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Special Issue Article: Tropical rat eradication

The response of black rats (*Rattus rattus*) to evergreen and seasonally arid habitats: Informing eradication planning on a tropical island

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ABSTRACT

Rat eradications on tropical islands have been less successful than operations in temperate climates. This is likely due to poor understanding of the factors unique to tropical regions that rat populations respond to, such as high numbers of land crabs, aseasonal climates and habitats not found at higher latitudes. On Aldabra Atoll, southern Seychelles, black rats were monitored for one year in three habitats over three climatic seasons to investigate changes in density and breeding to inform planning for a possible rat eradication. Rats bred all year in mangrove forest and in two of three seasons, including the dry season, in *Pemphis* forest, probably resulting from the saline tolerance of these habitats: lush vegetation and seeds were available there during the dry season. In contrast, rats from the adjacent mixed-scrub habitat only bred in the wet season due to desiccation of vegetation and lack of fresh water during other times of the year. Bait consumption trials showed that all rats ingested dyed bait when applied at 15 kg/ha, despite high rat densities and substantial bait interference by non-target species, but not at an application rate of 10 kg/ha. A novel 'bola' technique was tested for distributing bait into mangrove forest, where aerially applied rat bait would normally be lost due to tidal inundation. The method is likely to improve rat exposure to bait in mangrove forest and other habitats on tropical islands, and warrants further development.

1. Introduction

The introduction of invasive rats (*Rattus exulans, Rattus rattus, Rattus norvegicus*) to tropical islands has resulted in reductions of native animal and plant populations, often to extinction. Rats disrupt ecosystem function by causing cascades of collapse, through interruption of nutrient pathways and pollination, and by seed predation (Towns et al., 2006; Towns, 2009; Kaiser-Bunbury et al., 2009; Hilton and Cuthbert, 2010; Gibson et al., 2013).

As tropical islands are often biodiversity hotspots with high levels of endemism (Meyers et al., 2000), rat invasions have had an arguably worse impact on these islands than on temperate islands (Russell and Holmes, 2015). Island ecosystems damaged by rats can be restored through rat removal (Towns et al., 2006), and eradication techniques have been developed over the past 30 years. Rats have been successfully extirpated from islands of increasingly larger size (Howald et al., 2007) particularly on temperate islands. Although rat eradications are increasingly carried out on tropical islands they have been less successful overall (Holmes et al., 2015). Several possible factors, often unique to tropical islands, account for the reduced success, including higher productivity, bait interference by terrestrial crabs (Howald et al., 2004) and other non-target species, and/or the constant food availability on aseasonal humid tropical islands promoting year-round breeding and high population densities, in contrast to seasonal higher latitude islands (Rodriguez et al., 2006; Wegmann et al., 2011).

The lower eradication success and likely causal factors indicate that the role of invasive rat ecology in eradications on tropical islands is not yet well understood. This is also evident in the timing of tropical island eradications, which has to date been on a case-by-case basis in contrast to temperate islands (Ringler et al., 2014). Tropical islands invariably have unique native species assemblages and habitats which likely result in novel interactions with invasive rats, and differences in their population biology (Russell et al., 2011). Increasing the success of rat eradications on tropical islands therefore depends on improving understanding of both invasive rat biology and population dynamics in these ecosystems, and the effectiveness of eradication techniques in the presence of non-target species.

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Tropical islands also often contain extensive areas of mangroves. Mangroves present a unique challenge to rat eradications since these areas are subject to regular tidal inundation which thwarts the current bait distribution technique of aerial pellet application (Ringler et al., 2014). As a result, eradication of rats from mangroves has only been achieved on a few small islands (<30 ha) where baits are manually attached to mangroves along with bait 'bolas' thrown onto the mangrove forest canopy (Wegmann et al., 2008; Rodríguez and Samaniego, 2012). The problem mangroves pose for large-scale eradications is also confounded by the lack of knowledge of rat ecology in mangroves. Rats are known to not only occur (Delattre and Le Louarn, 1981; Ringler et al., 2014) but to thrive in mangroves: rats trapped in mangroves have been found to be larger and heavier than rats trapped in other habitats (Harper et al., in press). More information on seasonal dynamics of rats in mangroves is critical for eradication planning on islands with mangroves and is therefore a key focus of this research.

Here we present the results of research into the population dynamics of black rats *R. rattus* in three different habitat types, including mangroves, on the seasonally arid tropical atoll of Aldabra in the southern Seychelles. Our specific aims are threefold: first we assess seasonal and habitat differences in rat breeding, population density and survivorship to identify the optimal season for eradication. During the dry season rats would be expected to be more constrained by limited fresh water and food availability (Russell and Ruffino, 2012) and therefore in poorer condition and at lower densities than in the wet season (Tamarin and Malecha, 1971; Clark, 1980; Previtali et al., 2009). We also expected rats trapped in mangroves to show higher productivity and survivorship, and a longer breeding season relative to other habitats. Secondly, using small-scale trials, we assess the likelihood that toxic bait would be available to all rats in three habitat types during an aerial rat eradication attempt and quantify bait removal by non-target species. Finally, we conducted an initial trial of bait distribution by hanging 'bolas' in mangroves to assess uptake rates in this habitat. Aldabra's 2000 ha of mangroves encircle a 30 km long lagoon, making manual bait application logistically and economically unfeasible, especially as part of a larger eradication operation. An effective new technique would have potential to be developed for rat eradications in a habitat previously not possible to tackle on a large scale. The overall objective of our research is to inform planning for eradications on tropical islands, particularly those with large areas of mangroves, including Aldabra, by improving knowledge of rat ecology and the effectiveness of control methods in these ecosystems.

