Multi island, multi invasive species eradication in French Polynesia demonstrates economies of scale

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Abstract Eradication of invasive vertebrates on islands has proven to be one of the most effective returns on investment for biodiversity conservation. To recover populations of the critically endangered Polynesian ground dove (*Gallicolumba erythroptera*), the endangered white-throated storm-petrel (*Nesofregetta fuliginosa*), the endangered Tuamotu sandpiper (*Prosobonia cancellata*) as well as other native plant and animal species, a project was undertaken to eradicate five species of invasive alien vertebrates: Pacific rat (*Rattus exulans*), ship rat (*R. rattus*), feral cat (*Felis catus*), rabbit (*Oryctolagus cuniculus*) and goat (*Capra hircus*), on six islands spanning 320 km of open ocean in the Tuamotu and Gambier Archipelagos of French Polynesia. Using a ship to deliver supplies and equipment, a helicopter for offloading and bait application, and ground teams for follow up trapping and hunting, invasive vertebrates were successfully removed from five of the six islands. Pacific rats survived at one site. The project was planned and executed by a partnership consisting of international and local conservation NGO's, working together with local communities. Combining the different eradication operations into one expedition added complexity to project planning and implementation and increased the risk of the operation failing on any one island but generated greater returns on investment allowing six islands to be targeted at significantly less cost than if each island had been completed individually. An extensive and thorough planning effort, effective relationships with local stakeholders and communities, a good operational strategy and a partnership of stakeholders that each brought complementary capacities to the project contributed to its success.

Keywords: cat, conservation, goat, rabbit, rat, restoration, threatened species recovery

INTRODUCTION

The removal of alien species from islands, especially invasive vertebrates, offers one of the best returns on investment for the protection of indigenous biodiversity (Donlan & Wilcox, 2008; Genovesi, 2011). There is now a growing list of island species no longer regarded as endangered because a key invasive species threat has been lifted (Russell, et al., 2016). The San Nicolas island night lizard (*Xantusia riversiana*) (Rice & Clark, 2016), the Seychelles magpie robin (*Copsychus sechellarum*) (Burt, et al., 2016) and the northern tuatara (*Sphenodon punctatus*) (Towns, et al., 2016) are just three examples of the many species whose threat status has been downgraded to a more secure category as a consequence (IUCN, 2010).

Eradication projects can be expensive (Simberloff, 2002). The remote nature of many islands and the necessity to target every individual within a population requires extensive planning effort, meticulous execution (Cromarty, et al., 2002) and resourcing that often exceeds the means of a single organisation. For many island nations, eradication projects are simply unaffordable and for some projects, the cost may exceed the annual environmental expenditure of an entire country.

French Polynesia is an overseas collectivity (political unit) of the French Republic. It is composed of 118 geographically dispersed islands and atolls scattered over an expanse of more than 5,030,000 km^2 in the South Pacific Ocean. Like many other tropical island archipelagos, French Polynesia is biologically rich and its remoteness has led its flora and fauna to be characterised by high levels of endemism (Gillespie, et al., 2008; Meyer & Butaud, 2009). Sixty three percent of its plants and 72% of its birds are found nowhere else (Gillespie, et al., 2008; Meyer & Butaud, 2009). As witnessed elsewhere, French Polynesia has been severely affected by habitat loss and invasive species. Nineteen of its bird species have become extinct since the 16th century and of the 25 surviving endemic birds, 18 are listed as threatened and five as critically endangered (Zarzoso-Lacoste, 2013).

Invasive vertebrates are widely considered the most significant threat to French Polynesia's avifauna (Zarzoso-Lacoste, 2013). Interventions, to remove invasive vertebrates, could be made to improve security for many species. However, investment within the collectivity for the management of invasive alien species remains small and a national invasive species strategy has not yet been developed. The collectivity does not appear to have the financial mechanisms to undertake vertebrate eradications and outside financial support will be required if species extinctions are to be avoided.

In 2015, four species of invasive alien vertebrates, Pacific rat (*Rattus exulans*), ship rat (*R. rattus*), feral cat (*Felis catus*) and rabbit (*Oryctolagus cuniculus*), were successfully removed from five of six islands spanning 320 km of open ocean in the Tuamotu and Gambier Archipelagos of French Polynesia. The project failed to remove rats from one project site and completion of goat (*Capra hircus*) eradication from another was delayed until 2017.

