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Reducing the rat threat to island birds

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Summary

Invasions of alien mammals, particularly predators such as rats *Rattus* spp., have been a major cause of the disproportionately high number of extinctions of island birds. This paper outlines how introduced rodents affect these birds, describes administrative, management and scientific measures which should be taken to prevent the spread of these mammals to additional islands and to limit their impact, and provides practical information about how to control or eradicate the rodents. We use examples from New Zealand's experiences with islands and rats to illustrate the problems and solutions. The information and recommendations in the paper are directed particularly towards legislators, administrators and managers all over the world who are responsible for the conservation of island faunas. The paper gives examples of rat-free islands deserving the highest level of protection, and a step-by-step checklist for action to minimize the risks of rodent invasion.

Introduction

Although animal and plant species on isolated islands have always been vulnerable, the rate of extinctions has accelerated greatly since the time of first human contact with these islands. The loss of the Dodo *Raphus cucullatus* from Mauritius in the 1660s was the beginning of a wave of declines and extinctions that affected birds in Mauritius and on islands throughout the Indian and Pacific Oceans. King (1985) estimates that 93% of the land and freshwater birds that have become extinct since 1600 are birds of oceanic islands, even though such birds are only a small percentage of the global total of avian species.

The introduction of alien mammals from continents, particularly predators such as cats *Felis catus*, rats *Rattus* spp., and sometimes mongooses *Herpestes punctatus*, has been a major factor contributing to these extinctions. Oceanic islands were largely without these predators before human contact, with the result that their endemic birds, in contrast to those of continents, have lost behavioural adaptations that allowed them to coexist with these mammals.

In addition to their effects on birds, rats have probably contributed to extinctions of island mammals, snakes, geckos, skinks, frogs, and invertebrates such as land snails and larger insects (e.g. Brosset 1963, Whitaker 1973, Honegger 1981, Daniel and Williams 1984, Meads *et al.* 1984, Thomas 1985, Worthy 1987a,b, Towns 1991). Although mice have apparently caused few extinctions among vertebrates they are implicated in extinctions of invertebrates (e.g. Crafford and Scholtz 1987, Clark and Veal 1991). The spread of rodents to inhabited islands has also resulted repeatedly in economic losses to crops and stored food, and increased the incidence of human diseases such as hookworm, leptospirosis and filiariasis.

The species of rodent most commonly introduced by humans to islands are the Norway or brown rat *Rattus norvegicus*, the ship, black or roof rat *R. rattus*, of which there are two widespread chromosomal races (Yosida 1980), the Pacific or Polynesian rat *R. exulans*, and the mouse *Mus musculus*. The core of the rat problem is preventing *R. rattus* or *R. norvegicus* from reaching more islands, including those where other rodent species are already present.

The purpose of this contribution, which extends and updates Moors *et al.* (1989), is to outline briefly some of the effects rats have had on island birds, detail the measures that can be taken to limit the spread of rodents to additional islands, and examine other ways of reducing the threat they pose to island birds. We provide examples from New Zealand's experiences with islands and rats to illustrate our recommendations. Our paper is directed particularly towards land managers responsible for the protection of islands and their wildlife, and towards administrators responsible for the development and implementation of policies and legislation to achieve those objectives.

Effects of rats on island avifaunas

General effects

The effects of rats on island birds are not always predictable. Nevertheless, even when there are apparently no extinctions or declines of birds following a rat invasion, major changes in the trophic structure of island communities can frequently be observed. For example, the tuatara *Sphenodon p. punctatus*, an indigenous lizard-like reptile of New Zealand, is often a top predator on small islands. However on islands where Pacific rats have been introduced, there is compelling circumstantial evidence to show that competition for food and/or predation on eggs and juveniles by this rat has caused recruitment failures and extinctions of tuatara populations (Crook 1973, Cree *et al.* in press). The continuing invasion of islands by rats (Figure 1) should be seen as an important factor contributing to global losses of biodiversity.

Specific effects

The adverse effects of rats on birds differ according to which species of rat is involved. Birds nesting on or near the ground or in burrows are at greatest risk from *R. norvegicus* (Figure 2), whereas tree-nesting birds are at greatest risk from *R. rattus*. *R. exulans* takes birds on or near the ground as well as arboreally, but less is known about its predatory behaviour than that of the other two species. On oceanic islands *R. rattus* has caused greater losses of forest birds than any other rat in European times, while in the same period *R. norvegicus* has caused greater losses among seabirds (Atkinson 1985).

Size and behavioural differences between bird species determine their vulnerability to rats, and thus whether the relationship becomes one of coexistence or decline of the bird. Larger birds are less vulnerable, as also are those which nest or roost in sites less accessible to rats. If the bird has already evolved aggressive

