Introduced rodents in the Galápagos: colonisation, removal and the future

G.A. Harper[1,3] and V. Carrion[2]

[1]Charles Darwin Foundation, Casilla 17-01-3891, Quito, Ecuador. [2]Galápagos National Park Service, Puerto Ayora, Isla Santa Cruz, Islas Galápagos, Ecuador. [3]Rotoiti Nature Recovery Project, Department of Conservation, PO Box 55, St Arnaud 7053, New Zealand. <gharper@doc.govt.nz>.

Abstract Introduced rodents (ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*) and mice (*Mus musculus*)) have been present in the Galápagos Islands for at least 300 years. Their presence has resulted in adverse effects on native flora and fauna, including the likely extirpation of native rodents. Control of rodents has mainly been to protect native species like the dark-rumped petrel (*Pterodroma phaeophygi*) and to reduce effects on human infrastructure. Introduced rodent eradication attempts in Galápagos have been conducted since the 1980s, generally on small islands, and mainly using poison bait either hand-laid or in bait stations. Successful eradications have all been of ship rats in drier years, when reduced vegetation biomass apparently restricts rat populations through food limitation. Eradication attempts are being planned for larger islands using aerial poison applications with a view to scaling up to islands as large as 57,000 ha.

Keywords: *Rattus rattus*, *Rattus norvegicus*, *Mus musculus*, islands, brodifacoum, eradication

INTRODUCTION

Introduced rats (*Rattus* spp.) and house mice (*Mus musculus*) are considered responsible for a significant number of extinctions and ecosystem changes on islands worldwide (Towns *et al*. 2006). Over the past 30 years, increasing success in eradicating rats from islands has often been followed by spectacular responses by resident populations of native species and re-colonisation by species that had been extirpated (Bellingham *et al*. 2010). These responses have led to increased eradication attempts on archipelagos worldwide. Although the size of islands where rodent eradications are attempted is increasing, there have been failures (Howald *et al*. 2007). Reviews of the impacts of rodents on islands, and the outcome of eradication attempts, provides information that can justify and inform plans for rodent eradications elsewhere and are therefore useful for eradication practitioners worldwide. In the tropics, more information on eradications of invasive rodents on islands is required and should include information about improving efficiency to reduce cost and assessing risks to non-target species (Howald *et al*. 2007; Harper *et al*. 2011). The aim of this paper is to briefly review the impacts of introduced rodents in the tropical Galápagos Archipelago, outline the eradication attempts to date, and assess techniques and risks for the future.

INTRODUCED RODENTS IN GALÁPAGOS

Three of the four species of rodents commonly introduced to oceanic islands have reached the Galápagos Archipelago (total area: 777,000 ha): ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*) and house mice. The invasion history, and threats posed by introduced rodents to native flora and fauna of the Galápagos, are summarised below.

Ship rat

Ship rats were first introduced to Galápagos by pirates and whalers between 1600 and the 1700s. A population established at James Bay, Santiago Island (Fig. 1), where buccaneers careened their vessels. The first recorded specimen was collected at Santiago by Darwin in 1835 (Waterhouse 1839). Two subsequent waves of introductions were apparently associated with human colonisation of other islands in the archipelago (Patton *et al*. 1975). The first wave began in about 1830, when ship rats became established on Floreana and Isabela islands. The second wave began during the Second World War, when the rats became established on Baltra and Santa Cruz islands (Clark 1978) and were followed by introductions to smaller islands with increased human activity. Ship rats now inhabit 35 islands, which comprise 90% of the land area of the Galápagos.

Most of the knowledge about the impacts of rodents in the Galápagos relates to ship rats but even then information is scarce. Ship rats caused up to 70% reproductive failure in the dark-rumped petrel (*Pterodroma phaeophygi*), whose colonies are restricted to the highlands of Santa Cruz, Floreana, Santiago and Isabela islands (Cruz and Cruz 1987a, 1987b). On Punta Pitt, San Cristóbal Island, ship rats preyed on eggs and chicks of wedge-rumped storm-petrels (*Oceanodroma tethys*) and Madeiran storm-petrels (*O. castro*) leading to a dramatic decline in both populations (Valle 1996). Nesting success of the critically endangered mangrove finch (*Geospiza scandens*) was significantly higher where ship rats are controlled (B. Fessel pers. comm.). On Pinzón Island recruitment of

