

Eradication of invasive animals and other island restoration practices in Seychelles: achievements, challenges and scaling up perspectives

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Abstract In recent decades Seychelles has accumulated extensive experience in the management of invasive species and other island restoration practices. Non-government organisations (NGOs), governmental, parastatal and private stakeholders have conducted successful programmes to control and eradicate invasive animals and plants, particularly on small islands of high biodiversity value. Biosecurity protocols have been implemented to prevent (re)infestations. With at least 50 vertebrate populations (33 mammal, 16 bird and one reptile) from 14 different species successfully eradicated, Seychelles is the third country in the world after Australia and the USA for invasive vertebrate eradications from tropical islands, and the seventh when considering all countries. Twenty-four islands have benefited from invasive vertebrate eradications and other ecosystem restoration processes to create refuges for native biodiversity. About 470 ha of woodland have been rehabilitated through replanting and recovery of native vegetation, and at least 36 successful island translocations of native birds and reptiles have been conducted. This includes 16 conservation introductions or reintroductions of six endemic land birds (all but one threatened), two of a terrapin species and 18 of Aldabra giant tortoises. Recovery of native species and natural recolonisations have occurred on islands where invasive predators have been removed. As a result, four globally threatened endemic land birds have been down-listed in the IUCN Red List and dozens of other native species including seabirds, land birds, reptiles, invertebrates and plants have also benefited. Future challenges include increasing the proportion of the country's land area free of rats and cats from 3.9% to potentially 15.4%, mainly in the outer islands, and 50% in the long term if Aldabra and Cosmoledo are considered. Factors limiting future eradications and translocations are discussed. Alternative conservation approaches such as 'mainland-islands' are recommended for large islands, and the development of partnerships with nature-based tourism is encouraged to help fund further restoration.

Keywords: ecosystem recovery, habitat rehabilitation, invasive birds, invasive mammals, reintroductions, species recovery, species translocations, vegetation restoration

INTRODUCTION

The Republic of Seychelles comprises 115 main islands totalling 445 km² of land area within a marine Exclusive Economic Zone of 1,374,000 km². These are classified into the 'inner islands' archipelago, of granitic substrate (ca. 45), and the remote, coralline 'outer islands' (c.70) to the south and south-east, that include the Amirantes, Providence-Farquhar and Aldabra groups (Fig 1). Aldabra atoll, a nature reserve and World Heritage Site, represents about one third of the country area.

In recent decades, the restoration of small islands has been an effective conservation tool in Seychelles to create sanctuaries for native biodiversity (Rocamora, 1997; Nevill, 2001; Shah, 2001; Merton, et al., 2002; Shah, 2006; Asconit & ICS, 2010; Rocamora, 2010a; Samways, et al., 2010b; Nevill, 2011). This has been achieved by eradicating or controlling invasive alien predators and competitors. Native habitats have been restored by eliminating invasive alien plants and replanting native vegetation. Globally threatened species of endemic birds and other native wildlife have been translocated to these rehabilitated islands, contributing to their subsequent recovery (Kömdeur & Pels, 2005; Richardson, et al., 2006; Rocamora & Henriette-Payet, 2008; Shah, 2008). This paper updates the inventory of island restoration achievements in Seychelles documented in Rocamora (2015) and discusses future perspectives and challenges. It considers only actions for nature conservation purposes and excludes eradications of invasive species for agricultural (two declared; National Biosecurity Agency, pers. comm. 2017) or public health purposes. Names of islands are the ones normally used by the islanders as listed in the Constitution of Seychelles, with the exception of 'Ile du Nord' also referred to as 'North Island'.

MATERIALS AND METHODS

Rocamora (2015) used information from publications (Beaver & Mougat, 2009; Nevill, 2009), internal reports and newsletters, and unpublished information from personal knowledge, to construct a database recording all attempts made in Seychelles to eradicate vertebrate populations. For each eradication attempt the database records: island name, area, animal species, year(s), methods used, and the final outcome of the overall eradication programme but not to the immediate result of each method employed. This information was checked in 2014 and made consistent with the Database of Island Invasive Species Eradications (DIISE) managed by Island Conservation, to allow comparison of Seychelles' performance in eradication with that of other countries (DIISE, 2017). This information base was updated in 2017. No new eradication attempts have taken place since 2014. One operation formerly classified as control was re-classified as 'eradication' as the target species, the crested-tree lizard (*Calotes versicolor*), was eradicated. The status of the five operations that were ongoing in 2015, and finalised by 2017, was updated.

Rocamora (2015) also gathered information on the area of natural habitat rehabilitated (from reports, or estimates by island owners, managers or conservation staff) as a result of removing invasive plants and propagating and planting native vegetation. He also documented translocations of native species that occurred in Seychelles, i.e. reintroductions to islands where the species was formerly present, 'conservation introductions' to islands outside a species' known historical range (IUCN, 2013), and historical introductions or reintroductions of Aldabra giant tortoises (*Aldabrachelys gigantea*). For each translocation he recorded: species, island, year, type of translocation (reintroduction, conservation introduction), and outcome. He then analysed how island restoration practice has developed in Seychelles, together with nature-

based tourism, and how this has benefited the conservation of native biodiversity.

RESULTS

Eradication of introduced predators and competitors: the first step to ecosystem recovery

By September 2017, 68 attempts to eradicate invasive animals had been made on 24 islands. Three of these operations are still in progress (Table 1).

Most island eradications conducted in Seychelles have targeted mammals (44 attempts, 68%) and birds (22 attempts, 29%) on 22 islands of at least 10 ha, plus two mammal eradications on two islets smaller than 1 ha. In five of the 65 completed eradications, species that were not the main target (feral cats and barn owls) also disappeared following the removal of rats and on three occasions island populations of feral goats and chickens died out following control. Of the remaining 55 eradication attempts completed (excluding the two small islets), 40 (72.7%) succeeded and 15 (27.3%) had a failed outcome (i.e. survival or recolonisation before the island could be certified pest-free; see DIISE, 2017). When including the rat eradications on two islets (< 1ha), success rate is 73.7% and failure 26.3% (n=57).

