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FEEDING PATTERNS OF *RATTUS RATTUS* AND *RATTUS EXULANS* ON ENIWETOK ATOLL, MARSHALL ISLANDS

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ABSTRACT.—In conjunction with studies of the rodent populations of the former nuclear test site at Eniwetok Atoll, the feeding patterns of *Rattus rattus* and *Rattus exulans* were determined by food acceptance tests, histological examination of stomach contents, and observation of animals under both natural and cage conditions. Both species were active in all community types from the early successional stages to the shrub-tree stage. *R. exulans* was found mainly on islets having the remnants of coconut plantations, whereas *R. rattus* occurred on those extensively disturbed by nuclear testing. Plant foods predominated in the diets of both species; however, *R. rattus* used a wider range of foods, including a variety of insects. The apparent narrower preferences of *R. exulans* might explain its absence from islets that suffered habitat destruction and restriction of food sources during the nuclear test program.

In the summers of 1964 to 1968, studies of rat populations were conducted at Eniwetok Atoll. This paper reports the feeding patterns of the roof rat (*Rattus rattus*) and Polynesian rat (*Rattus exulans*) based on analyses of stomach contents of trapped specimens and the relative acceptability of various atoll plants to live rats. Observation of rats in cages and under natural conditions afforded additional information on their feeding behavior.

Eniwetok Atoll (Fig. 1) is a ring of 40 low coral islets located approximately at latitude 11°30′ N, longitude 162°15′ E, in the northern Marshall Islands. The land surface of the atoll occupies about 2.25 square miles (Woodbury, 1962). Islet size ranges from narrow bars, less than 1 acre, to about 300 acres for the larger islets, such as Engebi and Eniwetok. Annual rainfall is about 55 inches; but because of the poor holding capacity of the surface, most of the fresh water is lost through percolation and evaporation. Mean temperature at the atoll is 82°F, with little seasonal fluctuation; relative humidity averages near 80 per cent.

The atoll has been extensively disturbed—first by many years of human occupancy, then by the events of World War II, and most recently by the United States nuclear testing program during the years 1948 to 1958. In the course of nuclear testing, some islets were denuded of vegetation. Soil and organic material were evaporated in large areas around test centers and waves, generated by tests in the lagoon, washed and scoured parts of the atoll surface.

The atoll's most mature vegetation (on Igurin, for example) occurs as mixed forest among the old coconut plantations. Primary elements in these forests are *Cocos nucifera, Pisonia grandis, Cordia subcordata, Terminalia samoensis, Ochrosia oppositifolia, Guettarda speciosa,* and *Morinda citrifolia.* The extensively disturbed islets (for example, Engebi and Runit, Fig. 2) were revegetated first by grasses (*Lepturus repens*), sedges (*Fimbristylis atollensis*), and creeping morning glory (*Ipomoea* sp.). Later, shrub and tree vegetation, primarily

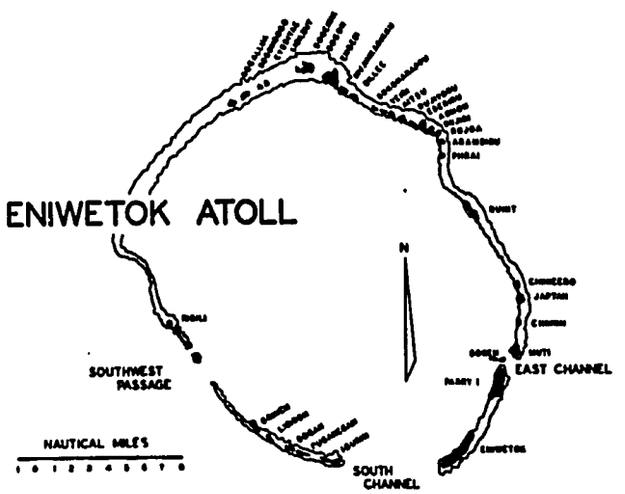

FIG. 1.—Map of Eniwetok Atoll, Marshall Islands.

Tournefortia (= *Messerschmidia*) *argentea* and *Scaevola taccada*, developed and now cover sections of these islets in rather scattered growth patterns. Other creeping herbaceous plants, such as *Triumfetta procumbens* and *Boerhavia diffusa*, were successful colonizers after some amelioration of the environment had occurred.

