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Miniature, transistorized radio transmitters were successfully adapted for use on rats (Rattus spp.) in Malaya. Weights of radio-tracked rats ranged from 106 to 365 grams, weights of transmitters from 16 to 32 grams. Ground-to-ground ranges of the transmitters varied from 50 to about 350 yards. During a 3-month period, nine wild rats were followed for periods of from 1 to 13 days. Three species, R. mülleri, R. sabanus, and R. r. jalorensis were radio-tracked successfully. Although there was some individual variation, the rats usually returned to the same den day after day. The rats were reluctant to expose themselves to visual observation. When dens were in heavy ground cover, rats sometimes emerged from them during daylight but remained under cover until darkness. In the absence of heavy ground cover, the rats left the dens just after the onset of darkness. The home ranges of many rats--of the same and of different species--overlapped. Leptospirosis-positive and leptospirosis-negative rats had overlapping home ranges. We followed two leptospirosis-positive R. mülleri by radio-tracking but could not isolate leptospires from soil samples collected in and near their dens. Standard diameters determined by radio-tracking were consistently smaller than the standard diameters found in the same general area by an earlier worker using livetrapping data.

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RADIO TRACKING RATS IN MALAYA - A PRELIMINARY STUDY

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INTRODUCTION

This paper presents the results of a 3-month project of radio tracking wild rats (Rattus spp.) in Malaya. Radios were placed on nine wild rats which were followed for periods ranging from 1 to 13 days. The objectives of the study were (1) to adapt miniature radio transmitters for use on rats, and radio tracking techniques for use in Malaya; (2) to train personnel of the U. S. Army Medical Research Unit, Kuala Lumpur, Malaya, in the construction of transmitters and in radio-tracking techniques; and (3) to obtain information on the home ranges and movements of wild rats in Malaya.

Several species of animals have been followed in the wild by attaching miniature transistorized radios to their bodies and determining their locations by triangulation using a radio direction finder (Anonymous, 1961a; Lord et al. 1962, Marshall et al. 1962, Cochran and Lord 1963, Verts 1963). Most of the studies reported previously have used animals the size of the cottontail rabbit (Sylvilagus floridanus) or larger. However, when Dr. H. E. McClure, U. S. Army Medical Research Unit, Institute for Medical Research, Kuala Lumpur, Malaya, was on leave in 1962, he visited the Illinois Natural History Survey and recognized the potential value of radio-tracking techniques for research on rats in connection with the Unit's studies of leptospirosis and scrub typhus. Col. Hinton J. Baker, Commanding Officer of the U. S. Army Medical Research Unit, requested assistance for this project from Dr. T. G. Scott, Head, Section of Wildlife Research, Illinois Natural History Survey.

Travel allowances for both authors, subsistence for the senior author, and all equipment for this study were furnished by the U. S. Army Medical Research and Development Command, Department of the Army, under Research Contract No. DA-49-193-MD-2389. Col. Baker and his staff, especially Dr. McClure, Lt. J. W. Gentry, and the Malayan employees (Cheng Sue Yueh, Raghavan, Alberto, Ahmad Nawi, Candido Felix, Mathew Marriappan, Soosai, Tan Kong Beng, Phang Ong Wah, Lee Kek Siong, Ya'acob Pangkat, Manikumar, Yusof Mat, Rudy, and Chong Teik Chee) who helped us so ably in many ways in the laboratory and in the field, contributed in many ways to the success of this project. Mrs. Mary Baker and her assistants tested most of the animals we tracked for leptospirosis and generously reported the results to us. Appreciation is expressed to Dr. T. G. Scott for encouragement and advice and to Mrs. Helen Schultz for editorial assistance.

The radio receivers used on this project were constructed by W. W. Cochran, Director of the Bioelectronics Laboratory, University of Minnesota, through the courtesy of Dr. Dwain W. Warner. Prior to our departure for Malaya, Mr. Cochran gave generously of his time, advising us on the latest models of transmitters he had developed. He continued to contribute time and technical advice to the project while we were in Malaya and, without his help, the project would have been less successful.

Scientific and common names used for the rats follow Harrison's (1957) nomenclature.

Our studies were conducted on three separate areas, two in the Ulu Gombak Forest Preserve and one in the lallang near Subang. The first area is called "13-mile Gombak," and the second (Col. Baker's leptospirosis study area) is known as "16-mile Gombak." These areas are in what Harrison (1957:2) calls "Forest," in an area of disturbed primary forest."

The 13-mile Gombak area was along a major branch of the Gombak River, approximately 1 mile northwest of the 13-mile marker on the Kuala Lumpur-Kuantan Highway, and at an elevation of approximately 500 feet. A logging road used almost every day by logging trucks bisected the area, following the stream. At normal levels, this branch of the river is approximately 1 foot deep. The stream bed averages approximately 25 feet in width, the water only about 12 feet. The distance between the banks of the stream averages approximately 40 feet, and the banks range from about 2 to 6 feet above the level of the stream bed. The flood plain averages approximately 100 yards in width and slopes upward rather sharply at each edge. The height of the water during floods varies widely according to the width of the stream bed, rock and log jams in the stream, and amount of rainfall. This section of the river is a few hundred yards upstream from its junction with another branch, described briefly in 1961 (Anonymous 1961b:139-140).

The 16-mile Gombak area was located between the highway and a second major branch of the Gombak River, at an elevation of approximately 1,000 feet. The area sloped sharply from the highway to the river for a distance of approximately 300 yards.

The third study area, located in the lallang near Subang, was approximately 10 miles west of Kuala Lumpur, at an elevation of approximately 100 feet. The lallang is described briefly by Harrison and Traub (1950:338) and by Harrison (1957:2). It consists of cleared forest land, abandoned after cultivation, which then becomes covered with a rank growth of tall coarse grass (Imperata cylindrica) (Dhaliwal 1961:354, photograph). Harrison (1957:2,8) reported that it was maintained by frequent burning and that unburned areas soon regenerated to scrub. Harrison and Traub (1950:338) reported that the lallang was "Of particular interest in the epidemiology of scrub typhus . . ." Audy and Harrison (1953:3) reported that the unsuccessful attempt to increase the production of food during the Japanese occupation by clearing forest and rubber plantations resulted in a greatly expanded acreage of lallang. They believed this expansion was largely responsible for the postwar upsurge in incidence of scrub typhus, from 250 recorded cases (1939-1941) to some 1,020 cases (1947-1949).

METHODS

The radio equipment and techniques used during this study were described by Cochran and Lord (1963) and by Verts (1963). Improvements in the portable receiver were described by Cochran and Nelson (1963), and modifications in the transmitters by Cochran and Hagen (1963). The transmitters we used on rats were adapted from those used on larger mammals such as rabbits, skunks (Mephitis mephitis), and deer (Odocoileus virginianus). The rats we tracked weighed from 106 to 365 grams each and the radios attached to them weighed from 16 to 32 grams each. Diameter of the loops varied from 1½ to 2 inches.

Wild rats of three species, Muller's giant rat (R. mülleri), long-tailed giant rat (R. sabanus), and Malaysian wood rat (R. r. jalorensis)

were livetrapped and brought into the laboratory. They were anesthetized with pentobarbital sodium or ether. While anesthetized, a dummy radio was attached to each rat, the animal was then placed in a cage to permit recovery from effects of the anesthetic. Each rat carrying a dummy transmitter was observed for a week or longer unless it damaged or escaped from the dummy radio sooner. By trial and error, we were able to develop a method of attachment which worked satisfactorily when the rats were caged. This method, however, was completely unsatisfactory when the animals were released in the wild; therefore, we had to modify the attachment.

After a successful method of attaching the transmitters had been worked out in the laboratory, we attempted to anesthetize lightly newly trapped rats in the field, attach the transmitters, allow the rats to recover, and release them at the points of capture. As this method was not successful, the rats were brought into the laboratory, the transmitters attached, and the rats held in cages from 4 to 24 hours before being released at the points of capture.

Rats were trapped in wire-mesh livetraps placed at suitable locations on the ground. Traps were baited with raw sweet potato or raw cassava (tapioca). Rats trapped on the leptospirosis study area were routinely brought into the laboratory, held in the live traps, fed banana or apple, and placed over enameled pans to collect urine specimens for testing. Each rat was toe clipped in a regular sequence to allow subsequent recognition of individuals and, on the morning following capture, was returned to the point of capture and released. Thus, attaching a radio to animals from the leptospirosis study area caused only minor variations in their customary procedures.

Rats carrying transmitters were released during daylight hours so that their first movements could be observed visually. The doors of the traps or carrying cages were opened and the rats allowed to escape. Each rat was watched as long as possible, the observers remaining immobile or moving only a step or two for better observation. In one case, a rat carrying a radio was observed visually for 40 minutes before it finally settled in what later proved to be its favorite den under a log. Radio receivers were turned on while the rats were still in traps or carrying cages to make certain the radios were operating satisfactorily. The receivers were left on and the rats were tracked until they settled in dens, usually a matter of minutes.