Here we describe the methods used to remove invasive vertebrates from the project sites and the logistics associated with the project. We explain how cost efficiencies were gained by combining operations and targeting multiple islands and define how the project partnership was instrumental to the project's success.

METHODS

Site description

Six islands in the south-east of French Polynesia were targeted for the removal of invasive vertebrates (Fig. 1). These included the two atolls of Vahanga and Tenania (Tenarunga) that, together with Tenararo and Matureivavao, make up the Acteon Island Group. Vahanga and Tenararo are identified as a Key Biodiversity Area (Atherton, 2007) and as an Important Bird Area (Raust & Sanford, 2007). Tenararo is one of four islands in French Polynesia never

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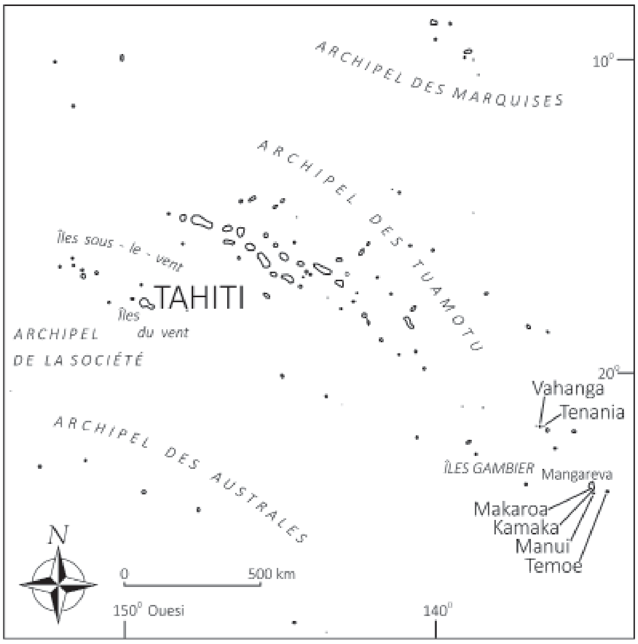

Fig. 1 Location of the six project sites within French Polynesia.

to have had invasive vertebrates and the atoll remains a stronghold for the critically endangered Polynesian ground dove and the endangered Tuamotu sandpiper as well as other native species (Blanvillain, et al., 2002). The operation also included Makaroa, Kamaka and Manui, three of the higher elevation islands that form Mangareva atoll complex and Temoe atoll, which lies to the south of Mangareva. Makaroa, Kamaka and Manui, together with the pest-free Motu Teiku, are classified as an IBA (Raust & Sanford, 2007). The endangered white-throated storm petrel breeds on both Manui and Motu Teiku.

All three of the atolls included in the operation were planted with coconut (*Cocos nucifera*) and used historically for copra production although only Tenania continues to be used for this purpose. Consequently, although areas of indigenous vegetation remain, *C. nucifera* dominates many of the forested parts of the atolls. Makaroa, Kamaka and Manui have also been extensively modified by burning, and the introduction of herbivores such as goats and rabbits. At the time of the project, little ground cover existed on Makaroa and large areas of Kamaka and Manui were covered in the invasive molasses grass (*Melinus minutiflora*). Of the six targeted sites, only the islet of Kamaka in the Gambier group is permanently inhabited. The atoll of Tenania in the Acteon group is occupied for part of the year for copra harvesting and Temoe is regularly visited by local fisherman. Table 1 summarises the general characteristics of the six sites.

Project feasibility and planning

Planning for rat eradication on Vahanga began in 2006 after a previous attempt undertaken in 2000–2001 was confirmed as having failed (Pierce, et al., 2006). Research was completed on the atoll to quantify the impact of terrestrial crabs on rodent bait availability, assess bait uptake by rats and quantify the effort required to hand broadcast bait across Vahanga (Griffiths, et al., 2011). Following this, an operational plan for rat eradication on the island was prepared (Broome, et al., 2011), but lack of funding delayed the project's implementation. A feasibility assessment for the removal of rats from Kamaka and Makaroa, completed in 2008 (Faulquier, 2008), stipulated the need for a helicopter due to the steep topography of these sites.