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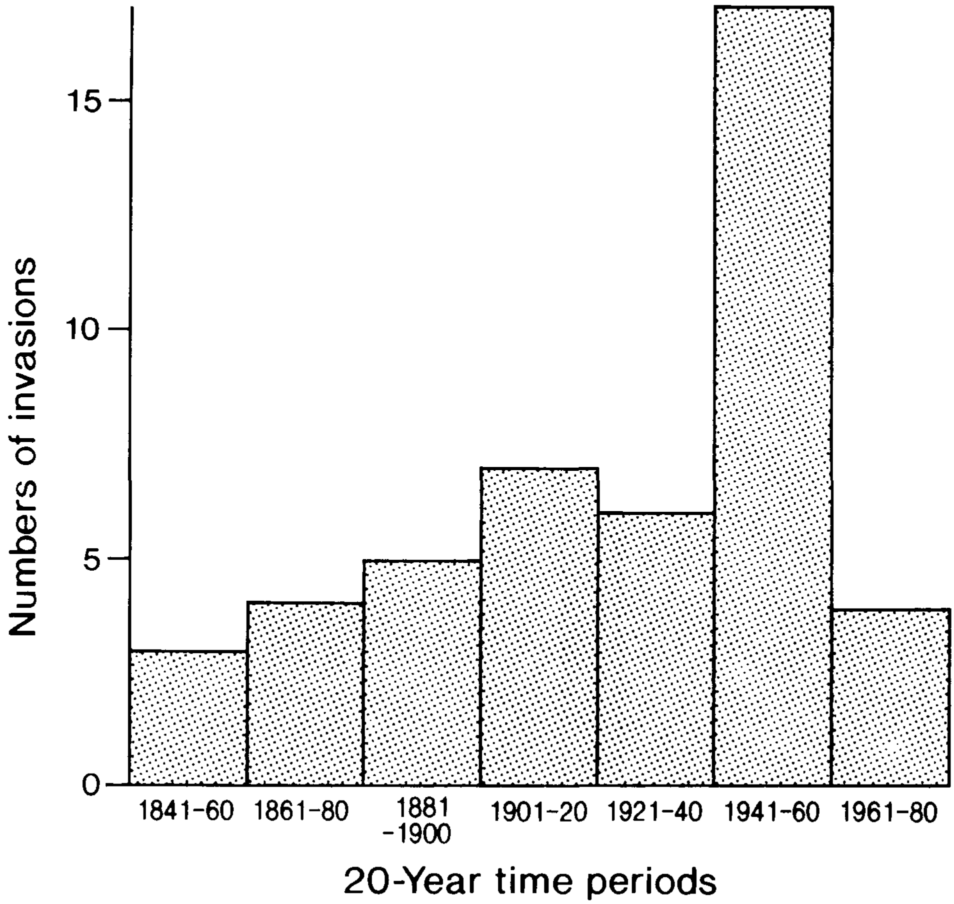

Figure 1. Changes in the rate of rat invasions between 1840 and 1980. The mean rate is 6.6 invasions per 20-year period. Invasions for the period 1941–1960 are significantly greater than the overall mean. (Reproduced with permission from Atkinson 1985.)

behaviour against rats and other predators native to the island, it appears better able to protect its nests from introduced rodents (Moors and Atkinson 1984, Atkinson 1985). Egg size and shell thickness, timing of the breeding season, number of broods per season, length of the fledging period, ability to re-nest after losing a brood, and the length of time for which chicks are left unattended are additional factors influencing a bird's susceptibility.

Many different kinds and sizes of bird are affected by rats, including surface-nesting and burrow-nesting seabirds, shorebirds, wetland birds and forest birds. Some, such as the now extinct Stead's Bush Wren *Xenicus longipes variabilis* on Big South Cape Island, New Zealand, weighed less than 20 g (Dr P. R. Millener pers. comm.), whereas others like the Laysan Albatross *Diomedea immutabilis* of Kure Atoll are much larger (2.5–3.0 kg).

It is essential to distinguish losses of birds that threaten the survival of a population from those that do not. This is not necessarily dependent on the scale of the losses: the killing of a few birds can be as damaging as the killing of many

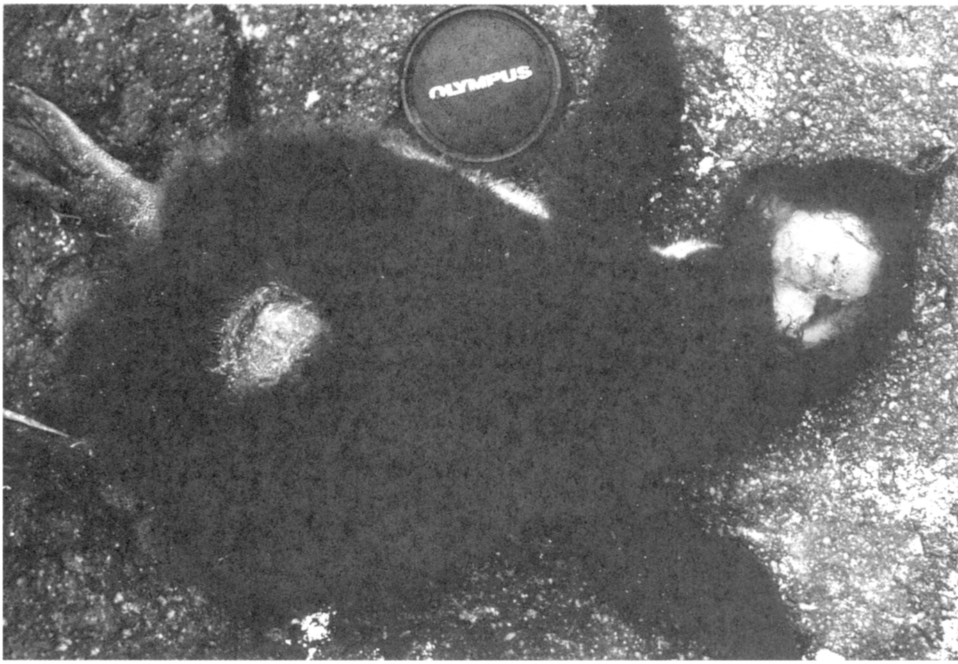

Figure 2. A Rockhopper Penguin *Eudyptes chrysocome* chick killed by *Rattus norvegicus* at the second attempt: the original wound is seen on the posterior of the chick.

if other factors together with rats increase annual mortality above annual recruitment (Moors and Atkinson 1984). For example, in a recent study of an endangered flycatcher, the Kakerori *Pomarea dimidiata* of Rarotonga, Cook Islands (McCormack and Künzle 1990), it was found that nesting success was improved from 15% to 78% by combining rat poisoning with banding of trees to prevent *R. rattus* from climbing to nests. Before poisoning and tree-banding began, the annual loss of eggs and chicks to rats was 6–11 individuals from a total population of less than 40 birds. This would have comprised only an incidental fraction of the rats' diet but was crucial in determining the decline of the flycatcher population.

Rats do not affect birds only as predators. In eating many parts of plants, including flowers, fruit, stems, leaves and sometimes seedlings, they may compete directly with certain bird species for food. They may also compete for shelter or nest-sites, but none of these competitive effects has been properly studied.

