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ABSTRACT: The commensal rodent pest species have spread from their ancestral homes in Asia to inhabit many natural ecosystems worldwide. The introduction of these exotics has often had a significant effect on endemic plant and animal species but their impact has, perhaps, been most severe on off-shore and oceanic islands where nesting birds, insects, terrestrial molluscs, reptiles and amphibians are all vulnerable. Conservationists have used a variety of control approaches either to reduce or eliminate the pressure of competition and predation exerted by introduced rodents on island populations of endangered species. Successful projects have involved a sequence of carefully-planned operations. Firstly, an assessment of the nature and scope of the rodent threat is undertaken to permit the development of a control programme with the maximum chance of success. A second element is the estimation of the likely impact of intended control operations on non-targets in these highly sensitive environments. A pilot study may be required prior to the third and final stage, that of implementation and then monitoring the effect of the programme on target pests, sympatric non-targets and the species that are the object of the conservation effort. The anticoagulant rodenticide brodifacoum (trade names 'Klerat' and 'Talon') is used in conservation projects worldwide. This paper puts forward general principles for adoption when employing this compound for conservation and exemplifies the approach advocated with descriptions of a number of projects undertaken for the benefit of a variety of endangered species.

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INTRODUCTION

The three now cosmopolitan commensal rodent pest species, *Rattus norvegicus, Rattus rattus* and *Mus musculus,* are believed to have evolved on the Asian continent. From there, they dispersed, probably in association with human systems of transport, and now are to be found throughout the world. Part of this process of dispersal occurred through the infestation of sailing ships during the main period of exploration of both the New and Old Worlds. Oceanic islands were important during this exploratory process both as aids in navigation and, once inhabited, as places where stores and equipment could be replenished. It is not surprising, therefore, that many oceanic island groups became infested with rats and mice during this period, and Atkinson (1985) has recorded the history of this process.

In the Pacific, a fourth rodent species, *Rattus exulans,* also underwent a period of human-aided range expansion. It travelled with the migrating Polynesian peoples from its ancestral home in the Indo-Malayan region to colonise all the islands inhabited by that race, from Hawaii in the north to Easter Island in the east. Once again, Atkinson (1985) has charted these events.

The effect of the three rats species on the island biotas they have invaded has been severe. All are omnivorous, preying upon birds, small mammals, reptiles, insects, amphibians and molluscs, and consuming a wide variety of vegetative material. However, the species differ somewhat in their behavioural characteristics and therefore in their potential ecological impact. *R. norvegicus* is large and fossorial; making ground-dwelling animals, ground-nesting birds and those that nest in burrows particularly vulnerable to its depredations. *R. rattus* is smaller but is an adept climber and preys most often on perching bird species. The smallest of these pests is *R. exulans* but amongst its prey are numbered the largest animals recorded to have been taken as adults by rats, the Laysan Albatross and the Great Frigatebird (Woodward 1972).

The number of extinctions brought about by these rodent invasions will never be known, because most occurred before accurate records were kept. However, the impact of these animals on island biotas is demonstrated by several recent, well-documented episodes (Atkinson 1985). For example, *R. rattus* invaded Lord Howe Island in 1918 and within a decade more than 40% of the island's landbird species had been eradicated. In 1943, a similar process was seen on Midway Island when two endemic birds were eliminated within 18 months of another *R. rattus* invasion. Most recently, the colonisation in 1962 of Big South Cape Island, off New Zealand, by the same rodent species resulted in the extinction of eight species of landbirds.

These dramatic events are only the most recent examples of the impact that the inadvertent introduction of rodents into vulnerable island biota has had on their endemic flora and fauna. The recognition that this destructive process continues to the present day has caused conservationists to consider strategies of rodent control to halt, and even to reverse, its highly detrimental effects.

CONSERVATION STRATEGIES

Over the past 20 years, many successful rodent control programmes have been mounted in which the principal objective has been the conservation of a species, community or biome. Of course, these programmes have varied greatly, both in their nature and scope, but generally they have involved three separate operations.

Rodent Control

The first operation is a detailed examination of the of the rodent population and this leads to a plan for the control programme. The effects of the rodents should be quantified, if possible, because it may be tempting to assume that obvious rodent depredation is the major cause of the decline of a scarce species while, in fact, it is only a minor contributory factor. However, if it is clear that rodents are having an important detrimental effect it becomes necessary to consider the options to halt this process.

