CAN BRODIFACOUM SAVE ENDANGERED SPECIES? RECENT EXPERIENCES FROM THE WEST INDIES

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Introduction

Commensal rats – in particular the black, ship or roof rat (*Rattus rattus*), Polynesian rat (*R. exulans*) and brown or Norway rat (*R. norvegicus*) – stand accused of a long list of offences against humankind, from destroying crops and food stores to gnawing power cables and spreading diseases. Their impacts on wildlife have been even more disastrous. Wherever people have gone, these adaptable rats have followed and multiplied. Island ecosystems have especially suffered as the omnivorous rodents have flourished with few, if any, natural predators to curb them.

Rats have colonised all but a handful of the 7,000 islands in the West Indies, devastating native biodiversity (Figure 1). Since 1500, these Caribbean islands – a mere 0.15% of the Earth's land area – have accounted for 10% of the world's bird extinctions, 35% of mammal extinctions and over 65% of reptile extinctions. Over two-thirds of extinctions on islands are attributed to invasive alien mammals, especially rats (Towns *et al.*, 2006).

Conservationists are now fighting back using rodenticides designed for controlling rats in cities and farms. Since the early 1990s, over 40 rat eradication operations have been accomplished on Caribbean islands to save wildlife (e.g. Johnston *et al.*, 1994; Witmer *et al.*, 2007; Lawrence & Daltry, 2015). This article describes two of the most ambitious operations to date, some of the lessons learned, and their effects on native wildlife.

Figure 1. *Rattus rattus* feeding on an endangered Redonda ground lizard (*Pholidoscelis atratus*). Black rats can reach record densities on islands and prey heavily on plants and animals alike. Despite their name, these omnivorous rats are more usually brown. Photo by Tom Aveling (Environmental Awareness Group and Fauna & Flora International).

Rodenticide choice

Worldwide, rat eradication operations have been carried out on more than 700 islands (http://diise.islandconservation.org/). More than two-thirds of operations use brodifacoum, widely agreed to be the best toxin for total eradications (Keitt *et al.*, 2015). Like other anticoagulant rodenticides, brodifacoum acts on vertebrate animals by blocking the synthesis of the vitamin K-dependent clotting factors in the liver. Death results from uncontrolled bleeding (within 3–10 days for rats: Hadler & Sahdbolt, 1975).

Because as little as 1.4 g of bait containing brodifacoum can kill a rat (compared with 5.6 g for bait containing bromadiolone or 9.0 g for difenacoum: LD_{50} data), a single feed can suffice. Resistance to this toxin is still rare, and brodifacoum can be lawfully used outdoors in most parts of the West

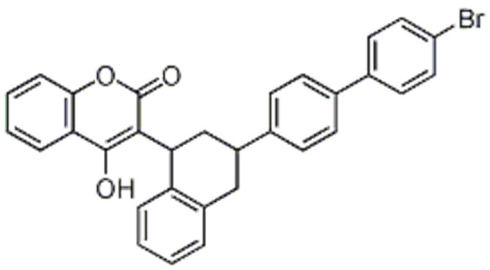

Figure 2. Brodifacoum.

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Figure 3. Brown boobies are among the 345,000 seabirds that now nest on Dog Island. The eggs and chicks of these trusting, ground-nesting birds were especially vulnerable to rat predation. Photo by Richard Brown (Dog Island Restoration Programme).

