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# THE POTENTIAL IMPACT OF INTRODUCED COMMENSAL RODENTS ON ISLAND FLORA

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**ABSTRACT:** The impact of introduced commensal rodents on island flora has been relatively little studied compared with their impact on the fauna. The effects on vegetation composition, regeneration, and decomposition are largely unknown, but potentially great. Preliminary studies were carried out in the Galapagos Islands between 1993 and 1994 on the diet of introduced rats, *Rattus* spp. and feral house mice, *Mus musculus*, seed recovery rates and subsequent germination rates of seeds. *R. rattus* diet was primarily vegetation and 48% of rats had seeds in their stomachs. Significant differences were found between body size and overall contribution of both vegetable and animal foods, larger rats eating proportionately more animal foods and less vegetable. There was no significant difference between the sexes in terms of main dietary components. There was no significant difference in the selection of food types between *R. rattus* and *R. norvegicus*, both species tended to prefer banana and avocado, and only rats from the Miconia zones showed a preference for Miconia berries. No intact seeds were found in the stomachs of feral house mice from the same sites. Recovered seeds of two native and two introduced plant species were successfully germinated under laboratory conditions. *R. norvegicus* is potentially a better dispersal agent for seeds as it has a greater tendency to ingest them intact. The implications of these findings for the conservation of island flora are discussed.

**KEYWORDS:** rodents, commensal rodents, Galapagos, Ecuador, vertebrate pest control, islands, introduced species

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## INTRODUCTION

The commensal rodents are known to cause considerable damage to island fauna where they have been introduced. This is particularly well documented with respect to depredations by rats, *Rattus rattus* and *R. norvegicus*, on nesting colonies of seabirds, reptiles, amphibians and invertebrates (Atkinson 1985; Daniel 1973; Dingwall et al. 1978; Moors and Atkinson 1984; Moors et al. 1992; Pye and Bonner 1980). What is less well known is their effect on the native flora of islands. The diet of all three species of commensal rodent is notoriously broad and opportunistic (hence their potential as pests in many different situations), and in the wild is known to include seeds, buds, bark, invertebrates and carrion (Allen et al. 1994; Barnett 1975; Clark 1980; Dingwall et al. 1978; Gales 1982; Laws 1984). The effect on the vegetation may be direct, by the consumption of buds, leaves, bark and seeds, and by acting as dispersal agents by transporting intact seeds in the gut away from the parent plant. Indirect effects on the vegetation may occur by the predation of rats and mice on the invertebrate population and subsequent effect on decomposition and regeneration (Allen et al. 1994; Bremner et al. 1984; Crafford and Scholtz 1987). Indirect effects can also include burrowing activities, which may weaken root systems or break up dense plant structures (Laws 1984; Snell et al. 1994). All these can affect both native and introduced plants. The activities of small mammals are a normal part of ecosystem function (Fraser 1990; Janzen 1971), but conservation issues arise where invasive species differ from native species in the selection of items, or the quantities consumed. Where there are no native seed predators the problem is particularly acute as many island systems have evolved in the absence of this selection pressure. Overall, these more subtle effects on island fauna and flora would be

expected to have a long term impact on the plant composition and vegetation turnover on islands.

This paper reports preliminary studies to investigate this aspect on four islands in the Galapagos archipelago, and is intended to generate awareness of the need for more research in this area.

## THE STUDY SITES

The Galapagos archipelago, Ecuador, lies on the equator and consists of 13 large and ca. 40 smaller islands. The Black rat, *R. rattus*, now occurs on ten islands, while the Brown rat, *R. norvegicus*, is a relatively recent arrival in the archipelago and occurs on two islands. Feral house mice, *Mus musculus* are found on seven islands. Four of the original seven species of native rice rat (*Oryzomys* spp. and *Nesoryzomys* spp.) are extinct, probably due to the arrival of the commensal rodents, and the remaining three species are found on two uninhabited islands still free of commensal rodents (Key and Heredia 1994). The study was undertaken in the arid vegetation zone, where the climate is typically hot and dry.

The study was carried out over two years, 1993 and 1994, on the four inhabited islands, Santa Cruz, San Cristobal, Isabela and Floreana. Three main aspects were investigated: diet, food preferences, and the recovery and germination of seeds consumed, focusing on some important introduced invasive plants and some native plants of conservation concern. Plants included were limited to those fruiting at the time of study.

