Pacific Science (1979), vol. 33, no. 3

Studies of Leptospirosis in Natural Host Populations I. Small Mammals of Waipio Valley, Island of Hawaii[1]

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ABSTRACT: The small Indian mongoose, *Herpestes auropunctatus* (Carnivora: Viverridae), and the roof rat, *Rattus rattus*, and the Polynesian rat, *Rattus exulans* (both Rodentia: Muridae), are abundant in Waipio Valley, island of Hawaii. Two other murid rodents, the house mouse, *Mus musculus*, and the Norway rat, *Rattus norvegicus*, are sporadic or rare in occurrence. As carriers of serotypes of the bacterium *Leptospira interrogans* (Spirochaetales: Treponemataceae), which is transmissible to humans, this assemblage of introduced mammals is of public health significance, for numerous cases of leptospirosis, or Weil's disease, have been traced to the valley. Population density of the mongoose was estimated at 2.3 per acre; for rats, it fluctuated seasonally from 1 to 11 per acre. The serotypes *icterohemorrhagiae* and *sejroe* were found in the mongoose in a 40:60 ratio by the kidney culture method. Combined kidney culture and serological tests on 180 mongooses showed a high of 34 percent overall infection in winter and a summer low of 9.4 percent. Of 33 house mice tested by culture only, *ballum* was isolated from 21 and *icterohemorrhagiae* from two. One isolation of *icterohemorrhagiae* was made from four Norway rats examined. For 126 roof rats tested by serology and kidney culture, 68 percent of adults and 26 percent of young were infected; and for 175 Polynesian rats, 34 percent of adults and 26 percent of young were infected. The Polynesian rat demonstrated a lesser persistence of the serum titer phase of the disease than did the roof rat. *Icterohemorrhagiae* made up 95 percent and *ballum* the remaining 5 percent of infections in the roof rat. For the Polynesian rat the ratio was 75:25. Free-ranging rats under observation for as long as 8 months acquired or lost infections, as determined by repeated serological tests. The wet subtropical climate of Waipio Valley supports conditions for transmission of leptospirosis among small mammals, and possibly to humans, even in times of drought. No prominent differences were observed in the infection rates in the lower valley at 30 ft above sea level and 1.7 miles inland at 120 ft. In the forested watershed of the valley rim at 3000 ft, conditions of infection by species of host and by serotype of *L. interrogans* matched closely those found on the valley floor. Tests of 152 water samples from streams, ponds, and taro patches resulted in isolations only of saprophytic leptospires, although temperatures, salinities, and pH concentrations appeared to be favorable for the support of pathogenic forms.

THE CAUSATIVE ORGANISM of leptospirosis is *Leptospira*, a pathogenic spirochaete bacterium that infects primarily mammals, including humans. These bacteria are now recognized as named serotypes of a single distinct species, *L. interrogans* (Turner 1967). Classically, the organism is shed in the urine of rodents and contracted by humans through contact with moist, contaminated environments. Rodents generally do not appear to be affected by the disease to

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the extent of showing gross clinical symptoms, but cattle, swine, and dogs may become ill with it. These larger animals may infect humans during their routine husbandry and care or through their contamination of sources of water used by humans.

Minette (1964) reviewed the history of leptospirosis in Hawaii and reported on the incidence of various serotypes of *Leptospira* in populations of the several rodents and a mongoose of the southeastern sector of the island of Hawaii. Human infections on this island were prevalent among sugarcane workers (Alicata 1944), especially until the hand cutting of sugarcane ceased. In more recent years, with increased application of clinical and laboratory procedures, the disease has been detected sporadically in several populated areas of the state. Shrader (1977), in an epidemiological study of leptospirosis, found that 54 (42 percent) of the statewide cases from 1962 to 1975 occurred in the sparsely populated northeastern section of the island of Hawaii. Many of these persons had histories of having lived, worked, or visited in Waipio Valley, which is situated in this region. Although the incidence of infection has lessened considerably since 1967, the potential for infection of humans in the valley remains high and resurgences may be expected.

This report on leptospirosis in small mammals of Waipio Valley is the result of research carried out from 1969 to 1974 in response to the frequency of human cases traced to the valley. Objectives were to identify and describe long-term patterns of *Leptospira* infections in populations of the small mammals in relation to prevailing environmental conditions and to explore the possibility of recovering leptospires directly from aquatic habitats.

DESCRIPTION OF THE STUDY AREA

Waipio Valley is a deep, ancient, erosion valley cut from the volcanic strata of Kohala Mountain (Figure 1). It consists of five steep-headed branches originating as much as 8 miles inland. These coalesce to form the main valley, which is nearly 1 mile wide at the mouth and opens to the north-northeast onto the Pacific Ocean. Taro, the principal agricultural crop, is grown in shallow ponds that are fed by an abundance of water in controlled streams and ditches. The main stream system drains sugarcane lands, pasture, and rain forest at the rim of the valley. This system is perennial, fed by numerous spring water sources when upland tributaries fail in times of drought. The valley is steep-sided and accessible only by a road that drops 800 ft in 0.8 mile to reach the valley floor. The rim is about 1000 ft high near the valley mouth and rises to 4000 ft at the more remote heads of the valley. The vegetation of the valley floor consists almost entirely of exotic trees, shrubs, herbs, and grasses. Except for the acreages under cultivation, the land is generally overgrown with weeds or is wooded with a weedy understory. There are some 25 human residents in the valley, living in the several habitable dwellings or under makeshift shelters with primitive sanitary facilities. The residents are generally engaged in subsistence gardening or part- or full-time taro farming. Others who cultivate taro enter the valley daily or on weekends but live in nearby communities. In addition, there is a transient population of day visitors and of campers who may stay for several days at a time. On any one day, as many as 35 to 50 persons may be present in the valley.

The climate is typical of wet coastal Hawaii. Mean annual temperature is near 73°F and the mean range is about 5°F (Blumenstock and Price 1967). The tropical character of the valley is enhanced by its partial protection from the prevailing northeast tradewinds and by accentuation of solar radiation on exposed shallow waters of taro ponds and marshy areas. Stream waters have a mean temperature of about 68°F and a range of 8°F (based on 20 consecutive monthly readings). Normal rainfall is 79 inches in the lower valley, but it increases to more than 175 inches in the headwaters of streams draining Kohala Mountain. Daily cloud formations and frequent rainfall are the rule in the higher watershed of Waipio.

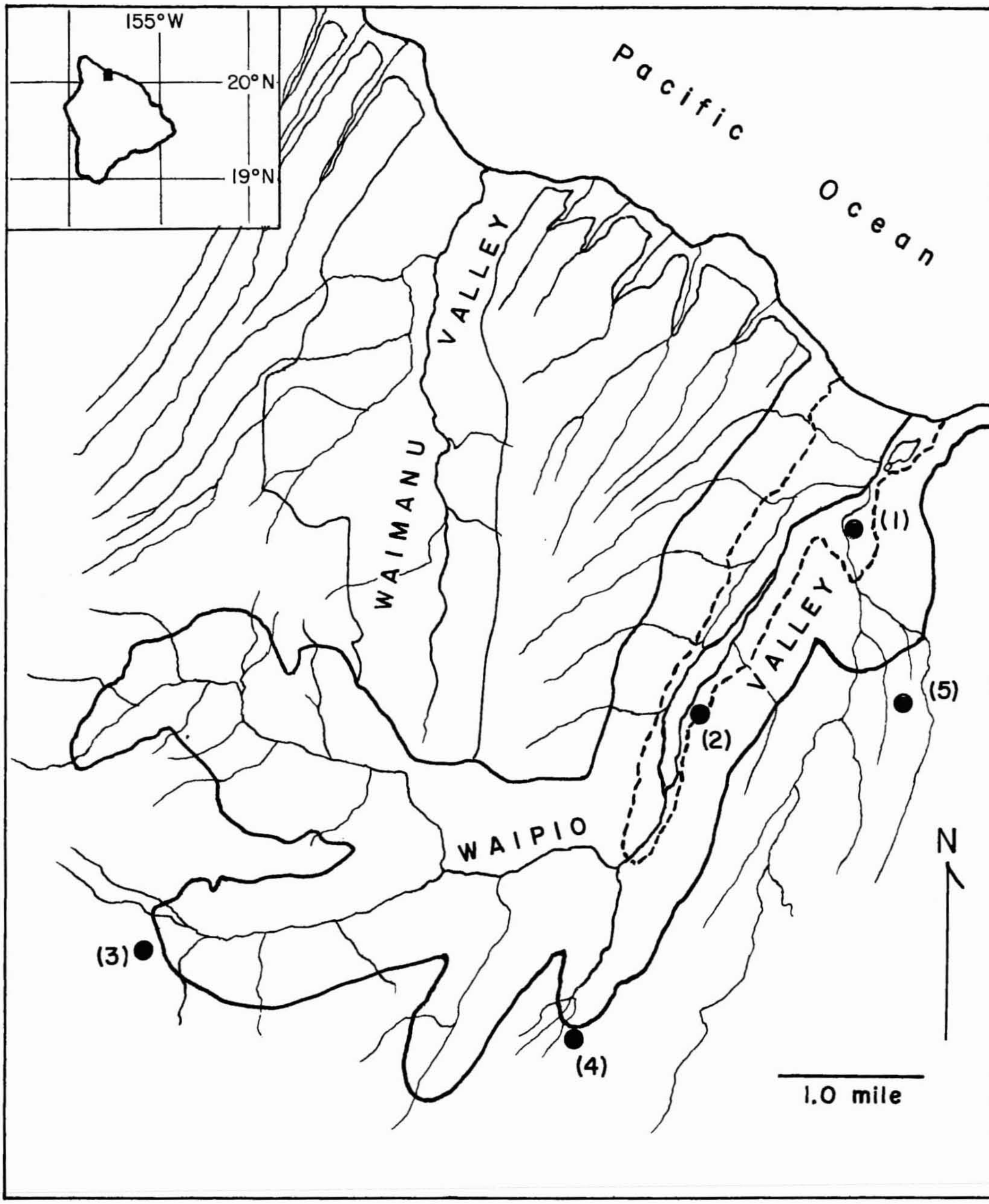

FIGURE 1. Drainage pattern of Waipio Valley and adjacent land forms. The dashed line marks the perimeter of the Waipio Valley floor. Numbered dots indicate sites where rodents and mongooses were trapped: (1) lower valley at 30 ft elevation above sea level; (2) upper valley at 120 ft, and on the valley rim; (3) head of Alakahi branch at 3800 ft; (4) head of Waima branch at 3000 ft; and (5) head of Hiilawe branch at 2000 ft. Inset map of the island of Hawaii locates the study area.