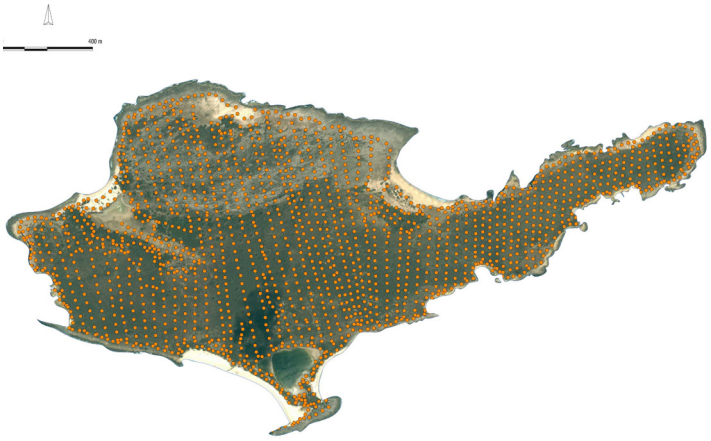

Figure 4. Dog Island, showing the arrangement of bait stations. 1,714 bait stations (orange dots) were placed not more than 40 metres apart in suitable habitats to help ensure every rat would find the bait. Image from Bell (2012).

Indies. Without care, however, the high potency of brodifacoum can also endanger other animals (Eason *et al.*, 2002). This potential risk can be mitigated to a large extent by the choice of bait – the edible material in which the rodenticide is presented – and how it is used. The grain-based Klerat® (Syngenta, Basel, Switzerland) contains 0.005% brodifacoum and has a number of features that make it unappealing to most animals; e.g. it is waxy, dyed blue and contains the harmless but foul-tasting Bitrex (denatonium benzoate). This bait has been used for at least 25 successful rat eradication operations in the West Indies since 1994, including two recent examples described below.

Eradicating rats from Dog Island

Part of the UK Overseas Territory of Anguilla, Dog Island is one of the biggest uninhabited islands in the Eastern Caribbean. The low-lying 207-hectare site, together with its two small offshore islets, was recognised as a global Important Bird Area because of its impressive number of nesting seabirds (Figure 3), but the colonfies suffered from heavy predation of their eggs and young by *Rattus rattus* – hereafter called black rats, although Caribbean populations of this species are usually brown. The island also supports rare lizards that were equally vulnerable. In a regional workshop in 2009, Dog Island was flagged as one of the Caribbean's top priorities for rat eradication. The island had no other mammals apart from bats and feral goats.

The first step was a Feasibility Study to determine whether and how the rat population could be eradicated (Varnham, 2007), followed by a more detailed, peer-reviewed Operational Plan, describing how the rat eradication work would be carried out (Bell, 2011). Klerat® in 20-gram blocks, was identified as the bait of choice, partly because it had been used successfully on other Caribbean islands without harming non-target animals (e.g. Daltry *et al.*, 2012). To ensure every rat could encounter the bait, it was first necessary to cut over 40 km of access trails in parallel lines across the island, 30–40 metres apart: an arduous process that took more than two months because much of the island was covered in dense, 2-metre high thorn scrub.

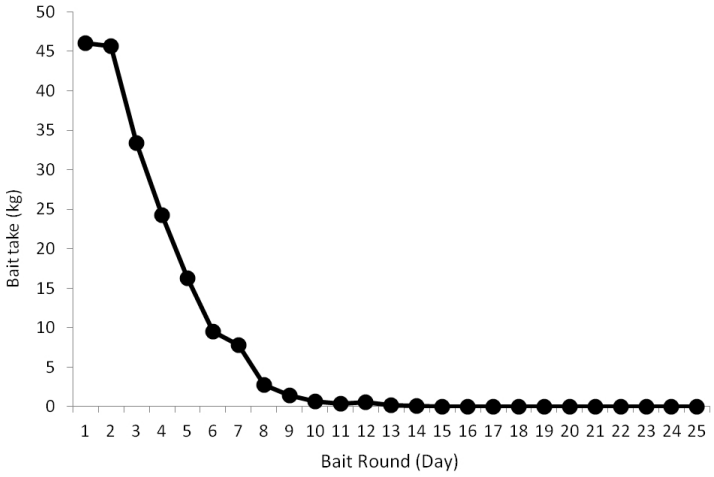

Figure 5. Changes in bait uptake by the rat population on Dog Island. Daily inspections of every bait station allowed the project team to monitor uptake and replace the bait as needed. These data indicate most of the rat population died during the first 10 days. Graph from Bell (2012).