By the end of 2017, 50 alien vertebrate (33 mammal, 16 bird and one reptile) populations had been eradicated from

islands in Seychelles. One operation targeting common myna (*Acridotheres tristis*) on Ile du Nord is almost finished and one (the ring-necked parakeet, *Psittacula krameri*, on Mahé) is in the final phase of monitoring. Fig. 2 lists the 14 species of vertebrates eradicated from islands in Seychelles (plus one yet to be confirmed) and gives the outcomes of eradication attempts. Success rates of eradication attempts vary: 33% for house mouse, 56% for common myna, 57% for feral goat, 75% for black rat (*Rattus rattus*) and brown rat (*R. norvegicus*) (excluding the two islets), and 100% for other species.

Domestic pigs (*Sus scrofa*) and cows (*Bos taurus*) were also removed from Cousine and Ile du Nord. These were small numbers: some of the animals were not completely wild and may have still depended on supplementary food from humans, so they were easy to catch, and it is unclear if some of them were reproducing in the wild (Samways, et al., 2010a; Bruce Simpson/North Island Ltd; pers. comm.; Victorin Laboudallon, pers. comm. 2015). Feral cats (*Felis catus*) died out on Picard after the 1970s, with no control or eradication programme involved. These pig, cow and cat cases are not included in the calculations as eradications, but we did include the reported eradication of goats on Aride by shooting before 1920 (Warman & Todd, 1984), the removal of feral goats from the Aldabra atoll islands of Polymnie and Ile Esprit in the 1970s in response to localised control (Nancy Bunbury/SIF, pers. comm.), and the extinction of feral chickens on Desnoeuvs in 2007 by local staff for consumption (Roland Nolin, pers. comm.).

The numbers of eradication attempts and success rates have varied over time (Table 2): 73% (over 11 attempts) before 1995, 64% (over 28 attempts) during 1995–2004, and after 2004 up to 89% (over 18 attempts finalised by 2017).

Removal of invasive alien plants and replanting native vegetation

Control of invasive plants and habitat rehabilitation has been important for restoring ecosystems and protecting native biodiversity (Table 3). Significant areas (over 60 ha) have been rehabilitated since the 1990s on Praslin (National Park) and Mahé (Morne Seychellois National Park). Most invasive plant control and native species replanting activities have taken place on small and medium sized granitic islands, as part of programmes to restore

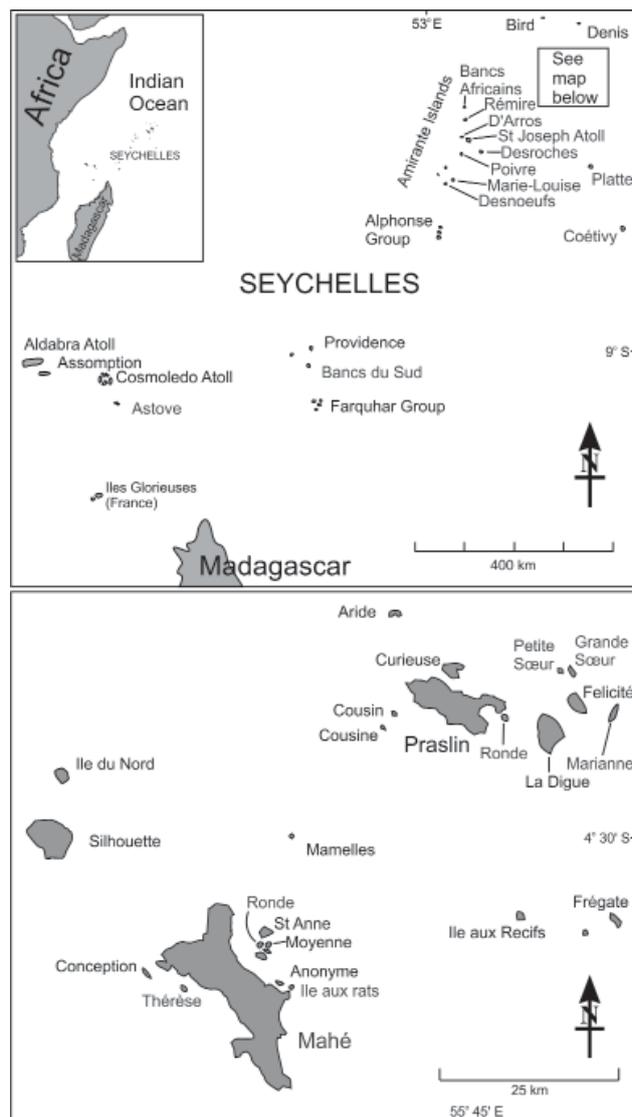


Fig. 1 Islands of the Republic of Seychelles.

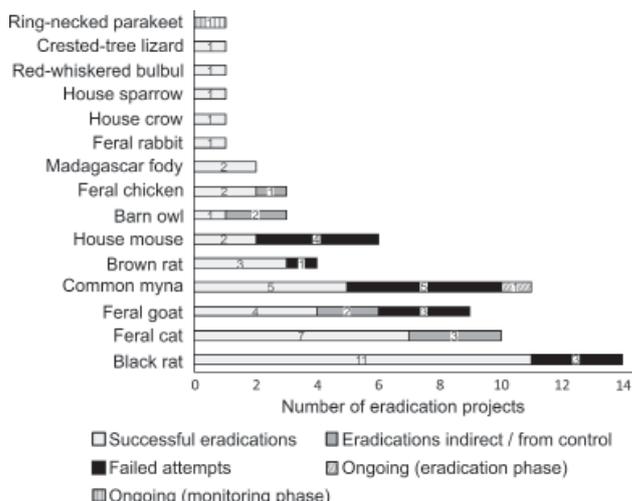


Fig. 2 Number of eradication attempts (n = 68), and success outcomes for the 15 species of invasive vertebrates targeted in Seychelles. Species are listed in increasing order of successful attempts. Success or failure refers to the final outcome of the operations (see text).

Table 1. Attempts to eradicate invasive alien animals from islands in Seychelles. Total number of attempts = 68 (65 completed; 3 in progress). Successful attempts (in **bold**) = 50 (42 direct; + 5 indirect eradications induced by rat removal and 3 from control, in brackets). Success or failure refers to the outcome of the operation. 'Failed' attempts involved animals that either survived or immediately reinvaded after a technically successful eradication phase. Only the active removal of individuals that had established a substantial wild breeding population is considered a genuine eradication attempt. Removal of small numbers of wild or semi-feral domestic animals (cattle, pigs, chickens), or populations of the same that died out naturally are not included here. * = eradications almost finished or in monitoring phase, to be confirmed in 2018. Occ. inc. = occasional incursions. Species and islands are listed in chronological order of their first eradication.