FIELD METHODS

The project was designed around a scheme of long-term sampling for the detection of leptospirosis in small mammals as this disease is related to factors of population and environment. Five species of terrestrial mammals inhabit the valley: the small Indian mongoose (*Herpestes auropunctatus*), the Norway rat (*Rattus norvegicus*), the roof rat (*R. rattus*), the Polynesian rat (*R. exulans*), and the house mouse (*Mus musculus*).

I established two major trapping sites and placed a grid of 40 traps in each. Traps were cage-style, arranged in four rows of 10 traps each, with spacing at 50 ft between rows and traps. The lower valley site (grid 1) was beside Hiilawe Stream near the mouth of the Hiilawe branch of the valley, 30 ft above sea level. The site is relatively flat and is the central area of the former Waipio Village. It is now overgrown with large kukui (*Aleurites*), Java plum (*Eugenia*), coconut (*Cocos*), mango (*Mangifera*), and guava (*Psidium*). One edge of the grid intruded into a poorly kept orchard of macadamia nut (*Macadamia*). The understory comprises young guava and kukui, mamaki (*Pipturus*), pikake honohono (*Clerodendrum*), and a mixture of other plants, including an aggressive taro vine (*Scindapsus*), which climbs to the tops of the tallest trees. The vegetation can be classed as a mixed forest of escaped or residual ornamentals. Ground cover includes white and yellow ginger (*Zingiber*), palm grass (*Setaria*), other grasses, and seedling macadamias.

The substrate is cobbly alluvium. There is at least one alternate channel of Hiilawe Stream, which demonstrates major past floodings. Several stone walls are present, representing boundary lines and other barriers in effect when the area supported an inhabited village. One frame house remains adjacent to the trapping grid and is in good repair.

Grid 2 was laid out in similar overgrown habitat 1.7 miles up the valley, near the Kahuku macadamia nut orchard. At this upper valley site, the forest consists principally of kukui trees but also includes thickets of rose apple and mountain apple (both *Eugenia*), and hau (*Hibiscus*). Ground cover is made up of ferns, grasses, and three kinds of ginger. This grid was situated on the bank of an active alternate channel of Waipio Stream. Here the rocky land slopes upward and merges with the steep wall of the valley, above the grid site.

A line of 40 cage traps was placed near each grid, beginning about 100 ft away. Line 1, in the lower valley, crossed the yard of an abandoned house and dense growths of exotics, as in grid 1, then crossed a stand of wetland fern (*Athyrium*), and ran along the dikes of three taro patches bordered by guava thickets. Line 2 was placed along the main valley road where the road bordered abandoned taro lands overgrown mainly with cattail (*Typha*), canna (*Canna*), and paragrass (*Brachiaria*). The spacing of 50 ft between traps, as in the grids, permitted the sampling with each line of a strip nearly 2000 ft long.

The grids were run for 3 days per month, beginning in October and November 1969, through January 1972. All animals caught were marked with ear tags and released at the site of capture. Biological data were taken and a blood sample was obtained by cardiac puncture.

The lines were run on the same schedules as the grids, but all animals captured on the lines were removed to the laboratory in Honokaa where they were killed and bled, and kidney cultures were taken.

In January 1972 the lines were discontinued and an 8-day trap-out was conducted in grids 1 and 2. Following this, grid 2 was removed and grid 1 was trapped out for 3 days bimonthly, with all animals being removed to the laboratory. The bimonthly trapping at grid 1 terminated in March 1974. A third grid, grid 3, was established at the densely vegetated site of the former line 1, across the valley road from grid 1; this ran bimonthly for 3 days from October 1973 through April 1974. This grid allowed comparison of populations in an adjacent area with the then heavily depleted population of grid 1.

Additional sampling was done when it became obvious early in the study that

TABLE 1

RATES OF CAPTURE OF THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, IN WAIPIO VALLEY, ISLAND OF HAWAII

TIME SEGMENT	NUMBER CAPTURED	TOTAL TRAP DAYS	NUMBER PER 100 TRAP DAYS
	UPPER VALLEY		
First 3-day runs (Nov. 1969 and Apr. 1970)	24	360 (120 × 3)	6.67
Later 3-day runs (Dec. 1969 through Dec. 1971)	24	5,880 (120 × 49)	0.41
	LOWER VALLEY		
First 3-day runs (Oct. 1969 and Apr. 1970)	9	360 (120 × 3)	2.50
Later 3-day runs (Nov. 1969 through Dec. 1971)	15	6,180 (120 × 51)	0.25

NOTE: Marked and unmarked animals are combined. Trapping time was 26 months.

insufficient numbers of mongooses were being taken in the limited areas of the two grids and two lines (established primarily for the study of rodents). Mongooses were then trapped out of several areas of the lower valley, in rotation, every month or every second month between June 1970 and September 1971. The lines consisted routinely of 15–30 traps set for 3 days at the more accessible sites from Nanaue Falls to the beach area. These traps were baited with meat scraps.

Animals at three sites on the rim of Waipio Valley at 3800 ft, 3000 ft, and 2000 ft were trapped during the period from April 1970 to June 1971 so that comparative samples of all small mammals in the watershed might be obtained (Figure 1).

LABORATORY METHODS

Kidney, blood, and water samples were tested in the Hilo laboratory, with standard methods (Sulzer and Jones 1976) being used. Diluted kidney emulsion was inoculated into semisolid EMJH medium and positive cultures were serotyped with Difco antisera. Blood sera were tested with pooled antigens obtained from U.S. Public Health Service sources, by means of the rapid macroscopic agglutination test. Water was tested by direct culture or by guinea pig inoculation, using EMJH medium. Specific identification of serotype was made only from kidney cultures because of the cross-reactions often obtained from antigen tests of sera.

POPULATION DENSITIES OF THE MONGOOSE

When the original grids and lines first were used, mongooses often were caught; however, few were taken thereafter in these traps. The record for 12,780 trap days in two grids and two lines of 40 traps each emphasizes this point. The lines were moved to new areas after 5 and 6 months operation; hence the two lines demonstrate two starts each. Coconut bait was used in the lines as well as in the grids.

The capture rate after the first runs of 3 days each diminished rapidly in subsequent months by a factor of about 10 to 15. The respective figures of 6.67 and 2.50 mongooses caught per 100 trap days demonstrate a probable greater density of mongooses in the upper valley (Table 1).

Lines set specifically for the mongoose, in the lower valley only, provided 85 of the 180 mongooses taken in the entire study. To maximize numbers taken, traps were moved to a new location after each standard 3-day sampling; thus, each run represented a new start comparable to the beginnings of the rodent lines and grids. The rather large

TABLE 2

POPULATION STRUCTURE OF THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, CAPTURED IN WAIPIO VALLEY, ISLAND OF HAWAII

SEX AND AGE OF ANIMALS	UPPER VALLEY	LOWER VALLEY	WAIPIO RIM	TOTAL AND PERCENTAGE BY SEX AND AGE
Adult male	21	51	5	77 (42.8%)
Adult female	13	36	2	51 (28.3%)
Juvenile male	2	17	0	19 (10.6%)
Juvenile female	12	21	0	33 (18.3%)
Total mongooses by area	48	125	7	180 (100.0%)

NOTE: Of the 180 mongooses, 128 (71.1%) were adults and 52 (28.9%) were juveniles. By sex, 96 (53.3%) were males and 84 (46.7%) were females.

TABLE 3

INCIDENCE OF LEPTOSPIROSIS IN THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, IN WAIPIO VALLEY, ISLAND OF HAWAII, FROM SEROLOGICAL TESTS, BY AGE AND SEX

AGE AND SEX	NUMBER EXAMINED	NUMBER POSITIVE	PERCENTAGE POSITIVE
	UPPER VALLEY		
Juvenile male	2	0	0
Juvenile female	12	4	33.3
Total juveniles	14	4	28.6
Adult male	21	6	28.6
Adult female	13	4	30.8
Total adults	34	10	29.4
Total number of animals examined in the upper valley	48	14	29.2
	LOWER VALLEY		
Juvenile male	17	3	17.6
Juvenile female	21	4	19.0
Total juveniles	38	7	18.4
Adult male	51	11	21.6
Adult female	36	8	22.2
Total adults	87	19	21.8
Total number of animals examined in the lower valley	125	26	20.8
Total number of animals examined in Waipio Valley	173	40	23.1

figure of 17.4 mongooses per 100 trap days resulted from this work.

