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INVASION NOTE

Response of mice (*Mus musculus*) to the removal of black rats (*Rattus rattus*) in arid forest on Santa Cruz Island, Galápagos

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Abstract A combined rat and mouse trapping grid was established in arid coastal forest on Santa Cruz Island, Galápagos over June and July 2009. Mouse traps were opened first and did not initially catch any mice. Rat traps were opened four days later and began catching rats on the second night. Mice were trapped in increasing numbers only after the rat catch-rate had declined substantially. Interference with bait at rat traps also increased. The estimated density of rats was 4.8 rats/ha and mice 32.3/ha. The results suggest mice were present but their activity and/or numbers were being suppressed by the larger rodent. This conclusion has implications for competitive exclusion of native Galápagos rodents by both introduced species. It also suggests caution for rodent abundance estimates and planned rodent eradications when two or more species are present.

Keywords *Rattus* · *Mus* · Galápagos · Introduced · Competition · Dominance

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Introduction

Dominance hierarchies in sympatric rodents are often, but not always, related to size, with the larger rodent species often the dominant species (Bowers et al. 1987; Harper 2006). When a dominant species is removed from a rodent guild the response of the subordinate species is often recorded as an apparent increase in their abundance or activity (Brown et al. 1996). This can be a problem for control or eradication operations targeting introduced rodents, where one species is effectively replaced by another (Innes et al. 1995; Witmer et al. 2007). In many cases where a subordinate species is present it is trapped much less often than the dominant species, probably due to interference competition, which confounds estimates of abundance of the subordinate species (Harper and Veitch 2006).

Introduced rodents have been present In the Galápagos archipelago since about 1600 when black rats *Rattus rattus* became established (Patton et al. 1975). Since then mice *Mus musculus* and, relatively recently, Norway rats *Rattus norvegicus* have established (Key et al. 1994) and on several islands are sympatric. In several cases the introductions of the exotic rodents has apparently resulted in the extirpation of the native rodent species *Nesoryzomys* spp. and *Oryzomys galapagoensis* (Key et al. 1994).

Several rodent eradication operations in Galápagos archipelago are planned for the near future and Floreana Island (17,000 ha, 90°25′W, 1°20′S) is one contender. Two rodent species, the black rat and mouse, coexist there. If rats are eradicated without removing mice it is likely mice will become very abundant or at least more active. Mice, when abundant, have similar adverse affects as rats on native species and ecosystem functioning (Angel et al. 2009), which would negate the aims of the planned eradication.

We set out to test whether mice abundance or activity was negatively affected by the presence of black and/or Norway rats in the Galapagos. We expected that selective removal of rats would result in an increase of observed abundance and activity of mice.

Methods

Study site

A rodent trapping grid was established on the northern boundary of the Galápagos National Park Service base and Charles Darwin Foundation station adjacent to Puerto Ayora, southern Santa Cruz Island (90°20′W, 0°45′S), in Galápagos province, Ecuador. The site was situated at approximately 10 m above sea level on a lava boulder field in the arid vegetation zone, where the dominant woody plants are *Acacia macracantha*, *Parkinsonia aculeata*, *Prosopis juliflora*, *Cordia Lutea*, *Bursera graveolens*, *Opuntia echios* and *Jasminocereus thourasii*. The median rainfall for Puerto Ayora is 277 mm but this varies widely and can exceed 2,000 mm during an El Niño event. Introduced feral cats (*Felis catus*) are likely to be the main rodent predator at the study site.

A 140 × 180 m grid was lightly cut in the forest in early June 2009. Rat traps (Tomahawk live traps 40 × 12 × 12 cm) were placed every 20 m, but not set, on 30 June 2009 and then opened on 2 July. A smaller grid of 40 mice traps (Sherman 'E' aluminum live traps 23 × 9 × 8 cm) placed every 10 m on a grid of 40 × 80 m, was established in the centre of the rat grid. The mice traps were placed, but not set, on 26 June and opened on 28 June. All traps were baited with a mixture of rolled oats and peanut butter, rolled into a ball within a small piece of grease proof paper. The bait was suspended from the top of the trap at the back with a short piece of wire to reduce interference by ants.

Any rats caught kept were transferred alive to the Charles Darwin Foundation station for other experimental work. All captured mice were humanely killed. All the traps were closed on 20 July 2009.

To estimate the effective trapping are (ETA) for the rats and mice a boundary strip was added to the edge of the trapping grids (Dice 1938). The width of the boundary strip was set by adding the radius (56 m) of a circular average home range of ship rats from a forested habitat (Hooker and Innes 1995) and of mice (29 m) from an island (Pickard 1984). The assumption underlying this calculation is that during an intensive and short trapping period immigration, emigration and reproduction would be nil (Brown et al. 1996).

Results

We caught 53 mice over 23 days of trapping (Fig. 1). No mice were caught in the first 9 days of mouse trapping until one was caught on day 10. Live mice were seen in the grid during the day, however. Mice increased rapidly in number after the 13th day of rat trapping, when rat trapping has declined to only three trapped rats.

We caught 50 rats over 19 days of rat trapping (Fig. 1). Only ship rats were trapped. Rats were caught in increasing numbers from the second day of rat trapping, reaching a maximum of 10 after 6 days of trapping. Numbers of trapped rats then declined to none on the 11th day and between one to three rats were caught daily from day 12 onwards.

