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Review article

# The catastrophic impact of invasive mammalian predators on birds of the UK Overseas Territories: a review and synthesis

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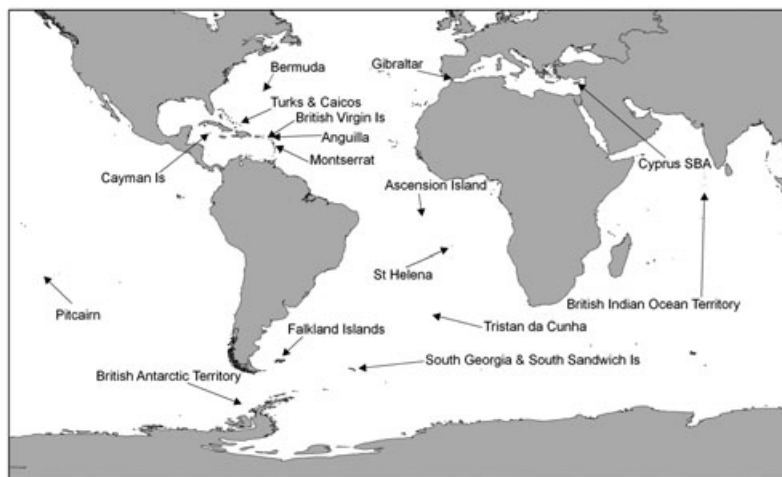
The UK has sovereignty over 16 Overseas Territories, which hold some of the world's great seabird colonies and collectively support more endemic and globally threatened bird species than the whole of mainland Europe. Invasive alien mammalian predators have spread throughout most of the Territories, primarily since European expansion in the 16th century. Here we review and synthesize the scale of their impacts, historical and current, actions to reduce and reverse these impacts, and priorities for conservation. Mammalian predators have caused a catastrophic wave of extinctions and reductions in seabird colony size that mark the UKOTs as a major centre of global extinction. Mammal-induced declines of threatened endemics and seabird colonies continue, with four Critically Endangered endemics on Gough Island (Tristan da Cunha), St Helena and Montserrat directly threatened by invasive alien House Mice *Mus musculus*, Feral Cats *Felis catus* and rats *Rattus* spp. Action to reduce these threats and restore islands has been modest in comparison with other developed countries, although some notable successes have occurred and a large number of ambitious eradication and conservation plans are in preparation. Priority islands for conservation action against mammalian predators include Gough (which according to one published prioritization scheme is the highest-ranked island in the world for mammal eradication), St Helena and Montserrat, but also on Tristan da Cunha, Pitcairn and the Falkland Islands. Technical, financial and political will is required to push forward and fund the eradication of invasive mammalian predators on these islands, which would significantly reduce extinction risk for a number of globally threatened species.

**Keywords:** cat, endemic species, introduced species, pig, rat, seabird.

Unbeknown to many of its citizens, the United Kingdom retains sovereignty over 16 Overseas Territories (hereafter UKOTs). With the exception of Gibraltar, Cyprus Sovereign Base Areas and British Antarctic Territory, the UKOTs comprise islands and archipelagos scattered across the Atlantic, Indian, Pacific and Southern Oceans and the Caribbean Sea (Fig. 1). As with other oceanic islands, they are of considerable importance to biodiversity (Procter & Fleming 1999), supporting 24 endemic breeding bird species, a similar number to the

whole of Europe including its northern Atlantic islands (BirdLife International 2009). Six of the Territories lie within global biodiversity hotspots (Myers *et al.* 2000, Conservation International 2009), and 10 of them comprise or lie within Endemic Bird Areas or Secondary Areas (Stattersfield *et al.* 1998). They also include some of the world's greatest seabird colonies, in particular on Gough Island (Tristan da Cunha) and South Georgia, where populations of tens of millions of albatrosses (Diomedidae), burrowing petrels (Procellariiformes) and penguins (Spheniscidae) occur (Prince & Croxall 1996, Angel & Cooper 2006) (Fig. 2). The global Red List (BirdLife

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**Figure 1.** Location of UK Overseas Territories.

International 2009) indicates that this biodiversity is under substantial threat. The UKOTs currently support breeding populations of 34 globally threatened bird species, and 22 of the 24 endemic breeding bird species are threatened or near-threatened. Nevertheless, the UKOTs' biodiversity remains surprisingly obscure in the scientific literature, and according to recent reports of the UK legislature (House of Commons Environmental Audit Committee 2008, House of Commons Foreign Affairs Committee 2008), receives rather little attention from the UK Government (which signs Multilateral Environment Agreements on the Territories' behalf).

While habitat loss and climate change are undoubtedly important threats, the role of invasive alien species in the UKOTs requires particular attention, as the threat of invasive species is particularly severe for island endemic species and seabird colonies (Millennium Ecosystem Assessment 2005). Invasive predatory mammals are a particular threat to bird species (Moors & Atkinson 1984, Burger & Gochfeld 1994), and here we review their spread across the UKOTs, their impacts on birds, both historical and current, recent efforts to mitigate their impact and future conservation prospects. The Caribbean UKOTs of Turks and Caicos Islands (TCI), Cayman Islands, British Virgin Islands and Anguilla, for which data on distribution and impacts of mammalian predators are less clear (e.g. see Varnham 2006), and which have few extant endemic bird species, are considered in less detail. We omit Gibraltar, as it is part of the

European mainland and inherently less likely both to be colonized by invasive mammalian predators and to be affected by them. We also exclude Crown Dependencies, the Cyprus Sovereign Base Areas, and British Antarctic Territory which are (debatably) not UKOTs in the strict sense.