Outer Islands chronological order of eradications	Ile Esprit, Aldabra		Picard, Aldabra		Malabar, Aldabra		D'Arros		Desnoeuufs		Grande Ile, Cosmoledo		Polyte, Cosmoledo		Petit Polyte, Cosmoledo		Grande Terre, Aldabra		Assomption	Total attempts	Successful outcomes
	Polymnie, Aldabra	475	51	940	2,680	140	35	143	21	<1	11,610	1,171									
Feral goat <i>Capra hircus</i>	(died out by 1976 after control)		(died out after control)	1993-95	1993-95 1987-88 failed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	3 (+2 control)
Feral cat <i>Felis catus</i>	-	-	(died out after 1970s)	-	2003	-	-	(2007)	-	-	-	-	-	-	-	-	-	-	-	3	1 (+2 indirect)
Feral chicken <i>Gallus gallus</i>	-	-	-	-	-	-	(died out by 2007 after harvest)	-	-	-	-	-	-	-	-	-	-	-	-	1	(+harvest)
Black rat <i>Rattus rattus</i>	-	-	-	-	-	-	-	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	3	3
Brown rat <i>Rattus norvegicus</i>	-	-	-	-	2003	2003	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
House mouse <i>Mus musculus</i>	-	-	-	-	-	2003 failed	-	-	-	-	-	-	-	-	-	-	-	-	-	1	0
Red-whiskered bulbul <i>Pycnonotus jocosus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(inc. 2012-14)	2012-14	2012-14	1	1
Madagascar fody <i>Foudia madagascariensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2012-15	2012-15	2012-15	2	2
Total attempts	1	1	1	2	3	3	1	2	2	1	1	2	2	2	1	4	2	2	2	20	11 (+2 indirect & 3 after control/ harvest)
Success (Outcome)	(1 from control)	(1 from control)	(1 from control)	1	2	2	(1 harvested for food)	1 (+1 indirect)	1 (+1 indirect)	1	1	1 (+1 indirect)	1 (+1 indirect)	1	2	2	2	2	2	20	11 (+2 indirect & 3 after control/ harvest)

Inner Islands																		
chronological order of eradication	Area (ha)	Aride	Mahé	Frégate	Cousine	Bird Island	Cousin	Curieuse	Denis	Sainte Anne	Anonyme	Ile aux rats (Ile du Nord)	Conception	Grande Sœur	Petite Sœur	Total attempts	Successful outcomes	
		73	15252	219	26	101	29	289	143	219	10	<1	201	69	85	35		
Feral goat <i>Capra hircus</i>	before 1920	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Feral cat <i>Felis catus</i>	1930s	-	-	1981-82	1983-85	-	-	2000	2000	-	-	-	2003	-	(2010)	-	7	6 (+1 indirect)
House crow <i>Corvus splendens</i>	-	-	1977-94 occ. inc.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Common myna <i>Acridotheres tristis</i>	1993-94 +occ. inc.	-	-	2010-11 (98-02 failed) +occ. inc.	2001-02 +occ. inc.	-	2000-02 +occ. inc.	-	2010-15 2000-01 failed	-	-	-	2006-09 failed. 2012- ongoing*	-	2011 failed	-	9 (+1 ongoing)	5
Feral chicken <i>Gallus gallus</i>	-	-	-	-	1996	-	-	-	-	-	-	-	2003	-	-	-	2	2
Feral rabbit <i>Oryctolagus cuniculus</i>	-	-	-	-	-	1996-97	-	-	-	-	-	-	-	-	-	-	1	1
Barn owl <i>Tyto alba</i>	1996 +occ. inc.	-	-	-	-	-	-	-	-	-	-	-	(2005) occ. inc.	-	(2010) occ. incv.	-	3	1 (+2 indirect)
Black rat <i>Rattus rattus</i>	-	-	-	-	-	1996-97	-	2000 failed	2002 2000 failed	-	2003 & 2006	2006	2005 2003 failed	-	2010	2010	11	8
Brown rat <i>Rattus norvegicus</i>	-	-	-	2000 1996 failed	-	-	-	-	-	-	-	-	-	2007	-	-	3	2
House mouse <i>Mus musculus</i>	-	-	-	2000	-	1996-97 failed	-	2000 failed	2002 2000 failed	-	-	-	-	-	-	-	5	2
House sparrow <i>Passer domesticus</i>	-	-	2003-04 +occ. inc.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Crested-tree lizard <i>Calotes versicolor</i>	-	-	-	-	-	-	-	-	-	2003- 14	-	-	-	-	-	-	1	1
Ring-necked parakeet <i>Psittacula krameri</i>	-	-	2012- ongoing*	-	-	-	-	-	-	-	-	-	-	-	-	-	(1 ongoing)	
Black-headed ant <i>Pheidole megacephala</i>	2014- ongoing*	-	-	-	(control 2008)	-	-	-	-	-	-	-	-	-	-	-	(1 ongoing)	
Total attempts	4 (+1 ongoing)	2 (+1 ongoing)	6	3	3	3	1	3	7	1	2	1	6 (+1 ongoing)	1	4	1	45 (+3 ongoing)	
Success (Outcome)	4	2	4	3	3	2	1	1	4	1	2	1	3 (+1 indirect)	1	1 (+2 indirect)	1	31 (+3 indirect)	

Table 2 Temporal distribution and success outcomes of attempts to eradicate invasive animals in Seychelles (n = 68). The few eradications declared successful after 2015 had their last individuals eliminated on this year or before.

	Pre-1995	1995–2004	2005–2015	Total attempts
Direct eradications	8	18	16	42
Indirect eradications	2	-	6	8
Failed outcomes	3	10	2	15
Ongoing attempts	-	-	3	3
Total attempts	13	28	27	68

Table 3 Approximate areas rehabilitated (see explanation in text) on islands where vegetation management (replanting and spontaneous native woodland recovery after exotic species removal) has been undertaken.

