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Review paper

Introduced mammals on Western Indian Ocean islands

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HIGHLIGHTS

- The distribution of introduced mammals was reviewed on the 28 Western Indian Ocean island groups.
- All island groups have been invaded by mammals, and invasive cats and rats in particular are ubiquitous.
- Introduced mammal eradications have occurred on 45 islands in the WIO region.
- Predator management has contributed to the recovery of 24 threatened species in the WIO region.
- Greater investment and prioritisation in island conservation in the region is warranted.

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ABSTRACT

The diversity of introduced mammals and their introduction history varies greatly across the Western Indian Ocean (WIO) islands, from ancient introductions in the past millennia on islands off the East coast of Africa where extant terrestrial native mammal communities exist, to very recent invasions in the past decades on islands in the Mascarene archipelago. We compile the distribution of 16 introduced mammal taxa on 28 island groups comprising almost 2000 islands. Through an exhaustive literature review and expert consultation process we recorded all mammal eradications, and species recoveries which could be attributed to introduced mammal eradication or control. All island groups have been invaded by mammals, and invasive cats and rats in particular are ubiquitous, but cultural contingency has also led to regional invasions by other mammals such as lemurs, civets and tenrecs. Mammal eradications have been attempted on 45 islands in the WIO, the majority in the Seychelles and Mauritius, and where successful have resulted in spectacular recovery of species and ecosystems. Invasive mammalian predator eradication or control in association with habitat management has led to improved conservation prospects for at least 24 species, and IUCN red-list down-listing of eight species, in the Mascarene Islands. Future island conservation prioritisation in the region will need to take account of global climate change and predicted sea-level rises and coastal inundation. Greater investment and prioritisation in island conservation in the region is warranted, given its high biodiversity values and the extent of invasions.

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1. Introduction

The islands of the Western Indian Ocean (WIO) span 37 degrees of latitude from Socotra in the north (12°71'N) to Madagascar in the south (25°61'S). These tropical islands vary from massive islands of evolutionary diversification such as Madagascar to isolated coral atolls such as the British Indian Ocean Territory (Chagos Archipelago), and together are identified as one of the world's biodiversity hotspots (Myers et al., 2000). The region includes UNESCO World Heritage Listing for six insular nature sites and three cultural sites. Culturally the region has been the interface of surrounding continental dispersions, from seafaring Arabians and Africans expanding from the west, Indians from the north, Austronesians from the east, and finally Europeans commencing with Portuguese discovery around the early 16th century. The history of human colonisation is long and mirrors that of other island groups in the world such as the Pacific.

The earliest human voyagers transported mammals with them, often species which served as food resources or had some cultural value (Fuller and Boivin, 2009). Some commensal mammal species, particularly rodents, were unintentional introductions. Following colonisation some introduced mammal species might become feral on an island, whereby they establish self-sustaining populations in the wild. These feral mammals can go on to have negative effects on populations of native fauna and flora, other introduced species, or on ecosystem functioning, and subsequently disperse or be transported to surrounding islands in a group (Courchamp et al., 2003). This has particularly been the case on islands where the number of introductions has often been high, and the impacts more pronounced (Jeschke, 2008). The Mascarene archipelago alone has lost at least 74 vertebrate species due to hunting, habitat loss and predation, following the early 16th century first arrival of humans and their commensal mammals (Cheke and Hume, 2008). As well as generating biological impacts through predation, competition, hybridisation, and behavioural modification, introduced mammals are also a vector of diseases (e.g. leptospirosis) that can affect native mammals (bats, endemic rodents, etc.) and human health, and drivers of further human-induced alterations to the environment (Burns et al., 2016). Despite a long history of human presence, islands can remain vulnerable to species invasions, particularly of mammals (Ruffino et al., 2009). These invasions may be historical or contemporary, but in all cases will have had and continue to have impacts on endemic species and ecosystem functioning, which must adapt to a new equilibrium (Courchamp et al., 2003). In response to the spread of feral mammal populations, eradications from islands are now routinely used as conservation tools to allow the restoration of island ecosystems (Keitt et al., 2011).

Regional reviews of mammal invasion in the WIO are available (Fuller and Boivin, 2009), including the Comoros (Louette, 2004), Mozambique Channel (Walsh, 2007), Îles Éparses (Russell and Le Corre, 2009), Seychelles (Nevill, 2009; Beaver and Mougial, 2009; Rocamora and Henriette, 2015) and Mascarenes (Cheke, 1987, 2010; Cheke and Hume, 2008), as well as further reviews of individual island groups (see Table 1). We build upon these published works to present a pan-WIO perspective on island invasion by introduced mammals, and their eradication and subsequent benefits. We hope this work will act as a catalyst for further island surveys and mammal eradications for species conservation in the WIO region.

2. Materials and methods

We delimit the WIO region as the marine area bounded to the north by the Socotra and the Maldives, to the east by the Mascarene archipelago, to the south by Madagascar, and to the west by the Zanzibar archipelago (Fig. 1). We include the 'Spice Islands' (Pemba, Unguju and Mafia) lying off the coast of Tanzania within the region, although their classification as outlying islands is unclear (Walsh, 2007). We do not include other smaller continental islands chains of the East African coast, or Masirah Island off Oman. Our definition of island group is one of geo-political convenience, more or less identical to current regional delimitations. Specifically, we discriminate and define island groups by their geographic isolation from one another, and political administration. Island groups may consist of one or more geological independent archipelagos or atolls, and within each archipelago or atoll may be one or more 'islands', comprising islands, islets, rock stacks or atoll sand bars where permanently present above the high-tide mark, but excluding mangrove and sand bar islands in the deltas of rivers.