When the rats became quiet in their dens, the observers returned to the laboratory for other duties and returned to the area, prior to the onset of activity in the evening, to resume tracking. Checking rats each half hour throughout the day soon established that rats seldom moved from their dens during the day. Dhaliwal (1961:350) reported that he caught no rats in livetraps in the daytime in Malaya. There was some variation in the onset of activity, depending upon the individual rat and upon the cover surrounding the den; however, activity seldom began before darkness. Onset of darkness in the tropics is rapid, especially in the forest, and occurred at approximately 7:00 PM on our study areas.

Rats were followed throughout the night and until they had settled in their dens the following morning. Tracking crews normally consisted of three individuals, usually with two portable receivers. One crew usually

worked until sometime between midnight and 1:00 AM; they were relieved by a second crew which worked until the rats ceased their movements about daylight. The tracking routine varied considerably, depending on such factors as the number of rats being followed, the number of receivers available, tracking difficulties caused by terrain or movements of individual rats, and how much was already known about an individual's habits. Our planned routine was to plot a rat's location on the hour, monitor its movements constantly for a half hour, plot the location on the half hour, and turn the receiver off for a half hour. This schedule was repeated throughout the night. Movements made by the rat during the half hour of constant monitoring were described in the field notes.

Because maps were lacking for two of the three areas we worked, numbered stakes were placed at strategic points on all study areas. We fixed the locations of these stakes by using compass bearings and pacing the distances between stakes; their positions were plotted on charts. The rats were located by taking two or more compass bearings (radio fixes) from the numbered stakes. An observer took a fix from one stake and then walked rapidly to another stake to take the next fix. Unless a rat was moving rapidly while the fixes were being taken, the time between fixes caused only minor difficulties.

Each time an individual rat was found in a different location, the new location was recorded and later plotted on the map. Thus, if a rat stayed in one location for an extended period of time, we plotted only one location for it. Only those nighttime radio fixes differing from the previous fix were used to calculate the "center of activity" (Hayne 1949:6).

Electric headlamps were worn at night to allow the observers to move about and take compass readings. Wherever possible, movements were made along roads, trails, and streams thus causing minimum interference with the movements of the rats. As far as we could determine, our movements only occasionally affected the movements of the rats. Even when we inadvertently got too close to rats, they merely moved rapidly away for a few yards and then resumed what appeared to be their normal movements.

When our calculations indicated it was time for the batteries to run down, livetraps were reset. Knowing exactly where an individual rat was moving and where it was spending its days enhanced our chances for recapture. After a rat was tracked for 1-2 weeks, it was retrapped. The radio was removed, batteries were replaced or a new transmitter attached, and the rat was again released at the site of capture.

Ground-to-ground range of the transmitters varied from 50 to about 350 yards, depending upon size of the loop, the individual radio, the terrain, and the cover. In most instances, these ranges were adequate to follow the rats we were tracking; however, greater range would have been helpful in a few cases. Apparently, the soils of Malaya are not as favorable for radio signals as the soils of Illinois. In Malaya, we obtained about half the range we expect from the same transmitter in Illinois; however, W. W. Cochran (Personal communication) told us that the ranges we obtained in Malaya were similar to those he obtained in Minnesota. He attributed the difference in ranges between Illinois and Minnesota to differences in soils, which affected the radio signals.

RESULTS

Because we followed only a few rats for a short time each, we do not have enough data to present a generalized picture of rat movements and home ranges in these areas in Malaya. Probably future studies in these and similar areas, using radio-tracking techniques, will obtain sufficient information to determine the general pattern. In this report, we present the data for each rat separately to emphasize individual differences.

Rattus mülleri

Four R. mülleri were radio-tracked on the 13-mile Gombak Area (Table 1). However, two of the four (GCS 5 and GCS 9) were followed for only a short time. These were the first two rats in Malaya (or anywhere, so far as we know) to carry radio transmitters; they were released primarily to test the equipment and to check tracking techniques. Both had been live-trapped approximately 2 weeks before their release on March 9, 1963. Radios, attached to both rats several days before they were released, continued to operate only a short time after release. Thus, movements of these two animals contribute only in a small way to our knowledge of the species. Their movements are not included in Fig. 1.

GCS 9, an adult male, was released at 10:10 AM. He was released about 10 feet from the edge of the stream, where he had been live-trapped. He moved upstream for 10 yards, stopped for 1 minute under cover, then moved 2 additional yards upstream, and climbed into brush adjacent to the road. At 10:45 AM, he was still moving around occasionally in the brush but remained in the same location. At 12:30 PM, and again at 4:50 PM when we left him for the day, he was inactive and in the same place. By 7:40 AM the following morning, he had moved across the stream into a clump of weeds 25 feet from the water and 50 feet from his location the previous day at 4:50 PM. He was in the same place at 4:50 and 5:55 PM. At 5:55 PM we began listening to his signal for 1 minute of each 5-minute interval. We detected the first movement at 6:45 PM but he did not leave his den. After 6:45 PM he continued to move about frequently within the den but had not left it by 7:30 PM when tracking was discontinued for the day. At 9:00 AM the following morning, we could not find his signal although we searched more than a half mile in all directions from his last known location. According to our calculations, the batteries on his transmitter were probably dead. Neither this rat nor his radio was seen again.

GCS 5, an adult female, was released at 11:20 AM on March 9, 1963. She was trapped and released at the same site as GCS 9. When released she ran 10 feet before stopping under thin cover. From 11:20 AM until 12:00 noon, this rat was seldom out of our sight for more than 1 minute at a time. She went under a log shortly after release but at 11:28 AM she slowly emerged from under the log and explored for 6 feet before returning to it. At 11:34 AM she went under a log lying midway between us, at approximately 5 feet. Her movements could be detected visually, from time to time, and we obtained two photographs although she went under cover at the slightest noise or movement from either of us. At 12:00 noon, she retreated further under the log and we lost visual contact with her; however, radio contact was maintained and she was at the same location at 12:30 PM when the receiver was switched off. She was inactive and in the same place when we returned at 4:50 PM. The following morning at 8:00 AM she was across the river and 220 feet downstream from where she was released (Fig. 1). She

was under an old stump approximately 20 feet from where another R. mülleri was first livetrapped. At 4:50 PM, we could get no signal within $\frac{1}{4}$ -mile radius of her last known location. At 9:00 AM on March 11, 1963, we were unable to pick up her signal and concluded that the batteries on her radio were dead. Neither this rat nor her radio was located again.

GCS 4, an adult female weighing 315 grams, was livetrapped and released on March 25, 1963, after a radio was attached to her. She was radio-tracked from 8:20 PM, March 25, 1963, to 2:45 AM, March 28, 1963. During this period her location was plotted 14 times during the hours of darkness and 2 times during the day (Fig. 1). The "center of activity" (Hayne 1949: 6) of the 14 nighttime locations was 108 yards from the site where she was livetrapped and released. At no time was she located at the trap site by radio tracking.

A rectangular area 1 unit wide by 2.7 units long (106 x 288 feet), drawn according to Stump and Mohr (1962:150), contained 90 percent of all locations for GCS 4, providing support for the linearity of home ranges as suggested by these authors. The linearity of home range for GCS 4 was hardly surprising because it followed the river (Fig. 1). Harrison (1957:12) cited the preference of R. mülleri "for low-lying rather marshy land . . .", and Harrison and Traub (1950:344) cited the affinity of this species for habitats near water.

Harrison (1958:196-198) trapped eight R. mülleri five or more times each and found that a circle 80 meters in diameter contained 50 percent of the captures for this species and a circle 152 meters in diameter contained 80 percent. The corresponding figures for GCS 4 were 71.4 and 100 percent (Table 2) respectively, indicating that in the short time she was radio tracked, this female did not range as widely as the rats studied by Harrison.

GCS 4's location was plotted during daylight hours on March 26 and 27 (Fig. 1). On the 26th her location was determined only at 10:15 AM; she was under a log 40 feet from the stream and 20 feet above the normal water level. On the 27th she was located at 10:15 AM and 7:05 PM and was under a log within the stream banks both times. With few exceptions, the rats we followed appeared to stay in the same place from daylight until they began to move at or near darkness.

The operation of the radio on GCS 4 was somewhat erratic. At 2:45 AM on March 28 we received a weak signal from this transmitter, but it was too weak to plot accurately. However, the rat appeared to be within her normal range of activity. This was the last time a signal from this transmitter was received, and we suspect the radio ceased to operate.

GCS 6, an adult male, was located more times and tracked for a longer period than any other rat we studied. He was first livetrapped on March 13, 1963, within 6 feet of the water's edge and was released at 11:25 AM on the same date at the site of capture after a transmitter had been attached. Upon release, he ran under a log located approximately 10 feet from the release site. We took no further radio fixes until 3:30 PM. He was then under the same log but approximately 10 feet further from the stream than at 11:25 AM. This log was in the same group of logs where GCS 5 was last plotted on March 10.

