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Black Rats in Mangroves: Successful and Intractable

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ABSTRACT: Despite the black rat being the most common invasive rat on tropical islands, little is known about habitat selection and seasonal changes in density on atolls. On Aldabra Atoll, a UNESCO World Heritage site in the Seychelles, Indian Ocean, black rats occur in all available forest types, including mangrove forest, at high densities. Mangrove forest appears to be particularly good habitat with larger recorded body sizes, larger juveniles, and in better body condition than rats trapped in 'terrestrial' forest. Any plans for black rat eradication on large islands with mangrove forest will be thwarted by the presence of rats in this habitat, where poison bait is unlikely to be aerially laid successfully due to tidal inundation.

KEY WORDS: Aldabra Atoll, atoll, black rat, body size, diet, eradication, forest, mangroves, population density, *Rattus rattus*, rodent control, Seychelles

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INTRODUCTION

Tropical islands are often biodiversity hotspots with high levels of endemism (Meyers et al. 2000), so the impact of invasive rats (*Rattus exulans*, *R. rattus*, *R. norvegicus*) is arguably worse than on higher latitude islands. Rats can reduce populations of native animals and plants, often to extinction, which disrupts ecosystem function by causing cascades of collapse through interruption of nutrient pathways and pollination, and by seed predation (Townsend et al. 2006, Townsend 2009, Kaiser-Bunbury et al. 2009, Hilton and Cuthbert 2010, Gibson et al. 2013).

Rat eradication techniques have been developed over the past 30 years to restore island ecosystems, and they have been extirpated from successively more islands of increasingly larger size (Howald et al. 2007). Most rat eradications have been carried out on temperate islands and although more eradications are now carried out on tropical islands overall, they have been less successful (Varnham 2010) due to several possible factors like preferential use of the tree canopy, bait interference by terrestrial crabs, and/or constant availability of food in contrast higher latitudes (Rodriguez et al. 2006, Wegmann et al. 2011). These factors indicate that ecology of invasive rats on tropical islands is not well understood. The population biology of rats may differ there (Russell et al. 2011), and with species and ecosystems present that are exclusive to tropical islands, it is likely novel interactions occur with invasive rats. Therefore, further research on rat biology on tropical islands is required to better understand the drivers of population dynamics and to improve success of rat eradication operations.

This research sought to investigate seasonal differences in population density and body condition of rats in 3 habitats on a seasonally arid atoll, to aid planning for an eventual eradication attempt. It was expected that during the dry season, rats would be in poor condition and at low density relative to the wet season, as arid conditions adversely affect rat populations elsewhere in the tropics (Tamarin and Malecha 1971, Clark 1980) and the optimal season for eradication would be when the rat population

is constrained by limited fresh water availability and food (Russell and Ruffino 2012).

METHODS

Study Site

Aldabra Atoll (9°25'S, 46°25'E), a UNESCO World Heritage site, is situated in the western Indian Ocean 420 km northwest of Madagascar and 640 km from the East African mainland. At 15,500 ha, Aldabra is the largest elevated coral atoll in the world at about 35 km long by 14 km wide. It is approximately 18 m above mean sea level at its highest point, although the greater part of the land lies only ~5 m above mean sea level. The atoll consists of 4 main islands that are separated by tidal channels, the widest being 300 m across. A small research station on Picard Island (930 ha) was established in 1971. Aldabra is administered by the Seychelles Islands Foundation for the Seychelles Government.

The mean rainfall for Aldabra is approximately 966 mm unevenly distributed through the year, with most rain (~600 mm) falling during a wet season from January to April with the remainder of the year being dry or very dry, averaging less than 10 mm per month over September and October for example (Walsh 1984). The atoll rock formations comprise 2 main types: highly pitted and eroded rock known as 'champignon,' and smooth pavement-like cemented limestone called 'platin.'

