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MANAGEMENT OF FRUIT BAT AND RAT POPULATIONS IN THE MALDIVE ISLANDS, INDIAN OCEAN

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ABSTRACT: The introduced black rat (Rattus rattus) and the endemic giant fruit bat (Pteropus giganteus ariel) are serious depredators of coconuts and fruits, respectively, in the Maldives. Differences in reproductive rate between rats (high) and bats (low) must be considered in implementing control programs. We estimate a rat population can fully recover from an island-wide reduction of 90% in less than 6 months. In contrast, a bat population may require 6 years to recover from a 90% reduction. Crown-baiting of coconut palms with anticoagulant rodenticides is effective in reducing rat damage, but villagers have been reluctant to adopt recommended baiting programs, allowing rat populations to quickly recover. We substantially reduced bat populations on islands (e.g., from 2.1 bats/ha to 0.7 bats/ha) after a few nights of mist netting and recommend this procedure for managing bat populations. Bat populations should not be reduced below 0.25 bats/ha on islands in the Maldives.

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INTRODUCTION

The Republic of Maldives is an archipelago of about 1,000 coral islands that stretches for 750 km across the equator 500 km south of India. The total land area is only about 300 km^2, most islands being <1 km^2 in size. The climate is tropical; annual rainfall averages about 210 cm and temperatures typically range from 25 to 32°C.

The human population in the Maldives has more than doubled since 1960 (Lateef et al. 1980), and is approaching 200,000 or >600 people/km^2. About 25% of the population resides on the capital island, Male. Agricultural land is limited to about 3,000 ha (10% of land area), and current estimates indicate 75% of the food (calories) is imported (Lateef et al. 1980). Coconuts are a mainstay of the Maldivian diet (Wickremasuriya 1975, Lateef 1980, Fiedler 1984). Tree fruit production (e.g., mangos, guava, bananas) for local consumption is also an important component of Maldivian agriculture; a survey in 1983 indicated 390,000 fruit trees of 11 species (Ash 1984).

The Maldivian government has placed a high priority on increased food production. Two mammal species, the introduced black rat (Rattus rattus) and the endemic subspecies of the giant fruit bat (Pteropus giganteus ariel) (Hill 1958), are considered major hindrances to achieving this objective. Black rats are a critical limiting factor in coconut production, reducing yields by at least 40% (Fiedler 1984). The giant fruit bat is a major depredator on certain fruits, such as almonds, guava and mangos, although losses have not been objectively quantified (Dolbeer 1987). There are no predators or extreme climatic periods to suppress population levels of these abundant species.

To develop programs to reduce losses from black rats and fruit bats, the Maldivian government in 1984 requested technical assistance from the Food and Agriculture Organization (FAO) of the United Nations. During 1986-87, FAO consultants made 4 visits to the Maldives to evaluate vertebrate pest problems, train Ministry of Agriculture (MOA) field officers in vertebrate pest control, and develop control programs where necessary. The objectives of this report are 1) to summarize results of rat and fruit bat control programs implemented during the 4 consultancies, 2) estimate the reproductive potential of rats and fruit bats and compare the predicted population responses of the 2 species following control measures and 3) make recommendations for control strategies for the 2 species based on the population control programs attempted and the predicted population responses.

METHODS

Rat Control - Coconuts

A demonstration control program, based on methods developed by Fiedler et al. (1982) in the Philippines, was established in 5 coconut areas on 3 islands during April 1986. In each area, 7.5-10% of the coconut palms were selected for crown-baiting with an anticoagulant bait (usually a plastic bag containing 100 g of rice with 0.025% warfarin or coumatetralyl). The plan was to have MOA employees supervise the baiting of these palms at 1-month intervals for 1 year. Green, rat-damaged nuts under each baited palm were counted and removed at each baiting. Fiedler (1986) provides details of the methodology.

Fruit Bat Control

The use of guns has been recommended for reducing bat numbers on islands (Ash 1984). However, the possession or use of firearms is strictly forbidden in the Maldives; therefore, this approach was not feasible.

The method of control we pursued was capturing bats in mist nets. Nets (10-20 m long, 2-m wide, 6.0-cm mesh) were strung at heights of 5-15 m between trees from ropes so that the nets could be raised or lowered. We located nets near roosting sites and fruit trees, placing the nets in flight pathways noted through observations. Netting was undertaken on 10 islands in 1986-87.