Extrapolation to a standard line of 30 traps (interval was 50 ft) provided density-per-acre figures. The method consists of adding a constant to each end and side of the line of traps so that a rectangle of land representing a probable source of mongooses attracted to the traps was constructed. The constant is derived from observed movements of mongooses caught in an earlier study in the Hamakua district and represents an average distance moved by mongooses caught more than one time in a 4-day trapping period. For males, the constant is 596 ft; for females, 518 ft (Tomich 1969).

The calculated effective acreage of my 30-trap line in Waipio was 7.2 acres for males and 5.9 acres for females. On this basis, there were 1.1 males per acre and 1.2 females per acre in the valley at the time of the study, or a total of 2.3 mongooses per acre in the more suitable habitats of the valley floor. Estimates for the entire 910 acres of the valley based on these data would be speculative.

For the total of 180 mongooses examined, the preponderance of adult males to adult

TABLE 4

INCIDENCE OF LEPTOSPIROSIS IN THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, IN WAIPIO VALLEY, ISLAND OF HAWAII, FROM KIDNEY CULTURES, BY AGE AND SEX

AGE AND SEX	NUMBER EXAMINED	NUMBER POSITIVE	PERCENTAGE POSITIVE
	UPPER VALLEY		
Juvenile male	1	0	0
Juvenile female	9	4	44.4
Total juveniles	10	4	40.0
Adult male	13	3	23.1
Adult female	9	2	22.2
Total adults	22	5	22.7
Total number of animals examined in the upper valley	32	9	28.1
	LOWER VALLEY		
Juvenile male	7	0	0
Juvenile female	11	0	0
Total juveniles	18	0	0
Adult male	33	9	27.3
Adult female	17	5	29.4
Total adults	50	14	28.0
Total number of animals examined in the lower valley	68	14	20.6
Total number of animals examined in Waipio Valley	100	23	23.0

females, 60.2:39.8, matches earlier results obtained in the Hamakua district. Adult males are more easily caught in traps than are females and juveniles, and they also have larger home ranges. Later maturity and seasonal breeding of females may account for the larger proportion of female juveniles to male juveniles, 63.5:36.5, in the samples. An actual differential in sex ratio is unlikely. Population structure is presented in Table 2.

INFECTION PATTERNS

The Mongoose

Of 180 mongooses in the study, 48 were from the upper valley, 125 from the lower valley, and 7 from Waipio rim; these animals were taken from October 1969 to January 1972. Infection rates of adults by sex were similar and ranged from 21 to 31 percent in all samples (Tables 3 and 4). There was a curious reversal in the prominence of sero-positive and culture-positive rates between the upper valley (higher by serology) and lower valley (higher by kidney culture). In juveniles, the data are less regular but the pattern of infection rates appears to be similar.

Combined infection rates in all mongooses were almost identical as determined by serological tests (23.1 percent) and by kidney culture (23.0 percent). In the 100 mongooses on which both kidney culture and serological data were obtained (Table 5), the infection rate was 36.0 percent. Among the 72 adults tested, this increased rate of infection was nearly identical in the upper valley (40.9 percent) and in the lower valley (40.0 percent). Thus, the reciprocal differences noted in Tables 3 and 4 are effectively canceled out. Among juveniles, the corresponding figures are 60 percent (6 of 10 positive; two in each of the three categories for positive tests) in the upper valley, and only 5.6 percent in the lower valley where only one sero-positive case was detected among 18 animals tested.

The sample from Waipio rim comprised five adult males and two adult females. Each was tested serologically, and one male proved to be positive. The two animals examined by kidney culture were males and both were negative.

In mongooses of Waipio Valley, two sero-

TABLE 5

SUMMARY OF INCIDENCE OF LEPTOSPIROSIS IN THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, IN WAIPIO VALLEY, ISLAND OF HAWAII, FROM KIDNEY CULTURES AND FROM SEROLOGICAL TESTS, BY AGE AND SEX

AGE AND SEX	NUMBER EXAMINED	C+, S+ (%)	C+, S− (%)	C−, S+ (%)	C−, S− (%)	TOTAL + (%)
		UPPER VALLEY				
Juvenile male	1	0	0	0	1 (100.0)	0
Juvenile female	9	2 (22.2)	2 (22.2)	2 (22.2)	3 (33.3)	6 (66.7)
Total juveniles	10	2 (20.0)	2 (20.0)	2 (20.0)	4 (40.0)	6 (60.0)
Adult male	13	0	3 (23.1)	3 (23.1)	7 (53.8)	6 (46.2)
Adult female	9	1 (11.1)	1 (11.1)	1 (11.1)	6 (66.7)	3 (33.3)
Total adults	22	1 (4.5)	4 (18.2)	4 (18.2)	13 (59.1)	9 (40.9)
Total number of animals examined in the upper valley	32	3 (9.4)	6 (18.8)	6 (18.8)	17 (53.1)	15 (46.9)
		LOWER VALLEY				
Juvenile male	7	0	0	0	7 (100.0)	0
Juvenile female	11	0	0	1 (9.1)	10 (90.9)	1 (9.1)
Total juveniles	18	0	0	1 (5.6)	17 (94.4)	1 (5.6)
Adult male	33	3 (9.1)	6 (18.2)	4 (12.1)	20 (60.6)	13 (39.4)
Adult female	17	1 (5.9)	4 (23.5)	2 (11.8)	10 (58.8)	7 (41.2)
Total adults	50	4 (8.0)	10 (20.0)	6 (12.0)	30 (60.0)	20 (40.0)
Total number of animals examined in the lower valley	68	4 (5.9)	10 (14.7)	7 (10.3)	47 (69.1)	21 (30.9)
Total number of animals examined in Waipio Valley	100	7 (7.0)	16 (16.0)	13 (13.0)	64 (64.0)	36 (36.0)

NOTE: C+, culture positive; C−, culture negative; S+, serology positive; S−, serology negative. Numbers within parentheses indicate percentages.

types of *Leptospira interrogans* were found: *icterohemorrhagiae* and *sejroe*. That they occur in a 40:60 ratio is shown in the 23 isolations obtained (Table 6). Minor differences in proportions of isolations between the upper and lower valleys do not appear to be significant, nor is it obvious that one serotype or the other has an affinity for mongooses by age or sex.

Although infections of leptospirosis in the individual animal may be either transitory or chronic, depending on the phase, prominent seasonal trends are indicated in overall rates of infection (Table 7). The 280 tests made on 180 animals showed a plateau of infections in the winter period, from January through April; during this time, more than 34 percent of all mongooses were infected. A low of 9.4 percent occurred in the midsummer July–August period, followed by a minor peak of about 18 percent in September–October.

These fluctuations appear to be real and may well be annually cyclic. The winter high of infections corresponds to a surge of activity in mongoose populations that is consistently reflected in trapping results. The summer decline and rise of infection rates are associated with a decline and rise of activity, again reflected in long-term trapping results. These trends in rates of activity have been interpreted as behavioral (Tomich 1969).

House Mouse

We found the house mouse (*Mus musculus*) only rarely in Waipio Valley during the first 2 years of the study. We caught none in the routine operation of grid 1 or grid 2, where all animals were tagged and released for a period of 27 months. On 28 January 1970, a male and a female, both adult, were removed from adjacent traps of

TABLE 6

SEROTYPES OF *Leptospira* IN THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, IN WAIPIO VALLEY, ISLAND OF HAWAII, BY AGE AND SEX OF HOST ANIMAL

AGE AND SEX	NUMBER OF ISOLATIONS (%) *icterohemorrhagiae*	*sejroe*	TOTAL NUMBER OF ISOLATIONS
	UPPER VALLEY		
Juvenile male	0	0	0
Juvenile female	1 (25.0)	3 (75.0)	4
Total juveniles	1 (25.0)	3 (75.0)	4
Adult male	2 (66.7)	1 (33.3)	3
Adult female	1 (50.0)	1 (50.0)	2
Total adults	3 (60.0)	2 (40.0)	5
Total number of animals examined in the upper valley	4 (44.4)	5 (55.6)	9
	LOWER VALLEY		
Juvenile male	0	0	0
Juvenile female	0	0	0
Total juveniles	0	0	0
Adult male	4 (44.4)	5 (55.6)	9
Adult female	1 (20.0)	4 (80.0)	5
Total adults	5 (35.7)	9 (64.3)	14
Total number of animals examined in the lower valley	5 (35.7)	9 (64.3)	14
Total number of isolations made from mongooses in Waipio Valley	9 (39.1)	14 (60.9)	23

TABLE 7

BIMONTHLY INCIDENCE OF LEPTOSPIROSIS IN THE SMALL INDIAN MONGOOSE, *Herpestes auropunctatus*, IN WAIPIO VALLEY, ISLAND OF HAWAII, FROM 280 TESTS OF SERA ONLY OR FROM SERA AND KIDNEY TISSUE

AGE GROUP	SEGMENT OF YEAR JAN.–FEB.	MAR.–APR.	MAY–JUNE	JULY–AUG.	SEPT.–OCT.	NOV.–DEC.	TOTAL NUMBER OF POSITIVE CASES
Juvenile	4/14 (28.6)	3/4 (75.0)	1/3 (33.3)	0/6 (0.0)	1/17 (5.9)	5/34 (14.7)	14/78 (19.0)
Adult	8/21 (38.1)	16/51 (31.4)	3/15 (20.0)	3/26 (11.5)	12/54 (22.2)	4/35 (11.4)	46/202 (22.8)
Total number of animals examined in Waipio Valley	12/35 (34.3)	19/55 (34.5)	4/18 (22.2)	3/32 (9.4)	13/71 (18.3)	9/69 (13.0)	60/280 (21.1)

NOTE: Fractions show number of positive tests/number tested. Numbers within parentheses indicate percentages of animals infected.

line 1. The next day, an immature female appeared in one of these traps and a second adult male was caught 600 ft away in the same line. All were negative for leptospirosis by kidney culture. As far as I was able to determine, this species was absent from the upper valley and from the sites sampled along the valley rim. Because of its small size, I did not attempt to obtain blood from the house mouse.

