Invasive rats on tropical islands: Their history, ecology, impacts and eradication

Karen Varnham
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Research Report

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Executive summary

From their original ranges in Asia, black and brown rats (*R. rattus* and *R. norvegicus*) are now present across much of the world, including many island groups. They are among the most widespread and damaging invasive mammalian species in the world, known to cause significant ecological damage to a wide range of plant and animal species. Whilst their distribution is now global, this report focuses on their occurrence, ecology and impact within the tropics and reviews key factors relating to the eradication of these species from tropical islands based on both eradication successes and failures.

The ecology of rats has allowed and continues to allow them to successfully colonise tropical islands:

- Ecological traits such as small body size and ability to exploit many habitats, including living commensally within human habitation, and their rapid dispersal ability, either spreading naturally or through exploiting human transport such as ships to move long distances between islands, have allowed rats to spread to many tropical islands
- Once invasive rats have reached new islands, their very high reproductive potential and omnivorous diet which can include plants, invertebrates and bird eggs as well as stored foodstuffs and crops, has allowed them to quickly become established
- Rats have been studied using a range of methods including radio tracking, spool and line tracking, capture-mark-recapture and most frequently through snap trapping

The impact of rats in the tropics:

- Direct predation of birds, including predation of eggs, nestlings and adult animals leading to population level impacts, and predation of a large range of other taxa including mammals, invertebrates and plants
- Biodiversity impact of rats may also occur through indirect mechanisms including habitat modification, competition for resources, hyper-predation (where the presence of rats can sustain populations of other more detrimental predators, e.g. feral cats), and the transmission of parasites/diseases from rats to native wildlife
- Different rat species have different ecological impacts on birds. In general, the more terrestrial brown rat is a particular threat to ground or burrow nesting birds, while the black rat is better at reaching nests in high or slender tree branches

The ecological effects of rat eradications on tropical islands:

- Population increases in numbers of native birds (the majority of studies), reptiles, invertebrates, plants and mammals have been recorded following rat eradication
- The majority of recorded ecological impacts following rat eradication have been beneficial, although relatively few species have been comprehensively monitored following eradication and such monitoring has usually been focused on species on which rats were known to have had a negative impact
- Negative ecological consequences following eradications include the rapid increase in the populations of other invasive species, such as mice, previously held in check by rats
• Long-term ecological consequences of rat eradications are so far poorly known and research and monitoring of a wide variety of taxa following eradication will help our understanding of the positive and potential negative effects of eradications

Techniques used to eradicate rats in the tropics:

• Rat eradication from islands is a recent but fast-developing field and has been most frequently used in temperate and sub-Antarctic environments where several hundred islands have been cleared. Of 97 eradication projects carried out on tropical islands where the outcome is known, 82% were successful. However, the success rate for non-tropical islands is 95%
• The great majority of tropical rat eradication projects have been carried out with anti-coagulant poisons, mainly the second-generation compound brodifacoum, with bait usually either distributed across the island via a grid of bait points/stations, or by aerially broadcasting bait from helicopters,
• Vulnerable non-target species must be identified before the start of an eradication project and the methods used may need to be adapted to minimise the risks to these species
• Rat-free islands should have detailed quarantine and contingency plans in place in order to minimise the risk of rats returning to the island, and also to allow rapid reaction to any suspected reinvasion. Post-eradication monitoring for rats is essential, both for finding surviving rats and for detecting reinvading animals
• Post-eradication monitoring should be extended to as many species as possible and continue for as long as possible in order to fully monitor the ecosystem-wide effects of removing rats

Lessons learned from eradication successes and failures:

• Failed rat eradication projects can provide valuable lessons for future projects but crucially are often under-reported
• Genetic samples of rats should be routinely collected before eradication projects, so that in the event of failure genetic analysis can determine whether subsequent rats are survivors of the original population or new arrivals, providing vital insights into the causes of failure
• Rat eradication projects in the tropics face a number of particular challenges, including climate, land crabs, capacity and support
• Features of successful eradication projects include good preparation, involvement of all necessary stakeholders, and using high quality staff, bait and equipment
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1. Introduction

The genus *Rattus* contains three high-profile invasive species; the Pacific rat, or kiore, *R. exulans*, the brown, common or Norway rat, *R. norvegicus* and the black, ship or roof rat, *R. rattus*. They are extremely widespread, and one or more of these species is reported from 82% of the world’s island groups (Atkinson 1985). Opportunistic and omnivorous, they have the potential to impact on a great many species, and have been implicated in the decline of native species across a broad taxonomic spectrum. However, precise information on their ecological impacts has been, until recently, largely unavailable, particularly for tropical islands. Over recent years the importance of gathering detailed ecological data on the impacts of invasive species has been, until recently, largely unavailable, particularly for tropical islands. Over recent years the importance of gathering detailed ecological data on the impacts of invasive species has been more widely acknowledged, and is becoming a standard part of any well-planned eradication project. In addition, several recent studies have sought to collate this data (e.g. Lorvelec and Pascal 2005, Towns et al 2006, Jones et al 2008, Harris 2009), which had previously been scattered often in unpublished reports or obscure journals. Similarly, information on eradication techniques, which have developed rapidly in the last thirty years, has also been slow to make its way into mainstream scientific literature. A few reviews have painstakingly gathered this information (e.g. Thomas and Taylor 2002, Courchamp et al 2003, Howald et al 2007), but the lessons of many rat eradication projects, with all their individual innovations, remain virtually unknown.

Confining this review only to tropical islands imposes perhaps a slightly arbitrary boundary, and there are of course many valuable lessons to be learnt from outside the region. The majority of rat eradication projects, and hence reports on their methodology and findings, have so far been carried out in temperate zones, notably in New Zealand, Australia and North America. Some examples will be given from outside the tropics where they are particularly relevant, but the review will concentrate on the areas between the equator and 23.5 degrees north and south of this line. This region is of great ecological importance for many terrestrial and marine taxa, and the species richness of many groups is concentrated in the tropics (Gaston 2000). In addition to their significant biodiversity, the tropics also include a great many islands and islands are well known for their high rates of endemism. Many of these islands are part of developing nations, where development pressure is often high and the value placed on conservation is often correspondingly low. This review will further narrow its scope by considering only two of the three widespread invasive *Rattus* species, the brown, common or Norway rat *R. norvegicus* and the black, ship or roof rat *R. rattus*. The Pacific rat, or kiore, *R. exulans*, although a known predator of many bird species (Atkinson 1985) is nowadays generally considered less of a problem than brown and black rats. Although still a problem on many Pacific Islands, the worst of its impact on biodiversity was probably completed as much as 3500 years ago, and it has now been out competed in much of its invaded range by the other two species (Atkinson 1985, Long 2003). It is also the subject of extensive study in New Zealand and there is a body of work concerning its impacts and methods of control (e.g. Campbell and Atkinson 1999, Veitch 2002).

Recent reviews have provided a valuable digest of recent developments in the fields of invasive species ecology and in practical eradication methods (e.g. Thomas and Taylor 2002, Howald et al 2007, Russell et al 2007). Such information can be extremely useful to land managers considering eradicating rats from islands in their care, to help them learn from the lessons of other projects, both successes and failures. The ultimate point of any such piece of work must be to provide accurate and up to date information on the subject, and thus to promote effective conservation of the world’s fragile island ecosystems.
2. History of rat introductions on tropical islands

As humans have travelled round the world and colonised new areas, rats have often been their companions, usually unintended. Black rats are believed to have originated in southern Asia (Long 2003) and are likely to have reached Europe with early explorers and traders (Atkinson 1985). The truly global dispersal of black rats occurred in the 16th to 18th centuries, when European explorers sailed to the New World and elsewhere, settling many oceanic islands previously untouched by humans and inadvertently introducing rats to many of them (Atkinson 1985). In the Atlantic, black rats are thought to have become established on St Helena by 1599 (Ashmole and Ashmole 2000), Ascension around 1701 (Atkinson 1985) and into the Caribbean from the early 17th century (Long 2003). In the Pacific they appear to have become established rather later, arriving in New Caledonia after 1774, the Galápagos in 1835 and Hawaii around 1870. In the Indian Ocean, Arab traders accidentally introduced them to Mauritius around 1500, before Europeans introduced them to many other islands including the Seychelles after 1770 and the Chagos Archipelago by 1840 (Long 2003).

The brown rat also originated from Asia, but from the north of the continent, probably in Siberia or Northern China (Long 2003). Its career as an invasive species appears to have begun fairly recently but has been extremely successful. Around 1700 they appear to have emerged from the northern steppe and spread rapidly westwards through Russia and into Europe (Lund 1994). From the early 18th century to around 1830 they became the commonest rat species at ports both in Europe and on the Eastern seaboard of the USA. As the dominant rat species aboard sailing ships, they therefore became the rats most likely to be introduced to islands during this time (Atkinson 1985). In the Atlantic Ocean, they are believed to have arrived on St Helena between 1730 and 1800 and into the Caribbean from 1700 onwards. In the Indian Ocean they are recorded as arriving on Mauritius between 1730 and 1750, Réunion in 1735, but not to have reached Christmas Island until the early part of the 20th century. In the Pacific, brown rats are believed to have reached Hawaii between 1825 and 1835, the Cook Islands between 1850 and 1885 and Santiago in the Galápagos sometime before 1900 (Atkinson 1985).

Atkinson (1985) calculates that between 1845 and 1985 rat invasions have occurred at a rate of at least 6.5 islands every 20 years. This figure has been recently updated by Russell et al (2007) to include the six known colonisations of previously rat free islands since 1985, which reduces the rate only slightly to 5.8 invasions every 20 years. Both authors show that the rate of invasions is not significantly slowing and thus the arrival of rats on islands is a continuing process. New invasions and reinvasions of islands previously cleared of rats are not an uncommon occurrence (Russell and Clout 2005). The threat posed by the arrival of rats, and the accompanying ecological havoc they can cause, is still very real for many of the world’s islands.
3. **Rat ecology on tropical islands**

Most studies of rat ecology, particularly on islands, have been carried out outside of the tropics, largely in New Zealand. However, the findings of these studies are likely to be applicable to rats on tropical islands and so data from outside the tropics have been included here.

3.1 **Reproduction and dispersal**

The success of rodents, including black and brown rats, as invasive species is due to a number of features, described by Macdonald and Fenn (1994) as ‘preadaptations to pestilence’. Their small size, high reproductive capacity, agility, and opportunism in exploiting a wide range of food sources make rodents highly effective at first reaching (usually with the unwitting assistance of humans) and then colonising new areas (Macdonald and Fenn 1994). On reaching an area with favourable conditions both species are capable of rapid population growth. They are sexually mature at 3-4 months, have a short gestation period of 20-30 days and can produce 5-6 litters of 5-10 offspring each year. They are generally short lived in the wild, living for about 12-18 months (Long 2003).

Rats tend to travel long distances by stowing away on human transport, especially ships. But in addition to this large-scale dispersal they are also well adapted to smaller scale dispersal, often under their own power. Russell and Clout (2005) review the records of detected rat incursions onto New Zealand islands, providing some useful information on the distances rats are capable of swimming. They record two cases where black rats appear to have swum about 500m of calm water to reach islands, but suggest that in most cases black rats reach islands by accidental transportation most of the way and then swimming when already close to the shore. Brown rats are much stronger swimmers and are responsible for most of the records of rat incursions. Russell and Clout (2005) report evidence that brown rats can cross up to 1km of water with ease, and up to 2km if there are mudflats or intermediate islets.

Once they have arrived on an island their rapid reproductive rate allows them to build up their population levels quickly. A single pregnant female brown rat can produce a colony of 300 rats within a space of 250 days (a little over eight months), assuming no mortality (Russell et al 2007). A recent example in the tropics is the invasion of 219ha Frégate Island in the Seychelles by brown rats. One rat was seen arriving on the island in a boatload of household supplies in July 1995. For the first eight-months the rat and its immediate offspring settled in one area, around 75 x 60m. However, dispersal appears to have been fairly rapid after this time and by September 1997, 26 months after the arrival of the first individual, rats were reportedly present over the whole of the island (Thorsen et al 2000). Similar data exist for black rats, following their colonisation of Big South Cape Island, New Zealand in 1962. In just over two years they had colonised the whole of this 939ha island (Atkinson and Bell 1973 in Russell et al 2007).