	Area of Planting after exotic sp. removal (ha)	Area of Woodland / Shrubland rehabilitation (ha)	Area of Woodland recovery (Pisonia dominated) (ha)
Frégate	60	-	-
Ile du Nord	45–50	-	-
Félicité	40	-	-
Denis	35	-	4
Praslin	25 (inc. 10 bare land)	20	-
Mahé	15–20	-	-
Curieuse	18–20	-	-
Aride	7	-	62
Cousin	?	-	27
Cousine	10	-	16
Conception	2 (coconut removal)	-	> 1
Bird (Island aux Vaches)	< 1	-	35
St Anne	1	-	-
Silhouette	< 1	-	-
Moyenne	0.5	-	-
Anonyme	0.5	-	-
Inner Islands	ca. 228	20	ca. 145
Desroches	12	-	-
D'Arros	11	-	-
Aldabra	(sisal removal)	<5	-
Alphonse	1	-	-
Outer Islands	ca. 72	<5	-
TOTAL	ca. 300	25	ca. 145

abandoned coconut plantations and lowland coastal forests previously dominated by invasive species.

Habitat rehabilitation was initiated on Aride and Cousin in the 1970s (Warman & Todd, 1984; Kömdeur & Pels, 2005), and since the mid-1990s has been implemented on Frégate, Ile du Nord, Denis, Curieuse, Cousine and Félicité as well as to a minor extent on other granitic islands. Very little vegetation restoration has taken place in the outer islands. On D'Arros, some 11 ha of former coconut plantations have progressively been replaced by plantations of native trees since 2009 (von Brandis, 2012; von Brandis, pers. comm. 2015). On Alphonse and Desroches, since 2006 and 2009 respectively, small areas have been cleared of exotics and replanted. At Aldabra, rehabilitation activities to control sisal (*Agave sisalana*) have taken place since the 1970s on Picard, Polymnie and Ile Michel and, since 2013, to eradicate it (van Dinther, et al., 2015).

In Seychelles, control and clearing of exotic plants has mostly been done physically, using machetes and chainsaws for woody plants, pulling by hand for creepers, and sometimes using heavy machinery, as on Frégate or Ile du Nord. Chemical treatments have rarely been used to eradicate invasive plants, although some trials have been conducted on several islands (Kaiser-Bunbury, et al., 2015). Elimination of coconut trees inland of the beach crest has been done on most of the rehabilitated islands that had, in the past, been exploited as coconut plantations. These have been replaced by forests dominated by native and endemic species, through natural regrowth or replanting.

Although precise figures are not available for all islands, we estimate that at least 220 ha have been actively cleared of alien invasives, replanted with native trees and maintained. This reaches 300 ha when including areas partially restored and ca. 470 ha when including natural recovery of native woodland. Rehabilitated vegetation now covers 17% (405/2,480 ha) of middle-sized and small inner islands, but only a tiny proportion (c.1%) of the country area.

Nurseries were established by successive ministries and associated public authorities responsible for the environment on Mahé and Praslin. On private islands such as Frégate (early 1990s), Ile du Nord (early 2000s) and Félicité (early 2010s), nurseries dedicated to propagating Seychelles native plants and trees have been created. These have successfully multiplied most of the 85 endemic plants of Seychelles and have produced tens of thousands of saplings that have been used in island rehabilitation. Based on the areas rehabilitated at the average density of 1,000 plants/ha normally used in Seychelles (Kueffer & Vos, 2004), we estimate that a minimum of 220,000 native trees have been planted in Seychelles over the last 50 years.

Species translocations to rehabilitated islands

Species translocations to predator-free islands with suitable habitats also contribute to the process of island restoration. Table 4 lists 20 documented translocations of eight rare and threatened species and one common species that have taken place to date on ten rehabilitated islands. This includes six species of Seychelles endemic land birds, one species of reptile and one very rare insect. Ninety percent of these translocations were successful (including nine reintroductions and 10 conservation introductions of rare and threatened species). In addition, a common land bird was successfully transferred to Bird Island (Ile aux Vaches). The two translocations which failed were of Seychelles leaf-insects, *Phyllium bioculatum*, to Conception and of Seychelles white-eyes, *Zosterops*

Table 4 Translocations of rare and threatened species (other than Aldabra tortoises) and common species to rehabilitated islands in Seychelles. X = naturally present; Normal case: reintroduction; Underlined: conservation introduction; Italic: failed attempt; *: initial transfer trials to Aride between 1978 and 1995 were unsuccessful; ©: cats eradicated; ®: rats eradicated; species are listed per chronological order of translocation; IUCN threat status between brackets likely to change due to status or taxonomic re-assessment; § endemicity questioned by Fritz, et al. (2013).

	IUCN Threat Status	Cousin -	Aride ©	Cousine ©	Frégate ©®	Denis ©®	Ile du Nord ©®	Conception ®	D'Arros ®©	Picard (Aldabra) ©	Bird ®	Total
Seychelles fody <i>Foudia sechellarum</i>	NT	X	2002	X	-	2004	-	-	1968	-	-	3
Seychelles warbler <i>Acrocephalus sechellensis</i>	NT	X	1988	1990	2011	2004						4
Seychelles magpie-robin <i>Copsychus sechellarum</i>	EN	1994–95	2002*	1995–96	X	2008						4
Seychelles white-eye <i>Zosterops modestus</i>	(VU)			2007	2001		2007	X				3
Aldabra rail <i>Dryolimnas (cuvieri) aldabranus</i>	(LC)									1999		1
Sey. black paradise flycatcher <i>Terpsiphone corvina</i>	CR					2008						1
Seychelles black-mud terrapin <i>Pelusios subniger parietalis</i> §	(CR)		2012				2008					2
Seychelles leaf insect <i>Phyllium bioculatum</i>	(LC)							2010				1
Number of translocations of rare and threatened species		1	4	3 (1 failed)	2	4	2	1 (failed)	1	1	0	19 (2 failed)
Seychelles sunbird <i>Cynniris dussumieri</i>	LC										2006	1
Number of translocations per island (all native species)		1	3	2	2	4	2	0	1	1	1	20 (2 failed)

modestus, to Cousine (Galman, 2011; Julie Gane / Cousine Island, pers. comm. 2015). The islands with the highest number of successful translocations are Denis (four) and Aride (three), then Cousine, Frégate and Ile du Nord (two), all other islands having benefited from only one species translocation.