Following several high profile rat eradication failures on tropical islands, a global review of eradication methods was undertaken in 2013 to increase success rates (Russell & Holmes, 2015). New best practice guidelines were published, recommending higher bait application rates and longer periods of bait availability (Keitt, et al., 2015). The new guidelines meant it would be extremely challenging logistically to complete a ground-based operation for Vahanga and the use of a helicopter was recommended.

Funding for rat eradication on Vahanga was eventually obtained in 2014. However, due to the costs associated with transporting a helicopter to the south-east corner of French Polynesia and the relatively low cost of including additional sites and invasive species, a decision was made by project partners to target five additional, high conservation value islands in the area. This decision was facilitated by broadening the project partnership and securing additional funding. An operational plan was devised that prescribed the aerial application of rodent bait containing brodifacoum to target rats followed by trapping and hunting to target cats, rabbits and goats across the six project sites (Derand, et al., 2015).

The target bait application rate for rat eradication was derived using the methods described by Pott et al. (2015) to interpret bait availability data collected by Griffiths et al. (2011). The proposed application rate, coupled with reported island sizes and areas derived from available satellite imagery and a 15% contingency for lost or damaged bait, were then used to estimate the total amount of bait required. Immediately before the project's implementation, higher resolution satellite imagery acquired from the Millennium Coral Reef Mapping Project (Andréfouët, et al., 2005)

Table 1 Characteristics of the six sites targeted for invasive vertebrate removal.

Island	Area (ha)	Elevation (m)	Location	Native threatened species expected to benefit	Targeted invasives
Vahanga	380	5	Acteon	Pacific ground-dove, Tuamotu sandpiper, atoll fruit-dove (*Ptilinopus coralensis*), Murphy's petrel (*Pterodroma ultima*), bristle-thighed curlew (*Numenius tahitiensis*), green turtle (*Chelonia mydas*)	*Rattus exulans*
Tenania	425	5	Acteon	Pacific Ground-dove, Tuamotu sandpiper, bristle-thighed curlew, green turtle	*R. exulans, R. rattus, Felis catus*
Kamaka	58	166	Gambier	Polynesian storm petrel, Murphy's petrel	*R. exulans*
Makaroa	22	136	Gambier	Polynesian storm petrel	*R. exulans, Capra hircus*
Manui	8	54	Gambier	Polynesian storm petrel, Murphy's petrel	*Oryctolagus cuniculus*
Temoe	431	5	Gambier	Murphy's petrel	*R. exulans*

and EVS-Islands digital earth imagery showed that initial estimates of island areas had been overestimated, in some cases by as much as 22%. Consequently, this made more bait available for distribution at each site than had been planned.

Project implementation

Staging

Ninety-two tonnes of rodent bait, 30,000 l of Jet A1 helicopter fuel, three bait-spreading buckets, and equipment and supplies necessary for the project were shipped from the port of Papeete to the project sites by the coastal freighter 'Nuku Hau'. Rodent bait was transported in 22.7 kg paper-walled sacks stacked inside Ox Boxes (waxed cardboard pods) (hereafter referred to as pods) and the fuel in 200 l drums. A single-engine Squirrel AS350 B2 supplied by Tahiti Helicopters was flown from Papeete by 'island hopping' between four intermediate islands (a total distance of 1500 km) before converging with the Nuku Hau at Vahanga to commence the offloading process.

Immediately prior to unloading, the island's coastal boundaries were flown to confirm the size of the area to be treated and revalidate the amount of bait and fuel to be unloaded at each site. All equipment and supplies were first offloaded from the Nuku Hau to a small barge which was then unloaded by helicopter in separate sling loads. Bait and fuel, sufficient for each atoll, were staged on Vahanga, Tenania, and Temoe with unloading taking between 4–6 hours for each atoll. Supplies for the three closely grouped Gambier Islets were staged in less than four hours on Kamaka. To minimise flying between island groups, two bait spreading buckets were offloaded in the Acteon Group, one for use on Vahanga and the other for Tenania. One bucket and a range of spare parts were stationed in the Gambier Islands for use on both Temoe and the Gambier Islets.