3.2 **Habitat requirements and use**

Both species are able to live in a wide range of ecological conditions and are found in almost all habitats except deserts and extreme polar regions. Black rats appear to be better adapted to warmer conditions, and are the predominant free-living rat species in warmer latitudes, though they are also found on some sub-Antarctic islands (Long 2003). Brown rats, adapted to the colder conditions of northern Asia, survive well on arctic and sub-Antarctic islands, and are found on Spitzbergen, the Aleutians, South Georgia and Kerguelen among others (Long 2003). They tend to do less well in the tropics and are generally only abundant there in the coastal ports and towns, where they live around human habitation. In tropical Papua New Guinea, for example, where it is a fairly recent introduction, the brown rat is less widespread than the black rat and found only in the main ports (Long 2003).
However, there are records of brown rats colonising tropical islands wholly or largely uninhabited by humans and becoming established there. Examples include Gunners Quoin, Mauritius (Bell 2002), Frégate Island in the Seychelles (Merton et al 2002) and Dennery Island, St Lucia (Varnham 2005).

Although some behaviours are more widely associated with one species or the other, both species show a great deal of behavioural and dietary plasticity. Generally black rats are much better climbers than brown rats and can have a largely arboreal existence, often nesting in trees (Lund 1994). Cox et al (2000) show that black rats in Australian forests prefer microhabitats with a deep cover of leaf litter and dense under-story with numerous vertical stems. In a study of black rats in the Galápagos Islands, Clark (1980) found them living in a wide range of habitats, from savannah, through tropical thorn scrub, to montane forest. Brown rats tend to spend almost all their time on the ground, though they are reasonably good at climbing, and usually nest in burrows. Both species are found in habitats ranging from forests to grasslands as well as around human habitation and agriculture (Lund 2003). Both are largely nocturnal, and rely more on their excellent senses of smell and hearing than on their relatively poor vision (Macdonald and Fenn 1994).

3.3 Population density

The population density and home range size of rats appears to vary widely across different habitats. Studies of black rats in forests in New Zealand and Australia show home ranges of broadly similar sizes, but are generally based on small sample sizes of animals. Dowding and Murphy (1994) review data on black rat home range sizes in New Zealand which, combined with their own research, show a typical winter home range size of 0.5-1ha. They also show evidence to suggest that males increase their home range size during the breeding season, while the home range sizes of females remain relatively constant throughout the year. Innes, Hooker and Williams (1992) (in Dowding and Murphy 1994) also report male home ranges overlapping each other and those of several females, while those of females were largely exclusive. MacKay and Russell (2005) include a review of rat population densities calculated in other studies as well as making calculations from their own study of black rats on Goat Island, New Zealand. They report rat populations over a wide range of densities, from 1.7 to 6.2 rats per hectare for four sites on mainland New Zealand, and between 2 and 50 rats per hectare on a sample of eight islands (mainly New Zealand but also including one observation an island in the Hebrides, Scotland). However, these data are from studies carried out at different times of year and so are not directly comparable. Data on rat densities in the tropics are less readily available. A mark-recapture study on Rat Island, St Lucia indicated a density of 22.8 rats per hectare on a 1.4ha island (Varnham 2004). Clark (1980) found black rat densities in the Galápagos Islands ranging from 0.4 to 18.9 per hectare, across different habitat types and at different times of year. He also found that rat density showed a positive relationship with both rainfall and vegetation density, suggesting that they were restricted by plant food availability (or consequent abundance of animal food depending on this plant availability). Differences in home range size and population density are likely to vary in response to food availability which, in many habitats, will change over time. Seasonal variations in vegetation abundance may be less marked in many tropical areas than in temperate zones but many tropical food resources will show seasonality and thus affect rat population levels. Breeding seabird colonies and seasonally fruiting trees, for example, provide an abundant food supply for some months of the year but rats will be forced to turn to other sources of food at other times.

3.4 Diet

Rats are notoriously omnivorous and are probably best known to humans as household and agricultural pests. In the tropics they have a serious effect on crops such as sugar cane, rice and oil palm (Wood 1994). It is estimated that around one-fifth of the foodstuffs planted each
year in the world is eaten or damaged by rodents, much of it contaminated by their faeces and urine (Long 2003). Rats reportedly eat \( \approx 10\% \) of their weight each day, equivalent to 9-18kg of matter each year per animal (Long 2003). This figure is alarming from the point of view of agriculture and economics, but perhaps of greater concern to conservationists is the presence of rats on islands and other areas of conservation importance, each one eating up to 18kg of biomass each year. The potential impact of a population of hundreds or thousands of rats on an island or other wild area is therefore extremely serious. Both black and brown rats are known to take a wide variety of foodstuffs including plants, seeds, fruits, invertebrates, molluscs and birds’ eggs as well as stored food products (Long 2003). The black rat is generally considered more dependent on vegetable material than the brown rat (Lund 1994), but there are still many records of it eating animal material, especially birds and their eggs (e.g. Cruz and Cruz 1987). Rats are great survivors, able to exploit a wide range of food sources, and are likely to take whichever foods are available to them.

### 3.5 Methods used to study rat ecology on tropical islands

A variety of methods have been used to study rat ecology, though relatively few studies have taken place in the tropics. Radiotracking has been used to investigate rat behaviour and habitat use in some studies (e.g. Cox et al. 2000, Russell et al. 2005), but is still relatively uncommon, due to the time and specialist equipment needed. Spool and line tracking, where a spool of thin, strong thread is attached to an animal and then followed after its release, is another useful technique. It is cheap, simple to use and capable of producing detailed data on habitat use. Key and Woods (1996) used spool and line devices to study the movements of black and brown rats on Santa Cruz in the Galápagos in areas of sympatry and allopatry. Cox et al. (2000) combined spool and line tracking with radio tracking and live trapping in a study of habitat use by black rats in Australia. In New Zealand, Innes and Skipworth (1983) used tracking tunnels, a simple device that preserves the footprints of animals travelling through them. They found this to be an effective technique for collecting data on rat movements and calculating home range sizes. However, probably the most common method of studying rat behaviour and ecology is the use of traps, either live capture or kill traps. Some researchers have carried out the capture-mark-recapture studies needed to calculate accurate population estimates (e.g. Clark 1980, Wilson et al. 2007), but most instead use snap traps to calculate indices of abundance, which are considerably less labour intensive and can produce data that can be compared across sites.

Setting a line of 50-100 snap traps, set in pairs at 25-50m intervals for three successive nights is the standard method for measuring rat abundance (Cunningham and Moors 1993). The results of these trap lines are usually expressed as the number of rat captures per 100 corrected trap nights (i.e. taking into account trap-nights lost to non-target species captures or traps being sprung without catching anything). The resulting figures can be used to compare rat abundance across different sites, providing that differences in make of trap, weather, trap
Invasive rats on tropical islands

spacing etc. are controlled for. However, most if not all methods of estimating abundance can potentially be confounded by seasonal changes in hunger and home range size, which can affect the likelihood of a rat taking bait or encountering a monitoring device.

Picture 2. Live trapping and snap trapping are common methods for studying rat ecology in the tropics (Photo: Richard Cuthbert, RSPB, Henderson Island, Pitcairn)

3.6 Rat ecology – summary

- Rats have been described as being ‘pre-adapted to pestilence’, with ecological traits such as small body size, omnivorous diet and high reproductive capacity
- They are good dispersers at a range of geographic scales, using human transport to travel long distances (e.g. by ship) but dispersing over smaller scales under their own power
- Their reproductive potential is very high, a single pregnant female rat being capable of producing 300 descendents in around 250 days
- Rats are able to live in a wide range of natural habitats and climatic conditions, being excluded only from deserts and extreme polar regions
- Population density and home range estimates vary widely. Evidence from the Galápagos islands suggests that population density is positively correlated with rainfall and vegetation density
- Rats are highly omnivorous and are known to eat a wide range of natural foods including plants, invertebrates and bird eggs as well as stored foodstuffs and crops
- Aspects of rat ecology have been studied using a range of methods including radiotracking, spool and line tracking, capture-mark-recapture and most frequently through snap trapping
4. Rat impacts on tropical biodiversity

4.1 Impact mechanisms

Although perhaps best known as predators of island wildlife, rats can also have negative impacts on native species in a number of other ways. Ebenhard (1988) (in Courchamp et al 2003) lists six mechanisms by which introduced species can impact on native ones. They can: a) affect plant populations and species living in the habitat structured by these plants; b) be predators of native prey; c) induce interference or resource exploitation competition; d) spread micro- and macro-parasites into native populations; e) induce genetic changes to native species through hybridisation; f) act as prey to native predators. Courchamp et al (2003) suggest that the last two mechanisms are relatively unimportant for islands, but that competition and transmission of pathogens are probably more important than the literature suggests, largely because these mechanisms are difficult to show unequivocally and thus are not much studied. Determining the exact nature of the impacts caused by rats is often confused by the presence of more than one invasive species on an island. Even with careful study it may be impossible to tease out the precise impacts caused by rats from those caused by cats, mongoose, rabbits or any number of other invasive species coexisting with them.

Most of the examples of rat impacts on tropical island biodiversity detailed in Table 1 concern predation, probably because it is the easiest impact to detect and also, to some extent, because it is the effect that researchers are expecting to find. However, in addition to examples of straightforward predation recorded here, there are some good examples from outside the tropics that illustrate some of the mechanisms listed above. It is very likely that these processes are also occurring on tropical islands, but have not yet been investigated and/or reported.

4.2 Spread of parasites

Incidences of rat-borne disease organisms on islands are poorly recorded. Smith and Carpenter (2006) report a potential impact of black rats on native deer mice *Peromyscus maniculatus* on Anacapa Island, California by increasing their parasite load. An intestinal helminth parasite, the whipworm *Trichuris muris*, is believed to have been introduced to the deer mice by invasive black rats, which have recently been eradicated. The parasite, however, is still found within the deer mice, where its long-term consequences remain unclear.

4.3 Competition and apparent competition

Rats can also have indirect effects on native populations. An established rat population provides a year-round food source, which can then become a substantial part of the diet of another predator, either native or introduced. This predator can then exist at higher population levels than if rats were absent, and so have a greater impact on native prey. This phenomenon, termed hyper-predation (a form of apparent competition), can then have a sustained impact on native species, even if they are not directly predated by rats. Atkinson (1985) describes a possible example of this from St Helena, where rats appear to have sustained...
the population of feral cats outside the seabird breeding season. This enabled cats to maintain a higher population and thus have a greater impact on breeding seabirds than they would have had if they were there in the absence of rats.

Rats also promote habitat degradation in other indirect ways. E. Sklad (pers. comm.) reports rats promoting apparent competition between the endangered native Bermuda palmetto Sabal bermudana and the invasive Chinese fan palm Livistonia chinensis. Rats preferentially predate the seeds of the native species, thus giving the Chinese fan palm an advantage, which is likely to allow it to spread faster than it would do in the absence of rats. On the island of Tenerife, Canary Islands, heavy predation by black rats on the fruit of the native shrub Viburnum tinus has impacted upon the operation of the bird-plant dispersal system previously in place (Delgado Garcia 2000, 2002 in Towns et al 2006). The long-term ecological consequences of these effects are still unknown.