On most islands, we attempted to census the number of bats before netting began. Major roosting groups usually could be located either by obtaining directions from villagers or by examining the largest banyan trees (Ficas bengalensis). Smaller groups could be found by walking slowly and systematically through all forested areas. Binoculars often were used to aid in counting individuals in roosting trees.

A team of 2 - 3 people could easily work 6 nets on an island, checking them 2-3 times per night (usually at 1900, 2200 and 0600 the following morning). Captured bats were killed humanely before they were removed from nets by placing a chloroform-soaked cloth over their noses and mouths. The number of nets used, number of nights of netting and number of bats captured were recorded. Body weight and forearm length were usually measured for each bat. The reproductive status was also determined for many female bats by dissection and examination of uteri. We were particularly interested in determining the timing of reproduction and the reproductive rate so we could estimate the potential population growth following control programs.

RESULTS

Rat Control - Coconuts

Black rats appeared abundant on most islands visited, and the ground under coconut palms was often littered with rat-damaged nuts. A survey of the ground under 90 palm crowns on 3 islands in April 1986 yielded 1.6 fresh (green) rat-damaged nuts per palm (Table 1). We did not obtain population estimates on any island. LaVoie (1988) mentioned that the rat population (Rattus rattus and Rattus norvegicus) on highly urbanized Male exceeded 20,000/km^2 in 1980.

The crown-baiting program implemented on 3 islands in April 1986 was designed to continue on a monthly basis for 1 year as a demonstration project. Unfortunately, the program was not sustained and little information was obtained. The initial results looked promising because the number of rat-damaged coconuts per palm had declined by over 50% at the time of the second baiting in July (Table 1). However, only 1 more baiting was made, in September, before the program was abandoned. Bait acceptance by rats appeared to be excellent (Dolbeer 1986).

Several factors caused the abandonment of this program. Logistically, it was difficult to transport MOA field officers to the islands each month to supervise the baitings and damage assessments. However, the more important factor was probably the lack of support for crown-baiting among MOA personnel and the palm owners. There is inherent difficulty in sustaining enthusiasm for a long-term baiting program, requiring climbing and bait costs each month or so, when the benefits (increased yield of nuts) will not be expressed until 6-12 months after the program begins. There is also a lack of appreciation for the rapidity with which rat populations can increase after initial control is achieved. LaVoie (1988) discusses these factors in more detail.

One successful rat baiting operation was developed on Malhous Island by a MOA employee, Abdul Latheef. Latheef, following the instructions and training of Fiedler (1986), initiated in November 1986 crown-baiting in 102 Goi (government land) palms, using 100 g of Racumin-rice bait per palm. Bait was replaced as it was consumed, first at 2-week intervals, then at 1-month intervals, and after February 1987, at 2-month intervals. Latheef routinely inspected the ground under each baited palm crown for fresh rat-damaged nuts and reported (December 1987) that no damaged nuts had been found since March 1967 (LaVoie 1988). The reason this program was successful can be attributed to the motivation of the MOA employee, his residence on the island allowing regular supervision and assessment of baiting, and outside financial support for baiting costs by a private foundation.

Fruit Bat Control

Population-Reduction-by-netting. Bats were common, but not overly abundant, on most islands visited in 1986-87. Population densities ranged from 0.6 to 2.1 bats/ha on 5 islands that were censused. Thoddoo Island, with at least 150 bats, had the largest bat population of the islands visited (Table 2). Banyan trees were by far the most common daytime roosting sites (Dolbeer 1987).

Our netting operations averaged about 1.5 bats/net/night, and we found that populations could be substantially reduced after a few nights of netting (Table 2). For example, the population on Feridhoo Island was reduced an estimated 67% (from 82 to 27 bats) after 10 nights of netting with 3-4 nets per night. At Thoddoo Island 83 bats were removed in 10 nights of netting, reducing the population an estimated 55%. Netting efficiency (bats/net/night) can probably be increased substantially over the values given in Table 2. We did considerable experimentation with net placement which probably reduced our capture rate.

Reproductive-Rate. Pregnant females were encountered only during the early April 1987 collections (Table 3). Litter size was always 1. Most fetuses were at a similar stage of development in early April (Table 3), indicating that the reproductive period was synchronized within the population and that parturition would take place from mid-April to early May. The distribution of bats by weight class at different times of the year also suggested that births occurred only in the April-May period. Immature bats (i.e., maternally independent bats weighing <300 g) were not collected during April but were collected at other times of the year (Table 4). This indicated that by April, bats born in the preceding April-

Table 1. Black rat (Rattus rattus) damage[a] assessments in coconut areas on 3 islands in Alif Atoll where 5 to 10% of palms were crown-baited with various anticoagulant rodenticides[b], April-September 1986, Republic of Maldives.