An increasing number of rat traps were also interfered with during the latter portion of the trial. Before day 10 no bait was taken in rat traps that did not catch a rat. However, after day 10 there was an increasing incidence of bait taken with no captures (Fig. 1). On some days up to 40% of the traps with bait taken were sprung with no captures. On three occasions mice were seen eating the fallen bait next to the trap. As no rats were trapped in these traps we concluded that the bait loss and sprung traps were caused by mice. There was some interference with the bait by ants and cockroaches but in these cases most of the bait remained hanging in the trap.

The ETA of the rat trapping grid was 8.34 ha. We trapped 40 rats over a ten day period before the catch rate declined to zero. After this the catch-rate then

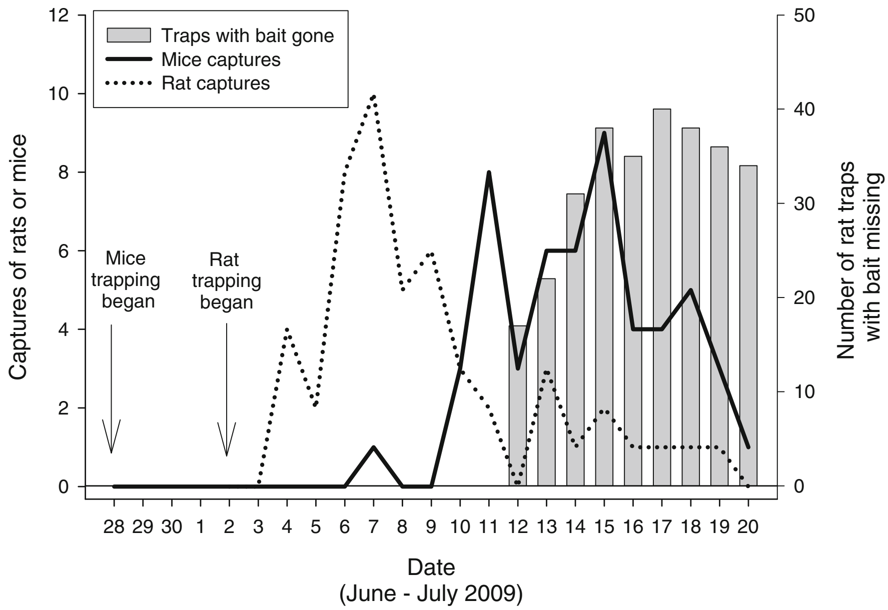

Fig. 1 Capture rates of black rats (*Rattus rattus*) and mice (*Mus musculus*) and bait loss from rat traps during a trapping operation in arid coastal forest near Puerto Ayora, Santa Cruz Island, Galápagos, June 28–July 20 2009

rose slightly to one to two per day. We are assuming that rats caught after the 40 rats were trapped are animals invading from outside the grid and are not included in the density calculations. Therefore the approximate density of rats on the grid was 4.8 rats/ha (95% CI: 4.5–5.1 rats/ha).

The ETA of the mouse trapping grid was 1.64 ha. We trapped 53 mice over a 14 day period before the catch -rate declined to one mouse caught on the last day of trapping. We are assuming that this is the total number of mice caught on the mouse grid. Therefore the approximate density of mice on the mouse grid was 32.3/ha (95% CI: 32.0–32.6 mice/ha).

Discussion

As expected, the response of mice to the severe reduction in density of rats was an increase in their abundance and activity. Brown et al. (1996) suggested that the increase in mouse tracking rates after the removal of black rats was a response to the removal of rats or a learned attraction to baited tunnels. We suggest that the latter hypothesis is less likely in our study as we had set, baited mice traps in place for 8 days before we began to catch mice. Brown et al. (1996) recorded an increase in mice tracking rates within 5 days of rat removal. In addition, interference of bait in rat traps by mice did not occur until after 14 days, after rat trapping rates were reduced to low levels. The increase in interference with the rat traps suggests that over the entire rat trapping grid mouse activity had increased markedly after rats were removed.

There is still little information on the causes of the increases in subordinate rodent abundance after the removal of a dominant species. The response is likely to be a functional, rather than numerical, response because of its rapidity but this is not certain. This conclusion then assumes a constantly present and relatively abundant subordinate, which begs the question of where and how the subordinate is operating when the dominant is present. Further manipulative and, if possible, telemetry studies need to be undertaken to shed some light on the habitat and home range use of subordinate rodents coexisting with dominant species.

Possible refuge sites for mice from ship rats may be interstitial gaps in the lava boulders as occurs on volcanic islands elsewhere (Miller and Miller 1995). Alternatively mice could be foraging and nesting in *Opuntia* in a similar manner as the native rat *Nesoryzomys swarthi* and where ship rats are not known to ascend (Harris et al. 2006).

No Norway rats were trapped on the grid, although they are very commonly trapped in the nearby town, approximately 300 m away (Key et al. 1994). This apparent exclusion of the larger Norway rat from forest by black rats mirrors results from other islands (Russell and Clout 2004; Harper et al. 2005; Harper 2006).

This study suggests that care should also be taken when planning an eradication on islands with two or more introduced rodents. As dominant rodents often exclude subordinate species from food (Brown and Munger 1985) and possibly bait. In the case of mice, which can still exert severe adverse effects on native animals and ecosystem functioning (Angel et al. 2009), their continued existence are likely to frustrate the restoration of an island ecosystem.

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