THE ECOLOGY AND SOCIOLOGY OF THE NORWAY RAT

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE • Public Health Service

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NORWAY RAT

by John B. Calhoun

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Dr. Calhoun is a member of the Laboratory of Psychology of the National Institute of Mental Health, National Institutes of Health, U.S. Public Health Service, Bethesda, Md. This report is based upon a study conducted under the auspices of the Johns Hopkins University School of Hygiene and Public Health. Analysis of the data and preparation of this report were made possible by facilities made available by the Walter Reed Army Medical Center and the National Institutes of Health. Dr. Calhoun's basic training is in ecology. Since 1949 his close association with psychologists, psychiatrists and sociologists has led him to orient his studies to provide insights relevant to concepts and problems in these disciplines. This report and these associations led to more precise experimental studies of social behavior among animals. The general conclusions of these studies, conducted at the National Institutes of Health between 1955 and 1962, are presented in reference (*91*) and in the February 1962 issue of Scientific American.

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FOREWORD

This study describes the way of life of the Norway rat observed over a 27 month period in a quarter-acre enclosure in which environmental conditions simulated those characterizing this species in its native haunts. Typically, this species lives in close relationship with man (*4*, *5*, *25*, *26*, *28*, *29*, *31*, *67*, *88*). The present report comprises a small segment of a broader program of investigation into the biology of this species and its relationship to man contributed to by a number of workers at the Johns Hopkins University (e.g., *3*, *4*, *5*, *6*, *8*, *9*, *22*, *23*, *25*, *26*, *28*, *34*, *35*, *66*, *68*, *84*, *88*). Among these investigators, I am particularly indebted to Drs. Curt P. Richter, John T. Emlen, Jr., David E. Davis, and Allen W. Stokes. Had it not been for the insights and techniques developed by them, the formulation and conduct of the present study would have been much less effective.

Their studies were conducted in various habitats, such as on farms, or surrounding human habitations where Norway rats normally occur. Under these circumstances rats may be trapped, marked, and recaptured, but normally great difficulty is experienced in following the history of any particular individual throughout its life. It is even more difficult to observe the behavioral relationships among known individuals in most situations where rats maintain a commensal relationship to man. In order to circumvent this difficulty I established a few rats in a quarter-acre enclosure. From a single successfully reproducing female there developed a total population of over 200 individuals spanning four generations during the 27 months of study.

Every rat was trapped and handled on many occasions. In addition every individual was marked by removing small spots of fur with a depilatory. This marking enabled observation of the behavior of the rats from a tower constructed outside the enclosure. Such observation permitted the accumulation of a large body of information regarding relationships among the members of the enclosed population. At the termination of this study I decided that its value lay in a detailed examination of all these relationships. This proved a more difficult and time consuming task than anticipated. During the next few years, following the termination of the study by June 1949, my superiors at three institutions provided me with the opportunity and facilities for making the necessary detailed analyses reported here. In this connection I am greatly indebted to the following persons and institutions:

1. Dr. J. P. Scott and the Roscoe B. Jackson Memorial Laboratory, Bar Harbor, Maine.
2. Dr. David McK. Rioch and the Walter Reed Army Institute of Research, Washington, D.C.
3. Dr. David Shakow and the National Institute of Mental Health, Bethesda, Md.

My objective in this report has simply been to describe the results derived from the 27 months' observation of this enclosed population. Although I have found it useful to coordinate certain data reported in the literature with my observations, no attempt has been made to evaluate all literature relevant to the ecology and sociology of the Norway rat. I have viewed this study as an opportunity to seek useful concepts, whose validation certainly requires further investigation. To this end I have frequently searched for implications beyond those definitely substantiated by the recorded observations. During the years since completion of this study I followed up some of the leads suggested by it (*16*, *91*, *100*, *101*, *102*).

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December 6, 1962.

