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Introduced mammals threaten the Grenadines transboundary tropical seabird hotspot

Juliana Coffey*[1] and Natalia Collier[2]

Abstract A minimum of nine species of introduced mammals inhabit at least 19 remote islands throughout the Grenadines—an archipelago that hosts globally and regionally significant colonies of breeding seabirds and represents one of the few remaining strongholds for seabirds in the Lesser Antilles. This paper presents a contemporary inventory of non-native mammal species on islands in the Grenadines, with a particular focus on breeding seabirds and protected areas, and explores the wider implications of complex sociocultural barriers to conservation.

Keywords eradication, Grenadines, introduced species, invasive species, island restoration, seabird

Resumen Los mamíferos introducidos amenazan el punto caliente de biodiversidad transfronterizo de aves marinas tropicales de las Granadinas • Un mínimo de nueve especies de mamíferos introducidos habitan al menos 19 islas remotas en las Granadinas, un archipiélago que alberga colonias de aves marinas reproductoras de importancia mundial y regional; y que representa uno de los pocos reductos que quedan para este grupo de aves en las Antillas Menores. Este artículo presenta un inventario actual de las especies de mamíferos no nativos en las islas de las Granadinas, con especial atención en las aves marinas nidifcantes y las áreas protegidas. Además explora las implicaciones más amplias de las complejas barreras socioculturales para la conservación.

Palabras clave aves marinas, erradicación, especies introducidas, especies invasoras, Granadinas, restauración de islas

Résumé Des mammifères introduits menacent un haut lieu transfrontalier pour les oiseaux marins tropicaux dans les Grenadines • Au moins neuf espèces introduites de mammifères vivent sur au moins 19 îles éloignées des Grenadines, un archipel qui abrite des colonies de reproduction d'oiseaux marins d'importance mondiale et régionale et qui représente l'un des derniers bastions pour les oiseaux marins dans les Petites Antilles. Cet article présente un inventaire contemporain des espèces de mammifères non indigènes des îles des Grenadines, avec un accent particulier sur les oiseaux marins nicheurs et les aires protégées, et explore les implications plus larges des barrières socioculturelles complexes vis-à-vis de la conservation.

Mots clés éradication, espèces envahissantes, espèces introduites, Grenadines, oiseaux marins, restauration insulaire

Non-native mammals introduced to areas beyond the limits of their native distributions are widely recognized as the cause of species declines, extirpations, and extinctions worldwide (Atkinson 1989, Steadman 1995, MacPhee and Flemming 1999, Campbell and Donlan 2005). Their direct and indirect impacts on ecological processes are particularly devastating in insular ecosystems, where many species evolved in the absence of predatory and large herbivorous mammals (Atkinson 1985, Steadman 1995, MacPhee and Flemming 1999, Courchamp *et al.* 2003, Donlan and Wilcox 2008). Seabirds, many of which nest on islands and exhibit high nest-site fidelity, are typically vulnerable and defenseless against non-native mammals in their colonies (Lack 1968).

Invasive species are introduced (or non-native) species that become destructive to the environment or human interests in a geographical area (IUCN 2018). Invasive species, particularly mammals, are regarded as having the highest overall impact on seabirds of any other identified threat (Croxall *et al.* 2012, Dias *et al.* 2019). Introduced mammalian predators often kill adults, chicks, and eggs, with the mortality of adults being the greatest threat to seabird populations (Ashmole *et al.* 1994, Jones *et al.* 2008). Large herbivores can eliminate critical nesting habitat, trample nests, and cause disturbance resulting in exposure of nests to unfavorable weather conditions and predators (Campbell and Donlan 2005). Such effects can lead to increased competition for suitable nest sites, failed nesting attempts, reduced breeding success, and abandonment of entire islands (Brooke *et al.* 2018). Since seabirds have declined globally by approximately

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70% since the 1960s (Paleczny *et al.* 2015), with declines in tropical areas believed to be more severe (Schreiber and Lee 2000), inventories of harmful introduced species at remaining seabird nesting sites are a crucial step towards their recovery.

Non-native mammal presence beyond their native distributions has been facilitated primarily by human movements (Blackburn *et al.* 2017). Expansion of human populations and settlements into new areas is associated with concurrent transport of domestic animals brought for personal benefit and survival (Borroto-Páez and Woods 2012). Such movements enabled unintended introductions of additional animals, such as rodents. More than 40 species of mammals have been introduced to islands in the West Indies (Borroto-Páez and Woods 2012), where they have influenced historical and ongoing seabird population dynamics (Masetti 2011, Coffey and Collier 2020). They have been directly responsible for dramatic declines in seabird populations, including the Endangered Black-capped Petrel (*Pterodroma hasitata*) and the possibly extinct Jamaican Petrel subspecies (*P. h. caribbaea*; Schreiber and Lee 2000).

Introduced mammals can cause changes in ecosystem services and productivity (Charles and Dukes 2008). Seabirds are ecological connectors; their guano transfers nutrients between the ocean and the land, which improves the growth of plants on the island as well as intertidal communities and coral reefs surrounding their colonies (Bosman and Hockey 1986, Savage 2019). As introduced mammals reduce seabird populations, they also consequently reduce the health of islands and productivity of surrounding coral reefs and fisheries (Graham *et al.* 2018).

Although their affinity for islands increases the vulnerability of seabirds, it is also their greatest chance for recovery. The limited geography of islands allows conservation strategies, such as eradications, to be focused and contained. Eradication of introduced mammals from islands has proven to be a powerful conservation tool and has become a core objective of seabird recovery programs worldwide (Clout and Veitch 2002, Campbell and Donlan 2005, Brooke *et al.* 2007, Lavers *et al.* 2010, Daltry *et al.* 2012). The purpose of this study was to compile existing information with new records pertaining to the contemporary distribution and diversity of non-native mammal species on the offshore, uninhabited islands of the Grenadines archipelago—specifically with a focus on islands with seabird colonies and in protected areas.

The Grenadines archipelago (12°34'02"N, 61°25'11"W) is a transboundary ecoregion overlapping the national jurisdictions of Grenada and Saint Vincent and the Grenadines (SVG). This island chain consists of more than 80 islands, islets, rocks, and cays, which span approximately 100 km between the mainlands of Grenada and Saint Vincent. Despite this jurisdictional division, the Grenadines are more ecologically similar to each other than they are to their respective mainlands. These islands emerge from the shallow Grenada Bank, situated at the convergence of the Atlantic Ocean and Caribbean Sea. The Grenadines region is characterized by extensive coral reefs, seagrass beds, a series of salt ponds, and mangroves (Moore *et al.* 2015, Coffey and Ollivierre 2019, Coffey and Collier 2020). The Grenadines are highly productive due to the geography of the Grenada Bank, with oceanographic processes providing nutrients for fauna such as fish, marine mammals, and seabirds.