Rodent control in island conservation frequently differs from conventional rat management in one important respect. Because of their isolated positions and limited size, islands may invite the complete eradication of their exotic rodent populations, whereas this is rarely feasible under normal circumstances. Eradication is, however, a very challenging objective (Moors 1985) and requires a level of resource and commitment beyond the scope of many projects. When eradication is to be a goal it is essential first to consider the possibility of reinvasion, for it is pointless to aim at eradication if it is likely that the cleared areas will quickly become recolonised. However, eradication has one substantial advantage over alternative strategics, that is, once achieved, its benefits are perpetual or, at least, very long-lived.

When eradication is not an option, either because rapid reinvasion is likely or because the task is beyond the scope of available techniques or resources, the objectives of the programme must be less ambitious (although not necessarily more easily achieved). For example, the objective may be the removal of rats, over a limited area or for a restricted period of time, or merely the reduction of rodent numbers in a given area, to reduce competition for a scarce resource such as food or nesting burrows. Several of the projects described below have objectives to provide rat-free nesting sites for birds during the breeding season, in the knowledge that the sites will quickly become rat infested when rodent control efforts cease. The disadvantage of such programmes is that they must be repeated season after season until the vulnerable population has sufficiently recovered to be left to its own devices. Even then the situation must be carefully monitored and intervention exerted again if there are signs of deterioration.

Perhaps the most difficult decisions to be made about the control programme relate to the choice of rat killing methods to be used. However, although many methods have been considered, the one most commonly adopted is the use of rodenticide baits. Among available rodenticides, the acute poisons such as sodium monofluoroacetate (compound 1080) and zinc phosphide have the advantage of being fast-acting; rats that take a lethal dose succumb to the poisons in a matter of hours. However, they have the substantial disadvantage that those taking a sub-lethal dose are able to relate the unpleasant symptoms of toxicosis with the poisoned bait recently consumed and refuse to eat it again. These 'bait-shy' animals are subsequently very difficult to control. Also, even the most skilled operators are unable to achieve complete control with these materials. The early anticoagulants, such as warfarin, do not cause bait-shyness because of their chronic mode of action and can give complete control. However, they are now rarely used in conservation rodent control programmes because a lethal dose is only accumulated after several consecutive days of bait consumption and in many circumstances this is an impractical expectation. The second generation anticoagulants combine the 'single feed' benefit of the acute rodenticides with the highly advantageous chronic mode of action. The most active of these compounds, brodifacoum (trade names 'Klerat' and 'Talon'), has now been widely used with excellent results in many conservation control programmes.

Environmental Impact Assessment

The initial plan for the control operation will define the nature and extent of poisoned bait applications and with this information available it is possible to begin the second stage of the programme—an environmental impact study. It is axiomatic that the habitats in which these programmes are to be carried out are highly vulnerable and the use of any vertebrate control agent in such circumstances necessitates the careful consideration of possible non-target effects. Non-target hazards fall into two categories, (1) primary hazards, those related to the direct consumption of poisoned baits by non-targets and (2) secondary hazards, those which occur as a result of non-target animals feeding on poisoned rodents. With a knowledge of the ecology of the non-target species present in the treated area, particularly their feeding patterns, and the characteristics of the control agents to be used, a competent field biologist will be needed to conduct an appropriate risk assessment. The benefits of the planned programme will then be set beside these risks and if the balance is favourable, as is almost always the case, implementation can proceed. However, it may be necessary to modify the programme if non-target hazard is unacceptable. If some effect is predicted, it will be necessary to establish the population size of the species at risk, so that numbers can be monitored during and after the treatments.

Finally, consideration should be given to the amount of disturbance that rodent control activities will cause. The application of poisoned bait requires frequent visits to treated areas and this may be to the detriment of the animals and plants living in them. Of course, it may be possible to conduct operations outside the period of residence of those bird species most vulnerable to disturbance but, if not, disturbance must be kept to an acceptable minimum.