We compile the distribution of 16 known introduced mammal taxa on island groups of the WIO. This was undertaken through an exhaustive literature review of both electronic and print resources of published and grey literature, personal

Table 1

Introduced mammals on Western Indian Ocean island groups. * = sovereignty disputed, m = number of archipelagos or atolls, n = number of islands, Native = native mammals, Rn = *Rattus norvegicus*, Rr = *Rattus rattus*, Mm = *Mus musculus*, 1 = present, 0 = absent, ? = status uncertain, D = died out, E = eradicated, N = native. In naming islands we follow the dominant linguistic nomenclature of the island group, e.g. 'Nosy' for islands and islets of Madagascar, 'Chissioua' for Comoros, 'îles and îlots' for islands in historically French dominated archipelagos, and 'islands' and 'islets' for English dominated archipelagos. For Seychelles, we use the official names as they are listed in the country's Constitution, together with the modern names of two island tourist resorts.

Full	Group	Admin	Area (km)	m	n	People	Popn	Native	Cat	Rn	Rr	Mm	Coat	Pig	Deer	Hare	Rabbit	Dog	Mongoose	Civet	Lemur	Monkey	Shrew	Tenrec	Total
1	Lakshadweep	Ind	32.7	3	36	Inhabited	64,429	0	1	0	1	1?	0	0	0	0	0	0	D	0	0	0	1	0	3
0	Maldives	Mal	298.0	26	1192	Inhabited	338,442	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	5
1	Chagos	BIOT*	49.6	1	58	Military	300	0	1	0	1	0	0	0	0	0	0	E	0	0	0	1	0	0	3
		(Mau)																							
0	Socotra	Yem*?	3796.0	1	6	Inhabited	55,000	0	1	0	1	1	1	0	0	0	0	0	0	1	0	0	1	0	6
		(Som)																							
0	Pemba	Zan	988.0	1	28	Inhabited	406,808	1	1	0	1	1	0?	1	0	0	0	1	0	1	0	N	1	0	7
0	Unguja	Zan	1554.0	1	31	Inhabited	896,721	1	1	1	1	1	0?	1	0	0	0	1	1	1	0	N	1	0	9
0	Mafia	Tz	435.0	1	15	Inhabited	46,000	1	1	0	1	0	0?	1	0	0	0	1	1	0	0	N	0	0	5
1	Latham	Zan*	<1	1	1	Uninhabited	0	0	0	1?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		(Tz)																							
	"Fungu Kizimkazi"																								
1	Grand Comore	UdC	1148.0	1	2	Inhabited	350,000	0	1	0	1	1	D	D	0	0	0	1	1	1	0	1	D	1	8
	"Ngazidja"																								
1	Anjouan	UdC	424.4	1	2	Inhabited	300,000	0	1	0	1	1	D	0	D	0	0	1	0	1	1	0	D	1	7
	"Ndzuan"																								
0	Moheli	UdC	211.0	1	19	Inhabited	40,000	0	1	0	1	1	D	0	0	0	0	1	0	1	1	0	0	1	7
	"Mwali"																								
1	Mayotte	Fr*	374.1	1	29	Inhabited	185,000	0	1	0	1	1	0	D	0	0	0	1	0	1	1	0	D	1	7
	"Maoré"	(UdC)																							
0	Madagascar	Mad	587 040.0	1	286	Inhabited	22,290,000	1	1	1	1	1	0	0	D	0	0	1	0	1	N	0	1	N	7
1	Glorieuse	TAAF*	4.7	1	2	Military	15	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	3
		(Mad/UdC)																							
1	Juan de Nova	TAAF*	5.6	1	1	Military	15	0	1	0	1	1	0	0	0	0	0	D	0	0	0	0	0	0	3
1	Europa	TAAF*	22.2	1	2	Military	15	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2
		(Mad)																							

(continued on next page)

Table 1 (continued)

Full	Group	Admin	Area (km)	m	n	People	Popn	Native	Cat	Rn	Rt	Mm	Goat	Pig	Deer	Hare	Rabbit	Dog	Mongoose	Civet	Lemur	Monkey	Shrew	Tenrec	Total
1	Tromelin	TAAF* (Mau)	1.0	1	1	1 Meteo	4	0	0	E	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
1	La Réunion	Fr	2510.0	1	2	Inhabited	839,500	0	1	1	1	1	1	D	1	1	D	1	0	0	D	0	1	1	10
1	Mauritius	Mau	1875.3	1	50	Inhabited	1,291,000	0	1	1	1	1	0	1	1	1	E	0	1	0	0	1	1	1	11
1	Rodrigues	Mau	110.7	1	17	Inhabited	37,922	0	1	1	1	1	D	D	1	0	D	1	0	0	0	0	1	0	7
1	Agalega	Mau	25.7	1	2	Inhabited	289	0	1	1	1	1	0	0	0	1	0	1	0	0	0	0	1	0	7
1	Cargados	Mau	4.5	1	34	Inhabited	63	0	E	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	3
1	Carajós	Sey	234.0	5	44	Inhabited	91,000	0	1	1	1	1	E	D	D	1	1	0	0	0	0	0	0	1	7
1	Granic	Sey	10.0	2	2	Inhabited	100	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1	Southern	Sey	11.2	3	29	Inhabited	150	0	1	E	1	1	0	0	0	0	1	0	0	0	0	0	0	0	4
1	Amirantes group	Sey	2.1	2	3	Inhabited	82	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1	Alphonse group	Sey	176.0	4	67	Ranger	40	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	5
1	Aldabra group	SIF & IDC	12.0	3	13	Inhabited	21	0	1	0	1	0	D	0	0	0	0	0	0	0	0	0	0	0	2
1	Farquhar group	Sey	601 355.8	68	1974		27 232 916	4	24	8	26	18	4	5	3	4	4	11	4	8	3	3	11	7	5.11
	Western Indian Ocean																								
							Percentage	14%	86%	29%	93%	64%	14%	18%	11%	14%	14%	39%	14%	29%	11%	11%	39%	25%	

Sources: Moreau and Pakenham, 1941; Gwynne et al., 1970; Stoddart, 1970, 1983, 1984; Pakenham, 1984; Cheke, 1987, 2010; Sinha, 1994; Zuhair, 1997; Barnett and Emms, 1998; Louette, 1999, 2004; Parr et al., 2000; Hill, 2002; Wranik, 2003; Gerlach, 2007; Walsb, 2007; Kock and Stanley, 2009; Russell and Le Corre, 2009; Van Damme and Banfield, 2011; Rocamora and Henriette, 2015.