Until recently, little was known about the presence and significance of breeding seabirds on the remote Grenadine islands. Between 2009 and 2010, Environmental Protection in the Caribbean (EPIC) conducted the first thorough investigations of the archipelago. Results indicated that the transboundary archipelago is critically important for breeding seabirds, with both nations hosting over 54,000 pairs of 12 breeding seabird species, three colonies meeting global Important Bird Area (IBA) criteria, and 18 colonies of regional significance (Lowrie *et al.* 2012, Coffey and Collier 2020). EPIC highlighted SVG as the most important nation in the Lesser Antilles for breeding seabirds due to the burgeoning colonies in the Grenadine islands, yet also the most threatened geographic area due to a complex suite of threats. The inclusion of the Grenada Grenadines for a "transboundary" perspective further strengthens the overall importance of this archipelago to breeding seabirds. Of the 12 species known to nest in the Grenadines, 7 are listed as Caribbean At-Risk Species (Bradley and Norton 2009).

To date, targeted investigations of introduced mammals inhabiting offshore islands in the Grenadines have been limited. In 2009, a researcher conducted invasive species investigations on Petit Rameau, Petit Bateau, and Baradal in the Tobago Cays Marine Park (SVG) during a single day (USAID 2010). In 2014, EPIC researchers visited Battowia, Catholic Island, Petit Bateau (SVG), and Frigate Island (Grenada) to conduct invasive species surveys using chew blocks and tracking tunnels over 2 days per island (Collier 2014). Browne and Culzac (2019) deployed chew blocks on Battowia over 1 week. Smart (2019) conducted rodent surveys on five islands in the Grenada Grenadines (Diamond Rock, Grass Island, Les Tantes East, Sandy Island, and Lee Rock) using chew blocks, tracking tunnels, and trail cameras to determine the effects of rodents on seabird nesting success between 2014 and 2017. Finally, researchers with Flora and Fauna International (FFI) conducted preliminary invasive species surveys overnight on Petit Nevis, Petit Canouan, Isle à Quatre, and Pigeon Island (SVG) in 2019 (S. Steele pers. comm.).

Non-native mammalian species were introduced to the Grenadine islands concurrently with the initial arrival and establishment of humans to the region. Early Amerindian arrivals to and inhabitants of the Grenadines since the ceramic period are known to have introduced several mammals to the archipelago, such as the guinea pig (*Cavia* sp.), armadillo (*Dasypus* sp.), peccary (*Tayassu pecari*), opossum (*Didelphis* sp.) and agouti (*Dasyprocta* sp.; Giovas *et al.* 2011). The establishment of Europeans in the Grenadines in the early 16th century gradually facilitated the purposeful (e.g., goats [*Capra aegagrus*], sheep [*Ovis aries*], and cows [*Bos taurus*]) and accidental (e.g., rats [*Rattus* sp.] and mice [*Mus* sp.]) introduction of additional mammal species, as occurred in the rest of the West Indies (Masetti 2011, Borroto-Páez and Woods 2012). Since the 18th century, the widespread practice of plantation agriculture has relied heavily on herbivorous species, such as goats and sheep, to provide a reliable food resource. In addition to feeding local residents, livestock was further supplied to nearby islands, such as Trinidad (Trendell 1886). By this time, species such as the agouti, armadillo, and opossum were considered wild, and generally regarded as a form of "bushmeat" (Trendell 1886). In the Grenadines, plantations of goods such as coffee, cocoa, tobacco, indigo,

cotton, and sugar cane occurred on many islands that are now uninhabited and abandoned (Howard 1952, DeGraff and Baldwin 2013). Historical records identify several types of introduced mammals associated with some of these sites (Ober 1880, Trendell 1886, Howard 1952).

Today, small-scale pastoralism involving introduced mammals plays a vital role in the livelihood of farmers in the Grenadines, both as a source of nutrition and as primary or supplemental income (FAO 2011). On the inhabited Grenadine islands, there is a tradition of releasing animals during the "let go" season (January–May) to forage, while others are grazed seasonally or year-round on nearby islands (Thomas 2000, Coffey and Collier 2020). Many livestock owners graze their animals on land where they are not the landholder (Cox *et al.* 1991). Overgrazing and the practice of freely roaming animals has significantly altered ecosystems and caused severe erosion on islands throughout the Grenadines (Richardson 1975, Freid and Glasgow 2015, Coffey and Collier 2020). The movement of both domestic and wild animals between the Grenadine islands, and ultimately between both nations, occurs regularly and in some cases illegally (Coffey and Collier 2020).

An inventory of invasive species throughout the Grenadine archipelago was identified as a priority action in the *Community-based Conservation Management Plan for the Seabirds of the Grenadines Archipelago* (Coffey and Collier 2020) and recommended for the whole region in the *Seabird Breeding Atlas of the Lesser Antilles* (Lowrie *et al.* 2012). Globally, the Convention on Biological Diversity listed developing inventories of non-native species as a critical initial step towards addressing their impacts at the national and international level (IUCN 2000). This paper collates all available information to guide such efforts in this critical seabird nesting region.

Methods

Given the dynamic nature of livestock release and removal from uninhabited islands in the Grenadines, we only considered references from the last 10 years pertaining to these species as "contemporary." Although we discuss historical livestock records, we did not consider them as contemporary in this study. We further excluded references to the nine human-inhabited Grenadine islands given the lack of nesting seabirds on main islands. For islands that had no records of introduced mammals, we assumed that there was no available information for the island, the island was not surveyed, or species were not detected during visits. We used the following methods to compile a contemporary inventory of introduced mammals at uninhabited Grenadine islands.

Surveys

Between 1 February 2019 and 5 December 2020, JC and EPIC's citizen scientist group "Grenadines Seabird Guardians" conducted boat- and land-based surveys of 35 islands in both the Grenada and Saint Vincent Grenadines (Appendix 1). The primary purpose of the surveys was to conduct seabird counts, while also noting threats such as presence of introduced mammals. The surveyors visited numerous islands on more than one occasion, totalling 62 boat-based surveys at 32 islands and 23 land-based surveys at 11 islands. While boat-based surveys were limited to a maximum of 1 hr of observation per visit to an island and offered only distant observation, land-based surveys afforded more detailed investigation, typically lasting up to a half-day.