## ARRIVAL AND SPREAD OF INVASIVE ALIEN PREDATORY MAMMALS

The mammalian species of major concern in the UKOTs are the same species that have invaded islands worldwide (Moors & Atkinson 1984). These are three species of commensal rat (Ship Rat *Rattus rattus*, Norway Rat *Rattus norvegicus* and Kiore or Pacific Rat *Rattus exulans*), and the Feral Cat *Felis catus*. Feral Pigs *Sus scrofa* are also significant predators. The Small Indian Mongoose *Herpestes auropunctatus* is known from just one of the Caribbean UKOTs, British Virgin Islands, although it is widespread in the Caribbean region (Kairo *et al.* 2003), and the Patagonian Fox *Dusicyon griseus* has been introduced to the Falkland Islands (Hall *et al.* 2002). House Mice *Mus musculus*, although extremely widespread on islands, and found on almost all UKOTs, are not generally considered to be significant predators of birds and their nests (Burger & Gochfeld 1994, Chapuis *et al.* 1994). However, recent evidence from Gough Island has demonstrated that they can evolve devastating predatory behaviour (Cuthbert & Hilton 2004, Wanless *et al.* 2007). Feral Dogs *Canis familiaris* are present on all UKOTs except

British Indian Ocean Territories (BIOT) and South Georgia and South Sandwich Islands (SGSSI). Domestic dogs undoubtedly predate birds on occasion, but it is not clearly established whether true feral populations exist anywhere in the Territories, although they are reported from Turks and Caicos, Cayman Islands and Montserrat (Sanders 2006, G. Hilton pers. obs.) along with historical occurrences on Tristan da Cunha (Cuthbert *et al.* 2009).

The vast majority of the land area of the Territories has been invaded by predatory mammals (Table 1). The few major islands free of mammalian predators include the South Sandwich Islands (310 km<sup>2</sup>) (which also lack terrestrial birds). Nightingale (400 ha) and Inaccessible Islands (1400 ha) (Tristan da Cunha) are mammal-free, although the latter did support a now-extirpated population of Feral Pigs. Among nearly 800 islands in the Falkland Islands, over 100 are believed to be free of mammalian predators, including several large ones such as Lively (5585 ha), Speedwell (5150 ha), George (2400 ha), and Carcass (1894 ha) (Falklands Conservation & RSPB unpubl. data). In the South Georgia territory, Annenkov (~850 ha), Bird Island (~400 ha), to Cooper Island (259 ha) and Willis Islands (~250 ha) are mammal-free. In BIOT, Danger Island (66 ha) and Nelson Island (81 ha) are mammal-free (Symens 1999), as are Ducie (74 ha) and Oeno (62 ha) in the Pitcairn group. Apart from this, no islands larger than 50 ha in the UKOTs are known to be free of invasive mammalian predators (RSPB unpubl. data).

With the exception of Pitcairn, to which Polynesian settlers apparently introduced Kiore over 1000 years ago (Weisler 1995), the invasion of the UKOTs by mammalian predators commenced with European exploration in the early 16th century (Table 1). New conservation threats from invasive mammals continue to the present: so far as is known, Feral Pigs began their spread on Montserrat following the abandonment of farmland in the wake of the volcanic eruptions of 1996–1998 (Montserrat Department of Environment pers. comm.).

## HISTORICAL IMPACTS OF INVASIVE MAMMALIAN PREDATORS

### Endemic species extinctions

BirdLife International (2009) reports that among 34 bird species believed to have been endemic to

the UKOTs in 1500 AD, 10 are now likely to be extinct, which puts the UKOTs fifth globally among countries and associated territories with the highest number of avian extinctions, the highest ranking being USA and its Territories, France and its Territories (both with 29 species), New Zealand (18), Mauritius (16) and Australia and its Territories (13). The concentration of extinctions on islands is well known, but this analysis demonstrates the extent to which the Overseas Territories of developed nations are major extinction hotspots. Although direct evidence is largely lacking, eight of the 10 UKOT extinctions have been ascribed wholly or partly to invasive alien mammals (BirdLife International 2009).

Seven of the documented extinctions took place on St Helena, with one each on Tristan da Cunha, Grand Cayman and Ascension. In addition to those extinctions sufficiently well documented to have been recorded in the World Bird Database (BirdLife International 2009), there may also have been an endemic Night-heron *Nycticorax olsoni* lost from Ascension (Bourne *et al.* 2003) and several land-bird species lost from Bermuda since human colonization (in both cases in the early 16th century) (Wingate 1985). Furthermore, a number of earlier anthropogenic extinctions have also been suggested. Four species known from archaeological investigation on Henderson Island (Pitcairn) are now extinct – a *Prosobonia* sandpiper, a *Ducula* pigeon, a Ground-dove *Gallicolumba leonpascoi* and an archaic pigeon *Bountyphaps obsoleta* (Weisler 1995, Wragg 1995). These extinctions occurred following, and presumably as a result of, Polynesian occupation of the island and the arrival of commensal Kiore. Species extinctions may have occurred on Pitcairn Island, as on Henderson, during the period of Polynesian occupation (Benton & Spencer 1995).

### Seabird colony depletion

It is difficult to estimate the size of seabird colonies that were lost in the early stages of human exploration of the UKOTs. Nevertheless, a number of lines of evidence point to widespread losses of vast numbers of seabirds (Table 2). On Henderson Island, inferences about historical seabird population sizes have been made based on backward extrapolation of current rates of decline and population sizes to the time at which rats colonized the island; they suggest that millions of pairs of gadfly

**Table 1.** Arrival and current extent of invasive mammalian predators on UKOTs.

Territory	Total area (ha)	Arrival of mammalian predators		Current proportion of Territory occupied			
		Species	Arrival date (AD)	<i>Rattus</i> spp. (%)	Feral Cat (%)	Other species (%)	Predator-free (%)
Ascension	9700	Feral Cat	1815	99.95	0	0	0.05
St Helena	12 200	Ship Rat	1654–1754	~99.5	~99.5	0	0.5
		Feral Cat	16th century				
Tristan da Cunha	18 040	Ship Rat	1513–1665	55	0	House Mouse 90	10 <sup>d</sup>
		Norway Rat	1730–1800				
		Feral Cat <sup>a</sup>	Feral by 1824				
		(Tristan)					
		Ship Rat (Tristan)	1882				
Falkland Islands	1217 300	Feral Pig (Inaccessible) <sup>a</sup>	1821	97.7 <sup>e</sup>	94.1 <sup>e</sup>	0 <sup>e</sup>	2.3 <sup>e</sup>
		Feral Pig (Tristan) <sup>a</sup>	Before 1811				
		Patagonian Fox	1930s				
		Norway Rat	1725–1833				
South Georgia	375 500 <sup>f</sup>	Ship Rat	Late 18th century (New Island)	96 <sup>f</sup>	0 <sup>f</sup>	0 <sup>f</sup>	4 <sup>f</sup>
		Norway Rat	1830s				
		Feral Cat	~1800				
Bermuda	5500	Ship Rat	By 1613	99.7	99.7	0	0.3
		Norway Rat	Mid-late 18th century				
Montserrat	10 900	Feral Cat	Unknown <sup>c</sup>	99.9	99.9	Feral Pig ~60; Feral Dog ~99.9	0.1
		Ship Rat	Unknown <sup>c</sup>				
		Norway Rat	Unknown <sup>c</sup>				
Anguilla	10 200	Feral Cat	Unknown	98.9–99.6	≥94	0	0.4–1.1
		Feral Pig	~1998				
		Ship Rat	Unknown <sup>c</sup>				
British Virgin Islands	15 100	Norway Rat	Unknown <sup>c</sup>	≥83 <sup>g</sup>	≥77 <sup>g</sup>	Small Indian Mongoose ≥42 <sup>g</sup>	None known <sup>g</sup>
		Feral Cat	Unknown <sup>c</sup>				
		Ship Rat	Unknown <sup>c</sup>				
		Norway Rat	Unknown <sup>c</sup>				
		Feral Cat	Unknown				
Cayman Islands	26 300	Feral Pig	~1998	100	100	Feral Dog ~100	0
		Small Indian Mongoose	Unknown				
		Ship Rat	Soon after 1503				
Turks & Caicos Islands	50 000	Norway Rat	Discovery Presumably 1500s <sup>b</sup>	100?	~96.5	Feral Dogs widespread	~1–2
		Feral Cat	16th or 17th century				
		Ship Rat	Unknown <sup>c</sup>				
		Norway Rat	Unknown <sup>c</sup>				
Pitcairn Islands	4516	Feral Cat	Unknown	97	0	0	3
		Kiore	~800				
BIOT	4360	Feral Cat (Pitcairn)	Unknown	95.3	62 <sup>h</sup>	0	4.7
		Ship Rat	By 1840				
		Feral Cat	Unknown				