Interaction of rat effects with other factors

Rats do not affect birds in isolation from other factors. The effect of a predator on a particular bird population may be influenced by the availability of alternative prey (Davis 1957). For example, Taylor (1979) concluded that introduced cats and Wekas *Gallirallus australis* exterminated the Macquarie Island Parakeet *Cyanoramphus novaezelandiae erythrotis* between 1881 and 1890 after rabbits became established on the island in 1879. Although cats had been present since at least 1820, their numbers had been restricted by scarcity of winter food. Rabbits removed this limitation for both cats and Wekas, thus allowing increased predation on the parakeets. Dr B. M. Fitzgerald (pers. comm.) has suggested that this kind of relationship can be pictured as a predator–prey triangle in which the addition of a new, common prey species to the system increases the numbers of a predator, thus increasing the predation pressure on another species, sometimes pushing it to extinction.

Rat interactions can involve plants as well as animals. Fleet (1972) showed that periods of intensified predation by *R. exulans* on Red-tailed Tropicbirds *Phaethon rubricauda* on Kure Atoll coincided with seasons in which late winter or spring storms had reduced the supply of plant foods for the rats.

On islands the effects of rats, and other predators and competitors, on bird populations often coincide with a decrease in the area available for a bird's habitat. Predation by rats can reduce the density of a vulnerable bird species, resulting in a need for a larger *total* area of habitat to maintain a viable population. Similarly, food competition by rats could reduce the available resources and hence decrease population density, necessitating a larger area of habitat to maintain a viable population. In either case, if the area of habitat available is also decreasing, as a result of fires or logging for example, then population size may decrease to a point where the species becomes threatened and declines to extinction (Atkinson 1989).

Rat-induced catastrophes

On a few islands rat invasions have had such a marked effect on the avifauna that they are best described as rat-induced catastrophes. The most dramatic example is that of Lord Howe Island where, following the grounding of the steamship "Makambo" in 1918, *R. rattus* escaped and established itself on the island. Within two years the numbers of landbirds had declined greatly. Ultimately five species, more than a third of the island's landbird fauna, became extinct as a result of this invasion (Hindwood 1940).

Other such catastrophes are the extinction of Laysan Rails *Porzana palmeri* and Laysan Finches *Psittirostra c. cantans* on Midway Island, Hawaii, after *R. rattus* became established in 1943 (Johnson 1945, Fisher and Baldwin 1946); and the major declines or extinctions of more than 40% of the landbird fauna on Big South Cape Island, off Stewart Island, New Zealand, between 1962 and 1964 (Atkinson and Bell 1973, Atkinson 1989).

Factors affecting rat establishment on islands

A very high proportion of oceanic islands or island groups has now been invaded and colonized by rats: 75% for islands in the Atlantic, 83% in the Indian and 81% in the Pacific Ocean (Atkinson 1985). Nevertheless, among island groups having rats, individual islands of biological value have sometimes remained rat-free, for example 24% of islands in the Hawaiian group, 30% in the Seychelles, and 53% in the Galápagos. Most of these rat-free islands are, however, small, low and uninhabited.

Although some island faunas are more vulnerable to rats than others, the

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circumstances that allow rats (or mice) to reach an island all derive from human activities: settlements; construction of wharves; boat slipways and airstrips; importation of foodstuffs; exploitation of the natural resources of islands and their surrounding waters (e.g. fishing, mining, oil drilling); establishment of military bases or weather and research stations; shipwrecks; and sometimes boating associated with tourism and recreation.

Reducing the threat of rodent invasion

Policy, management planning and access to islands

Snares Islands: lobsters or rats? The Snares are a group of rodent-free islands lying 124 km south of New Zealand. They provide an example of the complex human, economic and ecological problems which have to be resolved if an island is to be protected from rats. The Snares lack introduced mammals of any kind and are among the few unmodified forested oceanic islands left anywhere in the world. They support enormous populations of seabirds (Warham and Wilson 1982) and three endemic subspecies of landbird.

In the late 1970s it was discovered that the surrounding waters held an unexploited stock of New Zealand rock lobsters *Jasus edwardsii*. This rapidly attracted fishermen, who sought to moor their boats to the shore overnight in a small cove on the main island (North East Island). The New Zealand government department that administered the islands as nature reserves faced a serious management problem. How could it protect The Snares from rats on the fishing boats when it lacked jurisdiction beyond the low water mark?

Bearing in mind the international importance of the islands and the real risk of a rat invasion, the department proposed that all fishing boats should anchor at least 500 m offshore. This proved impractical because the waters were too deep and exposed. The only means of controlling the fishing boats lay with the New Zealand Fisheries Act, but the government declined to use the regulations in that way. The problem escalated into a major dispute when the fishermen, angered by claims that their boats could harbour rats and by the proposals to restrict their access to the fishing, publicly threatened to release rats onto The Snares.

Negotiations eventually produced a settlement, but one which seriously compromised rodent protection for the islands. The government agreed that annual permits would be issued to a small number of boats, allowing them to moor by lines to the shore. Poison stations for rodents were set up at departure points of the boats and also on The Snares, and the grave dangers of rat invasion were stressed to the fishermen. University researchers working on the islands were contracted to monitor the use of the moorings and maintain checks for rodents.

Fortunately, the fishing proved to be ephemeral, and both the catch and the number of boats working the area declined to low levels after a few years. The threat of rats getting ashore is still present, however, and would increase once more if the fishermen found a new resource. The Snares problem well illustrates how short-term economic pressures can seriously jeopardize long-term conservation objectives if these objectives are not backed by adequate legislation and policies.

Legal protection and management planning Many islands important for conservation, and exposed to the risk of rodent invasion, have no legal protection. Steps to reduce this risk must have a legal basis, because without it a government will not invest resources to protect the island. The government agency responsible for the island must have a clearly defined policy that translates relevant legal statutes into protective action. The policy must be combined with public education to increase awareness of the risks of rodent introductions, because education is the key to cooperation.