## METHODS

### Diet

Diet was determined by stomach content analysis of rats (*Rattus* spp.) and feral house mice. Rodents were live trapped in Tomahawk and Sherman traps, laid in

transects within 1 km inland of the port town on each inhabited island. A total of 65 traps was laid in each transect, placing alternate groups of three Tomahawk and two Sherman traps every 20 meters along the transect. Traps were baited with peanut butter, set at 1800 hrs and checked the following morning at 0600 hrs for four consecutive nights. Most of the rats caught were used for a study of behavioral ecology, of which results are presented elsewhere. Excess rats and all mice caught were sacrificed for stomach content analysis by an overdose of inhalation anaesthetic.

Stomach contents were flushed with water into a petri dish. Contents were examined with a x10 hand lens and 14 categories were identified: leafy vegetation, non-leafy vegetation, bait, meat, seeds, fruit, invertebrates, mucus, starch, metal (from the traps), fur, stones, cheese and unknown. The percentage contribution of each category by volume was estimated for each stomach, and then averaged for each species. This was carried out from July through August, 1994.

#### Food Selection

An investigation of food selection was carried out with rats on Santa Cruz island in 1993.

Rats were trapped at two sites on Santa Cruz island, the Miconia robinsoniana vegetation zone and around the port town, Puerto Ayora. Miconia zone rats eat a specialized diet based on Miconia berries due to the limited availability of alternative foods in this zone (Clark 1980). In contrast, rats living around the town have a wide range of foods available to them and so have a generalized diet. At both sites 5 to 20 Tomahawk traps were laid in transects along paths, or placed opportunistically where rats were expected to occur (e.g., near litter bins, toilets). At the Miconia zone, traps were left in place for five days prior to operation to overcome neophobia. Traps were baited with peanut butter, set at 1800 hrs, and checked at 2100 hrs and 0600 hrs. Captured rats were transported to the laboratory and maintained in cages; maximum journey time was ca. 2 hours. The aim was to have ten rats of each species (*R. rattus* and *R. norvegicus*) from each site. All feces produced in the traps were collected.

In the laboratory rats were housed in modified traps, 20 x 20 x 50 cm for *R. rattus*, and 30 x 30 x 60 cm for the larger *R. norvegicus*. Cages were raised off the floor to allow collection of droppings and scattered foods. Water and nesting material were provided ad lib. and all animals were maintained on a basic diet as shown in Table 1, designed to provide a balanced diet palatable for both species and developed on site (Platenberg 1994).

Caged rats were given seven days to habituate, and were then offered a selection of different foods known to grow locally: avocado (*Persea americana*), banana (*Musa* sp.), naranjilla (*Solanum quitoense*), cassava (*Manihot* sp.), tomato (*Lycopersicon lycopersicum*) and Miconia berries. Approximately 5 g of each food type was offered in a cafeteria selection, together with the basic diet, and the amount eaten was recorded on a daily basis. It was not possible to weigh the food uneaten due to the tendency of rats to scatter and soil foods, so the amount eaten was scored on a scale of 0 to 4: 0=food untouched; 1=food sampled; 2=about half of the food eaten; 3=most of the

food eaten; and 4=food completely consumed. Food preferences were averaged for each food type by using estimates of food taken over the five-day period.

These foods were offered every day for five days, except naranjilla which was only just coming into season and sufficient fruits were only available for one day. Other plants of interest, *Lantana camera*, guava (*Psidium guajava*) and blackberry (*Rubus* sp.), all serious invasive species in the islands, were not fruiting in abundance at the time of study and sufficient fruits were only available for the germination trials.

Table 1. Basic diet on which rats were maintained in captivity.

500 g	Quinea seeds ( <i>Chenopodium quinoa</i> )
500 g	flaked oats
350 g	wheat germ
325 g	maize flour
250 g	banana flour
150 g	sugar
150 g	vegetable oil
100 g	commercial seasoning
50 g	salt

#### Germination of Recovered Seeds

Rats of both species were given samples of various locally available fruits, both native and introduced, with relatively small seeds, estimated to be of a size to pass through the gut of a rat (approximately rice grain size and below). Feces were then collected and examined for the presence of intact seeds, and attempts were made to germinate them.