Literature review

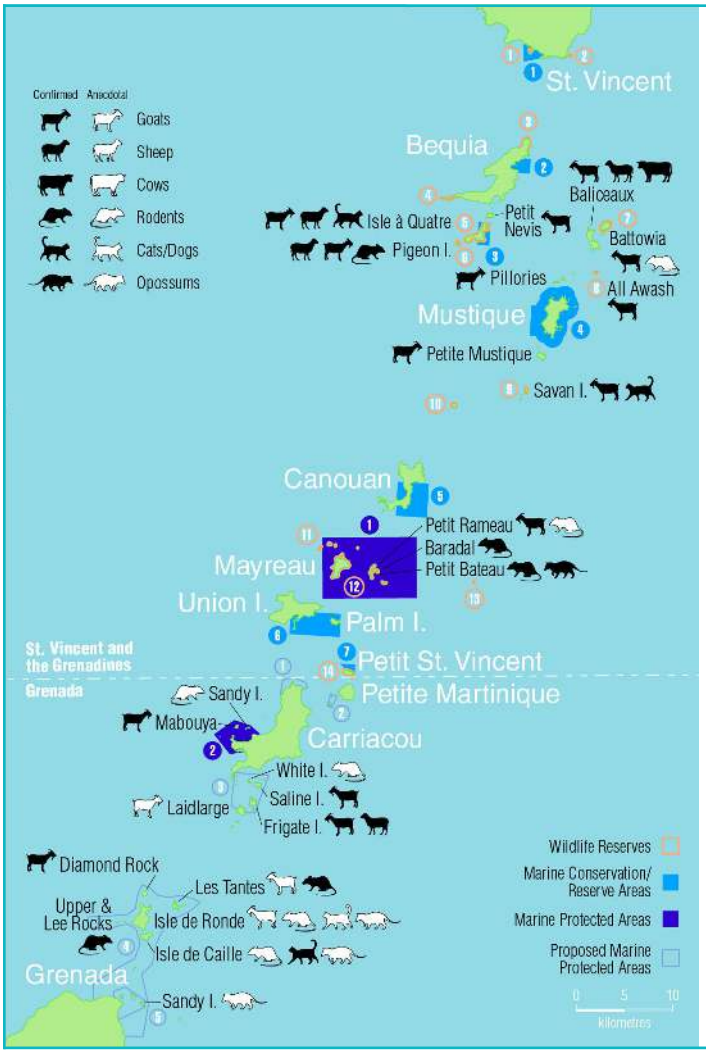
We conducted an extensive literature review of the Grenadine islands during our compilation of the *Conservation Management Plan for Seabirds in the Transboundary Grenadines* (Coffey and Collier 2020), in which invasive species at uninhabited islands was a core theme. We derived literature primarily through internet search engines (Google Scholar and Science Direct), from the Annotated bibliographic information on the Grenadines (Blackman *et al.* 2013), the Global Invasive Species Database (ISSG 2011), CABI Invasive Species Compendium (CABI 2020), and unpublished reports sourced from government departments, non-governmental agencies, and private individuals. References cited in reviewed papers were scanned for relevant sources. While available literature regarding invasive species surveys in the Grenadines was limited, we reviewed a broad variety of references pertaining to the Grenadine islands for any mentions of their historic or contemporary presence on Grenadine islands. Direct observations were derived primarily from non-seabird field investigation reports (e.g., avian, herpetofaunal, and vegetation surveys) at uninhabited islands, where observations were made directly by the author(s). Of the publications and reports we reviewed, 10 yielded confirmed and anecdotal reports of introduced mammals at offshore islands, and personal communication with two researchers (S. Steele and E. Freid) yielded additional confirmed records from field investigations.

Anecdotal information

We gleaned firsthand eyewitness accounts from reports detailing the results of workshops and community consultations where participants discussed or mentioned instances of non-native mammals on Grenadine islands. In 2013, fisherfolk at seabird harvesting workshops, held by Sustainable Grenadines, Inc. at Sauteurs (Grenada), Canouan (SVG), and Bequia (SVG), discussed introduced mammals as a threat to seabird populations (Sustainable Grenadines, Inc. 2014). EPIC collected information during informal communications and five fisherfolk workshops (83 total persons at workshops on Petite Martinique, Windward and L'Esterre on Carriacou, Mayreau, and Mustique) between February and December 2019 during the implementation of the "Conservation of Key Offshore Island Reserves" project (Coffey and Collier 2020). Firsthand eyewitness accounts from local residents familiar with the offshore islands (e.g., fisherfolk frequenting particular offshore islands) were considered to be credible. Local knowledge was a valuable asset due to the overall paucity of investigations for the Grenadine islands on this subject, as well as the familiarity of local resource users with the uninhabited islands. We did not, however, consider these as confirmed cases, but rather as areas for further investigation.

Results

Introduced mammals were present on 19 islands with a minimum of five additional islands suggested through anecdotal evidence to have one or more introduced species (Fig. 1, Table 1). A minimum of nine species—including goat, sheep, cow, dog (*Canis*



Wildlife Reserves

1 Young Island
2 Milligan Cay
3 Northern end of Bequia beyond Industry Point
4 Big Cay and West Cay
5 Isle à Quatre
6 Pigeon Island
7 Battowia (also an Important Bird Area)
8 All Awash
9 Savan Islands
10 Petit Canouan (also an Important Bird Area)
11 Catholic Rocks/Catholic Island
12 Tobago Cays/Tobago Cays Forest Reserve
13 Sail Rock
14 Palm/Prune Island

Marine Conservation/Reserve Areas

1 South Coast Marine Conservation Area
2 Bequia Marine Conservation Area
3 Isle à Quatre Marine Conservation Area
4 Mustique Marine Conservation Area
5 Canouan Marine Conservation Area
6 Union Island/Palm Island Marine Conservation Area
7 Petit St. Vincent Marine Conservation Area

Marine Protected Areas

1 Tobago Cays Marine Park
2 Sandy Island Oyster Bed Marine Protected Area

Proposed Marine Protected Areas

1 North Carriacou
2 Petite Dominique
3 South Carriacou Islands
4 Isle de Ronde Archipelago
5 Levera Islands

Fig. 1. Introduced mammal distribution in protected areas in the Grenadines (Tombolo Maps and Design).

familiaris), cat (*Felis catus*), black rat (*Rattus rattus*), brown rat (*R. norvegicus*), mouse, and opossum sp.—currently occur at uninhabited islands in the Grenadines.

