

Conservation gains and missed opportunities 15 years after rodent eradications in the Seychelles

J.E. Millett¹, W. Accouche¹, J. van de Crommenacker^{1,2}, M.A.J.A. van Dinther², A. de Groene³, C.P. Havemann⁴, T.A. Retief¹, J. Appoo¹ and R.M. Bristol⁵

¹Green Islands Foundation, PO Box 246, Victoria, Mahé, Seychelles. <jemillett2003@yahoo.co.uk>. ²Frégate Island Private, PO Box 330, Victoria, Mahé, Seychelles. ³WWF-Netherlands, Driebergseweg 10, 3708 JB Zeist, Netherlands. ⁴North Island, P.O. Box 1176, Victoria, Mahé, Seychelles. ⁵La Batie, Beau Vallon, Mahé, Seychelles.

Abstract The Seychelles was one of the first tropical island nations to implement island restoration resulting in biodiversity gain. In the 2000s a series of rat eradication attempts was undertaken in the inner Seychelles islands which had mixed results. Three private islands with tourist resorts successfully eradicated rats: Frégate (2000), Denis Island (2003) and North Island (2005). Frégate Island was successful with the first eradication attempt whereas North and Denis Islands were initially unsuccessful, and both required second eradication operations. All three islands have developed conservation programmes including biosecurity, habitat rehabilitation, and species reintroductions, and have integrated nature into the tourism experience. Conservation actions, including rat and other invasive species eradications, on these three islands resulted in the creation of 560 ha of mammalian predator-free land, the reintroduction of seven populations of five globally threatened birds (GTB) and the safeguarding of two existing GTB populations and several reptile and invertebrate species. However, on these and many other islands in the Seychelles, the potential of this conservation “model”, where island owners implement conservation programmes largely funded by the tourism businesses in collaboration with NGOs (Non Government Organisations), has not been fully realised. We review the rehabilitation on Frégate, Denis and North Islands from inception to the present, and assess factors that have facilitated the subsequent development of conservation programmes, the presence of receptive businesses and governmental/NGO/donor support and explore limitations on business-led island rehabilitation.

Keywords: eradications, invasive alien species, island conservation, rehabilitation Seychelles, tourism

INTRODUCTION

Islands harbour much of the world’s endangered biodiversity (Kaiser-Bunbury, et al., 2010) and island species are very vulnerable to the impacts of Invasive Alien Species (IAS). Over the last 500 years, the majority of documented plant or vertebrate extinctions have occurred on islands (Tershy, et al., 2015). Causes include habitat modification and over exploitation; however, IAS have played a key role. In particular, invasive mammals such as rats (*Rattus* spp.) have been implicated in numerous bird extinctions, extirpations and population declines (Moors & Atkinson, 1984; Burger & Gochfeld, 1994; Hilton & Cuthbert, 2010) as well as reptile declines and impacts on other taxa (Townes, 1991; Harper & Bunbury, 2015; Thibault, et al., 2016).

The eradication of rats and other invasive mammals, often with concomitant habitat rehabilitation, was initially pioneered in New Zealand and other temperate areas but has become increasingly practiced in tropical regions, (Russell & Holmes, 2015; Russell & Broome, 2016). The understanding of the measures required to successfully execute mammal eradications on tropical islands has improved (Keitt, et al., 2015). In the late 1990s, the Seychelles was one of the first tropical island nations to implement rodent and multispecies eradications (Merton, et al., 2002)

The Seychelles archipelago in the Indian Ocean extends over an Exclusive Economic Zone of 1,374,000 km² (Fig. 1). The ancient “inner” islands are situated approximately 4° S and 54° E and are composed of continental rock, while the much more recently formed “outer” islands are formed from raised reefs and sand cays (Stoddart, 1984) scattered for approximately 1000 km to the south-west of the inner islands. The Seychelles have high endemism (Stoddart, 1984) and the inner islands are an Endemic Bird Area (EBA100); supporting 11 endemic species of bird (BirdLife International, 2017).

Since the human colonisation of the Seychelles in the late 18th century, IAS have caused range reductions, population declines, and extinctions of native species (BirdLife International, 2000). Alien predators are considered the most destructive species (Harper & Bunbury, 2015): most inner islands have had populations of black rat (*Rattus rattus*) and feral cat (*Felis catus*), and some have had brown rat (*R. norvegicus*). Only a few inner islands remained free of mammalian predators, and in the 1980s only four islands larger than 20 ha remained free of rats (Aride, Cousin, Cousine and Frégate), although feral cats were on Cousine and Frégate, and house mice (*Mus musculus*) on Aride and Frégate. Construction projects on islands resulted in the introduction of rats including black rat to Bird Island in 1968 and brown rat to Frégate in 1995.

Four Seychelles’ bird species endemic to the inner islands were listed as Critically Endangered when at their lowest known population size: Seychelles magpie-robin (*Copsychus sechellarum*), Seychelles white-eye (*Zosterops modestus*), Seychelles paradise-flycatcher (*Terpsiphone corvine*), Seychelles scops-owl (*Otus insularis*). Four species were listed as Vulnerable: Seychelles warbler (*Acrocephalus sechellensis*), Seychelles fody (*Foudia sechellarum*), Seychelles kestrel (*Falco araea*) and Seychelles swiftlet (*Aerodramus elaphrus*) (BirdLife International, 2017) (Table 1).

Three species of bird that had been historically widespread (Gaymer, et al. 1969) became restricted to black rat-free islands: the Seychelles magpie-robin on Frégate (Gaymer, et al., 1969; Burt, et al., 2016), Seychelles warbler on Cousin (Komdeur, 2003), and Seychelles fody on Cousin, Cousine and Frégate (Vesey-Fitzgerald, 1940). The Seychelles white-eye had a small population in the uplands of Mahé and a larger population on Conception Island which had brown rats, but no black rats (Rocamora, 1997). Aride remained free of rats but did not retain

Table 1 Number of island populations and threat categories of birds endemic to the Granitic Seychelles Endemic Bird Area (EBA) since 1994.