4.4 Impact on other taxa
Most of the examples for tropical islands given in section 4.6 below detail impacts on birds, but examples from other areas illustrate the wider range of taxa also known or suspected of being negatively affected by rats. The arrival of black rats on Big South Cape Island, New Zealand in 1962 led to one of the worst ecological catastrophes ever recorded following a rodent invasion. In addition to major declines in, or extinction of, eight landbird species (Atkinson 1985), a population of bats disappeared and a species of weevil went extinct (Towns et al 2006). Another invertebrate species, the Lord Howe stick insect, Dryococelas australis, also suffered local extinction following the arrival of black rats on Lord Howe Island, Australia. The exact mechanism by which rats caused these impacts is unrecorded, but these and other examples show the range of effects rats can have on an ecosystem.
### Table 1. Detailed examples of rat impacts on species on tropical islands

<table>
<thead>
<tr>
<th>Island</th>
<th>Rat species</th>
<th>Impacted species</th>
<th>Nature of impact</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribbean</td>
<td><em>R. rattus</em></td>
<td>Antiguan racer snake <em>Alsophis antiguae</em></td>
<td>Predation of eggs and young. Prior to rat eradication more than half of the snake population were found with signs of serious rat-inflicted injuries.</td>
<td>Daltry <em>et al</em> 2001</td>
</tr>
<tr>
<td>White Cay, Bahamas</td>
<td><em>R. rattus</em></td>
<td>White cay iguana <em>Cyclura rileyi cristata</em></td>
<td>The presence of rats was considered detrimental to the recovery of the iguana population through predation of their eggs and young. Rat-free cays had densities of iguanas (+/- standard error) significantly higher than those on islands where rats were present (59.9 +/- 18.1 iguanas per hectare for rat-free islands compared with 10.2 +/- 3.1 iguanas per hectare for rat-infested ones).</td>
<td>Day <em>et al</em> 1998 Hayes <em>et al</em> 2004</td>
</tr>
<tr>
<td>Montserrat, UK</td>
<td><em>R. rattus</em></td>
<td>Montserrat oriole <em>Icterus oberi</em></td>
<td>Video analysis of nest predation shows that black rats are the main or sole rodent predator of oriole nests. During the period 2001-5 rats were thought to have predated c.40% of all oriole nests and were the dominant predator, responsible for c.70% of all nest predations.</td>
<td>Hilton <em>et al</em> 2005</td>
</tr>
<tr>
<td>Praslin Island, St Lucia</td>
<td><em>R. rattus</em></td>
<td>St Lucia whiptail lizard <em>Cnemidophorus vanzoi</em></td>
<td>Following the reinvasion of rats on Praslin Island a decline in observations of St Lucia whiptail lizards was recorded.</td>
<td>John 1999</td>
</tr>
<tr>
<td>Buck Island, US Virgin Islands</td>
<td><em>R. rattus</em></td>
<td>Lignum vitae <em>Guaiacum officinale</em>, Hawksbill turtle <em>Eretmochelys imbricata</em>, Least tern <em>Sternula antillarum</em></td>
<td>Black rats commonly damaged a range of native plants found on the island, including the endangered lignum vitae tree as well as other trees, shrubs and cacti. The authors do not specify the nature of this damage. Up to one-third of monitored hawksbill turtle nests lost eggs or hatchlings to rat predation, and some female turtles abandoned nesting attempts due to rat harassment. Prior to rat eradication, rats preyed on 10-20% of hawksbill turtle nests each year, destroying some nests completely. Rats affected turtles in a variety of ways, including feeding on eggs as they were being laid, preying on eggs during the incubation period and preying on emerging hatchlings. Rat predation on the eggs and hatchlings of the least tern during nesting attempts on the island has also been reported.</td>
<td>Witmer <em>et al</em> 1998 Witmer <em>et al</em> 2007</td>
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## Invasive rats on tropical islands

<table>
<thead>
<tr>
<th>Location</th>
<th>Species</th>
<th>Prey</th>
<th>Description</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ascension, UK</strong></td>
<td><em>R. rattus</em></td>
<td>Madeiran storm petrel <em>Oceanodroma castro</em>, Ascension Island rail <em>Atlantisia elpenor</em></td>
<td>Black rats are believed to have caused the extirpation of the band-rumped storm-petrel on Ascension, restricting it to rat-free Boatswain Bird Island. They also probably caused the extinction of the Ascension Island rail before the arrival of cats in the early 19th century.</td>
<td>Pickup 1999, Kinnear 1935 and Olson 1973 in Atkinson 1985</td>
</tr>
<tr>
<td><strong>St Helena, UK</strong></td>
<td><em>R. rattus</em></td>
<td>seabirds</td>
<td>It is hypothesised that black rats may have caused hyperpredation by cats on breeding seabirds, by sustaining the feral cat population in the months when seabirds were not present.</td>
<td>Atkinson 1985</td>
</tr>
<tr>
<td><strong>Indian Ocean</strong></td>
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</tr>
<tr>
<td><strong>Mauritius</strong></td>
<td><em>R. rattus</em></td>
<td>Olive white-eye <em>Zosterops chloronothos</em></td>
<td>Camera traps showed predation of dummy bird nests by black rats. Evidence of predation by rats on a high proportion of nests of the critically endangered olive white-eye. Fragments of chewed eggshell and nestlings suggested that young birds were predated both before and after hatching.</td>
<td>Carter and Bright 2002, Nichols et al 2005, R. Nichols, pers. comm.</td>
</tr>
<tr>
<td><strong>Gunners Quoin, Flat and Gabriel Islands, Mauritius</strong></td>
<td><em>R. rattus, R. norvegicus</em></td>
<td>Bojer’s skink <em>Gongylomorphus bojerii</em></td>
<td>Population densities of the endemic Bojer’s skink are low on three Mauritian offshore islets where they coexist with rats. In addition, the sizes of Bojer’s skinks on these three islands are skewed towards small individuals, arguably due to larger animals being easier for rats to catch. These figures are presumably in comparison with the populations of skinks on the three other Mauritian islands on which they occur (Round Island, Serpent Island and Ilot Vacoas), all of which are rat free. The low population densities and small sizes of individuals are believed to be due to rat predation (black rats on Flat and Gabriel Islands and brown rats on Gunners Quoin).</td>
<td>Jones 1993</td>
</tr>
<tr>
<td><strong>Ile aux Aigrettes, Mauritius</strong></td>
<td><em>R. rattus</em></td>
<td>Ebony <em>Diospyros egrettarum</em></td>
<td>Rat-gnawed fruits of the Mauritian endemic ebony tree were commonly found on Ile aux Aigrettes during a vegetation survey carried out in 1985. The authors also report that few native tree seedlings were found on the island, and speculate that this may have been due to rat predation on fruits and seedlings.</td>
<td>Parnell et al 1989</td>
</tr>
<tr>
<td><strong>Frégate Island, Seychelles</strong></td>
<td><em>R. norvegicus</em></td>
<td>Giant tenebrionid beetle <em>Polposipes herculeanus</em>, Seychelles magpie-robin <em>Copsychus sechellarum</em></td>
<td>Between March 1996 and November 2000 the number of adult endemic giant tenebrionid beetles (<em>Polposipes herculeanus</em>) declined by around 80% (rats arrived in 1995). In the 1999-2000 breeding season nineteen fledgling Seychelles magpie-robins, a critically endangered species restricted to Frégate Island, disappeared within a few days of leaving the nest. This species is</td>
<td>Merton et al 2002, Parr 1999 in Merton et al 2002</td>
</tr>
</tbody>
</table>
Invasive rats on tropical islands

<table>
<thead>
<tr>
<th>Location</th>
<th>Species</th>
<th>Threats</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird Island, Seychelles</td>
<td>R. rattus</td>
<td>Following the invasion of black rats in the 1970s, the island’s huge colony of sooty terns (numbering about half a million breeding pairs) suffered a ‘high level’ of rat predation (precise figures not given).</td>
<td>Merton et al 2002</td>
</tr>
<tr>
<td>Chumbe Island, Tanzania</td>
<td>R. rattus</td>
<td>Black rats reportedly ‘decimated’ (precise figures not given) a colony of roseate terns breeding on two small islets to the south of Chumbe Island in 1994, predating eggs and chicks. The colony was abandoned following this event.</td>
<td>Peters 2006</td>
</tr>
<tr>
<td>Christmas Island, Australia</td>
<td>R. rattus</td>
<td>Following the introduction of black rats in 1899 two species of native rat went extinct within 10 years. Individuals of R. macleari were observed to be heavily infested with a trypanosome also found in R. rattus in areas around the settlement where the two species co-existed.</td>
<td>Pickering and Norris 1996 and references therein in Harris 2009</td>
</tr>
<tr>
<td>Pacific Ocean</td>
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<tr>
<td>Rarotonga, Cook Islands</td>
<td>R. rattus (and possibly also R. exulans)</td>
<td>Rats are known to predate the nests of Rarotonga flycatchers. Before the start of rat control most nests failed during incubation, with scattered eggshell fragments and occasional rat droppings in nests indicating rat predation.</td>
<td>Robertson et al 1994</td>
</tr>
<tr>
<td>Islas Floreana, Santa Cruz, San Cristobal and Santiago, Galápagos</td>
<td>R. rattus</td>
<td>Black rats are reported to predate eggs and young of the endangered endemic Galápagos dark-rumped petrel. A study monitoring petrel burrows across the four islands in 1978-79 found that at least 128 of the 232 monitored eggs (55.2%) were predated by rats, either as eggs or chicks. Endemic rice rats have reportedly gone extinct on three islands (Santa Cruz, San Cristobal and Santiago) following the introduction of black rats, although the mechanisms by which this happened were not studied and remain unknown. The species of rice rat present on Santiago, Nesoryzomys swarthi, has since been rediscovered but only in a much reduced part of its former range.</td>
<td>Tomkins 1985, Clark 1980, Dowler et al 2000</td>
</tr>
<tr>
<td>Pinzón, Galápagos</td>
<td>R. rattus</td>
<td>Black rats are reported to destroy virtually all hatching giant tortoises on the island of Pinzón, and are believed to pose a threat to tortoises up to 2 years of age. On Pinzón, rats have reportedly killed every tortoise hatched in the wild in the past 100 years.</td>
<td>MacFarland et al 1974, Benchley 1999 in Long 2003</td>
</tr>
<tr>
<td>Location</td>
<td>Species</td>
<td>Description</td>
<td>Reference</td>
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<tr>
<td>Hawaii Island, Hawaii</td>
<td><em>R. rattus</em></td>
<td>Black rats were shown to predate dummy nests at a rate comparable to predation rates observed on nests of the endangered Palila bird, a honeycreeper, on the slopes of Mauna Kea.</td>
<td>Amarasekare 1993</td>
</tr>
<tr>
<td>Midway Island, Hawaii</td>
<td><em>R. rattus</em></td>
<td>Black rats arrived on Midway Island in 1943 and within 18 months two species of landbird were extirpated – the Laysan rail and the Laysan finch. Predation by black rats on the chicks of the Laysan albatross has also been reported. Black rats also affect reproductive success of Bonin petrels on the island by predating both unattended and incubated eggs.</td>
<td>Johnson 1945, Fisher and Baldwin 1946 and Fisher 1975 in Atkinson 1985, Seto and Conant 1996</td>
</tr>
<tr>
<td>Mokoli‘i, Hawaii</td>
<td><em>R. rattus</em></td>
<td>Extensive browsing by rats on the native coastal shrub naupaka has been reported, which has resulted in the death of some plants.</td>
<td>Smith <em>et al</em> 2006</td>
</tr>
<tr>
<td>Sangalaki Island, Indonesia</td>
<td><em>R. rattus</em></td>
<td>Black rats were observed predating green turtle eggs as they were being laid. Often whole nests, each containing around 80 eggs or hatchlings, were completely destroyed by rats in a matter of minutes. Rats were seen actively hunting and predating hatchling turtles, usually eating only their internal organs.</td>
<td>Meier 2003</td>
</tr>
</tbody>
</table>
4.5 Variation in impacts within and between rat species

Atkinson (1985) details the ecological differences between black and brown rats and how their impacts on bird faunas differ. The larger brown rat, being mainly terrestrial, is a particular threat to birds nesting on or near the ground or in burrows. The black rat, with its greater skill in climbing, can reach almost any bird’s nest, but tends to avoid predating larger birds. To complicate matters further, a particular species of rat does not always have the same impact on a particular species on every island where they occur together. The precise impact a rat species will have on a native species on any particular island depends on many factors including the presence of other introduced species, the state of the invaded ecosystem, the population size of native species and whether it is under any other stresses unrelated to the presence of rats.

Atkinson (1985) notes that bird faunas on islands between 15°N and 20°S (i.e. most of the tropics) do not appear to have suffered the catastrophic declines following the arrival of black rats that have occurred on many island groups outside this zone. He hypothesises that birds within these latitudes have evolved in the presence of terrestrial crabs and may have developed attributes or behaviours that make them less vulnerable to rat predation. Species that were highly vulnerable to crab predation presumably never successfully colonised islands with land crabs in the first place. An alternative view is that the ancestors of these island birds, which had evolved on the predator-infested mainland, did not lose the anti-predator behaviours they had already developed when they colonised islands where crabs were present. If rats later invaded an island on which the descendants of these birds were coexisting with crabs the birds had at least some relevant anti-predator strategies.