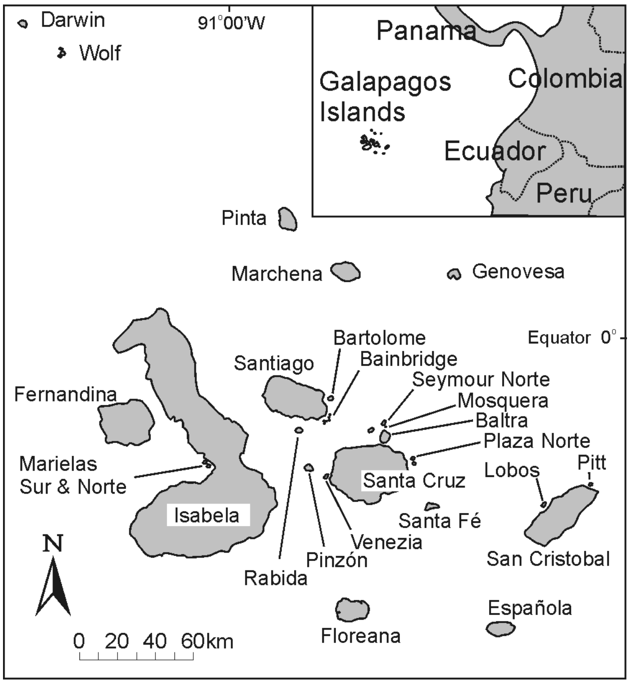

Fig. 1 Location of the Galápagos Islands and islands mentioned in the text.

Pages 63-66 In: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). 2011. Island invasives: eradication and management. IUCN, Gland, Switzerland.

the endemic giant tortoise (*Geochelone elephantopus ephippium*) consistently failed due to predation of eggs and young by ship rats (McFarland *et al*. 1974). There is also evidence that invasions by ship rats were responsible for the extinction of several species of the endemic rice rats *Nesoryzomys* spp. and *Oryzomys galapagoensis* (Clark 1984).

Norway rat

Norway rats, were first introduced to Santa Cruz and San Cristóbal islands in the 1980s, were recently discovered on Rábida Island and may be on Isabela Island (Key and Muñoz 1994). This species has been slow to spread through the Galápagos, possibly due to the widespread distribution of ship rats, which on forested islands can displace Norway rats (Russell and Clout 2004; Harper 2006). Norway rats are very common in urban areas and are trapped in the highlands where water is more freely available (Key *et al*. 1994). Their effect on birds in the Galápagos is unknown, but it is likely to be adverse, considering the effects of Norway rats on land birds and seabirds elsewhere (Towns *et al.* 2006; Jones *et al*. 2008). Norway rats occupy approximately 20% of the land area of the Galápagos.

House mouse

Mice were possibly introduced at the same time as ship rats in the 17th century (Key *et al*. 1994) and are now found on 12 islands. However, some populations of mice may have been overlooked during monitoring for the larger rodents, as mice are often cryptic in the presence of rats probably due to interference competition (Harper and Cabrera 2009). Little is known of the impacts of mice in the Galápagos. They are known to affect numbers and recruitment of the cactus (*Opuntia echios*) by digging around roots and affecting their stability during periods of high rainfall when cacti often become waterlogged. This adverse effect is then exacerbated by land iguanas (*Conolophus subcristatus*), which subsequently eat cladodes from the toppled cacti (Snell *et al*. 1994).

Mice have the potential to affect birds in the Galápagos in similar ways to those reported for seabirds in the Southern Ocean (Angel *et al*. 2009), but this possibility has yet to be examined. Mice do eat and contaminate crops and damage infrastructure, thus having an economic impact on human activity. For example, mice have reportedly damaged the wiring in electronic equipment at Baltra Airport. Mice are present on at least 90% of the land area of the Galápagos.

Rodent control and eradication

So far, the control of rodents in the Galápagos has focussed on rats for species protection and to reduce damage to infrastructure and the contamination of food supplies. Ship rats were first controlled for species protection using poison in bait stations on Cerro Pajas, Floreana Island, in 1983 to protect a population of dark-rumped petrels (Cruz and Cruz 1987a). This programme has since been extended to other petrel colonies in the highlands of Santa Cruz, Santiago and San Cristobal. Rat control is also carried out on the north coast of Baltra Island to prevent them from reinvading the adjacent Mosquera and Seymour Norte Islands from which the rats have been eradicated (Harper *et al*. 2011). Rats are also controlled on Baltra at the airport, the military base, and at the refuse tip. Local authorities carry out control in urban areas on inhabited islands.