Species	Smallest documented number of populations	Current no of populations	IUCN Threat category since 1994	Year
Seychelles magpie-robin	1	5	Endangered Critical	2005–2018 1994–2005
Seychelles white-eye	2	4	Vulnerable Endangered Critical	2016–2018 2005–2015 1994–2005
Seychelles paradise-flycatcher	1	2	Critical	1994–2018
Seychelles scops-owl	1	1	Endangered Critical	2004–2018 1994–2004
Seychelles warbler	1*	5	Near threatened Vulnerable	2012–2018 1994–2012
Seychelles fody	3	6	Near threatened Vulnerable	2004–2018 1994–2004
Seychelles kestrel	1	2	Vulnerable	1994–2018
Seychelles swiftlet	3	3	Vulnerable	1994–2018
Seychelles black parrot	2	2	Vulnerable	2014–2018

* First reintroductions of Seychelles warblers undertaken prior to 1994 endangered species categories being applied.

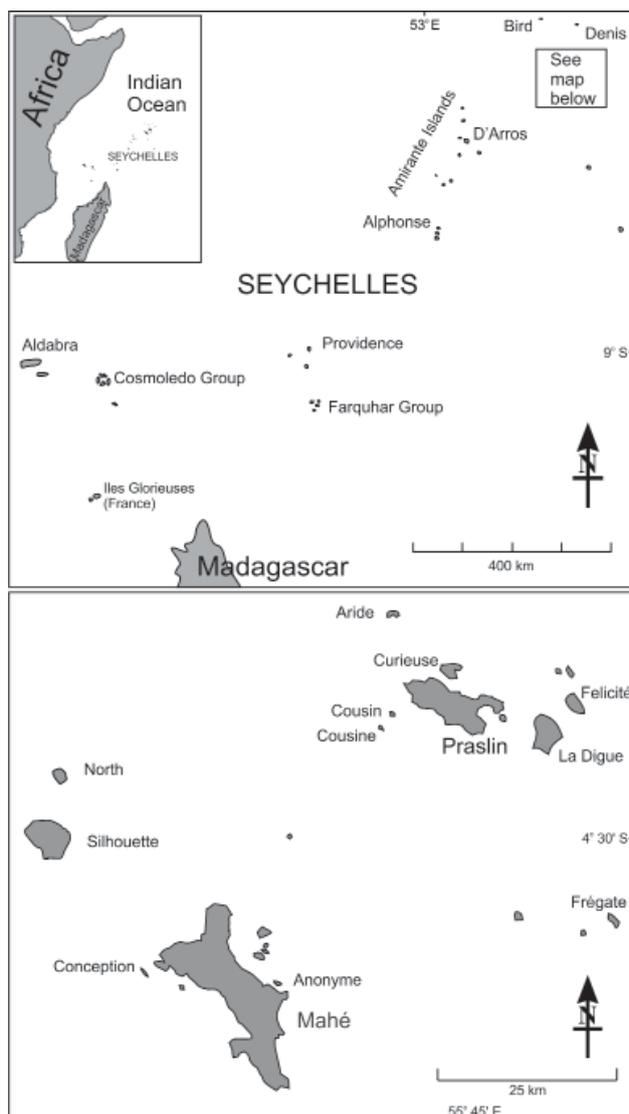


Fig. 1 The Seychelles showing islands mentioned in the text.

populations of endemic birds which may be attributed to forest loss and cat predation (eradicated in 1930s; Warman & Todd, 1984). The distributions of these endemic bird species suggest black rats were an important factor contributing to decline and extirpation of populations.

Initial conservation efforts focused on the purchase and protection of two rat-free islands (Cousin, 1968; Aride, 1973) by NGOs (Non Government Organisations). Successful attempts were made to reintroduce the Seychelles warbler to Aride and Cousine (Richardson, 2001; Komdeur, 2003). Attempts to introduce Seychelles magpie-robin to Cousin and Cousine met with success, but several introduction attempts to Aride were unsuccessful (Watson, 1978; Lucking & Ayerton, 1995).

Further progress was achieved with cat eradications on Frigate and Cousine during the 1980s (Rocamora & Henriette, 2015). Rodent eradications were not attempted in the Seychelles until 1996, when black rats were eradicated from Bird Island, and later in the early 2000s when a series of rat and multispecies eradications were initiated that included privately owned Frigate, Denis and North Islands. Subsequent habitat rehabilitation and endemic bird reintroductions were implemented (Thorsen, et al., 2000; Merton, et al., 2002; Samways, et al., 2010).

This paper reviews the conservation programmes on three privately owned islands and the conservation outcomes.

ISLAND DESCRIPTIONS: NORTH, DENIS, AND FRIGATE

North Island (Ile du Nord)

The native vegetation of North Island (201 ha) was replaced in the early 19th century by a coconut (*Cocos nucifera*) plantation, which was abandoned in the 1970s, and guano excavation left pits that are still present today. The island harboured black rats, cats, and feral cattle (*Bos taurus*). Hill (2002) identified the island as having a high rehabilitation potential; small enough to eradicate mammals, sufficiently isolated to manage reinvasion risk and a proportionally large coastal plateau that is likely to support rehabilitated forest suitable for Seychelles magpie-

robins and Seychelles paradise-flycatchers (Currie, et al., 2003). The island was privately purchased in 1997 by an eco-tourism company, which opened an exclusive resort in 2005, with the intention to ultimately fund the rehabilitation of the island. Conservation is promoted through all aspects of the tourism operation, whereby guests and staff are educated and encouraged to participate in environmental activities such as guided hikes, presentations, and data collection.

Denis Island

Denis is a coralline island of 140 ha located 80 km north of the capital island of Mahé. Early descriptions mention abundant land tortoises and seabirds (Bradley, 1940). The original vegetation of the island, as described in 1773, was of open grassy areas and forest; probably *Pisonia grandis* (Stoddart & Fosberg, 1981). Extensive guano deposits indicated the historical presence of seabirds. The island has been altered profoundly, first through the cultivation of coconuts from around 1890 (Stoddart & Fosberg, 1981), then through guano extraction in the 1930s (Baker, 1963), followed by the replanting of coconuts in the 1940s. In 1975, a new owner built an airstrip and a small hotel and abandoned the coconut plantation. In 1998 the island changed ownership again and today it is managed as a luxury tourist resort with 30 villas.