4.6 Detailed examples of rat impacts on island species

In their review of rat impacts on islands, Towns et al (2006) include many detailed examples from around the world. They specifically restricted their choice of examples to those where rats could be shown to be having a population level effect. In this review, slightly broader criteria have been applied and some examples have been included which illustrate the range of species predated by rats while not necessarily resulting in a proven effect at the population level. This information is summarised in Table 1.

4.7 Rat impacts – summary

- The most commonly recorded means by which rats impact on island ecosystems is through direct predation of birds, including predation of eggs, nestlings and adult animals. However, this is likely to be due to the fact that birds are conspicuous and well-studied, rather than their being particularly susceptible to rats.
- In addition to birds, rats are known to have caused population level impacts on a wide range of other taxa, including mammals, invertebrates and plants.
- Rats can also impact native populations through other ecological mechanisms. For example, rats on Anacapa Island (USA) have transmitted intestinal parasitic worms to native deer mice.
- Other indirect impact mechanisms include habitat modification, competition and apparent competition.
- Different rat species have different ecological impacts on birds. In general, the more terrestrial brown rat is a particular threat to ground or burrow nesting birds, while the black rat is better at reaching nests in high or slender tree branches.
5. Effects of rat eradication on biodiversity

5.1 Recording responses to rat eradication

Detailed examples of ecological responses to rat eradication are summarised in Table 2. Predicted effects of rat eradication projects are usually confined to the key species for whose benefit the eradication is being carried out. On islands with seabirds affected by rats, an increase in their numbers (recorded either as breeding success or some other measure) is generally predicted to follow the removal of rats. A few projects have attempted to predict ecosystem effects more widely, such as the work on French islands reviewed by Lorvelec and Pascal (2005). They describe a number of eradication projects which surveyed a range of different taxa before and after rat eradication, including small mammals, invertebrates and plants. Some of these were predicted to change and others were not. The range of expected and unexpected ecological responses they recorded shows the importance of carrying out proper surveys before and after invasive species eradication.

Since researchers tend to concentrate on the effects on a few key species (often vertebrates which are relatively easy to count), the impacts of rat eradication on the majority of species are probably never observed. Both positive and negative effects will be missed, which could provide vital information for planning better eradication projects (i.e. adapting methods to maximise benefits and reduce negative impacts). By concentrating monitoring efforts on only a few taxa it may be that researchers are building up a false picture of the true impact of rat eradication. Actual effects of rat eradication from islands are reported for a variety of taxa, but with varying levels of precision. Figures quantifying the actual effects of rat eradication are rare and, where they do exist, tend to be confined to the one or few key species known beforehand to be potential beneficiaries. Other effects have been reported in more general terms, usually based on changes to a small number of visible species.

Most reported changes are positive, e.g. improvements in the breeding success of seabirds following rat eradication on Hardy Island, Martinique (Lorvelec and Pascal 2005), but others are less welcome, such as the irruption in house mice following rat eradication from Buck Island, USVI (Witmer et al. 2007). Some of the examples below show consequences of rat control, rather than complete eradication, since they also provide evidence of changes occurring following a reduction in rat populations.

Picture 4. Eradicating rats often leads to increases in numbers and productivity of vulnerable native species. The red-footed booby has started to spread to islands cleared of rats in the Caribbean (Photo: ARCP archive, Redonda, Antigua)
Table 2. Detailed examples of responses to rat control and eradication

<table>
<thead>
<tr>
<th>Island</th>
<th>Rat species</th>
<th>Responding species</th>
<th>Response to rat eradication</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>Caribbean</td>
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<tr>
<td>Great Bird Island, Antigua and Barbuda</td>
<td><em>R. rattus</em></td>
<td>Antiguan racer snake, <em>Alsophis antiguae</em>, red-billed tropic bird <em>Phaethon aethereus</em>, various plant species</td>
<td>Numbers of the critically endangered Antiguan racer snake more than doubled within 18 months of rat eradication in 1995, from 51 to 114 individuals. The number of red-billed tropic birds also increased from about 6 pairs in 1995 to 15 pairs in 2000. Significant increases in vegetation biomass and diversity are also reported since the eradication of rats.</td>
<td>Daltry <em>et al</em> 2001, Ross 2000 and Daltry 1999 in Daltry <em>et al</em> 2001</td>
</tr>
<tr>
<td>Praslin, St Lucia</td>
<td><em>R. rattus</em></td>
<td>Yellow-crowned night heron <em>Nyctanassa violacea</em>, various plants and ground nesting birds</td>
<td>Rats were first eradicated from Praslin Island in 1993. Within six months the vegetation on the island had recovered, and numerous untouched seeds and seedlings were seen throughout the island. Ground nesting birds, including the brown noddy <em>Anous stolidus</em> were seen on the island, and a yellow-crowned night heron successfully fledged three chicks from a nest within 3m of the ground. According to the eradication project report, “in previous years the complete absence of birds had been noted” by two of the paper’s authors, but the report does not specify how much survey effort had been focused on the island in this time.</td>
<td>Johnston <em>et al</em> 1994</td>
</tr>
<tr>
<td>Buck Island, US Virgin Islands</td>
<td><em>R. rattus</em></td>
<td>Hawksbill turtle <em>Eretmochelys imbricta</em>, House mouse <em>Mus musculus</em></td>
<td>Following the eradication of black rats from Buck Island in 2002, the population of house mice increased dramatically. Mice had been occasionally seen on the island prior to rat eradication, but ruptured following rat eradication. The nesting success of hawksbill turtles has also improved substantially following the eradication project.</td>
<td>Witmer <em>et al</em> 2007</td>
</tr>
<tr>
<td>Hardy Islet, Martinique, France</td>
<td><em>R. rattus</em></td>
<td>Brown noddies <em>Anous stolidus</em>, Audubon’s shearwater <em>Puffinus iherminieri</em>, a land crab <em>Gecarcinus ruricola</em></td>
<td>Percentage breeding success of two seabird species, the brown noddies and Audubon’s shearwater increased significantly over the two years following the attempted eradication of black rats in 1999. For brown noddies breeding success increased from 5% in the year of the eradication attempt, rising to 90% after one year and 85% after two years. Breeding success of Audubon’s shearwater rose from 0% in the year of the eradication attempt to 61% after one year and 63% after two years. The abundance index of a native land crab species also increased from 0.85 to 1.36 captures per 100 trap nights over the course of three years. The response of the Audubon’s shearwater to rat</td>
<td>Pascal <em>et al</em> 2004, Lorvelec and Pascal 2005</td>
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</table>
eradication was expected, while those of the brown noddy and the crab were not.

<table>
<thead>
<tr>
<th>Location</th>
<th>Species</th>
<th>Action</th>
<th>Description</th>
<th>Source</th>
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<tbody>
<tr>
<td>Boodie Island,</td>
<td>R. rattus</td>
<td>Burrowing bettong <em>Betongia lesueur</em></td>
<td>Following the eradication of rats from Boodie Island in 1985, burrowing bettongs have been reintroduced from nearby Barrow Island to replace the original population lost during the rat eradication program. The new population are now found all over the island, whereas before the eradication of rats they had been confined to an area of limestone outcropping which made up around 15% of the island.</td>
<td>Morris 2002</td>
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<td>Australia</td>
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<td>Indian Ocean</td>
<td>R. rattus</td>
<td>Golden bandicoot <em>Isoodon auratus barrowensis</em></td>
<td>The abundance of golden bandicoots, as measured by percentage trap success rates, increased from between 4.3% and 6.8% pre-eradication to 36% just over a year after rat eradication had taken place.</td>
<td>Morris 2002</td>
</tr>
<tr>
<td>Middle Island,</td>
<td>R. rattus</td>
<td>An endemic gecko <em>Nactus condimirensis</em>, Bojer’s skink <em>Gongylomorphus bojerii</em>, Bouton’s skink <em>Cryptoblepharus boutonii</em>, various plant species including <em>Dracaena concinna</em>, <em>Latania loddigesii</em> and <em>Pandanus vandermeerschii</em> (native) and the creeper <em>Cissus</em> sp. (introduced)</td>
<td>Encounter rates of an endemic gecko before the eradication of brown rats in 1995 were between 0 and 0.8 geckos per person-hour. One year after the eradication this figure had risen to 2.5 geckos encountered per person-hour and by 2003-4 had risen again to 32.6 geckos per person-hour. Increased visibility of Bojer’s skink and Bouton’s skink on the island was reported almost immediately following the eradication of rats. Strong seedling growth has also been reported for three native plant species where previously rats are thought to have destroyed most, if not all, of their seeds. However, along with the native plants, weed species also benefited from the rat eradication and some, such as the creeper <em>Cissus</em> sp., may cause future ecological problems.</td>
<td>Cole 2005, Bell 2002</td>
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<tr>
<td>Australia</td>
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<tr>
<td>Gunners Quoin,</td>
<td>R. norvegicus</td>
<td>Seychelles magpie-robin <em>Copsychus sechellarum</em></td>
<td>During the 1999-2000 breeding season, 19 Seychelles magpie-robin fledglings disappeared within a few days of leaving the nest, believed to be due to rat predation. No mortality of recently fledged magpie-robin was recorded in the breeding season following the eradication of brown rats in 2000.</td>
<td>Merton et al 2002</td>
</tr>
<tr>
<td>Mauritius</td>
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</tr>
<tr>
<td>Frégate Island,</td>
<td>R. norvegicus</td>
<td>Seychelles magpie-robin <em>Copsychus sechellarum</em></td>
<td>During the 1999-2000 breeding season, 19 Seychelles magpie-robin fledglings disappeared within a few days of leaving the nest, believed to be due to rat predation. No mortality of recently fledged magpie-robin was recorded in the breeding season following the eradication of brown rats in 2000.</td>
<td>Merton et al 2002</td>
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<tr>
<td>Seychelles</td>
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<td>Location</td>
<td>Animal</td>
<td>Introduced Animal</td>
<td>Observations</td>
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<tr>
<td>Bird Island, Seychelles</td>
<td><em>R. rattus</em></td>
<td>Common nobby <em>Anous stolidus</em>, turtle dove <em>Streptopelia turtur</em>, yellow crazy ant <em>Anoplolepis longipes</em></td>
<td>According to reports, common noddies began nesting on the ground and turtle doves, which had not been seen on the island since 1973, became numerous following the eradication of black rats in 1996. The population of the introduced yellow crazy ant is reported to have exploded after the eradication and to have become a threat to some of the species that the rat eradication had aimed to protect. However, other authorities suggest that there is no real evidence that the ant irruption was a result of the removal of rats.</td>
<td>Feare 1999 in Merton <em>et al</em> 2002, Feare 1999 in Courchamp <em>et al</em> 2003, Merton <em>et al</em> 2002</td>
</tr>
<tr>
<td>Chumbe Island, Tanzania</td>
<td><em>R. rattus</em></td>
<td>Roseate tern <em>Sternula dougali</em></td>
<td>Eradication of black rats in 1997 was followed by the return of roseate terns in 2006, 12 years after they had reportedly abandoned the island following heavy predation.</td>
<td>Peters 2006</td>
</tr>
<tr>
<td>Rarotonga, Cook Islands</td>
<td><em>R. rattus</em> (and possibly also <em>R. exulans</em>)</td>
<td>Rarotonga flycatcher <em>Pomarea dimidiata</em></td>
<td>Within four years of the implementation of the rat control programme, numbers of flycatchers doubled from a low of 29 birds in 1999 to 60 birds in 2003. Although no direct predation of rats on adult birds was seen, annual adult mortality decreased significantly in the four years following the onset of rat control, from 24.3% to 6.4%. Following manipulation of levels of rat control in the 2002-3 breeding season, the presence of rat control was found to result in significantly higher breeding success. Areas with rat control resulted in an average of 0.95 fledglings per breeding territory, while areas without control produced only 0.30 fledglings per territory.</td>
<td>Robertson <em>et al</em> 1994, Robertson and Saul 2004</td>
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</table>

