Rat eradication in the Pitcairn Islands, South Pacific: a 25-year perspective

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Abstract This essay offers a 25-year overview of efforts to remove Pacific rats (*Rattus exulans*) from the four islands of the Pitcairn group. Following the 1991–1992 discovery that rats were severely reducing breeding success of gadfly petrels (*Pterodroma* spp.), Wildlife Management International proposed eradication. Eradication success was achieved using ground-based baiting on the small atolls of Ducie and Oeno in 1997, and there is now evidence of petrel recovery on Oeno, but two eradication attempts on inhabited Pitcairn (1997 and 1998) failed. By the early 2000s, the development of aerial baiting through the 1990s placed an eradication operation on the fourth island, Henderson, within reach. Preparatory fieldwork in 2009 allayed doubts in two key areas: the feasibility of maintaining a captive "back-stop" Henderson rail (*Porzana atra*) population, and bait uptake by crabs (*Coenobita* spp.). Royal Society for the Protection of Birds (RSPB) expertise secured the necessary funding of £1.5 million, and 75 tonnes of brodifacoum-containing bait were dropped in August 2011. Despite extensive mortality of free-living rails, the population, supplemented by released captive birds, returned to pre-operational levels in 2–3 years. Meanwhile those tending captive rails saw no rat sign before leaving Henderson in November 2011. Unfortunately, a rat was sighted in March 2012, and continuing rat presence confirmed in May 2012. Subsequently rat numbers have returned to pre-operational levels without any sign of population 'overshoot' as observed on Pitcairn. Genetic analysis suggests around 80 rats, roughly 1 in 1,000, survived the bait drop. With no evidence of imperfect bait coverage or deficiencies in bait quality or brodifacoum resistance, it seems some animals chose not to eat bait. Choice tests on Henderson Island rats suggest some rats prefer natural foods over bait. This adverse situation may have been exacerbated because, in August 2011, natural fruits were more abundant than anticipated due to drought earlier in the year. To overcome rat preference for natural food, any second Henderson attempt might benefit from more attractive bait. Without such developments, a second attempt risks another failure. Henderson's biota will survive the delay.

Keywords: brodifacoum, Ducie, Henderson, Henderson rail, Oeno, *Pterodroma*

INTRODUCTION

The Sir Peter Scott Commemorative Expedition to the Pitcairn Islands of 1991–1992 involved 35 personnel in the field over a span of 15 months. While short periods were spent on the sole inhabited island of Pitcairn (500 ha) and the low atolls of Oeno (c. 60 ha) and Ducie (c. 75 ha), Henderson Island (4300 ha) was the principal study site. Since Henderson had been designated a World Heritage Site in 1988 "as one of the last near-pristine limestone islands of significant size in the world" (<http://whc.unesco.org/en/list/487>), it had been appreciated that the natural history of the island was incompletely documented. The expedition aimed to rectify this omission, bringing together expertise in archaeology, geology and many branches of natural history.

One of the Expedition's unexpected findings was the very low breeding success of gadfly petrels (*Pterodroma* spp.) on Henderson: ca. 5% among Murphy's petrels (*P. ultima*), 10% in Kermadec petrels (*P. neglecta*), and 15–20% in Herald (*P. heraldica*) and Henderson petrels (*P. atrata*) (Brooke, 1995). This was especially concerning in the case of Henderson Petrels, split from Herald Petrels as a result of expedition work (Brooke & Rowe, 1996), endemic to Henderson and therefore without any source of immigrants to rescue the situation, and potentially on a downward trajectory to extinction within a few centuries (Brooke, et al., 2010a).

Field observations showed that the cause of this low breeding success was predation by Pacific rats (*Rattus exulans*), introduced to the island by Polynesians settlers about 700–800 years ago (Weisler, 1994). Hatching success was apparently not substantially reduced by rats. Rather, the problem arose in the first week after hatching, especially when the chick moved from under to beside the parent. Then the rats approached, pulled the chick away from the nest site, even in the presence of a brooding parent, and ate it (Brooke, 1995).

Observations on the atolls of Oeno and Ducie were too intermittent to establish whether rats there had a similar impact on the breeding success of petrels. However, the fact that petrel densities were 1–2 orders of magnitude higher on Oeno and Ducie than on Henderson prior to the eradications on the atolls suggested that rat impact was less, if not negligible. Probably because of the presence of rats and feral cats (*Felis catus)*, petrels do not breed on Pitcairn.