Both rat species were active in all community types. The Polynesian rat (*R. exulans*) was found mainly on islets having remnants of coconut plantations (Igurin and Muti, for example) at an estimated density (on Muti) of about 40 rats per hectare. Roof rats (*R. rattus*) were prevalent only on the more heavily disturbed islets (Engebi and Runit, for example) at an estimated density (in the short-grass habitats on Runit) of about 20 rats per hectare (Jackson, 1967). *R. rattus* was observed and collected on the beach and low-tide reef at Engebi.

Little quantitative information has been collected on the food habits of Pacific island rats, and most analyses have been based on gross examination of stomach contents. Baker (1946) found about 80 per cent plant material and 20 per cent insect remains in six stomachs of *R. exulans* on Guam. Marshall (1955) examined 11 stomachs of *R. exulans* from Arno Atoll that contained a vegetable material he identified as coconut flowers and coconut meat. Indirect evidence (accumulation of dried, broken husks) suggested the species also fed on the fruits of *Triumfetta*. The *R. rattus* examined by Marshall (1955) had eaten green coconut. Strecker and Jackson (1962) reported that the stomach contents of 25 *R. rattus* from grassland habitats on Ponape (Caroline Islands) consisted of 95 per cent plant material (estimated volume).

FIG. 2.—The north end of Runit Islet 10 years after the last nuclear tests. Bunch grass and creeping vines grow in the central part of the islet; *Scaevola taccada* and *Tournefortia argentea* are spreading inward from the edges. The density of *R. rattus* at this site was about 20 per hectare in 1965.

Seven of these stomachs contained arthropod remains. Stomachs from 46 *R. exulans* from several habitats on Ponape and Majuro Atoll had 94 per cent plant material (estimated volume); 19 of the stomachs had arthropod remains.

Harrison (1954) noted food habits of rodents in Borneo: stomachs from *R. exulans* trapped in grasslands contained mostly vegetable matter; less than one-fifth of the contents was insects, mostly termites; two grassland subspecies of *R. rattus* had a more varied diet. Food intake was about equally divided between insects, mostly termites, and vegetable matter. One rat had eaten a lizard.

More recently, Kami (1966) analyzed the stomach contents of several hundred murid rodents from various habitats on the island of Hawaii. Sugar cane was the predominant food of *R. exulans* trapped in the cane fields and in the bordering gulches. Grass stalks, kukui nuts, guava fruits, berries, and insects were additional items of importance in the diet of *R. exulans* in these habitats; percentages of the various food items varied seasonally. The diet of *R. rattus* collected in cane fields was similar to that of *R. exulans* in the same habitat, with sugar cane appearing as the most frequent food item. Telemetry studies (Hood, 1968) in the same area indicated that *R. exulans* living in gulches moved as much as 230 meters into adjacent, young (9-month-old) cane fields to feed, although as the cane matured rats increasingly resided within the fields.

In the gulch habitat, however, sugar cane was of minor importance to *R. rattus*, which made greater use of natural foods (Kami, 1966).

Methods

In 1964 and 1965 survey trapping was conducted on the islets of Engebi, Aomon-Biijiri-Rojoa, Runit, Muti, Bogen, Parry, Eniwetok, and Igurin. Victor 4-way snap-traps and Tomahawk folding live-traps, baited with fresh coconut, were set at 25-foot intervals in lines that covered each major islet habitat. The stomachs were removed from kill-trapped animals and placed in 70 per cent ethyl alcohol. Reference materials were obtained by depriving a live-trapped animal of food for 18 hours, then allowing it to feed on a particular food. The animal was then killed and its stomach preserved.

Prior to analyzing the samples, reference slides (and photomicrographs) were prepared by teasing a small amount of material on a slide, dehydrating in alcohol, clearing in xylol, and mounting in piccolyte. Staining was generally unnecessary in the reference specimens, as characteristic cell patterns were quite visible.

In examining the stomachs from the trapped specimens under a dissecting microscope, materials of different colors and textures were segregated. Stomach material was often nearly homogeneous, indicating recent feeding on a single food. A small quantity of each component was prepared on a slide; hematoxylin occasionally was used to enhance contrast. Some materials (*Scaevola* and *Tournefortia*, for example) had distinct cell patterns and were easily identified. Other materials had less distinguishable patterns, and several comparisons with reference materials were usually made for such items. Identified and unidentified components were weighed (wet) to the nearest 0.1 gram; total weight of the material in each stomach was determined by addition.