**Table 1.** (Continued)

Data from Symens (1999), Ashmole and Ashmole (2000), Hilton *et al.* (2001), Burton and Bloxam (2003), Angel and Cooper (2006), Sanders (2006), Varnham (2006) and sources therein.

<sup>a</sup>Subsequently extirpated.

<sup>b</sup>Given as this date in Varnham (2006) (with citation), but this seems unlikely given the generally much later spread of *Rattus norvegicus* worldwide.

<sup>c</sup>Date of arrival of rodents in the Caribbean UKOTs is little known, but in general, Ship Rats spread through the Caribbean from the early 17th century (Varnham 2006) and Norway Rats from 1700 onwards (Atkinson 1985, Varnham 2006).

<sup>d</sup>Calculation based on assuming that mice on Gough are predators of birds; for other Territories this assumption was not made and House Mouse presence is not reported.

<sup>e</sup>Percentages are based on a database of Falkland Islands containing predator information for 92% of the total area of the archipelago (Falklands Conservation & RSPB unpubl. data). Predator distribution among remaining area is unknown. Data for cats in Falklands includes Patagonian Fox.

<sup>f</sup>Area is the total area of South Georgia and surrounding islands. Percentage occupied by predators and predator-free is calculated based on the area free of permanent snow and ice only. Predator-free South Sandwich Islands (31 000 ha) are excluded from calculations.

<sup>g</sup>Comprehensive data for BVI were not found. Percentages occupied by cats and rats are minima based on sites of known presence. It seems probable that almost the entire land area is affected.

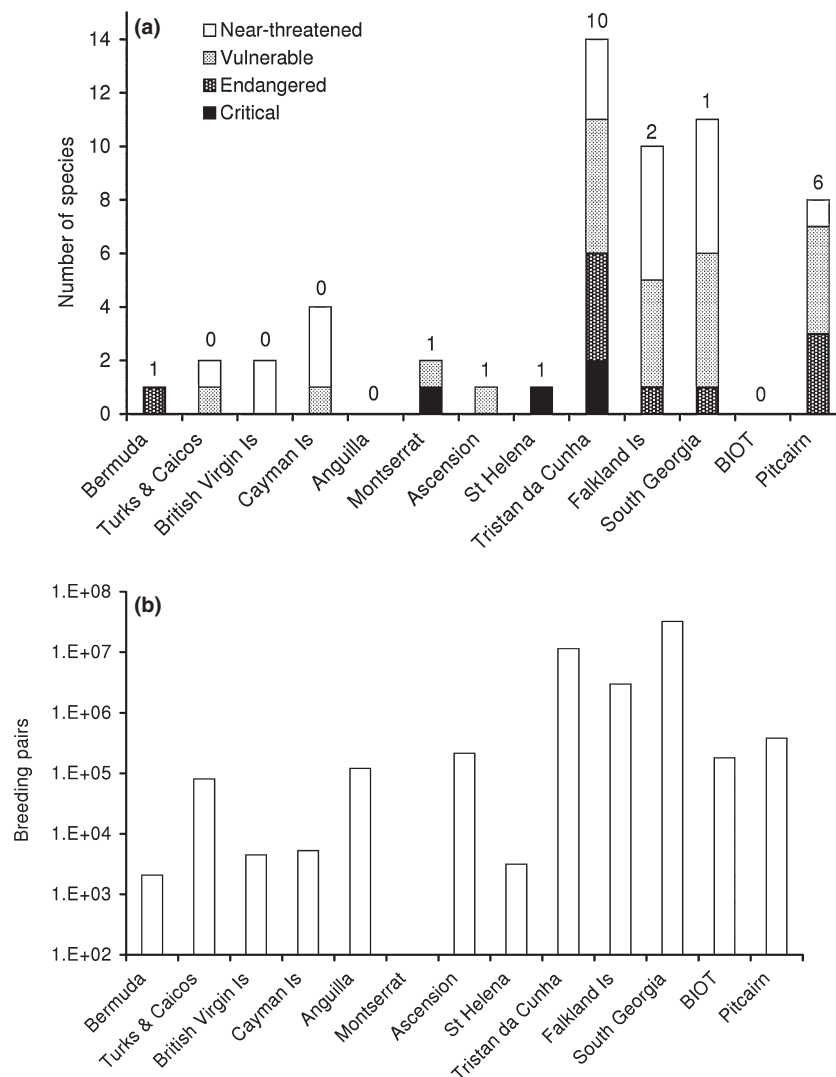
<sup>h</sup>Based on the assumption that cats are present on Diego Garcia only; presence on outer islands is not known, whereas an eradication programme has been underway on Diego Garcia in recent years.

**Table 2.** Inferred impacts of mammalian predators on breeding seabird community sizes in the UKOTs at selected islands where data exist to make comparisons.