Attempts to eradicate ship rats from islands in the Galápagos began in the early 1980s (Table 1). Until now, they have been focused on smaller islands, but with the eradication of ship rats on Seymour Norte (Harper *et al.* 2011) planning is underway to attempt larger islands.

An early ambitious attempt to eradicate rats on a large island using bait dumps almost succeeded on Pinzón Island (Table 1). During a very dry year over 45 days in November and December, a team of 47 people established bait dumps at 50m spacing across the entire island (Cayot *et al*. 1996). Each bait dump comprised 200gm of Racumin (Coumatetralyl) powder combined with rice in a paper bag, which equates to an application rate of 1 kg poison/ha. Brodifacoum (Klerat) blocks were also hand broadcast

Table 1 Attempted eradications of ship rats (*Rattus rattus*) on islands in the Galápagos Islands, Ecuador.

Island	Size (ha)	Nearest main island	Distance to main island (m)	Year of eradication attempt	Technique	Poison Bait type	Success	Year Confirmed
Venezia	13.3	Santa Cruz	30	Early 1980s	unknown	unknown	No	-
Pinzon	1815	Santa Cruz	10,399	1988	Hand-laid bait dumps/ broadcast 50 x 50m grid	Racumin Klerat	No	-
Marielas Sur	1.3	Isabela	848	June 1988	Bait stations 25m x 25m grid	Klerat	Yes	1999
Marielas Norte	0.24	Isabela	812	June 1988	Bait stations 25m x 25m grid	Klerat	Yes	2009
Pitt	0.4	San Cristobal	622	1989	Hand broadcast/ trapping	1080	Yes	1989
Bainbridge Islands (4)	#1: 11.4 #3: 18.3 #5: 4.1 #6: 4.5	Santiago	#1 1024 #3 630 #5 1167 #6 874	2000	unknown	unknown	unclear	-
Lobos	6.7	San Cristobal	162	2002	Bait stations 30m x 30m grid	Klerat	No	-
Mosquera	4.6	Baltra	406	Early 1980s	unknown	unknown	No	-
Mosquera	4.6	Baltra	406	2007	46 bait stations	Klerat, 1080	Yes	2009
Seymour Norte	184	Baltra	1464	2007	Hand broadcast 25m x 25m grid	Klerat	Yes	2009

between bait dumps. On coastal cliffs Klerat blocks were thrown onto cliff faces. Most bait take was on the coast and in the more humid highlands where the last rat sign was in loose rocks on the crater walls. Monitoring in January, February, April, May, July-August, October (two trips) and November 1989 detected no rat sign from February until the end of October when sign was found at a single bait station. Although poison bait was laid around that bait station, more comprehensive sampling in November found sign of rats at 10 stations in the central highlands and higher southern slopes. These areas were re-poisoned with Racumin and Klerat (Cayot *et al*. 1996). By January 1990, the beginning of the 'hot' season and associated increase in rainfall made bait distribution untenable and the project was abandoned. Observed short-term benefits of rat suppression for native wildlife included increases in the abundance of juvenile marine iguanas (*Amblyrhynchus cristatus*) (Cayot *et al*. 1994) and in populations of endemic Pinzón lava lizards (*Microlophus duncanensis*) and Galápagos doves (*Zenaida galapagoensis*). Successful giant tortoise nesting was also recorded. There was an apparent decrease in the population of Galápagos hawks (*Buteo galapagoensis*) and short-eared owls (*Asio flammeus*) (Muñoz 1990).

One of the first successful eradications was on Pitt Island, an islet off San Cristóbal after ship rats colonised around 1983 (Valle 1996). The eradication attempt was confirmed successful in 1989 (Table 1).

In 2000, attempts were made to eradicate ship rats from the Bainbridge islands where they had established on four of the eight islands (Table 1). By 2002, no rats were detected on two of the four islands attempted, but the success within the island group is still unclear and requires extensive sampling to confirm the outcome.

DISCUSSION

There have been 10 recorded ship rat eradication attempts in the Galápagos since the early 1980s and five (50%) have been successful. The result from one operation at the Bainbridge Islands is unclear but appears to have mixed success, with some islands with rats still extant and one or two islands where rats have been eradicated. Most of the islands attempted have been small (< 20ha), although the successful eradication on Seymour Norte and failed Pinzón operation are exceptions.