When all of the access tracks were ready, bait was distributed in a grid-like formation in 1,714 locations, 25–40 metres apart, by a dozen local and international biologists (Figure 4). Every station comprised a clear plastic tube – a 1.5-litre water bottle with the ends cut off – with between two and four 20-gram blocks of bait fixed to a wire inside. Every day, from 16 February 2012 to 30 March 2012, every block was inspected closely to determine what had been eating it and replaced as needed (Figure 5). Wiring the bait into tubes was a precaution against the bait being interfered with by feral goats, although they displayed no interest in eating the waxy blocks even when placed in the open (Bell, 2011).

The project team also removed all carcasses found, and, after several weeks of baiting, distributed a variety of monitoring tools every 20 metres along the tracks to help detect any remaining rats. These included non-toxic blocks of chocolate-scented paraffin wax, soap, Trakka™ tracking plates (cards with ink pads to detect animals from footprints) and camera traps. Bait continued to be deployed for two weeks after the

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last signs of rats were detected. In case any rats failed to take the Klerat, a second bait, Pestoff® (Orillion, New Zealand), containing 0.002% brodifacoum, was distributed from 21–24 March. There were no signs of any rats alive on the island by this stage, however, and none of that bait was eaten by rats to the best of our knowledge.

A total of 189 kg of Klerat was consumed by the rats on Dog Island. Some of the bait was also eaten by crabs, but the brodifacoum had no perceptible effect (invertebrate blood does not use vitamin-k dependent pathways). No vertebrates other than rats displayed any interest in eating the Klerat® even when presented with small fragments, and their droppings were free from the bait's blue dye. However, the crumbly and non-bitter Pestoff® bait used toward the end of the operation attracted Anguilla Bank ground lizards (*Pholidoscelis plei*) and was quickly withdrawn to avoid poisoning these or other non-target vertebrates (Bell, 2012). It is likely that some rat carcases were scavenged by these omnivorous ground lizards, but no lizards were observed to show ill effects: Evidence suggests reptiles are vastly more resistant to brodifacoum than rodents (e.g. Weir *et al.*, 2016).

The last live rat was detected on Dog Island on 14 March 2012, less than a month after the first bait was deployed. In early April 2012, the bait stations and any uneaten bait were withdrawn from the island. In 2014, two years after the operation, Dog Island was surveyed thoroughly and officially confirmed to be rat-free (Bell & Daltry, 2014).

Eradicating rats from Redonda

Redonda is the peak of an extinct volcano, rising 295 m above the sea. Part of Antigua & Barbuda, this rugged island is 22 km from the nearest land (Montserrat) and 56 km from Antigua. Redonda is a global Important Bird Area because of its impressive seabird colonies, which supported up to 120 bird guano miners from 1865 until the outbreak of World War I. This remote island also has rare and endemic lizards, all rated Critically Endangered due to predation and competition from alien black rats. Bell & Daltry (2012) found the rats to be remarkably large, abundant, and highly carnivorous. The outsized rodents were observed actively hunting and killing even relatively large lizards and seabirds during the day. The only other mammals recorded on the island when this project started were feral goats.

Although smaller than Dog Island and so badly deforested there was no need to cut access trails, Redonda presented major logistical difficulties (Figure 6) because the island is remote and encircled by high, eroding cliffs. To distribute bait, we decided to divide the island into zones and use a combination of bait stations on the upper slopes (where safe to walk or scramble), abseiling where there were cliffs with safe anchor points, and broadcasting bait by catapults and aerial drops from the helicopter on the dangerously unstable cliffs and scree slopes. While arguably the entire island could have been treated with aerial drops, having a team on the ground gave greater control over the amount of bait used and allowed us to monitor the rat population's response and mitigate any interference by non-target species.