Denis was considered a priority site for rehabilitation due to the large area of flat land conducive to rehabilitation, existing native woodland, and an owner who supported conservation, if black rats and feral cats were removed (Hill, 2002). The island appears to be in the natural range of some endemic birds as, in 2004, a Seychelles magpie-robin from Aride flew to Denis (Burt, et al., 2016) and in 2009 a Seychelles sunbird (*Cinnyris dussumieri*) flew from Bird Island to Denis (R. Bristol, pers. obs., 2009).

Frégate Island

The original vegetation of Frégate Island (219 ha) was removed to make way for spice and coconut plantations, that were abandoned in the 1980s, leaving coconut-dominated forest and several areas of the introduced tree

sandragon (*Pterocarpus indicus*). The original vegetation is unknown; however, a few relict plants including *Pandanus balfourii* and *Euphorbia pyrifolia* survived on rocky glacia areas, indicating some of the vegetation that existed before plantations (J. Millett, pers. obs., 2000). The availability of canopy-forming sandragon forest and the absence of rats contributed to the survival of Seychelles fody, the last Seychelles magpie-robin population, and rich assemblages of reptiles, amphibians, and invertebrates including two single-island endemics: a beetle *Polposipus herculeanus*, and a snail *Pachnodus fregatensis* (Canning 2011b; Gerlach, 2006). Frégate was re-developed in 1995–1999 as an exclusive resort, and brown rats were accidentally introduced in 1995 at the time of hotel construction (Thorsen, et al., 2000; Merton, et al., 2002). Management of the island's biodiversity was initially not highly prioritised, but renewed interest in conservation was created through increased awareness amongst stakeholders over how nature can contribute to tourism. In 2003 the hotel appointed its own environment staff, who conducted biodiversity management and monitoring (J. Millett, pers. obs., 2003).

Vertebrate eradications

The islands of Frégate, Denis and North were amongst a series of islands that had rodents and /or cats eradicated between 1982 and 2005. In total six islands over 10 ha in size had black rats successfully removed, and three had brown rats successfully removed (Rocamora & Henriette, 2015). Some of the eradications were implemented in multi-island projects; however, the work was not planned as a phased programme. On the three islands central to this paper, the rodent eradications were, in part, motivated by business interests, and two required second attempts. The eradication of rodents has been an iterative (and at times faltering) process but was ultimately successful on most islands (Table 2).

Interest in eradicating rodents in the Seychelles was stimulated in 1995, when the introduction of brown rats to Frégate Island raised national and international concerns over the impact on Seychelles magpie robins (Merton, 1996). A proposal, led by the Ministry of Environment and

Table 2 Black rat, brown rat, mouse and cat eradications in the Seychelles.

Island	Size (ha)	Species	Invasion date	Eradication date	Method	Outcome	Prevention measures
Bird	101	Black rat	1960s	1995	Ground Application	Success	Medium/Good
Frégate	219	Brown rat	1995	2000	Aerial Application	Success	Medium/Good
		Mice	?	2000	Aerial Application	Success	Good
		Cats	?	1982	Ground Application	Success	
Curieuse	286	Black rat	?	2000	Aerial Application	Reinvaded	Poor
		Cats		2000	Ground Application	Success	
Denis	143	Black rat	?	2000	Aerial Application	Reinvaded	Poor/None
		Cats	?	2000	Ground Application	Success	
Denis	143	Black rat	2001	2002	Ground Application	Success	Poor/Medium
North	201	Black rat	~1784	2003	Aerial Application	Failed	Poor/Medium
		Cats	?	2003	Ground Application	Success	
D'Arros	150	Brown rat	?	2003	Ground Application	Success	Good
		Cats	?	2003		Success	
		Mice	?	2003		Failed	
Anonyme	10	Black rat	?	2003	Ground Application	Success	Medium/Poor
North	201	Black rat	?	2005	Aerial Application	Success	Medium/Good

Transport (MET), to eradicate rats and other mammals on several islands in a combined operation led to the eventual attempted eradication of black rats on Denis and Curieuse, brown rats on Frégate, and cats on Denis and Curieuse. House mice present on Frégate and Denis were not specific targets of eradication, but they were eradicated from the former during the operation. The eradication operational costs on the private islands (Denis and Frégate) were financed by the island owners, and on Curieuse (state owned) it was funded by a grant from the Dutch Trust Fund (DTF) that also covered consultancy costs for the three islands (Merton, et al., 2002; United Nations, 2002; Rocamora & Henriette, 2015; John Nevill, pers. comm. 2018).

Rodent eradication operations commenced in June 2000 with two aerial applications of brodifacoum bait totalling 18 kg/ha applied to Denis with a nine day interval, and three aerial applications (23 kg/ha) to Frégate at five and 25 day intervals (Merton, et al., 2002). Areas that could not be covered through the aerial application, including buildings, work yards and hydroponic green houses were hand baited. The third application was in response to a lactating female rat trapped in an agricultural plot after the second application (J. Millett, pers. obs., 2000) after which no further rats were observed and the eradication on Frégate was successful. Cat eradication on Denis proceeded one week after the second rat-bait application using trapping and baiting with Compound 1080 (Merton, et al., 2002). The last cat on Denis was killed 14 months after the eradication started. On the same day the last cat was killed, black rats were confirmed as being present again and breeding on Denis (J. Millett, pers. obs., 2001). It was not possible to conclude if the population arose from survivors or reintroduction. However, given the short time duration between eradication and discovery and better understanding of factors influencing tropical island rodent eradications, eradication survival is likely (Rocamora & Henriette, 2015; Keitt, et al., 2015). Subsequently it was discovered the eradication attempt on Curieuse had also been unsuccessful (G. Climo, pers. comm., 2001), possibly due to reinvasion and/or survival (Rocamora & Henriette, 2015).

The owners of Denis Island decided to undertake a second eradication attempt to eradicate rats and mice. This proceeded with a ground-based operation in 2002, using brodifacoum poison in bait stations on a 40 m grid. Monitoring indicated that rats were killed quickly, but mice persisted for several weeks around the livestock farm where alternative food sources were available (G. Climo, pers. comm., 2002). Both species were eradicated successfully within two months.