After these findings had entered the public domain via the expedition report (Pitcairn Islands Scientific Expedition, 1992) and a special volume of the Biological Journal of the Linnean Society (Benton & Spencer, 1995), the late Brian Bell of Wildlife Management International contacted the author to propose rat eradication in the Pitcairn Islands (Bell & Bell, 1998). At this time, the mid-1990s, an eradication on Henderson was not feasible using ground-based methods. Therefore, the proposal was for eradications on Oeno and Ducie using tested ground-based methods to benefit three gadfly petrel species but, crucially, not the Henderson Petrel which was not confirmed as a nesting species on either atoll.

ACTIONS

Oeno and Ducie

The modest extent and flat accessible topography of the atolls meant that the proposed eradication campaigns were likely to be successful, given prior achievements elsewhere (Towns & Broome, 2003). The eventual source of funding was the UK's Department for International Development (DfID) whose interest lay principally in Pitcairn Island and its people. For this reason, the programme linked eradications on Oeno and Ducie, offering clear biodiversity gains with limited risk of failure, to an eradication attempt on Pitcairn where the risks of failure were higher

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because of the rugged and heavily vegetated topography and the complications associated with human presence. Nonetheless the project proceeded in late 1997 with approximately £100,000 of funding for Pitcairn and Oeno from DfID and a further £20,000 for Ducie from the World Wide Fund for Nature (Bell & Bell, 1998).

Success was duly achieved on Oeno and Ducie by hand-laying of bait (baiting rate unspecified) on a 25 m grid (Bell & Bell, 1998). The Oeno eradication has been followed by growth of the population of the seabird species most easily censused, Murphy's petrel, at an annual rate of 6% (Brooke, et al., 2017). There are no post-eradication census data from Ducie.

Pitcairn

Eradication was not achieved on Pitcairn in 1997. There, preceding bait laying, the endeavour of cutting a 25 m grid of paths through the dense scrub cloaking the island's extremely severe terrain taxed the endurance of the WMIL team, especially since, in the absence of prior reconnaissance, the severity of the task ahead had not been appreciated. Coverage of the cliffs was probably incomplete. A lesson was learnt: future operations of this magnitude must involve prior on-site reconnaissance by key personnel.

The WMIL team departed shortly after the completion of bait laying (overall baiting rate not specified), entrusting the task of follow-up monitoring to the Pitcairn Islanders (Bell & Bell, 1998). Given the many calls on the islanders' time, and their lack of appropriate expertise, this strategy was probably a mistake. With the benefit of hindsight, it would have been better if extra costs had been incurred and logistical difficulties overcome to allow some dedicated team members to remain on Pitcairn to detect any residual rat presence. While this change in protocol would not have guaranteed a successful outcome, it could only have increased the probability of success.

WMIL returned in 1998 to attempt to rectify the 1997 eradication failure. Unfortunately, the outcome reprised that of 1997 despite more intensive monitoring after the initial baiting, coupled with spot-laying of bait wherever rat sign was detected (Bell, 1998).

A striking feature of these failures was not simply the rapidity with which rats recovered to their pre-bait levels which, the reports of Pitcairners suggested, happened within 18–24 months. There was also a universal impression among the islanders and indeed myself on a visit in 2000 that numbers overshot the status quo ante, to a startling extent. For example, rats were frequently encountered in homes, even in cooking ovens left ajar. A possible explanation of this 'overshoot', that cannot be confirmed by any formal existing trapping or density data, is that, after the reduction in rat numbers due to baiting, a large amount of food accumulated, for example on or below Pitcairn's abundant fruit trees. This surfeit possibly nourished the extreme increase in rat numbers.

Henderson

Following the successful eradication of rats from several large New Zealand islands using aerial baiting techniques during the 1990s (Towns & Broome, 2003) and from 113 km^2 Campbell Island in 2001 (McClelland & Tyree, 2002), the possibility of an eradication project on Henderson Island using aerial baiting moved up the agenda. A feasibility report delivered a favourable verdict, subject to two caveats (Brooke & Towns, 2008). The first was that, in the areas of high land crab (*Coenobita* spp.) density behind Henderson's beaches, it should be demonstrated that sufficient bait could be scattered so that, even after substantial bait removal by crabs, enough bait remained to permit all rats to consume a fatal quantity. The second concerned the endemic flightless Henderson rail (*Porzana atra*). Given the recorded susceptibility of rails to brodifacoum in cereal bait (Eason, et al., 2002) – as would be used in a Henderson operation – there was a need to demonstrate that Henderson rails could be caught and then kept healthy in captivity. In the worst-case scenario, the elimination of the wild population during the eradication operation, the captives, once released after the disappearance of bait, would become the founders of the new wild population.

