bong 1981, King et al. 1994). Sodium monofluoroacetate derived from bait that is dislodged from bait stations will also be dispersed by water since it is water-soluble.

Zinc phosphide

Zinc phosphide is used extensively in Australia to control mouse plagues, and in the USA for controlling many species of rodents. This compound has been thoroughly researched in the USA and is supported by a full regulatory toxicology package to EPA standards for field use. The shelf life of baits is short, however, as zinc phosphide degrades rapidly and is less effective after contact with moisture (Bhatnagar et al. 1995). Currently Landcare Research is investigating a microencapsulated formulation of zinc phosphide (MEZP) that renders the compound undetectable, avoids the development of bait shyness, and is also shelf-stable. There may be future possibilities of including the microencapsulated formulation in a long-life field bait.

4.3 LURES

For an island protection programme, the incorporation of powerful attractants in baits is likely to be very important, although it is not essential for commercial products used principally for control rather than eradication. Lures will increase the sphere of influence of a bait and may also increase consumption of baits. However, these are different functions and may require two different attractants. Pennycuik & Cowan (1990) found that although some odours attracted the attention of house mice, they did not necessarily increase acceptance of the test food. Potential attractants can be divided into two classes:

- food-based (which may also act as flavours);
- animal-based (i.e. those relating to the physiology or biochemistry of the rodent, e.g. pheromones).

The manufacturers indicate that bait formulations have been designed to contain ingredients palatable to rodents. For example, Talon® includes tallow, castor sugar, and wheat, and Storm® includes crushed wheat, citric acid, and salt, which are intended to be attractive to rats. However, no commercially available baits contain lures specifically designed to attract rats. A number of other flavours are used as lures, generally based on individual user preference (e.g. white chocolate, D. Merton pers. comm.). Macadamia nut is currently a popular lure but the two main suppliers say that 'everyone wants something different' (S. Boswell pers. comm.).

Carbon disulphide (CS_2), present in the rodent breath, is responsible for inducing diet preference in rodents (Galef et al. 1988). The addition of CS_2 to a bait has also been shown to increase bait consumption and time spent at a site (Bean et al. 1988). Carbon disulphide is therefore a biologically meaningful odour to rodents that increases attractiveness of foods. However, in the decade since these results were published it has not been used in commercial baits. This may in part be due to its volatility and/or toxicity.

Although environmental marking by animals generally relays social, sexual, or reproductive status, it has also been shown that scent marking by Norway rats may play an additional function in communicating food preferences. Excretory deposits that surround food sites render those sites, and the food, more attractive to Norway rats than unmarked sites (Laland & Plotkin 1991). Further manipulation of this behaviour at a bait station may not lure a rat to the site but should assist in bait uptake.

4.4 DELIVERY SYSTEMS

4.4.1 Aerial application and traps

Most rodent eradications on islands during the last 10 years have been by aerial application of toxic baits, but this is very unlikely to be a method used for long-term protection of islands, where discrete use of toxic baits is recommended.

Despite the large array of commercial rodent traps available, the only type used in the field are snap-traps, and these have primarily been used for monitoring purposes.

There has been no efficiency or welfare testing of rodent traps in New Zealand, although for island invasions, which involve individual animals, it could provide a useful non-toxic tool.

4.4.2 Bait stations

Most rodent baits, except grain baits (particularly for mice), are used in bait stations. There are more bait station types on the market than baits, but most are very similar. They are generally either light- or heavy-weight plastic (though cardboard is also available), rectangular, or pipes, or tunnels, and often with some form of lockable lid. Many of the designs are specifically for use within buildings and are not appropriate for field use. There has been very little scientific evaluation of station design on either station acceptance or bait uptake. One trial overseas has evaluated eight different bait station designs and found that wild Norway rats showed the greatest delays in utilisation of the stations when they had more complex, internal baffles (Kaukeinen 1987). In addition, Kaukeinen (1987) comments that some materials, including some plastics, may have more repellent tendencies than others. In a less extensive comparison Bohills et al. (1982) found that house mice preferred smaller boxes to large boxes and cardboard to plastic. Another study with Norway rats has highlighted the problem of neophobia to new bait containers (Inglis et al. 1996). This avoidance behaviour was far stronger than the more extensively studied neophobia to new foods. Although the idea is untested, they suggest leaving bait stations in the environment before laying toxic bait so that the rats become familiar with them. Far more consideration should be given in bait station design to the behaviour of the target rodent, including the size of access holes, internal feeding area dimensions, and materials used.

Some distributors use the dispensing system to help improve bait longevity, for example, Contrac® and Ditrac® last longer because they are put on a wire and kept above the ground in the bait station. Similarly, the new cholecalciferol paste FeraCol® is marketed in a 'waxed paper bag', which will last at least three months if the bag is not broken.

The different behaviours (e.g. habitat and feeding preferences, and movement patterns) of the different species may mean several different bait station situations are required. Station placement has to have regard for rodent density and movement, regardless of where the operation is being undertaken. Ship rat home-range lengths in forest average about 100–200 m (Hooker & Innes 1995), whereas kiore home ranges were only 37–60 m on Tiritiri Island (Atkinson & Moller 1990). Rat movements will vary throughout the year and between individuals, but it would appear that closer bait station spacing would be required to eradicate kiore (Innes 1995). However, for an island protection system the movement and home-range sizes of very low density rodent populations (even one individual) are not known and will need to be considered for optimum station placement.