Project team members, 24 in total, were also deployed at this time. Team members were stationed on Vahanga (6), Tenania (5), Temoe (3) and Kamaka (1). The project manager, GIS analyst, baiting team (3), pilots (2) and helicopter mechanic travelled by helicopter between the islands to complete bait applications and one person, stationed in Mangareva, provided logistical support. In between bait applications, the project manager, GIS analyst and members of the baiting team deployed to different islands to provide support for monitoring, trapping and hunting.

On Tenania, large piles of broken coconut husks containing coconut flesh were found across the atoll. These byproducts of the recent copra harvest represented a signficant alternative food source for rats and a risk to the project's likelihood of success. To reduce risk, members of the project team systematically burned piles of coconuts. This laborious activity greatly reduced the amount of coconut available to rats but did not eliminate it.

Bait application

After staging was complete, bait application took place sequentially beginning on Temoe followed by the Gambier Islets, Vahanga and finally Tenania. Each of the three atolls took more than one day to complete due to the amount of bait applied and the requirement to break the circular atolls into multiple blocks. Dividing the operational area into blocks maximised the length of flight lines that could be flown thereby simplifying the operation for the pilot. Adjacent baiting swaths were overlapped by 50% to reduce the risk of gaps in coverage (e.g. Fig. 2). In addition to parallel flight lines across each island's interior, a swath with a deflector bucket (which spreads bait in one direction only) was completed along the edge of both coastal and lagoon vegetation. Additional bait was applied by helicopter over areas considered to be higher risk, such as areas of human habitation or sites known to support the highest crab densities. At the same time as bait was applied by helicopter, rodent bait was placed in small dishes within all buildings still in use and scattered by hand underneath buildings and inside all derelict or abandoned structures.

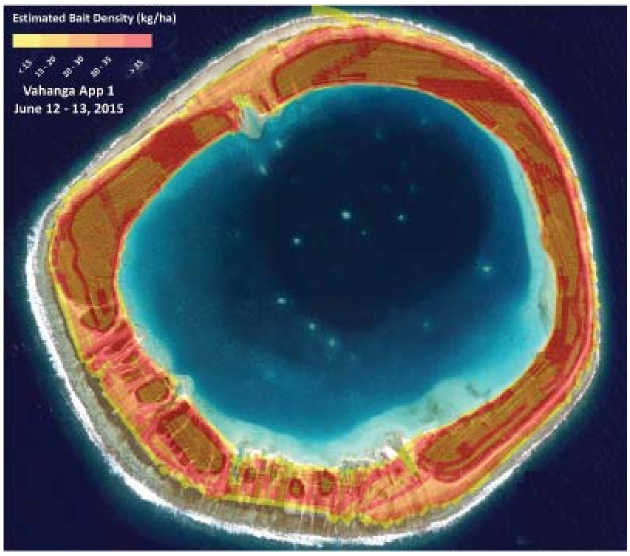

Fig. 2 First bait application completed on Vahanga.

Following an 18 day interval, a second application of bait was completed at the project sites in the same sequence. The length of the interval was dictated by a desire to ensure that all individuals (including juveniles) within the targeted rat populations were exposed to bait, as discussed in Keitt, et al. (2015), and also by the resource limitations of the project partnership. Operational specifications for the second bait application were the same, except for the exclusion from bait application of barren storm-washed coral habitat across all three atolls. Bait availability monitoring and anecdotal observations suggested negligible disappearance of bait from these atolls and thus no advantage in re-treating these areas. This action was also seen as a means of reducing risk to non-target species such as Tuamotu sandpiper (*Prosobonia cancellata*). Operational areas treated were thus smaller in the second application for Vahanga, Tenania and Temoe (Table 2). Dates of bait application and the application rates achieved are provided in Table 2. No significant delays because of sustained rainfall or excessive winds were encountered.

Loading of bait spreading buckets was undertaken from platforms constructed from an 18 mm thick plywood sheet set atop two pods. A second plywood sheet was placed on the ground in front of these pods to ensure a level footing for the spreader bucket. The helicopter was fitted with a VHF radio for ground to air communications with the bait loading team.