Table 5 Main islands free of rats and cats in Seychelles. Islands are listed in order of decreasing size. Small islands of less than 10 ha in *italics*. Islands naturally free of rats and cats are also marked by *. *Note: Conception was found to have been recolonised by rats in late 2017, while writing up this paper.*

Islands free of rats and cats	Area (ha)	Rats eradicated	Cats eradicated
Inner Islands			
Frégate	219	X	X
North Island (<i>Ile du Nord</i>)	201	X	X
Denis	143	X	X
Bird Island (<i>Ile aux Vaches</i>)	101	X	
Grande Sœur	85	X	X
Aride	73		X
Conception	69	X	
Petite Sœur	35	X	
Cousin*	29		
Cousine	26		X
Ile aux Récifs*	20		
Anonyme	10	X	
Mamelles*	9		
Ile aux Vaches Marines*	5		
Ile aux Cocos*	2		
Ile aux Rats	1	X	
Outer Islands			
Grande Ile (Cosmoledo)	143	X	X
D'Arros	140	X	X
St Joseph atoll*	122		
Bancs du Sud (Providence)*	71		
Marie-Louise*	53		
Desnoeufs*	35		
Ile du Sud-Ouest (Cosmoledo)*	30		
Bancs Africains*	31		
Goëlettes (Farquhar)*	25		
Grand Polyte (Cosmoledo)	21	X	X
St Francois (Alphonse)*	17		
Ile du Nord (Cosmoledo)*	11		
Ile du Nord-Est (Cosmoledo)*	9		
Banc de Sable (Farquhar)*	7		
Pagode (Cosmoledo)*	6		
Goëlettes (Cosmoledo)*	5		

Translocations of Aldabra giant tortoises (IUCN Red List category 'Vulnerable') have been accounted for separately as many are ancient and/or poorly documented (dates uncertain; possible failures not accounted for). After the giant tortoises naturally present on most of the granitic islands had been overexploited and driven to extinction (Fauvel, 1909), 18 successful translocations of Aldabra giant tortoises have taken place. Eight granitic islands have been repopulated since 1850, including Frégate, Curieuse and Cousin where they were reintroduced before 1950, Moyenne (probably in the 1970s), and Ile du Nord, Cousine, Grande Sœur and Silhouette that were last repopulated during the period 1993–2012 (Gerlach, et al., 2013). Aldabra giant tortoises have also been introduced or reintroduced to 10 coralline islands (Bird, Denis, D'Arros, Desroches, Rémire, Alphonse, Farquhar, Providence, Assomption, Cosmoledo) during the past 25–50 years, although some of these populations are small and of uncertain long-term viability (Gerlach, et al., 2013). Four of these translocations were to rat and cat free islands (Cousin, Cousine, Frégate and Bird). The reintroduction of giant tortoises to Aride in 1933–34 is not counted, as the animals were removed in 1951 and brought to Cousin (Warman & Todd, 1984); however, some are planned to be reintroduced from Frégate Island in 2018.

Including the reintroductions of giant tortoises, the total number of successful species translocations between islands in Seychelles is 36.

DISCUSSION

With 50 island populations of invasive vertebrates (of 14 species) eradicated from islands, Seychelles stands as a world leader. In 2014, it was ranking third after Australia and the USA for tropical islands, and seventh when all islands are considered (DIISE, 2017; Rocamora, 2015). Despite more eradication attempts during the period 1995–2004, a lower success rate (64%) was recorded compared to the following decade (89%). This may be a result of improving project selection, field implementation, and post-eradication biosecurity measures to prevent reinvasions.

Global conservation impacts of Seychelles island restoration

Population translocations to islands that have benefited from predator eradications and habitat rehabilitation have improved the conservation status of endemic species threatened with global extinction in Seychelles (Henriette, 2011; Nevill, 2011; Russell, et al., 2016). Island restoration has allowed 17 successful reintroductions or conservation introductions of eight rare and threatened species and the down-listing of four globally threatened birds on the IUCN Red List: the Seychelles warbler (*Acrocephalus sechellensis*) from Critically Endangered to Near Threatened; the Seychelles magpie-robin (*Copsychus sechellarum*) and Seychelles white-eye (*Zosterops modestus*) from Critically Endangered to Endangered and Vulnerable respectively; and the Seychelles fody (*Foudia sechellarum*) from Vulnerable to Near Threatened. The Seychelles black paradise flycatcher (*Terpsiphone corvina*), which was transferred to Denis Island, is still considered Critically Endangered. The Aldabra giant tortoise (Vulnerable) has also benefited from 18 successful translocations (Gerlach, et al., 2013).

Ecosystem recovery

The recovery of native fauna and flora on rehabilitated islands where introduced predators and competitors have been eradicated has already been observed on many islands around the world (Mulder, et al., 2011; Veitch, et

al., 2011; Russell & Holmes, 2015). This is also occurring in Seychelles, where monitoring of birds, reptiles, invertebrates and plants has been undertaken and casual observations collected (Rocamora & Henriette, 2015). After the eradication of introduced predators and competitors, some species that had become inconspicuous started to reappear (e.g. giant millipedes *Sechelleptus sechellarum* and endemic snails *Stylodonta unidendata* on Conception; Galman, 2011). Five species of seabirds (*Ardenna pacifica*, *Gygis alba*, *Anous tenuirostris*, *Phaethon lepturus* and *Sula dactylatra*) have (re)established nine new breeding populations on seven rehabilitated islands. Populations that already existed have increased, as observed on most other islands where invasive mammals have been eradicated around the world (Brooke, et al., 2017). Reptiles and land birds have typically shown increasing or stable trends and some (e.g. Seychelles blue pigeon *Alectroenas pulcherrima*, common moorhen *Gallinula chloropus*) have recolonised islands, whereas invertebrates showed mixed responses, including strong decreases for some groups. This is probably linked to the increase in native land birds, reptiles and large invertebrates that had previously been preyed upon by rats and cats (Galman, 2011). As part of a global study to demonstrate the impact of mammal eradications on native wildlife (Jones, et al., 2016), 67 populations of 26 native vertebrates (13 land birds, eight seabirds, five reptiles) were identified as having benefited from these operations in Seychelles (Rocamora & Henriette, 2015). This illustrates how important it is to undertake ecosystem monitoring before and after eradications to measure and understand the ecological changes that occur on islands under rehabilitation.