2. Methods

2.1. Study site

Aldabra Atoll (9°24′S, 46°20′E), a UNESCO World Heritage site, is part of the Seychelles archipelago in the Western Indian Ocean (Fig. 1). With a terrestrial area of 152.6 km^2, Aldabra is among the largest elevated coral atolls in the world at *c.* 34 km long by 14.5 km wide. It is *c.*18 m above mean sea level at its highest point, although the greater part of the land lies only *c.* 5–8 m above mean sea level. The atoll consists of four main islands that are separated by tidal channels, the widest being 300 m across. A research station on Picard Island was established in 1971 (Fig. 1). Aldabra is managed and protected by the Seychelles Islands Foundation for the Seychelles Government. Mean annual rainfall for Aldabra is approximately 975 mm unevenly distributed throughout the year, with most rain (~600 mm) falling from December to April and the remainder of the year being dry or very dry, averaging <10 mm/month in September and October (Walsh, 1984, SIF Unpubl. data). Temperatures vary little seasonally with the mean minimum temperature in the coldest month (July; 22.2 °C) only 2.7 °C less than the warmest month and similarly the mean maximum temperature (February; 31.2 °C) is only 3.6 °C warmer than in July.

Aldabra's rock formations comprise two main types: highly pitted and eroded limestone known as 'champignon', and smooth flat limestone called 'platin'. The three principal vegetation types relevant for this study are; '*Mixed scrub*', a variable community of shrubs 3–5 m tall which may have a very open or closed canopy and thin soil; '*Pemphis scrub*', dominated by *Pemphis acidula*, which often forms dense pure stands up to 6 m tall on champignon, with little soil and a saline water table; and '*Mangrove forest*', up to 10 m tall, which comprises eight mangrove species and covers most of the lagoon coastline. On Picard, *Pemphis* covers the largest area, while mangrove forest covers *c.* 150 ha.

Aldabra's native terrestrial fauna includes the Aldabra giant tortoise *Aldabrachelys gigantea*, whose population exceeds 100,000 individuals, several species of native gecko and skink, a large population of nesting green turtles *Chelonia mydas*, one endemic land bird species (Aldabra drongo *Dicrurus aldabranus*) and 11 subspecies of breeding landbird including the flightless Aldabra rail *Dryolimnas cuvieri aldabranus*. Several seabird species breed on the atoll, including boobies, large numbers of frigatebirds, several tern species, and a subspecies of tropical shearwater, *Puffinus lherminieri colstoni*, apparently confined to Aldabra. Four species of bats occur, three of which are endemic. Of the insects, *c.* 38% of the estimated 1000 species are endemic. Several mammal species were introduced to Aldabra by 1900 following settlement (Stoddart, 1971). Of these, only two species remain, feral cats *Felis catus*, and black or ship rats *R. rattus.* Cats no longer occur on Picard where this research was undertaken. On Aldabra, rats are known to prey on many native invertebrate, reptile and bird species (including several life stages) and also eat seeds, seedlings and damage vegetation (Frith, 1976).

2.2. Habitat differences in breeding seasonality and productivity

Rat trapping transects were set up in all three habitats on Picard (Fig. 1), using Victor™ snap-traps for three nights. Fifty traps on a transect were zip-tied to trees at 25 m intervals about 1.5 m above ground (See Harper et al., in press for further details). Three sessions of kill-trapping were completed in 2013; January/February (wet season), June (transitional season), and October (dry season). The breeding status of trapped female rats, including the number of uterine scars and embryos, was recorded by dissection. Any possible differences in the number of embryos per female among habitats were tested using a GLM with Poisson distribution. Statistical analyses were performed using R 2.03 (R Core team, 2013). Results are presented ± SE unless stated otherwise.

2.3. Rat population density, home range estimates and survivorship

To estimate rat population density and factors influencing it, and estimate survivorship, live-trapping grids were established in all three habitat types, consisting of a seven by seven trap grid at 10 m spacing (covering *c.* 0.36 ha). We conducted three trapping sessions in 2013 to cover seasonal changes; February/March (wet season), July (transitional season), and October (dry season). Rats were trapped for 10 consecutive nights. Trapped rats were given a mild anaesthetic (Halothane®) in a plastic bag before each rat was ear-tagged with an individually-numbered metal fingerling tag. Sex, age (adult, juvenile) and weight were recorded before being released. All captures and recapture locations within the grid were noted. Population density was calculated using spatially explicit capture recapture (Borchers and Efford, 2008) with