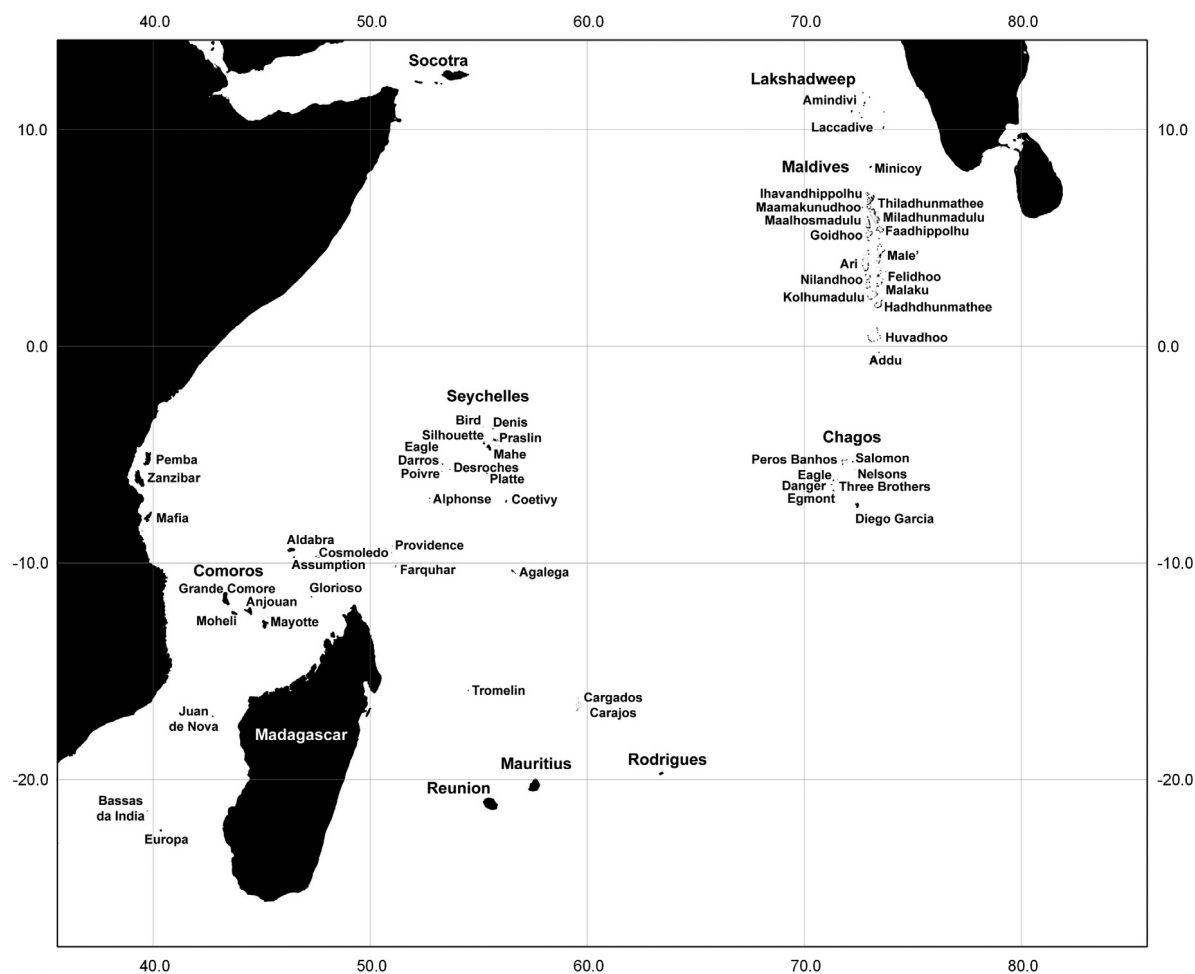


Fig. 1. Western Indian Ocean and islands.

observation and knowledge of the co-authors, and consultation with regional experts (see Acknowledgements). Only feral populations of animals are recorded, and so instances of domesticated pigs, goat and rabbits, for example, are not included here if they were deemed not to have become naturalised. We do not consider introduced cattle and sheep. Some taxa are only classified to Genus given where multiple species may have been introduced, or taxonomy remains uncertain (Mongoose: *Herpestes* spp. [*auro-punctatus*, *javanicus* or *ichneumon*]; Lemur: *Eulemur* spp. [*fulvus* or *mongoz*]; Shrew: *Suncus* spp. [*murinus* or *etruscus*]; and Deer: *Cervus* spp. [*timorensis* or *nippon*]). We do not include introductions of bush pigs (*Potamochoerus larvatus*) [Spice Islands and Madagascar], banded mongoose (*Mungos mungo*) [Unguja] or black and white ruffed lemur (*Varecia variegata*) [La Réunion] as they number too few. We note that being politically part of India the oceanic Lakshadweep islands are technically in the native range of black rats (*R. rattus*), but rat introduction to this group was by humans, and so they must be considered non-native. We consider *Rattus tanezumi* as a synonym for *R. rattus* (Aplin et al., 2011). We also list the governing body for each archipelago, and where relevant any international disputes and claims over sovereignty, as these can play a role in conservation management. We also compile the terrestrial land areas and most recent human population estimates for each island group, as well as the presence of any other native non-volant mammal species (i.e. we exclude bats). Where island group surveys are comprehensive, we also present island lists of mammal distribution and island habitation. For these archipelagos we estimate the total island area in each archipelago invaded by each species as the sum of island areas for invaded islands divided by the sum of all island areas in the archipelago, excluding principal islands which would otherwise dominate the calculation. This provides a powerful metric for measuring progress in island conservation through mammal eradication (e.g. Russell et al., 2015).