A black rat eradication was attempted on North Island in 2003 with an aerial baiting operation using three aerial applications of brodifacoum. In March 2004 black rats were still present (G. Climo, pers. comm., 2004; Rocamora & Henriette, 2015). Cats were eradicated successfully at this time with a combination of poisoning with Compound 1080 and trapping. A second attempt to remove rats was made in 2005 with four aerial applications and a grid of bait stations on the whole plateau and in the vicinity of housing (Climo & Rocamora, 2006). In response to a rat being captured four days after the third application a fourth application was conducted (Climo & Rocamora, 2006) which ultimately resulted in the eradication of rats.

Not only mammals have proved to pose problems for endemic island species: introduced Indian myna birds (*Acridotheres tristis*) attack some native birds and compete for nest sites with Seychelles magpie-robin (Burt, et al., 2015; Feare, et al., 2017). An attempt to eradicate mynas on Frégate in 2000–2003 by shooting was unsuccessful

(Millett, et al., 2005) but eradication succeeded using traps in 2011 (Canning, 2011a). Eradication on Denis Island using an avicide (Starlicide) and shooting commenced in 2000 but was unsuccessful. A subsequent attempt used trapping with follow-up shooting, which succeeded in 2015 (Feare, et al., 2017). On North Island, in 2006, an attempt to eradicate mynas with Starlicide was unsuccessful due to difficulties importing a rifle to start the shooting phase when poisoning had reduced the population to fewer than 100 birds; shooting was finally conducted in 2008–2009 but the population had recovered and was too numerous to be effective (Rocamora & Henriette, 2015). It was reattempted with a decoy trapping campaign from May 2016 to March 2017, followed by shooting. This reduced the population to three individuals by June 2018 with the eradication attempt ongoing (Havemann, pers. obs., 2018).

Overall experiences on Denis, North and Frégate indicate that sustained trapping programmes using small decoy traps located in areas frequented by foraging mynas, followed by shooting with an experienced hunter, is effective. Shooting as a standalone measure and using avicides appear to create aversion and have not worked well. Disruption or cessation of culling results in a population recovery (Millett, et al., 2005; Feare, et al., 2017).

BIOSECURITY

Biosecurity controls have been implemented on each of the three islands since undertaking rodent eradication. North Island has rigorous biosecurity with pre-departure inspections of all cargo on Mahé, inspections on arrival, the processing of cargo and baggage through a pest containment room, and fumigation and permanent bait stations locate close to landing areas, human habitation and beaches (North Island, 2015). Frégate Island has a rodent abatement protocol which includes cargo inspection and controls as well as permanent rat bait stations (Rocamora, 2015). There is also a rodent-proof fence around the harbour, made of steel mesh set in to the ground and topped with a smooth metal strip. However, maintenance of the structure has remained a challenge, especially where the ends of the fence meet the water and are influenced by wave action (J. Millett, pers. obs., 2018). Denis Island has a rodent prevention protocol (GIF, 2015). The protocol is focussed on rodent control with measures including baiting on boats, baiting arrival points and contingency measures to respond to an incursion: Denis Island still brings cargo to the island using a beach-landing barge, which increases reintroduction risk.

On all three islands, visiting vessels need to be in possession of a rat-free certificate which is obtained after a thorough check for rats on board prior to departure from Mahé. All of the protocols have been implemented voluntarily and devote greater effort to inspection and containment of rodents on the islands and less on loading controls at departure. Although all plans concentrate on rodent prevention, they are likely to be effective at reducing wider biosecurity risks.

FOREST REHABILITATION

Endemic birds rely on forest (Vega, 2005; Njoroge, 2002). Most other native vertebrates and invertebrates are also forest dwelling species; some have been able to adapt to gardens and plantations. Invertebrate densities and diversity on foliage tended to be higher for native trees, yielding greater food availability for species such as the Seychelles warbler and Seychelles paradise-flycatcher (Komdeur, 1991; Komdeur, 1992; Richardson, 2001; Hill, 2002). Accordingly, rehabilitation of native forest has been

a prerequisite to restoring endemic bird populations. The original vegetation on Frégate, Denis and North Islands is uncertain but evidence from remnant species and vegetation of similar, less modified islands suggests that the original contained *Pisonia grandis* and other native coastal trees including *Thespesia populnea*, *Heritiera littoralis* and *Calophyllum inophyllum* (Hill, 2002). The objective of rehabilitation has been to create habitat for native species, not to recreate pre-human forest.

North Island

Vegetation rehabilitation started in 2001 with the removal of invasive plant species such as *Lantana camara*, planting of native species on the coastal plateaux (including *Terminalia catappa*, *Barringtonia asiatica*, *Heritiera littoralis*) and attempts to rehabilitate vegetation on the hills by planting *Pyrostria bibracteata*, *Dodonaea viscosa* and other robust native shrubs. By 2017, approximately 60 ha of the coastal plateau was a native-dominated forest with *T. catappa* and *C. inophyllum* being the most abundant species. The establishment of native species on the hills has been slower and more labour intensive with <2 ha restored. The current area of native-dominated woodland is approximately 30% of the island's total surface area.

Denis

In 2001, approximately 20 ha of coconut plantation that was naturally reverting to native forest dominated by *T. catappa*, was cleared of coconuts and planted with native tree species (Hill, 2002). In 2007–2008, 12.5 ha were rehabilitated with the aim of creating habitat for Seychelles paradise-flycatchers (Bristol, et al., 2009). The rehabilitation involved removing coconut, *Nephrolepis biserrata* fern and other introduced weeds and replanting with tree species including *Terminalia catappa*, *C. inophyllum*, *Thespesia populnea*, *Cordia subcordata*, *B. asiatica*, *Ficus lutea*, *Guettarda speciosa*, *Hernandia nymphaeifolia*, *H. littoralis*, *Ochrosia oppositifolia*, *Pandanus balfourii*, *P. grandis*, *Ficus reflexa*, *Hibiscus tiliaceus* and *Morinda citrifolia*. In 2013–14, a further 2.5 ha area was cleared of coconut and *Casuarina equisetifolia* and replanted with *C. inophyllum* and *Mimusops sechellarum* and ca. 18 ha of *T. catappa* woodland were weeded. The current area of native-dominated woodland

is approximately 40 ha (Bristol, 2014), comprising 29% of the island's total surface area.