Both these issues were successfully addressed by a field expedition in August/September 2009 (Brooke, et al., 2010b; Cuthbert, et al., 2012), paving the way for an eradication operation in 2011. The feasibility report (Brooke & Towns 2008) suggested the late winter months of September/October as the period of lowest food availability and therefore the most suitable for bait-laying. This suggestion was based on a 1-year study of plant phenology (Brooke, et al., 1996), and drew on the fact that *Rattus exulans* includes a proportion of vegetable material in its diet. In the absence of any data whatsoever on the intra-annual variation in the availability of invertebrates and their contribution to the rats' diet, this potential factor

Table 1 Summary table of rat eradication operations on the four Pitcairn Islands. Details from Bell & Bell (1998), Bell (1998), Torr & Brown (2012) and E. Bell (pers. comm.).

Island	Type	Method	Year baited	Month(s) baited	Bait type	No. baitings	Successful?
Pitcairn	Volcanic	Hand broadcast	1997	June – August	Pestoff 20R; wax-covered chocolate bait for 3rd baiting	3	No
Pitcairn	Volcanic	First two: hand broadcast. Then bait stations and spot-laying	1998	April – July	Pestoff 20R. Later baitings supplemented by wax-covered chocolate bait	3+	No
Oeno	Atoll	Hand broadcast	1997	July – August	Pestoff 20R	2	Yes
Ducie	Atoll	Hand broadcast	1997	November	Pestoff 20R	2	Yes
Henderson	Makatea	Aerial	2011	August	Pestoff 20R	2	No

could not be addressed in project planning. In the event, late August 2011 became the provisional project date. Fund-raising for the £1.5 million budget proceeded apace under the aegis of the Royal Society for the Protection of Birds (RSPB).

The operation was logistically complex involving the 298-tonne Alaskan crab-fishing vessel, the *Aquila*, sailing from the United States. Carrying two helicopters, the *Aquila* undertook other rat eradications in the central Pacific (Palmyra Atoll followed by Enderbury and Birnie in the Phoenix Islands) before loading the 76 tonnes of bait required for Henderson in Samoa. She then sailed east to Henderson.

Meanwhile the rail-catching team were landed on the island on 8 July 2011. The team immediately noticed that fruit was more abundant than expected – of which more anon. Catching of rails proceeded satisfactorily but adapting birds to captivity proved more problematical than in 2009, and 22 died before the solution was found, enticing the birds to the food bowls with live bait such as immobilised moths (Oppel, et al., 2016). In retrospect, it appears that, by chance, the smaller 2009 batch of rails (26 caught: two died) simply included few birds reluctant to adapt to captivity (Brooke, et al., 2010b; Brooke, et al., 2012).

The losses meant that the number of captive rails, 75, at the time of the *Aquila*'s arrival on 14 August, was lower than the target of 100 birds, but not so much lower as to cause a postponement or cancellation of baiting. The details of bait spreading are covered in the report of the project leaders (Torr & Brown, 2012). Overall the process went remarkably smoothly, with bait buckets filled on board the *Aquila*, obviating the need for any onshore storage of bait. GPS mapping of the island, prior to the first bait drop, revealed the area to be 43 km^2, an enlargement over the 37 km^2 that had been the basis for planning. Fortunately there was sufficient contingency bait that this unexpected expansion necessitated no adjustment of planned bait densities.

Excluding enhanced bait application in the areas of high crab density (Cuthbert, et al., 2012) and in the coconut groves, the application rate was 10 kg/ha of pellets (brodifacoum concentration of 20 ppm) over the majority of the island for the first drop carried out between 15 and 17 August, and 6 kg/ha during the second bait drop on 21 and 22 August. The 5-day interval between drops was slightly less than originally planned because settled weather prompted a decision to proceed immediately, rather than delay until the planned interval of seven days (Torr & Brown, 2012).