Area/Island	Total palms	April: No. of palms baited	April: No. of damaged nuts	July: No. of palms baited	July: No. of damaged nuts	September: No. of palms baited	September: No. of damaged nuts
Goi/Thoddoo	750	50	102	33	44	38	55
Private/Thoddoo	120	12	17	12	11	9	24
Kuramathi	180	18	0	18	0	14	3
Goi/Feridhoo	29	3	11	5	0	3	2
Private/Feridhoo	68	7	10	10	0	10	9
Total		90	140	78	55	74	93
Damaged nuts/palm			1.57		0.71		1.26

[a]Only freshly damaged (green) nuts on the ground under each baited palm crown were counted.
[b]Each palm was baited with either 100 g of 0.025% warfarin/rice, 100 g of 0.025% coumatetralyl/rice, or 60 g of 0.005% brodifacoum/wax block.

May period had grown beyond 300 g. If births occurred at other times of year, some immature bats should have been captured in April.

Table 2. Population density of fruit bats (Pteropus giganteus) on 5 islands and results of mist netting operations to reduce bat numbers on 4 islands, Republic of Maldives, 1986-87.[a]

Island	Minimum bat population before netting: N	Minimum bat population before netting: N/ha	Netting statistics: No. of nights netting	Netting statistics: Total net nights	Netting statistics: Bats/net night	Netting statistics: No. of bats caught	Minimum bat population after netting: N	Minimum bat population after netting: N/ha	% reduction
Thoddoo	150	0.9	10	62	1.4	83	67	0.4	55
Feridhoo	82	2.1	10	35	1.6	55	27	0.7	67
Malhous			7	14	1.4	19			
Meedhoo/Hithadhoo			15	51	1.5	75			
Alifushi	79	2.1	10			63	16	0.4	79
Mulaku	40	0.8							
Kuramathi/Rasdhoo	50	0.6							

[a]In addition at least 151 fruit bats have been removed from 5 islands (Mulak, Muli, Nalaafushi, Vehvah and Kolhufushi) in Meemu Atoll (MOA files).

Table 3. Number of pregnant and nonpregnant female fruit bats (Pteropus giganteus) collected by netting, Republic of Maldives.

Status of Females	No. of females examined (litter size, $\bar{x} \pm SD$)			
	18 Aug-9 Sept[a] 1986	3-13 Apr[b] 1987	19-25 Oct[c] 1987	17-20 Dec[d] 1987
Pregnant	0	22 (1 ± 0)[e]	0	0
Nonpregnant	11	13	9	6

[a]Muli, Feridhoo, and Thoddoo Islands.
[b]Thoddoo Island.
[c]Malhous Island.
[d]Feridhoo and Thoddoo Islands.
[e]Fetuses were well developed (50-69 g) in 14 of the 22 pregnant females; fetuses over 60 g were furred and appeared close to parturition.

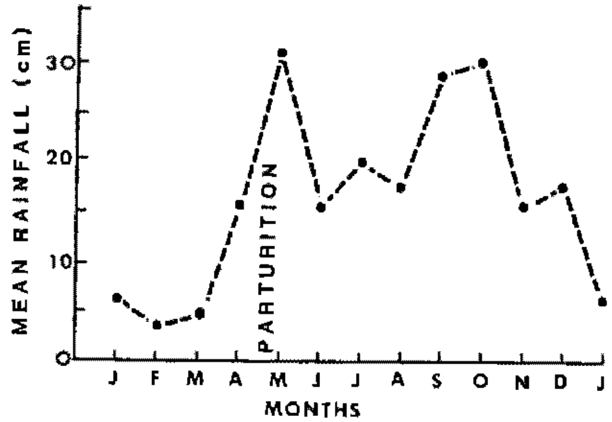

Fig. 1. Approximate period of parturition for fruit bats (Pteropus giganteus) on Thoddoo Island in 1987 in relation to mean monthly rainfall at Hulule Airport, Republic of Maldives. Rainfall data are from Lateef (1980).

Table 4. Weight class distribution of fruit bats (Pteropus giganteus) collected by netting for 3 time periods of year, Republic of Maldives, 1986-1987.