Frégate

A small amount of native tree planting was undertaken in the 1990s to benefit Seychelles magpie-robins and, in 1998, the hotel development used mostly native tree species for landscaping. A wilt disease caused by *Fusarium oxysporum* (Boa & Kirendall, 2004) killed all the Sandragon trees on Frégate in the early 2000s. Most of the sandragon forest was on the hills and these areas were replanted with native species, mostly *Ficus reflexa*, *F. lutea*, *Premna serratifolia* and *Tabernaemontana coffeoides*. Some further coastal areas were replanted with *T. catappa* and *Guettarda speciosa*, which has resulted in approximately 30 ha of native-dominated forest, comprising 15% of the island's total surface area. In addition, quite a lot of non-native forest was under-planted with native species but, unfortunately, the habitat rehabilitation is not well documented.

ENDANGERED SPECIES RECOVERY AND INTRODUCTIONS

The eradication of vertebrate predators on three islands with a total area of 560 ha, and associated improvement in forest habitat for native birds, has contributed to the recovery of several endangered bird species by increases in existing populations or by reintroducing populations (Table 3).

North Island

In 2007, 25 Seychelles white-eyes were introduced to North Island from Conception (Rocamora & Henriette-Payet, 2008). The population established and in 2017 was estimated at between 127 and 140 birds using direct census of groups with colour-ringed and unringed birds (Pietersen, 2017).

Denis Island

Four bird species have been introduced; 47 Seychelles fodies were translocated from Frégate in February 2004 (Bristol, 2005), and the current population is estimated at 600 individuals (van de Crommenacker, pers. obs.,

Table 3 Species conservation outcomes – an estimate of the number of endangered birds on rehabilitated private islands.

Species	Frégate Island	North Island	Denis Island	Other populations	Percentage of Seychelles population on Frégate, Denis & North Islands.	
Seychelles magpie-robin	145 ^c	0	76 ^a	Cousin	46	
				Cousine	32	
				Aride	10	
Seychelles warbler	209 ^c	0	400 ^d	Cousin	320	
				Cousine	210	
				Aride	1,850	
Seychelles white-eye	200 ^{c, g}	134 ^b	0	Conception Mahé	3,140 ^g 25-35 ^h	50
Seychelles Paradise-flycatcher	0	0	84 ^a	La Digue	ca. 400	21
Seychelles fody	1,182 ^f	0	600 ^c	Cousin	1,000	
				Cousine	430	
				Aride	ca. 500	
				D'Arros	250	

Data: Birdlife International, 2017 except: ^a Bristol & Gamatis, 2017; ^b Pietersen, 2017; ^c van de Crommenacker, pers. obs., 2017; ^d Lopera-Doblas, et al., 2015; ^e Gala, 2017; ^f Vega, 2005; ^g Rocamora & Henriette, 2015; ^h Rocamora, pers. obs., 2017.

2016) using a grid point count with 58 counting points located every 150 m. Fifty-eight Seychelles warblers were introduced from Cousin in 2004, and the most recent population estimate is 400 individuals (Lopera-Doblas, et al., 2015; van de Crommenacker, pers. obs., 2016). Twenty Seychelles magpie-robins were introduced in June 2008, 16 from Frégate and four from Cousin (Burt, et al., 2016), and the population in June 2017 was 76 individuals, estimated by monitoring colour ringed birds (Bristol & Gamatis, 2017). Twenty-three Seychelles paradise-flycatchers were introduced from La Digue in November 2008 and the population in June 2017 was 84 individuals, surveyed in a direct count Bristol & Gamatis, 2017).

Frégate Island

The population of Seychelles magpie-robin prior to conservation efforts was very small, with as few as 39 in 2000 (Burt, et al., 2016). Habitat for this territorial species was limiting (López-Sepulcre, et al., 2010). Increased habitat area and quality allowed the population to rise to 137 by 2015 (Burt, et al., 2016) and approximately 145 in 2017. This was estimated by an ongoing programme to colouring as many birds as possible to allow identification in the field. Then, by searching the whole island for presence of birds and their nest locations, group associations and behaviour, a territory map was constructed along with a status list with the identity of all birds within each territory (van de Crommenacker, pers. obs., 2017). The Seychelles fody population was estimated to have a population of 1,182 using mark and re-sight methods (Vega, 2005).

Frégate was considered suitable to reintroduce Seychelles white-eyes because of the abundant fruiting trees, including the non-native cinnamon (*Cinnamom vernum*). Reintroduction was undertaken between 2001 and 2003, with 37 birds from Conception (Henriette & Rocamora, 2011). The most recent estimate is at least 200 individuals, based on point counts (van de Crommenacker, pers. obs., 2017). The habitat suitability for Seychelles warbler was investigated (Hammers & Richardson, 2011) and found to be suitable. Accordingly, 59 individuals were translocated from Cousin in 2011 (Wright, et al., 2014); the population was estimated to be at least 209 individuals in 2017 (Gala, 2017).

Other species appear to have benefitted from island rehabilitation, including the endemic beetle *Polposipes herculeanus* which showed a dramatic decline between 1995 and 2000, probably due to rat predation, but appears to have subsequently recovered (Lucking & Lucking, 1997; Canning, 2011b).

FACTORS THAT INFLUENCED ISLAND REHABILITATION

The Seychelles endemic birds' crisis in the 1970s and 1980s resulted in interventions by international organisations including the Royal Society for Protection of Birds (RSPB), International Council for Bird Preservation (ICBP), BirdLife International, and the Royal Society for Nature Conservation (RSNC), initially by direct funding and deployment of staff and later through the establishment and support of the local NGOs Nature Seychelles and Island Conservation Society (ICS). The investment, at its height, contributed several hundred thousand British pounds each year, and facilitated the involvement of technical expertise from New Zealand in an advisory role. The potential benefits of rodent eradication for tourism, farming and nature inspired island owners to finance eradications. At the same time a proactive approach was taken by the Seychelles government which wanted to promote eradication programmes and donor funding was available. International funding to help finance eradications

and reintroduction operations was obtained by NGOs and Government through Global Environment Facility, Dutch Trust Fund and Fonds Français pour l'Environnement Mondial, among others.

As such, an enabling policy context (where a national biodiversity plan was in place and being implemented), international support, private sector interest, motivators with a "can do" approach, and finance all came together to facilitate change. At the time, the risk of failure in tropical rodent eradications was not estimated (Keitt, et al., 2015), and was therefore not perceived as a constraint.