Klerat® in 20-gram blocks was again identified as the best available bait, having proved so effective on Dog and other islands. In zones accessible on foot or by abseiling, it was distributed and monitored in the same way as on Dog Island, i.e. in plastic tubes not more than 40 metres apart (Figure 7). Where the bait had to be dropped or thrown by hand, we again aimed to leave no spot more than 40 metres from bait. Bait was distributed from 14 February to 2 April 2017. As on Dog Island, the project team camped on Redonda throughout and removed, and autopsied, all carcasses found. As bait uptake by rats fell, camera traps and other monitoring devices were placed every 20 metres in accessible areas. Bait was left out for 3 weeks after the last signs of rats were detected and, as a further precaution, a second waxy bait (Final All Weather Blox®, Bell Laboratories Ltd., USA), also containing 0.005% brodifacoum but no bittering agent, was distributed for several days. However, there was no evidence of any rats left alive by the time the second bait was deployed, suggesting the Klerat® had completed the task.

Figure 6. Redonda before the rats were eradicated. Both black rats and feral goats contributed to this rugged island becoming deforested and severely eroded. Photo in 2016 by Adam Long (British Mountaineering Council and Access Techniques Ltd).

Figure 7. Black rats gathering around a bait station on Redonda. Every bait station was a plastic tube containing bait (in this case, four blocks of Klerat fixed to a wire). Camera trap images show the rats taking it in turns to enter the tube to feed.

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At least 170 kg Klerat was eaten by the estimated 5,000-7,500 rats on Redonda. As on Dog Island, the only other animals that showed interest in eating this bait directly were crabs and certain other invertebrates, which showed no effect. However, one non-target animal was confirmed to have suffered from secondary poisoning: a single migratory peregrine that had atypically hunted rats on Redonda (Bell *et al.*, in prep.).

The last two known rats – both juveniles born around the time the first bait was deployed – were detected and culled on 8 March, and the rat eradication team was withdrawn on 7 April 2017. No signs of rats have been detected on routine checks since, but another major survey is planned in 2018 to verify Redonda is rat-free.

Effects of the rat eradications on native wildlife

Because the primary purpose of eradicating black rats from Dog Island and Redonda was to conserve wildlife, close attention was paid to monitoring native biodiversity before, during and after treatments. As reported above, both islands were searched daily by trained biologists while baiting was taking place, and all bait uptake was monitored closely. No evidence of direct poisoning was observed, and only one non-target animal – a single bird – showed signs of secondary poisoning. Other operations that have used different types of bait, often in considerably greater quantities, have been less fortunate (e.g. Howald *et al.*, 2009; Pitt *et al.*, 2016).

Since the rat eradication was completed on Dog Island in March 2012, native wildlife populations have grown by leaps and bounds. Standardized monitoring on Dog Island in March 2016 recorded a four-fold increase in the density of endemic lizards (Figure 8), a more than three-fold increase in land birds, and significant increases in seabirds nesting on the island, including 50% more frigatebirds, 64% more masked boobies, and over six times more tropicbirds. At least three seabird species – least terns, Audubon's shearwaters and brown pelicans – have also recolonised the island naturally since rats were eradicated in 2012, and Dog Island now attracts a rising number of local people and tourists eager to see the spectacular seabirds. The Anguilla Bank skink (*Spondylurus powelli*), an endangered lizard that was glimpsed only twice on Dog Island prior to the rat eradication, can now be seen daily. Even though the island's vegetation is still affected to a large extent by feral goats, certain species, including cacti in the genera *Opuntia* and *Melocactus,* have increased measurably.

Less than one year has elapsed since the 2017 rat eradication operation on Redonda, but promising changes can be seen already. These include a conspicuous increase in insect abundance and plant biomass (Figure 9) and, for the first time in decades, the reappearance of tree seedlings, bats and several species of land birds. Monitoring will be ongoing. Redonda's transformation is especially dramatic because the island was in such dire condition when the project began, and because the resident herd of feral goats was also removed from the island in 2017.