Territory/Island	Impacts	Current population
Henderson Island/Pitcairn	'Gadfly Petrels... probably much less numerous than formerly, by 1–2 orders of magnitude' Back-calculating current Henderson Petrel population and decline rate suggests five million pairs at time of Kiore arrival (de Brooke <i>et al.</i> 2010)	39 600 pairs of <i>Pterodroma</i> spp. (de Brooke 1995b)
St Helena	'combined numbers were probably in the millions' (McCulloch 2004)	1000–10 000 pairs of all species (Ashmole & Ashmole 2000, McCulloch 2004)
Ascension	'numbers are...probably only a tiny fraction of those originally present' (Rowlands 2006)	~215 000 pairs of all species (Rowlands 2006, Hughes <i>et al.</i> 2008)
Tristan da Cunha	'before the introduction of rodents and cats...there were...probably millions of pairs' (Angel & Cooper 2006)	~25 000 pairs of all species (Angel & Cooper 2006)
BIOT	seabird density ~20× greater on rat-free islands ( $n = 8$ ) than rat-infested ( $n = 39$ ) (Symens 1999)	~100 000–180 000 pairs of all species (Symens 1999, McGowan <i>et al.</i> 2007)
South Georgia	'in rat-infested coastal areas...smaller burrowing petrel species have been eliminated' (Poncet 2006)	~35 million pairs of all species (Poncet 2006)

petrels *Pterodroma* spp. may have been lost (de Brooke *et al.* 2010). On St Helena and Ascension, early historical accounts, sub-fossils and the evidence of large guano deposits provide evidence of the former presence of very large seabird colonies, again with inferred losses of hundreds of thousands or millions of pairs.

A further way of making inferences about lost populations is to compare community structure of ecologically similar predator-free and predator-infested islands, such as the islands of Tristan, Nightingale, Inaccessible and Gough in the Tristan da Cunha Group (Fig. 3). Based on this figure, it is reasonable to surmise that in the order of millions

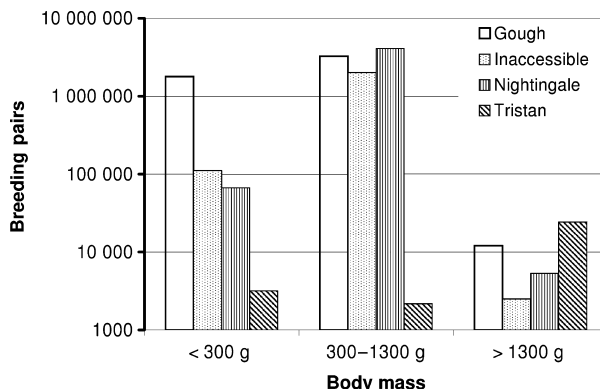


**Figure 2.** Summarized bird conservation value of the UK Overseas Territories. (a) Numbers of globally threatened and endemic bird species breeding on the Territory. Numbers above bars are number of bird species endemic to the Territory (BirdLife International 2009). (b) Estimated number of breeding seabird pairs. Data source for seabird population estimates: All wider Caribbean Territories: Bradley and Norton (2009); Ascension: Rowlands (2006), Hughes *et al.* (2008); BIOT: Symens (1999); Falkland Islands: Woods and Woods (1997), Catry *et al.* (2003), Reid and Huin (2005); Pitcairn: de Brooke (1995a,b, 2006); South Georgia and South Sandwich Islands: Prince and Croxall (1996), Poncet (2006); St Helena: Ashmole and Ashmole (2000), McCulloch (2004); Tristan da Cunha: Angel and Cooper (2006), Ryan (2005).

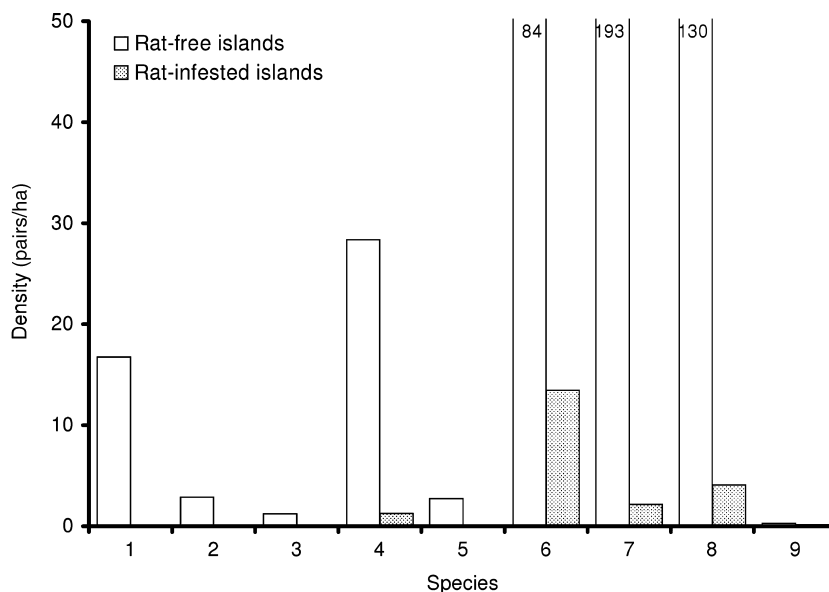
of smaller and medium-sized seabirds have been lost from Tristan, where introduced rats, Feral Cats and Feral Pigs are all likely to have had major impacts.

In cases where an archipelago comprises a mixture of predator-free and predator-infested islands, it is difficult to determine whether some species of seabirds have been reduced in number, or have simply redistributed to predator-free islands, with archipelago-wide populations being limited by

marine resources (Fig. 4). These questions are perhaps particularly pertinent for BIOT, South Georgia and Falkland Islands, which retain large populations of predator-sensitive seabirds on the remaining rat-free areas, and for which historical data on population sizes are lacking. Similarly, where mammalian predators have reached an island, it is conceivable that the total number or biomass of seabirds remains relatively constant, despite the loss of predator-sensitive species,



**Figure 3.** Abundance of procellariiform seabirds in different size classes at different islands in the Territory of Tristan da Cunha. Small procellariiforms are typically acutely vulnerable to rats because they may be predated as adults as well as eggs/chicks, and may thus suffer reduced adult survival. Mid-sized procellariiforms tend to be chronically vulnerable because they mainly suffer lower productivity. Larger procellariiforms are, in general, invulnerable to rats (Burger & Gochfeld 1994). Note the very low numbers of birds at Tristan – the only island in the group with rats – in the small and medium body size classes. Gough Island, where procellariiforms suffer major mouse predation on chicks, shows no obvious size-class difference to predator-free Inaccessible and Nightingale Islands, possibly because Gough mice are, peculiarly, known to impact even the largest procellariiform species (Wanless *et al.* 2007). The island areas are in the range 4 km<sup>2</sup> (Nightingale) to 99 km<sup>2</sup> (Tristan). Data are from Richardson (1984), Ryan (2005), Angel and Cooper (2006) and references therein.