The pod and pallet containment system withstood crushing (some pods were stacked up to seven high in the hold of the Nuku Hau), being dipped in saltwater (as they were airlifted onto the islands), tropical temperatures and periods of heavy rain. Water was found inside the internal plastic bag (used to protect sacks of bait) in just four pods and of these pods only the bags at the bottom of the pod were affected. Only four of the 4,065 bags (<0.1%) of bait shipped were considered unfit for application. Water ingress into pods was primarily a result of damage incurred to the cardboard during shipping and unloading, coupled

Table 2 Bait application summary.

Date	Island	Application	Bait used (kg)	Island area treated (ha)	Average bucket sow rate (kg/ha)*	Operational hours	Bait spread (T/hr)	Average ground application rate (kg/ha)+
June 8–9	Temoe	1st	15,111.9	429.1	24.4	11	1.37	35.2
June 26–27	Temoe	2nd	16,433.5	341.5	29.9	9	1.83	48.1
			31,545.4	**429.1**	**26.8**	**20**	**1.57**	**73.5**
June 10	Gambier	1st	3,797.8	88.2	32.3	3	1.27	43.1
June 28	Gambier	2nd	2,986.9	86.6	21.1	2.75	1.09	34.5
			6,784.7	**88.2**	**26.8**	**5.75**	**1.18**	**76.9**
June 12–13	Vahanga	1st	11,715.5	382.6	21.8	7.5	1.56	30.6
July 3	Vahanga	2nd	14,272.8	333.3	27.7	6.5	2.20	42.8
			25,988.3	**382.6**	**24.5**	**14**	**1.86**	**67.9**
June 14	Tenania	1st	13,479.3	419.6	24.3	9	1.50	32.1
July 4–5	Tenania	2nd	14,315.3	394	23.5	8	1.79	36.3
			27,794.6	**419.6**	**23.9**	**17**	**1.64**	**66.2**

*Average rate at which bait was spread from the bucket (bait used/TracMap recorded area). +Average rate at which bait was available on the ground (bait used/island area treated).

with water pooling on the lid of the pod. Intact pods showed no sign of water ingress despite water pooling.

Rabbits

Based on the results of other projects (e.g. Griffiths, et al., 2014), most rabbits were expected to consume rodent bait and succumb to poisoning on Manui. This proved to be the case, with just four survivors found and one of these appeared to be close to death at the time it was shot. Two staff began follow-up work targeting surviving rabbits, nine days after the first application of bait, to eliminate survivors before the team departed French Polynesia.

All accessible areas of the island offering apparently suitable habitat were searched for sign and surviving rabbits during the day and at night, using powerful head lamps (see Fig. 3). Some inaccessible parts of the island such as cliff faces were searched with spotlights at night, but comprehensive searching of these areas was not possible. To manage search effort and spatial data, the island was divided into zones. Generally, the same zone was searched during the day and then again at night. Areas where fresh sign was found, or a live rabbit sighted were searched more intensively. Search effort was logged using handheld GPS and a map used to identify areas that had not yet been visited. Waypoints were recorded for any fresh sign found and live rabbits sighted.

Two trail cameras were established on the island from 26 April 2015 and seven added from 10 June. Three cameras were kept at the same locations throughout the operation while the remaining four were moved to locations where fresh sign was found or where rabbit presence was suspected. Old rabbit sign (faeces and chewed vegetation) was found in most parts of the island except within the molasses grass sward and the coastal littoral zone. Ten freshly dead rabbits (presumed poisoned) were found. Carcasses were found in three discrete locations and were generally associated with areas of concentrated old sign.