The results of island rehabilitation, in particular rodent eradications, have not only been sustained but enhanced by hotel businesses who value it as part of their tourism product. Each island has a conservation manager and a small team of conservation staff and volunteers who implement biodiversity monitoring, biosecurity, habitat rehabilitation and education and awareness activities, including activities for hotel guests. These businesses have been able to access funds to support conservation management including directing Corporate Social Responsibility Tax (CSRT) to conservation programmes, donations from clients and paying volunteers. Each island has used independent approaches and methods to sustain this work, and cooperation improved when North Island, Denis Island and Frégate Island began working in partnership with the Green Islands Foundation (GIF), which was established in 2005 with the objective of improving cooperation and conservation work on islands. GIF has been able to assist with coordinating conservation programmes, apply for funds and manage projects on behalf of island conservation programmes and, importantly, act as a representative and advocate at national meetings related to the environment.

Limitations to biodiversity conservation on private islands

Recent years have seen a cessation of rodent eradications and species reintroductions, with no rodent eradications undertaken since 2010 (Rocamora & Henriette, 2015). International partners progressively reduced support to the Seychelles before ceasing funding, mainly due to the reduced threat to endemic birds and Seychelles being no longer considered a low-income country. National policy still supports island rehabilitation and species conservation (Nevill, et al., 2014), but specific actions are not being proactively promoted. Major donors' priorities have shifted and the national project portfolio is dominated by climate change adaptation and energy (Programme Coordination Unit, 2017). In principle, funding is available for island rehabilitation, but it is not being requested by the government.

Very few native animal species that are not birds have been introduced to Frégate, Denis or North Islands. Moreover, predator-free North Island's potential to support populations of endangered species has not yet been realised. One of the reasons is that habitat rehabilitation requires a number of years to produce a canopy-forming forest that is suitable for endemic birds and the forest has only recently become suitable for species such as Seychelles black paradise flycatcher (Bristol, 2017). Moreover, consensus building for species reintroduction takes time and may be influenced by views that are not necessarily evidence-based or pro-conservation.

There are several inner and outer islands with conservation potential for rehabilitation that have not been subject to eradication of invasive predators. For example, the inner island Félicité has potential for rehabilitation (Hill, 2002) and is currently suitable for the reintroduction of Seychelles paradise flycatchers, a species tolerant of rats, (Bristol, 2017) and potentially more endemic species

if cats and rodents were eradicated. Several outer islands already have hotels that support conservation programmes run by ICS and four islands are proposed as protected areas (UNDP, 2016). Rodent and cat eradications, if feasible, are likely to be beneficial for seabird populations and other biodiversity and well as tourism (Millett, et al., 2016).

Globally, many island-based businesses have nature orientated tourism, and many islands have undertaken rat eradications. However, comparable examples, whereby tourism businesses have undertaken, often with the support of local NGOs, invasive species eradication, habitat rehabilitation and endangered species reintroductions have not been observed in other island regions such as the Pacific or Caribbean. There may be reasons for this: for example, islands may have complex traditional ownership, species that are conservation priorities may not be suited to smaller islands or eco-tourism may be less valued by tourism sectors in other regions.

CONCLUSION AND RECOMMENDATIONS

The contribution of private islands to national conservation objectives is substantial, with 560 ha of predator-free land on three islands supporting nine populations of five species of globally threatened birds. The self-financing private sector, the enabling role of the Seychelles government and the contribution played by NGOs in facilitation, information exchange and advocacy are important. Whilst the priorities and contributions of international networks and some NGOs have focussed on other areas of work, others, notably GIF and ICS, are still attempting to increase networking and cooperation between these and other islands.

Lessons and recommendations for future work are:

1. Local NGOs should work more closely together and with business to improve knowledge exchange, build capacity, and enhance rehabilitation programmes;
2. Opportunities for the restoration of species on predator-free islands should be taken to the full, notably on North Island;
3. Develop a shared biosecurity facility on Mahé to reduce the risk of invasive species reintroduction;
4. Promote mammal eradications and habitat rehabilitation on suitable inner islands including Félicité, the proposed protected areas in the outer islands of the Seychelles;
5. Government should translate national policies including the NBSAP into implementation plans for species and sites;
6. The allocation of resources for island rehabilitation should be advocated by the government of Seychelles to international donors for large-scale national projects;
7. The approach adopted by Frégate, North and Denis Islands should be promoted as good practice internationally by organisations that facilitate collaboration and information sharing between small island states.