GCS 6 was tracked at night and located during the day until 5:00 AM

on March 15, when the signal disappeared. However, during this period there was some difficulty in tracking. The signal would be strong at one time and quite weak a short time later. At 6:00 AM on March 15, the signal disappeared completely. At 9:30 AM, GCS 6 was found in a trap approximately 75 yards upstream from the upper bridge (Fig. 1). The radio had come off his body and was held perpendicular to the ground by the collar around his neck. Both rat and radio were taken to the laboratory, where a good signal was obtained from the radio. Apparently, the abnormal position of the radio had accounted for the erratic signal obtained during the first 3 days of tracking. The radio was disconnected at 10:50 AM. A collar of Fiber Thin (Labisky and Mann 1962:393) was attached to the inside of the transmitter and sewn snugly around the body behind the front legs in the manner described by Verts (1963:337) for fastening radios around the necks of striped skunks. The radio was turned on at 3:00 PM on March 16.

We held GCS 6 in captivity, with the radio operating, until 9:07 AM on March 18 to see if the new method of attachment would keep the radio in place. When released at the point of last capture at the edge of the river, he jumped into the river and swam diagonally across the stream under the water, with the radio operating all the way. On the opposite bank, he ran under a nearby log and continued to move short distances until 10:28 AM, at which time he arrived "home" under the log where he spent virtually all his days (Fig. 1). He was located successfully each day and several times during each night until 11:50 PM, March 22. At this time, the signal of his transmitter began to fade. We received a weak signal at 4:00 AM on March 23 but, by 6:40 AM of the same day, we had received no more signals. At 11:00 AM, GCS 6 was in a livetrapped at the site of his original capture. The transmitter appeared to be working well, so he was released at the point of capture. He went under the same logs as when released after his first capture. On March 24, we could not locate his signal. On March 25, he was again in the livetrapped at the site of his original capture. Both rat and radio were taken to the laboratory, where the batteries were found to be dead. A urine specimen was collected and tested for leptospirosis (negative). Fresh batteries were installed and the radio reattached to the rat. He was released at the point of capture at 7:10 PM the same day. Although he moved around within the immediate vicinity, he stayed in this same location until 1:20 AM, March 26, before he began to move in a normal manner.

He was successfully tracked each night and located each day until 10:00 AM, March 26. We did not attempt to locate him again until the morning of March 28, when he was in a livetrapped near the river (Fig. 1). We released him at 9:30 AM, a few minutes after we found him in the trap. He again swam the river, but this time with his nose out of water. He went into the nearest cover, spending 5 minutes there before moving downstream, and by 10:10 AM was back "home." Between 8:30 and 9:00 PM on March 28, GCS 6 stopped his nocturnal movements and stayed in the same location. We checked, and found him in the livetrapped at the site of his original capture. He was released at 9:05 PM and tracked until 5:50 AM on March 29, at which time it was necessary to abandon this area and transfer our investigations to Col. Baker's leptospirosis study area. However, we continued to locate this rat during the daytime through 1:00 PM on March 31; at this time, the signal from his transmitter was quite weak. On April 1 at 11:30 AM, we could get no signal. The livetraps were reset and, on April 4, the radio from GCS 6 was in the livetrapped where he had been caught on March 28. Apparently, after the rat entered the livetrapped, the radio became entangled on the trigger wire and GCS 6 was able to twist around and chew his way

out of the radio. He then escaped from the livetrapped because of a defective door lock. GCS 6 was trapped in the same trap at the same location the following day.

During this period of tracking, the location of GCS 6 was plotted 77 times while he was moving during darkness. On most days, his daytime locations were recorded also.

A rectangular area one unit wide by 8.5 units long (81 x 688 feet), drawn as described by Stumpf and Mohr (1962:150), contained 90 percent of the nighttime locations. Again, this is hardly surprising, because the rectangular area contained the stream and the rat's movements were closely tied to the stream. In fact, GCS 6 spent approximately 75 percent of his time, while we were following him, within the banks of the river. Contrary to Stumpf and Mohr's (1962:154) report, the center of activity was near the center of the rectangle. The center of activity was located at the bridge across the river. GCS 6 spent a considerable amount of time under this bridge and also went back and forth under it many times each night. His main den was under a log 80 feet upstream from the bridge, and his secondary den, near which he was usually livetrapped, was approximately 140 feet downstream from the bridge. The trapping and daytime locations were not used in calculating the center of activity.

Table 2 indicates that the movements of GCS 6 were more restricted than those reported by Harrison (1958:196-198) for the same species in the same general area. For example, 74 percent of the fixes for GCS 6 fell within a circle 80 meters in diameter, centered on the center of activity, compared with the 50 percent reported by Harrison. Harrison found 80 percent of the trapping locations within a circle 152 meters in diameter, compared to 93.5 percent of this rat's radio fixes. Harrison (1958:195) did not calculate a center of activity but measured "the number of points which could be included within measurements of 200 M., 180 M., 160 M., etc., and treated these as if they were the numbers included within circles of those diameters."

Three adult R. mülleri were tracked on the 16-mile Gombak Area (Table 1). This was Col. Baker's leptospirosis research area, and his assistants routinely livetrapped rats on the area and brought them to the laboratory to collect urine for testing. We selected three rats from this area for tracking, two positive and one negative for leptospirosis. All three were released at their respective sites of capture about midday on March 29, 1963. All three radios were slipped over the rats' heads and front legs, but no Fiber Thin collars were used.

On this area, Col. Baker asked that we follow exact movements of leptospirosis-positive rats, especially for the first few minutes after they left their dens, and then collect soil samples at these precise spots to test for leptospire. We, therefore, made several attempts to arrive early enough in the evening to station ourselves sufficiently near the "home" area to observe leptospirosis-positive rats as they left their dens. We soon learned that in the heavy cover of bamboo thickets on the 16-mile Gombak Area, R. mülleri often left their dens earlier than we ever observed them leaving on the 13-mile Gombak Area, where heavy ground cover--especially along the stream where the R. mülleri were living--was generally lacking.

One leptospirosis-positive rat, G-30, an adult female, was released at 11:25 AM. She ran under the stream bank a few feet from the release point (Fig. 2) and stayed hidden for 2 minutes. She then came out, circled a tree growing on the bank, and moved upstream for 15 feet and into a hole in the ground at the base of a tree (Hole 2, Fig. 2). The hole was 8 feet above the water level in the stream. She was in the same hole at 12:05 PM.

When we returned at 7:00 PM, she was 20 feet from Hole 2, moving about under heavy bamboo cover. Radio fixes were taken until 6:00 AM the following morning. When we returned at 10:00 AM on March 30, 1963, she was in Hole 1 (Fig. 2), approximately 40 feet from Hole 1. Fig. 2 shows that she was located in this same hole on 5 different days.

We could not locate G-30 on April 1; however, soil samples were taken near and in the entrances to Holes 1 and 2. These samples were tested for leptospirosis by routine procedures used in Mrs. Baker's laboratory; they were negative. G-30 was retrapped on April 2. She had pushed the radio to the rear of her body and chewed through the wiring. The batteries were replaced and the radio reattached, this time with one Fiber Thin collar around her neck and another inside the radio behind her front legs. She was released at the site of capture at 6:45 PM on the same day. She immediately began to move in what appeared to be a normal manner and did not enter a den, so far as we could determine, until 10:15 PM. Then she went into Hole 1 and stayed there until sometime between 3:20 and 4:00 AM. At 9:25 AM the same day (April 3), she was in Hole 1, but when we returned to track for the evening, she was out of the den and moving under heavy cover at 6:30 PM. She continued to move until 1:15 AM. Then she entered Hole 1 where she stayed until tracking was discontinued for the night at 6:00 AM. She was in the same hole at 9:30 AM (April 4); but at 4:45 PM when we returned, she was out of the den and moving under heavy cover. She continued to move until 7:15 PM, at which time trouble developed in our receiver. We were unable to obtain any more fixes until 3:00 PM on April 5, when we located her in Hole 2. We then began to watch Hole 2 in the hope of observing G-30 when she emerged. Although we had not seen her leave Hole 2, at 5:25 PM she was moving 10 yards south of it, under heavy cover. Apparently, this den had another entrance which was hidden in the bamboo thicket. The receiver was not functioning properly, but we followed her until 6:45 PM before we were forced to quit.

The following 2 days were virtual repeats of April 5. We were stationed at positions to observe G-30 as she left her den, but we never saw her, even for a moment. She began to move at 5:25 PM on April 6 and at 6:05 PM on April 7. On April 8, we could not locate her signal; on April 9, she was livetrapped. The batteries in her radio were dead. The radio was removed, and she was released into Hole 1 without a radio on April 10 at 5:00 PM. The empty trap was set over the one visible entrance to this den. At 5:07 PM, she came out of a hole 3 feet away--which was covered with dead bamboo leaves and stems--and scurried off into the heavy bamboo cover without stopping. The following day she was retrapped and released, apparently in good condition.

According to data in Table 2, G-30 showed less than the average movement for the species, as determined by radio-tracking, and less than Harrison (1958:198) reported for the species (Table 3). Ninety-one percent of the radio fixes for this rat fell within a circle 80 meters in diameter, compared with an average of 71.5 percent for the species. A rectangle one unit wide by 1.7 units long (135 x 231 feet) contained 90.7 percent of the

43 nighttime radio fixes obtained for G-30.