After the January 1972 trap-out of grid 1, during the bimonthly removal trapping that followed, two mice were caught in March 1972; these were found to be negative by the kidney culture method. In November 1972 no mice were taken; then quite suddenly, in

January 1973, a moderately large number was trapped. Ten were trapped in the January 1973 sample, and the serotype *ballum* was isolated from the kidneys of three of them.

Thereafter, through April 1974, 37 mice were taken in a total of 1200 trap nights, or about three per 100 trap nights. Of 33 tested, 23 were positive. *Ballum* was isolated from 15 adults and six immatures, and *icterohemorrhagiae* was isolated from two adults.

Norway Rat

The Norway rat (*Rattus norvegicus*) rarely was found in Waipio Valley during the study, with only four being trapped. A male adult marked in grid 2 in August 1970 and never recaptured was negative for leptospirosis by serological test. A second male adult, taken from line 1 in November 1970, was positive by serology and kidney culture; and a female immature from line 2 in February 1971 was negative by both tests. On the final day of the field program, in April 1974, a male adult removed from grid 3 was positive by serology but negative by the culture method. The single isolation from the Norway rat was the serotype *icterohemorrhagiae*.

Although apparently sparsely distributed and unable to form a significant density of population, the Norway rat does participate in the maintenance of leptospires in the valley. A rapid and unexplained decline of the Norway rat occurred from 1958 to 1961 in the adjacent Hamakua sugarcane belt (Tomich 1970). There have been generally small populations found since that time, almost always in the villages and near hog and poultry farms where foodstuffs are plentiful. Waipio Valley apparently resembles cane fields in that it supports very few Norway rats.

Roof Rat and Polynesian Rat

POPULATION DENSITY: The roof rat (*Rattus rattus*) appeared in the traps less frequently than did the Polynesian rat (*R. exulans*), but both species formed moderately large populations in the wooded habitats of the valley floor. Removal trapping had the effect of reducing populations of rats in time and also, to an extent, of holding these populations below expected levels of density. Overall comparative data were obtained simply by recording the numbers of rats taken per unit of traps set. Absolute densities in rats per acre were estimated for the grids. Each grid of 40 traps spaced at 50 ft apart (four rows of 10 traps) bordered on a running stream. Thus, the constant of 100 ft, representing the average daily movement of a rat (Tomich 1970), was added to three sides only, and produced a figure of 3.7 acres as the effective size of each grid.

During mark-and-release sampling of the grids, the population of roof rats was estimated at 4–8 per acre in the winter highs and at about 1 per acre during summer lows. There were more Polynesian rats and these generally registerd 6–10 per acre in winter and about 2 per acre in summer. These estimates were based on the likelihood that not more than half the resident population was trapped in any 3-day period. In the trap-out of grids 1 and 2 (upper and lower valleys) at the close of the mark-and-release study, 83 rats were taken in 8 days of trapping over a period of 2 weeks. This represents an actual population density of 11 rats per acre. Some of these may have been replacement animals that had moved into the grids from adjacent lands as the resident population was depleted. At this time the roof rat was becoming less significant in the grids and made up only 31 percent of the population. Trends in population densities during the 27 months of mark-and-release trapping are shown in Figures 2 and 3.

In Figure 2, typical cycles of abundance and scarcity of rats are demonstrated for the relatively undisturbed populations of grids 1 and 2 that were bled and released. Population highs were reached in the winter, about the turn of the year, and lows occurred in summer. Secondary seasonal fluctuations were less pronounced, but there was a definite trend toward an annual bimodal distribution of highs and lows. This pattern was similar both for the roof rat and the Polynesian rat.

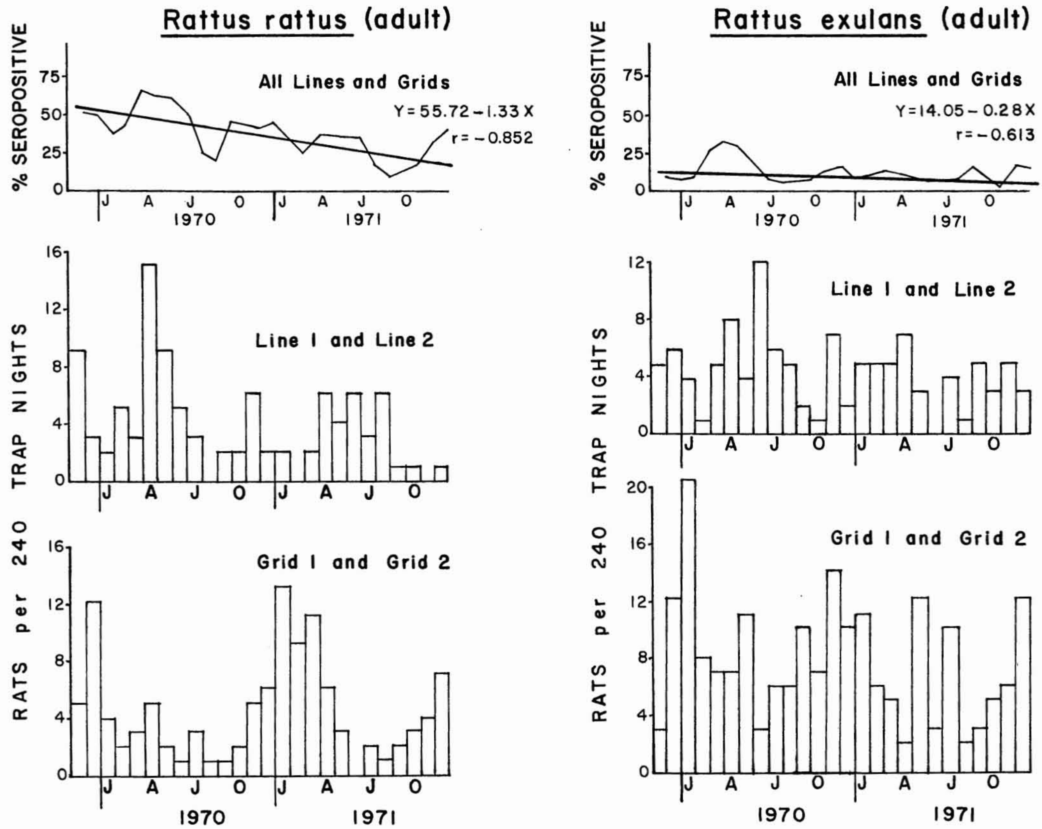

FIGURE 2. Summary of trapping results and rates of infection with leptospirosis in adult roof rats (*Rattus rattus*) and adult Polynesian rats (*R. exulans*) of Waipio Valley during the 26-month period from November 1969 to December 1971. Key months, January, April, July, and October, are indicated by initials. The figure of 240 trap nights represents a standard unit of trapping effort: two lines or two grids of 40 traps each set for 3 consecutive nights in a particular month.

For lines 1 and 2, the data are perhaps less reliable indicators of normal population fluctuations because (1) routine removal of trapped rats may have had a disruptive influence on population structure; and (2) the lines were moved each April to an adjacent locality and were returned each September to the original locality. The lines were moved in this way so that populations would not be depleted and so that reasonably good sample sizes might be assured. The effect of moving the traps seems to have been to shift several months ahead the times of highs in rates of capture, to coincide approximately with the lows in the grid results.