We also list and compile information about all intentional island-wide mammal eradications (i.e. excluding incursions or localised 'eradications') from islands of the WIO, where achieved through an orchestrated campaign intending complete eradication, usually for conservation purposes. This list includes the island and its area, the target species, operational start and finish (not confirmation) dates, eradication outcome, and our sources. In the few cases where conflicting records are found we favour the record which we believe has most credibility based on our regional experience and judgement. We

do not include instances of introduced mammals populations dying out, even if after control, which are covered in detail elsewhere (Cheke, 1987; Louette, 2004; Cheke and Hume, 2008; Cheke, 2010). Finally we list species which have benefited directly from invasive mammal eradication or control leading to improved conservation status and consider prospects for future island conservation with regards to introduced mammal management in the region.

3. Results

We distinguished 28 island groups in the WIO, comprising 68 archipelagos and atolls, with a total land area of just over 600,000 km² and populated by over 27 million people. Nearly all island groups are either inhabited or have a military presence (Îles Éparses and Chagos), except uninhabited Latham Island, Tromelin Island inhabited by météo service staff, uninhabited Cosmoledo atoll, and Aldabra atoll inhabited by rangers. We count approximately 1974 islands within these groups. Uncertainty is associated with the number of offshore islands around Madagascar, which were estimated from Soviet Union maps, and the changing number of islands in some groups (e.g. Cargados Carajos) due to changing geomorphology of sand bars in particular. Some uncertainty will always remain in counting the number of islands in each archipelago, and for some island groups a consensus already exists on the number of islands in the group which we observed. In the Seychelles, for example, 155 islands are listed in the Constitution, but a number of islets in remote atolls like Cosmoledo or Aldabra have no name.

3.1. Introduced mammal distributions

Introduced mammals are present on every island group in the WIO (Table 1). Only four island groups have native terrestrial non-volant mammal communities; the Spice Islands (Pemba, Unguja and Mafia) and Madagascar. We catalogued a mean number of five (SD 2.8, range 0–11) introduced mammals per island group. On some island groups some mammal species have naturally died out, particularly large mammals which were a food resource, or have been entirely eradicated for biodiversity conservation, such as cats and rats (see Introduced mammal eradications).

Introduced cats (86% of groups), black rats (93% of groups) and mice (at least 64% of groups) are ubiquitous on island groups of the WIO. Mice may be under-reported on some islands groups where they are presumed absent due to masking by invasive rats (Caut et al., 2007), and so records of mouse absence should be treated cautiously. In contrast, brown rats are present on fewer island groups in the region (25% of groups). The large herbivores (goats, pigs and deer) are patchily distributed across island groups of the region, their distribution generally reflecting the cultural history of islands (e.g. Islamic dislike for pigs) and geographic proximity (e.g. deer throughout the Mascarenes). Lagomorph introductions (rabbits and hares) have been limited to the Seychelles and Mascarene (Mauritius and its dependencies, and La Réunion) island groups. Peculiar introductions include lemurs to Comoros islands, monkeys to Mauritius, mongoose to Mauritius and Spice Islands, civets to Comoros and Spice Islands, tenrecs to Comoros and Mascarene islands, and shrews to various islands. Lemurs were introduced as pets and food, monkeys as pets which subsequently became unwanted, mongoose in the hope of rat control, civets for perfume, tenrecs for food, and shrews as human commensals.

Introduced mammal distributions by island are available for 75% ($n = 21$) of island groups, but these include only 20% ($n = 397$) of islands. These included the well-documented islands of the Mascarene archipelago (La Réunion, Mauritius and Rodrigues), the Seychelles islands, the Comoros archipelago (excluding Mohéli) and the Îles Éparses (Table 1). Such data were not available for Maldives, Madagascar and Spice Islands, and obtaining them must be considered a pre-requisite to establishing island conservation priorities. Within island groups, mammals tend to be distributed on the largest islands, in correlation with human inhabitation and as the body-size of the species dictate minimum population carrying capacity (Russell et al., 2004). Rodents have often dispersed by swimming to small islands lying just off the coast of principal islands where they arrived by human vector (Russell et al., 2008). On average most (87%) of the offshore island area (i.e. excluding the dominating principal islands for groups such as the Comoros and Mascarene archipelagos) are currently occupied by introduced mammals, although notable low anomalies exist such as Mauritius (62%), Cargados Carajos (62%) and Lakshadweep (75%), although the latter two probably reflect a lack of records. Within the Seychelles certain atolls are also notable for their absence of introduced mammals such as St Joseph. Although mammals may remain absent from some islands within a group, these tend to be only small and isolated islands. Nonetheless these small historically or by eradication mammal-free islands are the arks for conservation of all types of species (seabirds, landbirds, reptiles and plants) in the WIO region (Parr et al., 2000; Bell, 2002; Jones, 2008; Rocamora and Henriette, 2015).

The tiny and isolated Latham Island (Fungu Kizimkazi) off the coast of Tanzania is noteworthy as having only had a single mammal (rat) species recorded, which has not been detected following the Indian Ocean tsunami of 2004 (Crawford et al., 2006). Although the species of rat on Latham Island was described as 'brown rat', the common name for *R. norvegicus*, it is possible this may be the brown colour morph of *R. rattus*, where this confusion has been made elsewhere in the WIO (for example on Glorieuse Island; Russell and Le Corre, 2009). The presence and identity of this species of rat on Latham Island should be confirmed. The Cargados Carajos group of Mauritius has had only occasional species surveys (e.g. 1996, 1997 and 2010), but the most recent of these suggest that the status of introduced mammals is in a state of flux, with some populations possibly dying out or having been eradicated (particularly cats), while other new invasions continue to occur (particularly rats) (N. Cole. pers. obs). The Maldives contain over 60% of the islands in the WIO region, but very little data are available on