The immediate impact of the bait drop on the wild free-living rails was dramatic – as it was on rats. Sixteen of 16 rails that were radio-tagged, and whose fate could therefore be determined with certainty, died. However, mortality island-wide was not total. The best estimate is that 93 percent of free-living rails died, leaving c. 500 survivors (Oppel, et al., 2016). A few weeks after the drop, these birds began breeding. Their numbers were supplemented in October and November by the release of the captive birds, and the population has since completely recovered (Oppel, et al., 2016). Although, in the event, the captive birds were not essential for the species' persistence, the outcome was in doubt in the anxious days after the bait drops, and there is no question that a similar captive rail population must be established, should there be another eradication attempt in the future. This recommendation only gains force if, for example, the bait drops occur over a longer time period, or there are three drops instead of two. No other bird species is known to have been adversely affected by the bait drops on Henderson.

At the time the team caring for the captive rails left Henderson in November, three months after the bait drop, no signs of surviving rats had been noticed. Disastrously, a surviving rat was seen and captured on video by a visitor in March 2012. A follow-up visit, in May, confirmed continuing rat presence and, as expected, rat numbers had returned to 'normal' about two years later with no sign of the overshoot noted on Pitcairn (Bond, et al., 2019).

The eradication failure immediately prompted a review of the operation and a search for possible operational errors. None has been discovered (Internal RSPB documents). There were no apparent gaps in bait coverage, and none of the batches of bait, deliberately retained for post-operational testing, was shown to have incorrect toxin loading. Such post-hoc testing cannot absolutely exclude the remote possibility that some bags of bait did not have toxic baits, a factory error. Finally, fieldwork on Henderson in 2013 tested the rats, presumably animals descended by several generations from the actual survivors, for resistance to brodifacoum. No such resistance was found (Churchyard, et al., 2015).

Genetic studies after failure excluded the possibility that Pitcairn or other islands elsewhere in the Pacific had been a source of rats that had somehow reached Henderson and re-populated the island. In any case, knowledge of boat traffic made this scenario extremely unlikely. Thus, there had been a failure of eradication and not a re-introduction. Because rat samples had been secured before the operation, and were then obtained afterwards, it was possible to use the change in microsatellite allele frequency to estimate how many rats survived (Amos, et al., 2016). The answer was about 80 individuals, very roughly one in a thousand of the rats present on Henderson before the operation (Brooke, et al., 2010b). It is a total compatible with the absence of observations of living rats for around seven months after the bait drops.

Can this total, neither indicating a tiny number of survivors that might be ascribed to chance nor several hundreds, even thousands, indicating serious deficiencies in operational protocol, suggest improvements that might be made for a second attempt?

Mention has already been made of the fact that the rail team encountered more fruit than expected on Henderson in July 2011. This was probably a delayed consequence of a drought that afflicted Pitcairn, and presumably also Henderson, from November 2010 to March 2011. When this drought broke, it is likely that the trees became greener, flowered and then fruited, at a time that was inopportune for the rat eradication, especially if flowering and fruiting were accompanied by increased numbers of invertebrates. Although there has been one year-long study of the leafing, flowering and fruiting phenology of Henderson's plants (Brooke, et al., 1996), this is clearly inadequate to understand how plant phenological schedules may change from year to year, and how they are altered by annual variations in weather. That would require around 20 years of study, an impossible task on isolated Henderson. Thus, tailoring a rat eradication to a particular window of plant food scarcity will always be difficult, if not impossible. And no subsequent findings have altered the cautious recommendations of the feasibility study (Brooke & Towns, 2008), derived from the Brooke, et al. (1996) plant phenology study, that September or a month either side is the most suitable period.

Compounding this problem is that the operation must be set in train – boats chartered, bait ordered and so forth – at least six months before baiting (Parkes & Fisher, 2017). It would, in theory, be possible to cancel an operation at a late stage, for instance if there were reports of a surge in fruit abundance, but the penalties for such a late cancellation could well approach £500,000.

Following their helicopter flights across the island in 2011, the pilots reported, to universal surprise, a few tens of coconut trees (*Cocos nucifera*) emerging from the canopy growing on the raised atoll lagoon. Since the ground is about 30 m above sea level, these trees must have involved human intervention. They were certainly not planted by members of the Sir Peter Scott Commemorative Expedition of 1991–1992. There are two other known possibilities. The first is that the Pitcairners who, during World War II, cut a network of paths across the island, some several kilometres from the coast, were responsible. Another possibility is that the helicopter presence associated with the visit of the USS Sunnyvale in 1966 provided an opportunity for coconuts to be 'bombed' from overhead.