The second leptospirosis-positive rat, G-28, an adult male, was released a half hour after G-30, at 12:10 PM on March 29, 1963. He ran in a straight line to a small log on the bank about 10 feet above the stream bed and 40 feet from the trap and release site. The log was covered with dead bamboo leaves and stems. We did not attempt to locate him again until 7:05 PM the same day.

The movements of this animal proved to be drastically different from those of any other rat we tracked. He appeared to move almost at random over a larger area than was covered by the other rats, and it was usual for him to spend each day in a different den. Unfortunately, we were not able to follow him long enough to determine whether there was a regular pattern to his wanderings and whether he returned to the same daytime dens at longer than daily intervals. We found him in the same daytime den on April 5 and 6 and in another den on April 8 and 9. He was in a third daytime den on April 3, 11, and 12 (Fig. 2).

We began following G-28 at 7:05 PM on the date of his release, March 29. At that time, he was moving in the same general area as G-30, the other leptospirosis-positive rat. We continued to track G-28 until 6:30 AM, at which time the night's tracking ended. He was located in his daytime den at 10:15 AM, on March 30, but we were unable to find him again until 9:30 AM on April 1, when we momentarily located a strong, constant signal on his frequency, which soon faded. His radio was constructed with a pulsing signal. Because of the change in signal from pulsing to constant and the erratic nature of the signal, we concluded that the transmitter was not functioning properly. The rat was retrapped on April 2 and brought into the laboratory. He also had pushed his radio to the rear and had chewed the radio badly enough to damage it. The radio from a R. sabanus (GCS 8; see below) we had been tracking on another area was recovered on this date when the rat was retrapped. This radio had performed well. New batteries were installed; the radio was attached to G-28 by the improved method, and the rat was released at 6:30 PM at the site of capture.

After his release, G-28 ran across the tiny stream and up the bank, slowly working his way 20 feet downstream and finally stopped behind a tree, where he was visible. We watched him grooming until 6:40. Then, thinking that perhaps he was not moving because of the radio, we approached him. As we drew near, however, he ran into a hole at the base of the tree, and the radio did not appear to hinder him unduly. From this time until 6:45 PM on April 12, G-28 was radio-tracked most nights and located in a den most days (Fig. 2 gives details).

Some observations of G-28 are worth noting. Even though several of them differed somewhat from most of the observations made during this preliminary study, they will probably prove to be typical of some individuals after a sufficient number of rats of this species have been studied. On April 3 at 9:30 AM and again at 6:30 PM, G-28 was in Hole 3. We tracked him constantly from 6:50 to 7:20 PM. The overcast skies were clearing, there was a half moon, the air temperature was 77 F, and deep twilight occurred at 7:05 PM. At 6:55 PM, he left the den but stayed under a large log and moved 40 feet away from the den. By 7:00 PM, he was back within 10 feet of the den, where he stayed until 7:15 PM and then repeated his

earlier movements. He stayed under cover the entire time; and even though we did not move and stared intently at his known locations, we were unable to observe him. At 7:20 PM, he began to move away from the den.

The following day (April 4) between 9:30 and 10:00 AM, the skies were clear and the air temperature was 85 F. G-28 was moving in a bamboo thicket. He was in the same location at 5:00 PM but was not moving. Unfortunately, trouble developed in the receiver and we were not able to determine when he began to move that evening. This was the only movement from 7:00 AM to 5:25 PM that we detected for any of the rats studied.

When we arrived on the study area at 5:00 PM on April 8, G-28 was still in his den. We immediately cleared the leaves and vegetation at the entrance to his den and stationed three observers to watch for his emergence. He was followed constantly by radio from 6:05 to 7:15. He began to turn in the den at 6:20 and continued to turn at irregular intervals until 7:10 PM, when he emerged from the den just as it was too dark for us to see him. He moved 40 yards toward the river, then turned and arrived back at his daytime location by 7:15. He moved toward the river again and began his wider-ranging nightly activities. Soil samples collected from in and around his daytime den were all negative for leptospires. At 9:20 PM, a full moon broke through the clouds. At 9:50, G-28 moved directly toward us, and we got a brief glimpse of him in the moonlight as he turned and ran away. At 10:20, we climbed on a large rock in the river and followed his movements with the receiver. He started toward us at 10:40 and we had a glimpse of him as he raced across the bare rock to the edge of the river about 15 feet from us. He stayed in a shadow at the water's edge (apparently drinking) for about 1 minute, then started back into the forest. At this point, we used our flashlights and got a good look at him as he hurried across the bare rock into heavy cover. These movements emphasized what we had concluded earlier--that all the jungle rats we followed were extremely reluctant to expose themselves to visual observation. When in heavy ground cover, they would emerge from their dens during daylight but would remain in the heavy cover until darkness obscured their movements. In more exposed situations, their emergence from dens coincided almost exactly with onset of darkness. On bright moonlight nights, the rats moved primarily under heavy cover. Even though we had the advantage of knowing where the rats were, we were rarely able to get even a glimpse of them.

After we observed G-28 with our flashlights at 10:46 PM, he continued to move in a normal pattern until 12:55 AM. By 1:15 AM he was in a den, and was still there at 6:00 AM when that night's tracking was discontinued. He was in the same location the next day at 10:15 AM and at 5:15 PM. At 5:15, we stationed four observers to watch for his emergence. At 6:25, he became active in the den and was alternately active and quiet until 6:45. From 6:45 until 7:00 PM, he was very active; and at 7:00, one of the four observers saw him come out of the hole. He sat at the entrance for 3 minutes, moved 18 inches away where he stayed for 2 minutes, returned to the entrance for 2 minutes, then moved off under heavy ground cover. All the time he was under observation he was grooming and cleaning his body but was not observed to urinate; it was so dark, however, that the only one of the four observers able to see him may not have witnessed all his actions. Soil samples were collected and tested for leptospires, but all were negative. Since our attempts to observe the animal had caused the entrance to this den to become rather exposed, and since four observers were each stationed approximately 25 feet from the den, perhaps this rat did a minimum of grooming before leaving the den area.

On April 10, G-28 was found in his daytime den at 5:05 PM. He was tracked constantly from 5:50 to 7:05 PM. The first movement in the den was detected at 6:33. Slight movements in the den continued until 6:50, at which time he came out and began constant movements under heavy cover. These movements continued until 7:05 when tracking was terminated. During this time, the rat was never more than 10 yards from his daytime den. On April 11, he began to turn in his daytime den at 6:50 PM and came out at 7:00. Although no special attempt was made to observe him on this date, he was seen to come out of the den, walk slowly about 3 feet, and then was lost to sight in heavy cover. He stayed near the den until 7:15. Again, soil samples collected were negative for leptospires.

By April 12 the batteries were getting weak on G-28's radio. Traps were set in hopes of recovering the radio. At 6:40 PM, the rat was located in Hole 3. At 6:50, he was moving in the den; at 7:07, he came out of the den and stayed near the entrance until 7:15, when one of the nearby live-traps was sprung. At 7:20, the flashlight was switched on and G-28 was in the trap. The next morning the radio was removed and the rat released. He was not radio-tracked any more but was retrapped on April 18 and a urine specimen was collected. It was positive for leptospirosis.

Table 2 indicates that G-28 ranged more widely than the average R. mülleri, because only 49 percent of his radio fixes were within a circle 80 meters in diameter around the center of his activity. This was a smaller percentage than was found for any other R. mülleri radio-tracked and was also smaller than the percentage reported by Harrison (1958:198) for the species. Table 2 does indicate a slightly greater total movement for GCS 6 than for G-28; however, Fig. 2 indicates that G-28 spent 2 days a considerable distance from the center of his activity. These points were not used in calculating the center of activity because only nighttime radio fixes were used to calculate movement patterns. During the period when G-28 was apparently a considerable distance away from the center of his activity (Fig. 2), our receivers were not working properly and we were not able to follow him at night (April 5-7).

G-28's home range showed less linearity than most of the ranges we studied. A rectangle one unit wide by 2.26 units long (206 x 465 feet) contained 88.9 percent of the 45 nighttime radio fixes obtained.

We had a considerable amount of trouble with the transmitter on the third rat tracked on this area, G-31, an adult female that was leptospirosis-negative. She was released at 11:10 AM on March 29. She ran up the side of a hill to a height 10 feet above stream level and then downstream 20 feet to a large log. Here she stopped, then went under the log and stayed there. The meager data for this animal are shown in Fig. 2. The pertinent observation on G-31 is that the home range of this leptospirosis-negative rat apparently is overlapped by the home ranges of both leptospirosis-positive rats.

The distribution of radio fixes around the centers of activity for four adult R. mülleri are shown in Table 3. The 20-meter intervals were chosen to facilitate comparisons with Harrison's (1958:195-197) data.

Rattus sabanus

We only radio-tracked one rat of this species. An immature male weigh-

ing 278 grams (GCS 8) was livetrapped on the 13-mile Gombak Area on March 14, 1963, and brought into the laboratory. A transmitter was fastened around his chest at 4:30 PM on March 16, and he was released at the point of capture at 10:05 AM on March 18 (Fig. 3). The final plot was made on him at 10:10 AM on March 26, and he was livetrapped and the radio with its dead batteries was recovered at 10:00 AM on April 2. During this period, his nighttime movements were plotted 82 times, and on 8 days he was located during daylight hours.