REFERENCES

- Boa, E. and Kirendall, L. (2004). *Sandragon Wilt Disease, Seychelles*. Unpublished report for Government of Seychelles, Mahé, Seychelles: CABI.
- BirdLife International. (2000). *Threatened Birds of the World*. Barcelona and Cambridge, UK: Lynx Edicions and BirdLife International.
- BirdLife International. (2017). 'Country Profile: Seychelles'. <www.birdlife.org/datazone/country/seychelles>. Accessed 25 July 2017.
- Baker, B.H. (1963). 'Geology and mineral resources of the Seychelles Archipelago'. *Memoir of the Geological Survey Kenya* 3: 1–140.
- Bradley, J.T. (1940). *The History of Seychelles*. Victoria, Seychelles: Clarion Press.
- Bristol, R. (2005). 'Conservation introductions of Seychelles fody and warbler to Denis Island, Seychelles'. *Re-introduction News* 24: 35–36.
- Bristol, R., Barra, A. and Rose, M. (2009). *Denis Island Habitat Rehabilitation Final Report*. Unpublished report for Green Islands Foundation, Mahé, Seychelles: Darwin Initiative Project 15-009.
- Bristol, R. (2014). *Denis Island Habitat Rehabilitation Plan 2015–2019*. Unpublished report for Green Islands Foundation, Mahé, Seychelles.
- Bristol, R. (2017). *Proposal to Translocate Seychelles Paradise Flycatchers to Félicité and Curieuse Islands*. Unpublished Report for Government of Seychelles. Mahé, Seychelles: Darwin Initiative project 23-006.
- Bristol R. and Gamatis I. (2017). *Seychelles Paradise-flycatcher Population Census on Denis Island, June 2017*. Unpublished report for Green Islands Foundation, Mahé, Seychelles.
- Burger, J. and Gochfeld, M. (1994). 'Predation and Effects of Humans on Island-nesting Seabirds'. In: D.N. Nettleship, J. Burger, M. and Gochfeld (eds) *Seabirds on Islands: Threats, Cases Studies and Action Plans*, pp. 39–67. Cambridge: BirdLife International.
- Burt, A.J., Gane, J., Olivier, I., Calabrese, L., de Groene, A., Liebrick, T., Marx, D. and Shah, N. (2016). 'The history, status and trends of the endangered Seychelles magpie-robin *Copsychus sechellarum*'. *Bird Conservation International* 1: 1–19.
- Canning, G. (2011a). 'Eradication of the invasive common myna (*Acridotheres tristis*) from Frégate Island, Seychelles'. *Phelsuma* 19: 43–53.
- Canning, G. (2011b). 'Population assessment of the Frégate Island giant tenebrionid beetle (*Polposipus herculeanus*)'. *Phelsuma* 19: 69–78.
- Climo G. and Rocamora G. (2006). *The Successful Eradication of Black Rats from North Island (Seychelles) in September 2005 and Proposed Strategies to Reduce the Risks of Reinvasions*. Unpublished report. *Réhabilitation des Ecosystèmes Insulaires (FFEM)* Project. Seychelles: Island Conservation Society and North Island.
- Currie, D., Bristol, R., Millett, J., Hill, M., Bristol, U., Parr, S.J. and Shah, N.J. (2003). 'Habitat requirements of the Seychelles black paradise flycatcher *Terpsiphone corvina*: A re-evaluation of translocation priorities'. *Ibis* 145: 624–636.
- Feare, C.J., van der Woude, J., Greenwell, P., Edwards, H.A., Taylor, J.A., Larose, C.S., Ahlen, P.A., West, J., Chadwick, W., Pandey, S., Raines, K., Garcia, F., Komdeur, J. and de Groene, A. (2017). Eradication of common mynas *Acridotheres tristis* from Denis Island, Seychelles. *Pest Management Science* 73(2): 295–304.
- Gala, C. (2017). 'Exploring the Effect of an Invasive Lepidopteran on an Endemic Insectivorous Bird'. MSc thesis. University of East Anglia: Faculty of Biological Sciences.
- Gaymer, R., Blackman, R. A. A., Dawson, P. G., Penny, M. and Penny, C. M. (1969). 'The endemic birds of the Seychelles'. *Ibis* 111: 157–176.
- Gerlach, J. (2006). *Terrestrial and Freshwater Mollusca of the Seychelles Islands*. Leiden: Backhuys.
- Green Island Foundation. (GIF) (2012). *Denis Island Rodent Protocol*. Seychelles: Green Islands Foundation.
- Harper, G. and Bunbury N. (2015). 'Invasive rats on tropical islands: Their population biology and impacts on native species'. *Global Ecology and Conservation* 3: 607–627.
- Hammers, M. and Richardson, D.S. (2011). *Assessment of the Suitability of Frégate Island for Seychelles Warblers Acrocephalus sechellensis 2011*. Unpublished report. University of Groningen and University of East Anglia.
- Henriette, E. and Rocamora, G. (2011). 'Comparative use of three methods for estimating the population size of a transferred island endemic: the endangered Seychelles white-eye *Zosterops modestus*'. *Ostrich: Journal of African Ornithology* 82(2): 87–94.
- Hill, M. J. (2002). 'Biodiversity surveys and conservation potential of inner Seychelles islands'. *Atoll Research Bulletin* 495: 1–272.
- Hilton, G. M. and Cuthbert, R. J. (2010). 'The catastrophic impact of invasive mammalian predators on birds of the UK Overseas Territories: a review and synthesis' *Ibis* 152: 443–458.