**Figure 4.** Density of commoner seabird species in BIOT in relation to the presence of rats. For most species, population densities are far higher among rat-free islands. This may imply that the presence of rats on ~95% of the land area has caused a proportionate decrease in total seabird numbers. However, it is not easy to determine the extent to which redistribution of seabirds onto rat-free islands means that losses are smaller than this. Data from Symens (1999). Species with total BIOT populations >100 pairs are used. Population densities were calculated as total number in each island-class divided by the total area occupied by that island class. *n* = eight rat-free and 39 rat-infested islands. Species: 1 = Wedge-tailed Shearwater *Puffinus pacificus*; 2 = Audubon's Shearwater *Puffinus lherminieri*; 3 = Masked Booby *Sula dactylatra*; 4 = Red-footed Booby *Sula sula*; 5 = Brown Booby *Sula leucogaster*; 6 = Sooty Tern *Sterna fuscata*; 7 = Brown Noddy *Anous stolidus*; 8 = Lesser Noddy *Anous tenuirostris*; 9 = White Tern *Gygis alba*.

through a shift towards predator-insensitive species. For example, the penguins and albatrosses of the South Atlantic Territories, and possibly the tropical

booby *Sula* species appear to be relatively resistant to most mammalian predators (Burger & Gochfeld 1994, Jones *et al.* 2008) and could conceivably have



benefited from reductions in populations of smaller, predator-sensitive species.

## CURRENT IMPACTS

### Endemic bird species

Of the 22 threatened or near-threatened endemic breeding birds of the UKOTs, the World Bird Database suggests that invasive mammalian predators are a threat to 21, and the most severe threat to 14 (BirdLife International 2009). For seven of the most highly threatened species, the entire population is in ongoing decline as a result of invasive predators. For the Critically Endangered Tristan Albatross *Diomedea dabbenena*, Gough Bunting *Rowettia goughensis* and Montserrat Oriole *Icterus oberi*, the impacts are acute, resulting in a high risk of imminent extinction (Hilton *et al.* 2003, 2005, Cuthbert *et al.* 2004, Ryan & Cuthbert 2008, Wanless *et al.* 2009). The situation is marginally less severe for the Critically Endangered St Helena Plover *Charadrius sanctahelenae* and Endangered Atlantic Petrel *Pterodroma incerta*, Henderson Petrel *Pterodroma atrata*, and Pitcairn Reed Warbler *Acrocephalus vaughani* only by virtue of slightly slower decline rates (de Brooke 1995b, Cuthbert 2004, BirdLife International 2009, de Brooke *et al.* 2010).

A second group of UKOT endemic species are not currently declining as a result of mammalian predators but are believed to be very sensitive to any future introductions. Some of these appear robust to the invasive predators with which they currently co-exist, such as the four Vulnerable endemic land-bird species on Henderson Island, which co-occur with Kiore (de Brooke 1995a), Gough Moorhen *Gallinula comeri* (also Vulnerable), which apparently tolerates House Mice on Gough Island (Cuthbert & Sommer 2004), Atlantic Yellow-nosed Albatross *Thalassarche chlororhynchos* (Endangered), which appears tolerant of rodents on Tristan da Cunha, and the non-threatened Falkland Steamerduck *Tachyeres brachypterus*, which is abundant throughout the islands (Woods & Woods 1997). Conversely, two of these species (both globally Vulnerable) have their natural range entirely on mammal-free islands – Inaccessible Rail *Atlantisia rogersi* (endemic to Inaccessible Island, Tristan da Cunha) and Grosbeak Bunting *Nesospiza wilkinsi* (endemic to Inaccessible and Nightingale Islands).

A third group of six species have suffered major historical range reductions, but have persisted on mammal-free areas within their range. Tristan Bunting *Nesospiza acunhae* (Vulnerable) has been extirpated from Tristan da Cunha and Tristan Thrush *Nesocichla eremita* (Near Threatened) nearly so, but both persist on the much smaller mammal-free Nightingale and Inaccessible Islands (Angel & Cooper 2006). Cobb's Wren *Troglodytes cobbi* (Falkland Islands) and South Georgia Pipit *Anthus antarcticus* appear to be completely intolerant of rats (Prince & Croxall 1996, Hall *et al.* 2002). Their extinction has been averted by the continued presence of rat-free remnants on their respective Territories. However, the spread of rats through their ranges is ongoing. For example, Bleaker Island (2070 ha), a major predator-free area in the Falklands, was invaded by Norway Rats as recently as the mid 1980s, with the subsequent loss of Cobb's Wren (Falklands Conservation & Falkland Islands Government 2008). In South Georgia, Saddle Island (~100 ha) was invaded by Norway Rats, perhaps across an ice bridge, during the last decade (S. Poncet pers. comm.), and in places where glaciers formerly came down to sea level, creating physical barriers, glacial retreat is likely to expose new areas of the main island to rat colonization (Poncet 2006, BirdLife International 2009). By 1951, Bermuda Petrel *Pterodroma cahow*, formerly widespread and abundant on Bermuda, was reduced to 18 pairs on <1 ha of offshore islets by mammalian predators; extinction was averted because these low-quality nesting areas were free of all but occasional rat incursions, and the population is now recovering due to conservation action (see below) (Wingate 1985, BirdLife International 2009). Similarly, Ascension Frigatebird *Fregata aquila* was extirpated from the main island of Ascension by cat predation and now breeds only on a 3-ha offshore stack (Ashmole & Ashmole 2000, Ratcliffe *et al.* 2008), although cat eradication from the main island appears to have created the conditions for recovery (see below). Finally, Spectacled Petrel *Procellaria conspicillata*, endemic to Inaccessible Island, was driven to near extinction by Feral Pigs by the early 20th century; its survival and subsequent recovery is apparently due to the serendipitous eradication of the Pigs for non-conservation reasons before extinction occurred (Ryan *et al.* 2006).