Implementation of the Control Programme

The third stage of the programme is that of implementation. It is impossible to be specific about this operation because each programme has its own unique characteristics. One feature common to them all, however, is that the difficulties of logistics are always more important than those presented by the application of the control techniques themselves. Treatment sites are usually remote, resulting in problems of transportation, and in most cases terrain is very difficult. Frequently, manpower and financial resources are limiting, and often only short periods of time are available to complete complex and challenging tasks.

In outline the programme at this stage comprises three operations, the rodent control scheme, monitoring its effect on target populations and, where necessary, assessment of any impact on non-targets. Differences and similarities between programmes will be apparent in the following description of a number of recent conservation rodent control projects carried out using baits containing the anticoagulant, brodifacoum.

THE USE OF BRODIFACOUM IN CONSERVATION PROJECTS

Eradication Campaigns Against Norway Rats on the Noises Islands, New Zealand

Norway rats colonised the Noises Islands, probably within the last 50 years, either by swimming from infested neighbouring islands or by being carried ashore on rafts of refuse routinely dumped in the sea nearby. The first recorded rat sighting was in 1957 and soon afterwards Norway rats were held responsible for the deaths of hundreds of White-faced storm petrels *(Pelagodroma marina).* Some of the smaller islands in the group were successfully disinfested in the 1960s with the intensive use of warfarin baits. However, rat populations remained on the larger islands of Otata and Motuhoropapa.

A campaign to eliminate rats from the 22ha island of Otata began in late 1979. A total of 107 covered bait stations were set out in a grid of roughly 40 x 40m, with additional stations along the shoreline. The stations were designed to exclude ground-feeding birds, which were the main non-target risk there being no other land mammals on the island. At first, baits containing compound 1080 were used after prebaiting but these proved to be largely ineffective. A second baiting campaign employed an experimental brodifacoum-based 5g wax block formulation. Blocks were placed at 5m intervals on transects spaced 40m apart, giving an application density of 330 blocks/ha. About 37 man-days of effort were required for this operation, which was thought to have resulted in the virtual elimination of the rats. However, the island was checked regularly for rat signs over the next nine months and a second baiting campaign was initiated when rodent activity was discovered in the only human habitation on the island. Once again, 1080 was used followed by brodifacoum baiting. This time the bait was a commercially available formulation, 'Talon 50WB,' a 15g briquette containing 50ppm of the active ingredient.

Frequent visits to the island, during the period October 1980 to February 1984, failed to reveal any subsequent sign of rodents and it appears that the island was cleared of rats by these measures. The eradication of Norway rats from neighbouring Motuhoropapa island followed a broadly similar course.

The Noises Islands projects were conducted by the New Zealand Wildlife Service and have been reported by Moors (1985). A number of valuable lessons were learned, among them that Norway rats did not readily enter the white polythene bait stations used in the later baiting programmes and that, as rats became increasingly scarce, it was very difficult to monitor their low numbers with accuracy. Several techniques were used in attempts to verify that the islands had been cleared. Soft-wood gnawing stakes soaked in cooking oil, on which rats leave characteristic tooth marks, were the most reliable method but trapping and searches for other signs of rodent activity also proved useful. It is interesting to note that, although many intensive poison baiting campaigns were mounted, there was no evidence that animals other than rats had been killed.

The Removal of Norway Rats From Breaksea Island, New Zealand

The successful eradication of rats from the Noises Islands led to several organisations in New Zealand initiating similar projects on other off-shore islands. In 1986, a team from the Ecology Division, Department of Industrial and Scientific Research, successfully eradicated Norway rats from the 9ha Hawea Island, off Fiordland, as a prelude to a much larger enterprise, the clearance of rats from the neighbouring 170ha Breaksea Island (Taylor and Thomas 1989).

Earlier, biological surveys of the area had recorded the rich flora and fauna of adjacent, rat-free Wairaki Island and this was in contrast to the impoverished ecology of Hawea and Breaksea. In particular, Fiordland skinks (*Leiolopisma acrinasum*) and several endemic weevils were abundant on Wairaki but absent from the other two larger islands.