It is obvious from the movements of GCS 8 (Fig. 3) that his area of activity was not as closely allied with the stream as were the activities of R. mülleri in the same area (GCS 6). Harrison (1957:18) pointed out the preference of R. sabanus for the higher and drier parts of the forest. On March 23, this rat was located in a secondary den at 11:00 AM. As we were walking around the small log under which the den was located--to make certain he was in this den--he became disturbed and ran from the den. He crossed the river on a small log and did not attempt to swim, as one of the R. mülleri (GCS 6) did on two different occasions. The den of the R. sabanus was well up the hillside away from the stream, in a much drier situation than were the dens of the R. mülleri.

A rectangular area one unit wide by 5.0 units long (109 x 545 feet) contained 85.4 percent of the nighttime locations for GCS 8. This rectangular area included part of the stream; however, only 5 of the 82 nighttime plots were across the stream from the main area of activity. While this rat did visit the stream from time to time, it did not influence the pattern of his activities to the degree that it influenced the movements of the R. mülleri.

Table 4 indicates that the movements of GCS 8 were reasonably similar to those reported by Harrison (1958:196) for the same species; however, his methods of calculation were slightly different, and his data were based on livetrapping. There are apparent differences indicated by this table. More data from both livetrapping and radio-tracking are necessary to determine whether the differences are real or whether they result from the different methods. A comparison of the data obtained by the two methods is made here to demonstrate one way to evaluate differences caused by different techniques. Table 3 shows a greater percentage of livetrapping recoveries for R. mülleri than of radio fixes in circles 80 meters or less in diameter. There was corresponding increase in the percentage of radio fixes in circles 100 meters or more in diameter. If this difference proves to be real, it may indicate that rats are more frequently caught in the traps located near the centers of their activities than would be due to chance alone. Again it must be emphasized that one radio-tracked R. sabanus compared with four livetrapped R. sabanus warrants only conjectures, not conclusions.

Rattus jalorensis

Because of time limitations, only one rat (Subang 4) of this species was tracked. An adult female weighing 106 grams was livetrapped on April 18, 1963, at the junction of a lallang field and a narrow strip of forest along an intermittent stream. She was brought into the laboratory; a urine specimen was collected and tested for leptospirosis (negative), and a dummy transmitter was attached. When it became apparent that she would tolerate a transmitter in captivity, a radio was constructed to fit her small size. This radio weighed 16 grams, had a loop 1½ inches in diameter, and an estimated capacity of 140 mah (milliampere-hours). This transmitter was at-

tached to the female on April 24, and she was released at the point of capture at 4:25 PM the same day.

Two other R. jalorensis and one R. argentiventer from this same general area were livetrapped and brought into the laboratory. Attempts to attach transmitters to these three animals were unsuccessful: two of the rats died as a result of handling and anesthesia, and one would not tolerate the transmitter.

When Subang 4 was released, the skies were clear and the air temperature in the lallang was 87 F. Upon release, she ran approximately 10 yards on compass bearing 305° into heavy ground cover in the narrow strip of forest. She remained in this same location, occasionally turning, until 7:00 PM. The receivers were switched off from 7:00 until 7:30 PM. When the receivers were switched on the rat had moved, and a weak signal was coming from the lallang. Subang 4 was 45 yards from the point of release, and the signal from the tiny radio was too weak for a satisfactory fix to be made from stakes near the release site. We slowly searched the lallang with the receivers until she was located. Then one of the laboratory assistants held a flashlight near her location while compass readings were taken from stakes near the release site. Our movements at this time probably caused the rat to enter a den; however, once we determined her new area of activity, we found stakes--marking one of the established trap lines--which were close enough to use as plotting stations.

From 7:30 PM on April 24, when she went into the lallang, until 11:00 PM on April 29, the last time her signal was picked up, so far as we know Subang 4 never left the lallang. Harrison and Siew-Keen (1962:3) pointed out that this species is closely related to R. rattus and may be but a subspecies, although in Malaysia it behaves as a distinct species. They further noted that R. jalorensis is normally found in the forest although, when R. r. diardii is absent, R. jalorensis will live as a house rat. Harrison (1957:6) reported that R. r. jalorensis "typically occurs in areas of mixed scrub and grassland. It also occurs in rubber plantations, and is a major pest of oil palm plantations." It is impossible to judge from following one rat for a few days whether this rat was living in an abnormal situation because of the handling and the radio or whether some individuals live exclusively in the lallang.

During this period, Subang 4 was located 20 times during the night hours and once during the daytime (Fig. 4). On April 29, 1963, her signal was coming from a den in the lallang. At 11:00 PM the same night, the signal was coming from the same hole and the rat did not appear to be moving. There was no signal from the hole on April 30 at 10:15 AM, and we could not locate the signal by walking in widening circles around the entire area. We dug out the den, thinking that the radio might have dead batteries or the rat might be dead. We were unable to locate either rat or radio in the den; however, a shortage of time prevented us from excavating the entire den.

The center of activity of the 20 nighttime locations was 100 yards from the site where Subang 4 was livetrapped and released. She was not located at the trap site by radio-tracking. A rectangular area one unit wide by 3.6 units long (100 x 360 feet) contained 90 percent (18 of 20) of all nighttime locations. This animal was in an area of rather uniform habitat without the obvious linear aspects noted for the species previously described.

Harrison (1958:198,200) trapped 27 R. jalorensis four or more times each in grassland habitat and found that a circle 67 meters in diameter contained 50 percent of the captures. For the single rat (Subang 4) radio-tracked, a circle of similar size contained 80 percent of the radio locations (Table 5). Harrison (1958:200) pointed out that "In the grassland the rat was largely confined to a gallery of open scrub extending through the area and the individual ranges are probably extended rather than circular, so that the diameters are overestimated." That this is true of the rat we studied is apparent from Fig. 3 and from the data above which indicated that 90 percent of all nighttime locations were within a rectangular area 1 unit wide by 3.6 units long.

Upon release (at 4:25 PM) Subang 4 ran into nearby cover and stayed there until sometime between 7:00 and 7:50 PM. From 7:50 PM until 12:15 AM, she was moving almost constantly. From 12:15 AM until 5:00 AM, she stayed in the same general location, moving only occasionally. Between 5:00 and 5:30 AM she moved about, but from 5:30 until 7:00 AM when the receiver was switched off, she remained in one place. On April 25, it rained very hard from 4:20 to 5:25 PM. She was moving at 5:55 PM when we first attempted to locate her after the rain. She continued to move until 7:45 PM but stayed near the same place from 7:45 PM until 6:30 AM the following day, at which time the receiver was switched off. On April 26, tracking was begun at 5:20 PM under cloudy skies. The rat did not move until 6:07 PM, and from then until 9:45 PM she moved only in the den or in the immediate vicinity of the den. From 9:45 until 10:15 PM, she was very active in the vicinity of the den. From 10:15 PM, until 6:00 AM the next morning there were only minor movements in the vicinity of the 9:45 PM locations. She was still moving within a restricted area at 6:30 AM, the time the receiver was switched off.

A summary of the movement information indicated that Subang 4 alternated periods of intensive activity with extended periods of intermittent local activity and inactivity. The onset of her activity in the evening ranged from some time before 5:55 PM to about 9:45 PM (perhaps influenced by weather conditions). The cessation of her activity in the morning varied but occurred prior to full daylight.

DISCUSSION

The standard diameter (Harrison 1958:198) of four radio-tracked R. mülleri was 70 meters (Table 6), compared with 117 meters found by Harrison for 10 live-trapped animals.

The standard diameter (Harrison 1958:198) of the R. sabanus that was radio-tracked was 72 meters (Table 6), compared with 98 meters (based on incomplete data on four animals) found by Harrison for the same species. The standard diameter was determined from Fig. 5 as described by Harrison (1958:198). Harrison (1958:200) found the standard diameter of the R. jalorensis he studied by livetrapping to be 102 meters, compared with 58 meters (Table 6) for the R. jalorensis followed by radio. Again it is impossible to say whether this difference is caused by individual variation or by the technique used.

It appears obvious that home ranges of jungle rats in this area overlap. On the 13-mile Gombak Area, the range of R. sabanus (GCS 8) overlapped the home range of R. mülleri (GCS 6), Figs. 1 and 3. On the 16-mile Gombak Area, the home ranges of the three adult R. mülleri all overlapped (Fig. 2).