The reintroduction of giant tortoises, which dominated the terrestrial ecosystems of Seychelles for millions of years, is an essential step in the island restoration process. These animals fill an important (but still poorly known) role in the ecosystem by dispersing and promoting the germination of seeds, fertilising native plants, and influencing soil invertebrate communities through their dung. These mega-herbivores are used as ecological analogues to replace extinct tortoises and help restore island ecosystems in Mauritius and Rodrigues (Griffiths, et al., 2010; Hansen, et al., 2010; Griffiths, 2014). The (re)introduction of Seychelles white-eyes (Rocamora & Henriette-Payet, 2008), which disseminate many native berry-producing trees, also contributes to the restoration process. Future challenges include a more integrated 'ecosystem approach', aiming at rehabilitating entire habitats and communities (including invertebrates), rather than focusing only on 'flagship' threatened species (Asconit & ICS, 2010; Kaiser-Bunbury, et al., 2010; Galman, 2011).

Seabirds play a critical role in ecosystem recovery as they boost soil nutrients thereby assisting the development of the ground microfauna (Mulder, et al., 2011). Seabird recolonisation can be slow, although decoys and sound recordings to attract passing adults can speed this process (Jones & Kress, 2012). In Seychelles, this has only been done for the sooty tern (*Onychoprion fuscatus*) on Denis Island, with little success (Feare, et al., 2015). Seabird translocations may also be tried in future in Seychelles; this technique has been employed successfully in the Pacific (Kappes & Jones, 2014) and is being trialled in Mauritius (Carl Jones & Nik Cole, pers. comm., 2016).

Scaling up eradication projects and increasing the rat and cat free area of Seychelles to create more biodiversity refuges

Since the 1970s, ecosystem restoration has taken place on 25 small and medium sized islands of Seychelles (i.e. < 2,000 ha; see Fig. 2). As a result, island refuges for native biodiversity and particularly for rare species threatened

with extinction have multiplied. This process was started on NGO-owned islands in the 1970s, then followed on government and privately-owned islands, the public trust Seychelles Island Foundation and more recently on government islands managed by the parastatal Island Development Company and associated partners (private hotel/villa owners and the Island Conservation Society).

With about 30 small and medium-sized islands free of rats and cats (see Table 5), Seychelles probably has proportionally more territory (3.9%) free of invasive predatory mammals than most island countries. Rats and cats have been removed from 11 islands larger than 10 ha. Between 1996 and 2011, the number of islands of ≥ 10 ha free of rats has increased from four (Aride, Cousin, Cousine, Ile aux Récifs) to 12, and the total rat-free area of Seychelles has more than tripled from 581 ha to 1,757 ha (Fig. 3).

Nevertheless, there is scope for more eradications to benefit both wildlife and humans. This would require scaling up the size of islands tackled for eradications. Rats

Table 6 Additional islands in Seychelles where rodents and cats could be eradicated and their reinvasion prevented with currently available techniques. X = presence. Moyenne, Longue and Ronde (Ste Anne group) would require a combined operation owing to their mutual proximity.

	Area (ha)	Black rat	House mouse	Feral cat
Inner Islands				
Curieuse	286	X	?	
Félicité	230	X		X
Marianne	100	X		X
Bird (Ile aux Vaches)	101		X	
Aride	73		X	
Ronde (Praslin)	19	X		
Thérèse	74	X		X
Longue	17	X	?	X
Moyenne	9	X		
Ronde (Mahé)	2	X		
Outer Islands				
Assomption	1,171	X		X
Coétivy	931	X		X
Astove	660	X		X
Ile du Sud (Farquhar)	400	X		X
Desroches	394	X		X
Ile du Nord (Farquhar)	300	X		X
Poivre	255	X		X
Alphonse	174	X		X
Providence	157	X		X
D'Arros	140		X	
Platte	54	X		X
Rémire	27	X		X
Manahas (Farquhar)	10	X		X
Marie-Louise	53		X	
Desnoeuufs	35		X	

and cats could be removed from another 22 islands with currently available techniques (Table 6). This includes five more granitic (inner) islands, plus three small islands in the Ste Anne group which would require a permanent grid of rat bait stations owing to their proximity to other infested islands.

The outer islands have greater restoration potential, with 14 islands where rats (and cats) could be eradicated. However, reinvasion may be difficult to prevent through strict biosecurity on three of the larger islands (Coëtivy, Assomption, Desroches) depending on future developments envisaged. The maximum potential area that could be cleared of rats and cats is currently ca. 7,000 ha or 15.4% of the total area of the country (see Fig. 3 for inner and outer islands totals). Clearing rats and cats from these additional 19–22 islands would open huge possibilities for ecosystem rehabilitation and population recovery of many species (land birds, seabirds, reptiles, amphibians, invertebrates and plants). The eradication of rats from Aldabra and Cosmoledo (Menai Island) atolls, which have large extensions of mangroves, is not considered currently feasible. However, this may change if new techniques become available in future, in which case up to half (49.7%) of the country area could be made rat and cat free in the long term.

Eradication operations should now be extended to invertebrates such as invasive ants, moths or snails that also have a high negative impact on native biodiversity.

However, the ability to apply permanent biosecurity protocols will be critical for these islands to retain their pest free status. In the low-lying coralline outer islands, options for translocation of native species may be limited by sea-level rise in future decades.

Developing partnerships associating nature-based tourism to fund ecosystem restoration

Seychelles provides some examples of collaborations between private island owners, parastatals, government agencies and NGOs to achieve successful control or eradication of invasive species and to develop ecosystem rehabilitation programmes (Asconit & ICS, 2010; Government of Seychelles, 2011; Kueffer, et al., 2013). By creating synergies, such partnerships can speed-up the long-term process of ecosystem rehabilitation, and can help meet the financial, technical and ecological challenges of these complex operations (Rocamora, 2010a). Many islands are engaged in tourism activities that can help

conservation funding (Rocamora & Payet 2002; Nevill, 2004; Skerrett, 2010). The successful record of Seychelles in invasive species management and ecological restoration of many small islands is attributable, at least in part, to the fact that these operations can make economic sense for private owners or investors wishing to generate revenue through ecotourism operations. High densities of rats are incompatible with tourism, and eradication and biosecurity procedures are more cost-effective than long-term pest control. The progressive rehabilitation of an island ecosystem to recreate a wildlife sanctuary with its original fauna can be marketed as an attraction (Rocamora, 2010b; Samways, et al., 2010a). The development of partnerships associating sustainable nature-based tourism with funding ecosystem restoration must be strongly encouraged.