Fresh rabbit sign was found in three discrete locations during the period of follow up searching. In each case the discovery of fresh sign led to the location of freshly dead or surviving rabbits within the same area. One adult female was found during the day on 19 June and shot. This individual superficially appeared to be in good condition but was presumed to be in the last stages of anticoagulant

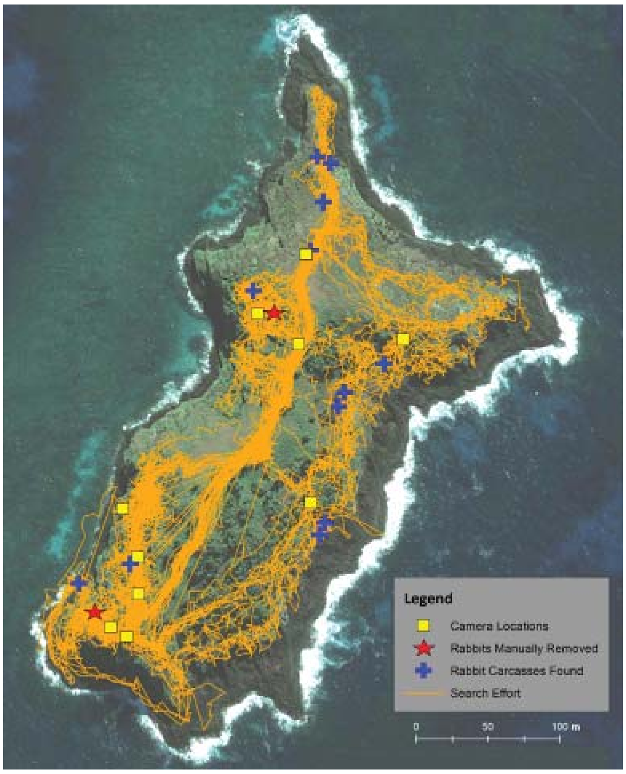

Fig. 3 Search effort and location of surviving rabbits on Manui 10 June to 3 July 2015.

poisoning as it did not move when approached and, although not evident in the gut, the lower intestine was full of blood.

Two young rabbits (a male and female) were found together while spotlighting and shot.. These individuals appeared healthy and a necropsy indicated no evidence of bait ingestion or anticoagulant poisoning. The last surviving rabbit was shot 100 m further north also after finding fresh sign. This individual, an adult female, was in excellent condition and showed no sign of bait ingestion or anticoagulant poisoning. Following removal of this individual, no further fresh sign or images on cameras were found during five more days of search effort.

Cats

Cat trapping on Tenania began on 6 June prior to the 1st bait application and continued until 4 July when the team departed. A total of 564 trap nights (sum of the number of active traps for each trap night) were achieved. Trapping was conducted primarily with leg hold traps, No. 2 Bridger padded, and No. 1.5 Oneida/Victor unpadded leg hold traps set in a combination of cubby, trail and bucket sets. Traps were baited with either canned or fresh fish, lured with a commercial lure or left un-baited in the case of some trail sets. Every 2–3 days, traps that had sprung were triggered and reset. Trap locations were changed as necessary when sign (tracks, scat, and visual observation) was encountered in the field and camera data collected.

Traps were raised (i.e. positioned on top of sand filled buckets) or left unlured to minimise crab interference. However, traps were often triggered by what remaining sign indicated was crabs, mostly *Coenobita perlatus*. Spotlight surveys were undertaken but only one cat detected using this method and this method was not pursued. A total of 10 remote trail cameras were installed on 5 June and data collected daily, in most cases, to inform trap placement. Monitoring with cameras continued until 4 July. Camera data were also used to verify the identity of captured cats. Ten distinct individual cats were detected with trail cameras and, of these, nine were caught: five female and four male. All were mature adults and one female was pregnant with three foetuses at the time of capture. Feral cat captures were made exclusively with leg-hold traps; three were caught in cubby sets, five in trail sets and one in a bucket set. The last cat captured displayed signs of internal haemorrhaging, likely due to secondary exposure to brodifacoum. The last feral cat detected by trail camera on 29 June was not captured, despite concentrated trapping in the vicinity of detection, and is assumed to have succumbed to secondary poisoning. An individual with distinct black and white fur patterns, seen during the first spotlight survey, was also never observed again despite follow-up surveys.

All cats captured appeared to be in excellent body condition. When the captured cats' stomach contents were examined, the only prey remains observed were rodents. Interestingly, the stomachs of two cats captured contained coconut flesh. Rat remains encapsulating the observed coconut within one individual, indicated rats to be the source; however, the other had its stomach completely full of coconut.