Many islands in New Zealand are classified as nature reserves under the Reserves Act 1977. This statute incorporates a requirement that entry permits must be obtained before people land on an island. The permit requires the holder to meet various conditions, some of which relate specifically to the exclusion of rodents from stores and equipment, the way in which vessels are moored, and the transport of goods and people ashore. In addition, marine legislation in New Zealand can be used either to exclude fishermen from the inshore regions of some oceanic island reserves, or to restrict the amount of fishing that can be done there.

An effective way of administering a reserve is through a management plan which sets out the policy objectives and the management practices necessary to achieve them. Management plans in New Zealand are advertised for public comment, and there is a statutory obligation to consider all criticisms and make amendments as necessary. Once accepted, plans bind the authorities to the stated management policies and practices. The plans are reviewed and reopened for public comment every five years. These reviews allow the management policies to be re-examined, especially if circumstances have changed substantially.

Invasions of rats or mice are emergencies in island conservation which should be treated as urgently as a fire. This can best be achieved if a rodent contingency plan has been prepared as part of the island's management plan. The details of each plan will depend on the island concerned, but the following summary illustrates the actions planned for New Zealand island reserves.

If a ship founders within 2 km of the shore, flotsam is to be checked for rats within 24 hours whenever practicable, and poison and trap stations established around the wreckage. If a ship comes ashore, about 200 poison bait stations are to be set out as soon as possible within 200 m of the wreck, together with 50 kill-traps. These are to be maintained for at least 30 days, using several kinds of bait station, bait and poison. Trapping is necessary to provide carcasses for identification, and also because on islands already inhabited by rats it is unlikely that the presence of a new species can be confirmed from sightings alone. If a rat escapes during unloading of cargo, the same procedures are to be followed around the unloading point. Kits containing bait stations, traps, poison, a rodent identification key, tissue preservative, and instructions are maintained on each inhabited island and at various mainland centres.

Salvage operations also present a threat. With the urgency of events following a wreck, it is easy for the salvors to forget precautions against introducing rodents from their own vessels, or even against spreading rodents from the wreck as a result of salvage operations. While it is in the interests of the reserve to have the wreck rapidly removed, and maximum cooperation with the salvage operators is necessary, there should be no slackening of precautions against introducing rodents.

Island reserve boundaries The statutory boundary for an island reserve usually extends to the mean low water mark, leaving no control over the surrounding waters. The offshore users of island reserves (e.g. scientists, fishermen, tourists, or users of small boats) pose a threat of rat invasions from moorings and wrecks, or by their boats carrying rats from one island to another. Policy and implementation will be most effective in a reserve which encompasses both the island and its adjacent waters. Often land and marine reserves are not administered by the same government department. Conflicting interests or inadequate legislation in departments with responsibilities for territorial seas can easily confound overall management policies for an island reserve.

The best protection against introducing rats is to designate oceanic islands and their surrounding seas as reserves which exclude all exploitative activities such as oil and mineral prospecting, mining and fishing.

Access to island reserves Disturbance to vulnerable island nature reserves can be minimized by restricting visitors to management and scientific staff and sometimes media representatives. Managers are active in conservation work on the islands, while scientists should be required to pursue research that has a direct benefit for managing the island or some of the species it supports. Film-makers and journalists provide public education and encourage support for conservation activities.

There is an increasing demand by tourists to visit islands, for which a system of entry permits does not automatically provide a safeguard against rodents getting ashore. In New Zealand permits are issued for groups rather than individuals, and effective protection depends on the integrity and ability of the group's leader. There is a danger of the managing department losing control of the quality of protection unless a ranger is present to ensure that rodent protection measures are carried out. The likelihood of rats landing could increase with larger groups because of the greater frequency of boat landings and the presence of large vessels within rat-swimming distance for longer periods of time.

Regulations governing hygiene on ships No ship is rat-proof and all vessels must be regarded as potential sources of rat infestation. Enforcing a rodent protection policy is difficult, especially when ships visit remote or uninhabited islands. Vessels can enter restricted waters without the authorities being aware of their presence. Also, under the law of the sea, ships in distress can be moored or even beached on an island at which entry is normally prohibited.

The International Health Regulations 1969 require ships plying overseas trade to carry either a de-ratting certificate (confirming that the vessel has been fumigated for rats) or a de-ratting exemption certificate (confirming that a visual inspection has revealed no signs of rat infestation). A ship and its certificate are normally inspected at the first port of call in each new country, or when a new certificate is being issued (they are valid for six months). If a rat infestation is found the ship can be held in port for whatever eradication treatment is prescribed.

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These regulations have practical limitations which make it unwise to rely on them to ensure that ships are rat-free. The thoroughness of inspections and the effectiveness of eradication treatments vary from port to port and depend on the skill and motivation of the staff. Heavy infestations are easy to see, but light ones can be overlooked, especially if crews disguise them in order to avoid the costs of fumigation and detention. A ship working regularly from ports within the one country may be initially rat-free, but later pick up an infestation which goes undetected until the next inspection. The regulations do not apply to naval vessels, coastal traders, or to passenger and fishing boats which make only local voyages. In many parts of the world local fishing boats are exactly the vessels which visit islands most often and are most likely to be infested.

Tourist ships may pose less of a threat because there are fewer of them than fishing or cargo boats, and operators of nature cruises may already have some appreciation of conservation values – it is in their own interest to protect the quality of their destinations. Nevertheless, both international and local operators should be fully instructed on rodent precautions when they receive their landing permits.

Methods of preventing rat introductions

Prevention of rat infestations should always be the primary aim because eradication is much more expensive, and sometimes impossible, once rats have become established. Preventative measures apply to the packing, storage and stowage of cargo, to ships and aircraft calling at islands, and in the preparation of detailed contingency plans. Precautions need to be taken not only in obvious situations, but also when the risks may mistakenly be thought negligible – such as inter-island transfers in small boats.