Fruits offered were as follows: maracuya (*Passiflora* spp.), guava, naranjilla, tomato, Galapagos tomato (*Lycopersicon cheesmanii*), blackberry and Miconia. Fruits were offered for one day and feces collected for the following two days, before another fruit type was offered.

The first germination trial simulated conditions in which feces containing viable seeds would occur in the natural environment. Vermiculite was used as a sterile substrate, and plastic drinking cups, with drainage holes in the base, were three-quarters filled and kept slightly damp by daily checking and watering, as required. Two treatments were compared. In the first, recovered feces were placed in the vermiculite, just below the surface. In the second, recovered feces were soaked for 48 hours in water, and then placed in the vermiculite just below the surface. After a minimum of 19 days, the cups were checked through for signs of germinated seeds. In total, 167 pots were established, with 12 control pots containing seeds extracted directly from the fruit types tested. As soon as it became evident that whole feces in damp vermiculite rapidly became very moldy, an alternative method of seed germination was tested. A total of 712 recovered feces were soaked in water, gently teased apart and examined individually for the presence of intact seeds. These were isolated and placed on damp tissue paper in petri dishes which were maintained in dark,

humid conditions. The dishes were checked daily for signs of germination for up to two months.

## RESULTS

### Diet

A total of 76 *R. rattus* and 24 house mouse stomachs were examined from the four islands (Table 2). No *R. norvegicus* were caught outside the vicinity of buildings and so are not included. As sample sizes for individual sites were not consistent, results are summed for analysis. Results for *R. rattus* and house mice are shown in Table 3. One rat had a stomach completely full of blood (presumed to be a victim of anticoagulant poisoning) and is excluded from the analysis.

Table 2. Numbers of stomachs examined from rats, *Rattus rattus*, and feral house mice, *Mus musculus*, on four inhabited islands, Galapagos.

Island	<i>R. rattus</i>	<i>M. musculus</i>
Isabela	16	6
San Cristobal	47	14
Floreana	3	0
Santa Cruz	10	4
Total	76	24

It can be seen that non-leafy vegetation and bait from the traps make up the greatest contribution to the stomach contents for both rats and mice. All 14 categories were identified from rat stomachs, with seven (starch, stones, leafy vegetation, metal, fur, cheese and unknown items) contributing on average less than 1% by volume. The fur was probably ingested while grooming, and the metal

came from damaged Sherman traps. The starch and the meat are both believed to come from human waste in the town, as the meat was not associated with fur. A total of 36 rats had recognizable seeds in their stomachs, comprising an average of  $8.7 \pm 1.4\%$  by volume. There was no significant difference in diversity of diet between male and female rats ( $t = -1.49$ ,  $df = 39$ ,  $p > 0.05$ ), with males consuming an average of  $2.5 \pm 0.3$  ( $n = 21$ ) categories of food, and females an average of  $2.98 \pm 0.2$  ( $n = 54$ ). A maximum of six categories was recorded from any one female, and five from any one male rat. When the diet of adult sized rats (head and body length 136 mm) was examined, there was found to be a significant correlation between size and total contribution of animal food (bait + invertebrates + meat + cheese) ( $r = 0.4$ ,  $n = 37$ ,  $p < 0.01$ ). There was no significant difference in the mean contribution by volume of animal food and sex ( $t = 0.54$ ,  $df = 32$ ,  $p > 0.05$ ), with adult male rats consuming  $32.2 \pm 7.7\%$ , and adult females  $26.7 \pm 6.7\%$ . The same analysis was done for the overall contribution of vegetation (non-leafy vegetation + seeds + fruit + leafy vegetation) and there was a significant negative correlation between consumption of vegetation and size ( $r = -0.4$ ,  $n = 37$ ,  $p < 0.01$ ). There was no significant difference between the mean contribution by volume of vegetation and sex ( $t = -0.01$ ,  $df = 32$ ,  $p > 0.05$ ), with adult males consuming  $66 \pm 8.6\%$  and adult females  $66 \pm 7.5\%$ .