However the coconuts arrived, it is not surprising that they have been growing unknown for decades since most parts of this impenetrable island have remained unvisited for centuries. The relevance of these observations is that the research visit of 2013 (Churchyard, et al., 2015) conducted captive trials to test which natural foods, if any, were preferred by rats to bait pellets. Given a four-way choice between coconut (removed from its shell), *Myrsine* fruits, *Pandanus* nuts and Pestoff bait pellets, coconut was preferred, with pellets second. Moreover 11 of 30 rats ate no pellets whatsoever in a 3-day trial (details in Churchyard, et al., 2015). These findings were confirmed by further similar research in 2015 that also indicated the preference for natural food could not be overcome by increasing the relative abundance of bait pellets, an experimental adjustment equivalent to increasing the bait application rate during helicopter operations (Lavers, et al., 2016).

Although the coconut groves behind the North and North-West Beaches received deliberately high applications of bait pellets (Torr & Brown, 2012), this was not the case for the unknown isolated trees in mid-island. However, there are no data bearing on where on the island the 80 surviving rats lived and whether their home ranges were in the vicinity of coconuts.

It is evident that an absence of coconuts is not a sine qua non of a successful rat eradication. Success was achieved on Oeno (coconuts present) and Ducie (no coconuts). Projects failed on Henderson and Pitcairn, both with coconuts. More generally, numerous islands with coconuts have been cleared of rats, including the island of Palmyra (</www.fws.gov/refuges/news/PalmyraAtollRatFree.html>) visited by the *Aquila* two months before it reached Henderson.

Although Henderson's coconuts could have contributed to the project's failure (Holmes, et al., 2015), removing this possible cause would not be easy. Reaching every mid-island coconut would require a helicopter to insert a small group of "coconut destroyers" close to each tree, perhaps via a winch. Their task would be to destroy all the nuts and possibly the tree as well. That would still leave the coastal coconuts. It is unlikely that their total destruction would be countenanced by the Pitcairn Islanders and, in any case, their flowers are a significant food of the endemic Stephen's lorikeet (*Vini stepheni*) (Trevelyan, 1995). Even destroying or removing off-island all the fallen nuts, weighing several tens of tonnes, would not be easy. But the practicalities should be explored.

The discussion has reached the stage where the 2011 eradication appears to have failed, not because of any operational blemishes and not because of any brodifacoum-resistance but because a small number of rats failed to consume a fatal dose, approximately one pellet, of bait. Instead they chose to eat natural food in preference to bait (Keitt, et al., 2015). This picture is entirely compatible with the more general observation that tropical rodent eradications are less likely to be successful than those on temperate islands (Russell & Holmes, 2015)

If a second eradication attempt is to have an improved chance of success, some aspects of the protocol may have to change. The impracticalities of guaranteeing that a bait drop occurs at a time of minimal food abundance have already been discussed. The challenge of reducing the availability of coconuts needs further thought. Finally, I strongly advocate consideration of a further option, the development of a more attractive bait formulation that will entice even those rats that might have shunned the pellets used in 2011 to eat bait. It will probably never be known whether these crucial rats did not eat bait pellets because a more palatable natural food was available, and/or whether illness or pregnancy affected their appetite for novel foods (neophobia). Altering the formulation of bait pellets by the addition of such flavours as chocolate or peanut has already been trialled by Orillion, the manufacturers of PestOff pellets (Bill Simmons, pers. comm.). However, it remains uncertain whether these changes would demonstrably reduce the risk to an operation of such rat behaviours as neophobia.

Although modest alteration of pellets may not engender regulatory problems in UK Overseas Territories (Bill Simmons, pers. comm.), the development of pellets of enhanced attractiveness could pose technical problems. For example, any additives must not make the pellets more 'sticky' and liable to clog the hoppers underslung from bait-distributing helicopters. But, optimistically, such developments will occur as New Zealand develops the expertise to rid itself of alien predators by 2050, as other countries follow New Zealand's lead, and as the relative intractability of tropical islands is addressed.

Meanwhile, from my 25-year perspective, Henderson will probably not change greatly in the next decade. A patient approach will hugely increase the likelihood that any second rat eradication attempt on Henderson is made when the chances of success are demonstrably higher. It will also avoid the mistake made on Pitcairn, of undertaking an eradication project because money was available rather than because a rational, even hard-nosed, assessment confirmed that the chances of success and the biodiversity gains of success outweighed the costs and risks of failure.

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