Rats on the dockside The first element of prevention is to stop rats infesting cargoes. Cargo and stores should be packed and held in rodent-proof buildings. Rat-proof boxes and crates should be constructed so that a brief inspection will reveal if rats have gained entry. Re-usable rat-proof plastic barrels or boxes are an advantage for regular visitors to islands. All containers should be thoroughly inspected immediately before loading aboard ship. Any suspected or found to be infested, and any which are impractical to inspect, must be properly fumigated. Cargoes most likely to harbour rats include foodstuffs, fibrous bales such as hay or straw, building materials, and raw primary products (especially if bagged and stacked on pallets).

Containerized cargo presents similar problems. Containers are usually packed and unloaded away from docks in places lacking rodent control, and by people who do not realize the dangers of rats being carried to islands. The containers are not always rat-proof, and rats can survive in them for weeks under favourable conditions – for example, they have been transported alive from Vietnam to the United States. It is essential that precautions taken for other types of cargo also be applied to containers.

Wharves and warehouses have long provided ideal rat habitats. Infestations can be substantially reduced by maintaining permanent poison-bait stations, having high standards of cleanliness, and removing or isolating food sources

Figure 3. Mooring lines offer convenient routes for rodents moving from docks to ships, which may then transport them to an island free of rodents. The number of lines used should be minimized.

and cover for rats. Opportunities for rats to board ships can be reduced by berthing only when necessary, removing unwanted gangways and safety nets at night when rats are most active, and by using the minimum number of mooring ropes (Figure 3). Rat guards on mooring ropes are barely effective, particularly against agile climbers like *Rattus rattus*. Installation of rope guards certainly does not remove the need for rat control on the docks themselves. Similarly, rats are not deterred if mooring lines are partly submerged – they simply swim the gap. They also swim to ships anchored close inshore. At these anchorages decks should be cleared of food and cover, and doors and holds kept closed.

Rats on ships Rat precautions on ships calling at islands of conservation importance will fail unless fully supported by the crews, and by the governments responsible for the islands. Cooperation from both groups will depend particularly on their understanding the likely consequences of rats getting ashore. Explaining these consequences is a fundamental educational responsibility of conservation agencies.

Island-going ships should be inspected regularly for rodents by trained staff and have poison-bait stations operating continuously. Crews should be given incentives to maintain shipboard cleanliness, report the presence of rats and assist in removing them. These practical measures should be reinforced by observing the International Health Regulations and by the local enactment of whatever additional regulations are necessary. Ultimately, however, the successful exclusion or eradication of rats from ships will depend not on laws but on the commitment and actions of the people directly involved.

Rats getting ashore Unloading while anchored offshore is the single most effective means of preventing rats getting ashore. No wharf is needed, no mooring lines link the ship with the island, and all cargo must be repeatedly handled, making detection of rats more likely.

Thus a lack of berthing facilities is a definite advantage from the conservation viewpoint. There are examples of populated islands in the Pacific Ocean (e.g. Pitt in the Chatham group, Tokelau, Rennell and Christmas) where, in the absence of large wharves, neither *R. rattus* nor *R. norvegicus* have become established. Conversely, there is strong circumstantial evidence that the spread of these two species in Hawaii was closely linked with the construction of wharves for deepwater shipping (Atkinson 1977).

New wharves or slipways should not be built at islands which are rat-free or have high conservation values. Wharves and slipways already present on such islands should be dismantled whenever possible. If ships are berthed at island jetties, the numbers of mooring lines and gangways should be minimized, and vessels should anchor in the stream at night if practicable. Rat guards on mooring lines must be fitted in reverse to keep rats on board. Stores should be carefully checked during unloading and any suspect boxes retained on the ship and unpacked. Ashore, unpacking should be done in rat-proof rooms, where any stowaway rats can be caught before they escape. Permanent poison stations are necessary on the wharf and within a radius of about 200 m as added precautions against escapes.

Recreational boats occasionally carry rats. This is more likely to occur in warm waters where *R. rattus* is liable to swim to boats more often than in cold waters. When a small boat carrying a rat is beached, the risk of that rat getting ashore is very high indeed.

Rats on aircraft Planes and helicopters transport rat-infested stores just as efficiently as ships do (Geary 1968). All the precautions previously described for cargoes on ships apply to aircraft. Since flight times between islands are often very short, a stowaway rat runs a good chance of not being found before it leaves the aircraft at the next landing place. Therefore flights between infested and uninfested islands involve an increased risk of unknowingly introducing rats.

Control and eradication of rats

Control and eradication differ fundamentally in underlying attitudes and the commitment necessary for success. Control aims to reduce numbers to some acceptably low level, usually on a regular basis, whereas eradication aims to kill the last individual, whatever the cost. Eradication demands a long-term commitment because success may take many months to achieve. Administrators must understand this and not stop the campaign when the cost of each rat killed becomes great. The last rats are certainly the most expensive and exacting to destroy, but obviously they are also the most vital if the campaign is to succeed.

Control operations are usually undertaken to achieve short-term local benefits, such as protection during the breeding season of a seabird colony, or of an endangered species with a localized population. They can also be used to reduce the chances of rats swimming out to anchored boats that are making regular visits to rodent-free islands (Hickson *et al.* 1986). Re-invasion by rats from neighbouring areas is inevitable, and the treatment must be repeated if the protection is to be maintained. Although individual treatments may be relatively cheap, overall expenses mount with each repetition. Over several years the total cost of local campaigns can approach or even exceed the cost of eradication, which would have benefited the whole island. These cost–benefit factors need to be borne in mind when choosing between control or eradication. Continuity of well-trained staff throughout the campaign will improve its efficiency. Training and development of techniques should never be carried out on the target population because of the risk of making individual rodents shy of poisons or traps (Taylor and Thomas 1989).

Islands up to 173 ha in size have been cleared of rats. *R. norvegicus* and *Mus* were exterminated from Flatey Island (50 ha) in Iceland between 1969 and 1971 with intensive campaigns of warfarin poisoning in winter (Petersen 1979). In New Zealand, at least 15 islands have been successfully cleared. These include eradications of *R. exulans* from six islands of up to 56 ha; of *R. norvegicus* from seven islands of up to 173 ha (Thomas and Taylor 1988); and of *R. rattus* from two forested islands of 22 and 26 ha.