When tracking two or three rats on the same area at the same time, we found it helpful to have one constant-signal and one pulsing-signal transmitter or two pulsing-signal transmitters with extreme variations in the pulsing rate. Since the radios were on different frequencies, the rats could be recognized by their respective frequencies, but we found it easier to remember a rat by his transmitter's distinctive signal than by his frequency.

a. SUMMARY OF ALL RESULTS

Miniature, transistorized radio transmitters have previously been used on cottontail rabbits, striped skunks, raccoons, opossums, and ducks. Transmitters adapted from these models were successfully used on rats in Malaya. Radio-tracked rats weighed from 106 to 365 grams, and the transmitters used on them weighed 16-32 grams. Ground-to-ground ranges of the transmitters varied from 50 to about 350 yards. Usually, these ranges were adequate for following the rats; however, a longer range would have been desirable. During the 3 months of this project, nine wild rats were followed for periods ranging from 1 to 13 days. Three species, Muller's giant rat (*R. mulleri*), long-tailed giant rat (*R. sabanus*), and Malaysian wood rat (*R. r. jalorensis*) were radio-tracked successfully. The limited radio-tracking data indicated that these jungle rats usually returned to the same dens day after day, although some individual variation was noted. These studies showed that jungle rats were reluctant to expose themselves to visual observation. When dens were located in heavy ground cover, rats sometimes emerged from their dens during daylight but remained under cover until darkness. In the absence of heavy ground cover around the dens, the rats emerged just after the onset of darkness and, when the moon was bright, seldom crossed open areas. The home ranges of many rats--of the same and of different species--overlapped. Leptospirosis-positive and leptospirosis-negative rats also had overlapping home ranges. We followed two leptospirosis-positive *R. mulleri* by radio-tracking but were unsuccessful in our attempts to isolate leptospires from soil samples collected in and near their dens.

Standard diameters determined by radio tracking were consistently smaller than the standard diameters found in the same general area by an earlier worker using livetrapping data. More data are needed before we can determine whether these differences were caused by the different methods of study. The radio-tracking data demonstrated a consistent linearity in the home ranges of all rats studied. They also showed, as had previously been reported on the basis of livetrapping data, that *R. mulleri* prefers to live near streams whereas *R. sabanus* prefers drier situations.

Lt. J. W. Gentry, Dr. H. E. McClure, and at least four Malayan employees learned to construct miniature radios. These six, and at least eight additional Malayan employees, learned to radio-track rats that were wearing radio transmitters. After our return to the United States, Lt. Gentry wrote that they were continuing the radio-tracking project with considerable success.

All specifications for component parts, catalogues of parts, and price lists were left on file with the U. S. Army Medical Research Unit, Kuala Lumpur. Thus, it will be possible for the Unit to reorder components and to continue constructing transmitters. The Unit has also been placed on a mailing list to receive literature on recent developments in radio-tracking.

Contacts were made with electronics personnel in the British Army Signal Squadron and the Technical College, both in Kuala Lumpur. Personnel at

both places were extremely helpful and became familiar with the receivers. Thus, in order to keep their receivers functioning properly, the U. S. Army Medical Research Unit can obtain expert electronics help on a cooperative basis at no cost.

b. DISCUSSION OF THE SIGNIFICANCE OF THESE RESULTS

The radio-tracking technique is not the answer to all the biologist's problems; however, it does make possible the acquisition of data unobtainable by any other method currently in use. Placing a radio transmitter on a leptospirosis-positive rat makes it possible to know where the rat is at virtually all times. The advantages of knowing where a particular rat spends its time, how far it moves, how its home range and movements are related to the home ranges and movements of other individuals of its own and other species--both positive and negative for leptospirosis--how its home range and movements are related to the habitat, and other relevant information, are obvious to anyone interested in studying leptospirosis. Comparable data can be obtained for rats carrying chiggers, which are involved in the spread of scrub typhus.

While our brief studies in Malaya were primarily with rats--we did place transmitters on two mouse deer (Tragulus javanicus)--the radio-tracking technique is applicable to a wide variety of wild animals. In fact, rats present more than average difficulties for radio-tracking because of their relatively small size and the difficulty of attaching radio transmitters to them. Thus, at any time disease studies of the U. S. Army Unit in Malaya may call for studying the role of precise movements of other animals (including birds) in the transmission of disease, personnel now with the unit should have little difficulty in adapting their transmitters and tracking techniques to these other species.

c. BIBLIOGRAPHY

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Table 1. (cont.)

Rat Number	Species	Sex	Weight (g)	Age- Class	Date		Area	Radio Number	Weight of Radio (g)	Remarks
					Released	Last Signal				
Subang 4	R. l.	F	106	Ad	4-4-63	4-9-63	Subang	Cheng #7	32	Retrapped 4-9-63, radio re- covered.
					4-24-63	4-29-63		GCS #13	16	No signal 4-30-63, batteries probably dead. Radio lost.

Table 2. Percentage of nighttime radio fixes in circles of various diameters, located around the centers of activity of four adult R. mülleri, compared with data obtained from livetrapping eight individuals of the same species.

Diameter (meters)	Harrison (1958:158) <u>R. mülleri</u> . Percent of Total	GCS 4, Female		GCS 6, Male		G-28, Male		G-30, Female		Totals*
		Number Fixes	Percent of Total	Number Fixes	Percent of Total	Number Fixes	Percent of Total	Number Fixes	Percent of Total	Number Fixes
80	50	10	71.4	57	74.0	22	48.9	39	90.7	128
152	80	14	100.0	72	93.5	44	97.8	43	100.0	173
195	90			75	97.4	45	100.0			177
232	95			76	98.7					178
301	99			77	100.0					179

* Totals include only the data from radio tracking.

Table 3. Percentage of nighttime radio fixes in circles of increasing diameters, located around the centers of activity of four adult R. mülleri.

Diameter of Circle (meters)	<u>R. mülleri</u> (Adults)		Probits
	Number of Radio Fixes	Percent of Total	
20	26	14.5	0.2084
40	56	31.3	0.4029
60	100	55.9	0.7695
80	128	71.5	1.0691
100	144	80.4	1.2930
120	166	92.7	1.7928
140	172	96.1	2.0642
160	177	98.9	2.5427
180	178	99.4	2.7478
200	178	99.4	2.7478
220	178	99.4	2.7478
240	179	100.0	

Table 4. Percentage of nighttime radio fixes in circles of increasing diameters, located around the center of activity of one immature R. sabanus, compared with a summary of recoveries (based on livetrapping data) of four specimens of the same species.

Diameter of Circle (meters)	<u>Harrison (1958:196) R. sabanus</u>		<u>R. sabanus, GCS 8</u>		Probits
	Number of Recoveries*	Percentage of Live- trapping Recoveries	Number of Fixes	Percent of Total	
20	1	11	1	1.2	0.0150
40	2	22	10	12.2	0.1535
60	4	44	22	26.8	0.3425
80	6	67	52	63.4	0.9320
100	7	78	68	82.9	1.3690
120	7	78	74	90.2	1.6546
140	9	100	79	96.3	2.0858
160			81	98.8	2.5121
180			81	98.8	2.5121
200			82	100.0	

* Number of distances between trapping points, not number of trapping points (Harrison 1958:195).

Table 5. Percentage of nighttime radio fixes in circles of increasing diameters, located around the center of activity of one adult female R. jalorensis, compared with a summary of recoveries (based on livetrapping data) of 27 specimens of the same species.

Diameter of Circle (meters)	Harrison (1958:198) <u>R. jalorensis</u>	<u>R. jalorensis</u> , Subang 4		
	Percentage of All Trappings	Number of Fixes	Percent of Total	Probits
20	--	6	30.0	0.3853
40	--	13	65.0	0.9346
60	--	16	80.0	1.2816
67	50	16	80.0	1.2816
80	--	16	80.0	1.2816
100	--	16	80.0	1.2816
120	--	20	100.0	
129	80			
166	90			
197	95			
275	99			

Table 6. Estimates of standard diameters as described by Harrison (1958:198). A comparison of livetrapping results with radio-tracking results. Number of rats is given in parentheses.

	Standard Diameter (meters)	
	Harrison (1958:200)	This Study*
<u>R. mülleri</u> , forest	117 (10)	70 (4)
<u>R. sabanus</u> , forest	98 [†] (4)	72 (1)
<u>R. jalorensis</u> , grassland	102 (27)	58 (1)

* From data presented in Fig. 5.

† Data based on an incomplete sample.