Goats, Sheep, and Cows

Goats are the most observed non-native mammal in the Grenadines and the most abundant and widespread large herbivore. Goats were present, primarily as feral populations, on at least 15 islands, with unconfirmed reports from additional islands (Table 1; Sustainable Grenadines, Inc. 2014, Freid and Glasgow 2015, Noonan 2015, Smart 2019, Coffey and Collier 2020). Goats were present on both islands hosting globally important seabird colonies (Battowia and Les Tantes), almost all of the islands hosting regionally significant seabird populations, and most of the government-owned wildlife reserves and marine protected areas, despite being prohibited by legislation in both nations (Fig. 2; Grenada Fisheries Act 1986, SVG Wildlife Act 1987, Coffey and Collier 2020). Some of these islands host ground- and burrow-nesting seabird species that are particularly vulnerable to goat presence, such as Audubon's Shearwater (*Puffinus lherminieri*) and Laughing Gull (*Leucophaeus atricilla*). Goats were also present in several proposed marine protected areas. Exploitation of seabirds and their chicks and eggs was reported to occur concurrently with goat hunting on offshore islands, contributing to disturbance of seabird colonies (Coffey and Collier 2020). Anecdotal reports indicate that goats are frequently placed upon and hunted from islands by local residents, suggesting a dynamic and ongoing removal and reintroduction of goats to uninhabited islands. These reports were supported by observations during seabird surveys of islands and discussions during community consultations (Coffey and Collier 2020). A resident of Carriacou, for example, indicated that goats had previously been released on Mushroom Island (Grenada) and quickly removed by others (Coffey and Collier 2020).

The extent of goats' impact is unknown, although deterioration of vegetation from overgrazing on islands is visible even from satellite imagery (Coffey and Collier 2020). Freid and Glasgow (2015) observed that goats had caused severe erosion and plant reduction on several islands in the Grenadines (Fig. 3), including those with substantial seabird populations such as Battowia. They further noted that a lengthy historical presence of livestock on Baliceaux (SVG) had severely deteriorated vegetation such that seedlings no longer regenerate due to overgrazing—a claim that was supported by Noonan (2015) during herpetofaunal

surveys. Freid and Glasgow (2015) also noted the depletion of vascular plants on Pigeon Island (SVG). It is likely that the disappearance of any breeding seabirds that may have historically existed on Baliceaux can be attributed, at least in part, to the extensive and continuous presence of livestock and human activity. Similar conditions exist for some of the Grenada Grenadines, such as Large Island, where there is an overall paucity of seabirds and an extensive record of human activity and associated livestock presence (Howard 1952). Lowrie *et al.* (2012) witnessed overgrazing on many islands, such as Battowia, Pillories, and Petite Mustique, as well as Frigate, Les Tantes, Isle de Ronde, Diamond Rock, and even Mushroom Island, which is less than 1 ha.

Sheep were present at four locations (Baliceaux, Isle à Quatre, Pigeon Island, and Frigate Island), and a single cow was present on Baliceaux in 2015 (E. Freid pers. comm., S. Steele pers. comm.).

Rodents

Rats were present on five islands (Table 1). Smart (2019) documented *Rattus* sp. using a camera trap on Lee Rock and Les Tantes East (Grenada). Les Tantes and Lee Rock contain globally and regionally significant seabird colonies and are located within a proposed marine protected area. *Rattus* sp. were also reported on Pigeon Island Wildlife Reserve (SVG) during invasive species investigations conducted by FFI (S. Steele pers. comm.), and on Petit Bateau and Baradal in the Tobago Cays Marine Park (USAID 2010). Residents of Bequia indicated that seabirds on Pigeon Island have been declining in recent years (S. Steele pers. comm.), and researchers attribute the lack of avian diversity in the Tobago Cays in part to rodent presence (USAID 2010). Anecdotal reports suggest that rodents are present on at least six additional islands (Lowrie *et al.* 2012, Collier 2014, Sustainable Grenadines Inc., 2014, Smart 2019, Coffey and Collier 2020, Ocean Spirits pers. comm., R. Compton pers. comm., V. Thomas pers. comm.). Of these, Battowia (SVG) is a national Wildlife Reserve, an international IBA, and hosts globally and regionally significant seabird populations (Culzac 2008, Lowrie *et al.* 2012). Of the remaining islands, two are within marine protected areas (Petit Rameau and Sandy Island) and the three others are within proposed marine protected areas (Isle de Ronde, Isle de Caille, and White Island, Grenada). White Island supports nesting Audubon's Shearwater (Lowrie *et al.* 2012)—a species that is likely vulnerable to rodent predation, as illustrated with other shearwater species (Lee 2000, Mackin 2016). While Allen (1911) and Varona (1973) reported mice (*Mus musculus*) on Baliceaux and Isle de Ronde, their current status is unknown. A resident of Isle de Ronde reported that introduced cats had removed rodents from the island (Collier 2014). We recommend follow-up investigations to determine their presence, although both islands have been almost entirely depleted of nesting seabirds.

Cats and Dogs

Dogs were present on two islands (Isle à Quatre and Savan Island (SVG); Table 1; Freid and Glasgow 2015). Cats were observed on two islands (Savan Island and Isle de Caille) and suggested to be present on one additional island (Isle de Ronde; Collier 2014, Freid and Glasgow 2015, Ocean Spirits pers. comm.). These four islands have semi-permanent fishing camps and an overall paucity of nesting seabirds (Lowrie *et al.* 2012). A resident of Isle de Ronde claimed that cats were released on Isle de Caille to address rodent issues (Collier 2014). Two of these islands (Isle à Quatre and Savan Island) are national Wildlife Reserves, where both cats and dogs are prohibited, while the remaining two (Isle de Ronde and Isle de Caille) are within a proposed marine protected area. Transient presence of pet dogs on uninhabited islands is also linked with recreational activities from residents of nearby islands and visiting tourists, which likely occurs more frequently than reported (Lowrie *et al.* 2012, Coffey and Collier 2020). Visitors traveling through the archipelago and visiting uninhabited islands often travel with pets, such as dogs, that they bring ashore for brief periods and allow to interact with native species and depredate seabirds, chicks, and eggs. Lowrie *et al.* (2012) observed dogs flushing nesting birds on several islands, including those in the Tobago Cays Marine Park. Local residents occasionally bring dogs on recreational trips to nearby islands, such as for hunting or barbeques (Coffey and Collier 2020).