INFECTION WITH LEPTOSPIROSIS: Because I was unable to obtain kidney cultures from rats released alive, my most numerous and consistent data were from serological results. Figures 2 and 3 show monthly test results for the 26-month period of November 1969 to December 1971. Data are expressed as percent positive for adult and immature rats from all lines and grids. The graphs were smoothed initially by application of a 2-month moving average. Maximum smoothing was achieved in plotting preferred fits by four-way linear regression analysis, which revealed a steady decline of infections in the 2 years of study. Infection rates were

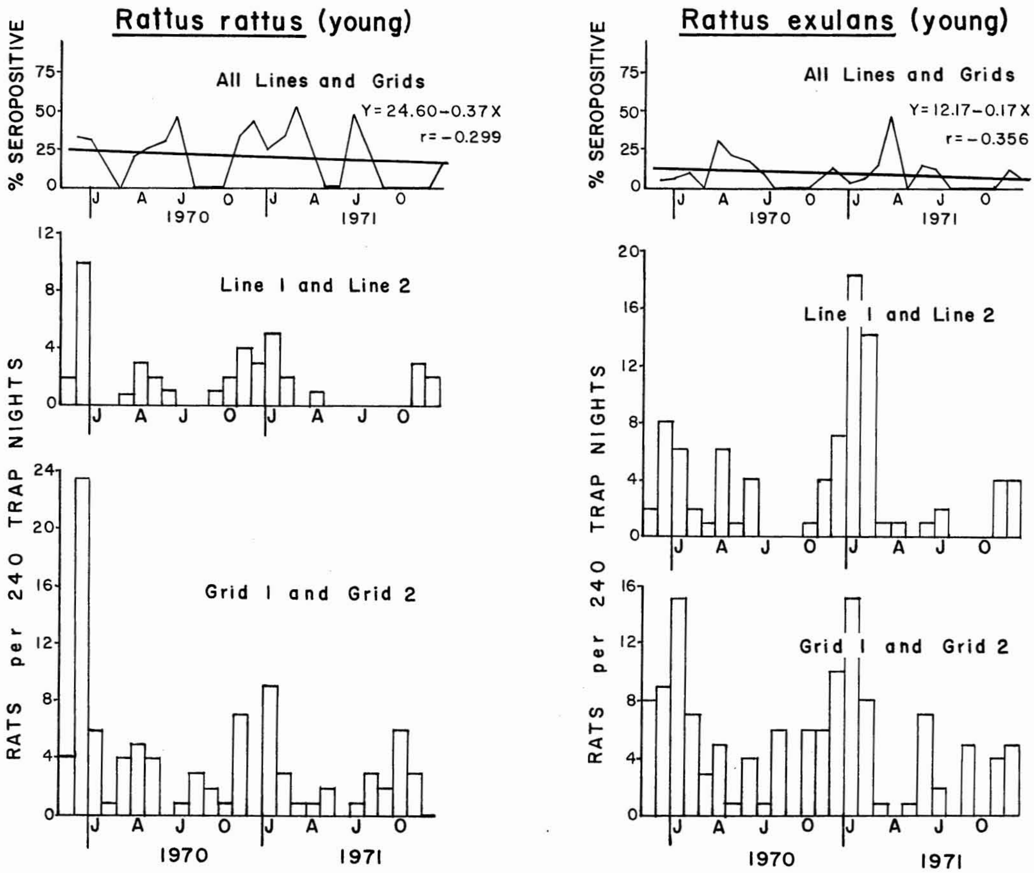

FIGURE 3. Summary of trapping results and rates of infection with leptospirosis in young roof rats (*Rattus rattus*) and young Polynesian rats (*R. exulans*) of Waipio Valley during the 26-month period from November 1969 to December 1971. Key months, January, April, July, and October, are indicated by initials. The figure of 240 trap nights represents a standard unit of trapping effort: two lines or two grids of 40 traps each set for 3 consecutive nights in a particular month.

strongly bimodal, with highs in early winter and early summer and lows in midwinter and midsummer. The patterns were similar in this respect in the older rats and in immature rats. Patterns were particularly well demonstrated in adult roof rats, where percentages of infection were more than twice those of Polynesian rats. Decline in rates of infection tended to accompany a decline in rainfall.

Figure 3 shows that the pattern of scarcity and abundance of young rats from lines as well as grids matches closely the pattern of adults from the grids; that is, removal trapping did not alter the seasonal rhythms of appearance of young rats in the population. Annual bimodal cycles of population density are perhaps better demonstrated in the young than in adults and may be rather exact indicators of the timing of breeding cycles that precede the rise in total numbers of rats.

Generally, smaller samples of young rats with no young appearing for several months at a time resulted in a greater amplitude of the percentage of infections. High rates in

TABLE 8

SUMMARY OF INCIDENCE OF LEPTOSPIROSIS INFECTION IN THE ROOF RAT, *Rattus rattus*, AND THE POLYNESIAN RAT, *Rattus exulans*, IN WAIPIO VALLEY, ISLAND OF HAWAII, AMONG 301 ANIMALS EXAMINED BY KIDNEY CULTURE AND BY SEROLOGICAL TESTS

AGE CLASS	NUMBER EXAMINED	C+, S+ (%)	C+, S− (%)	C−, S+ (%)	C−, S− (%)	TOTAL + (%)
		Rattus rattus				
Adult	87	32 (54.2)	18 (30.5)	9 (15.3)	28 (32.2)	59 (67.8)
Immature	39	6 (60.0)	1 (6.7)	3 (33.3)	29 (74.4)	10 (25.6)
Total number of roof rats examined	126	38 (55.1)	19 (27.5)	12 (17.4)	57 (45.3)	69 (54.7)
		Rattus exulans				
Adult	97	8 (24.2)	19 (57.6)	6 (18.2)	64 (66.0)	33 (34.0)
Immature	78	10 (50.0)	6 (30.0)	4 (20.0)	58 (74.4)	20 (25.6)
Total number of Polynesian rats examined	175	18 (34.0)	25 (47.1)	10 (18.9)	122 (69.7)	53 (30.3)

NOTE: C+, culture positive; C−, culture negative; S+, serology positive; S−, serology negative. Numbers within parentheses indicate percentages.

the young tended to lag slightly behind highs among adults. Overall, however, the patterns in the two groups were similar.

KIDNEY CULTURE COMPARED TO SERUM TESTS: Complete data were obtained on 126 roof rats and 175 Polynesian rats, allowing direct comparisons of infection rates detected by the two standard methods used, according to species of host and its age group. No real differences were apparent between populations of the upper valley and lower valley or between sexes. Therefore, the data have been grouped accordingly (Table 8), with information from the stations at the rim of the valley also being included.

For roof rats, a general infection rate of nearly 55 percent was obtained: 68 percent of the adults and 26 percent of the young. Overall, only 10 young rats (7.9 percent of all roof rats examined) were infected, indicating that as a group their role in leptospirosis is minor. The trends, considering sample size, were similar in adults and young as far as stage of infection was concerned (serum only, kidney only, or both). The data suggest a low, transitory, serum titer of only 17.4 percent, a moderate kidney infection of only 27.5 percent, but a combined infection of 55.1 percent, which is higher than the single infections taken together.

The Polynesian rat appears to be less susceptible to leptospirosis. Only about 34 percent of the adults were infected, but, as with the roof rat, 26 percent of the immatures were infected. The 20 infected young, or 11.4 percent of the 175 rats examined, again showed a relatively small portion of the entire population to be infected young animals. Trends for the intensity of infection were similar in adults and young, with 18.9 percent detected from serum only, 47.1 percent from kidney only, and 34.0 percent from both. The high of 57.6 percent kidney-only infections in adult Polynesian rats indicates a lesser persistence of the serum titer phase than occurs in the roof rat.

SEROTYPES OF *Leptospira*: Two serotypes, *icterohemorrhagiae* and *ballum*, were isolated from the roof rat and the Polynesian rat, with a total of 96 isolations (Table 9). *Icterohemorrhagiae* was prevalent in both species of rats, but *ballum* occurred more frequently among isolates from the Polynesian rat than it did among those from the roof rat.

TABLE 9

SEROTYPES OF *Leptospira* IN THE ROOF RAT, *Rattus rattus*, AND THE POLYNESIAN RAT, *Rattus exulans*, IN WAIPIO VALLEY, ISLAND OF HAWAII, BY AGE AND SEX OF HOST ANIMAL

AGE AND SEX	NUMBER OF ISOLATIONS (%) *icterohemorrhagiae*	*ballum*	TOTAL NUMBER OF ISOLATIONS
	Rattus rattus		
Juvenile male	0	0	0
Juvenile female	6 (100.0)	0	6
Total juveniles	6 (100.0)	0	6
Adult male	22 (95.7)	1 (4.3)	23
Adult female	25 (92.6)	2 (7.4)	27
Total adults	47 (94.0)	3 (6.0)	50
Total number of roof rat isolations	53 (94.6)	3 (5.4)	56
	Rattus exulans		
Juvenile male	3 (60.0)	2 (40.0)	5
Juvenile female	4 (80.0)	1 (20.0)	5
Total juveniles	7 (70.0)	3 (30.0)	10
Adult male	9 (90.0)	1 (10.0)	10
Adult female	14 (70.0)	6 (30.0)	20
Total adults	23 (76.7)	7 (23.3)	30
Total number of Polynesian rat isolations	30 (75.0)	10 (25.0)	40
Total number of isolations made from rats in Waipio Valley	83 (86.5)	13 (13.5)	96

NOTE: Numbers within parentheses indicate percentages.

LEPTOSPIROSIS IN FREE-RANGING RATS: Grids 1 and 2 were established primarily for the purpose of monitoring leptospirosis infection in marked animals that had been released at the site of capture. The rats were marked with a serially numbered metal tag that was attached to one ear. This is an established procedure that is well adapted to the present study. The animal was quieted with ether and biological data were taken; it was then bled by cardiac puncture and released. Those animals recaptured in the 3-day trapping period were not bled a second time in any one month. Few mongooses were taken in the grids and they yielded no useful data through recapture. The cardiac puncture method was nearly always successful in producing the required blood sample. A maximum of 1.0 cm^3 was withdrawn from the roof rat and 0.6 cm^3 from the smaller Polynesian rat. We used a 1.0 cm^3 syringe equipped with a 25-gauge 5/8-inch needle.