## Seabird communities

It might seem reasonable to assume that, except where invasive species continue to spread to new areas (see above), seabird populations in the UKOTs have now reached stable equilibria with respect to the impacts of mammalian predators. In most cases, data are inadequate to determine whether this is the case, but several lines of evidence suggest that some populations and communities may still be in decline. de Brooke *et al.* (2010) have shown that where breeding success of long-lived petrel species is chronically reduced by invasive predators, population declines can continue over many centuries before extirpation finally occurs. This is particularly likely to occur where predation is largely on eggs/chicks rather than on adults – as is typically the case where rodents are the only predators, and/or the seabirds are not very small (Jones *et al.* 2008). The implications of this for seabirds on the UKOTs' two World Heritage Sites – Gough and Henderson Islands – are potentially severe. Thus it is thought that populations of *Pterodroma* petrels on Henderson are continuing their downward trajectory following the Polynesian introduction of Kiore a millennium ago (de Brooke 1995b). For Henderson Petrel, which is not known to have source populations on other islands, extinction will eventually occur, and Phoenix Petrel *P. alba* may already have been extirpated from the island (Murphy & Pennoyer 1952). Similarly, heavy mouse predation on chicks of Tristan Albatross and Atlantic Petrel is sufficient to drive population declines even though the mice have been present for up to 200 years (Cuthbert 2004, Wanless *et al.* 2009). It is not clear what proportion of Gough's wider seabird community of 20 extant species is also in long-term decline. Angel and Cooper (2006) speculate that smaller burrow-nesting species, and in particular those that have chicks in the nest during winter, are likely to be particularly susceptible – which might implicate winter-breeding Great-winged Petrel *Pterodroma macroptera* and Grey Petrel *Procellaria cinerea* as well as the small storm-petrels (Hydrobatidae) and diving-petrels (Pelecanoididae). Angel and Cooper (2006) also suggested that the remnant petrel populations reported as having survived long-term rat and cat predation on Tristan da Cunha in the early 1970s (Richardson 1984) were still likely to be declining, and some may already have been lost, except where immigration

from nearby predator-free sources maintains small sink populations.

Ratcliffe *et al.* (2008) showed that where seabirds are confined to nesting on small predator-free islands near to (often much larger) islands that have predators, predation of adult seabirds that attempt to settle on the predator-inhabited islands can limit the size of the population as a whole. This probably applied to the endemic Ascension Frigatebird prior to cat eradication on Ascension's main island (Ratcliffe *et al.* 2008), and might plausibly apply even for large seabirds on St Helena, parts of the Falkland Islands and several of the Caribbean Territories, where cats, Patagonian Foxes and mongooses are variously present on large islands close to remaining seabird colonies. It might also affect small seabirds that are vulnerable to predation of adults by rats at sites such as Ascension, Tristan da Cunha, South Georgia and BIOT.

There are certainly anomalous situations in the UKOTs (as elsewhere) where seabirds unexpectedly tolerate mammal presence, the most striking of which is at New Island (2363 ha, Falkland Islands), where two million pairs of Thin-billed Prion *Pachyptila belcheri* persist, and appear to have high breeding success, in the presence of Ship Rats and Feral Cats (Catry *et al.* 2007). Similarly, the impacts of rodents on a number of tropical seabird species seems to be rather variable and unpredictable (Jones *et al.* 2008). For sites where tropical seabird populations persist in the presence of rats, such as BIOT (Symens 1999, McGowan *et al.* 2007), Dog Island (Anguilla) (Hodge & Holliday 2006) and Henderson Island (de Brooke 1995b), data are simply not adequate to determine whether their continued presence indicates population stability, or whether in fact the populations are declining and/or sustained by immigration (and therefore acting as a sink to the wider population).

## CONTROL AND ERADICATION OF INTRODUCED MAMMALIAN PREDATORS IN THE UKOTs

Rat and cat eradications from islands have become a major conservation industry in recent years, with recent reviews showing that around 300 and 50 islands have been cleared of the two taxa, respectively (Nogales *et al.* 2004, Howald *et al.* 2007). A number of control and eradication actions have taken place in the UKOTs (Table 3). One of the earliest and most important rat eradications took

**Table 3.** Control and eradication attempts for invasive mammalian predators in UKOTs.

Territory	Species	Activity	Date	Bird population response
Ascension Island	<i>Felix catus</i>	Eradication from main island (9700 ha)	2001–2004	Recolonization by at least five seabird species; Sooty Tern population increasing
Tristan da Cunha	<i>F. catus</i>	Eradication from Tristan da Cunha (9837 ha)	1970s	No published data
Tristan da Cunha	<i>Sus scrofa</i>	Eradication from Tristan da Cunha and Inaccessible Islands (1400 ha)	Early 20th century (for hunting)	Probable recovery of Spectacled Petrel on Inaccessible Island
Falkland Islands	<i>Rattus norvegicus</i>	Eradication from ~25 islands (~465 ha)	2001–2009	No published information. Evidence of increasing land-bird populations; no Cobb's Wren colonization (R. Woods unpubl. data)
Falkland Islands	<i>Dusicyon griseus</i>	Eradication on Tea Island (310 ha)	2008	Too early for bird population response
Bermuda		Eradicated from Nonsuch Island (5.8 ha)	Before 1985	Increased productivity and population recovery of Bermuda Petrel
Turks & Caicos	<i>Rattus rattus</i>	Eradication from four small cays (5.7 ha)	2002	No published information
Turks & Caicos	<i>F. catus</i>	Eradication from Long Cay (111 ha)	1999	No published information
Cayman Islands	<i>F. catus</i> & <i>Canis familiaris</i>	Control in two Grand Cayman Blue Iguana <i>Cyclura lewisi</i> sites	From 2001	No published information for birds
Montserrat	<i>R. rattus</i> & <i>R. norvegicus</i>	Control in 13 ha of Centre Hills forest	2006–2008	No published information
Montserrat	<i>S. scrofa</i>	Control in Centre Hills forest (~1200 ha)	2002–2004	No data published
British Virgin Islands	<i>R. rattus</i>	Eradicated on Sandy Cay (5.7 ha)	2002	No data published
BIOT	<i>R. rattus</i>	Failed eradication on Eagle Is (244 ha)	2006	No impact expected
BIOT	<i>F. catus</i>	Control towards eradication, Diego Garcia (2720 ha)	~2001 onwards	Apparent increase in Red-footed Booby colony
Pitcairn	<i>F. catus</i>	Eradication from Pitcairn (660 ha); subsequently reintroduced	1997	No published information
Pitcairn	<i>Rattus exulans</i>	Eradication from Oeno (62 ha) and Ducie (74 ha); failed on Pitcairn	1997	No published information