Work started on Breaksea in January 1987 when volunteers began to cut a series of tracks on contours at 60m intervals and, in early 1988, a base hut was built. Before the poisoning campaign began in May 1988, eight pairs of New Zealand robins (*Petroica australis*), the main non-target species at risk, were removed to Hawea. A total of 743 bait stations, each a 40cm length of flexible pipe of 10cm diameter, were put out at 25 or 50mintervals on the contour paths cut earlier. The poison bait used was again 'Talon 50WB.' Two of these 15g baits were put in each station on the first day of application and replaced daily, if taken by rats, for 21 days. The baits proved very attractive, 80% were taken on the first night and 100% for several more nights until the poison took effect and consumption began to fall off at the end of the first week. The pattern of bait take from stations was carefully monitored and, when the team left the island, only two stations remained active, the amount of bait taken from them indicating that rats there had already taken a lethal dose.

The effect of the campaign on non-targets was also closely monitored. Although the bait stations were designed to exclude birds, there was evidence that some baits found outside them had been partly chewed by Keas (*Nestor notabilis*). The only casualties found, however, were two robins that may have eaten bait crumbs scattered by rats. Nevertheless, standardised counts of robins indicated similar numbers inhabited the island before and after the treatment.

On their return to the island one month later, members of the team found no active signs of rats. Fresh poisoned baits were put out in all of the bait stations and pieces of eating apple were placed nearby. None were taken by rats. This process was repeated on several occasions over a period of two years with the same result. The eradication of Norway rats from Breaksea was confirmed.

The natural wildlife of Breaksea will now be reconstructed by re-introducing chosen species from other refuges. The clearance of Hawea and Breaksea had the added benefit of removing the risk of rats crossing from them to the uninfested Wairaki.

The Protection of the Madeira Freira

A remnant population of *Pterodroma madeira,* Europe's rarest seabird, breeds on inaccessible cliff ledges on mainland Madeira (Zino and Zino 1986). Probably, less than 30 reproductive pairs of these petrels remain and they are under threat from infestations of Ship rats which are abundant in the vicinity of the breeding colony. For several years during the mid-1980s the birds apparently failed to breed and this was attributed to predation on eggs and chicks by rats.

In early 1987, the International Council for Bird Preservation, National Museum of Funchal and Natural Park of Madeira, supported by several other agencies in the UK, initiated a project to protect the petrels (Buckle and Zino 1989). The site of the colony, a ledge on a precipitous cliff, was a very difficult situation in which to conduct a rat control programme. The plan involved climbers placing a total of about 70 bait boxes, both on the ledge and in all accessible areas within about 100m of the colony. This was to be done in an attempt to reduce the rat populations near the breeding birds and to remove them entirely from the nesting ledge. The programme was to maintain bait in the bait stations the year round but to make the greatest effort in the months immediately prior to the return of the birds to breed in April. Visits to the ledge would be hazardous and often precluded by poor weather conditions. Therefore, large quantities of bait (l kg in each bait station) would be put out each time the bait points were replenished.

A non-target impact study was carried out before this plan was implemented. With the exception of the ledge itself, the site was intensively grazed by sheep and goats and these were the main primary risk. Sturdily-constructed bait boxes overcame this problem and the 'Klerat' 20g wax block baits used were fixed inside them on wires. A baffle prevented any small bait particles falling from the boxes. Other non-target species were relatively scarce, although populations of a number of bird species were present, including predators and scavengers such as buzzards (*Buteo buteo*), Bam owls (*Tyto alba*) and Herring gulls (*Larus argentatus*). However, the hazard to these birds was considered to be very low, because of the sparse populations of both target and non-target species, and no non-target casualties have ever been found.

The baiting programme began in February 1987 and quickly resulted in a substantial reduction of rat activity, as indicated by the take of poisoned bait. The birds returned to the ledge but once more failed to breed. The baiting continued in 1988 and that year, for the first time, the ledge was clear of signs of rats when the petrels reappeared but, once again, breeding was unsuccessful. However, the efforts of the determined team on Madeira were rewarded in 1989. Again the nest site was virtually clear of rats when the birds returned and this time four chicks were fledged, the first for many years. This success was repeated in 1990 and 1991, when more young petrels were produced on the baited ledge. Nevertheless, the future of the Madeira Freira is not secure. The baiting programme will be needed for the foreseeable future because those rats killed are quickly replaced by others that probably come up from the coniferous forests below the petrel colony. It seems unlikely that the efforts of the climbers can be maintained indefinitely. Clearly, a less labour-intensive, but equally environmentally acceptable, baiting strategy is required.