Trauma, leading in some cases to death, did result from the cardiac puncture technique. Small Polynesian rats were particularly prone to injury. In the first 13 months of the work 5 of 93 (5.4 percent) roof rats and 27 of 165 (16.4 percent) Polynesian rats were killed. After initial practice, the losses declined. All rats sighted 1 or 2 days after being bled appeared to be normal, but some that were released in an obviously depressed condition probably died soon after.

Rats have considerable mobility, and the strict area of each trapping grid (approximately 2 acres) was less than a usual home range for either species that is common in Waipio Valley. Many rats examined may have used only a part of either grid; others may have been residents of it in the sense of having established nests and burrows, or were nightly visitors from nearby sites.

The spatial distribution of rats in grids 1 and 2 is shown in Figure 4. Physical features of the trap areas have been described. Rates

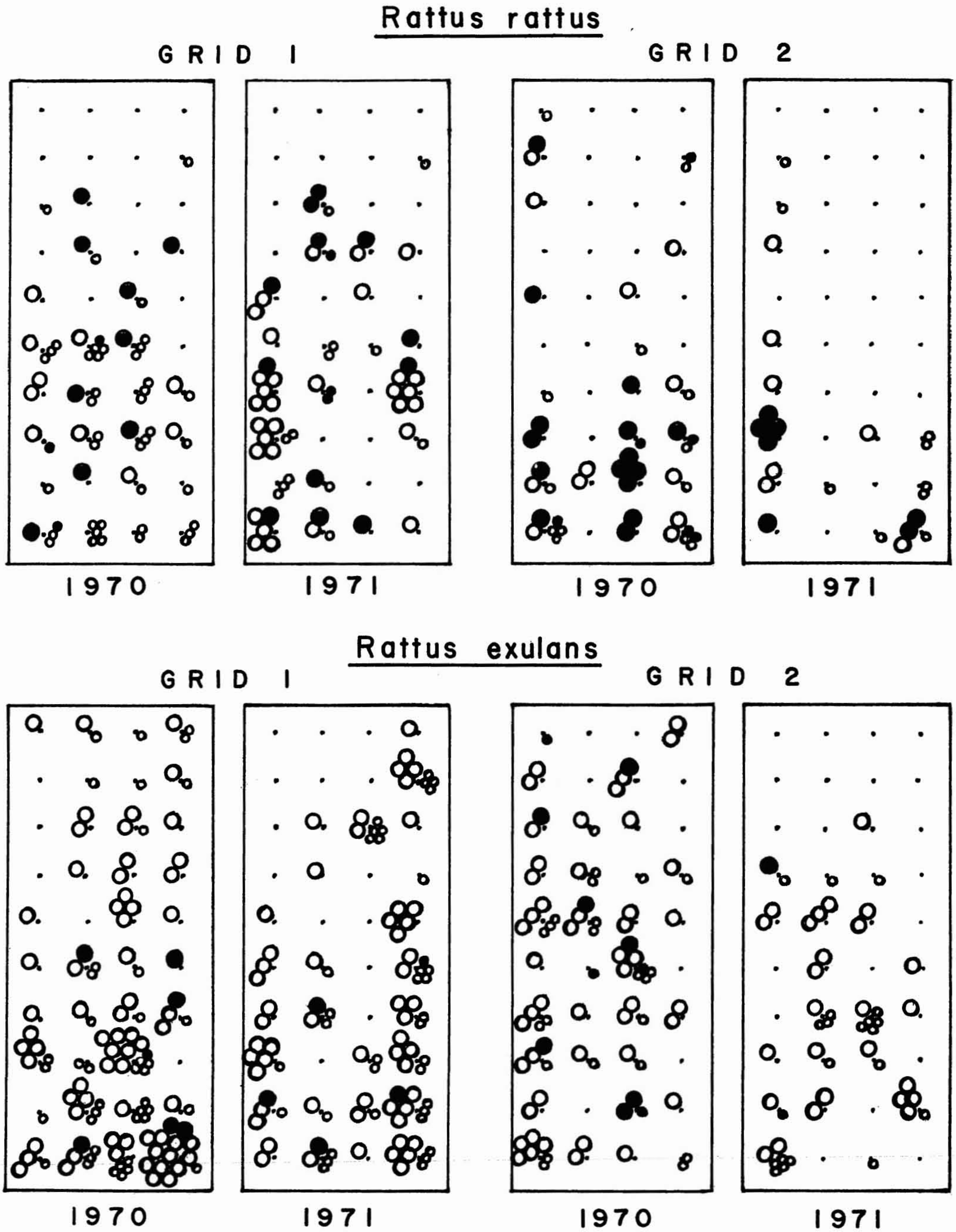

FIGURE 4. Capture sites of rats marked with ear tags in two trapping grids of Waipio Valley for a 2-year period. Streams formed a boundary for one side of grid 1 and for one side of grid 2. The regular pattern of dots represents trap sites. Large open circles represent adult rats, small open circles represent young rats, and solid circles represent infected rats of these respective age classes.

TABLE 10

COURSE OF INFECTION OF LEPTOSPIROSIS IN THE ROOF RAT, *Rattus rattus*, AND THE POLYNESIAN RAT, *Rattus exulans*, IN WAIPIO VALLEY, ISLAND OF HAWAII, AS DETERMINED BY SEROLOGICAL TESTS OF MARKED, FREE-RANGING ANIMALS

SPECIES OF RAT	NEGATIVE			NEGATIVE TO POSITIVE			POSITIVE			POSITIVE TO NEGATIVE			TOTAL RATS
	NUMBER EXAMINED	MEAN (months)	RANGE (months)	NUMBER EXAMINED	MEAN (months)	RANGE (months)	NUMBER EXAMINED	MEAN (months)	RANGE (months)	NUMBER EXAMINED	MEAN (months)	RANGE (months)	
Roof rat, *R. rattus*	12	2.7	1–8	17	4.0	1–7	10	4.7	1–13	2	10.5	8–13	41
Polynesian rat, *R. exulans*	30	2.7	1–7	0			1	2.0		1			32

TABLE 11

BODY WEIGHTS OF THE ROOF RAT, *Rattus rattus*, IN WAIPIO VALLEY, ISLAND OF HAWAII, BY SAMPLING SITE, TRAPPING METHOD, AND QUARTER OF THE YEAR

	ADULT MALE		ADULT FEMALE		IMMATURE MALE		IMMATURE FEMALE	
	N	WEIGHT	*N*	WEIGHT	*N*	WEIGHT	*N*	WEIGHT
Sampling Site								
Grid 1	37	152 ± 13.1	31	137 ± 8.1	39	81 ± 7.2	34	79 ± 7.6
Grid 2	15	152 ± 12.2	19	136 ± 9.2	20	102 ± 13.1†	14	86 ± 7.1
Lines 3, 5	41	137 ± 8.2	47	134 ± 6.5	20	67 ± 11.4	19	85 ± 13.9
Lines 4, 6	5	125 ± 20.6	11	129 ± 11.4	8	72 ± 17.1	0	
Trapping Method								
Lower valley								
Grid 1	37	152 ± 13.1	31	137 ± 8.1	39	81 ± 7.2	34	79 ± 7.6
Lines 3, 5	41	137 ± 8.2	47	134 ± 6.5	20	67 ± 11.4*	19	85 ± 13.9
Upper valley								
Grid 2	15	152 ± 12.2	19	136 ± 9.2	20	102 ± 13.1	14	86 ± 7.1
Lines 4, 6	5	125 ± 20.6*	11	129 ± 11.4	8	72 ± 17.1*	0	
Quarter of the Year								
Oct.–Dec.								
Grids	17	159 ± 12.3	26	135 ± 8.5	30	95 ± 9.6	25	87 ± 6.5
Lines	12	156 ± 14.2	19	137 ± 12.2	21	68 ± 11.8†	10	72 ± 13.1
Jan.–Mar.								
Grids	22	148 ± 15.4	15	139 ± 10.9	13	97 ± 6.8	12	80 ± 10.9
Lines	7	122 ± 19.8	7	147 ± 8.3	4	75 ± 20.1*	4	86 ± 28.9
Apr.–June								
Grids	8	167 ± 15.0	5	125 ± 15.3	9	58 ± 19.3	4	75 ± 36.0
Lines	22	127 ± 9.3†	22	128 ± 7.9	2	66 ± 86.3	5	112 ± 25.7
July–Sept.								
Grids	5	144 ± 18.3	4	153 ± 21.9	7	73 ± 14.9	6	66 ± 25.7
Lines	5	144 ± 20.0	10	130 ± 12.3	1	43	0	

NOTE: *N*, sample size, and mean weight in grams ± 2 SD are given for each age and sex class.
* Denotes pairs of values that are significantly different.
† Denotes pairs of values that are highly significantly different.

of recapture were low, partly because of mortality induced by handling but also because of natural rapid turnover of the population. Rats marked and released in the first 13 months of the study but monitored for the entire 26 months of the work demonstrated this point (grids 1 and 2 combined). Of 80 roof rats in the sample, only 20 (25 percent) were seen again. Of 138 Polynesian rats released, only 29 (21 percent) were recaptured.