References: Nogales *et al.* (2004), Carr (2005, 2006), Angel and Wanless (2006), Mitchell *et al.* (2006), Rowlands (2006), Ryan *et al.* (2006), Falklands Conservation & Falkland Islands Government (2008), Hughes *et al.* (2008), Miller (2008), BirdLife International (2009), G. Hilton (pers. obs.).

place in the UKOTs: the pioneering removal of rats from Nonsuch Island in Bermuda, which played an important role (with other interventions) in allowing the recovery of the then Critically Endangered Bermuda Petrel (Wingate 1985, BirdLife International 2009). Similarly, one of the world's largest cat eradication programmes took place on Ascension Island during 2001–2006. From data in

Nogales *et al.* (2004) and Howald *et al.* (2007), it is evident that among developed nations with substantial island possessions, New Zealand and Australia have made far more progress in removing mammalian predators from islands than have the UK, the USA or France (Table 4).

A major scaling-up of rodent eradication efforts is being planned for the UKOTs, with feasibility

**Table 4.** Eradications of invasive mammalian predators among islands of developed nations and their overseas territories.

	Island eradication coverage			
	Rodents		Cats	
	No. of islands	Total area (ha)	No. of islands	Total area (ha)
Australia	34	3328	5	13 884
France <sup>a</sup>	34 (20)	1191 (1097)	1 (1)	145 (145)
NZ	89	27 012	10	6937
UK <sup>a</sup>	22 (18)	1418 (236)	2 (2)	771 (771)
USA <sup>a</sup>	12 (3)	1114 (296)	3 (3)	721 (721)

Data are from Nogales *et al.* (2004) and Howald *et al.* (2007). There have been many operations subsequent to these publications, but no comprehensive database has been published.

<sup>a</sup>Figures in parentheses are for the Overseas Territories of the country. For USA, Hawaii is included as part of the 'metropolitan' USA.

studies and operational plans completed or in development for major sites such as Gough Island (House Mouse, 6400 ha (Parkes 2008)), Tristan da Cunha (Ship Rat and House Mouse, 9837 ha (Brown 2007a,b)), Henderson Island (Kiore, 3700 ha (de Brooke & Towns 2008)), and even South Georgia (D. Christie, Government of South Georgia pers. comm.). However, the funding required for eradication on this scale (>£1 million, see Martins *et al.* (2006)) has not yet been obtained for any of these potential operations.

### PRIORITIES FOR MAMMALIAN PREDATOR CONTROL AND ERADICATION

The largest island hitherto cleared of rats is 11 300-ha Campbell Island (New Zealand), of cats is 29 000-ha Marion Island (South Africa), of mice is 710-ha Enderby Island (New Zealand) and of pigs is 58 465-ha Santiago (Galapagos Island, Ecuador, Cruz *et al.* (2005)), with maximum sizes increasing rather rapidly over time (Towns *et al.* 2006). The eradication of House Mice from Gough Island is clearly a high priority (see above; Cuthbert & Hilton 2004, Angel & Cooper 2006, Wanless *et al.* 2007), but the largest island cleared of mice is an order of magnitude smaller than Gough. However, an eradication of mice was conducted on 1200-ha Coal Island (New Zealand) in 2008, with the outcome currently unconfirmed (N. Torr pers. comm.), and in 2010 there will be an attempt to remove House Mice, Ship Rats and Rabbits *Oryctolagus cuniculus* from 12 200-ha Macquarie Island (Australia) in a single operation (Anon 2007).

An obvious obstacle to island restoration in the UKOTs is that eradication methods for islands inhabited by humans are in their infancy (Merton *et al.* 2000, Brown 2007a), meaning that eradications (especially of rodents) – and subsequent quarantine – from the 'main islands' such as Ascension, St Helena, Tristan, most of the Caribbean Territories and Pitcairn – would be breaking new ground. However, alternative options do exist for reducing mammal impacts at such sites. Large-scale mammalian predator control is now successfully deployed across large areas of New Zealand and Australia (Saunders 2000, Gillies 2002); for example, the Te Urewera Mainland Island in Northern New Zealand covering several thousand hectares. Mammal exclusion through fencing has also achieved some notable successes, such as the 3400-ha Maungatatauri Sanctuary (New Zealand) (<http://www.maungatrust.org>) and even the 225-ha Karori Sanctuary, which has excluded mammals, including House Mice, from a natural area in the capital city, Wellington (Lukis & Bell 2007). This indicates that almost all of the uninhabited islands (or those with human populations substantially <1000 such as Pitcairn, many of the Falkland Islands, Tristan da Cunha, and some in the Caribbean) in the UKOTs are broadly within the compass of what has already been achieved for eradication of mammalian predators – the exceptions being the very large main islands of the Falklands and South Georgia. Meanwhile, there is potential for predator control and exclusion at selected locations within other Territories, such as Ascension, St Helena and Montserrat.

Given this broad range of possibilities, some thought should clearly be given to prioritization.

Apart from birds, there are many other native and endemic populations, communities and habitats for conservationists to consider in a prioritization exercise – perhaps especially the considerable numbers of endemic reptiles and plants in the UKOTs (Procter & Fleming 1999). Other taxon specialists are required to undertake similar analyses in the UKOTs, allowing a more comprehensive assessment. However, purely in the context of control and eradication of mammalian predators of bird species, a number of priority conservation actions suggest themselves (Table 5).

de Brooke *et al.* (2007) and Ratcliffe *et al.* (2009) described systems for prioritizing island eradications based on the magnitude of benefits to threatened bird species and the estimated financial cost. A re-analysis of de Brooke *et al.*'s (2007) global analysis incorporating changes in species' Red List status since the paper was published results in Gough being the highest priority island in the world for mammal eradication. As the authors pointed out, this analysis offered only a partial prioritization, because it ignored effects on non-threatened bird species, perhaps especially on seabird communities (as opposed to the threatened species therein, which were included), which are particularly important on UKOTs (and other islands). However, as Gough is also 'arguably the world's greatest seabird island' (Collar & Stuart 1985), and it is suspected that several of the non-threatened seabird species are also being impacted by mice (Angel & Cooper 2006), the conclusion that Gough should be top of the world's island restoration priorities is likely to hold. Mouse eradication on Gough would greatly reduce the probability of extinction for three UKOT endemic bird species, of which two are Critically Endangered. Activities on St Helena, Montserrat, Henderson, Pitcairn, Tristan da Cunha and the Falkland Islands would also significantly benefit globally threatened endemics (Table 5). The Centre Hills of Montserrat also support the world's only population of the Critically Endangered Montserrat Galliwasp *Diploglossus montiserrati* (Reptilia: Diploglossidae) and one of the last remaining populations of Mountain Chicken *Leptodactylus fallax* (Amphibia: Ranidae), also Critically Endangered. Both are believed to be highly sensitive to mammalian predators and action against such predators is strongly recommended in recent action plans (Martin *et al.* 2007, L. Martin, M.N. Morton, G.M. Hilton, R.P. Young, G. Garcia, G. Gray & S.