Perspectives and challenges in invasive species management and restoration

The creation of island refuges where invasive species management enables the (re)introduction of species that cannot survive in the presence of invasive predators has proven to be extremely effective in improving the conservation status of various species, including endemic birds of Seychelles that had come very close to global extinction. However, several factors limit the further development of this strategy.

Availability of additional islands suitable for restoration and preservation

Although Seychelles still has considerable potential to increase its area free of alien predatory mammals, the number of islands where such operations can be conducted is limited. In the inner islands, there are currently five to eight islands left which could be made, and kept, free of rats and cats. Most of these have actual or planned development projects or do not presently fulfil the required strict biosecurity conditions to prevent reinvasion.

Challenges to eradicate rats from larger islands in a humid, tropical climate

Techniques currently available to eradicate rats are more successful in temperate and sub-Antarctic climates than in tropical environments, particularly humid ones (Russell & Holmes, 2015). Here, rains (that can seriously affect the attractiveness and palatability of rat pellets) and abundant natural food (which reduces the likelihood that rats will eat the bait) can be present for much of the year (Varnham, 2010; Keitt, et al., 2015). Whereas rats (*Rattus rattus* and *R. norvegicus*) have been eradicated from islands of over 10,000 ha outside of the tropics, the largest tropical eradication of black rats to date is Cayo Centro, Chinchorro Bank (539 ha, Mexico) and for brown rats Frégate Island (219 ha, Seychelles) (DIISE, 2017).

Mangroves are also a limiting factor and the main obstacle to a large-scale rat eradication on Aldabra atoll (15,380 ha; c.1,300 ha of mangroves). Although small areas of mangroves can be dealt with by placing bait stations or tying rodenticide blocks to trees (Samaniego-Herrera, et al., 2015; Samaniego-Herrera, et al., 2017), using ‘collars’ or ‘bolas’ (Harper, et al., 2015; Rocamora & Henriette, 2015), efficient methods to eradicate rats from large tropical islands are not yet sufficiently well developed (Russell & Holmes, 2015).

Rat eradications may prove challenging on large islands with high densities of coconut trees, where nuts provide abundant food for rats both in the trees and on the ground, (Climo & Rocamora, 2006). This requires bait to be available at high densities and for a long-time period. Unpredictable rainfall and the year-round high primary productivity of Seychelles ecosystems add further challenges to conducting rat eradications. Abundance of

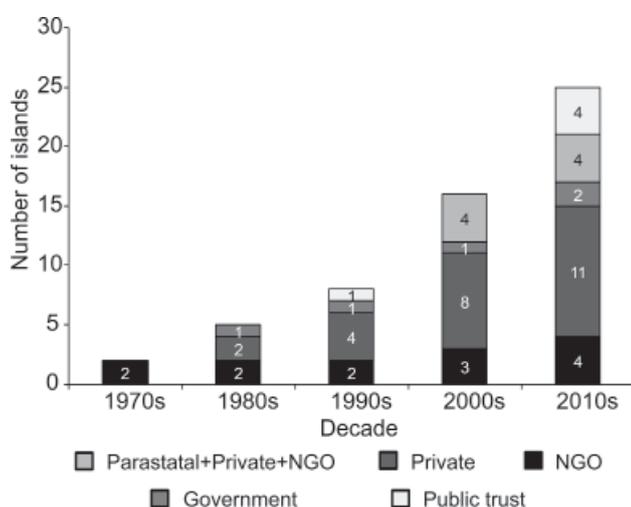


Fig. 3 Cumulated number of small and medium sized islands that have benefited from invasive species management and other forms of ecological restoration in Seychelles since the 1970s, and type of management.

bait-eating crabs can also cause problems (Griffiths, et al., 2011; Wegmann, et al., 2011; Keitt, et al., 2015) but this has not so far been a major problem in Seychelles.

Suitable habitats on restored islands non-existent or too limited for some species

Some rare and threatened species require very specific habitats that may not be found on small to medium sized islands. Examples include the Critically Endangered Seychelles sheath-tailed bat (*Coleura seychellensis*) and the Vulnerable Seychelles swiftlet (*Aerodramus elaphrus*), both of which occur only on the larger granitic islands, breeding in caves and feeding on flying insects. Such limitations also apply to endemic plants and animals (reptiles, amphibians, invertebrates) found exclusively at altitudes above 300–400 m on Mahé and Silhouette where much of the terrestrial diversity of Seychelles is concentrated (Senterre, et al., 2013). Most of these species would probably not survive on the low-lying small islands, where climatic conditions differ from the more

humid and colder high altitudes. Some species may also require large expanses of specific habitats that could not be made available on small islands, such as the Vulnerable Seychelles black parrot (*Coracopsis barklii*), which requires extents of palm-dominated forests (Rocamora & Laboudallon, 2013).

Increased interspecific interactions on small islands with multiple (re)introductions

The number of species that can coexist on a given island is limited by the quality and diversity of habitats available on the island (MacArthur & Wilson, 1967), which is influenced by island area and characteristics. The survival of any small newly (re)introduced population will depend on interactions with the species already there (Blondel, 1979). This factor may partly account for the failed translocation of Seychelles leaf insects to Conception Island, many of which were preyed on shortly after their release (Galman, 2011). On Cousine Island (26 ha), the 23 Seychelles white-eyes translocated in 2008 established a small breeding population, but predation of nests and fledglings and high adult mortality did not allow this population to grow despite considerable efforts. Young fledglings had to be caged and fed through the mesh by adults as they were repeatedly preyed on by another introduced species, the Seychelles magpie-robin (Rocamora, 2013). Such problems were not observed after the introduction of white-eyes to two larger islands, Ile du Nord (201 ha), and Frégate (219 ha) where a large population of Seychelles magpie-robins was present. This suggests a limit to the number of (re) introduced species that a small island can host. In other words, it will become more difficult to ‘squeeze in’ new species into small rehabilitated islands as their ecosystems become increasingly saturated.