Fig. 2. Frigate Island (Grenada) hosts three regionally important seabird colonies and is heavily populated by feral goats (J. Coffey).

Fig. 3. Severe erosion caused by feral goats on Frigate Island, Grenada (J. Coffey).

Table 1. Overlap of introduced mammals, seabird colonies, and offshore Important Bird Areas (IBAs) in the transboundary Grenadines archipelago. Islands are arranged from north to south within each country.

			Breeding Species[a,b]											Mammals[d]					
Island	Size (ha)	Distance from Nearest Inhabited Island (km)	AUSH	BRTE	BRBO	BRNO	LAGU	MAFR	RBTR	RFBO	ROST	SOTE	Protected and IBA Status[c]	Goats	Sheep	Cows	Rodents	Cats/Dogs	Opossums
Saint Vincent Grenadines																			
Pigeon Island	7.7	4.5 (Bequia)	b			b			b				WR	C	C		C		
Battowia	62.7	7.9 (Mustique)			R	b	R	b	G	G			WR, VC011	C			A		
Baliceaux	135.5	5.5 (Mustique)											–	C	C	C			
All Awash	3.1	3.9 (Mustique)			b	b			b		b	b	WR, VC012	C					
Isle à Quatre	149.2	2.2 (Battowia)				b			b		b		WR	C	C			C	
Petit Nevis	29.4	1.0 (Battowia)											–	C					
Pillories	2.0/3.0/7.6	1.4 (Mustique)	R	b		b	b		b		b	b	–	C					
Petite Mustique	47.3	2.1 (Mustique)		b		b	R		b				–	C					
Savan Island	9.8	5.5 (Mustique)				b			b				WR	C				C	
Petit Rameau	8.5	2.3 (Mayreau)											MPA	C			A		
Petit Bateau	8.1	2.2 (Mayreau)											MPA				C		C
Baradal	2.6	2.9 (Mayreau)		b		b							MPA				C		
Grenada																			
Sandy Island (Carriacou)	1.5	0.8 (Carriacou)											MPA				A		
Mabouya	8.6	0.8 (Carriacou)					b		b				MPA	C					
Saline Island	26.5	1.3 (Carriacou)											pMPA	C					
Frigate Island (Carriacou)	40.0	2.5 (Carriacou)	R	b		b	R		R			b	pMPA	C	C				
White Island	4.7	1.1 (Carriacou)	b			b			b				pMPA				A		
Laidlarge	59.8	2.8 (Carriacou)							b				pMPA	A					
Les Tantes	7.5/25.7	11.6 (Grenada)		b	b[e,f]	b	b		b[e,f]	G			pMPA	C			C		
Isle de Ronde	254.8	7.8 (Grenada)							b				pMPA	A			A	A	A
Isle de Caille	63.8	6.8 (Grenada)				b	b						pMPA				A	C	A
Diamond Rock	22.1	11.2 (Grenada)		b	R[e]	b	R		R[e]	R			pMPA	C					
Upper Rock/ Lee Rock	0.4/0.6	7.7 (Grenada)		b	b[f]	b	b		b[f]	b		b	pMPA				C		
Sandy Island (Grenada)	8.8	1.9 (Grenada)		b			b		b				pMPA						A
											Total Confirmed			15	4	1	5	3	1
											Total Anecdotal			2	0	0	6	1	3

[a]Species Codes: AUSH = Audubon's Shearwater (*Puffinus lherminieri*), BRTE = Bridled Tern (*Onychoprion anaethetus*), BRBO = Brown Booby (*Sula leucogaster*), BRNO = Brown Noddy (*Anous stolidus*), LAGU = Laughing Gull (*Leucophaeus atricilla*), MAFR = Magnificent Frigatebird (*Fregata magnificens*), RBTR = Red-billed Tropicbird (*Phaethon aethereus*), RFBO = Red-footed Booby (*Sula sula*), ROST = Roseate Tern (*Sterna dougallii*), SOTE = Sooty Tern (*Onychoprion fuscatus*). b = breeding, G = colony meets Global IBA criteria, R = colony meets Regional IBA criteria

[b]Lowrie *et al.* 2012, Coffey and Collier 2020

[c]Codes: WR = Wildlife Reserve, MPA = Marine Protected Area, pMPA = proposed Marine Protected Area, VC011, VC012 = BirdLife International Important Bird Areas (Culzac 2008)

[d]Status: C = Confirmed, A = Anecdotal

[e]Diamond Rock and Les Tantes combined have globally significant populations of Red-billed Tropicbird, Brown Booby

[f]Upper Rock/Lee Rock and Les Tantes combined have regionally significant populations of Red-billed Tropicbird, Brown Booby

Although this transient presence of dogs and cats on uninhabited islands can contribute to destruction of native species, the difficulty in tracking the frequency of such events precluded their consideration in our results.

Opossums

Opossums are thought to have been introduced to the Grenadines by Amerindians prior to European contact (Giovas *et al.* 2011, Masetti 2011). Their presence on offshore islands is poorly known. Opossums subsist on an omnivorous diet, including items such as insects, plants, eggs, birds, and turtle hatchlings, produce a high number of offspring per year, and have no natural predators (Brown *et al.* 1993, USAID 2010). While only confirmed on Petit Bateau, anecdotal evidence suggests that opossums are present on at least three other uninhabited Grenadine islands (Isle de Caille, Sandy Island, and Isle de Ronde) and historical accounts support their presence on Isle de Ronde (Table 1; Borroto-Páez and Woods 2012, Sustainable Grenadines, Inc. 2014, Smart 2019, Ocean Spirits pers. comm.). Fisherfolk attributed the elimination of the remaining seabird populations on Isle de Ronde to cats and opossums (Lowrie *et al.* 2012), and reduced vegetation and seabird species richness on Petit Bateau are also thought to be linked to their presence (USAID 2010).