**Pacific Ocean**

<table>
<thead>
<tr>
<th>Location</th>
<th>Animal</th>
<th>Introduced Animal</th>
<th>Observations</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isla Floreana, Galápagos</td>
<td><em>R. rattus</em></td>
<td>Galápagos dark-rumped petrel <em>Pterodroma phaeopygia phaeopygia</em></td>
<td>No losses of nesting dark-rumped petrels were reported in the three years following the setting up of a rat control program around breeding colonies.</td>
<td>Cruz and Cruz 1987</td>
</tr>
<tr>
<td>Midway Island, Hawai`i</td>
<td><em>R. rattus</em></td>
<td>Bonin petrel <em>Pterodroma hypoleuca</em></td>
<td>Following the onset of rat control around nests of Bonin petrels, the number of predated nests was significantly lower in sites where rodenticide was applied than in untreated control sites.</td>
<td>Seto and Conant 1996</td>
</tr>
<tr>
<td>Location</td>
<td>Species</td>
<td>Threatened Species</td>
<td>Description</td>
<td>Reference</td>
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<tr>
<td>Mokoli’i, Hawaii</td>
<td><em>R. rattus</em></td>
<td>Wedge-tailed shearwater <em>Puffinus pacificus</em>, various intertidal invertebrates and native plants including <em>Panicum fauriei</em> var. <em>carteri</em> and <em>Scaevola sericea</em></td>
<td>Only one wedge-tailed shearwater chick survived between 1999 and 2001, but this number increased to 126 in 2002 (the year of rat eradication) and 185 birds in 2003. An apparent increase in numbers of intertidal invertebrates and native plants following rat eradication was also reported, including an endangered grass species, <em>Panicum fauriei</em> var. <em>carteri</em>, although no quantitative data were collected. The coastal shrub <em>Scaevola sericea</em> also showed signs of regeneration on rat-grazed plants following the eradication.</td>
<td>Smith <em>et al</em> 2006</td>
</tr>
<tr>
<td>O’ahu, Hawaii</td>
<td><em>R. rattus</em></td>
<td>Elepaio (a flycatcher) <em>Chasiempis sandwichensis</em></td>
<td>Rat control around nesting sites resulted in a 112% increase in recruitment of the ‘elepaio over a period of four years. In addition, a 66% increase in the survival of female ‘elepaio was reported, along with an increase in the population growth rate from 0.76 to 1.00 over the four years following the introduction of rat control.</td>
<td>Vander Werf and Smith 2002</td>
</tr>
</tbody>
</table>
5.2 Eradication effects – summary

- Birds make up the biggest proportion of named species for which population level impacts have been recorded following the eradication of rats from islands, largely because bird protection is the driving force behind many such eradication projects.
- Other species for which post-eradication impacts have been recorded include reptiles, invertebrates, plants and mammals.
- Of the recorded ecological impacts following rat eradication from islands, the majority have been beneficial. However, this is due at least partly to the fact that few species are monitored following rat eradication, and often only those known to have previously been predated by rats are monitored at all.
- Negative ecological consequences following rat eradication include the rapid increase in the populations of other invasive species apparently held in check by rats, e.g., the irruption of house mice following the eradication of rats from Buck Island in the US Virgin Islands.
- The long term ecological consequences of rat eradication have so far been poorly studied, with the result that both positive and negative effects are likely to have been missed.
- Better data on the long-term consequences of rat eradication for a wide variety of taxa could allow eradication methods to be tailored in order to maximise ecological outcomes and reduce negative impacts.
6. Techniques to eradicate rats from tropical islands

6.1 History of island rat eradications
The total eradication of rats from islands was, until relatively recently, considered unfeasible. The chairman of a 1976 conference on rat control in New Zealand nature reserves concluded “…complete extermination (of rodents) on islands is remote, or at least a very, very difficult thing indeed” (Coad 1978 in Thomas and Taylor 2002). In fact, the first island rat eradications had probably already been achieved by the time this statement was made, following a poisoning project in 1975 on 32ha Titi Island, New Zealand. However, no follow up monitoring occurred until 1981-82, when the absence of rats was finally confirmed (Gaze 1983 in Thomas and Taylor 2002). Further research in New Zealand in the late 1970s and 1980s developed the ground-based approach now used in many rat eradications, where poison bait is set at regular intervals across an island and replenished until no rat sign remains. Throughout the 1980s and 1990s these techniques began to be used in other parts of the world, including tropical islands such as Ile aux Aigrettes, Mauritius in 1987 (Howald et al 2007). The development of aerial baiting, where bait is dropped from a helicopter guided by an extremely accurate GPS navigation system has been used successfully to eradicate rats from islands since 1986, and is now the usual method for tackling rats on large, densely vegetated or topographically complex islands (Howald et al 2007).

The ‘recipe’ for a successful rat eradication is a simple one. A method known to be lethal to 100% of rats needs to be applied across a whole island so that all rats will definitely come into contact with it. Then the process needs to continue until all the rats are either dead or fatally poisoned. Of course, the detail of how exactly all this is done is far from simple in many cases, especially where the presence of non-target species or legal obstacles restrict the use of poisons, or where getting to or around the island is complicated by rough seas or rugged terrain. In this section I outline the methods generally used in the eradication of black and brown rats from islands, methods that stay much the same whether the islands are in the tropics or the subantarctic. I also discuss the follow up work essential to maintaining the rat free status of islands.

6.2 Poison bait
6.2.1 Active ingredients
The great majority of rat eradication projects use poison of some kind (see section 6.4 for more detail on the range of poisons used in tropical island rat eradications). Rat eradication from islands only became possible following the development of modern anti-coagulant poisons, the first of which, warfarin, was developed in the late 1940s. Warfarin and other similar compounds, including coumatetralyl, diphenacine and pindone, are known as first generation anti-coagulants. They were used widely following their discovery but by the late 1950s resistance to their effects had developed in some rodent populations. Second-generation compounds, such as brodifacoum, flocoumafen and difenacoum, began to be developed in the 1970s and are now more widely used than first-generation compounds (Buckle 1994).

The key to the success of these compounds is their slow action. Although omnivorous, rats are not indiscriminate feeders and will often be wary of novel sources of food. On encountering a new foodstuff they tend to eat only a very small amount, apparently waiting for any potential ill-effects. Fast acting (or acute) poisons therefore usually fail to kill entire populations of rats, as there will be some individuals who have eaten a sub-lethal dose. They are then able to associate their feelings of illness with the novel poison bait and never touch it again (MacDonald and Fenn 1994). Anti-coagulant poisons act over a much longer timescale, allowing rats to eat a lethal dose before feeling any ill effects (Buckle 1994).
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Anticoagulant poisons work by inhibiting one of the enzymes in the blood clotting cascade reaction, leading to an increase in clotting time until, if the dose is high enough, the point where no clotting occurs at all and fatal haemorrhage ensues. The greater potency of second-generation compared to first-generation compounds is due to their greater affinity for the enzyme vitamin K-epoxide reductase, essential for the completion of the blood clotting process. Second-generation compounds bind more persistently to this enzyme, causing them to accumulate to higher levels and to persist for longer in the bodies of animals that have consumed them. First-generation compounds can only effectively block the enzyme for short periods, meaning that repeat feeds are necessary to cause the eventual death of the animal. Second-generation compounds, by binding more persistently to the enzyme, can cause death after a single feed (Buckle 1994). The differences in the way first and second-generation compounds act have implications for their use in conservation projects. Second generation compounds have traditionally been used more widely than first generation compounds in island-wide rat eradication projects, reflecting their wider use in commercial pest control. However, in recent years there has been a move towards using first generation products since they are far less toxic to key non-target species, especially birds.

Very occasionally different types of poison are used in eradication projects. Howald et al (2007) record two other classes of poison being used in successful tropical island rat eradications. The subactute toxin bromethalin was used to eradicate black rats from 133ha Eastern Island in the Midway Atoll, Hawaii, in combination with trapping. Black rats were eradicated from 0.4ha Pitt Island, Galápagos using the acute toxin sodium monofluoroacetate (also known as 1080), again in combination with traps.

6.2.2 Formulation

These active ingredients are commercially available in a range of formulations, including liquids, pastes, cereal pellets and wax blocks of varying sizes. Liquid and paste formulations are rarely used on a large scale in tropical island eradications, due to their being less convenient to transport and handle in field conditions and prone to drying out. However, they can be a useful addition to any project to use on small scale, perhaps for targeting a few last rats that appear unwilling to take the main formulation. Generally, rat eradications are carried out using pressed cereal pellets or wax blocks, consisting of poison-laced grain held together by a paraffin wax matrix. The choice of which to use in any particular case depends on a number of factors, such as the climate and humidity of the island (pellets tend to go mouldy faster than wax blocks) and which non-target species are present. Wax block formulations are commonly sold as 20g block with a central hole. The hole can be a valuable feature as it allows the bait to be fixed inside a
bait station, which can be useful in preventing non-target bait take.

6.3 Distributing poison

The commonest method involves laying bait at fixed points, usually on a regular grid, and checking and replenishing it as necessary. Grid spacings of 10 to 100m have been used for rat eradications. Black rats are typically eradicated using grids up to 50 x 50m, while grid spacings up to 100 x 100m are used for eradicating brown rats (Thomas and Taylor 2002). The bait is often put inside a bait station of some kind, to protect it from the attentions of non-target species and/or the weather. However, if there are no non-target species and the weather permits, the bait can be put either directly on the ground or fixed using nails or wire to trees or other habitat features. Bait stations also have the advantage that they keep the bait in one place, allowing its uptake to be monitored, and also allowing staff to identify, from feeding sign, which species are taking it. Another ground-based method involves hand-broadcasting the bait, usually from trails marked a fixed distance apart. With this method staff walk along the trails throwing measured quantities bait at regular intervals, to ensure an even coverage of the island. Hand broadcasting of bait has been shown to be more slightly more cost effective in some situations than using bait stations. This potential cost saving was one of the reasons behind the development of using helicopters to broadcast bait (McFadden 1992 in Thomas and Taylor 2002).

In aerial broadcast operations the bait is put in a specially adapted hopper, suspended beneath the aircraft. The hopper releases bait at a uniform, pre-set rate while the helicopter flies straight lines, guided by GPS navigation systems, thus ensuring even coverage. In areas where the right kind of helicopters, the necessary specialist equipment and experienced pilots are available, this method has become widely used. It is now a commonly used method for baiting islands, as well as mainland areas of conservation importance, in Australia, New Zealand and the USA.
costs of hiring, fuelling and maintaining helicopters are offset on large islands by the savings made on preparatory work. However, broadcasting bait, by hand or by helicopter, is not suitable for all islands and can only be done where there are non-target species likely to take the bait.

6.4 Identifying and reducing risks to non-target species

With any planned rat eradication project there is a need for a detailed risk assessment process, looking at all the wildlife already present on an island and considering the risks of different poisons and presentational techniques to each species. The risks of primary (i.e. direct consumption of the bait) and secondary (i.e. consumption of animals that have themselves eaten the bait) poisoning need to be considered separately for each taxa. Birds, for example, are very susceptible to second-generation anticoagulants, which some species may take directly, e.g. if using freely distributed cereal pellet baits, while others may consume the toxins indirectly. For example, South Island robins Petroica australis are known to have died of anticoagulant poisoning after eating bait crumbs (Taylor and Thomas 1993). Ravens Corvus corax, Western weka Gallirallus australis australis and Eastern screech-owls Otus asio are all known to have died following consumption of rodents which had themselves eaten bait containing the anticoagulant brodifacoum (Howald et al 1999 and references therein). Invertebrates are unlikely to be killed by exposure to anticoagulants due to their different metabolism (Eason and Spurr 1995), however they pose a risk of secondary poisoning of other species that feed on them. Direct examples of such secondary poisoning are relatively rare, although Godfrey (1985) reports on the mortality of insectivorous birds after they had fed on ants and cockroaches that had consumed brodifacoum bait. While invertebrates pose some risks for secondary poisoning of other species, information on brodifacoum residues indicates that toxins do not persist in invertebrates for extended periods and that the risk of secondary poisoning from invertebrates may be most acute in the days immediately following an operation (Morgan and Wright 1996).

Once the risks to various taxa have been identified, then the eradication plan needs to be adapted so as to reduce these risks to an acceptable minimum. One way of reducing risk to non-target species is to use different poisons. First-generation anticoagulants are sometimes used instead of the more potent second-generation poisons in order to reduce the risk to birds, which are far less susceptible to e.g. diphacinone than to brodifacoum. Using a different bait formulation can also be effective. Wax bait blocks, for example, are less palatable and are harder to eat for many species than cereal pellets, so using wax blocks can reduce the risks to a range of non-target species.