PRE-PUBLICATION STATEMENT

Preparation of the manuscript in a form suitable for publication from the original text completed in 1956 has been attended by delays causing a lapse of 6 years from completion of the manuscript to its publication. For this reason references to pertinent literature omit consideration of a number of important papers since 1955. However, in view of the fact that the main intent of this report is simply to present the results of the study, it has been considered advisable to present this report in its present form. Evaluation of this study, as well as later ones conducted by me at the National Institutes of Health, in the light of more recent studies by others has been included in other papers I have recently published, or which are in preparation.

John B. Calhoun
Sept. 12, 1962

CONTENTS

ORIGIN AND AIMS OF THE STUDY

1. *General Background*

Dr. Curt P. Richter (*1*) showed that rats are capable of choosing nutritive substances and avoiding harmful ones. One of his hypotheses was that there was a relationship between the taste of substances and their nutritive value. While investigating this hypothesis he (*2*) found that phenyl thiourea was lethal to rats in minute quantities. Although domesticated rats normally took sufficient food containing phenyl thiourea to be lethal, field tests on wild populations of rats were unsatisfactory in producing significant kills. Wild-caught rats transported to the laboratory demonstrated marked ability to avoid food containing phenyl thiourea, choosing, instead, unpoisoned food. There followed a search for a toxic thiourea derivative which lacked the bitter taste of phenyl thiourea. The result of this search led to the selection of Alpha-Napthyl Thio-Urea (ANTU) as a suitable rodenticide. These investigations occurred at the beginning of World War II when the normal sources of several previously proven rodenticides were cut off.

There developed a cooperative program of rat control and research between the city of Baltimore and the Johns Hopkins University (*3*). In the normal course of block by block treatment with ANTU, 50 to 85 percent reductions were regularly obtained. Depending upon the extent of reduction of the original population, recovery to the prepoisoning level took between 15 and 44 months (*4*). This necessitated repeated applications of ANTU poison. It soon became apparent that, whereas poisons played an integral part in rat control, they were no panacea. The continued support of the International Health Division of the Rockefeller Foundation to the Johns Hopkins School of Hygiene and Public Health enabled a broad approach to the problem. As a result, mainly through the efforts of Dr. David E. Davis, the emphasis of technical procedures in rat control turned from poisons to environmental control. The understanding of the philosophy underlying this shift in the emphasis requires an appreciation of the rat (*Rattus norvegicus*) as an organism. We must understand how they manage to live in close association with others of their kind; and how as individuals or as groups conditions of the environment modify the satisfaction of those basic requirements necessary to survival.

The study presented in this publication attempts to provide this understanding. In addition, the findings will point to the usefulness of the rat in investigating other topics which have little or no relationship to the problem of rat control. The author was given complete freedom to make such investigations as he thought would be most productive in revealing the nature of the rat's biology. At the time he joined the staff of the Rodent Ecology Project, there was one fact amply documented by Drs. John T. Emlen, Jr., and David E. Davis and Mr. Allen W. Stokes. This was that each city block where rats were poisoned would, following termination of poisoning, ultimately arrive at a stable population level closely approximating its original prepoisoning level. This posed the general problem of why the populations leveled off, and furthermore, why two blocks of approximately the same size would have different stable levels or carrying capacities.

As an initial probing into this problem the author (*5*) introduced into a stable population a number of alien rats caught from distant blocks. The number of aliens was approximately 65 percent of that of the resident population. Following this introduction considerable dislocation of the population occurred. This affected both the residents and the introduced members. Rats of both groups invaded yards where previously they had not been observed. Under these conditions of disruption of normal population equilibrium there was an increase in mortality in both groups, but the mortality rate for the aliens was approximately three times that of the residents. Emigration from the block was negligible. These observations suggested a negative correlation between the degree of stability of social relationships and the mortality rate. Under these conditions of unusual disruption of social relationships, mortality appeared to be due primarily to increased exposure to predation by man and dogs. However, the previous experience of the various workers in the Rodent Ecology Project had led to the impression that predation by dogs and cats and the sporadic attacks by the resident human population did not appreciably affect the density of the rat population. Although we had no quantitative data on this point, this conclusion was arrived at through the general observation that city blocks supporting high densities of dogs and semiferal cats frequently also supported a high population of rats. One other general observation was pertinent to the formulation of the hypothesis. This was that many blocks maintained a stable population without further increase even in the presence of a superabundance of food in open garbage containers and an excess of space, which was potentially suitable for the construction of burrows but which actually was never utilized.