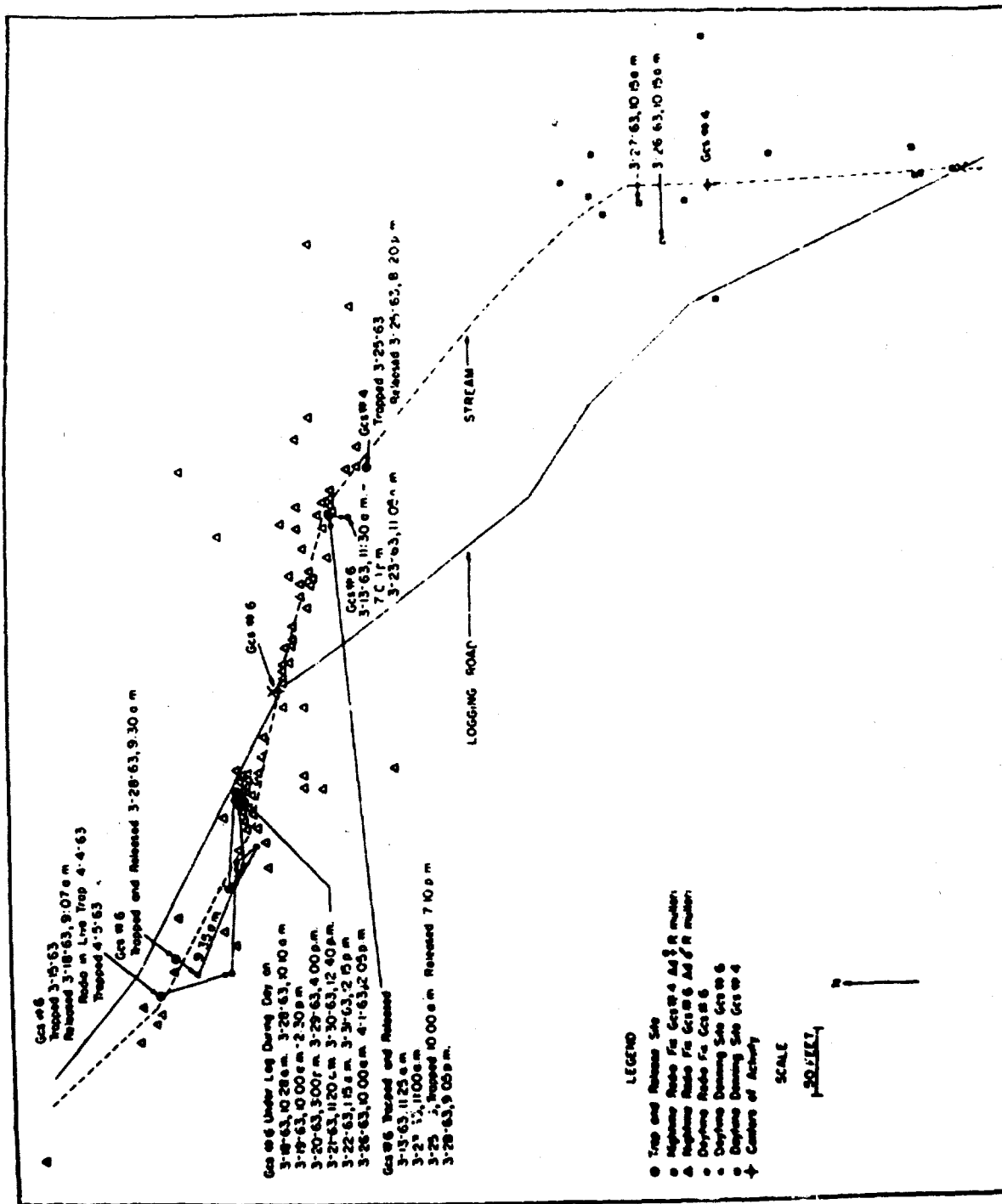


Fig. 1. Results of radio tracking two R. milleri on the 13-mile Gombak Area.

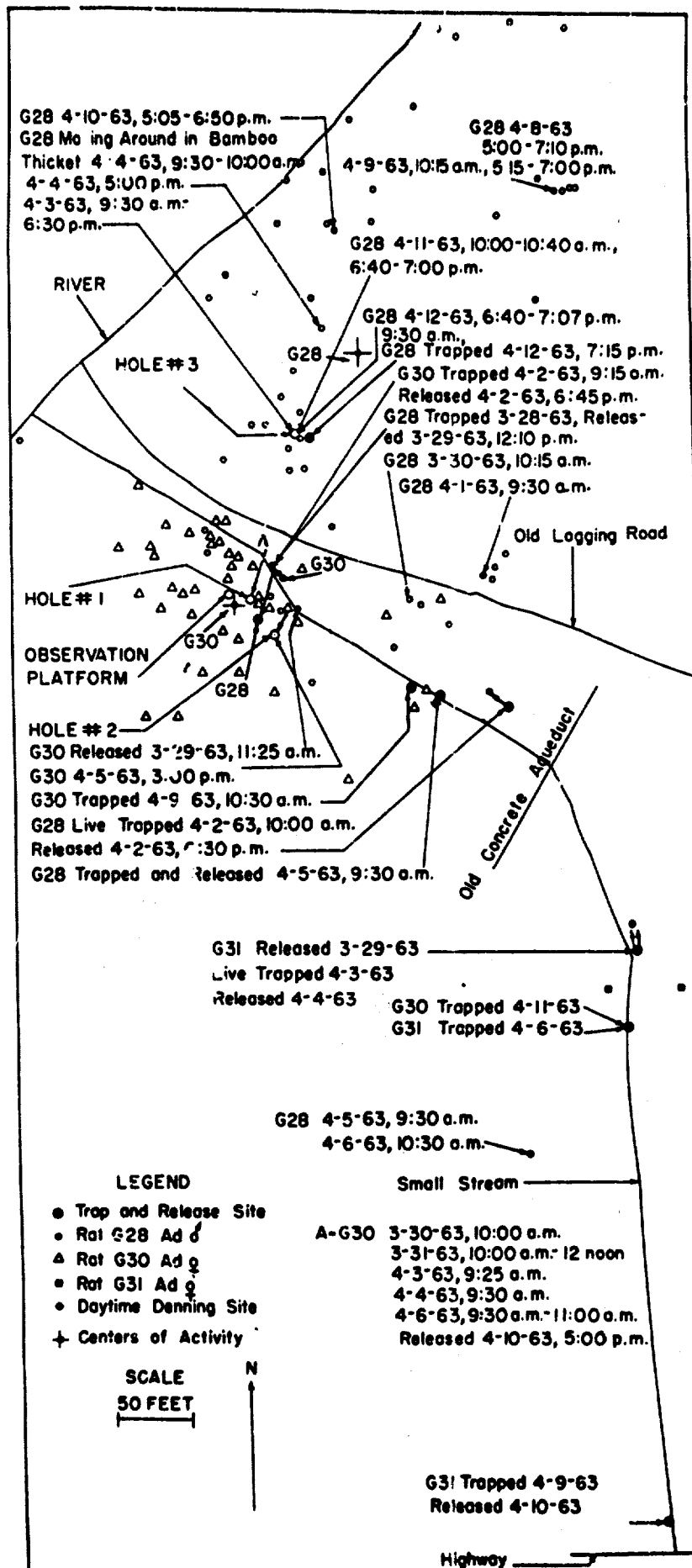


Fig. 2. Results of radio tracking three R. mülleri on the 16-mile Gombak Area.

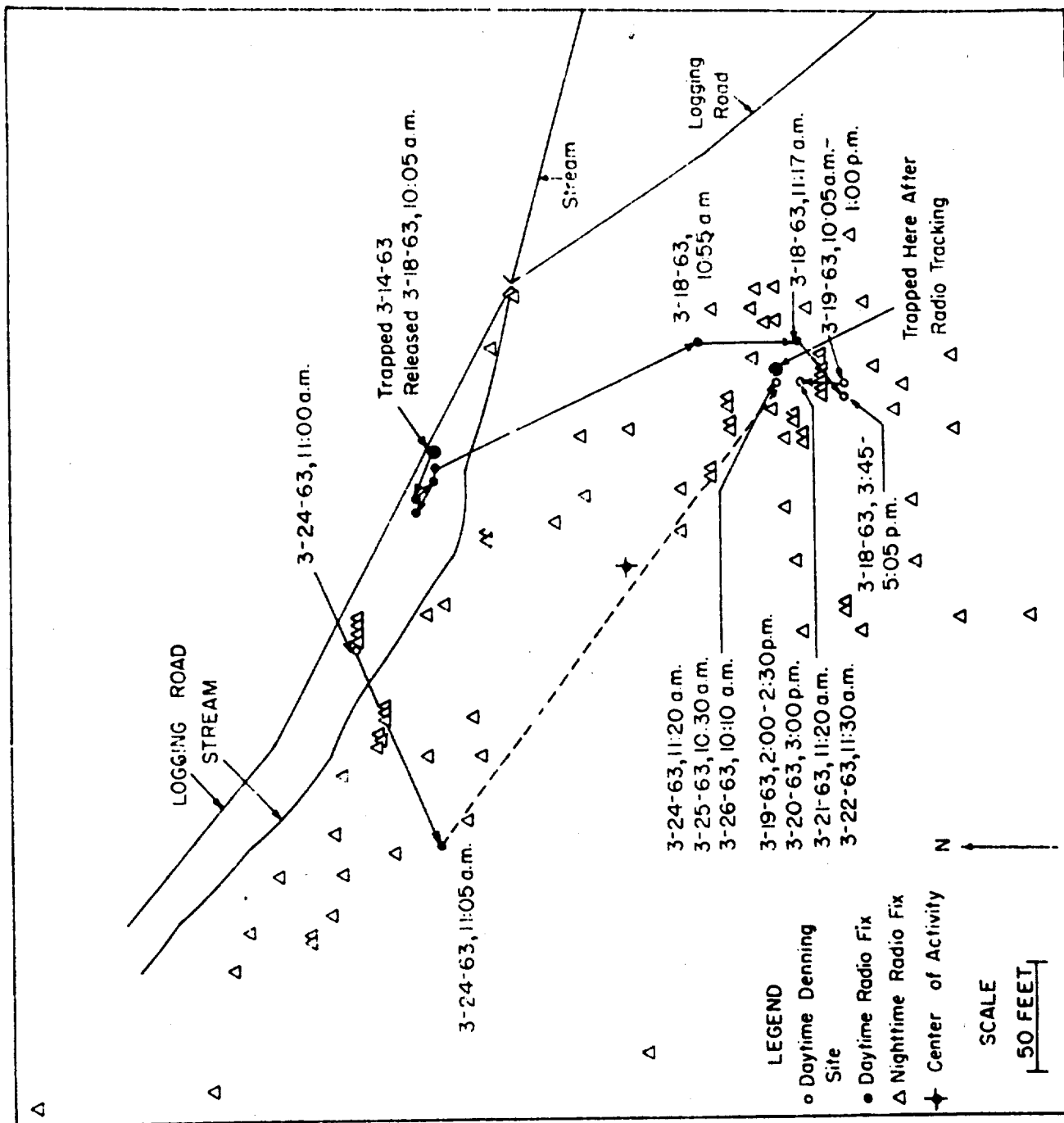


Fig. 3. Results of radio tracking one immature male *R. sabanus* (GCS 8) on the 13-mile Gombak Area.