Perhaps the most effective way of reducing bait take by non-target species is to put the bait inside a bait station. A wide range of bait stations are commercially available, all of which follow the basic design of a closed box with entrance holes large enough to admit a rat but nothing much bigger. If the bait only needs to be protected from larger species, such as goats or other livestock, then home-made (and often cheaper) stations of a simpler design can be used, consisting of sections of plastic drainpipe, or even plastic bottles.
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Hermit or other land crabs can be a real nuisance for many tropical eradication projects (Wegmann 2008). While the crabs themselves are unaffected by anti-coagulant toxins due to their very different blood systems (Pain et al 2000), it is important for several reasons to try and exclude them from the bait. Firstly, they may pose a risk of secondary poisoning to their predators, including some shore birds. Secondly, by consuming the bait themselves they reduce the amount left for rats. Thirdly, they may physically block rats from entering bait stations as they cluster around them (the reason for the initial failure to eradicate rats from Long Cay, Bahamas (Hayes et al 2004)). It can be difficult to prevent crabs from reaching bait as they are extremely good climbers and many of them are smaller than rats, so can get through any bait station entrance large enough to admit a rat. A number of projects have tried to find ways of restricting crab access to bait, mainly exploiting the difference that crabs cannot jump while rats are extremely good at it, and that rats generally have a longer reach. These methods generally involve raising the stations above the ground (e.g. Hayes et al 2004, Witmer et al 2007) or putting some kind of barrier around the bait that crabs cannot climb over but that rats can reach around (e.g. Varnham 2005).

Some projects take a different or additional approach and, instead of excluding the non-target species, they set up a captive community which are released back into the wild once the poisoning phase is over. This may be done in cases where it is impossible or simply not cost-effective to exclude the particular native species from the bait, or where the native species is so rare that every measure must be taken to protect it. It may also be done where the non-target species is affected by secondary poisoning, which is likely to be impossible to prevent. A proportion of or, in some cases, all of the population can be held in captivity. The entire world population of Seychelles magpie robins (39 birds) was taken into captivity for the duration of the second rat eradication attempt on Frégate Island, following the poisoning of some individuals during the first attempt (Merton et al 2002). A variation on this theme is to accept the loss of the original population, and instead to reintroduce the non-target species from a separate population from a different island or mainland area. The risk here though is that unique genetic diversity may be lost with the original population, so in the absence of compelling molecular evidence that the target island population is not
genetically distinct, then it is better to maintain at least a fraction of the original population. For example, Morris (2002) reports the (inadvertent) loss of the burrowing bettong from Boodie Island, off the north coast of Western Australia. The whole population of approximately 20-50 bettongs died out along with the rats. However, bettongs have since been reintroduced from nearby Barrow Island and have now colonised the whole island.

6.5 Results from known eradications on tropical islands

Records are available for 100 black and brown rat eradication projects in the tropics. Of these, 80 were successful, 17 are known to have failed and the outcome of a further three is unknown (data mainly taken from Howald et al 2007, with additional information from Daltry et al 2007 and Varnham 2004, 2005 and pers. obs.). Table 3 summarises the available data on the 97 tropical projects with a known outcome. Only four of these projects were aimed at brown rats, on islands around the Seychelles and Mauritius in the Indian Ocean, and St Lucia in the Caribbean. The number of successful and unsuccessful projects for each country is shown in Table 4.

A variety of methods were used to carry out rat eradication projects in the tropics. Sixty-five projects used poison bait in bait stations as their primary method (67%), followed by 17 records of hand broadcast of bait (17%), 8 records of aerial drops of bait (8%) and two records of using traps alone (2%). For the remaining five eradication attempts (5%) the method is not recorded. 92 out of the 97 projects (95%) are known to have used poison as their primary method of eradication, with two projects using traps and the method used in another three projects not recorded. Of the projects known to use poison as their primary method, the commonest poisons were brodifacoum, used in 69 projects (75%) and pindone, used in 12 projects (13%, all in Western Australia). First generation anticoagulants were used in 15 projects (16%), second-generation anticoagulants in 75 (82%) of projects and subacute (bromethalin) and acute (1080) poisons used in one project apiece (1% each). The subset of failed projects in the tropics all used second-generation compounds, the great majority (15 out of 17, or 88%) using the commonest poison, brodifacoum, with just one failure each for bromadiolone and coumatetral. These data are summarised in Table 5.

Although the number of projects where rat eradication has succeeded in the tropics far outweighs the number which have failed, the total combined areas of ‘successful’ and ‘unsuccessful’ islands are actually very similar (successful eradications (n=80) cover 5581ha of tropical island, while unsuccessful eradications (n=17) cover 5065ha). The large combined area of ‘unsuccessful’ islands however is mainly due to three failed projects on islands in excess of 1000ha. This gives a large difference in the mean values (‘successful’ = 71.6ha and ‘unsuccessful’ = 298.0ha), but differences between the median values are considerably less striking (‘successful’ = 14.5ha and ‘unsuccessful’ = 47.0ha) though still significantly different (Wilcoxon rank sum test, W=371.5, n1=17, n2=78, p=0.005). Data showing the number of projects and the total area treated by the various methods and toxins are also shown in Table 5. The results of logistic regression analysis on success/failure of eradications, shows that size does not affect the likelihood of a successful eradication (odds ratio=1, p=0.80) and neither is there an interaction between size and whether an island is in the tropics (odds ratio=1, p=0.069). However, eradications from non-tropical islands are more likely to have been successful (odds ratio=0.2, p=0.31, p=0.028). Using their whole data set, (n=387 eradication campaigns, including all three species of invasive Rattus and house mice), Howald et al (2007) produce some interesting statistics. The second-generation anticoagulant brodifacoum was used in 71% of island rat eradication attempts, but covered 91% of the total area treated (although this latter figure is influenced by a few very large eradication operations, e.g. Campbell Island 11,300 ha). The subset of tropical island rodent eradications with known outcome (n=97) shows similar results – brodifacoum was used in 75% of projects, but only in 70% of the total area covered.

<table>
<thead>
<tr>
<th></th>
<th>Known successes</th>
<th>Known failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of projects</td>
<td>80</td>
<td>17</td>
</tr>
<tr>
<td>No. of separate islands</td>
<td>74</td>
<td>16</td>
</tr>
<tr>
<td>Total area (ha)</td>
<td>5582</td>
<td>5065</td>
</tr>
<tr>
<td>Mean island size (ha)</td>
<td>71.6</td>
<td>298</td>
</tr>
<tr>
<td>Median island size (ha)</td>
<td>14.5</td>
<td>47</td>
</tr>
<tr>
<td>Island size range (ha)</td>
<td>0.4-1022</td>
<td>7-1815</td>
</tr>
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</table>


<table>
<thead>
<tr>
<th>Country</th>
<th>Number of rat eradication projects</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Successful</td>
<td>Unsuccessful</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Antigua &amp; Barbuda</td>
<td>7</td>
<td>1</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>31</td>
<td>6</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Bahamas</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ecuador (i)</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>France (ii)</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mauritius</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Mexico (iii)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Seychelles</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>St Lucia</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tanzania</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>UK (iv)</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>USA (v)</td>
<td>9</td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

(i) All these projects were in the Galápagos Islands
(ii) Four projects in Martinique, one in Guadeloupe, two in New Caledonia and one in French Polynesia
(iii) This is the only recorded eradication project in tropical Mexico. Many successful projects have been carried out in Mexico’s more northerly latitudes
(iv) Four projects in the Turks and Caicos Islands, one in the British Indian Ocean Territory and one in the British Virgin Islands
(v) Four projects in Hawaii, three in Puerto Rico and three in the US Virgin Islands

<table>
<thead>
<tr>
<th>Primary method</th>
<th>Known successes</th>
<th>Known failures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ha) (%)</td>
<td>No. of projects (%)</td>
</tr>
<tr>
<td>hand broadcast</td>
<td>528 (9)</td>
<td>14 (18)</td>
</tr>
<tr>
<td>aerial broadcast</td>
<td>1853 (33)</td>
<td>6 (8)</td>
</tr>
<tr>
<td>traps</td>
<td>15 (&lt;1)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>bait stations</td>
<td>3029 (54)</td>
<td>54 (68)</td>
</tr>
<tr>
<td>unknown method</td>
<td>157 (3)</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Primary rodenticide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>brodifacoum</td>
<td>4309 (77)</td>
<td>54 (68)</td>
</tr>
<tr>
<td>bromadiolone</td>
<td>30 (1)</td>
<td>5 (6)</td>
</tr>
<tr>
<td>bromethalin</td>
<td>133 (2)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>coumatretyl</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>diphacinone</td>
<td>73 (1)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>pindone</td>
<td>1008 (18)</td>
<td>12 (15)</td>
</tr>
<tr>
<td>1080</td>
<td>0.4 (&lt;1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>no or unknown poison</td>
<td>29 (1)</td>
<td>5 (6)</td>
</tr>
</tbody>
</table>

The complete data set from Howald et al (2007) shows that aerial broadcast accounted for just 15% of the number of projects (n=57), but 76% of the area treated, as most large islands were cleared of rats in this way. For the tropical islands, only 8% (n=8) of projects used aerial bait drops as their primary eradication method, and these projects accounted for 29% of the total area treated. The failure rate for black and brown rat eradications from the complete data set (i.e. tropical and non-tropical islands) was 10% (24 out of 244 projects). However, the failure rate from the tropical data set alone was almost twice as high at 18% (17 out of 97 projects), while the failure rate for non-tropical islands was only 5% (7 out of 147 projects). Comparing the failure rates from tropical and non-tropical islands separately shows that the rate on tropical islands is significantly higher ($\chi^2=10.37$, df=1, p=0.001). Howald et al (2007) point out that failed rat eradication projects are probably less widely reported than successes, so it is likely that the numbers of failed projects given here are underestimates. However, there is no reason to assume there is a bias between reporting failures in tropical and non-tropical islands, so the difference in failure rates remains. Potential reasons for the difference in failure rates of eradications on tropical islands are discussed in Section 7.3.2.

6.6 Post-eradication monitoring

This is a vital part of any invasive species eradication, both in confirming the initial success or failure of the project and also in alerting staff to any incidences of rat reinvasion. A variety of methods can be used, all of which aim to collect evidence of the presence of rats and to preserve that evidence until it can be checked. Ideally, as wide a range of methods should be used as possible to account for possible variations in rat behaviour, though they need only be used at densities of 1-2 devices per ha (Russell et al 2007). Detecting rats at low densities is difficult and their behaviour at low densities has been shown to be atypical; recent evidence suggests that newly colonising rats range long distances when first arriving on a rat-free island (Russell et al 2005). This has management implications for detecting and targeting new arrivals. Methods of controlling rats at high densities, where they are usually food limited, cannot be relied on to work against low density populations such as...
new invaders or eradication survivors (Russell et al 2007).

The best methods to use on any particular island will depend on many factors including the frequency with which the island can be visited, the climate, the non-target species present and, to some extent, the skills and preferences of the staff carrying out the checks. There are a number of so-called passive methods, which can be used to detect rat sign over relatively long periods. These include chewsticks and wax monitoring blocks (including ‘chocolate wax’ blocks), which preserve signs of rat teeth marks, tracking tunnels and sand traps, which preserve their footprints, or simply looking for rat sign such as droppings, runs, burrows and feeding sign.

A number of these methods can be integrated into one unit, sometimes known as a ‘rat motel’ (Dilks and Towns 2002, Russell et al 2007). These work on the principle of providing a range of possible attractants and monitoring methods and consist of a wooden box containing materials such as wax or wooden blocks to detect teeth-marks, nesting material, a snap trap, and possibly also some poison bait. The boxes protect the bait and other contents and may provide an attractive nesting site for rats. More labour intensive ‘active’ methods such as live or snap trapping and using dogs trained to respond to rodent scent can also be used.

In addition to rat motels and other monitoring devices, permanent stations containing a reservoir of poison bait can play a useful dual role in protecting islands where an eradication attempt has been made. They can act both as a monitoring and a control device, providing evidence of the presence of rats by preserving teethmarks and/ or droppings but also providing a means of killing the rats entering them. However, bait can quickly lose its palatability, especially in humid conditions and recent laboratory studies have shown that less than 20% of black and brown rats ate a lethal dose of weathered bait on first encountering it (Morriss et al in press, in Russell et al 2007). If using permanent poison stations, it is important to check them regularly and maintain a fresh supply of bait.