The most recent eradication of *R. exulans* was from Burgess Island (56 ha), Mokohinau group, where for the first time most of the poison bait was distributed from a helicopter. On islands with suitable terrain and vegetational cover, aerial spreading should reduce labour costs. If trials of the technique are successful elsewhere, they will open the possibility of eradicating rats from much larger islands than was once contemplated. It should be noted, however, that distribution of poison bait from the air will increase the chances of affecting non-target species.

Mice have been eradicated in New Zealand from three islands, of which the most outstanding success has been Mana Island (217 ha).

Identification and presence of rats

Before an eradication or control programme begins it is important to identify the species, distribution, and abundance of the target rodent, and any species of wildlife at risk from the campaign and needing protection. It is essential to know which species of rat is being dealt with in order to assess the overall severity of the threat to an island's fauna and flora, and particularly for the planning of control or eradication projects. Identifications should be made only by examining specimens, because sightings are rarely conclusive. The main distinguishing features of the three species of rat and the mouse are set out in Table 34 of King (1990).

The existence of a well-established rat population can usually be readily confirmed, but if rats have arrived only recently, or a new species lands on an island already inhabited by other rodents, signs of the new arrival can be extremely difficult to discover. Droppings of *R. norvegicus* can usually be distinguished by their size from those of *R. rattus*, using discriminant functions derived by Huson and Davis (1980).

The presence of rats can often be confirmed from their tracks in soil or mud, feeding sign, droppings, remains of rat carcasses, dark smears on the undersides of beams and rafters, or burrows and runways (especially for *R. norvegicus*). Traps and tracking systems can also be used. If the tracks need to be preserved for identification or counting, a powder or paper-and-ink system should be used (King and Edgar 1977, Innes and Skipworth 1983). *R. norvegicus* seems to be deterred by ink pads, but this system works well with the other two species. The frequency of tracking can be increased by supplying bait.

Other detection techniques include the use of unpoisoned baits, devices for collecting rat hair (Suckling 1978), detection of rat urine by fluorescence in ultraviolet light, and the use of specially trained dogs. Softwood gnawing sticks soaked in cooking oil have been useful for detecting *R. norvegicus* in New Zealand (Moors 1985).

Wace (1986) has experimented with sterilized female rats as decoys. The rats were maintained in oestrus, making them sexually attractive to males, by regular hormone injections. This method is likely to be selective, the caged decoys only attracting rats of the same species and probably only males. This could be an advantage when a known new arrival is being sought on an island already inhabited by other species of rats.

Information on the abundance and distribution of rats can aid the planning of campaigns, and is essential for assessing progress once operations have started. An index of abundance (Nelson and Clark 1973) can be obtained using kill-trapping or tracking tunnels. Cunningham and Moors (1983) give trapping details and explain how the index is calculated.

Effects of behavioural differences

The behaviour of all three species is strongly affected by age, sex, social status and experience. *R. norvegicus* is particularly wary and will avoid strange objects encountered in otherwise familiar surroundings. This "new object reaction" lasts at most a few days, but can substantially reduce trapping success or acceptance of poison baits. *R. rattus* is less wary of new objects, and *R. exulans* may even be attracted by them.

If only one rat species inhabits an island, that species will occupy most available habitats. However, if predators or additional rodents are present, rat distribution may become restricted to preferred habitats. Home ranges vary in area from less than one to several hectares, but generally become larger with increasing size of rats. The density of baits and traps should be such that each rat has at least one in its home range; thus, for example, trap density needs to be greater for *R. exulans* than for *R. norvegicus*. Large rats also tend to be socially dominant and are able to monopolize centralized food sources. It is better, therefore, to offer baits at several sites rather than at a single central one. Details of home range sizes of mice living in a New Zealand evergreen forest are given by Fitzgerald *et al.* (1981).

R. rattus and *R. exulans* are agile climbers, quite at home in tree-tops and ceilings. Arboreal stations speed the removal of these rats, but while advisable they are not essential because all individuals visit the ground at some time. Where they coexist, *R. norvegicus* usually remains on the ground or in the basements and ground floors of buildings, whilst the other two species occupy the trees or upper storeys.

The behavioural differences between *R. rattus* and *R. norvegicus* can be exploited. For example, the New Zealand Saddleback *Philesturnus carunculatus* usually roosts, and may nest, in cavities near the ground. However, on islands where *R. norvegicus* occurs, Saddlebacks can be trained to use artificial nest- and roost-boxes placed above the normal climbing range of this rat (Dr T. G. Lovegrove pers. comm.). However it is not clear yet if this behaviour can be passed on to succeeding generations of Saddlebacks.

Poisoning

Poisoning is the most cost-effective means of killing rats in large numbers or in isolated places. Rodenticides are of two general types: chronic poisons requiring several doses before a lethal concentration accumulates and taking 3–7 days to cause death, and acute poisons which act within a few hours of a single dose. Chronic anticoagulant rodenticides are the first choice for island conservation campaigns. These compounds interfere with blood clotting, leading to fatal internal haemorrhages. Those in widespread use are either hydroxycoumarin derivatives (e.g. warfarin, fumarin, coumatetralyl, difenacoum, brodifacoum, bromadialone, flocoumafen), or indandione compounds (chlorophacinone, pival, diphacinone).

Anticoagulants have two main advantages: vitamin K_1 is an effective antidote, and there is a much-reduced likelihood of bait shyness or sub-lethal dosing because of the delay between consumption and death. Against these, continued use of warfarin over many years has led to the development of resistant rats in some countries. A similar problem has recently arisen in a few places with difenacoum, coumatetralyl and bromadialone. However, the "second generation" hydroxycoumarin derivatives brodifacoum and flocoumafen are effective against resistant rats. Also, these rodenticides are fatal after a single small dose, although death is still delayed several days.