Ship rats have been heavily suppressed or eradicated in the Galápagos with low poison application rates and this may be related to climatic conditions. On Pinzón approximately 1 kg/ha of Racumin was applied with rice as a bait which equated to 7.5g coumatetralyl/ha. Although there is no information on the rates of Klerat bait broadcast between Racumin bait dumps it appears that the application rates were relatively low. On Seymour Norte less than 3 kg/ha of Klerat bait was applied (Harper *et al*. 2011) which was equivalent to 150g brodifacoum/ha. In temperate islands applications routinely apply bait at rates of 12 kg/ha or more (Empson and Miskelly 1999; McClelland 2002) which equates to 240g brodifacoum/ha. In the Galápagos, the 1988 Pinzón Island eradication attempt, successful 1988 Marielas Islands, and 1989 Pitt Island eradications were carried out in particularly dry years. For example, in 1988 and 1989 78.5mm and 82.5mm annual rainfall respectively were recorded at Puerto Ayora (M. Gardener pers. comm.) instead of a median rainfall of 277mm. In contrast, an eradication attempt on Lobos Island in 2002 failed during a relatively wet year (577mm).

In the Galápagos, population densities of rats during dry years in all vegetation types rarely exceed five rats/ha whereas in particularly wet years densities reach 19 rats/ha (Clark 1980; Harper and Cabrera 2010). Ship rat populations on the Galápagos show food limitation with a positive correlation between population density and vegetation biomass (Clark 1980). The generally arid conditions that prevail in the Galápagos during the dry season and in non El Niño years thus appear to restrict ship rat populations. Strong food limitation for ship rats in the dry season was suggested by the apparent palatability of wax-based Klerat to the low density ship rat population on Seymour Norte (Harper *et al*. 2011). Failed rat eradications on tropical islands elsewhere were often timed at the end of wet seasons when abundant food was available (Rodríguez *et al*. 2006).

The information presented here suggests that relatively low poison bait application rates may be suitable for eradication attempts in dry years. Poison operations should be timed for the last three months of the dry season and in particularly dry years if possible. Low application rates will reduce resources and time required, as well as risks to non-target species, and should be tested on smaller islands in the Galápagos with a view to scaling up to larger operations.

Grid spacing of bait stations or hand-laid baits does not appear to have had any appreciable affect on the success of eradications although the sample size is small. Grids of ≤ 25m on three islands have all resulted in successful operations (Table 1). The grid spacing for the Pinzón operation was 50 x 50 but Klerat was hand sown between the bait dumps, effectively reducing the grid size.

Future operations

In April 2007, international rat eradication experts met in the Galápagos and drafted a plan, Project Pinzón, to eradicate rats from several larger islands in the archipelago (Cayot 2007). The plan included improving eradication experience in the Galápagos by beginning with rat eradications on smaller islands, then with the information and experience gained, scaling up eradication attempts to islands as large as Santiago (57,728 ha).

Since that meeting, rats have been eradicated on Seymour Norte. An operational plan has been completed for the eradication of ship rats on Pinzón Island and Norway rats on Rábida Island (499 ha) using aerially distributed brodifacoum 25D bait (Bell Labs) in late 2010 or 2011 (Harper 2009). The 2010 El Niño event may postpone the operation if it results in substantial vegetative growth and an associated increase in rat abundance which would threaten the success of operation. Some smaller islands will be treated concurrently, including Roca Beagle Sur (8.7 ha); Roca Beagle Oeste (4.3 ha); Bartolomé (124 ha); Bainbridge Islands No.3, No. 5, No. 6; and Plaza Norte (8.8 ha). All of these islands have ship rats except for Plaza Norte, which has mice.

Keeping islands rodent-free

The success of the planned eradications will depend in part on substantially improved biosecurity measures. There are substantial numbers of small boat journeys between Galápagos islands for tourism, domestic fishing, and personal travel. All of these journeys pose risks for further introductions to islands and reintroductions of rodents to islands where they have been eradicated. The development and implementation of biosecurity measures that can capture every boat journey and detect rodents as small as mice is a challenge but will be essential if Galápagos Islands are to remain free of introduced rodents.

ACKNOWLEDGEMENTS

This work would not have been possible without the financial and logistical support of the Galapagos National Park Service and the Government of Ecuador. The Charles Darwin Foundation and numerous overseas donors also assisted with finances and staff. Staff of Island Conservation also helped in no small way. But most of all, our gratitude to the field staff of the Galapagos National Park Service who put in substantial effort and time to rid the islands of rodents.

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