Weight class (g)	No. (%) of bats in weight class		
	Aug-Sept[a]	Oct-Dec[b]	April[c]
101-300	36 (33)	36 (33)	0 (0)
301-500	56 (52)	25 (23)	45 (54)
501-700	14 (13)	38 (35)	37 (45)
> 700	2 (2)	10 (9)	1 (1)
Total	108 (100)	109 (100)	83 (100)

[a]From Muli, Feridhoo and Thoddoo Islands.
[b]From Meedhoo, Hithadhoo and Malhous Islands.
[c]From Thoddoo Island.

Table 5. Number and characteristics of pregnant and nonpregnant female fruit bats (Pteropus giganteus) collected by netting, Thoddoo Island, Republic of Maldives, 3-13 April 1987.

Status of female	Number of females	Weight (g) $\bar{x}$ SD(n)	Forearm Length (cm) $\bar{x}$ SD(n)
Visibly pregnant	22	534A[a] 77(22)	157A 7(15)
Not visibly pregnant	13	368B 50(13)	146B 8(8)

[a]Means within same column with differenct letters are significantly ($P < 0.01$) different, t-test.

Data from additional years are needed before any firm conclusions can be reached regarding the timing of the reproductive period. It is interesting to note that parturition for these bats in 1987 coincided with the average onset of the rainy season in the Maldives (Fig. 1). McCann (1940) mentioned that the majority of fruit bats (Pteropus giganteus) in India give birth during March-April.

Thirteen of the 35 females collected in April were not pregnant. The mean body weight and mean forearm length of these bats were significantly less than were those for pregnant bats (Table 5), suggesting they were younger immature bats. We hypothesize that most of these nonpregnant females were first-year bats that typically do not breed until their second year.

Population changes in relation to control. The removal Of 68 bats (83% of the estimated initial population) on Feridhoo between September 1986 and December 1987 resulted in a 70% reduction in the estimated population on the island (Table 6). These data suggest that local reproduction and immigration from other islands were low during the 15-month period, especially since most of the removals occurred in September 1986. The closest island to Feridhoo with bats is Malhous, 8 km south.

On Thoddoo Island, one of the largest and remotest islands in the Maldives, the removal of 127 bats (85% of the estimated initial population) between April and September 1987 has resulted in only a 29% reduction in the estimated population (Table 6). These data suggest that reproduction and/or immigration following the removals was higher on Thoddoo than on Feridhoo. The closest island with bats, Rashdoo, is 18 km. However, unlike the situation on the smaller Feridhoo Island, we believe the initial count of the bat

Table 6. Population changes in fruit bat (Pteropus giganteus) populations on Feridhoo and Thoddoo Islands in relation to numbers removed by netting, September 1986-December 1987. Values in parentheses refer to numbers/ha.

Island	Minimum estimated population (Sep 1986)	No. of bats removed (Sep 1986-Dec 1987)	Minimum estimated population (Dec 1987)
Feridhoo	82 (2.1)	68[a]	25 (0.6)
Thoddoo	150 (0.9)	127[b]	107 (0.6)

[a]55 removed in Sep 1986 and 13 in Dec 1987.
[b]83 removed in April 1987 and 44 in Sep 1987.

population in September 1986 on Thoddoo was an underestimate because portions of the large (30 ha) forested area were not adequately censused at that time. If the actual population in September 1986 had been 200 bats instead of our estimated 150, then the recruitment rate following control would look similar to what occurred on Feridhoo. Regardless, the results from both islands indicate populations can be suppressed by netting (Table 6).

Population-growth potential—Rats-vs-Bats. Because there are no predators or stressful climatic extremes in the Maldives, rat and fruit bat populations that are reduced to low levels on an island should initially rebound at their biologically maximum (exponential) rate (i.e., r(max) [Caughley 1978]).

Table 7. Assumptions regarding reproductive life history of black rats (Rattus rattus) and fruit bats (Pteropus giganteus) used in calculating exponential growth rates for population.

Reproductive parameter	Black rats[a]	Fruit bats[b]
Breeding frequency	every 4 months	once per year
Age at sexual maturity	3 months	2 years
Gestation period	< 1 month	> 2 months
Litter size	6	1
r(max)	4.17	0.40
Exponential growth equation[c]	$N_t = N_o e^{4.17t}$	$N_t = N_o e^{0.40t}$

[a]Values for black rats based on data in Storer (1982).
[b]Values for fruit bats based on present data.
[c]N_t = Population at time t; N_o = Population at time 0; t = time in years; r(max) = intrinsic rate of increase.