![Picture 10. Monitoring is essential after an eradication operation for determining that rats have been successfully eradicated and can include looking for feeding sign on ‘chew sticks, wax monitoring blocks and ‘chocolate-wax’ blocks as in the photo above (Photo: Elizabeth Bell: Wildlife Management International, New Zealand)](image)

6.7 Preventing reinvasion

Good monitoring methods are vital, but they need to be used as part of a coherent plan that aims primarily to prevent rats reaching islands, but also to detect and respond to them effectively if they do arrive. Russell and Clout (2005) detail at least 42 records of rodent incursions of New Zealand offshore and outlying islands, several of which have resulted in full-scale reinvasions. Atkinson (1985) lists a number of factors associated with high risks of rat invasion, which are extremely useful when considering islands for rat eradication. Factors associated with a high risk of rat invasion (or reinvansion) of an island are: the presence of a permanent settlement, wharves large enough for ocean-going vessels; importation of foodstuffs (especially cereals), exploitation of natural resources on the island or in its surrounding waters, establishment of military bases, and proximity to continents, major trade routes or shipwrecks. Where an island meets one or more of these criteria, measures to detect and respond to reinvasion must be especially well developed.
Good quarantine measures are also essential, both on the island and at mainland points of departure. Particular care should be taken with the movement of bulky supplies, which should never be left packed overnight on the mainland prior to transport to a rat-free island. On islands, stores and bulky equipment should be unpacked in a secure area, so that any rodents present can be isolated and killed. Equipment to deal with known or suspected rat incursions should be available at all times (e.g. a selection of traps, poisons and monitoring methods). In their detailed list of practical recommendations for preventing rat invasion of islands Russell et al (2007) state that every vulnerable island should have its own biosecurity plan. This should include a clear plan of action in case of suspected rodent incursions, assigning specific responsibilities to specific individuals and agencies. Fully stocked ‘contingency kits’, containing all the equipment needed to deal with the suspected incursion (poison, monitoring devices etc.), should be also kept on each island. As well as each island having a biosecurity plan it is also essential that appropriate legislation be in place to ensure that biosecurity measures are enforced.

6.8 Other post-eradication work
Post-eradication ecological monitoring should continue for as long as possible to record the long-term responses to rat eradication. Ideally, this monitoring should occur over as wide a range of taxa as possible and not be restricted to known or suspected prey species. Only in this way will the full impact of rat eradication be understood. Eradicating rats is also only the first step in restoring an island habitat and, unless they have only been present for a short time, it is unlikely that simply removing rats will return the habitat to its original state (Courchamp et al 2003). If rats have been impacting solely through predation, and population levels of their prey species remain viable, then full recovery may occur without the need for any further active management. But, if populations have been reduced to non-viable levels or extirpated then the species may need to be reintroduced from alternative sources, or be actively encouraged to return in some other way. If rats have damaged the habitat in other ways, for example affecting vegetation structure by preferential predation of particular seeds, then selective weeding and perhaps cultivation and replanting of native plants may be necessary. In defining the success of a rat eradication project the restoration of a functioning ecosystem, rather than the simple removal of rats, must be seen as the goal (Courchamp et al 2003).

6.9 Eradication techniques – summary

- The eradication of rats from islands is a recent but fast-developing field
- The great majority of rat eradication projects have been carried out with anti-coagulant poisons, mainly the second-generation compound brodifacoum
- Poison bait is usually distributed across an island in one of two ways: on the ground, using a regular grid of bait points/ stations or by dropping the bait from a helicopter guided by a GPS navigation system
- Vulnerable non-target species must be identified before the start of an eradication and the methods may need to be adapted to minimise the risks to these species
- Of the 97 eradication projects carried out on tropical islands where the outcome is known, 82% were successful. The success rate for non-tropical islands was 95%.
- Post-eradication rat monitoring is vital, both for finding surviving rats and for detecting reinvading animals. A wide variety of methods can be used to detect rat presence, including non-toxic monitoring devices such as chewsticks and wax tags, snap traps and wax poison blocks.
- Rat-free islands should have detailed quarantine and contingency plans in place in order to minimise the risk of rats returning to the island, and also to react quickly to any suspected reinvasion
- Post-eradication monitoring should be extended to as many species as possible and continue for as long as possible in order to fully monitor the ecosystem-wide effects of removing rats
7. Lessons learnt from eradications on tropical islands

7.1 The lessons of failed eradications

As rat eradication has become a widely accepted conservation management tool, projects have been carried out in more and more complicated circumstances - on islands that are more remote, more topographically complex, have vulnerable non-target species etc. The risks of failure of these pioneering projects are higher, but they are vital in pushing the boundaries of rat eradication and in developing new and improved eradication techniques. Eradication of rats from islands is a young and rapidly developing branch of conservation biology and expecting a 100% success rate is unrealistic. Even projects which fail in their main aim of wholly eradicating rats from an island are likely to have valuable lessons for future rat eradications. This underlines the importance of good scientific reporting of all eradication attempts, successes and failures alike.

Many failed rat eradication projects do not make it into the literature, but those that do are extremely useful in helping to plan further projects. Existing reports of failed eradication projects detail a number of ways in which failure can occur. Firstly, projects may fail for the simple reason that not all the target animals have been killed. This can happen in several ways - either the project is halted while rats are known to still be present, or the rats are wrongly believed to all be gone. Falsely believing all the rats to be dead can in turn be due to a number of different reasons. This could reflect an absence of effective monitoring of rat activity as the project progresses, or indeed no monitoring at all. The second main route of failure is if rats return to, and become re-established on, the island following eradication. In such cases, the actual rat eradication has been successful, but the longer-term aim of maintaining a rat free island has not.

Genetic analyses are currently providing new insight into the causes of eradication failure and can have a very practical management application (Abdelkrim et al 2005, 2007). Rats found on an island after an eradication attempt are either survivors of the original population, or are the result of a new colonisation event. Using molecular techniques to distinguish between these two possibilities can provide valuable information for future rat control on the island. If not all the rats were eradicated, then the field eradication methods need to be reviewed and weaknesses identified. If there has been a new colonisation event, then the ‘eradication unit’ (the geographic area within which gene flow occurs, such as a group of islands close enough for rats to swim between, Robertson and Gemmell 2004) needs to be redefined.

7.2 Detailed examples of failed rat eradications in the tropics

Examples presented in Table 6 highlight the variety of ways in which eradication projects can fail to achieve their aims. Failures can be divided into the following categories:

- Operations abandoned before completion
- Operations carried out as planned, but some rats survived
- Operations carried out successfully, but later reinvasions occur

See Table 6 for detailed examples and explanations.

7.3 Challenges of eradicating rats from tropical islands

The relatively high rate of failure for tropical rat eradications compared to those outside the tropics (see section 6.5) raises the question of whether these projects are inherently more difficult or less likely to succeed. Certainly there are differences between tropical and non-tropical islands, but do these explain the differences in the success rates of rat eradication projects? In this section I consider the traits of tropical islands which may affect
the likelihood of successfully eradicating rats from them.

7.3 Complicating factors

**Climate:** Excessive heat may be extremely uncomfortable to work in though it could be argued that experienced field workers should have no more trouble working in hot conditions than cold. There are possible physiological constraints such as heatstroke or dehydration, but for properly equipped and trained staff these risks should be manageable, and no more of a risk than hypothermia in cold conditions. From a technical point of view, conditions of high rainfall and/or humidity may make some bait formulations unusable (especially cereal-based pellets), and cause some equipment to deteriorate faster than in cooler, less sunny conditions. This could be easily tested and should be reported.

**Aseasonality:** There is often less clear demarcation between the seasons in many tropical areas, or even no change at all. This means that there may be natural food sources available year round, and thus no clear window of opportunity where rats are more likely to take poisoned bait.

**Land use history:** A number of the tropical islands that now have some conservation value are former plantations or have been used for other agricultural purposes. In these situations naturalised former food crops may be present even many years after they were abandoned (e.g. coconut palm plantations). This can provide food for the rat population, making them less likely to take poison bait.

**Development status and/or remoteness:** Many tropical islands are part of developing nations, where conservation may reasonably be considered a lower priority than securing essential basic services for the human population. In such areas it may be difficult to get access to the site, to build partnerships with local organisations, or to get personnel and equipment to and from the site. Proximity to centres of conservation or land management expertise is another consideration. Some tropical islands (e.g. Galápagos and Hawaii) have centres of relevant expertise, but many others are reliant on expertise being flown in from overseas, usually for short periods. In addition, some conservation projects are dependent on the efforts of students and recent graduates keen to work in conservation. In small and/or developing countries, universities are often few and far between and may have a limited capacity for teaching ecology and conservation. This has the result that students are either not available for this kind of work or do not consider it relevant to their studies or future careers. There may also be difficulties in sourcing equipment, especially good quality bait and rat survey equipment. Remote and/or less developed islands are less likely to have the necessary equipment available locally, pushing up costs for shipping it in. It may also be a problem to find funds within country to pay for necessary follow-on monitoring, leading to problems with staff retention and project continuity.

**Crabs:** A number of species of land crabs are known to readily take poison bait intended for rats. Having a completely different blood biochemistry, they are not themselves susceptible to the poison and can return again and again to feed on it. Even a relatively small population of crabs can take considerable amounts of bait, meaning that less is available for rats. Excluding crabs from bait can be very difficult as some species are extremely agile and persistent. A lot of effort is currently being put into overcoming these problems (e.g. Buckelew et al 2005 and review by Wegmann 2008)

**Absence of basic ecological knowledge:** In some small and/or developing nations it may be difficult to source accurate information about local natural history. Field guides and other printed information may be unavailable, incomplete or out of date. While there will always be people with a keen interest in nature, they may be difficult to find if they do not belong to the organisations with which the
Table 6. Detailed examples of eradication failures and reasons for failure

<table>
<thead>
<tr>
<th>Island (area)</th>
<th>Summary of failure</th>
<th>Detail of eradication failure</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operations abandoned before completion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monito Island, Puerto Rico (15ha)</td>
<td>Use of poison stopped due to legal issues</td>
<td>The failure of the first attempt to eradicate black rats from this island (1992-93) is attributed to legal disputes between land management authorities over the use of anticoagulant poison. Bait use was suspended until further research into its safety for use around an endemic lizard (<em>Sphaerodactylus micropithecus</em>), obliging the eradication attempt to continue for a time with only snap traps</td>
<td>Garcia <em>et al</em> 2002</td>
</tr>
<tr>
<td>Frégate Island, Seychelles (219ha)</td>
<td>Abandoned following losses of key non-target species</td>
<td>Efforts were made to eradicate a newly arrived population of brown rats approximately one year after their invasion of Frégate Island. Poisoning using wax block bait and cereal pellets in bait stations, combined with monthly applications of hand-broadcast cereal pellets, were begun in June 1996 but stopped after 19 nights after the discovery of a dying Seychelles magpie-robin. Rats were successfully eradicated in 2000 after an aerial drop of cereal pellets containing brodifacoum. On this occasion, all 39 of the island’s magpie-robins were caught before the start of the poisoning campaign and held in captivity for its duration</td>
<td>Thorsen <em>et al</em> 2000, Merton <em>et al</em> 2002</td>
</tr>
<tr>
<td><strong>Operations carried out as planned, but some rats survived</strong></td>
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<tr>
<td>Low Cay, Bahamas (10.8ha)</td>
<td>Some rats survived due to excess bait take and bait station blockage by hermit crabs</td>
<td>An attempt to eradicate black rats from Low Cay failed in 1999 due to a dense population of hermit crabs overwhelming the bait stations and blocking access to them. Rats were successfully eradicated the following year using the same bait stations elevated 15-20cm above ground level on a plastic stake.</td>
<td>Hayes <em>et al</em> 2004</td>
</tr>
<tr>
<td>Location</td>
<td>Status Description</td>
<td>Cause Description</td>
<td>Reference(s)</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
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</tr>
<tr>
<td>Eagle Island, British Indian Ocean Territory (243ha)</td>
<td>Probably survival of remnant population, though possibly reinvasion</td>
<td>The exact causes of failure to eradicate black rats from this remote island are unknown. The report produced following the rediscovery of rats in March 2007, following a ground-based eradication attempt in January-March 2006, lists a number of possibilities. One is that some rats living in the tops of coconut trees did not feed from the bait stations, which were placed on the ground or on tree trunks. Another possibility is that rats were reintroduced, probably accidentally, by fishermen visiting the island following the initial eradication attempt. The long interval between the eradication and the first return monitoring visit meant that, by the time rats were rediscovered, they were already too widespread to deal with without repeating the entire island-wide eradication. This interval was caused by the original return monitoring visit being cancelled. Due to the island's remoteness and restricted status (it cannot be visited without the permission of the UK authorities) arranging travel to the island is logistically complicated and subject to good weather conditions.</td>
<td>Daltry et al 2007</td>
</tr>
<tr>
<td>Fajou, Guadeloupe (120ha)</td>
<td>Survival of remnant population</td>
<td>Genetic analysis, investigating molecular evidence of genetic bottlenecks, suggests that not all of the original population of rats were killed, rather than recolonisation occurring. There is no available information on the reasons why not all of the rats were killed.</td>
<td>Abdelkrim et al 2005</td>
</tr>
<tr>
<td>Poirier Islet, Sainte Anne Archipelago, Martinique (2.1ha)</td>
<td>Survival of remnant population, caused by insufficient bait</td>
<td>Genetic analysis suggests that some rats survived the first eradication attempt in 1999. The initial failure to eradicate rats from the island is attributed to poor efficiency of the poison bait used. Rats were successfully eradicated from all four islands in the Sainte Anne Archipelago by 2002.</td>
<td>Abdelkrim et al 2007, Lorvelec and Pascal 2005, Pascal et al 2004</td>
</tr>
</tbody>
</table>
Invasive rats on tropical islands