The principal vegetation types on Aldabra are: 1) mixed scrub, which is a very variable community of shrubs about 3-5 m tall and may have a very open or closed canopy; 2) *Pemphis* scrub dominated by *P. acidula*, which can form dense pure stands up to 6 m tall and is found on rough dissected limestone with little soil and where the water table is saline; 3) Mangrove forest up to 10 m tall, which comprises 8 species on most of the lagoon coast; and 4) extensive open shrubland of *Lumnitzera* and *Thespesia* at the eastern end of the atoll (Stoddard and Fosberg 1984). On Ile Picard, the first 3 vegetation types predominate with *Pemphis* covering the largest area, and mangrove forest about 150 ha.

Of the terrestrial fauna, the most obvious is the

Aldabra giant tortoise *Aldabrachelys gigantea*, which is found virtually everywhere, with a population that exceeds 100,000. In addition there are several species of geckos and skinks, and large populations of green turtles *Chelonia mydas* and hawksbill turtles *Eretmochelys imbricata*. Twelve extant species of endemic landbird species or subspecies breed on the atoll along with at least 12 other landbird species largely derived from Madagascar. Several species of seabird breed on the island including boobies (*Sula* spp.), frigate birds (*Fregata* spp), and several terns (*Sterna* spp.), and a race of tropical shearwater (*Puffinus lherminieri colstoni*) that apparently is confined to Aldabra. Four species of bats are present. Endemic insects comprise some 38% of the estimated 1,000 species.

Several mammal species were introduced to the islands of Aldabra Atoll, Seychelles, by 1900 following settlement there (Stoddart 1971), and of these only 2 remain, the feral cat *Felis catus*, and the black or ship rat (*R. rattus*), where they probably extirpated the Aldabran brush warbler *Nesillas aldabranus*, which was only first described in 1967 (Prys-Jones 1978) and was extinct within 20 years (Roberts 1987). Cats are not present on Ile Picard where the study was undertaken. Rats prey on many native invertebrate, reptile, and bird species and their young on Aldabra (Frith 1976, Seabrook 1990) and also eat seeds and seedlings and damage vegetation.

Rat Trapping

Rat trapping transects were established to gather information on the relative abundance, population structure, breeding status, morphometrics, and diet of rats in the main habitats on Ile Picard. Rats were trapped using Victor™ snap-traps for 3 days in mixed scrub, *Pemphis* scrub, and mangrove forest. The scrub habitat was an area of open mixed scrub immediately behind coastal *Casuarina* forest. The *Pemphis* habitat was in thick *pemphis*-dominated shrubland about 1.5 km inland from the coast. The mixed mangrove forest was on the southern corner of Picard Island. Trapping took place 3 times in 2013, January/February, June, and October, the last trapping session being in the dry season. Twenty-five pairs of traps, about 3-5 m apart, were attached to trees at 25-m intervals using zip-ties at about 1.5-2.0 m above the ground to reduce non-target captures and interference from hermit crabs and coconut crabs *Birgus latro*, in particular. Traps were baited with a mix of peanut butter and rolled oats. Information on sex, age, morphometric measurements (weight, head-body length, tail length), and breeding status and history were recorded later in the laboratory and stomachs removed for diet analysis. Diet items were measured by frequency of occurrence and recorded including leaves, plant material, seed or fruit; any insect exoskeleton remains or mollusc opercula; and vertebrate flesh, feathers, or eggs. A simple body condition ratio was calculated for each animal by dividing its weight by its head-body length. ANOVAs were calculated using $R = 2.03$ (R Core team 2013). The frequency-occurrence diet item percentages and body condition ratio was arc-sine transformed for statistical analysis.