The need for alternative conservation approaches on large islands

In Seychelles, the availability of many small islands suitable for rehabilitation, and the presence of private island owners willing to develop ecotourism has favoured the *in situ* approach. In other countries, such as Mauritius or New Zealand, more intensive and costly *ex situ* techniques, which require the additional step of readapting the captive reared animals into the wild, have also been used (Jones & Merton, 2012). In view of the limitations of the ‘small island restoration’ model, ecosystem restoration programmes may be developed on the large islands of Seychelles through the creation of ‘mainland islands’ where invasive species are controlled or excluded to enable native species to thrive, as in New Zealand, Australia and Hawaii (Innes & Saunders, 2011). Predator control and habitat rehabilitation programmes are being developed at large scales in Mauritius and La Réunion for the conservation of threatened land birds (Vikash Tatayah & Marc Salamolard, pers. comm., 2016). Similar operations could be conducted in selected priority sites on the largest granitic islands of Seychelles. Innovative management techniques such as predator-proof fences, self-resetting traps, more effective or target-specific bait, etc. will be key to success. The only Seychelles example to date is permanent rat control using grids of bait-stations at the main breeding areas of the Endangered Seychelles white-eye on Mahé (25–40 ha) since 2006 (Rocamora & Henriette, 2015). More such projects could bring some of the rarest birds of Seychelles, now restricted to remote small island sanctuaries, back to the main islands where they once lived. By providing better access to these species and native wildlife in general, such ‘mainland islands’ would benefit environmental education programmes for the public and school children. This in turn would increase awareness of, and hopefully support for, pest management programmes.

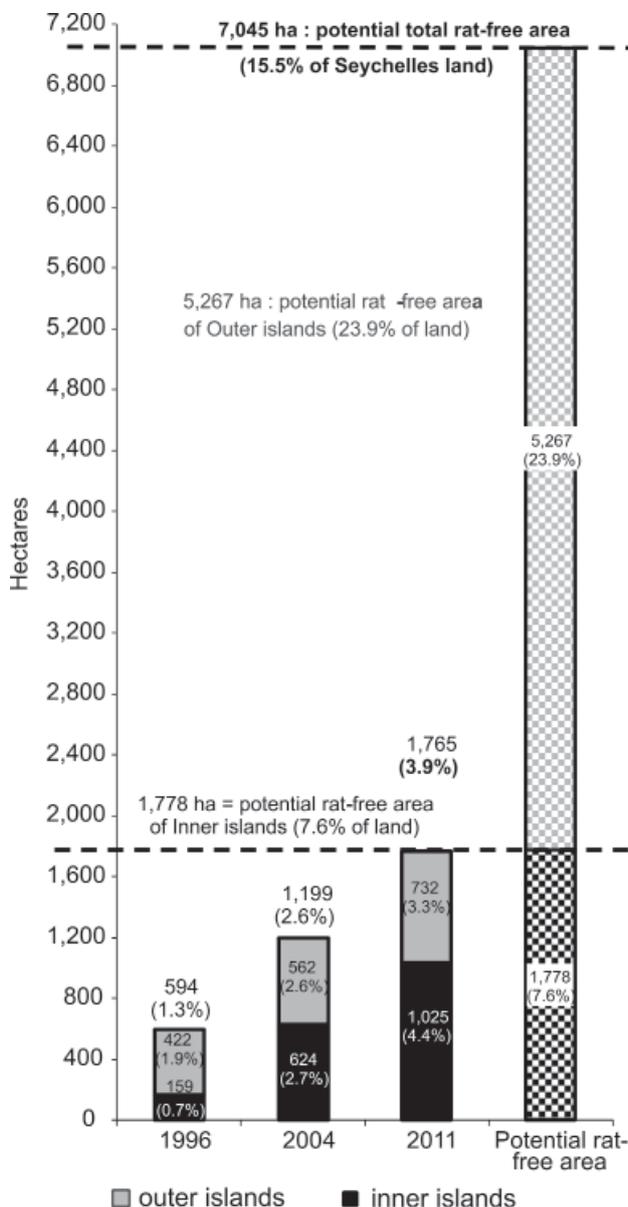


Fig. 4 Time progression of the rat and cat free area in the inner islands, the outer islands and the whole of Seychelles (reported in hectares and as % of the land surface). The total land surface that could potentially be freed of rats and cats with currently available techniques is also indicated.

CONCLUSION

Seychelles' achievements with invasive species management and other island restoration practices are remarkable. This includes a minimum of 50 island eradications of invasive vertebrate populations, the rehabilitation of ca. 470 ha of natural habitats, and at least 36 successful island translocations of native species. The rehabilitation of small and medium sized islands has made possible the down-listing of four globally threatened land birds in the IUCN Red List and the recovery of many other native animals and plants.

Scaling up the size of islands for eradications is now required in Seychelles. Factors limiting rat eradication on larger islands include high densities of coconut trees and the presence of mangroves, especially on Aldabra atoll. Invasive predators such as rat and cats could be eradicated from 19–22 more islands with existing techniques, mainly in the outer (coralline) islands. As a result, the proportion of the country's land area free of rats and cats would increase from 3.9% to 15.4%, but new techniques will be needed to remove rats from Aldabra and bring this proportion to 50%. Making half of Seychelles rat and cat free by 2030–2050 could be a commitment made by Seychelles government and the main stakeholders involved as part of the Honolulu Challenge on Invasive Alien Species, launched at the 2016 IUCN World Conservation Congress in Hawaii.

Eradication operations need to be extended to invertebrates such as invasive ants, moths or snails that also have a high negative impact on native biodiversity. Apart from the availability of islands free of invasive predators, limiting factors to further translocations of rare and threatened species include lack of suitable habitats and increased interspecific interactions on small islands with multiple (re)introductions. Because of global warming and sea-level rise, the long-term relevance of island restoration and species translocations to outer low-lying coralline islands is questioned.

Local partnerships and financial support from nature-based tourism have been key to past successes. We recommend for these to be enhanced and alternative conservation approaches such as 'mainland-islands' be developed on large islands. Most importantly, biosecurity protocols will be critical to prevent (re)invasion of invasive species, as lack of vigilance and poor biosecurity could undo so much of what has already been achieved.

ACKNOWLEDGEMENTS

I wish to thank J.P. Sibley (MNHN), J.Y. Kernel (Biotope), and A. Grieser-Johns (Project Coordinating Unit UNDP-GEF-Government of Seychelles) for authorising the publication of updated figures and modified short text sections initially published in Rocamora & Henriette (2015), the English of which had been reviewed by Jeanne Mortimer (IBC centre of UniSey). Two anonymous referees reviewed the manuscript and provided much appreciated fruitful comments and improvements.

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