This single-dose toxicity has a practical disadvantage, however. Because rats do not begin to experience the toxic effects until a day or two after eating the fatal dose, they often continue feeding and consume far more bait than is needed to kill them. This wastes bait if rats are abundant, and the excess poison in carcasses presents a serious hazard of secondary poisoning for predators or scavengers. "Pulse baiting" reduces these problems by offering small amounts of bait several days apart (Dubock 1984), although in an eradication campaign it may increase the likelihood of bait shyness or human-induced phobias (Taylor and Thomas 1989).

Most acute rodenticides are extremely toxic to animals and humans, which limits their value in conservation programmes. These poisons include sodium monofluoroacetate (compound 1080), fluoroacetamide, arsenic, strychnine, silatrane, zinc phosphide, alpha-chloralose, calciferol, bromethalin and pyrinuron. Each of these compounds has some serious disadvantage in relation to toxicity, palatability to rats, safe usage, or dangers of secondary poisoning. Detailed information about composition, toxicity, concentration in baits, and performance of both chronic and acute rodenticides is provided by Meehan (1984).

When selecting a poison several factors must be considered, including cost, toxicity and palatability to rats, the type of operation being mounted, whether a single-dose poison is needed, toxicity to other animals and the chances of accidentally poisoning them, and the types and sizes of bait being offered. Warfarin is cheap and readily available. It is also much less toxic to birds than to rats and so reduces the dangers of accidental poisoning. It is therefore suited to many situations where only a reduction in rat numbers is required. Recent eradication campaigns in New Zealand, however, have relied on brodifacoum and bromadialone because of their single-dose effectiveness. The greater toxicity of these rodenticides brings increased dangers of killing non-target animals, especially birds of prey feeding on carcasses of poisoned rats.

Baits, their presentation and their longevity in the field must also be carefully considered. Those with a wax matrix or other waterproofing will last longer in moist conditions. In addition to commercial preparations, good baits include whole and kibbled grain, flour, jam, tinned pet food, dog biscuits, eggs, water (in dry habitats) and fish. Sometimes otherwise acceptable baits cannot be used because they attract birds and other non-target wildlife. Attractiveness to birds can be reduced by dyeing the baits green and adding a bittering agent (e.g. Bitrex). Acceptability of baits to rats should always be tested with unpoisoned bait; lures and food flavouring sometimes improve palatability. Variation of baits

Figure 4. Poison station made from plastic agricultural pipe. These have been used successfully in New Zealand for pulse baiting with brodifacoum and bromadialone rodenticides.

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and poisons is essential for eradication campaigns and long-running control operations in order to minimize bait and poison shyness. Covered bait stations (e.g. wooden or plastic boxes, plastic piping, or grain-dispensing silos) are generally necessary for protection from the weather and to prevent non-target animals having access (Figure 4). In many cases they may improve bait acceptance as well.

Trapping

Trapping is more labour-intensive than poisoning and less successful in most situations. However, it does have a part to play in eradication programmes, where as many methods as possible for killing rats should be employed, and it is the preferred method when rodenticides are undesirable.

Snap-traps (break-back) are used most commonly; small gin and Conibear traps (steel-jawed) set with hair-trigger plates are also effective. Live-traps are often avoided by *R. norvegicus*. Traps should be set near runways and at other sites where there is evidence of rat activity. Trapping success can be increased if the traps are baited but not set for several days. Suitable baits include peanut butter, peanut butter mixed with rolled oats, tinned pet food, cooked sausage or salami, fruit, carrots, cheese, chocolate, or leather soaked in vegetable or fish oil. Desiccated or mouldy baits should be replaced immediately. Details of trapping methods are given by Cunningham and Moors (1983).

Other methods

Fumigation is highly effective against rats infesting buildings, ships and cargo, but its usefulness in field operations is limited to killing rats in burrows. The commonest fumigants are cyanide, methyl bromide, chloropicrin, phosphine and carbon dioxide.

Chemosterilants have the practical disadvantage of reducing reproduction rather than killing rats. Therefore treated populations decline only slowly. In the meantime, rat damage can continue. Also, compounds tested so far have been most unpalatable, making it difficult to sterilize a high proportion of the population. Rats breed promiscuously and production of young can be maintained by relatively few fertile adults. For this reason, chemosterilants for female rats are more effective in lowering productivity than those for males.

Although various chemicals are known to repel rats, practical applications have been few and mostly unsuccessful. Careful trials of ultrasonic sound generators have shown that rats soon become conditioned to the "noise" and are not driven from buildings or food sources (Brooks and Rowe 1979).

Better methods of killing rats need developing. The apparently high cost-effectiveness of aerial application of poisons on large islands needs proper documentation, as does investigation of a potential increase in the likelihood of non-target poisonings. Useful new lines of research include synthetic rat pheromones as lures, new chemosterilants, genetic manipulation, and biological control (disease, parasites, predators) (Wace 1986). Fitzgerald (1978) proposed releasing a temporary single-sex population of rat predators (e.g. male stoats *Mustela erminea*) onto an island to remove rats. The idea has not been tested, but it could be useful in an eradication campaign provided the additional predation did not endanger other animals.

What do administrators and managers of islands need to do now?

The first step is to identify all islands of conservation importance and place them in the following three categories: those that are free of all introduced rodents, those free of introduced rats, and those free of *R. rattus* and *R. norvegicus* but having *R. exulans*. This is a task for an international body such as the International Council for Bird Preservation.

The second step is to identify the major conservation values associated with each island. Such values include: (1) degree of representation of the original flora and fauna; (2) degree of representation of the original natural communities; (3) degree of freedom from other introduced animals; (4) presence of species of plant and animal unique to the island or island group, whether threatened or not. In some instances the presence of other introduced animals will partly nullify the biological value of a rat-free island, but these other species are sometimes easier to eliminate than rats. Integrated measures for eradicating more than one alien species should always be considered so that eradicating one species does not make it more difficult to eradicate others subsequently.