Rabbits, Hares, and Deer

Rabbits and hares (*Oryctolagus cuniculus* and *Lepus europaeus*, respectively), which were brought to the West Indies by Europeans to be hunted, were previously reported on Baliceaux and Isle de Ronde. However, they are not reported to exist in wild populations on any island in the Grenadines today, nor are deer that were historically reported on Baliceaux (Trendell 1886, Howard 1952, Masetti 2011, Borroto-Páez and Woods 2012). Although anecdotal information discusses wild rabbit or hare presence on Isle de Ronde, it is unclear if this report referred to historical or contemporary presence and it was therefore excluded from our results (Coffey and Collier 2020). Some residents maintain rabbits as a supplemental food source on inhabited islands (JC pers. obs.). While Whitetail deer (*Odocoileus virginianus*) were historically reported on mainland Grenada, and both *Mazama* and *Odocoileus* genera are documented in prehistoric occupation sites on Carriacou, it is unknown which species was present on Baliceaux (Borroto-Páez and Woods 2012, Giovas 2018). Wild donkeys were also noted by Howard (1952) causing damage to vegetation on Baliceaux, but they were not present in recent visits (Freid and Glasgow 2015).

Discussion

The presence of goat populations on all of the islands hosting globally important seabird colonies, and on most of those with regionally significant populations, is a serious conservation concern. Lowrie *et al.* (2012) listed Battowia (SVG) as the most important island in the entire Lesser Antilles due to the presence of two globally important seabird colonies and several regionally important colonies, yet the island is heavily overgrazed by goats. The colony of Red-footed Boobies (*Sula sula*) on Battowia is thought to be the largest in the Lesser Antilles, and one of only four islands in this region with a population exceeding 50 pairs. Battowia was recently confirmed to host one of five Magnificent Frigatebird (*Fregata magnificens*) colonies in the entire Lesser Antilles, and the only known site for both nations (Coffey and Collier 2020). Diamond Rock and Les Tantes (Grenada) also host regionally and globally important populations of seabirds and both islands have goat populations. Frigate Island (Grenada) is thought to have the largest Laughing Gull colony in the entire Lesser Antilles and to be regionally important for Red-billed Tropicbird (*Phaethon aethereus*) and Audubon's Shearwater, yet is heavily populated with goats and a popular site for goat hunting, which is reported to occur in tandem with seabird egg harvesting (Coffey and Collier 2020). The Grenadines Seabird Guardians additionally documented a flock of sheep on Frigate Island that had been introduced in 2020. The government-owned Pillories qualify as an IBA, as each of the three islands hosts Audubon's Shearwater populations, yet the site is not legally protected and is used for grazing goats (Lowrie *et al.* 2012, Coffey and Collier 2020).

Goats are physiologically resilient to extreme conditions, such as acutely arid environments with minimal water availability (Silanikove 2000, Hess *et al.* 2018). While they are known to derive the majority of their water content directly from plants (Robbins 1994), they have also been observed drinking salt water (Burke 1988). These characteristics, combined with their generalist diet and high reproductive rates, allow feral goat populations to persist in areas where other herbivores cannot survive, including areas without regular access to fresh water (Parkes 1993). Globally, goats have been attributed as the exclusive driver of seabird declines on several islands (Moran 1996). Their persistence on offshore Grenadine islands is likely due to their physiological ability to cope with extreme conditions, such as the acute annual dry season coupled with the lack of fresh water sources.

Ground- and burrow-nesting seabird species in the Grenadines are particularly vulnerable to the effects of goats and may suffer damage to critical nesting habitat, trampling of nests, and exposure from disturbance. This damage can be limited through enforcement of existing wildlife protection designations prohibiting such animals in wildlife reserves and protected areas. Petit Saint Vincent, a private resort island of SVG, has eradicated all goats, resulting in enhanced native plant biodiversity (Freid and Glasgow 2015). Prevention and elimination of goats from Grenadine islands was identified as a top priority for botanical conservation as islands with goats have reduced plant cover and biodiversity (Freid and Glasgow 2015).

Non-native rodents have the potential to decimate seabird colonies through direct predation of adults, chicks, and eggs. Rats are classified as the most destructive and widespread of all invasive species (Atkinson 1985, Jones *et al.* 2008, Dias *et al.* 2019). Despite their small size, the potential for mice to cause significant harm to seabirds in the Grenadines should not be underestimated. They have been observed attacking very large seabird species in other areas (Wanless *et al.* 2007). Because peak seabird nesting activity overlaps with the dry season, rodents may be attracted to seabird chicks and eggs due to limited food and water resources (Caut *et al.* 2008). Responses to surveys by Smart (2019) revealed that only 1 of 32 local respondents considered rats to be harmful to breeding seabirds, indicating a substantial need for further public education on the subject.

The elimination of rodents from offshore islands is a crucial

step towards preserving seabird colonies and other biodiversity, such as regionally endemic herpetofaunal species. The Grenada Bank features several endemic herpetofauna species, such as the Union Island Clawed Gecko (*Gonatodes daudini*), the Grenada Bank Treeboa (*Corallus grenadensis*), anole species (*Anolis aeneus* and *Anolis richardii*), and the IUCN-Vulnerable Grenadines Sphaero (*Sphaerodactylus kirbyi*) (Henderson and Berg 2006, Powell and Henderson 2011, Hedges *et al.* 2019). Although there are few nesting seabirds on Isle à Quatre, for example, the island is known to contain the Grenadines Sphaero and Grenada Bank Treeboa (Henderson and Berg 2006, Powell and Henderson 2011). The lack of juvenile iguanas observed on islands in the Tobago Cays Marine Park is thought to be associated with the presence of rats and opossums (USAID 2010). Rodents additionally prey upon sea turtle hatchlings (Caut *et al.* 2008), an issue of concern for the many islands in the Grenadines that have important turtle nesting beaches.

Although cats and dogs were not reported to be widespread or abundant on offshore islands in the Grenadines, they can be expected anywhere there is temporary or permanent human habitation, such as fishing camps. Cats are known to be direct predators of seabirds (Greenwell *et al.* 2019) and one of the most destructive invasive species encountered by seabirds worldwide (Dias *et al.* 2019). Daudin and De Silva (2011) suggested that cats were responsible for the reduction in native snakes and near-extirpation of a ground lizard (*Ameiva ameiva tobagana*) on the inhabited island of Mayreau and indicated that a cat control program has been implemented on Mustique. Potential adverse encounters at offshore islands could be minimized through enforcement of existing protected area legislation, government-issued regulations for sensitive areas not yet protected, and periodic advisories, such as the requirement that pets must be kept on a leash in such settings and are prohibited from known seabird breeding islands during breeding seasons.