These observations may be stated as premises:

1. Mortality rate increased with increases in the disruption of established social relationships.
2. Gross predation is an insignificant factor in the usual determination of the stable level of a rat population.
3. The growth of a population of rats will cease (reach the upper asymptote of the growth curve) even in the presence of a superabundance of food and an excess of potential harborage sites.

The hypothesis derived from these premises: The growth rate of a population will be inhibited in the absence of predation and in the presence of an excess of food and harborage. This inhibition arises through the social interaction among the members of the population with respect to the distribution of goals and barriers through the environment.

The genesis of this hypothesis is influenced by two sets of concepts in the field of ecology. First, it has long been recognized that social interaction through both cooperation and competition influences population density where either food or harborage or some other requisite aspect of the environment is limited. Second, the defense of territory will limit populations irrespective of the density dependent variables which may happen to be distributed through the territories. This latter situation has been somewhat overlooked, but its implication has recently been pointed out by Davis (*6*).

The exact methodology of executing an experimental study of a mammalian population presented quite a problem. It is obvious that one could not utilize the normal man-influenced environment in which the rat most characteristically occurs. In the first place, the physical configuration and distribution of objects through space is so highly irregular and changing as to preclude any hope of sorting out the influence of the variables. In addition, human interference in field studies of rats in the city situation often proves disconcerting. Even such a simple procedure as trapping, marking, and releasing rats meets with such obstacles as having someone kill them in the traps, release them, or move the traps about so as to defeat the original aims of the study. Investigation of the hypothesis necessitated construction of an artificial environment where at least some of the variables could be controlled. The space requirements posed problems of a magnitude not encountered by investigators in experimental population dynamics working with such insects as *Drosophila* or *Tribolium*. Also, I knew of no other experimental studies on the mammalian level where even the space requirements necessary to satisfy home range or territorial behavior were satisfied. Therefore, the structure of the experimental environment finally decided upon had to be made mostly on an empirical basis.

Although Norway rats accommodate to several types of human environments such as ships, warehouses, farms, and residential areas, it was decided to model the experimental environment after that encountered in the "row house" type of residential area (figs. 1 and 2) found through large sections of the city of Baltimore, Md. It has been within such a habitat that the majority of the Rodent Ecology Project research effort has been concentrated. Typ-

Figure 1.—Typical backyard scene in the row-house area of Baltimore where the various members of the Rodent Ecology Project conducted many of their studies on the biology of the Norway rat. Photograph by John T. Emlen, Jr.

ically, a "row house" block consists of a solid row of houses facing one street with the doors opening directly on the sidewalk. Adjoining houses have a common sidewall. The width of houses varies from about 16 to 25 feet and there are usually 14 to 20 units joined together. Backyards are of similar width and extend from 20 to 60 feet in depth. An alley runs through the center of the block. Adjoining the alley on the other side are another series of backyards belonging to the row of houses facing a street on the opposite side of the block. Occasionally there is also a small group of row houses at either end of a block. Surrounding many of the yards there is a near-solid board fence approximately 6 feet high. Through the fences there are occasional breaks due to broken or loose boards or where the rats have gnawed through or dug under. Fences are barriers which restrict movement through the block. The major portion of the rats live out of doors. Occasionally additional space becomes available to them in the basements or even in the house proper. Protection from the weather and predators is also provided by garages, outhouses of various types, outdoor toilets in some cases, and all sorts of miscellaneous junk. At the time of the initial studies made by the Rodent Ecology Project ample food was available in practically every yard in open garbage containers which ranged from pasteboard boxes to 20-gallon galvanized garbage cans, which however lacked adequate covers. In the early 1940's, at least, before the municipal program of environmental control had any effect, this description fits to varying degrees the habitat available to rats in substandard housing areas, as well as in those which were given a higher rating.