In order to measure rat population density, trapping grids were established in each of the 3 habitats. The grids consisted of 7 lines of traps 10 m apart with 5 tomahawk collapsible cage traps on each line at 10 m apart, making a grid of encompassing 0.49 hectares. Rats were trapped for 10 nights. Each rat was ear-tagged with an individually-numbered metal fingerling tag and the sex, age (adult, juvenile) and weight recorded before being released. All recaptures and locations within the grid were noted in each season rats were caught. Population density was calculated using the programme DENSITY 5.0 (Efford et al. 2004) whereby density is estimated using a combination of closed population capture-recapture data and distance sampling techniques. Whereas mark-recapture analysis can estimate population size (N), density cannot be estimated, as the true trapped area is unknown. In contrast, the home range centre of a repeatedly trapped animal can be estimated as a function of the probability of detection of the individual. The 2 methods are combined within a conditional maximum likelihood framework so the range centres of the trapped rats within and outside the trapping area are combined and the overall density estimated. Range centres are assumed to be random (Poisson distribution) with a density of D , with the hazard curve detection function adjusted by a combination of g_0 , the detection probability when $r = 0$ (range centre and trap coincide), (the spatial scale of movements), and b (shape parameter). The relationship between the parameters and statistics from simulated samples is described by fitting a linear model. The model is then inverted and applied to statistics from the field sample, hence inverse prediction (Efford et al. 2004). In this way population density may be inferred from closed population capture-recapture data without the need to estimate effective trapping area. DENSITY assumes the population is closed, without births, deaths or immigration, and that there are no changes in the rat home range use and size while traps are active.

Measures of relative abundance, derived from numbers of rats caught on kill-trap lines (rats caught per 100 corrected trap-nights; Nelson and Clark 1973) in the 3 habitats, were also used as supplemental data on seasonal changes in density.

RESULTS

Rat Density and Abundance

Mangrove forest yielded 131 trapped rats over the 3 seasons, with 109 trapped in scrub and 88 in *Pemphis* habitat. The sex ratio was approximately equal for all the habitats.

Rat population density varied from 20-42 per hectare across all the habitats, with no significant seasonal variation in density between the wet or dry season ($F_{2,6} = 0.67$, $P = 0.55$) or between habitats ($F_{2,6} = 0.28$, $P = 0.77$). Similarly, there were no significant differences in relative abundance of rats between habitats ($F_{2,6} = 0.85$, $P = 0.47$), although there was a trend for higher relative rat abundances during the wet season, but this was not statistically significant ($F_{2,6} = 3.5$, $P = 0.09$, Figure 1).

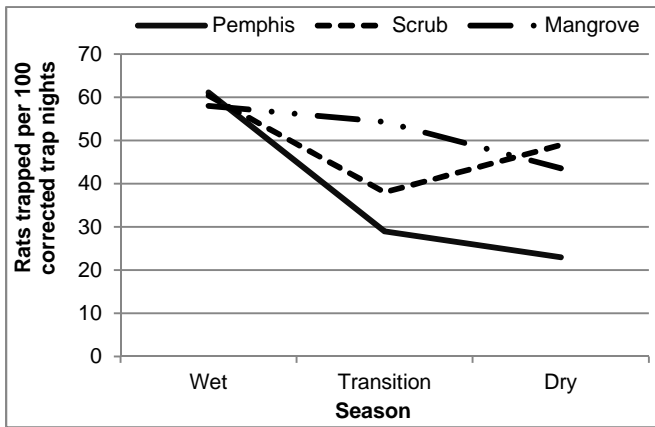


Figure 1. Seasonal changes in the relative abundance of black rats kill-trapped in 3 habitats on Ile Picard, Aldabra Atoll, Seychelles.

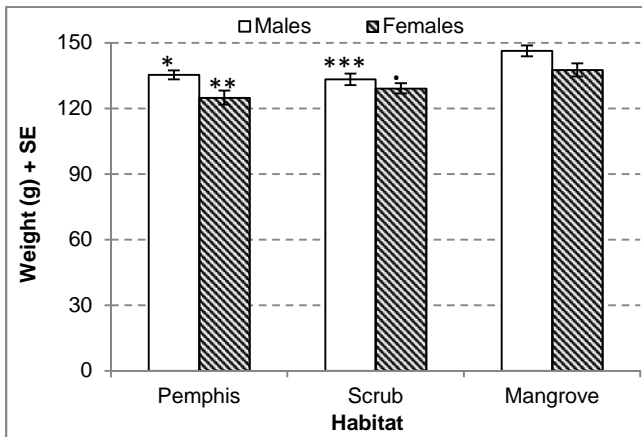


Figure 2. Weights of male and female rats trapped in 3 habitats on Ile Picard, Aldabra Atoll, Seychelles. Statistically significant differences in weights between rats from mangrove forest and other habitats is shown thus: * P = <0.001, ** P = <0.01, *P = <0.05, P = 0.05-0.08.**