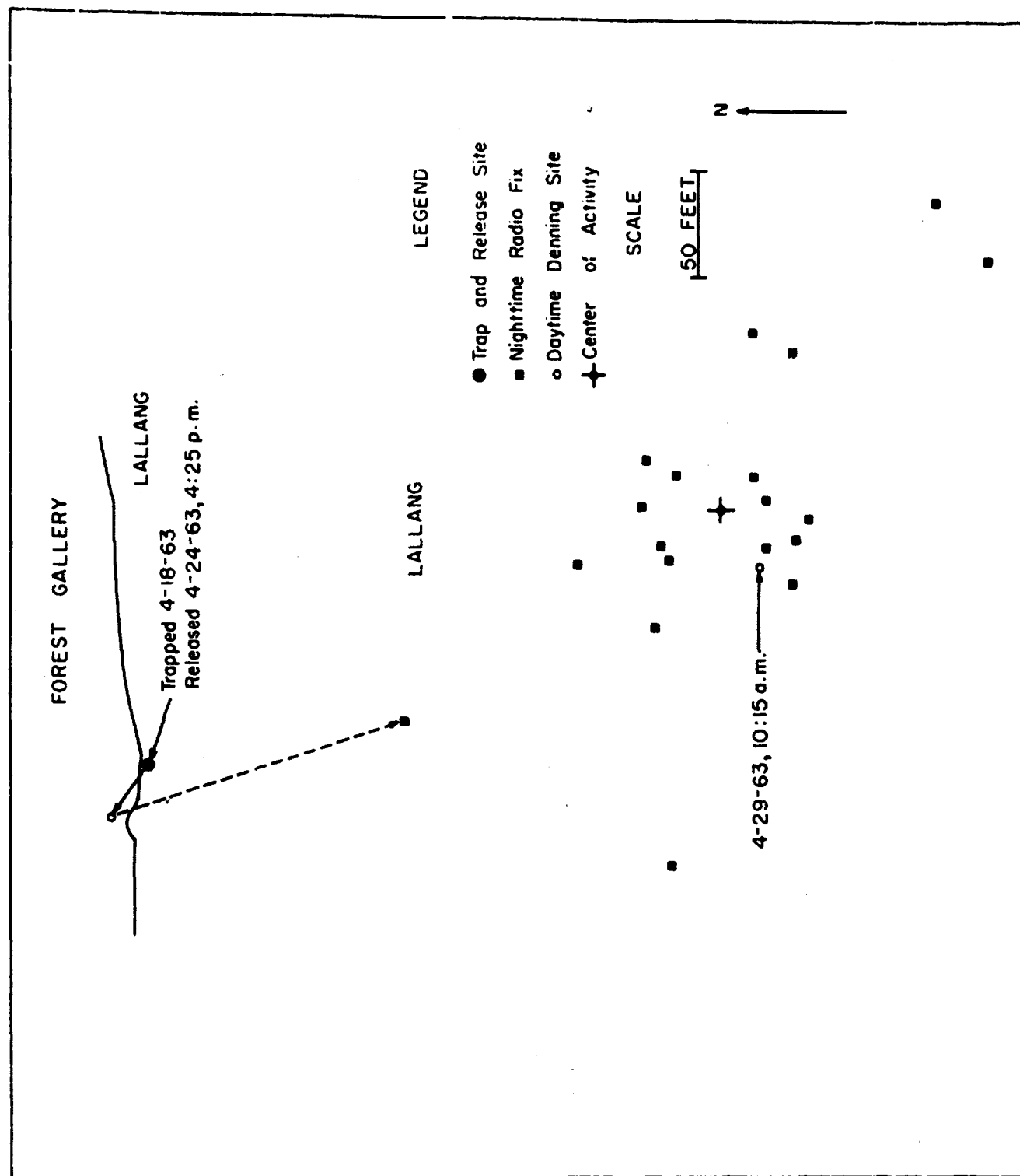


Fig. 4. Results of radio tracking one adult female R. jalorensis (Subang 4) near Subang.

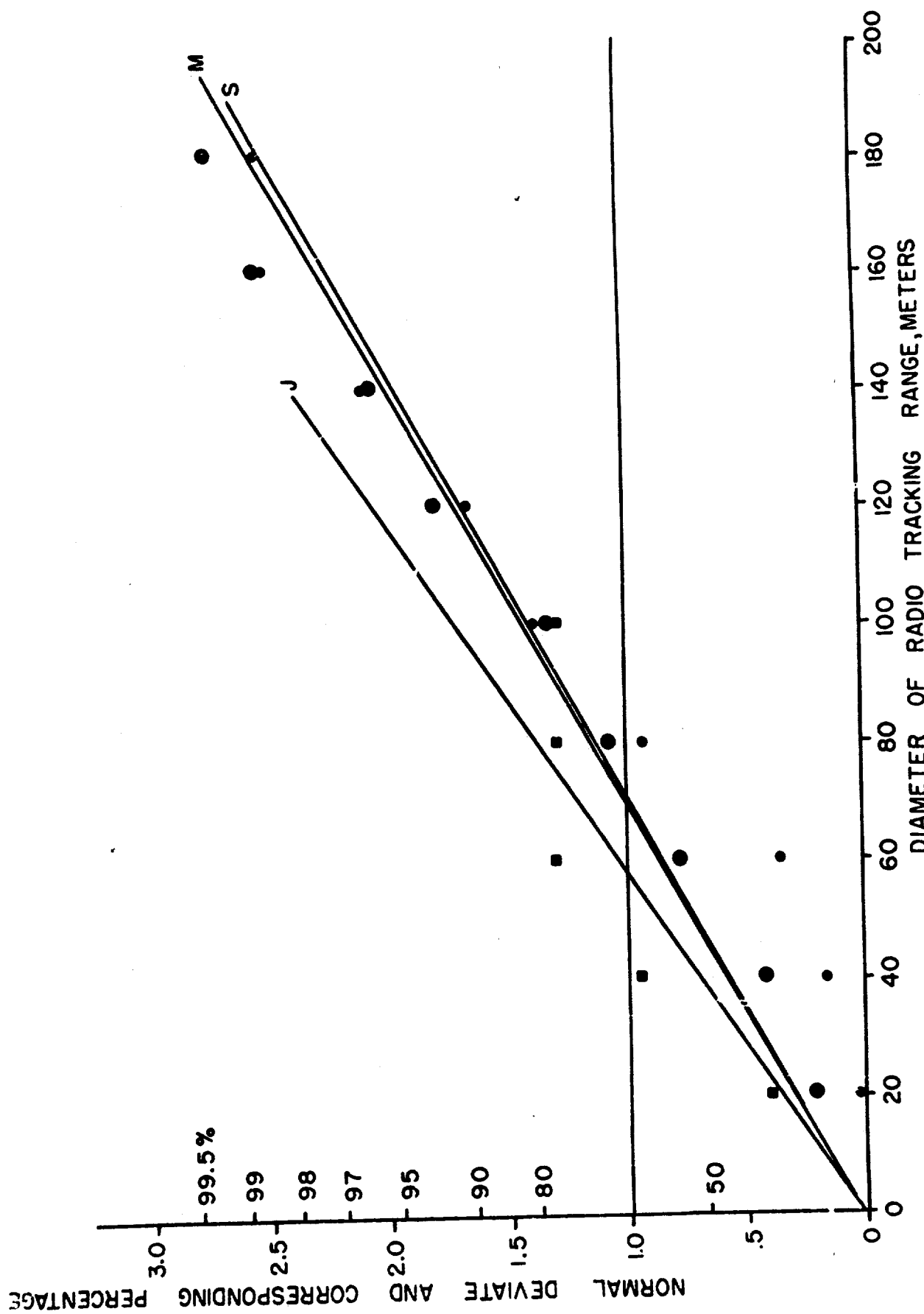


Fig. 5. *Rattus mulleri* (M and circles); *R. sabanus* (S and dots); and *R. jalorensis* (J and crosses). Four adult *R. m.*, one immature male *R. s.*, and one adult *R. j.*

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