The third step is to identify the degree of "rodent risk" to each island check-listed. This risk will be influenced by: (1) the kind and intensity of human use; (2) the geographic position of the island; (3) characteristics of the island's native fauna; (4) the presence of other introduced or natural predators; (5) the proximity of other rat-infested islands.

The fourth step is to relate rodent risk to conservation values so that a priority list of islands can be prepared. This would show which islands required the greatest preventative efforts against rats. Islands that are already the focus of funded conservation programmes may deserve a higher priority than others. For example, rabbits have been eliminated from both Round Island in Mauritius and Philip Island in the Norfolk Island group. Both these rat-free islands have indigenous animals vulnerable to rats – for example, eight species of lizard and snake on Round Island. Therefore the most stringent precautions to prevent the entry of rats to these islands are justified.

We suggest, based on the criteria discussed above, that any priority list of islands should include such rat-free islands as Trindade, Gough, Nightingale and Inaccessible in the Atlantic Ocean. In the Indian Ocean, Prince Edward, Cochons and East of the Crozet group, and Frégate Island in the Seychelles group should be included. Rat-free islands in the Pacific deserving priority attention include Nihoa and Laysan of the Hawaiian group, Fernandina and Marchena of the Galápagos group, Pitt and South East of the Chatham group, and the Antipodes, Auckland and Snares Islands south of New Zealand. The list should also include such Pacific islands as Christmas in the Line group, Rose in the Samoan group, Henderson in the Pitcairn group and Rennell in the Solomon group, all of which have been colonized by *R. exulans*, but not by either *R. rattus* or *R. norvegicus*. There would undoubtedly have been major effects on the biota of these islands when *R. exulans* arrived, but new invasions by either of the other two rats would result in additional losses of species.

The final and crucial task is education. Renewed efforts must be made to persuade the appropriate governments or controlling authorities that there is a need and great value in protecting particular islands from rodent invasions. Where an island of high conservation value is inhabited, it is vital to involve the island's people in efforts to conserve that island's fauna, flora and biotic communities. In this way precautions against rats and mice can be accepted as part of a broader programme to protect nature.

A checklist for action

Island priorities for protection

1. List islands important for conservation that are free of introduced rodents, of introduced rats, or of both *Rattus rattus* and *R. norvegicus*.
2. Identify the major conservation values associated with each of these islands.
3. Identify the rodent risks to each of the islands listed, noting islands with animal or plant species at high risk from rodent invasion (referred to below as "rodent-vulnerable").
4. Relate island conservation values to rodent risk, and prepare a priority list of islands where the most stringent preventative actions must be taken against rat entry.

Legal and technical aids to prevent invasion

1. Where not already present, establish a *legal basis for protecting islands against rodents*.
2. Prepare *rodent contingency plans* for all rodent-vulnerable islands as a precaution against rodent escapes from shipwrecks, moored vessels, small boats that have been beached, or landed cargo. These plans must specify methods and materials to be used against rats or mice, administrative responsibilities, and the staff to be involved. This will necessitate the maintenance on the island (if inhabited) or at a convenient centre on the mainland or nearby island (for uninhabited islands) of *rodent destruction kits* containing bait stations, poison baits, traps and instructions for use.
3. Ensure that where *permits* are necessary to allow individuals or parties to enter a rodent-vulnerable island, these contain clear instructions concerning the precautions to be taken against introducing rats and mice.
4. *Seal and rat-proof all boxes and crates* destined for rodent-vulnerable islands. Boxes and crates should be constructed so that a brief inspection will reveal if rats or mice have gained entry.
5. Pack and hold cargo and stores destined for rodent-vulnerable islands *in rodent-proof buildings* until loading commences. Particular care must be taken with *freight containers*, especially if these are loaded in places where rodents are not controlled.
6. Inspect cargo and stores destined for rodent-vulnerable islands by boat, plane or helicopter to *ensure that such cargo or stores are rodent-free*.
7. *Re-check cargo and stores for rodent sign during unloading* at a rodent-vulnerable island. Boxes suspected of containing rats or mice must be retained on the

ship or aircraft. *Special care must be taken when travelling between infested and rodent-free islands* in the same group.

8. Place *permanent rodent-poison stations* on the wharf and within a radius of about 200 m of the wharf as a further precaution against rats or mice establishing themselves on a rodent-vulnerable island.

Special precautions

These precautions must be taken for islands where excluding rodents is of paramount importance.

1. *Ships visiting rodent-vulnerable islands of very high conservation value must carry rat-poison stations* that are in continuous operation. Crews of such ships must be given incentives to maintain a hygienic ship, report the presence of rats, and assist in removing them.
2. *No wharves, jetties, slipways or airstrips* should be built on any rodent-vulnerable island, mooring lines and gangways should be kept to a minimum, and vessels using any existing wharf should be anchored in the stream at night. If rat guards are used on mooring lines, they must be fitted in reverse to restrict rats to the ship. Where boat slipways are absolutely necessary, *thorough checking and poisoning of a boat from another harbour or port* is essential before removing it from the water.
3. Where buildings exist on a rodent-vulnerable island of very high conservation value, stores should be unpacked in a *rodent-proof room* to ensure that any stowaway rats or mice can be caught before they escape outside.
4. For rodent-vulnerable islands of exceptional conservation value, routine trapping and searches for rat sign should be made yearly or more frequently by skilled personnel to ensure *early detection of any rats* before they become properly established.

Education and research

1. *Persuade governments and other controlling authorities* of the need to protect certain islands from invasion by rodents.
2. *Educate* the inhabitants and other users of rodent-vulnerable islands and their surrounding seas in the benefits of preventing rodent introductions.
3. *Study current and past effects of rats and mice* on island floras, faunas and ecosystems in order to improve understanding of the problem and assist education.
4. *Study methods of detecting and eradicating rats* when they are present only in low numbers.
5. *Publicize case histories of successes and failures* in excluding rodents from rodent-vulnerable islands and distribute them to conservation agencies and island managers world-wide.

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