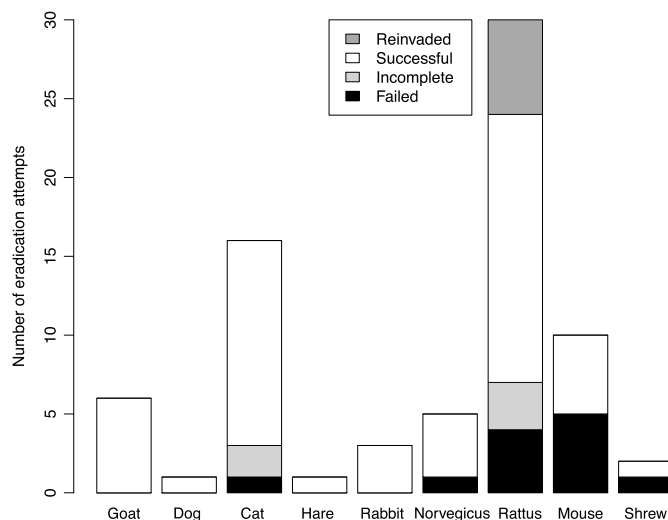


Fig. 2. Eradication attempts of introduced mammals on Western Indian Ocean islands by species.

the distribution of introduced mammals within the archipelago, although it appears rats are widely distributed within the island group (Dolbeer et al., 1988), and could easily naturally disperse the small distances among islands within atolls.

3.2. Introduced mammal eradications

We documented 74 eradication attempts of introduced mammals from 45 islands in the WIO region (Fig. 2, Table 2). Almost all of these are from islands of the Seychelles (19), Mauritius and its dependencies (12), or the Îles Éparses (4) administered by the Terres Australes et Antarctiques Françaises (TAAF) since February 2007. The earliest eradication was nearly a century earlier of goats from Aride Island in the Seychelles in 1920, but three quarters have been since 2000. A complete summary of mammal eradications in the Seychelles is also provided by Rocamora and Henriette (2015). Eradications have been attempted of nine introduced mammal species, including large herbivores (goats) for five islands up to 11,115 ha, lagomorphs (hares, rabbits) for four islands up to 219 ha and small predators (cats, rats and mice) for 61 islands up to 286 ha. Other notable eradications of more unusual species have included shrews from tiny Ile de la Passe (Varnham et al., 2002). The success rate of mammal eradications has been 100% except for rodent and shrew eradications (84% for rats from 32 completed operations, 50% for mice from 10 completed operations and 50% for shrews from 2 completed operations) and one poorly managed and documented cat eradication which apparently failed (Frégate Island in Rodrigues). Reinvasion by rats occurred following eradication on six islands. For some ongoing eradications of cats, successful completion depends on an absolute commitment by the island administrative body and on the protocols in place. Three eradications of rats had been operationally completed but not confirmed at the time of writing. Twelve other eradications of cats and rodents in 1995 from small islands in the Rodrigues were not able to be verified, and were possibly localised control operations, and so were not included in our table.

3.3. Native species recoveries

Invasive mammalian predator eradication or control and associated habitat restoration (e.g. alien plant removal) have benefited 17 bird and 7 reptile species from WIO islands (Table 3). This has contributed to preventing the complete extinction of 14 of these species, and local extirpations of many more species (not detailed). This has ultimately led to the down-listing of eight species from the WIO region in the IUCN Red data list.

4. Discussion

Although some terrestrial mammals are undoubtedly native on some WIO island groups (e.g. Socotra; Van Damme and Banfield, 2011), on others their presence is probably an undiagnosed introduction from very early historical human colonisation (e.g. Spice Islands; Walsh, 2007). Mammals have been widely introduced by humans to all the island groups of the WIO since at least the second half of the first millennium AD (Walsh, 2007). New introductions continue, both unintentionally (e.g. shrews arrived in Rodrigues in 1998) and intentionally (e.g. rabbits intercepted at Socotra island airport in 2006). Evidence of the impacts of some of these invasive mammals is clear, including catastrophic losses of landbirds (Gaymer et al., 1969), seabird colonies (Russell and Le Corre, 2009), and reptiles (Arnold, 1980) from predators and competitors (dogs, cats, mice, mongoose, rats, shrews), coupled with alteration of forest communities by herbivores (deer,

Table 2

Introduced mammal eradication attempts on Western Indian Ocean islands. ® = reinvaded.