Only nine of the categories were identified from mouse stomachs, with five (meat, fruit, leafy vegetation, fur, and stones) contributing on average less than 1% to total stomach contents (Table 3). Contents were dominated by the presence of trap bait which occurred in 22 of the 24 animals and comprised 75% by volume. Diversity of diet was lower than for rats, with mean number of categories  $2.1 \pm 0.1$ , and no stomach contained more than three categories.

Table 3. Mean percentage contribution  $\pm$  SE by volume of 14 categories of food found in 75 *R. rattus* and 24 *M. musculus* stomachs at four sites in the Galapagos islands.

Category	<i>R. rattus</i>		<i>M. musculus</i>	
	<i>n</i>	%	<i>n</i>	%
Vegetation	71	$55.0 \pm 3.9$	14	$17.3 \pm 5.6$
Bait	36	$18.6 \pm 3.3$	22	$75.4 \pm 5.8$
Seed	36	$8.7 \pm 1.4$		
Invertebrates	23	$3.3 \pm 1.9$	6	$2.5 \pm 1.2$
Fruit	16	$5.1 \pm 1.6$	2	$0.4 \pm 0.3$
Meat	7	$2.7 \pm 1.3$	2	$0.6 \pm 0.5$
Mucus	6	$3.3 \pm 1.9$		
Starch	5	$0.9 \pm 0.4$	2	$2.9 \pm 2.2$
Fur	4	$0.5 \pm 0.3$	1	$0.2 \pm 0.2$
Leafy vegetation	3	$0.3 \pm 0.2$	1	$0.3 \pm 0.3$
Metal	2	$0.4 \pm 0.4$		
Stones	2	$0.7 \pm 0.6$	1	$0.4 \pm 0.4$
Cheese	1	$0.4 \pm 0.4$		
Unknown	1	$0.1 \pm 0.1$		

## Food Preferences

Unfortunately, severe losses of caged rats occurred, both through escape (due to faulty cages) and death by anticoagulant poisoning. This was particularly evident with rats caught in the Miconia zone where a control campaign was in operation near the trapping site at the time of the study and data were consistently collected only from the town caught rats, with an effective sample size of ten *R. norvegicus* and eight *R. rattus*.

There was no significant difference in the selection of food types by *R. rattus* ( $X^2=13.26$ , df 7,  $p>0.05$ ) or by *R. norvegicus* ( $X^2=16.07$ , df 9,  $p>0.05$ ). The median proportions of food types selected are shown in Figure 1 where it can be seen that both species tended to prefer banana and avocado to the other foods offered. The selection of Miconia alone was compared to the selection of all other food types using a Wilcoxon matched pairs test. *R. rattus* avoided Miconia when offered other choices ( $T=36.0$ ,  $p < 0.05$ ,  $n=8$ ), while *R. norvegicus* showed no significant difference in selection ( $T=36.5$ ,  $p>0.05$ ,  $n=9$ ).

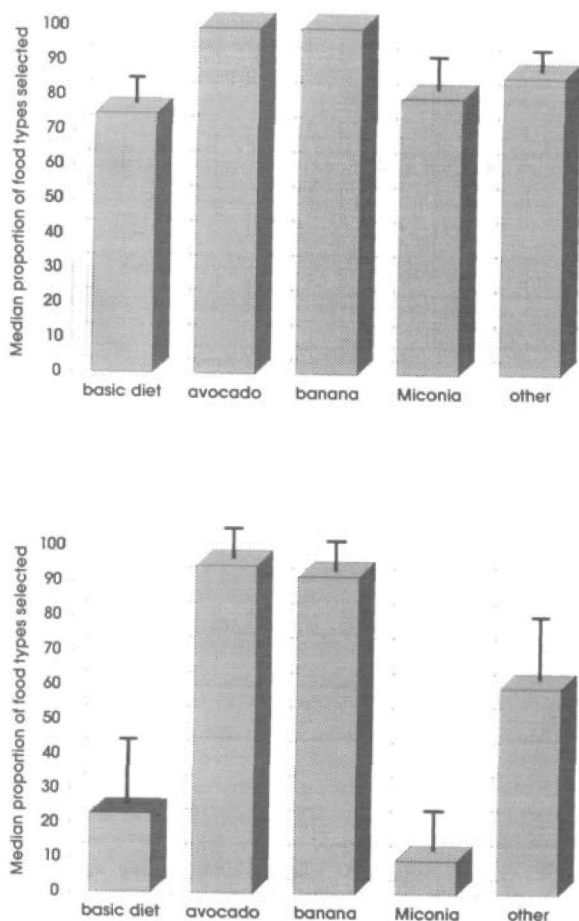


Figure 1. Food preferences of *Rattus norvegicus* (top) and *Rattus rattus* (bottom) showing median taken  $\pm$  third quartile for five food types offered.