COURSE OF INFECTION AS DETECTED FROM SERUM SAMPLES: Marked rats, bled on successive capture at intervals of 1 or more months and tested by the serological method, were classed into four categories relative to infection with leptospirosis: (1) negative with no change, (2) negative to positive, (3) positive with no change, and (4) positive to negative. These four states related to observed duration of life in months (Table 10). In all, 73 records were available.

These results demonstrate the relative lower rates of infection in the Polynesian rat. Whereas 30 of 32 remained negative during periods up to 7 months of observation, only 12 of 41 roof rats remained so, for periods up to 8 months. Only three rats in all were recorded as having changed from positive to negative by serological test. It is probable that many of both species had active kidney infections not identifiable by our field methods.

BODY WEIGHT: Body weights by age and sex class were not found to be consistently

TABLE 12

BODY WEIGHTS OF THE POLYNESIAN RAT, *Rattus exulans*, IN WAIPIO VALLEY, ISLAND OF HAWAII, BY SAMPLING SITE, TRAPPING METHOD, AND QUARTER OF THE YEAR

	ADULT MALE		ADULE FEMALE		IMMATURE MALE		IMMATURE FEMALE	
	N	WEIGHT	*N*	WEIGHT	*N*	WEIGHT	*N*	WEIGHT
Sampling Site								
Grid 1	76	69 ± 2.4	51	63 ± 3.0	36	44 ± 3.3	48	43 ± 2.9
Grid 2	52	65 ± 3.2*	26	62 ± 5.0	19	44 ± 5.1	28	38 ± 3.2*
Lines 3, 5	35	63 ± 3.4	38	61 ± 3.4	32	46 ± 3.3	25	38 ± 3.7
Lines 4, 6	11	64 ± 6.0	26	38 ± 4.2	20	38 ± 5.8*	16	39 ± 4.2
Trapping Method								
Lower valley								
Grid 1	76	69 ± 2.4	51	63 ± 3.0	36	44 ± 3.3	48	43 ± 2.9
Lines 3, 5	35	63 ± 3.4*	38	61 ± 3.4	32	46 ± 3.3	25	38 ± 3.7*
Upper valley								
Grid 2	52	65 ± 3.2	26	62 ± 5.0	19	44 ± 5.1	28	38 ± 3.2
Lines 4, 6	11	64 ± 6.0	26	60 ± 4.2	20	38 ± 5.8	16	39 ± 4.2
Quarter of the Year								
Oct.–Dec.								
Grids	51	69 ± 2.6	21	61 ± 6.3	25	44 ± 3.6	27	39 ± 3.5
Lines	14	63 ± 4.4*	19	61 ± 5.9	23	41 ± 3.6	11	35 ± 5.0
Jan.–Mar.								
Grids	38	67 ± 3.9	18	65 ± 5.3	20	46 ± 4.0	28	48 ± 2.9
Lines	10	64 ± 6.5	12	56 ± 3.6*	23	47 ± 5.3	19	40 ± 3.6†
Apr.–June								
Grids	15	67 ± 5.2	22	63 ± 4.0	5	37 ± 13.7	8	34 ± 4.9
Lines	6	70 ± 13.2	16	65 ± 5.6	0		2	25 ± 9.0
July–Sept.								
Grids	24	67 ± 5.1	16	61 ± 4.6	5	39 ± 12.2	13	35 ± 4.3
Lines	16	61 ± 4.2	17	57 ± 2.9	6	30 ± 11.5	9	43 ± 5.3*

NOTE: *N*, sample size, and mean weight in grams ±2 SD are given for each age and sex class.
* Denotes pairs of values that are significantly different.
† Denotes pairs of values that are highly significantly different.

different by location or by season of the year (Tables 11 and 12). Most of the variation occurred in the young animals. A trend was evident for lighter-weight (hence smaller and presumably younger) roof rats found in lines as compared to grids. The killing of those animals trapped in the lines tended to hasten departure of the larger (older) animals from the population, so that new, young animals may have been attracted from surrounding areas. The trend for heavier adults in grids than in lines was more pronounced for the roof rat than it was for the Polynesian rat.

Waipio Valley Rim

The Waipio watershed supports lower populations of small mammals than does the valley itself. I sampled three localities (see Figure 1), and the results are given below along with a brief description of environmental conditions.

DWARF FOREST AT HEAD OF ALAKAHI BRANCH: Here the elevation is 3800 ft and rainfall is estimated to be 180 inches per year. The vegetation is a low scrubby forest in which ohia (*Metrosideros*) is a major brushy component, often flowering when only as tall as 2 ft, or even less. The prominent tree is olapa (*Cheirodendron*), and much of the ground is boggy, supporting patches of peat moss (*Sphagnum*). With a total of 720 trap nights in June–July 1970 and February 1971, five roof rats were trapped, with no positive results being obtained for leptospirosis from serum or kidney tissues. Mongoose tracks were seen occasion-

TABLE 13

ANNUAL RAINFALL IN INCHES FOR WAIPIO VALLEY, ISLAND OF HAWAII, AND ADJACENT STATIONS ON THE VALLEY RIM, 1970–1973

YEAR	SITE AND ELEVATION: WAIPIO VILLAGE, 30 ft	HAWAIIAN IRRIGATION CO., 980 ft	KAHUKU ORCHARD, 120 ft	LALAKEA DITCH, 1955 ft
1970	99.52	99.86	112.91	115.36
1971	48.43	45.20	54.01	58.35
1972	51.65	57.49	57.85	69.02
1973	71.94	68.23	75.15	79.16
Mean annual rainfall	67.88	67.72	74.98	80.47
Normal annual rainfall	—	78.64 (30 years)	—	94.57 (19 years)

ally in the area. As anticipated, the Polynesian rat was absent at this high elevation.

OHIA—TREE FERN FOREST, HEAD OF WAIMA BRANCH: At this elevation of 3000 ft the annual rainfall is 125 inches. The ohia forest is well developed with a typical understory of tree fern (*Cibotium*) and other associated native species. Along the ditch trails and road are prominent patches of introduced gingers. This was the most intensively sampled rim site. Six periods of trapping were completed from April 1970 through June 1971, with a total of 1680 trap nights. Of 17 roof rats trapped, nine (52.9 percent) were positive for leptospirosis by serum or culture tests, or both; and of 15 Polynesian rats trapped, 11 (73.3 percent) were positive by the same criteria. Two mongooses were examined and one positive serum was detected. There were nine isolations of *Leptospira interrogans* in all, eight of *icterohemorrhagiae*, and one of *ballum*. The *ballum* was found in a Polynesian rat caught in April 1970 and the eight *icterohemorrhagiae* were from five roof rats and three Polynesian rats taken in December 1970 and June 1971.

OHIA—PASTURE LAND AT HEAD OF HIILAWE FALLS: This area is at 2000 ft and rainfall is estimated at 100 inches per year. The land is an open ohia forest with the understory having been depleted by cattle. Ginger is prominent in the numerous small gulches. With 240 trap nights in July 1970, one roof rat, one Polynesian rat, and four mongooses were taken. These animals were all negative by serum test only.

Water as an Environmental Factor

PRECIPITATION: Rainfall data were collected during the 4 years from 1970 to 1973. Employees of the Honokaa Sugar Company made weekly readings of two standard rain gauges. One gauge was placed near grid 1 (30 ft elevation) at Waipio Village; and the other, at grid 2, a distance of 1.7 miles up the valley (120 ft elevation). I also received data from two plantation gauges near the valley rim. Above grid 1 was the Hawaiian Irrigation Company (HIC) Kukuihaele station at 980 ft, and above grid 2 was the Lalakea Ditch station at 1955 ft. Results are shown in Table 13.

The rainfall pattern is regional, the amount increasing with the altitude of major land masses. This pattern is carried into the deep cleft of Waipio Valley and the valley floor receives about the same precipitation as does the adjacent rim.

Normal rainfall for HIC Kukuihaele (30-year mean) is 78.64 inches per calendar year. In the study period 1970–1973 there was 1 wet year, 2 dry years, and 1 year of relatively

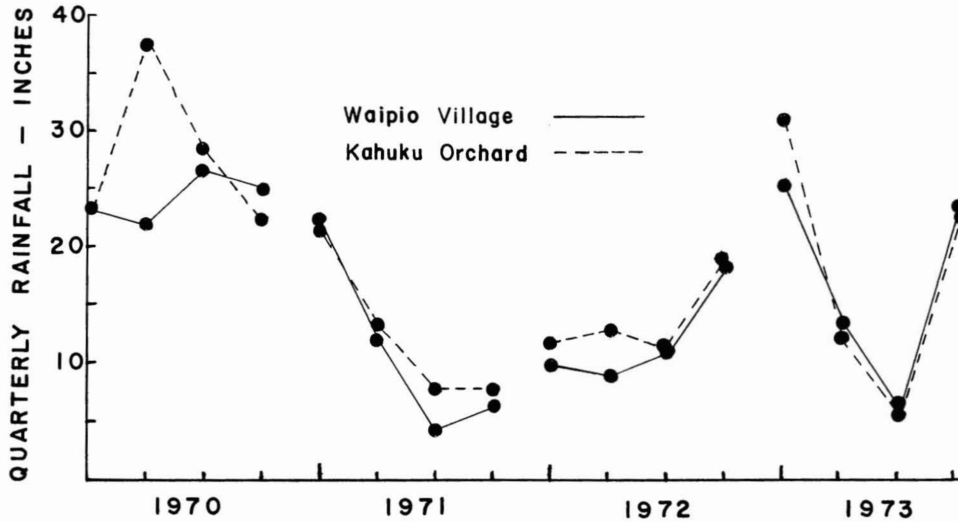

FIGURE 5. Rainfall at Waipio Village (30 ft elevation) and Kahuku orchard (120 ft) in Waipio Valley for the 4-year period 1970–1973. The major disparity in the record for these two sites, which are 1.7 miles apart, was caused by a local cloudburst in April 1970 near the upper valley location.

normal rainfall. In all, the mean was 86.1 percent of normal. The wettest year (1970) was 127.0 percent of normal and the driest (1971) was only 57.5 percent of normal. This pattern can be applied proportionately to the upper valley and lower valley sites (Figure 5).

