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Seabird recovery and vegetation dynamics after Norway rat eradication at Tromelin Island, western Indian Ocean

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ABSTRACT

Seabirds are notoriously sensitive to introduced mammalian predators and eradication programs have benefitted seabird populations and their habitats on numerous islands throughout the world. However, less evidence is available from the tropics as to the benefits of rat eradication. Here, we report the seabird recovery and vegetation dynamics on a small coralline island of the tropical western Indian Ocean, eight years after Norway rat (*Rattus norvegicus*) eradication. Two species of seabirds were breeding before rat eradication (red-footed and masked boobies, *Sula sula* and *Sula*, *dactylatra*) and, in both species, the number of breeding pairs had an apparent increase of 22–23% per year after rat eradication. Such a high annual growth rate cannot be achieved by auto-recruitment only and our data suggest that immigration from other source populations never occurred in at least one of these species. We suggest that it is rather due to a rapid increase in breeding success, which rapidly increased the observed number of breeders since birds remained in the available-for-counting-as-breeders group for much longer. Two other species, the white tern (*Gygis alba*) and the brown booby (*Sula leucogaster*) were recorded breeding in 2014. The former species has not bred on the island since 1856 and the latter has never bred on the island. Plant cover (monospecific formation of the ruderal herb *Boerhavia diffusa*) dramatically increased from less than 30% of surface coverage to more than 70%. Although the initial restoration project was to eradicate all introduced mammals of the island simultaneously, house mouse (*Mus musculus*) eradication failed. Mouse density was high 8 years after rat eradication (32 mice/ha in dry season and 52 mice/ha in rainy season) but not higher than at a comparable tropical island of the region (Juan de Nova) where mice coexist with introduced black rats (*Rattus rattus*) and feral cats (*Felis catus*). These results are discussed in terms of the direct positive effects of rat eradication on seabirds and plants and the indirect positive effects of post-eradication seabird increase on soil manuring and vegetation recovery. Overall, our results show that on tropical islands, seabird and habitat recovery can be very rapid after rat eradication and should be implemented as a restoration tool wherever possible.

1. Introduction

Seabirds are notoriously sensitive to introduced predators, like rats (Towns et al., 2006; Jones et al., 2008). By preying on eggs and chicks, rats reduce breeding success (see for instance Thibault 1995; Pascal et al., 2008), which has long-term effects on bird recruitment, population dynamics, population size and breeding distribution (Ruffino et al., 2009). Rats are also able to prey on adults of the smallest seabird species, like storm-petrels or auklets (Whitworth et al., 2005; De Leon et al., 2006; Jones et al., 2008), which has an even greater impact on the population dynamics of these species. Numerous seabird populations are threatened by or have become locally extinct as a consequence of rat predation (De Leon et al., 2006; Jones et al., 2008). But considerable effort has been made to eradicate rats from islands over the last four decades, thus promoting the conservation and recovery of native flora and fauna (Towns and Broome 2003; Howald et al., 2007; Aguirre-Munoz et al., 2008). The positive effects of these eradications are numerous and have been well documented in

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temperate regions (see for instance Towns and Broome 2003; Jones 2010a). For seabirds, the removal or control of rats on islands increases breeding success and population size (Whitworth et al., 2005; Smith et al., 2006; Pascal et al., 2008; Jones 2010a; Bourgeois et al., 2013). New species, including those previously driven to local extinction, can eventually return if the restored islands are within the prospecting range of unsettled adults (Micol and Jouventin, 2002; Buxton et al., 2014), or if populations have been actively reintroduced (Miskelly et al., 2009).

As mesopredators and aggressive competitors, rats can also regulate mouse populations on islands where both alien mammals have been introduced (Caut et al., 2007). As such, rat eradication can result in the release of mouse populations, if mice are not eradicated in the same time, which can lead to increased mouse damage to seabirds, plants or insects (Caut et al., 2007; Witmer et al., 2007; Ruscoe et al., 2011).

Rats can also have detrimental effects on native vegetation by direct consumption of the plants, seedlings and seeds (Mulder et al., 2009). On the other hand, seabirds can also positively affect island vegetation by soil manuring, which boosts the growth of nitrophilous species (Smith 1979; Wainright et al., 1998; Anderson and Polis 1999 and see the review of Ellis 2005). On islands functionally dominated by seabirds, rats can have indirect and often cascading impacts on ecosystem functioning, by depleting seabird densities and can thus disrupt across-ecosystem nutrient subsidies (Fukami et al., 2006; Towns et al., 2009; Mulder et al., 2009; Jones 2010b).

Although rats have been introduced to more than 80% of the island groups of the world, including many in the tropics (Varnham, 2010), the effects of these predators on tropical seabirds are less documented than on islands of high latitudes (Jones et al., 2008; Varnham, 2010, but see Ringler et al., 2015). Furthermore, fewer attempts have been made to eradicate rats from tropical islands and the success rate of these efforts often lower than on temperate islands (Holmes et al., 2015). When successful, the effects of these eradications on tropical island biodiversity and ecosystems are rarely reported (Russell and Holmes, 2015).