Periodic checks made over the night on foods consumed first and last indicated that banana and avocado were the food types most often selected before other items. Both species ate these two foods within the first half hour 63% (*R. rattus*) and 70% (*R. norvegicus*) of the time over four nights. The basic diet was chosen within the first half hour by *R. rattus* and *R. norvegicus* 9% and 20% of the time, respectively, over the same four nights. In contrast, Miconia was consistently eaten only after these other food items had been consumed. Only limited supplies of fruits of Lantana camera and blackberry were available. Observations suggest that rats predate Lantana seeds and do not swallow them whole. Blackberry did not appear to be palatable to *R. rattus* and was not eaten, while it was accepted by *R. norvegicus* and seeds were recovered from the feces.

## Germination of Recovered Seeds

Black rats appear to chew their food more finely than do brown rats, and more intact seeds were recovered from *R. norvegicus* than *R. rattus*. For example, a mean of  $4.9 \pm 6.5$  Galapagos tomato seeds were recovered from 108 *R. rattus* droppings, compared to a mean of  $12.8 \pm 16$  recovered from 153 *R. norvegicus* droppings. The high standard deviations indicate the variation found.

Miconia, guava, tomato and Galapagos tomato seeds germinated having passed through the guts of rats (Table 4). Maracuya seeds were not recovered intact from gut feces. Sample sizes are small, but it can be seen that seeds which germinated did so both when recovered from rat feces and directly from fruit, indicating that passage through an animal gut is not a prerequisite for germination in these species.

## DISCUSSION

The diet of *R. rattus* reported here differs from other studies in being relatively low in animal food. The main component found in stomachs was vegetation, fruit and seeds, and invertebrates made up only 3.3% volume, having been consumed by only 30% of the rats. Clark (1980) studying rats at similar sites in the Galapagos found  $>30\%$  by volume of animal food in adult rats. Animal food has also been found to predominate in the diet of black rats in New Zealand (Daniel 1973; Gales 1982). The mean contribution of seeds and fruit combined is similar to that found by Gales (1982), but rats appear to be consuming a much greater proportion of vegetation. The reasons for this are unclear, but may relate to the nutritional qualities of the specific plants and plant parts consumed, which were not identified in this study. The results may be an artifact of the summing of specimens from four different sites, and the close proximity of houses offering alternative foods. The presence of starch, meat and cheese in the stomachs, and what was presumed to be an animal suffering from anticoagulant poisoning, indicate that rats are traveling up to 1 km to the houses in the town.

The significant correlation between body size and the consumption of animal food is typical of a breeding population of *R. rattus* in the Galapagos (Clark 1980). Larger animals were eating proportionately more animal foods and less vegetable foods. The diversity of diet for individual rats reported here is an underestimate as

Table 4. Percent germination of seeds recovered from droppings of *R. rattus* and *R. norvegicus*, and from unconsumed fruits, using the vermiculite (A) and petri dish (B) methods of germination. Sample size is given in parentheses.

Seed Type	Source		
	<i>R. rattus</i>	<i>R. norvegicus</i>	Fruit
<u>Introduced species</u>			
<i>Lycopersicon lycopersicum</i>			
A	*	*	*
B	17% (6)	50% (6)	100% (8)
<i>Psidium guajava</i>			
A	+	*	*
B	33% (3)	0% (22)	21% (14)
<i>Rubus</i> spp.			
A	*	*	*
B	*	0% (10)	0% (59)
<i>Solanum quitoense</i>			
A	*	*	*
B	0% (31)	0% (48)	0% (100)
<u>Native species</u>			
<i>Lycopersicon cheesmanii</i>			
A	*	*	*
B	0% (30)	<0.1% (242)	<0.1% (159)
<i>Miconia robinsoniana</i>			
A	*	+	+
B	0% (323)	0% (280)	+