Conservation of the North Island Kokako, New Zealand

About 65 kokako (*Callaeas cinerea wilsoni*) live in the 1400ha Mapara reserve of New Zealand's North Island. The species is listed by the ICBP as 'threatened' (Collar and Andrew 1988). The main danger to the birds is predation of their eggs and chicks by introduced mammals, including Ship rats. In 1989, the Department of Conservation initiated a rodent control project to protect some of the birds.

The widespread distribution of *R. rattus* in the New Zealand forests (King 1983) meant that eradication was not a viable strategy. Instead, 13 grids of bait points containing 'Talon 50WB' were established. Each grid consisted of 64 bait stations in an 8x8 pattern, with 50m spacing, and was located to protect the territory of a kokako pair. Baiting began in September 1989 and continued throughout the kokako breeding season until April 1990. At first, three of the brodifacoum briquettes were placed in each station weekly but, after five weeks, six baits were replaced monthly.

The success of this treatment was monitored by a team from the Forest Research Institute using several methods, including the measurement of rat activity in tracking tunnels baited with peanut butter. Prior to poisoned baiting, over 70% of tunnels showed rat activity. During the treatment, the percentage of tunnels with tracks fell to less than 8%, while rat activity on untreated grids nearby remained at high levels (72-87%).

Unfortunately, the effect of the rodenticide treatment on the breeding success of the kokako was not reported. What is certain, however, is that the treated areas were rapidly reinvaded by rats when the baiting stopped. The work demonstrated that it is possible to reduce predation pressure during the breeding season, presumably with a beneficial effect on kokako chick survival, but that the poisoning campaign must be repeated yearly to ensure the future of the kokako.

Control of Polynesian Rats on Rose Atoll, American Samoa

Rose Atoll National Wildlife Refuge comprises Rose and Sand Islands, of which Rose, at 6ha, is the larger. The atoll is a major breeding site for the 'threatened' Green turtle (*Chelonia mydas*), the 'endangered' Hawksbill turtle (*Eretmochelys imbricata*) and numerous seabirds. Polynesian rats were first recorded in 1920 and there have been many reports of them preying upon the eggs and newly-hatched young of both turtles and birds.

A programme aimed at the eradication of rats from Rose Island began in October 1990; the project being a joint initiative of the US Department of Agriculture, the US Fish and Wildlife Service and the Department of Marine and Wildlife Resources, Government of American Samoa.

An initial estimate of rat population density, obtained by removal trapping, put the number of rats present at up to 3,120; the removal process itself accounting for 919 of these. The break-back (snap) traps employed also caused the deaths of two New Zealand cuckoos, two Lesser Pacific plovers and a Sooty tern, however, and their use ceased after 18 days of trapping.

The poisoning programme began immediately after the population estimate. A total of 24 bait stations, made of 30cm lengths of 7.5cm diameter PVC pipe, was set out. Each station contained two 20g 'Talon' WeatherBlok wax baits, containing 50ppm brodifacoum, which were checked and replenished daily as necessary. Bait consumption reached a peak on day 5 when 58 of the available 62 baits were taken by rats. At this stage, an additional 9 stations were put out and active rat burrows were also baited with blocks. A total of 263 dead rats were recovered and the smell of decay was very strong in many places on the island, indicating that only a few of those poisoned by the bait were recovered.

Hermit crabs were attracted to the bait blocks and attempts to exclude them from the stations with wire and sticks were only partially successful. The rodenticide appeared, however, to have no deleterious effect on the crabs. After 33 days of baiting, no further bait takes were observed and live-capture traps were no longer catching rats. Thirty four wooden stakes soaked in peanut oil were set in place, all bait stations were provided with four foil-wrapped bait blocks and the project team left the island.

Two subsequent visits, at approximately six-month intervals, were made to the island. Both revealed a very low level of rat activity and some modifications were made to the baiting programme. The bait stations were raised up off the ground to deter the entry of hermit crabs and the number of stations was increased substantially, to 148.