Due to the structure of the blocks each formed the limits of a single population. There was little exchange of members between adjoining blocks. Even within a block there was considerable restriction of ranging by rats. Studies of marking and release conducted by Emlen, Stokes, Davis, and myself have regularly shown that the population of a single block is composed of smaller aggregates or colonies. Each has its own restricted home range, but there is some overlap in the space encompassed by the movements of members of adjoining colonies.

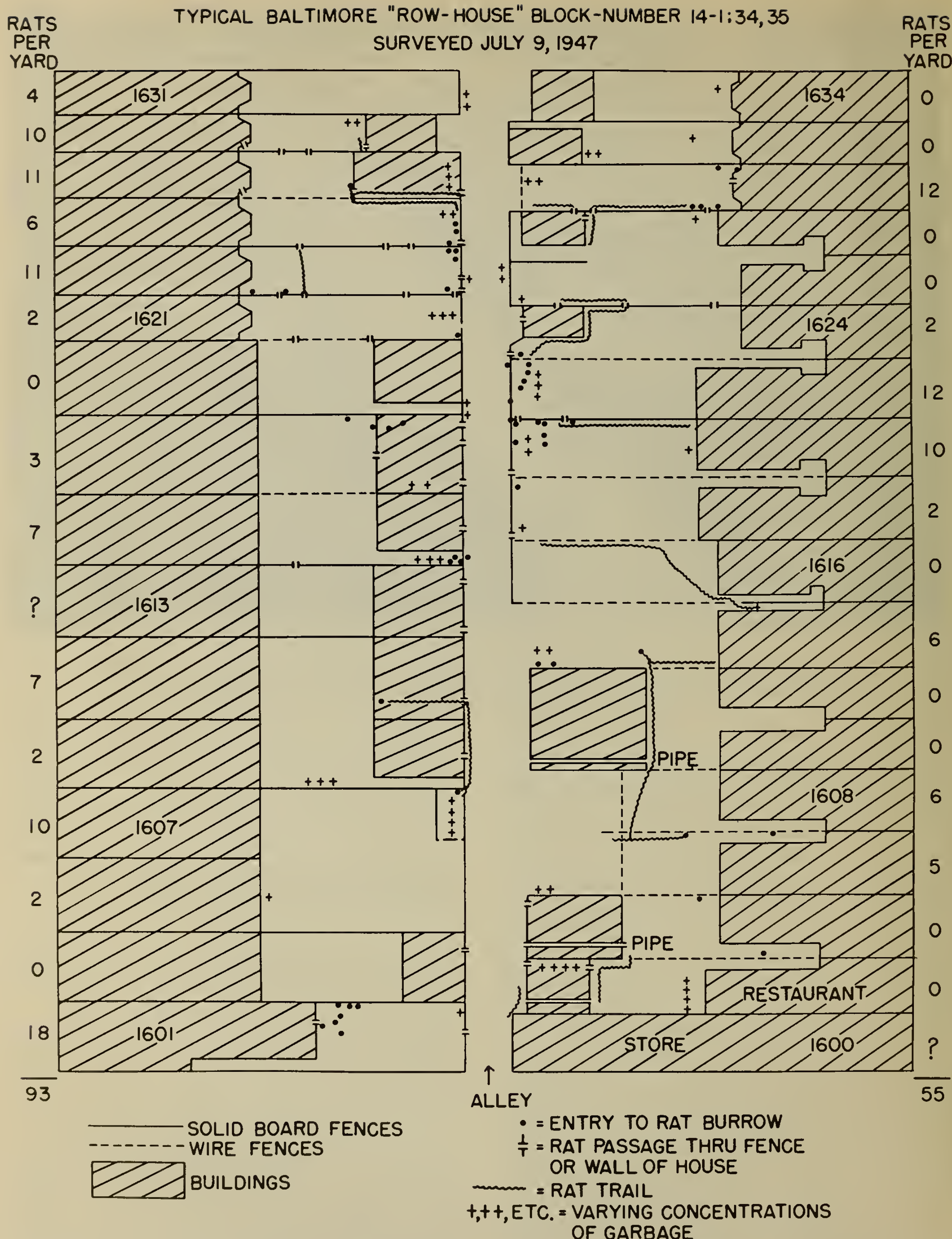

Figure 2.—The utilization of a typical Baltimore row-house block by rats.

2. *The Experimental Pen*

The following criteria were used in arriving at more exact details of the design of the pen and the establishment of the colony:

1. The pen should be large enough to accommodate several local colonies and yet at the same time be small enough that the observer from a tower could observe the rats at all points in the pen.
2. The pen should be enclosed by a barrier fence which would prevent the emigration of resident rats, or the migration into it by aliens.
3. Predation by vertebrate predators should be eliminated.
4. Food and water should be restricted to a single location accessible to rats living at all points in the pen.
5. Some artificial harborage should be provided, although the rats should have the opportunity to construct burrows at locations of their own selection.
6. Internal barriers with passages through them should be provided. This would enable the formation and delimitation of local colonies, while at the same time it would facilitate the observation of interactions among rats.