Mendes in prep., Young 2008). Major conservation benefits would probably also accrue on many islands that lack sensitive threatened bird species if mammalian predators were eradicated, controlled or excluded, as there is potential for at least partial recovery of the massive lost seabird colonies of Ascension, St Helena, South Georgia, BIOT and possibly also the Caribbean Territories.

Clearly, other actions against invasive species, such as preventing further incursions and rapidly responding to any that do occur, are of great conservation value, in addition to the control and eradication priorities discussed here. Predator-free islands that support endemic land-birds – Inaccessible and Nightingale Islands (Tristan da Cunha) – are major priorities for quarantine and rapid-response, and action has recently been taken to reduce the possibility of rodent incursion onto Nightingale (C. Stringer pers. comm.). Of comparable importance would be the prevention of more aggressive rodent species (Ship Rats or Norway Rats), or even cats, reaching Henderson and Gough Islands.

We have not attempted a detailed costing of the activities listed in Table 5 here. However, published assessments indicate one-off costs of rodent eradication from Tristan da Cunha at 2.5 million GBP (Brown 2007b), Gough at 1.5 million GBP (Parkes 2008), and Henderson at 1.33 million GBP (de Brooke & Towns 2008), while Martins *et al.* (2006) provide models that broadly predict costs of mammal eradication as a function primarily of island size. Costings for mammal control and exclusion are less well developed. Overall, RSPB (2007) estimated that £3.92 million per year was needed between 2007 and 2011 to control introduced mammals for biodiversity conservation. Existing levels of expenditure have not been collated across the UKOTs as a whole, although they are well below the levels estimated to be required to achieve biodiversity conservation goals (RSPB 2007).

In conclusion, this synthesis highlights the enormous loss of avian biodiversity that has occurred in the UKOTs over several centuries of occupation by mammalian predators, and the magnitude of the ongoing threat to what remains. However, reviewing what has been achieved in terms of eradication and control in recent years gives a strong indication that restoration activities could realistically deliver major long-term gains for UKOT birds.

**Table 5.** Island restoration priorities for bird conservation in the UK Overseas Territories.

Island/ Territory	Action	Threatened species to benefit	Other potential bird benefits	References
Gough (Tristan da Cunha)	House Mouse eradication	<b>Tristan albatross</b> (Cr) Grey Petrel (NT) <sup>a</sup> Atlantic Petrel (En)	Unknown part of one of the world's greatest seabird colonies would recover	Angel and Cooper (2006), Parkes (2008)
Montserrat	Pig, cat and rodent control/exclusion	<b>Montserrat Oriole</b> (Cr) Forest Thrush <i>Cichlerminia</i> <i>lherminieri</i> (Vu)		Hilton <i>et al.</i> (2003, 2005)
St Helena	Cat and rodent control/exclusion	<b>St Helena Plover</b> (Cr)	Depending on location of site, potential recovery of seabird populations	BirdLife International (2009)
Henderson Island (Pitcairn)	Kiore eradication	<b>Henderson Petrel</b> (En) Phoenix Petrel (En) <sup>b</sup> Murphy's Petrel <i>Pterodroma</i> <i>ultima</i> (NT)	Recovery/recolonization of other seabirds Potential recovery from population limitation by four endemic landbirds	de Brooke and Towns (2008), de Brooke <i>et al.</i> (2010)
Pitcairn	Cat and Kiore eradication	Phoenix Petrel (En) <sup>b</sup> <b>Pitcairn</b> <b>Reed-warbler</b> (En)	Recovery/recolonization of other seabird populations.	de Brooke and Towns (2008)
Tristan da Cunha	Ship Rat and House Mouse eradication or localized control/exclusion <sup>c</sup>	Atlantic Petrel (En) Tristan Bunting (Vu) <sup>d</sup> Tristan Thrush (NT)	Recovery of other vulnerable seabird populations	Angel and Cooper (2006), Brown (2007a)
Falkland Islands	Patagonian Fox, cat and rodent eradication from feasible islands	<b>Cobb's Wren</b> (Vu)	Recovery of vulnerable seabird populations	Falklands Conservation & Falkland Islands Government (2008)
South Georgia	Norway Rat eradication from offshore islands, parts or all of main island	<b>South Georgia</b> <b>Pipit</b> (NT)	Recovery of vulnerable seabird populations	BirdLife International (2009)
Ascension	Rat control/exclusion/ eradication on main island		(Increased rate of) recovery of vulnerable seabird populations	
BIOT	Ship Rat eradication from some or all infested islands		Recovery of vulnerable seabird populations	Symens (1999), Carr (2006)
TCI, BVI, Anguilla, Cayman	Cat, mongoose and rodent eradication from offshore islands		Recovery of vulnerable seabird populations	Varnham (2006)

Islands are presented in descending order of priority, based on the number of threatened bird species to benefit, and their level of threat. Threatened species listed are only those for which invasive species are a threat, and hence which are expected to benefit. Species in bold are endemic to the island in question. Cr = critically endangered, En = endangered, Vu = vulnerable, NT = near threatened (BirdLife International 2009).

<sup>a</sup>Mouse impacts on Grey Petrel unconfirmed, but suspected as it is a winter-breeder (Angel & Wanless 2006).

<sup>b</sup>Thought to have been extirpated, but potential re-colonist.

<sup>c</sup>Control/exclusion would probably benefit Atlantic Petrel and other colonial seabirds, but impacts on the more dispersed and wide-ranging land-birds would probably be minimal.

<sup>d</sup>Extirpated; could potentially be reintroduced, though would probably be a different subspecies.

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