These rapid changes corroborate the findings from other rat eradication operations on islands. For example, since black rats (and a lone raccoon) were removed from White Cay in the Bahamas, the world population of White Cay iguanas (*Cyclura rileyi cristata*) has exploded from only 150 individuals to more than 2,000 (Knight, 2017). Eliminating alien rats has also played a major part in the recovery of the Saint Croix ground lizard (*Pholidoscelis polops*), Antiguan racer (*Alsophis antiguae*) and a wide range of seabirds, among many others (e.g. Jones, 2010; Daltry *et al.* 2012, 2017; Platenberg, 2017).

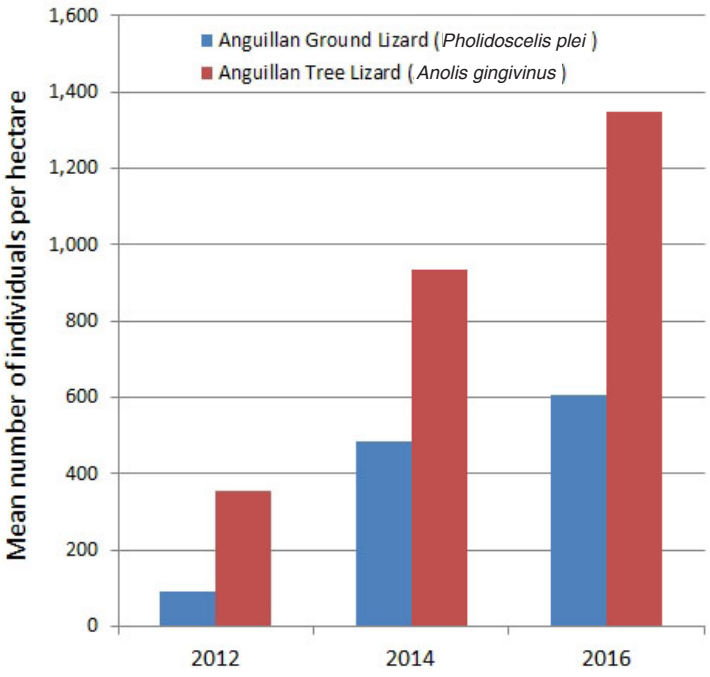

Figure 8. Changes in density of lizards on Dog Island, before and after rat eradication. Data on two species were collected using the 10-minute point count method.

Figure 9. Project team members on Redonda in November 2017. Showing the striking increase in vegetation cover only eight months after rats were eradicated. Many of these plants had survived in the seedbank. Photo by Shanna Challenger (Redonda Restoration Programme).

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Conclusions

The projects to eradicate black rats from Dog Island in 2012 and Redonda in 2017 were logistically challenging but went according to plan using predominantly ground-based methods. While more labour intensive than aerial baiting, the use of bait stations allows for much greater control over the quantity and distribution of bait, further reducing the risk to non-target animals. Based on this experience – combined with more than two dozen operations in this region – brodifacoum can be used safely and effectively to eradicate rats from Caribbean islands, with almost zero risk to native wildlife as long as the right bait and methods are used.

With bait placed at intervals of not more than 40 metres, our primary bait Klerat® appeared fully successful in eradicating the rats within 4 weeks. Contrary to concerns by some operators (e.g. Keitt *et al.*, 2015), the bittering agent Bitrex did not deter the black rats from consuming the bait but may have helped prevent other animals from eating it.

At the time of writing, a further six islands in Anguilla and Antigua are scheduled for the removal of invasive alien rodents using the same bait, including islands home to endangered Lesser Antillean iguanas, Sombrero ground lizards and lignum vitae trees (*Guaiacum officinale*). A growing number of such animals and plants owe their recovery to rat eradications, and islands that have been cleared of rats can in turn become attractions to nature-loving tourists and enjoyed by local people.

There are thousands of islands that still have invasive alien rats, and whose native biodiversity is dwindling. In this race to prevent more island species becoming extinct, brodifacoum is proving to be one of the greatest tools that conservationists have.

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