Country	Island	Area (ha)	Species	Start	Completed	Success	Reference
Unguja	Chumbe	16	Rr	1997	1997	Y	Riedmiller (1998)
TAAF	Europa islet	3	Rr	2008	2008	Y®	Russell and Le Corre (2009)
TAAF	Ile du Lys	12	Rr	2003	2003	Y	Russell and Le Corre (2009)
TAAF	Juan de Nova	561	Cat	2006	ongoing	NA	Russell and Le Corre (2009)
TAAF	Tromelin	97	Rn	2005	2005	Y	Russell and Le Corre (2009)
TAAF	Tromelin	97	Mm	2005	2005	N	Russell and Le Corre (2009)
Seychelles	Aldabra: Grand Terre	11 114.9	Goat	1993	2012	Y	Bunbury et al. (2013)
Seychelles	Aldabra: Malabar	2585.0	Goat	1993	1994	Y	Bunbury et al. (2013)
Seychelles	Aldabra: Picard	938.5	Goat	1993	1994	Y	Bunbury et al. (2013)
Seychelles	Anonyme	9.6	Rr	2003	2003	Y®	Rocamora and Jean-Louis (2009)
Seychelles	Anonyme	9.6	Rr	2006	2006	Y	Rocamora and Jean-Louis (2009)
Seychelles	Aride	68	Goat	unknown	1920	Y	Warman and Todd (1984)
Seychelles	Aride	68	Cat	1925	1932	Y	Warman and Todd (1984)
Seychelles	Conception	69	Rn	2007	2007	Y	Rocamora and Jean-Louis (2009)
Seychelles	Cosmoledo: Grand Île	143	Rr	2007	2007	Y	Rocamora and Henriette (2015)
Seychelles	Cosmoledo: Grand Polyte	21	Cat	2007	2007	Y	Rocamora and Henriette (2015)
Seychelles	Cosmolédo: Grand Polyte	21	Rr	2007	2007	Y	Rocamora and Henriette (2015)
Seychelles	Cosmolédo: Petit Polyte	1	Rr	2007	2007	Y	Rocamora and Henriette (2015)
Seychelles	Cousine	25	Cat	1983	1985	Y	Beaver and Mougai (2009)
Seychelles	Curieuse	286	Mm	1996	1996	N	Merton et al. (2002)
Seychelles	Curieuse	286	Cat	2000	2001	Y	Merton et al. (2002)
Seychelles	Curieuse	286	Rr	2000	2000	N	Merton et al. (2002)
Seychelles	D'Arros	150	Cat	2003	2003	Y	Kappes et al. (2013)
Seychelles	D'Arros	150	Rr	2003	2003	Y	Kappes et al. (2013)
Seychelles	D'Arros	150	Mm	2003	2003	N	Beaver and Mougai (2009)
Seychelles	Frégate	219	Cat	1981	1982	Y	Watson et al. (1992)
Seychelles	Frégate	219	Rn	1995	1996	N	Thorsen et al. (2000)
Seychelles	Frégate	219	Mm	2000	2000	Y	Merton et al. (2002)
Seychelles	Frégate	219	Rn	2000	2000	Y	Merton et al. (2002)
Seychelles	Grand Sœur	84	Cat	2010	2010	Y	Rocamora and Henriette (2015)
Seychelles	Grand Sœur	84	Rr	2010	2010	Y	Rocamora and Henriette (2015)
Seychelles	Ile aux Rats	0.8	Rr	2006	2006	Y	Rocamora and Henriette (2015)
Seychelles	Ile aux Vaches (Bird)	101	Rr	1996	1996	Y	Merton et al. (2002)
Seychelles	Ile aux Vaches (Bird)	101	Rabbit	1996	1996	Y	Merton et al. (2002)
Seychelles	Ile aux Vaches (Bird)	101	Mm	1996	1996	N	Merton et al. (2002)
Seychelles	Ile Denis	143	Cat	2000	2001	Y	Merton et al. (2002)
Seychelles	Ile Denis	143	Rr	2000	2000	N	Merton et al. (2002)
Seychelles	Ile Denis	143	Mm	2000	2000	N	Merton et al. (2002)
Seychelles	Ile Denis	143	Rr	2002	2002	Y	Beaver and Mougai (2009)
Seychelles	Ile Denis	143	Mm	2002	2002	Y	Beaver and Mougai (2009)
Seychelles	Ile du Nord	201	Cat	2003	2003	Y	Climo (2004)
Seychelles	Ile du Nord	201	Rr	2003	2003	N	Climo (2004)
Seychelles	Ile du Nord	201	Rr	2005	2005	Y	Beaver and Mougai (2009)
Seychelles	Petite Sœur	34	Rr	2010	2010	Y	Rocamora and Henriette (2015)
Rodrigues	Ile aux Sables	9	Mm	1995	1995	Y	Bell (2002)

(continued on next page)

pigs, goats, hares and rabbits). For some introduced mammal species impacts are less (e.g. lemurs and civets) or not properly documented (e.g. monkeys and tenrecs). On some islands the impact of introduced mammals as drivers of biodiversity loss is overlooked or underestimated (e.g. Pande et al., 2007). However, on islands with native mammal communities (Spice Islands and Madagascar) the impact of invasive mammals is dampened through interactions which restrict the abundance and distribution of introduced mammals, and predispose the endemic fauna and flora to mammalian predator defences (Moors et al., 1992). Once an island group is invaded, including the principal island(s) and any number of offshore islands, the percentage of land area invaded becomes rapidly high, and similar to other invaded island groups in the world (Hilton and Cuthbert, 2010).

Novel eradication technologies (Roy et al., 2002; Campbell et al., 2015) are required to target some species such as mongoose (globally only eradicated from islands ≤ 115 ha; Barun et al., 2011) and shrews (≤ 2.5 ha; Varnham et al., 2002) on larger islands, but the rate of applying standard eradication methodologies (shooting, trapping and aerial baiting) to widespread species such as herbivores and predators should also be increased. This will require refinement of existing eradication methods (Keitt et al., 2015) coupled with biological studies (e.g. Ringler et al., 2014 and Harper et al., 2015) to overcome challenges associated with eradication campaigns in the tropics (Holmes et al., 2015; Rocamora and Henriette, 2015). Indirect impacts from eradication programmes should always be considered, but the direct impacts of these introduced mammal species on flora and fauna are most severe and should take precedence (Russell and Le Corre, 2009; Ringler et al., 2015). In all cases following mammal eradication diligence to biosecurity and preventing reinvasion has been required to maintain the conservation benefits accrued. A rat incursion to Ile aux Aigrettes was successfully intercepted due

Table 2 (continued)