During the 1965, 1966, and 1967 visits to the atoll, live-trapped rats were returned to Eniwetok Marine Biological Laboratory on Eniwetok Islet for food acceptance tests. In the laboratory, rats were housed individually in plastic cages or in live-traps and were supplied with fresh coconut (which both *R. exulans* and *R. rattus* ate readily) and water *ad libitum*. At least 6 hours before an acceptance test coconut was removed, and the rats were placed in an undisturbed, darkened room for the 24-hour test period. Test material supplied to each rat was fresh, but generally not in weighed quantity; biological units such as stems, seeds or fruits were examined or counted after a test to determine parts that had been eaten or gnawed. Because of the short time available, tests usually were conducted with about 10 rats and several plant materials. Most rats were used for only one test, because maintaining groups in the laboratory for more than a few days was inconvenient.

Relative acceptance categories were used to classify the data: "untouched" (no detectable feeding or gnawing); "slight" (evidence of slight feeding or gnawing on the material); "moderate" (between one-fourth and one-half of a test material actually consumed); and "substantial" (one-half or more of a material eaten). To facilitate comparison of the response of *R. exulans* and *R. rattus* to various foods, acceptance indices were calculated by weighting the acceptance categories as 0, 1, 2, and 3. The percentage figure in each category was multiplied by the weight of the category; the weighted figures then were added for each material. If 100 per cent of the test specimens ate none of the test material, the calculated index was 0; if 100 per cent of the test specimens ate substantial amounts of a material, the index was 300. Since this index took no account of the number of individuals tested, it was subject to sampling variation when only a few animals were tested. Its utility lies in providing a simplified summary of the responses of these two species of *Rattus*.

Observations of feeding behavior were made on rats in cages and in various atoll habitats—forest, grassland, and beaches. Nocturnal observations using lantern light or jeep headlights were possible because the rats, unaccustomed to humans or predators, generally continued their activity except when sudden noises or movements occurred. Individual rats oc-

TABLE 1.—*Frequencies of occurrence and percentage (wet weight) of materials contained in the stomachs of 85* R. rattus *and 83* R. exulans *from Eniwetok Atoll. Weights of stomach parasites have been excluded from the calculations.*

Food item	*Rattus rattus*			*Rattus exulans*		
	No.	Per cent	Per cent weight	No.	Per cent	Per cent** weight
Scaevola	55	65	46	42	51	45
Tournefortia	14	16	16	30	36	33
Cocos	2	2	4	2	2	1
Ipomea	2	2	1	4	5	6
Morinda				1	1	1
Cenchrus	3	4	2	1	1	1
Guettarda	2	2	2	2	2	1
Grasses*	3	4	9			
Other plants*	24	28	10	23	28	10
Seeds*				2	2	1
Ants	1	1	1			
Beetle larvae	3	4	1			
Insect larvae*	6	7	1			
Insect parts*	24	28	4	7	8	1
Animal tissue*	4	5	1	1	1	1
Other material*	9	11	2	8	10	2
Nematodes	32	38	–	13	16	–

* Not identified.
** Total differs from 100 per cent due to rounding.

casionally were observed during daylight hours, but feeding usually began in late afternoon as twilight approached.

RESULTS AND DISCUSSION

Members of the genus *Rattus* generally accept a wide spectrum of foods. To what extent food preferences determine niche differences is not known, because separation of such preferences from responses to habitat and various physical conditions is difficult. Differences in food preferences evident in our studies might have been a factor in better survival of *R. rattus* during periods of habitat disruption (Jackson, 1969).

Plant foods predominated in the diets of both species (Table 1). *Scaevola* and *Tournefortia*, on a weight basis, accounted for four-fifths of the diet of *R. exulans* but only two-thirds of the diet of *R. rattus*. In the laboratory preference tests, *Scaevola* had full acceptance by both species, *Tournefortia*, somewhat less (Table 2). The high prevalence of both in the diet reflected their being the most abundant shrubs in virtually all habitats.