In this paper we report the dynamics of the seabird community of Tromelin Island, a small (100 ha) remote coralline island of the tropical western Indian Ocean, where Norway rats (*Rattus norvegicus*) were successfully eradicated in December 2005. The initial plan was to eradicate both Norway rats and house mice (*Mus musculus*) over the same time period but mouse eradication failed (see below). We estimated mouse density 7–8 years after rat eradication to assess the current or potential impact of mice on Tromelin's terrestrial ecosystems. We also studied the changes to vegetation cover and diversity after rat eradication, so to investigate any direct effects of rats and mice on vegetation or any indirect effects of seabird recovery on vegetation after rat eradication.

2. Material and methods

2.1. A short history of Tromelin Island

Tromelin (15°53′S, 54°31′E, Fig. 1) is a 100 ha flat coralline island of the western Indian Ocean. Tromelin has a typical tropical marine climate with a wet and warm season from December to April and a dry and cool season from May to November. Average annual rainfall ranges from 1000 to 1500 mm, more than half of which occurs between January and March. The average temperatures range from 20 °C during the dry season to 26 °C during the wet season (Météo France pers. comm.). The island is frequently hit by tropical storms and cyclones during the wet season.

Tromelin originally had a diverse and abundant seabird community, with between six to eight breeding species (great and lesser frigatebirds *Fregata minor* and *Fregata ariel*, sooty terns *Onychoprion fuscatus*, white terns *Gygis alba*, red-footed and masked boobies *Sula sula* and *Sula dactylatra*, brown and lesser noddies *Anous stolidus* and *Anous tenuirostris*, see le Corre 1996). The island is thought to have remained undisturbed until July 1761 when the ship l'Utile, which was doing illegal slave trading between Madagascar and the Mascarene Archipelago (Mauritius, Réunion and Rodrigues), shipwrecked with at least 183 people on board (including 60 slaves and 123 French mariners). Part of this group managed to leave the island two months later using a self-made boat but the slaves were left on the island and "forgotten." They lived there for 15 years and fed on marine turtles, fish and seabirds. Finally in November 1776 the Chevalier de Tromelin, captain of the ship La Dauphine, rescued eight survivors including seven women and an 8-month-old baby (Laroulandie and Lefevre 2013).

A recent archaeozoological analysis of almost 18,000 bird bones found during an archeological excavation campaign conducted by Guérout and Romon, has shown that at least 5 species of seabird were present on the island at the time of the wreck and were hunted by the forgotten slaves (Laroulandie and Lefevre 2013). Sooty terns and brown noddies, among others, appear to have been particularly abundant. The excavations have also shown that a tropicbird (probably the red-tailed tropicbird *Phaethon rubricauda*) was regularly hunted and so probably also bred there at the end of the 18th century.

The island remained unvisited until December 1856 when an English hunter, Layard, visited the island. He mentioned 8 seabird species among which 6 where breeding (Brooke 1981). The next visit was almost one century later (1954), when French meteorologists set up a meteorological station, which remains operational today. Only 4 breeding seabird species were recorded at the time of this visit, the great and lesser frigatebirds and the red-footed and masked boobies (Brygoo 1955). Forty years later, the two species of frigatebird were no longer breeding on the island, probably as a consequence of human disturbance at colonies as people permanently occupied the island from 1954 (Le Corre 1996). For a complete description of Tromelin and its past and present avifauna see le Corre (1996) and Laroulandie and Lefevre (2013).

The introduction of rats and mice at Tromelin is not well documented but mice were present since at least 1859 (Russell and Le Corre, 2009). Both rats and mice were present in 1954 (Brygoo 1955). It is worth noting that a single bone of a small mammal was found during the archeological excavations mentioned above (Laroulandie pers. comm.). This suggests that rats and/or mice may have been introduced during the wreck of l'Utile or possibly even before.

2.2. Rat and mouse eradication method

The eradication attempt was performed from 5 December 2005 to 2 January 2006. We used an extruded chocolate flavoured, blue block bait (Pestoff Rodent Blocks) containing 0.02 g/kg brodifacoum for use in bait stations and 10 mm diameter pellet baits (Pestoff Rodent Bait 20R) with 0.02 g/kg brodifacoum for hand broadcast. A total of 25 kg of blocks were used in bait stations and 1 tonne of pellets (10 kg/ha) was broadcasted manually in a single application throughout across the island. This broadcast application rate is in the lower range of what is generally done in such operations (see for instance Keitt et al., 2015; Russell and Holmes, 2015). The bait stations were regularly placed over a 100 × 100 m grid on the whole island.

Eighty-one stations, with one bait block each, were set during a single pass of the entire island and each was then revisited daily from 7 December to 1 January, over which time it was noted whether each bait had been partially or totally eaten by rats or mice. Baits were replaced only if necessary (with blocks or pellets).