Country	Island	Area (ha)	Species	Start	Completed	Success	Reference
Rodrigues	Ile Cocos	21	Mm	1995	1995	Y	Bell (2002)
Rodrigues	Ile Frégate	12	Cat	1999	1999	N	Cheke and Hume (2008)
Mayotte	Chissioua Kola Issa	3.5	Rr	2005	2005	Y [®]	Rocamora and Said (2005); Rocamora et al. (2009)
Mayotte	Chissioua Pengoua	3	Rr	2005	2005	Y [®]	Rocamora and Said (2005); Rocamora et al. (2009)
Mayotte	Chissioua Pouhou	0.63	Rr	2005	2005	Y [®]	Rocamora and Said (2005); Rocamora et al. (2009)
Mayotte	GombeNdroumbe	0.67	Rr	2009	2009	Y	Rocamora et al. (2009); Rocamora et al. (2012)
Mauritius	Flat Island	253	Cat	1998	1998	Y	Bell (2002)
Mauritius	Flat Island	253	Rr	1998	1998	Y	Bell (2002)
Mauritius	Flat Island	253	Mm	1998	1998	Y	Bell (2002)
Mauritius	Gabriel Island	42	Rr	1995	1995	Y	Bell (2002)
Mauritius	Gunners Quoin	70	Rn	1995	1995	Y	Bell (2002)
Mauritius	Gunners Quoin	70	Hare	1995	1995	Y	Bell (2002)
Mauritius	Gunners Quoin	70	Rabbit	1998	1998	Y	Bell (2002)
Mauritius	Ile aux Aigrettes	26	Goat	1987	1987	Y	Jones and Hartley (1995)
Mauritius	Ile aux Aigrettes	26	Cat	1987	1987	Y	Jones and Hartley (1995)
Mauritius	Ile aux Aigrettes	26	Rr	1987	1991	Y	Jones and Hartley (1995)
Mauritius	Ile aux Aigrettes	26	Shrew	1999	2000	N	Seymour et al. (2005)
Mauritius	Ile aux Singes	0.3	Rr	2008	2008	Y [®]	Cole et al. (2009)
Mauritius	Île de la Passe	2	Shrew	2000	2000	Y	Varnham et al. (2002)
Mauritius	Round Island	219	Goat	1976	1979	Y	Bullock et al. (2002)
Mauritius	Round Island	219	Rabbit	1986	1986	Y	Bullock et al. (2002)
Cargados Carajos	Albatross Island	67	Cat	NA	NA	Y	N. Cole pers. comm.
Cargados Carajos	Coco Island	95	Cat	NA	NA	Y	N. Cole pers. comm.
BIOT	Diego Garcia	3015	Dog	1971	1975	Y	
BIOT	Diego Garcia	3015	Cat	1999	ongoing	NA	Hilton and Cuthbert (2010)
BIOT	Eagle Island	236	Rr	2006	2006	N	Hilton and Cuthbert (2010)
BIOT	Ile du Sel	2.2	Rr	2014	2014	NA	G. Harper pers. comm.
BIOT	Ile Jacobin	2.1	Rr	2014	2014	NA	G. Harper pers. comm.
BIOT	Ile Vache Marine	10.4	Rr	2014	2014	NA	G. Harper pers. comm.

to robust biosecurity surveillance and response protocols. Nonetheless, increased investment in biosecurity procedures and incursion responses is needed (Russell et al., 2008), particularly given evidence that some failed eradication campaigns were likely due to lapsed biosecurity (Merton et al., 2002). In some island groups, particularly for groups without large offshore islands (e.g. Grand Comore and La Réunion), mammal eradications will not be possible and alternative conservation tools must be considered, such as 'mainland island' landscape pest control such as on La Réunion (Ghestemme and Salamolard, 2007), or habitat management such as on Mauritius (Carter and Bright, 2002), as undertaken in New Zealand (Russell et al., 2015). On all island groups emphasis and legal mechanisms must also be in place for effective border control and biosecurity protocols to prevent further invasive species introductions and reduce the risks of established invasive species spreading to offshore islands.

Mammals are not the only introduced species present on islands in the WIO region. A number of introduced bird species are considered invasive or are at least requiring management. Eradications have occurred of crows (Socotra, Suliman et al. (2011); Seychelles, Rocamora and Henriette (2015)), Indian mynas (Seychelles, Canning (2011), Rocamora and Henriette (2015)), barn owls (Seychelles, Rocamora and Henriette (2015)) and red-whiskered bulbul (Seychelles, Rocamora and Henriette (2015)). A number of alien reptile species are also widespread with ongoing introductions (e.g. a snake detected on Diego Garcia in 2002; toads established in Madagascar in 2014, Kolby, 2014) likely to have impacts, including geckos, toads and snakes (Cole et al., 2005, Cole and Harris, 2011, Buckland et al., 2014). Plant invasions are pervasive (Kueffer et al., 2004). Island conservation in the WIO must consider the concurrent and emerging threats from these taxa at the same time as introduced mammal management.

Eradications of introduced mammals from islands in the Seychelles have led to rapid recoveries of insular ecosystems and allowed conservation of globally threatened bird species that cannot co-exist with introduced predators (Butchart et al., 2006; Rocamora and Henriette, 2015; Jones et al., in press). Similar results have been achieved in Mauritius with predator eradication and control (Bell, 2002; Jones, 2008), although often requiring supplementation with captive rearing and post-release management. Habitat management through vegetation rehabilitation (invasive plant removal and native species replanting) has been widely used in both countries (Carter and Bright, 2002; Rocamora and Henriette, 2015). Promising results are also emerging from early work in the Îles Éparses (Le Corre et al., 2015). Further island conservation actions will reverse the decline of many other species and open islands for the translocation and reintroduction of threatened species. Isolated uninhabited groups such as the Îles Éparses and British Indian Ocean Territory (Chagos), and other island groups where complete eradication of some species is possible, such as Cargados Carajos, Agalega and the Outer Seychelles, should all be prioritised for introduced mammal eradication, due to the substantial gains which can be relatively easily obtained.

Table 3

Averted extinctions, introductions and re-colonisations of species associated with invasive mammalian predator eradication or control on Western Indian Ocean islands (Seychelles, Mauritius, La Réunion and Îles Éparses).