The use of an appropriate bait station can help in decreasing the chances of non-target exposure. A long-life, durable, and rodent-specific bait station would be ideal for island protection. Although in some instances caching may provide a real advantage for rodent control, because baits will be taken to places where there are other rats and where rats feel comfortable feeding, there are other non-target risks associated with baits being left or cached in the environment.

The increased concern for non-targets and the low rat densities expected in island protection programmes mean there will be fewer chances for social influences to affect bait consumption. We would recommend systems that avoid bait removal.

5. Conclusions

Sustained control is required for an island protection system, but this should be accomplished through discrete amounts of a bait in targeted areas, rather than the total coverage principle required for eradication. The bait also needs to be highly attractive to all rodent species, even when there are plenty of other foods available.

There are five different anticoagulants in 15 rodenticide bait formulations currently available in New Zealand. Of these formulations, seven (including one new anticoagulant bait) are a wax block (or egg), which is assumed to be the most durable of the bait types. There have been no comparative field tests of the efficacy, palatability, or durability of these rodenticides.

Although there are concerns about possible insect interference and cereal baits breaking down under warm and humid weather conditions, the comparative durability of the commercial wax block formulations, or their palatability to insects, has not been established.

At least two options need to be developed for island protection: (i) a potent second-generation anticoagulant, and (ii) for areas of high risk to non-targets from either primary or secondary poisoning, an alternative such as cholecalciferol should also be available.

A critical part of a successful system would be the specificity of the delivery system and best placement of the bait stations. Environmental longevity may also be improved by the bait station design (i.e. protected from the weather and the ground).

6. Recommendations

Our recommendations for the development of an island protection system are based on a step-wise process (see also Fig. 1):

Step 1

a. The palatability and environmental longevity of four wax block formulation rodenticides (i.e. Pestoff® Rodent block, Talon® 50WB, Contrac®, and Baraki®) should be assessed. These four are recommended initially because they contain potent second-generation toxicants in wax block formulations. The baits should also be tested under different environmental treatments (i.e. temperatures and humidity).
b. The bait consumption of the best bait identified in (a) then needs to be tested when plenty of natural foods are available to ensure consumption of a lethal dose on first exposure for all rodent species.

Step 2

The extent of non-target consumption of bait by indicator bird, lizard, and insect species needs to be determined for the currently available bait types.

Step 3

The best current bait should be redesigned and improved, if required. Prudent additives, lures, insect, lizard or bird repellents could be evaluated in conjunction with bait manufacturers to improve palatability, durability, or target specificity.

Step 4

Systematic investigation of bait stations is needed to not only determine that they are rodent-specific, excluding non-target species (particularly birds), but also that they are readily used by all rodent species. We will need a better understanding of rodent species movement patterns, social and feeding behaviour, so that the most effective and targeted control systems can be developed.

Final Outcome

A highly palatable and attractive bait delivered in a target-specific and weather-proof bait station for island protection use.

We also recommend the development of an alternative toxicant bait (i.e. an acute toxicant or first-generation anticoagulant) which also satisfies the specifications for an island protection system.

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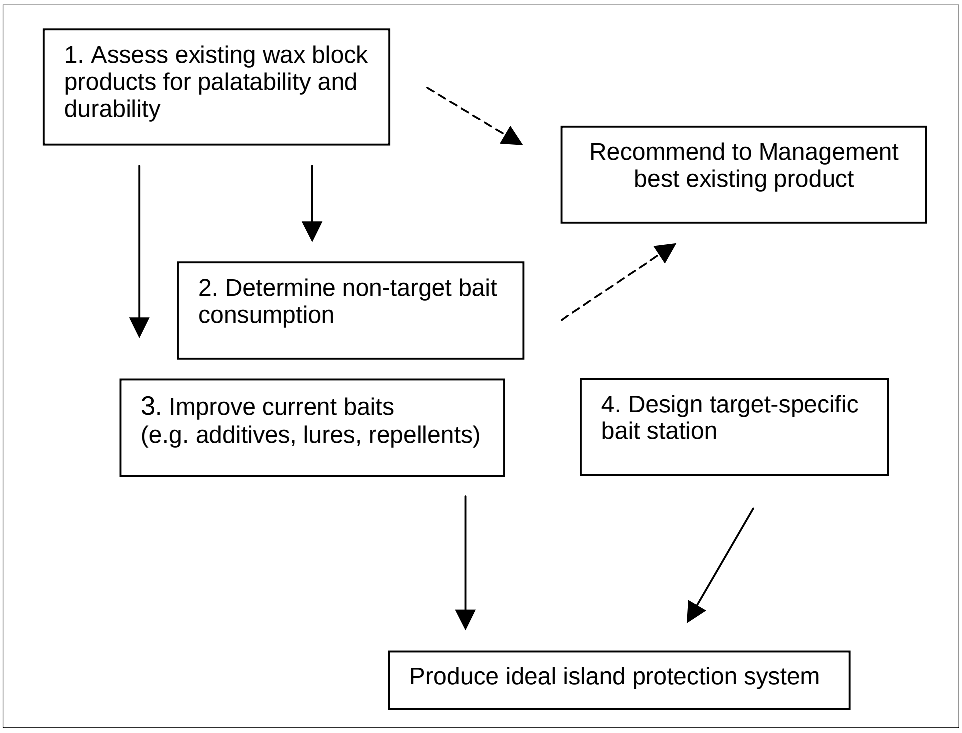

Figure 1. Diagram of proposed step-wise procedure for developing an island protection system.

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