Despite their long-term habitation, opossum presence on some islands has potentially contributed to declines in seabirds since their introduction. Diligent efforts should be made to ensure opossums are not introduced to additional islands, especially those with significant seabird populations or sensitive species, such as endemic reptiles. Given that opossums are subject to a managed hunting season in both nations, hunting, trapping, and relocation could be an effective alternative to traditional methods, conditional on seasonal and protected area regulations. Any rodent eradication efforts must avoid risks to human health, such as through consumption of harvested opossum that may have ingested poisonous bait.

Although mongooses (*Herpestes auropunctatus*) are present on the neighbouring mainlands of Grenada and Saint Vincent, there are no existing records for any islands in the Grenadines. Mongooses have been detrimental to many West Indian faunal populations, including those in Grenada (e.g., the Critically Endangered endemic Grenada Dove [*Leptotila wellsi*]) and Saint Vincent (e.g., extinction of the Saint Vincent rice rat [*Oligoryzomys victus*]; Borroto-Páez and Woods 2012). Given the presence of sensitive and endemic species in the Grenadines and the importance of the archipelago for nesting birds, prevention of mongoose expansion into the Grenadines, including inhabited islands, should remain a high priority (Henderson and Berg 2006).

Conclusion and Recommendations

Existing breeding seabird populations in the Caribbean have been drastically reduced from the burgeoning populations that formerly bred on main islands prior to human occupation of the region, and breeding sites have been constricted to the most remote and inaccessible locations (Schreiber and Lee 2000). Despite the significant breeding seabird populations remaining in the Grenadines, the presence of introduced mammals at breeding sites throughout the archipelago is most certainly supressing wildlife populations and biodiversity. Addressing the threat of introduced mammals requires immediate attention to prevent extirpations at remaining seabird nesting sites, which are crucial for rebuilding decimated Caribbean populations. Eradications of introduced mammals have proven to benefit seabird colonies (Daltry *et al.* 2012) and other native species (Knight 2018, Donihue *et al.* 2020) globally, including in the Caribbean region.

Priority actions should focus on addressing the presence of introduced mammals on islands that meet global and regional IBA criteria, with seabird species that are most susceptible to their negative impacts, and considering the presence of additional sensitive species, such as endemic reptiles and nesting sea turtles. Priority islands for restoration actions are: 1) Battowia Island, the only island in the Lesser Antilles that hosts two globally important seabird colonies, a BirdLife International IBA, and a national Wildlife Reserve, 2) Les Tantes East, which hosts a globally important seabird colony, and 3) Diamond Rock, which hosts four regionally important seabird colonies. Islands with nesting Audubon's Shearwater should be assessed for rodent presence due to their vulnerability to animal predation (Catholic Island, Pillories, Frigate Island, Rose Rock, and White Island; Bradley and Norton 2009). Frigate Island, although hosting three regionally significant populations, is subject to intense human activity and would therefore benefit from a customized management approach involving the landholders (Coffey and Collier 2020). Each of the aforementioned islands are also popular sites for harvesting seabirds, chicks, and eggs. Islands in the Tobago Cays Marine Park and Sandy Island Oyster Bed Marine Protected Area can avail of their protected statuses to access funding for restoration and enforce existing regulations with current personnel.

Anecdotal information, while not considered confirmed records, may prove useful in identifying areas for follow-up investigations, particularly where several independent accounts from individuals familiar with an island exist. Although "presence" is a valuable indicator, assessing abundance of introduced mammal populations would provide insight into the intensity of threat to seabird colonies and other native species.

Human dimensions present a complicated context for conservation and restoration of uninhabited Grenadine islands. Government-owned islands and protected areas can be targeted for invasive species removal programs given justification of existing legislation and convenience of ownership. Many islands, however, are privately owned, including some with protected status, others with seabird colonies meeting global IBA criteria (Battowia and Les Tantes), and many of the islands with regionally significant colonies. Privately owned islands could benefit from outreach programs and landholder arrangements, such as compensation for removal of goat populations or installation of exclusion fences. Some introduced mammals may temporarily

contribute to human food security, particularly the goats on uninhabited islands. While goats are known to withstand extreme dry conditions, many of the small island ecosystems in the Grenadines likely cannot sustain increasing populations of other ungulates long-term, particularly given the pronounced dry season and decreasing amount of vegetative cover. Though seabirds and the overall terrestrial and nearshore biodiversity could benefit from reducing introduced mammal presence on uninhabited islands, ownership, land use, and reliance on livestock by local inhabitants must be considered. Prevention and removal of non-native mammals are traditional conservation strategies, though alternative management arrangements such as a zoning program may prove useful in some cases. Such a zoning program could range from individual island to a national level, especially in the context of shared transboundary resources and common conservation issues (e.g., development and seabird harvesting). A transboundary marine zoning scenario was previously proposed for the Grenadines, but no similar efforts have been made for terrestrial areas (Baldwin 2012).

Failed eradication efforts are often attributed to socioeconomic and cultural factors, such as being denied access to private lands, lack of political support, and lack of support from local residents (Campbell and Donlan 2005). Public support is crucial for ensuring success of any eradication campaigns and to prevent reintroductions of species, particularly goats, to offshore islands (Clout and Veitch 2002). Given the financial expense involved in eradications, consideration must be given to the likelihood of reintroduction. Under such circumstances, funds and efforts to mitigate reintroductions, such as public education, would be justified (Carrion *et al.* 2011). Education campaigns detailing the effects of invasive species, applicable prohibitive legislation, and benefits of eradication or control efforts to biodiversity must occur in tandem with any management programs. The usefulness of seabirds to fisherfolk in both nations for locating schools of fish, navigating, and understanding weather patterns is well documented and provides a tangible link between local livelihoods and protecting seabird populations (Coffey and Ollivierre 2019, Coffey and Collier 2020). Further socioeconomic rationale for reduction or elimination of introduced mammals from islands must be identified to provide strategic reasoning for local communities, such as impact assessments of non-native mammals on biodiversity and agricultural operations (Hagen and Kumschick 2018).

Given the dynamic and ongoing nature of livestock reintroductions to offshore islands in the Grenadines, periodic monitoring and removal programs are necessary to ensure continued protection of native flora and fauna from invasive species. Enforcement of protective legislation pertaining to invasive species, such as the release of livestock in designated wildlife reserves and protected areas, is imperative to deter future occurrences. Monitoring and enforcement programs could benefit from alternate technologies, such as drones and remote camera traps. Actions to remove introduced mammals and prevent their destruction of native flora and fauna will only prove successful when complemented by sufficient monitoring and strict enforcement. Given the large geographic scope and remote, inaccessible setting of many Grenadine islands, citizen-science programs could contribute valuable information and prove to be more cost-effective than traditional monitoring approaches (Coffey and Collier 2020).