Other plant species had high or intermediate acceptance scores, but their infrequent presence in stomach contents resulted from their scarcity or seasonal availability of fruits. The indistinct cell patterns of some plants (*Triumfetta*, for example) also might account for a low rate of positive identifications. All ripe fruits were eaten readily by both species. Green fruits and hard stems

TABLE 2.—*Comparison of the food preferences of* R. rattus *and* R. exulans *based on relative acceptance indices for selected plant materials at Eniwetok Atoll.*

Plant materials	*Rattus rattus*		*Rattus exulans*	
	No. of animals	Acceptance index*	No. of animals	Acceptance index*
Scaevola fruits	9	300	4	300
Triumfetta fruits (green)	1	300	3	300
Triumfetta stalks and leaves	11	135	11	9
Guettarda fruits (ripe)	2	300	10	230
Guettarda fruits (green)	5	160	not tested	
Cenchrus fruits and stems	11	246	4	275
Tournefortia fruits (mature)	6	234	4	200
Morinda fruits (ripe-soft)	6	233	2	250
Morinda fruits (white-hard)	8	189	1	0
Morinda fruits (green-hard)	8	62	not tested	
Cordia fruits (green)	13	116	not tested	
Pandanus fruit sections	2	200	5	0
Ipomoea fruits	6	183	4	150

* An index of 300 indicates substantial amounts of a food were eaten by all animals tested; an index of 0 indicates no feeding or gnawing on a food by any of the animals tested.

were ignored generally by *R. exulans*, but usually were examined and gnawed by some of the *R. rattus*.

On most Pacific atolls where either or both of these rats are present, only *R. rattus* climbs coconut trees and feeds on the green nuts (Strecker, 1962). We found no evidence that *R. exulans* lived or fed in the crowns, but trapping and observation revealed that they frequently traversed fronds of small palms and climbed the lower trunk sections of mature trees (McCartney, 1970). *R. exulans* fed occasionally on fallen nuts, especially if they had been opened by coconut crabs (*Birgus latro*), and Polynesian rats quickly found, and began feeding on, fresh nuts that were opened and placed at observation posts. Of the islets occupied by *R. rattus*, only Parry had significant numbers of mature coconut trees. There *R. rattus* occasionally opened green nuts.

Although insect parts constituted a small fraction of the stomach contents on a weight basis, they occurred in about one-third of the *R. rattus* stomachs but in less than 10 per cent of the *R. exulans* stomachs. This differential could not be related to the relative abundance of insect prey, because *R. exulans* lived in the more stable environment with the less variable microclimate and presumably with the greater invertebrate population. However, the scrub and bunch-grass vegetation on such islets as Runit and Engebi might make ants, beetles, and other insects more vulnerable to predation than their counterparts in the forest. We have observed roof rats catching flying insects on these islets.

Stomach nematodes (*Mastophorus muris*) were more than twice as prevalent in *R. rattus* than in *R. exulans*. Most of this effect was introduced by an extremely high rate of parasitism on Engebi, where 79 per cent of the rats

were infected. In many specimens the stomachs were filled and distended with nematodes. *R. rattus* from Runit, in contrast, showed no evidence of parasitism by *Mastophorus*.

Despite the relative abundance of lizards, no field evidence was found that either species of rat used them for food. Rats were trapped and observed within and near colonies of ground nesting terns, but there was no evidence of predation by rats on young birds. Predation on incubating adult birds comparable to that described by Kepler (1967) was absent.

Other animal foods may have been taken occasionally, especially by *R. rattus*. We have observed this rat at night, foraging on the beach and exposed reef at low tide. Under cage conditions it fed on ghost crabs, *Ocypode* sp. (Jackson and Carpenter, 1966). Feeding on carcasses might occur also, although hermit crabs are the principal scavengers in this atoll.

These observations have generally supported earlier studies, in which *R. exulans* has been found to feed almost entirely on softer plant tissues, whereas *R. rattus* had a more varied diet, including animal materials when available. Certainly both species might feed on a wide range of foods, but the apparent narrower preferences of *R. exulans* might explain its absence from islets where there was extensive habitat destruction during the nuclear test program and consequent restriction of food sources. *R. rattus* now lives on the larger of these islets, in part because of accidental introductions by man, but also because of its greater adaptability.

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