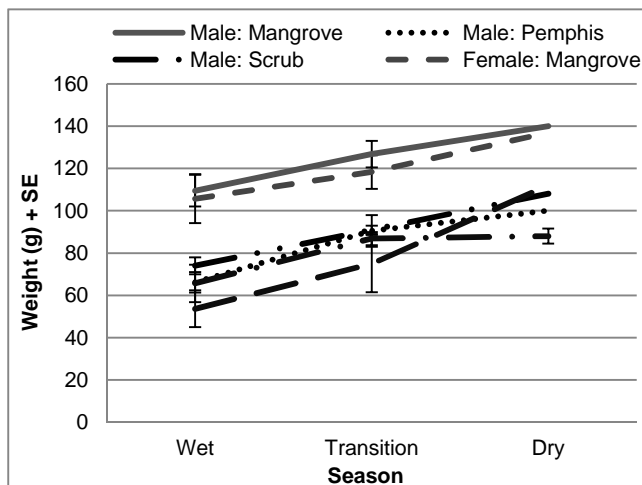


Figure 3. Mean weight gain of marked black rats recaptured over three seasons in three habitats on Ile Picard, Aldabra Atoll, Seychelles.

Morphometrics

Male black rats trapped in mangrove forest were significantly heavier ($F_{2,161} = 8.81, P < 0.0001$, Figure 2) with longer head-body lengths ($F_{2,161} = 7.15, P < 0.001$) than males from both *Pemphis* and scrub habitats with a significantly better body condition index than animals trapped in *Pemphis* ($F_{2,156} = 4.72, P = 0.01$). Similarly, female rats from mangrove forest were heavier than females from the other habitats ($F_{2,161} = 5.05, P = 0.007$, Figure 2) and significantly from *Pemphis* (Tukey's test $P = 0.008$) and weight differences approached significance when compared with females trapped in scrub (Tukey's test $P = 0.08$). Female rats trapped in mangrove forest were significantly larger than conspecifics in scrub (Tukey's test $P = 0.002$) and body size differences approached significance when compared with females trapped in *Pemphis* (Tukey's test $P = 0.09$). The body condition of females from mangrove forest was significantly better than females from other habitats ($F_{2,160} = 4.22, P = 0.02$), although closer analysis revealed they had significantly better condition than females trapped in *Pemphis* forest (Tukey's test $P = 0.01$), but not scrub (Tukey's test $P = 0.55$). There was no seasonal difference in body condition in female rats.

Although young rats repeatedly live-trapped in the trapping grid in the mangrove forest grew at a similar rate to young rats from the other habitats, they were also significantly heavier during all seasons (Figure 3).

Diet

There was no significant difference in the frequency of occurrence of diet items of rats between habitats for invertebrates, plant matter, or vertebrate matter, but significantly more mollusc remains were found in stomachs from rats trapped in mangrove forest than in the other habitats (Figure 4).