- Kaiser-Bunbury, C.N., Traveset, A. and Hansen, D.M. (2010). 'Conservation and restoration of plant-animal mutualisms on oceanic islands'. *Perspectives in Plant Ecology, Evolution and Systematics* 12(2): 131–143.
- Keitt, B., Griffiths, R., Boudjelas, S., Broome, K., Cranwell, S. and Millett J. (2015). 'Best practice guidelines for rat eradication on tropical islands'. *Biological Conservation* 185: 17–26.
- Komdeur, J. (1991). 'Cooperative Breeding in the Seychelles Warbler'. PhD thesis. Cambridge: University of Cambridge.
- Komdeur, J. (1992). 'Importance of habitat saturation and territory quality for evolution of cooperative breeding in the Seychelles warbler'. *Nature* 358: 493–495.
- Komdeur, J. (2003). 'Adaptations and maladaptations to island living in the Seychelles warbler'. *Ornithological Science* 2(2): 79–88.
- Lopera-Doblas, L., McClelland, S., van der Woude, J. and van de Crommenacker, J. (2015). *Seychelles Warbler Population Census on Denis Island August–October 2015*. Unpublished report. Seychelles: Green Island Foundation.
- López-Sepulcre, A., Kokko, H. and Norris, K. (2010). 'Evolutionary conservation advice for despotic populations: Habitat heterogeneity favours conflict and reduced productivity in Seychelles magpie-robins'. *Proceedings of the Royal Society of London Series B* 277: 3477–3482.
- Lucking, R.S. and Ayrton, V. (1995). *The Seychelles Magpie Robin Recovery Plan. Aride Translocation: Summary Report, November 1992–November 1994*. Unpublished report. Mahé, Seychelles: BirdLife International.
- Lucking, R. and Lucking, V. (1997). 'Preliminary results of monthly surveys of *Polposipus herculeanus*'. *Phelsuma* 5: 5.
- Merton, D. (1996). *Frégate Island Rat Crisis – Implications, Recommendations, Eradication Plan, Indicative Budgets 1996 and 1997*. Republic of Seychelles: Unpublished report. BirdLife International and Division of Environment, Ministry of Environment and Transport.
- Merton, D., Climo, G., Laboudallon, V., Robert, S. and Mander, C. (2002). 'Alien mammal eradication and quarantine on inhabited islands in the Seychelles'. In: C.R. Veitch and M.N. Clout (eds.) *Turning the tide: the eradication of invasive species*, pp. 182–198. Occasional Paper SSC no. 28. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.
- Millett, J., Climo, G. and Shah, N.J. (2005). 'Eradication of common mynah *Acridotheres tristis* population in the granitic Seychelles: Successes, failures and lessons learned'. *Advances in Vertebrate Pest Management* 3: 169–183.
- Millett, J., Bristol, R., Feare, C., Duhec, A., Risi, M., Nogués, P, Morgan, M. and Blumel, J. (2016). *Seabird Management Plans for the Outer Islands of the Seychelles*. Unpublished report. Mahé, Seychelles: Island Conservation Society.
- Moors, P.J. and Atkinson, I.A.E. (1984). 'Predation on seabirds by introduced animals, and factors affecting its severity'. *ICBP Technical Publication* 2: 667–690.
- Nevill, J., Prescott, J., Shah, N.J. and Jeremie M. (2014). *Seychelles Biodiversity and Action Plan 2015 – 2020*. Seychelles: Government of Seychelles.
- Njoroge, P. (2002). 'The Seychelles Magpie-robin *Copsychus sechellarum*: Territory Quality, Demography and Conservation of a Threatened Species'. PhD thesis. UK: University of Reading.
- North Island (2015). *Manual for the Conservation Work, Environmental Management and Sustainability Efforts of North Island*. Seychelles: Wilderness Collection.
- Pietersen, D.W. (2017). *Assessment of the Seychelles White-eye, Zosterops modestus Newton 1867, Population on North Island, Seychelles. North Island Annual Report 2017*. Seychelles: Wilderness Collection.
- Programme Coordination Unit. (PCU) (2017). 'Ongoing Projects'. <<http://www.pcusey.sc/index.php/pcu-projects/ongoing>>. Accessed 4 July 2017.
- Richardson, D. S. (2001). *Species Conservation Assessment and Action Plan: Seychelles Warbler (Timerl Dezil)*. Unpublished report. Norwich: Nature Seychelles and University of East Anglia.
- Rocamora, G. (1997). *Rare and Threatened Species, Sites and Habitats Monitoring Programme in Seychelles: Monitoring Methodologies and Recommended Priority Actions*. Unpublished Report. Seychelles: Government of Seychelles.
- Rocamora, G. and Henriette-Payet, E. (2008). Conservation introductions of the Seychelles White-eye on predator-free rehabilitated islands of the Seychelles archipelago, Indian Ocean. In: Soorae, P. (ed.) *Global Reintroduction Perspectives. Reintroduction case studies from around the globe*, pp. 121–129. Gland, Switzerland: IUCN.
- Rocamora G. (2015). *Biosecurity Protocols for the Transportation of Vessels, Cargo and People Between Islands, with Special Reference to Protected Areas and Islands of High Biodiversity Value*. Report for project 'Mainstreaming Prevention and Control Measures for IAS into Trade, Transport and Travel across the Production Landscape'. Seychelles: Government of Seychelles-UNDP-GEF.
- Rocamora, G. and Henriette, E. (2015). *Invasive Alien Species in Seychelles: Why and How to Eliminate Them? Identification and Management of Priority Species*. Seychelles: Island Biodiversity & Conservation centre, University of Seychelles; Mèze: Biotope Editions, and Paris: Muséum National d'Histoire Naturelle (Inventaires & Biodiversité series).
- Russell, J.C. and Holmes, N.D. (2015). 'Tropical island conservation: Rat eradication for species recovery'. *Biological Conservation* 185: 1–7.
- Russell, J.C. and Broome, K.G. (2016). 'Fifty years of rodent eradications in New Zealand: Another decade of advances'. *New Zealand Journal of Ecology* 40(2): 197–204.
- Samways, M.J., Hitchins, P.M., Bourquin, O. and Henwood, J. (2010). *Restoration of a tropical island: Cousine Island, Seychelles*. Biodiversity and Conservation 19: 425–434.
- Stoddart, D.R. (1984). *Biogeography and Ecology of the Seychelles Islands*. Monographiae Biologicae Volume 55. The Hague/Boston/Lancaster: Dr. W. Junk Publishers.
- Stoddart, D.R. and Fosberg, F.R. (1981). 'Bird and Denis Islands, Seychelles'. *Atoll Research Bulletin* 252: 1–46.
- Tershy, B.R., Shen, K., Newton, K.M., Holmes, N.D. and Croll, D.A. (2015). 'The importance of islands for the protection of biological and linguistic diversity'. *Bioscience* 20: 1–6.
- Thibault, M., Brescia, I.F., Jourdan, H. and Vidal, E. (2016). 'Invasive rodents, an overlooked threat for skinks in a tropical island hotspot of biodiversity'. *New Zealand Journal of Ecology* 41(1): 74–83.
- Thorsen, M., Shorten, R., Lucking, R. and Lucking, V. (2000). 'Norway rats (*Rattus norvegicus*) on Frégate Island, Seychelles: The invasion; subsequent eradication attempts and implications for the island's fauna'. *Biological Conservation* 96: 133–138.
- Towns, D.R. (1991). 'Response of lizard assemblages in the Mercury Islands, New Zealand, to removal of an introduced rodent: The kiore (*Rattus exulans*)'. *Journal of the Royal Society of New Zealand* 21: 119–136.
- United Nations (2002). 'Seychelles Country Profile'. <www.un.org/esa/agenda21/natlinfo/wssd/Seychelles.pdf>. Accessed 4 July 2017.
- UNDP. (2016). *Seychelles' Protected Areas Finance Project: Project Document*. GEF ID 5485 / Project ID 00095320. Seychelles: United Nations Development Programme.
- Vega, L.B. (2005). 'The Ecology and Conservation of the Seychelles Fody or Toc-toc *Foudia sechellarum*'. PhD thesis. UK: University of Reading.
- Vesey-Fitzgerald, D. (1940). 'The birds of the Seychelles 1. The endemic birds'. *Ibis* 4: 482–489.
- Watson, J. (1978). *The Seychelles Magpie Robin. WWF Project 1590: Endangered land birds, Seychelles*. Final Report 1(a). Gland, Switzerland: World Wildlife Fund. Mimeo.
- Warman, S. and Todd, D. (1984). 'A biological survey of Aride Island Nature Reserve, Seychelles'. *Biological Conservation* 28: 51–71.
- Wright, D.J., Shah, N.J. and Richardson, D.S. (2014). 'Translocation of the Seychelles warbler *Acrocephalus sechellensis* to establish a new population on Frégate Island, Seychelles'. *Conservation Evidence* 11: 20–24.