Goats

Despite local reports to the contrary, eight goats were still present on Makaroa in 2015 at the time of the project's implementation. One of these (a young female) was shot, but further hunting effort was abandoned due to insufficient capacity, a lack of suitable firearms and the remaining goats being extremely wary due to having been hunted recently. Two experienced hunters returned in 2017, each with a .308 calibre rifle and thermal imaging equipment. Eighteen goats were removed during the first four days and no more were seen in the subsequent six days of intensive search effort (Table 3). It is unknown whether goats ate rodent bait, but its application to remove rats had no apparent impact on the population, and the presence of goats did not impact the success of the rat eradication.

Non-target species mitigation

The proposed application of rodent bait posed a potential risk to non-target native species such as the Polynesian ground dove and the Tuamotu sandpiper. Tuamotu sandpiper were considered at high risk based on observations made on Tahanea Atoll during a rat eradication in 2011 (Pott, et al., 2014). Concerns were also held for Polynesian ground dove although other projects had targeted rats in the presence of conspecifics without apparent losses (Griffiths, 2014). Both species were recorded in very low numbers at just one of the project sites (Vahanga) and, because of their conservation status, mitigation was undertaken.

Prior to bait application, efforts were made to catch all Polynesian ground dove on Vahanga and translocate them to Tenararo. Of the five to six birds observed, two were captured and transferred. The others evaded capture and were monitored over the course of the project's implementation, along with two individuals sighted on Tenania. Transferred birds had two of the outermost primaries of each wing removed to lessen the chances of them flying back to Vahanga.

Efforts were also made to capture and transfer Tuamotu sandpiper. More birds were found on Vahanga than had been anticipated and five of the six birds present were caught. One escaped, but four were translocated to Tenararo with outermost primaries plucked on both wings (1–3 per wing, depending on bird condition) to prevent their return to Vahanga.

Table 3 Monitoring completed to confirm eradication success at the six project sites.

Island	Invasive species	Monitoring effort				Outcome
		Corrected trap nights	Spotlighting (hrs)	Sign searches (hrs)	Trail cameras (hrs)	
Vahanga	Pacific rat	345	16	112	0	Successful
Tenania (Tenarunga)	Pacific rat, ship rat, cat	213	17	112	420	Successful
Temoe	Pacific rat	455	25	128	0	Successful
Kamaka	Pacific rat	612	-	-	0	Failed
Makaroa	Pacific rat, goat	210	8	188	440	Successful
Manui	Rabbit		20	232	1,230	Successful

These interventions were partially effective for both species with 90% of captured birds resighted in 2017 (R. Pierce pers. comm.). Ground dove that remained on Vahanga and Tenania were resighted throughout the period of implementation, suggesting any risks to this species were low. Sightings of an uncaptured Tuamotu sandpiper displaying symptoms of poisoning were made on Vahanga. This individual was not seen again highlighting the vulnerability of this species.

ERADICATION SUCCESS

Trapping, spotlight searches and searches for sign of invasive vertebrate presence, conducted in April and May 2017 nearly two years after the project was implemented, confirmed the project was successful at removing invasive vertebrates at five of the six sites. No rats were found on Vahanga, Tenania, Temoe or Makaroa. No cats were found on Tenania or rabbits on Manui and goats were finally removed from Makaroa. The monitoring effort expended for each site to confirm eradication success is provided in Table 3. Despite Kamaka being inhabited, rats were not detected until monitoring was instigated nearly 12 months after the project was implemented. Rats are now widespread on the island. Analysis of DNA confirmed that some rats survived the operation.

OUTCOMES

In removing invasive species from five islands, the project increased the total number of islands free of invasive vertebrates within French Polynesia from four to nine and created an additional 1,426 ha of secure habitat, effectively tripling the area available for Polynesian ground dove and Tuamotu sandpiper recovery. Early signs of recovery were observed in 2017 with more individuals of Polynesian ground dove seen on both Vahanga and Tenania in 2017 and Tuamotu sandpiper recorded on Tenania for the first time. Recovery of native vegetation was observed on both Manui and Makaroa. Longer term monitoring is required to confirm trends.