These 2 mammal species present an interesting contrast in population growth because of their extreme differences in reproductive rates (Table 7). Using these reproductive rates, the exponential growth of populations of rats and bats can be calculated and the value of r(max) estimated for each species (Table 7). These calculations indicate that a fruit bat population in the Maldives can increase at a maximum rate of 49% a year whereas a rat population can increase 6,300% in a year.

If we solve the exponential growth equation in Table 7 for t (i.e., time in years), we can estimate the minimum time (years) necessary for a population of rats or bats to recover to its previous population level following control (Table 8). The results suggest that a fruit bat population reduced by 75% (similar to our control operations on Feridhoo or Alifushi, Table 2) would take at least 3.5 years to recover whereas a rat population would recover in 4 months. A 99% reduction in a fruit bat population would require over 11 years for recovery, but only 1 year for a rat population. We note that these predicted recovery times are based on optimum population growth and no immigration. Actual recovery times might be shorter if immigration occurs or longer if reproductive or survival rates decline due to extrinsic factors such as weather or disease.

CONCLUSIONS

Black rat and fruit bat populations in the Maldive Islands require vastly different control strategies. Control programs for rats require continual attention if they are to be successful. For example, even if a rat population on an island is initially reduced 90% through a successful control program, the population is capable of returning to precontrol numbers within 6 months if control efforts are discontinued (Table 8). The recovery could be even faster if control efforts are not island-wide and immigration occurs from untreated areas. This concept of sustained control must be emphasized in future attempts to develop rat control programs in coconuts, other agricultural crops, and villages. Most rat control programs in the Maldives, such as described in this paper, have failed because of this inability to sustain baiting and trapping programs after initial reductions. Obviously, concurrent programs to reduce the carrying capacity of the habitat for rats (e.g., vegetation management in coconut plantings) will provide more permanent relief than poisoning and trapping programs alone.

Bat populations, in contrast, can be successfully reduced and subsequently managed with considerably less frequent interventions than with rats. Netting programs that reduce populations by 75% on islands should have to be repeated only every 3 to 4 years, assuming minimal immigration from other islands. The advantage of population reduction through netting, combined with careful censuses, is that the number of bats can be rather precisely managed on an island with a modest investment effort. One obvious recommendation from this study is that netting operations will be most effective in March and April. Pregnant females can be removed at this time of year, increasing the time for the population to recover. We emphasize that the goal of netting

Table 8. Estimated time (years) for initial populations of 10,000 black rats (Rattus rattus) and 100 fruit bats (Pteropus giganteus) on an island in the Republic of Maldives to recover from control programs of various levels of effectiveness.

Initial population[b]	Efficacy of control program: Percent reduction	Number killed[b]	Number remaining[b]	Time (years)[a] for population to recover to initial level: Black rat	Fruit bat
10,000	25	2,500	7,500	0.07	0.72
10,000	50	5,000	5,000	0.16	1.72
10,000	75	7,500	2,500	0.33	3.46
10,000	90	9,000	1,000	0.55	5.75
10,000	99	9,900	100	1.10	11.51

[a] $t = \frac{\ln N_i - \ln N_c}{r}$ where $r = 4.17$ for rats and 0.40 for bats
N_i = Initial population (10,000 for rats, 100 for bats)
N_c = Population immediately after control
t = Number of years for population to recover to initial level

[b]Divide population numbers by 100 to obtain realistic population level of bats on an island.

is to manage bat populations to reduce loss of fruit rather than to exterminate this interesting, endemic subspecies from islands. Fruit bats may play an important role in pollination and seed dispersal for certain trees in the Maldives as they do elsewhere (Wiles and Payne 1986). We recommend at this time that bat population never be reduced below 0.25 bats/ha on an island. This density translates to 10 to 20 bats for a typical 40- to 80-ha island, a number large enough to ensure survival of the population but small enough to minimize damage to the domestic fruit crops.

A final note is made regarding rat and bat population management. The goal is not population reduction per se; rather, it is reduction of agricultural losses. Further studies are needed to better quantify the relationship between population densities of rats and bats and agricultural losses in the Maldives. The determination of thresholds of population density above which significant damage occurs will allow control programs to be implemented more judiciously and efficiently. Furthermore, the use of nonlethal methods, such as mechanical barriers to exclude rats from palms and timely harvest of fruit to prevent bat damage, should be incorporated whenever possible to augment lethal control programs.

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