7. The rats to be introduced into the pen should be members of a wild population and yet be as nearly homozygous genetically as possible. This precaution was desirable in order to make more certain that such variability of data as might become evident would primarily be due to environmental conditions.

The manner in which these objectives were satisfied are mainly illustrated in figures 3, 4, and 5. The area enclosed by the pen was approximately one-quarter acre. In the city blocks the area available to rats ranges from ¼ to 1½ acre. However, since portions of yards are not available to rats, because of their use by man, the area in the experimental pen closely approximated the average amount available to rats in city "row house" blocks. A tower, whose floor was 20 feet above the ground, was placed on the southwest side of the pen. Although the behavior of rats on the half of the pen nearer the tower could be observed in more detail, it was still possible to identify individual rats at even the farthest points with the aid of 6-power binoculars.

The problem of preventing rats from escaping was solved by constructing a fence of hardware

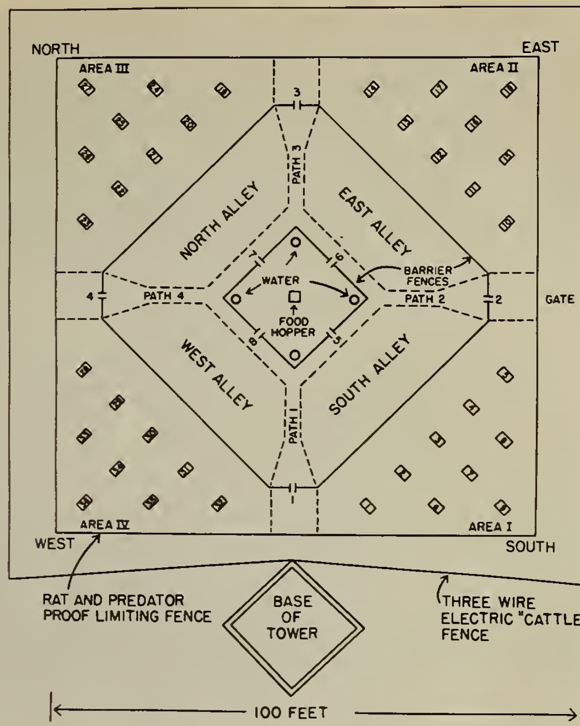

Figure 3.—Diagram of the experimental area. The numbered rectangles in each of the corner areas represent the positions of the sunken wooden harborage boxes. The dashed lines enclose paths or areas, which were maintained free of vegetation. The eight passages through the barrier fences are referred to in the text as here numbered.