With the removal of rats, the risk of rodent-borne leptospirosis has been eliminated from Tenania and the quality and quantity of copra produced appears to have increased, although the increase in income generated for the local community has yet to be quantified. Local skills to undertake future eradication projects were developed and support from policy-makers, funders and the public for future rodent eradications on other atolls/islands generated.

PROJECT COST

The operational cost of the project was estimated based on expenditure records kept by project partners. The total cost of the project, from when concerted planning began in 2014 to completion of the operation in 2015, was €1.4M with the largest costs being the helicopter, shipping, rodent bait and personnel. The cost efficiency of the project gained by targeted all six islands was assessed by comparing the total cost of the project with estimates completed separately for eradicating invasive mammals independently at each site (Table 4). Costs such as helicopter, shipping and staff travel would all have added significantly to cost if each island had been completed as a standalone project. Postponement of goat eradication on Makaroa increased costs for this component of the project but only by a relatively small margin as the cost of goat eradication was small (<€20,000).

DISCUSSION

Implementing the project described in this paper was challenging due to the remote nature of the islands, the number of sites, the range of invasive species targeted, and the lack of infrastructure and resources available within French Polynesia. Overcoming these challenges required an extensive and thorough planning effort. An added benefit of the time taken for project planning was the clear identification of roles and responsibilities for each project partner. Each of the project partners provided capabilities that could not readily have been supplied by the other partners.

An operational strategy, informed by a contemporary review of rat eradications on tropical islands (Keitt, et al., 2015) contributed to project success although, as noted, rats survived on Kamaka despite the application of best practice guidelines. Reasons why rats survived on Kamaka are unknown but an investigation to determine causal factors is currently underway. The project also benefited from generally favourable weather through the implementation phase. In hindsight, sufficient time, effort and resources were put in place to ensure successful cat and rabbit removal from Tenania and Manui. However, more time spent on each of these islands would have increased the level of confidence held by departing teams that surviving individuals had been removed. Local reports that goats were no longer present on Makaroa proved incorrect and eradication of this species had to be postponed.

The cost efficiencies gained in this project through removing invasive species from multiple islands are evident. Completing each of the islands as a standalone project would have increased the total cost of removing invasive species from the six sites by a factor of three. Resources for conservation are scarce and similar approaches will need to be considered for many projects to make them economically viable. The proposed removal of rats and cats from five uninhabited islands in the Marquesas archipelago is one such example. The high costs of shipping and helicopters would rule out doing any one of the islands as a standalone project.

Interventions to mitigate the impacts of the operation to non-target species were largely effective (Pierce, et al., 2015) and the level of mortality sustained will be outweighed by the anticipated benefits to populations following the removal of rats from Vahanga. Although it is too early to measure the full impact of this conservation intervention, Polynesian ground dove and Tuamotu sandpiper should increase in abundance on both Vahanga and Tenania, eventually forming self-sustaining populations. The number of populations of Polynesian ground dove will increase from three to five and for

Table 4 Projected standalone project costs and the actual costs incurred for removing invasive vertebrates from the six project sites.

Island	Projected cost	Actual cost[1]
Vahanga	€1.1M	€0.3M
Tenania	€1.1M	€0.3M
Temoe	€1.1M	€0.3M
Kamaka	€0.4M	€0.15M
Makaroa	€0.5M	€0.2M
Manui	€0.4M	€0.15M
Total	€4.6M	€1.4M

[1] Costs such as flying the helicopter from Tahiti were divided equally between project sites.

Tuamotu sandpiper from six to eight. Polynesian storm petrel (*Nesofregetta fuliginosa*) along with other sea birds are expected to recolonise Makaroa increasing the number of breeding sites for this species from at least six to seven. Translocations of these species and others are also now possible.

Completion of the project provided greater security from extinction for a number of plant and animal species but most importantly for bird species listed as critically endangered or endangered by the IUCN (IUCN, 2010), Polynesian ground dove, white-throated storm petrel and Tuamotu sandpiper. The project also delivered socio-economic benefits to local communities through increased production from a coconut plantation on Tenania and greater resilience for harvested seabird populations on Temoe. In doing so, the project provides a precedent for further action within French Polynesia to protect endemic biodiversity and livelihoods.

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