Non-native mammals present on uninhabited islands, although destructive, are but one of many factors influencing seabird populations in the Grenadines. Lowrie *et al.* (2012) listed seabird exploitation by residents of both Grenada and SVG as the primary threat to seabirds in the Grenadines, which continues to be extensive (Coffey and Collier 2020). Additional threats such as uncontrolled development, pollution, deterioration of habitat, disturbance through visitation, and vegetation control fires on uninhabited islands present a complex conservation and management scenario for the preservation of native biodiversity. A cumulative effects analysis of threats to seabirds and the overall biodiversity on uninhabited islands in the Grenadines would contribute to their preservation in this transboundary ecoregion.

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Title Page Illustration

Feral goats (*Capra hircus*) cause disturbance to a regionally important Laughing Gull (*Leucophaeus atricilla*) colony on Frigate Island, Grenada in 2017. Goats can be found throughout globally and regionally important seabird colonies in the transboundary Grenadines. Photo by Juliana Coffey.

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Appendix 1. Dates and number of surveys per year (in brackets) of boat- and land-based surveys conducted on each island in the Grenadines by JC and Grenadines Seabird Guardians 2019–2020.

	Boat-based Surveys			Land-based Surveys		
Island	**2019**	**2020**	**Total**	**2019**	**2020**	**Total**
All Awash	—	16 Jul [1]	1	—	—	0
Baradal	6 May, 27 Jul, 19 Aug [3]	3 Aug [1]	4	13 Jul [1]	—	1
Battowia	—	—	0	13 Dec [1]	16 Jul [1]	2
Big Cay	23 Feb [1]	—	1	—	—	0
Catholic Island	6 May, 2 Jun [2]	3 Aug [1]	3	—	—	0
Diamond Rock	21 Mar, 20 May, 5 Jul, 4 Aug, 16 Aug, 20 Aug [6]	3 Jul, 17 Jul, 19 Jul, 29 Aug [4]	10	—	—	0
Ellen Rock/Round Cay	2 Jun [1]	—	1	—	—	0
Frigate Island	9 Mar, 12 Apr, 28 May, 14 Jul [4]	4 May, 4 May, 8 Jun, 20 Oct, 5 Dec [5]	9	4 Apr, 27 Apr, 14 Jul [3]	16 Jul [1]	4
Isle à Quatre	23 Feb [1]	—	1	—	—	0
Isle de Caille	—	—	0	—	4 Jul, 5 Jul [2]	2
Isle de Ronde	11 Jul [1]	29 Aug [1]	2	—	—	0
Jack A-Dan	21 Oct, 27 Oct [2]	10 Feb, 13 May, 3 Jun, 19 Jun, 27 Jun, 2 Sep, 31 Oct, 21 Nov [8]	10	—	15 Jul [1]	1
Jamesby	6 May, 27 Jul, 19 Aug [3]	3 Aug [1]	4	—	—	0
Large Island/Laidlarge	9 Mar [1]	14 May, 8 June, 16 Jul, 20 Oct, 5 Dec [5]	6	—	—	0
Les Tantes	5 Aug [1]	3 Jul [1]	2	—	—	0
Little Mel/Little Mushroom	9 Mar [1]	—	1	—	—	0
London Bridge	20 May [1]	—	1	—	—	0
Mabouya	11 Mar, 15 Apr, 15 Jul, 7 Sep, 9 Sep, 20 Sep, 21 Oct, 28 Oct [8]	10 Feb, 9 Apr, 13 May, 3 Jun, 19 Jun, 27 Jun, 15 Jul, 2 Sep, 11 Oct, 31 Oct, 21 Nov [11]	19	—	11 Oct [1]	1
Mushroom (GwoCola/Cola)	8 Feb, 9 Mar, 12 Apr [3]	4 May, 14 May, 8 June, 16 Jul, 20 Oct, 29 Oct, 2 Nov, 5 Dec [8]	11	—	—	0
Pelican Cay/Flat Cay	2 Jun [1]	—	1	—	—	0
Petit Canouan	4 Jun [1]	—	1	14 Dec [1]	—	1

Appendix 1 cont.

	Boat-based Surveys			Land-based Surveys		
Island	**2019**	**2020**	**Total**	**2019**	**2020**	**Total**
Petit Cola	9 Mar [1]	20 Oct, 29 Oct, 5 Dec [3]	4	—	—	0
Petit Nevis	23 Feb [1]	—	1	—	—	0
Petit Rameau	6 May [1]	—	1	—	—	0
Pigeon Island	23 Feb [1]	—	1	—	—	0
Pillories (Big, Small, and Middle)	13 Dec [1]	16 Jul [1]	2	—	—	0
Rose Rock	—	14 May, 8 Jun, 5 Dec [3]	3	—	—	0
Saline Island	11 Feb [1]	5 Dec [1]	2	9 Mar, 12 Apr, 1 Jul [3]	17 Jul [1]	4
Sandy Island CCOU	3 Mar, 11 Apr, 15 Jul, 20 Sep [4]	10 Feb, 13 May, 3 Jun, 19 Jun, 27 Jun, 15 Jul, 2 Sep, 31 Oct, 21 Nov [9]	13	19 Apr [1]	—	1
Sandy Island GRE	—	—	0	5 Aug [1]	4 Jun, 14 Jun, 24 Jun, 23 Jul, 24 Jul, 20 Sep [6]	7
Sisters Rocks (Large and Small)	11 Mar, 19 Apr, 15 Jul, 18 Aug, 8 Sep, 9 Sep, 20 Sep [7]	10 Feb, 29 Apr, 13 May, 3 Jun, 19 Jun, 27 Jun, 15 Jul, 2 Sep, 6 Oct, 31 Oct, 5 Nov [11]	18	—	—	0
Syrup/Chirrup Cay	23 Feb [1]	—	1	—	—	0
Upper Rock and Lee Rock (The Sisters/Brothers)	5 Jul, 11 Jul, 4 Aug, 20 Aug [4]	3 Jul, 17 Jul, 19 Jul, 29 Aug [4]	8	—	—	0
West Cay	23 Feb [1]	—	1	—	—	0
White Island	9 Mar, 12 Apr [2]	14 May, 8 Jun, 17 Jul, 20 Oct, 5 Dec [5]	7	16 Mar [1]	27 Sep [1]	2