cloth (fig. 6) which extended 4 feet above the ground and 2 feet underground. In addition, the underground portion of the fence had a 2-foot shelf of hardware cloth extending out into the pen at a depth of 2 feet. Thus, when the rats burrowed down, they would strike this shelf. No rats ever surmounted this underground baffle although a few dug down that far on very rare occasions. At the top of the 4 feet of fence above ground there was an 18-inch overhang sloping downward, which was sheathed with "screen glass". This is window screen with the space between the meshes filled with a clear plastic. Actually very few rats ever climbed this high since a wire carrying a high voltage, as used on cattle fences, was placed a few inches above the ground on the inside surface of the fence. Rats soon learned not to climb fences.

The problem of eliminating predators was not quite so simple but it was effectively solved. Posts supporting the limiting fence were placed at 10-foot intervals. On the top of each and at the base of each a steel trap was left permanently set. Forty-nine predators were removed during the 27 months of the study: barred owls (*3*), great-horned owls

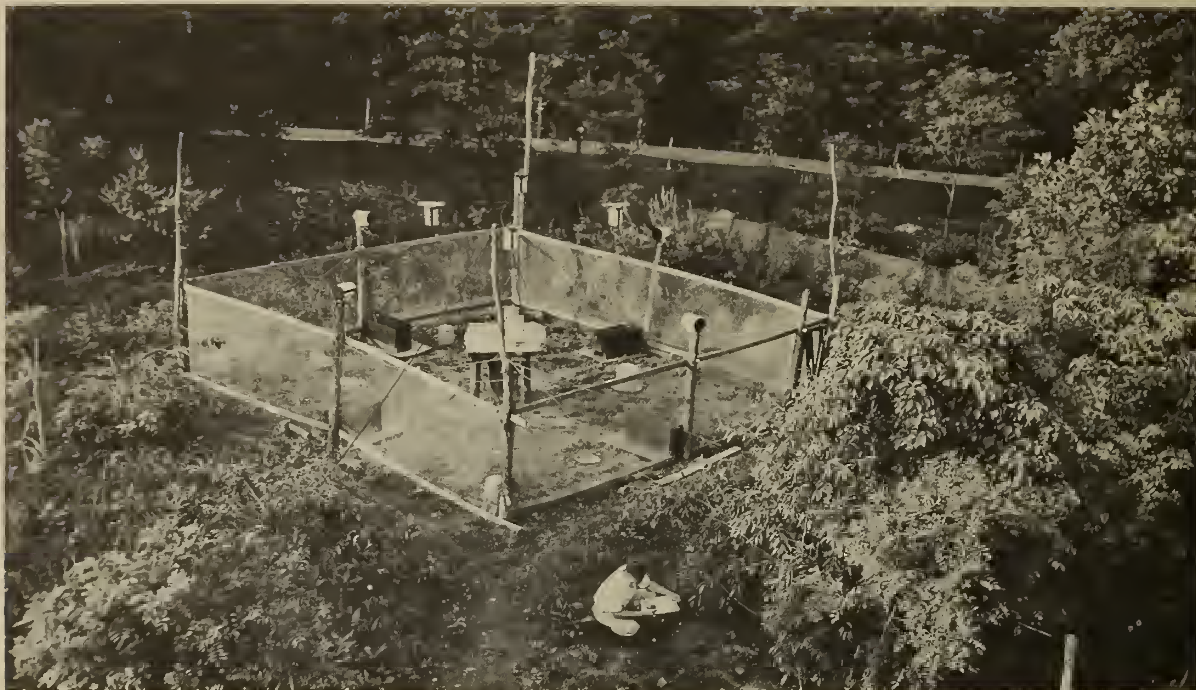

Figure 4.—View of the pen in late April 1948 looking northeast from the observation tower. The South Alley Burrow is located just to the right of where the observer is taking notes. At the four entrances to the Food Pen in the center are placed the activity recorders in the black tunnel boxes. Photograph by F. Di Gennaro.