IUCN	Common name	Species	Country	Island(s)	Improvements	Outcome	Reference
CR	Seychelles black paradise flycatcher	<i>Terpsiphone corvina</i>	Seychelles	Ile Denis	rat & cat eradication	Conservation introduction	Rocamora and Henriette (2015)
EN ^a	Seychelles magpie robin	<i>Copsychus sechellarum</i>	Seychelles	Ile Denis, Frégate, Aride	rat & cat eradication	Averted extinction, conservation introduction	Rocamora and Henriette (2015)
EN ^a	Seychelles white-eye	<i>Zosterops modestus</i>	Seychelles	Frégate, Ile du Nord, Conception, Mahé	rat & cat eradication; control	Conservation introductions	Rocamora and Henriette (2015)
VU ^a	Seychelles warbler	<i>Acrocephalus sechellensis</i>	Seychelles	Ile Denis, Frégate, Aride	rat & cat eradication	Conservation introductions	Rocamora and Henriette (2015)
NT ^a	Seychelles fody	<i>Foudia sechellarum</i>	Seychelles	Ile Denis	rat & cat eradication	Conservation introduction	Rocamora and Henriette (2015)
LC	Wedge-tailed shearwater	<i>Ardenna pacifica</i>	Seychelles	Ile Denis, Ile du Nord, Conception, Petite Sœur, D'Arros, Round Island, Ste Anne	rat eradication; control	(re)colonisations	Rocamora and Henriette (2015)
LC	White-tailed tropicbird	<i>Phaethon lepturus</i>	Seychelles	Ile du Nord	rat eradication	(re)colonisation	Rocamora and Henriette (2015)
LC	Lesser noddy	<i>Anous tenuirostris</i>	Seychelles	D'Arros	rat eradication + habitat restoration	(re)colonisation	Rocamora and Henriette (2015)
LC	White tern	<i>Gygis alba</i>	Seychelles	Grande Ile, Grand Polyte (Cosmoledo)	rat eradication	(re)colonisation	Rocamora and Henriette (2015)
LC	Masked booby	<i>Sula dactylatra</i>	Seychelles	Grande Ile (Cosmoledo)	rat eradication	(re)colonisation	Rocamora and Henriette (2015)
CR	Mauritius olive white-eye	<i>Zosterops chloronothos</i>	Mauritius	Mauritius, Ile aux Aigrettes	rat, cat & mongoose control; goat, cat & rat eradication	Averted extinction, conservation introduction	Cheke and Hume (2008)
EN	Round Island keel-scaled boa	<i>Casarea dussumieri</i>	Mauritius	Round Island, Gunner's quoin	goat & rabbit eradication, rat, hare & rabbit eradication	Averted extinction, conservation introduction	Bullock et al. (2002)
EN ^a	Echo parakeet	<i>Psittacula echo</i>	Mauritius	Mauritius	rat, cat & mongoose control	Averted extinction	Cheke and Hume (2008)
EN ^a	Mauritius fody	<i>Foudia rubra</i>	Mauritius	Mauritius, Ile aux Aigrettes	rat, cat & mongoose control; goat, cat & rat eradication	Averted extinction, conservation introduction	Cheke and Hume (2008)
EN ^a	Mauritius kestrel	<i>Falco punctatus</i>	Mauritius	Mauritius	rat, cat & mongoose control	Averted extinction	Cheke and Hume (2008)
EN ^a	Pink pigeon	<i>Nesoenas mayeri</i>	Mauritius	Mauritius, Ile aux Aigrettes	rat, cat & mongoose control; goat, cat & rat eradication	Averted extinction, conservation introduction	Cheke and Hume (2008)
VU	Telfair's skink	<i>Leiopisma telfairii</i>	Mauritius	Round Island, Gunner's quoin, Ile aux Aigrettes	goat & rabbit eradication; rat, hare & rabbit eradication; goat, cat & rat eradication	Averted extinction, conservation introduction	Bullock et al. (2002)
LC	Wedge-tailed shearwater	<i>Ardenna pacifica</i>	Mauritius	Round Island	goat and rabbit eradication	(re)colonisations	Bullock et al. (2002)
N/A	Bojer's skink	<i>Gongylomorphus bojerii</i>	Mauritius	Round Island	goat & rabbit eradication	Averted extinction	Bullock et al. (2002)
N/A	Durrell's night gecko	<i>Nactus durrelli</i>	Mauritius	Round Island	goat & rabbit eradication	Averted extinction	Bullock et al. (2002)
N/A	Günther's gecko	<i>Phelsuma guentheri</i>	Mauritius	Round Island, Ile aux Aigrettes	goat & rabbit eradication; goat, cat & rat eradication	Averted extinction, conservation introduction	Bullock et al. (2002)

(continued on next page)

Table 3 (continued)

IUCN	Common name	Species	Country	Island(s)	Improvements	Outcome	Reference
N/A	Lesser night gecko	<i>Nactus coindemirensis</i>	Mauritius	Gunner's quoin	rat, hare & rabbit eradication	Averted extinction	Bullock et al. (2002)
N/A	Orange-tailed skink	<i>Gongylomorphus cf fontenayi</i>	Mauritius	Gunner's quoin	rat, hare & rabbit eradication	Averted extinction	Bullock et al. (2002)
CR	Réunion cuckooshrike	<i>Coracina newtoni</i>	France	La Réunion	rat control	Averted extinction	Ghestemme and Salamolard (2007)
LC	Brown booby	<i>Sula leucogaster</i>	France	Tromelin	rat eradication	(re)colonisation	Le Corre et al. (2015)
LC	White tern	<i>Gygis alba</i>	France	Tromelin	rat eradication	(re)colonisation	Le Corre et al. (2015)

^a IUCN status down-listed as a result (N/A = not categorised).

Offshore islands of larger inhabited principal islands, such as the Mascarenes, Madagascar and Comoros could also be made pest-free, to become arks for threatened species conservation and to provide important demonstration sites for local human communities.

5. Conclusions

The eradication of introduced mammals from WIO islands will provide immediate relief to populations of plants and animals on those islands, and improve prospects for translocation (Russell et al., in press). However, in the longer-term global climatic change processes, particularly sea-level rise, climate niche shifts and increased human land-use, will pose new risks to threatened species of the WIO islands (e.g. Gerlach et al., 2013). Coral atolls make up 74% of WIO islands, and will be extremely vulnerable to climate change, with many likely to be inundated under projected sea-level. In some cases these impacts may negate previous conservation gains from eradications when islands become partly or completely inundated. However, these islands only constitute 0.1% of total island land area in the WIO. Prioritisation of mammal eradications in the WIO region is a logical next-step following our study, and will need to incorporate regional aspects of predicted climate change (Bellard et al., 2015), and climate change resilient islands should be the long-term focus of island conservation measures (Courchamp et al., 2014). In particular the comparatively wealthy and well-studied islands of the Granitic (Inner) Seychelles and Mauritius, where much island conservation always occurs, will continue to have prominence in island conservation. Offshore islands of Madagascar, the Comoros and Spice islands could also be important but island conservation prospects in these regions will also depend heavily on regional and national politics to integrate nature conservation and economic development. In the Maldives, basic introduced mammal island distribution and impact data are urgently needed before any further conservation work can occur.

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