+ indicates unquantified positive germination

\* indicates not tested

individual items were not identified, and as such compares well to findings by Clark (1982) who found ca. 4 items per rat stomach in 2+ broad categories. Food preferences for both species of rat in the laboratory were for the relatively soft, moist and nutritious foods, banana and avocado. *Miconia* berries were preferred only by rats from that vegetation zone, suggesting that *Miconia* is not inherently palatable to rats. The implication, therefore, is that the recent spread of *R. norvegicus* into the area (Key et al. 1994) is a result of population pressures and dispersal of rats from the adjacent, optimal agricultural area. Poison baits would, therefore, be expected to be more acceptable to *R. norvegicus* in this area than to the established *R. rattus*, at least in the short term. The basic diet was found to be palatable to both species in the food preference trials, but this may be a result of conditioning.

The stomach contents of feral house mice in the Galapagos were dominated by bait, reflecting the small stomach size and, clearly, trapping for mice with food baited traps is an unsuitable method of studying mouse diet. A subsequent study including the diet of feral house mice on Ilheu Chao, of the Desertas Islands, Madeira, using traps baited with vanilla essence found vegetation to

be the main food component, with 81% of mouse stomachs containing amorphous plant material, 22% recognizable fiber, and 37% seeds. Only 16% contained invertebrates, but the study was undertaken in the dry season when invertebrate populations would be minimal (Key et al. 1995). Other studies on feral house mouse diet have varying findings, with mice on Marion Island taking a large proportion of animal foods (Gleeson and van Rensburg 1982), on sub-Antarctic islands the diet was dominated by grass seeds (Laws 1984), while in different areas in Australia mice have been variously reported as granivores, omnivores and insectivores (Watts and Morton 1983). Mice are generally considered to be primarily granivorous but are clearly able to adapt to local resource availability.

The seed germination study indicates that rats are capable of acting as passive dispersal agents for both native and introduced plants in the Galapagos. Higher seed recovery rates were found from *R. norvegicus* than from *R. rattus*, and the brown rat is considered to have more potential for the spread of plants. It must be emphasized that this study was severely limited by the number of animals caught, the fruits seeding at the time

of study, and by the time available for the subsequent germination of seeds. Many plants require long periods to germinate, often following treatment in the form of chilling, or passage through an animal's gut. Rates and times to germination are not known for most Galapagos plants (Andre Mauchamp, CDRS, pers. comm.), but native plants (especially K-selected island endemics) would be expected to have lower germination rates and longer germination times than agricultural plants, such as the tomato. As an illustration of this, Clout and Tilley (1992) studying the New Zealand miro tree (*Prumnopitys ferruginea*) found no germination occurred for 18 months, and then continued for four years. Results presented here should, therefore, be considered only as an indication of potential.

On some islands in the Galapagos, such as Santa Cruz, introduced rats, *Rattus* spp., have replaced native rice rat species (*Oryzomys* and *Nesoryzomys*) whose feeding ecology is unknown, and the relative impact of the introduced species cannot be evaluated. Long-term conservation problems will particularly arise on islands where there are no native rodent species, and the vegetation and invertebrate fauna lack a native predator. No data were collected in this study on *R. norvegicus* diet in the Galapagos, but in other studies of island populations it has been found to include vegetation, seeds and invertebrates in varying proportions (Bremner et al. 1984; Goulding 1994; Moors 1985). The impact of commensal rodents on island flora is seen from two points, on their initial introduction to a new system, and also following their eradication. Some plant species increase, released from seed and seedling predation by rats, but others decrease as invertebrate herbivores increase, themselves released from rats predation (Allen et al. 1994). Extremes of predator-prey interactions occur on islands (Janzen 1971) and it would, therefore, be expected that introduced predators would selectively take introduced prey, the native species having developed severe chemical defenses against predation. This could have a positive effect on the conservation of the native flora in the Galapagos, if rats are selectively avoiding native plants in the presence of invasive, pest species. It is hoped that this paper will catalyze further work on this neglected aspect of the ecology of introduced rodents and long-term studies on the restoration of island systems will be initiated.

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