Isla Isabel, Mexico (194ha)

Unknown, possibly due to abundant local food supply or loss of bait to non-target species

Black rats survived a six-week poisoning programme using brodifacoum wax block bait laid on a grid measuring approximately 20m x 20m. Bait was replenished daily as needed but bait take did not approach zero over a six-week period, and even increased over time in some parts of the island. After six weeks baiting was abandoned in order to avoid disturbing the large numbers of seabirds which began returning to the island to nest. Various possible reasons for this failure, with suggestions it may have been caused by a lack of knowledge about the rats’ ecology and behaviour. In particular, the eradication attempt was carried out at the end of the rainy season, at a time when seeds and fruits were abundant on the island and may have presented a more palatable food source of food to the rats. No attempt had previously been made to assess the palatability of wax block bait to rats on the island. The design of bait station may have limited the rats’ access to bait in areas where stations were used (around one fifth of the island). Where bait stations were not used, the bait blocks were placed directly on the ground and, of these, an unknown number were taken by hermit crabs. A concurrent attempt to eradicate cats from the island was successful.

Rodriguez et al 2006

Operations carried out successfully, but later reinvasions occur

Green Island, Antigua and Barbuda (43ha)

Reinvasion

Black rats were first eradicated from Green Island in 2001 and regular monitoring of permanent bait stations showed no sign of rats for almost five years. Rats were rediscovered in early 2006 at a number of sites on the island. The island is less than 100m from mainland Antigua and is visited annually by many small boats. It is unknown where rats first came ashore and thus difficult to tell whether they swam from the mainland or arrived by boat. A second eradication was carried out in 2006.

Varnham 2008

Maiden Island, Antigua and Barbuda (9ha)

Probable reinvasion

An attempt was made to eradicate black rats from Maiden Island in 1999 in a ground-based project using brodifacoum bait set out on a 20 x 20m grid. Rat sign was rediscovered the following year when the first post-eradication check was made. In the meantime a small restaurant had been built (illegally) on this otherwise uninhabited island. While it is possible that some rats were missed in the initial eradication, it is more likely they were reintroduced during the transport of building materials or foodstuffs to the island.

Varnham, pers. obs.
### Hardy Islet, Sainte Anne Archipelago, Martinique (2.6ha)

**Reinvasion, possible remnant population and inefficient bait**

Geneic analysis suggests that rats had reinvaded the islet between 1999 and 2002, but also that some individuals may have survived the original eradication attempt. The initial failure to eradicate rats from the islands is attributed to poor efficiency of the poison bait used.

- *Abdelkrim et al 2007, Pascal et al 2004*

### Praslin Island, St Lucia (1.1ha)

**Reinvasion**

This small island is very close to mainland, and situated opposite the mouth of a river. Large amounts of debris are washed down river following heavy rains, and rats could easily be swept the short distance from the mainland to the island. A sandbar covers part of the distance between the island and the mainland at low tide, which may also assist rats. The island has been reinvaded on at least two occasions since the first eradication in 1993.

Invasive rats on tropical islands

7.3.2 Conclusions of challenges

Some of the factors outlined above are unalterable, such as climate and a lack of seasonality, but, with careful planning, the effects of these and others can be reduced. If the climate restricts the hours available for work each day, then this needs to be taken into account and the length of the project and/ or the staffing levels adjusted accordingly. The effects of climate on equipment also need to be considered, especially in terms of choosing a bait formulation able to withstand the conditions (e.g. wax blocks tend to last better in wet and humid conditions than cereal pellets or grain baits). The effect of a lack of clear seasons (especially of a predictable season of lower food availability) needs to be judged on an island-by-island basis. Aseasonality in itself is not a problem, it only becomes one if it causes a year round food supply that rats prefer to poison bait. Depending on the circumstances of the island, it may be solved by intensively harvesting and destroying the alternative food source (e.g. if a small number of mango or coconut trees are present). Alternatively, trials with a variety of bait types could be carried out to find a specific formulation or flavour that rats on that island consistently prefer to the natural food source.

In my own experience of planning and carrying out rat eradication projects, on islands in both tropical and temperate zones I see no reason why rat eradications should be less likely to succeed in the tropics. The striking difference in the failure rate of rat eradications on tropical and non-tropical islands seen in the data collected by Howald et al (2007) is, I believe, due largely to the fact that fewer projects have so far been carried out in the tropics. I predict that the failure rate will decrease steadily as more projects are carried out in these latitudes and existing eradication methods are adapted to better suit tropical conditions. The rat eradication methods now widely used have been developed in temperate regions (chiefly New Zealand and Australia), and are arguably better adapted to these conditions. For example, bait is less likely to go mouldy in cooler and less humid conditions, there is a clear season of low food availability and there are no problems with land crabs.

A second crucial factor is, I think, the presence of local expertise. Many rat eradication projects have been carried out in New Zealand, Australia and the USA, where there are now considerable bodies of expertise available in country. Eradications in these areas are often carried out with the involvement of people who have at least some knowledge of both the area and of rat eradication methods. In areas without this expertise, eradication practitioners are flown in, often for a short period of time and perhaps with little local ecological knowledge to draw upon. There may also be problems in recruiting and retaining local counterparts to work on the project, as these people (often rightly) may consider that there is no money or future in rat eradications within their country, and that their talents are better used elsewhere.

A third factor, related to the issue of local expertise, is that in the countries where the most rat eradications have been carried out, something of a ‘production-line’ approach has developed, which has its own benefits. Organisations specialising in rat eradication projects have the opportunity to build up a great deal of experience in island eradications. The organisations that are successful are those most likely to keep going, either government agencies such as the New Zealand Department of Conservation, NGOs such as Island Conservation, or private companies such as Wildlife Management International Ltd. A virtuous circle then develops, as the organisations that keep going will get further experience and further refine and strengthen their methods. In countries without this
expertise, particularly smaller countries, there may be only one or a few islands that will benefit from rat eradication. These projects may be done either by local conservation groups, or by bringing someone in briefly from overseas, but both approaches involve a certain amount of learning from scratch, which is likely to result in a less certain outcome.

In short, rat eradication practitioners in temperate zones are now benefiting from what has been learnt from the mistakes made by the technique’s pioneers up to 30 years ago. In the tropics, the history of rat eradications is shorter and the mistakes are still being made, but in the near future people working in these areas will also come to reap their rewards in the form of innovative, well-tested and robust methods for eradicating rats from tropical islands.

7.4 Some features of successful projects

Successful projects, in any part of the world, tend to be those that are well thought out, realistic, properly equipped and adequately funded to cope with all eventualities. The following areas are particularly important.

7.4.1 Preparation

A good feasibility study is essential, accurately identifying the species present, any potential non-target species and any specific logistical issues such as transport to and from the site, access to all parts of the island, and any legal or cultural issues that need to be addressed. The feasibility study should also closely examine potential routes of reinvasion and recommend measures to reduce or remove these risks. Project timing also needs to be carefully considered, ideally taking place at the time when the rats will have the lowest amount of natural food. A thorough risk assessment of the planned eradication methods should also be carried out, looking at the ways in which native wildlife might be harmed, either by poisoning, trapping or other project activities. Good preparation also involves securing funding for the full duration of the project. This should include the costs of post-eradication monitoring and responding to future reinvasions as well as the costs of running the actual eradication campaign. It is also very important to find people with knowledge of the natural history of the island and also any relevant material that may be held in the archives of government and NGO groups active in the area. Successful preparation should also include taking an ecological baseline (plants, seabirds, invertebrates etc.) so future impacts and changes resulting from eradications can be measured.

7.4.2 Stakeholder, legal and staffing issues

Successful projects are those that seek to engage all stakeholders from the outset and spend time consulting with all groups that may be affected by the eradication project. This might include local fishermen and tour operators, recreational users of the island, such as hunters and picnickers, as well as animal welfare groups and local scientists. This process should begin as early as possible and seek to inform and educate people about the need for and likely benefits of the eradication project. The eradication methods chosen should be open to scrutiny, and developed within the laws of the relevant country. The choice of project staff is also important. It is important to use well-motivated staff who understand exactly what they are meant to be doing and why it is important. In small island states with few experienced conservationists, it may be better to bring in at least some staff or volunteers from outside the region who already have an understanding of the requirements of an eradication project. These people can then work closely with local staff wherever possible, training them in eradication techniques. It is important to encourage ownership of the project and to build responsibility for protecting conservation areas. This may involve education (of the public as well as organisations involved), and high quality training, both in country and, where relevant, overseas. Ideally, local staff are then equipped to take over the long term monitoring to ensure the island remains rat free. Preparation should also include reviewing local and national legislation regarding the use of toxins and biosecurity.

7.4.3 The poisoning campaign
Rat eradication campaigns should use good quality, fresh and correctly stored bait, of a formulation likely to last well in the climatic conditions of the island. The data from Howald et al (2007) show that the majority of reported projects have used the second-generation anticoagulant brodifacoum. This is an extremely effective compound, highly toxic to rats, but is no guarantee of success in itself, as all but two of the 17 failed rat eradication projects in the tropics also used brodifacoum. The exact choice of bait will depend on the ecological conditions on the proposed island, as well as complying with any legal requirements. Second generation compounds are generally better for short, intensive campaigns, where there are no vulnerable non-target species (especially birds). If any of these conditions are not met, then first generation compounds are probably preferable. They have been used successfully in projects in the tropics and elsewhere and should not be considered as a ‘second-best’ option.

Lines of bait stations should be set out so as to ensure that all the bait points (or stations, if used) are clearly marked, can be easily located and are uniquely identified (i.e. all bait points have a unique alphanumeric or similar code). Bait should be available to every rat on the island simultaneously and, ideally, be replenished as often as is necessary to ensure good quality, palatable bait is available to every rat continuously for the duration of the project. Checking bait stations frequently (ideally daily, or at least every other day) allows staff to adapt the methods as necessary to respond to potential problems, e.g. unacceptable levels of bait take by non-target species or deterioration in bait quality.

7.4.4 Follow up and monitoring
Eradicating rats is of course only the first step in providing rat-free habitat. If rats have reached an island once, then there is always a chance that they might do so again. A clear programme of monitoring visits should be included in the original project proposal, and funding should be sought for these as a core component of the eradication, rather than as an optional add-on or afterthought. Follow up monitoring needs to follow seamlessly on from the original eradication, and should be well prepared to deal with any surviving rats.

7.5 Eradication lessons – summary
- Failed rat eradication projects can provide valuable lessons for future projects but are often under-reported
- Genetic analysis can be used after failed eradications to determine whether newly-detected rats are survivors of the original population or new arrivals, providing useful insights into the causes of failure
- Tropical rat eradication projects face a number of particular challenges, including climate, land crabs and capacity issues
- Features of successful eradication projects include good preparation, involvement of all necessary stakeholders, and using good quality bait and equipment
Picture 11. Features of successful eradication projects include good preparation, involvement of all necessary stakeholders, using good quality bait and equipment, and teamwork (Photo: Chagos Ecological Restoration Project archive, Eagle Island, Chagos)

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