For the lower valley in the 17-month period from December 1969 to April 1971, as much as 14 inches of rain fell in 1 month, and the mean was 8.18 inches. In the following 18-month period through October 1972, the precipitation only once exceeded 5 inches, the minimum was 0.58, and the mean was only 2.93. In the final segment of the record, the 13 months through December 1973, rainfall twice exceeded 14 inches per month and the mean was a moderately wet 6.03 inches.

Waipio Valley has a generally moist to wet environment, although extended periods of drought may occur. The soils drain rapidly except in the swampy areas, but the water table lies only a few feet beneath the surface. Although abundance and distribution of rainfall may promote the maintenance and transfer of leptospires more in the valley than in the arid regions where the disease is not found, my data do not show any specific correlations between patterns of rainfall and the incidence of infections in rats. It seems that the threshold for maintenance and transfer of leptospires is rather constantly present, if not on the surface of the ground and in the vegetation, then in the burrows and other retreats of the host mammals.

STREAMS AND PONDS: Water flow in the Waipio Valley streams is moderate even in times of prolonged drought because of the many springs that contribute to the stream system. Water is generally fast-flowing until it reaches the lower flat segment of the valley below the inflow of Hiilawe Stream. Small diversions of loose stone control the circulation of water through ditches and channels serving the taro patches. Often the overflow from one patch irrigates those below it. Taro is usually flooded throughout the crop cycle with a constant but small flow of water. Water is also found in the valley in one small active fish pond and two large ones that have been abandoned for many years. These larger ponds are in the beach area with seepage connections to seawater.

Monthly water samples in the 20-month

TABLE 14

PHYSICAL CHARACTERISTICS OF WATER AT EIGHT SITES IN WAIPIO VALLEY, ISLAND OF HAWAII, DURING A 9-MONTH PERIOD, FEB.–OCT. 1973

	(1) BRANCH STREAM			(2) TOKO TARO			(3) LOO DITCH			(4) ARAKI POND			(5) ARAKI TARO			(6) HIILAWE STREAM			(7) MAIN STREAM			(8) BEACH POND		
MONTH	°C	*p*H	Cl^-	°C	*p*H	Cl^-	°C	*p*H	Cl^-	°C	*p*H	Cl^-	°C	*p*H	Cl^-	°C	*p*H	Cl^-	°C	*p*H	Cl^-	°C	*p*H	Cl^-
February	19.0	7.3	8	18.5	7.3	8	18.5	6.9	8	18.0	7.2	8	18.0	7.1	8	18.0	7.4	8	18.5	7.1	22	19.0	7.1	270
March	20.0	7.1	8	21.0	7.0	8	20.0	7.2	8	19.0	7.0	8	19.0	7.1	8	19.5	7.3	8	21.0	7.1	18	23.5	7.1	300
April	18.0	6.9	5	19.5	6.9	4	18.0	6.9	4	19.0	6.5	6	20.5	6.9	5	18.5	7.1	5	19.5	6.9	9	21.5	7.1	90
May	19.5	7.1	8	20.0	7.1	8	19.5	6.9	8	19.5	7.0	7	20.0	7.0	8	18.0	7.1	8	24.0	7.1	18	26.0	7.0	165
June	19.0	6.9	6	20.0	7.0	7	19.5	7.0	8	19.5	6.9	6	19.5	7.0	5	19.0	7.0	6	21.5	7.1	16	23.5	7.1	180
July	20.0	6.9	7	20.0	6.9	6	20.0	7.0	6	20.5	6.9	5	22.0	6.9	6	20.0	6.9	5	21.0	7.0	15	25.0	7.1	240
August	22.0	7.1	8	22.0	7.0	8	22.0	7.0	8	20.5	7.1	6	20.5	7.0	6	20.5	7.0	6	22.0	7.0	22	22.5	7.1	280
September	20.0	7.0	8	20.0	7.1	8	20.0	6.9	7	21.0	7.0	6	21.0	7.2	6	19.5	7.0	6	21.5	7.0	26	22.0	6.9	58
October	20.0	7.1	8	20.0	7.0	8	20.0	7.0	8	19.0	6.9	6	20.0	7.0	6	19.5	7.0	6	20.0	7.0	20	21.0	7.2	500
Means	19.7	7.04	7.3	20.1	7.03	7.2	19.7	6.97	7.2	19.5	6.99	6.4	20.0	7.02	6.4	19.2	7.09	6.4	21.0	7.03	18.4	22.7	7.08	231

NOTE: °C, temperature in degrees Celsius; *p*H, hydrogen ion concentration; Cl^-, chloride ion concentration in milligrams per liter. Sites 1–3 are in the upper valley; sites 4–8 are in the lower valley.

period from April 1972 to October 1973 were taken from eight sites: two streams and one taro patch in the upper valley; and two streams, one taro patch, and two fish ponds in the lower valley. One of these ponds was a brackish marsh just behind the beach dunes, and was rapidly filling with cattail. Table 14 summarizes data from the eight sites for the period from February to October 1973, reporting on 72 of the 160 samples taken.

Sampling was done between 0800 and 1100 hours. Some sites were normally shaded part or all of each day, whereas others received sunlight for much of the day. Water was taken at the edge of each body sampled and included sediments stirred from the bank or bottom. Water temperature was taken at the time of sampling; pH and chloride determinations were made on the following day at the Hilo laboratory.

Although a variety of sites was sampled, water temperatures were found to be remarkably uniform among sites and seasons of the year. Sites 1–3 were related to the upper valley stream system, sites 4–6 were related to the Hiilawe Stream system, and sites 7 and 8 were related to the lower section of Waipio Stream. Taro patches (sites 2 and 5) were warmer than free-flowing streams (sites 1 and 6), a ditch (site 3), and a small fish pond (site 4); but were cooler than the sluggish lower Waipio Stream (site 7) and the abandoned beach area fish pond (site 8) which has no outlet.

Waipio waters, being neither acid nor basic, were close to neutral, regardless of site or season of the year. The pH range of 6.9–7.4 and all means rounding off to 7.0 or 7.1 suggest a slight trend to the alkaline side of neutral.

Chloride ion averaged a little greater for all the upper valley stream sites (7.2–7.3 mg/liter) compared to Hiilawe Stream sites (6.4 mg/liter). The lower segment of Waipio Stream (18.4 mg/liter) apparently is subject to tidal infiltration of salts, and the beach area pond is definitely brackish (231 mg/liter). The low chloride readings for April 1973 may be attributed to a heavy rainstorm and minor flooding that occurred a few days before the samples were taken on 10 April.

TESTS FOR LEPTOSPIRES: I have suspected that the waters of Waipio Valley might at times be infested with pathogenic leptospires because of the high incidence of infections in small mammals that have access to these waters. Possible other sources of infestation could be bullfrogs, fishes, and various crustaceans and snails, although our laboratory has been unable to examine any of these aquatic organisms. The larger mammals—cattle, horses, mules, and dogs—also have a potential for infection of water.

Water samples totaling 152 specimens were tested during the 20-month period of water study. Direct culture and inoculation of guinea pigs were used on these samples, again using standard methods. All tests were negative for pathogenic *Leptospira*. However, 70 percent revealed unidentified saprophytic leptospires recovered by direct culture of the water or from culture of kidney tissue from inoculated guinea pigs.

During the 9-month period from February to October 1973, all of the eight collection sites (Table 14) showed an overall rate of nearly 78 percent infection with saprophytic leptospires in the nine monthly samples taken from each site: site 1, nine isolations of saprophytic leptospires; site 2, eight; site 3, eight; site 4, five; site 5, eight; site 6, seven; site 7, nine; and site 8, three. What is remarkable about these data is that site 4 (Araki fish pond) showed saprophytic leptospires in only five of the nine tests, and that site 8 (the brackish beach pond area) was positive in only three. Certainly, I am unable to draw any inference from these data concerning pathogenic leptospires, except that they may not be frequently waterborne in Waipio Valley or that more refined methods are needed for detecting them.

ACKNOWLEDGMENTS

I received generous assistance in the pursuit of this study from several staff persons in the State of Hawaii Department of Health. Marie Shimizu provided the testing for leptospirosis at the Waiakea Health Center in Hilo, C. Kalaihi processed specimens at the Honokaa laboratory, and S. Kaaekuahiwi, E. Auna, and H. Masuya performed field work in Waipio Valley. Audrey W. Mertz and John M. Gooch were instrumental in planning many aspects of the project and in reviewing its progress. William S. Devick provided statistical advice and performed a portion of the calculations.

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