Although the complete eradication of rats so far has not been achieved, the project is deemed a success. There has been a dramatic regeneration of the island's flora and some seabirds, not found to have nested in the last 10 years, have returned (Murphy, personal communication). Efforts to exterminate the remnant rat population will resume this year (1992) (Ohashi, these Proceedings).

The Eradication of Norway Rats and Rabbits From Stanley Island, New Zealand

Perhaps the most dramatic conservation pest control project was conducted on Stanley Island, New Zealand, in 1991. The preliminary objective of the programme was the reduction of rabbit (*Oryctolagus cuniculus*) and Polynesian rat populations by a single air drop of 'Talon 20P'. This formulation, containing 20ppm brodifacoum, was developed in New Zealand for rabbit control. The plan was, subsequently, to complete the eradication of rats from the lOOha island by the hand placement of 'Talon 50WB' and the eradication of rabbits by shooting.

The intention to use the potentially hazardous method of air dropping for poisoned bait application made it essential to conduct careful non-target risk assessments. An initial, theoretical analysis indicated that the major risks would be those of secondary poisoning of predatory and scavenging birds, such as Marsh harriers (*Circus aeruginosus*) and Moreporks (*Ninox novaeseelandiae*), the primary exposure of finches to the pelleted bait and the accidental ingestion of baits by ground-feeding birds, such as blackbirds (*Turdus merula*) and saddlebacks (*Philesturnus carunculatus*). A practical evaluation of primary hazard was obtained by purposely exposing unpoisoned baits to possible consumption by non-targets. This experiment showed that the bait had very low attraction to saddlebacks, a New Zealand endemic of particular concern.

The air drop by helicopter of 1.75 tonnes of 'Talon 20P' took place on 25 September 1991. It was timed during a brief period of dry weather, so that the bait would remain in good condition long enough for most rats and rabbits to encounter it, and during a shortage of other foods, so that they would find it attractive. Approximately 100kg of 'Talon 50WB' was also laid by hand.

The island was visited both in October and November, when snap traps were set, apple baits were put out and careful searches for signs of rats and rabbits were conducted. No indication of the presence of either species was found. Further evidence of the absence of rabbits was the emergence of about 100 taraire seedlings, the first produced on the island for a century.

It is too early yet to confirm the eradication of rats and rabbits from Stanley Island. Additional searches will be conducted this year. However, apparently, a single air drop of bait has dramatically reduced, and perhaps extinguished, vertebrate pests on the island. This technique has considerable advantages in terms of reduced manpower requirements over the more labour-intensive methods used on Breaksea. However, these benefits are offset, at least in part, by the need for detailed non-target impact studies. Such studies conducted on Stanley have revealed that the baiting had very limited effects on non-targets. Of 43 saddlebacks in a colour-banded study population present before the baiting, 40 were found to be healthy in October, a survival rate of 93% if all the birds missing succumbed to the poison. A total of 15 birds, of several species, were found dead after the treatment. However, the conservation team confidently expect any losses quickly to be made good by the increased biological productivity resulting from the reduction of competition and predation by rabbits and rats. Already, lizard numbers determined after the baiting are higher than ever before recorded on Stanley Island.

CONCLUSION

The introduction of second-generation anticoagulants has brought many well-recognised advantages to those conducting rodent control programmes (Hadler and Buckle, these Proceedings). Brodifacoum has several specific advantages, however, that result in its widespread use in conservation rodent control. Perhaps the most important of these is its proven effectiveness (Kaukeinen andRampaud 1986) against all the major rodent species confronting those planning control programmes. This means that brodifacoum-based baits can be used without the need for costly and time-consuming verificatory studies. It is also the most potent of the compounds available and this confers the benefit that only the smallest quantities of bait are required to deliver a lethal dose to the target rodents; particularly valuable when feeding from bait stations may be sporadic. However, the characteristics of the formulation used are almost as important as those of the active ingredient. All of the programmes described above have used proprietary 'Klerat' and 'Talon' wax block bait preparations that were developed to provide the optimum compromise between high palatability to rodents, low attractiveness to birds and long-term stability in use. Now that the unique value of these tools in conservation is recognised it may be possible, in small part, to repair some of the catastrophic damage that Man has wrought world-wide by the accidental introduction of rodents onto off-shore and oceanic islands.

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