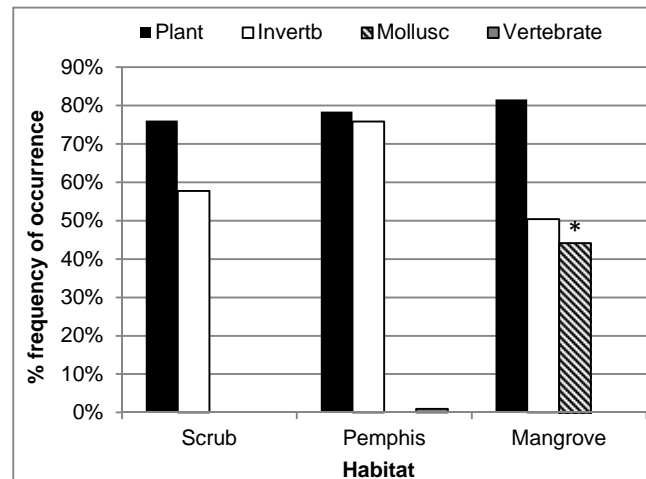


Figure 4. Mean frequency of occurrence of food items in black rat stomachs from 3 habitats on Ile Picard, Aldabra Atoll, Seychelles. Statistically significant differences in weights between rats from 2 habitats and mangrove forest is shown thus: *P = <0.05.

DISCUSSION

In seasonally arid islands, rainfall strongly influences resource availability, which in turn drives population dynamics in rodents with peaks in population density occurring soon after significant rainfall (Clark 1980, Previtali et al. 2009, Russell and Ruffino 2012). Therefore, it was surprising that there was no detectable seasonal decline in rat population density or body condition on Ile Picard through the dry season of 2013, which suggests sufficient fresh water and food resources were available to maintain individual condition and population numbers year round.

The consistency in diet composition with plant material and invertebrates present in stomach samples throughout the year reflects black rat diet studies elsewhere (St Clair 2011). However, there was no seasonal decline in the frequency of occurrence in invertebrates occurring in their diet, which was expected as capture rates of invertebrates are higher in the wet season on Ile Picard, although Lepidoptera did not exhibit seasonal variation in abundance (Frith 1979), so caterpillars may provide a consistent food source for rats there. However, rats do apparently suffer a degree of water stress as the bark of *Sideroxylon inerme*, *Mystroxydon aethiopicum*, *Ficus reflexa*, and *Acalypha claioxloides* (Euphorbiaceae) are chewed by rats during the dry season (Hamblen et al. 1985, Roberts and Seabrook 1989, Seychelles Islands Foundation unpubl.).

The reasons for the lack of an 'aridity effect' on the rat population are unknown and deserve further investigation.

Although black rats have been recorded in mangrove forest in Florida (Dunson and Lazell 1982), Hawaii (Steele et al. 1999), and reducing nesting success in herons in Iran (Etezadifar et al. 2010), little research has been conducted except in Guadeloupe in the 1970s (Delattre and Le Louarn 1980, Delattre and Le Louarn 1981). Contrary to expectations, the size and condition of rats in mangrove forest exceeded that of rats in more terrestrial habitats and their population density was also high. Mangrove forest could be regarded as sub-optimal habitat for black rats due to twice daily tidal inundation, but it appears the littoral habitat has possible resource advantage for rats with a substantial proportion of the diet being composed of molluscs, likely of marine origin. Marine-derived diet items, including molluscs, have been recorded in black rat diet present in coastal environments (Stapp 2002, Harper 2006) and marine molluscs have increased in abundance after a black rat eradication in Hawaii, suggesting predation of molluscs by rats in the inter-tidal zone (Smith et al. 2006). Where black rats had a diet dominated with marine-derived food, they were heavier and longer than conspecifics trapped at inland sites (Stapp 2002), and these results suggest black rats with access to marine-derived food resources have improved growth and condition relative to rats in purely terrestrial habitats.

Although eradication of rats in small areas of mangrove forest (<30 ha) has been achieved using ground-based techniques (Wegmann et al. 2008, Rodríguez and Samaniego 2012), eradication of rats from large areas of mangrove will be virtually impossible using

current aerially-applied poison techniques, as twice-daily tides will wash bait out to sea. Possible applications of poison bait into treetops, as has been conducted for brown tree snake control, hold promise (Savarie and Tope 2004), but the lead-in time required for technique development and trials of application rates mean it will be some time before large islands with a mix of mangrove and terrestrial forest like Aldabra can be considered for cost-effective rat eradication.

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