(*2*), screech owls (*9*), sharp-shinned hawks (*3*), broad-winged hawk (*1*), skunks (*13*), opossums (*15*), weasels (*3*). Since the avian predators normally alight on the posts rather than fly directly in, no loss was attributed to them other than by the great-horned owls which would fly directly into the Food Pen. Probably five rats were lost to them before this problem was solved by placing traps on top of 12-foot poles surrounding the Food Pen. An opossum managed to get over in the pen during the summer of 1948 and was in for several days before being detected. It was a young animal and the evidence was that it may have destroyed one or two litters of unweaned rats. The three-strand electrified barrier fence, 10 feet peripheral to the main rat-proof fence, effectively kept dogs away. Initially cats were quite a problem although there was no evidence that any rats were killed by them. At first there was only a single strand of electrified wire on top of the fence. One day a cat was observed to make a leap from the ground over the top of the 4-foot fence, and over the electrified wire immediately on top of it, and land on the overhang from which it jumped into the pen. Following that incident three more strands of electrified wire were placed on top of this fence. This effectively eliminated disturbance by cats (see fig. 6).

A hopper which provided a continuously available source of Purina laboratory pellets was placed directly in the center of the pen. Here 10 to 15 rats could obtain food simultaneously without crowding. The Food Pen was surrounded by a barrier fence through which there was a 3-inch diameter opening in the center of each of the four sides. This pen was 20 feet in diameter. A single water fountain was placed in each corner of the Food Pen. These were 2½ gallon chicken-watering-troughs around which it was possible for several rats to drink simultaneously. Food and water were continuously and abundantly available at this central location. Additional food in the form of garbage from the author's home or neighboring grocery stores was occasionally provided.

Nine artificial harborage boxes (figs. 7, 54, and 55) were placed in each of the four triangular corner areas of the pen. The center of each box was 10 feet from the center of adjacent ones. An 18-inch long and 3-inch diameter clay drain led from the surface of the ground down into each of of the boxes which were sunk into the ground. These 36 harborages were designated as boxes 1

Figure 5.—View of the pen from the tower in February 1949 looking toward the north corner. Photograph by U.S. Army Signal Corps.

to 36 as shown in figure 3. Although the boxes were of 1-inch thick wood the removable tops were given further protection with a sheet of insulation board. The only place that rats were not allowed to dig burrows was in the Food Pen. These were regularly destroyed shortly after they were formed. Elsewhere in the pen burrows constructed by the rats were rarely disturbed.

The division of the pen into definite tracts which might affect the behavior of the rats was accomplished by the establishment of two internal barrier fences. The first was the fence forming the Food Pen. The second barrier fence was parallel to the first and 20 feet distant from it. As may be seen in figure 3, this latter barrier fence served to produce a band about the Food Pen 20 feet in width in which no artificial harborage was provided, while at the same time it separated off a triangular area in each corner of the main pen. A 3-inch diameter passage was placed through this barrier fence at the points where the corner triangular areas adjoined. This system of barrier fences and passages through them provided for alternate equivalent-length routes of travel. A rat starting from the center of one of the triangular areas and going to the Food Pen could leave the triangular area through the passage at either the left or the right end of the base of the triangle formed by the barrier. At this passage the rat would find itself equidistant from two passages leading through the barrier fence into the Food Pen. The purpose of this provision for alternate choices in travel was that, in the eventuality of a passage being defended or blocked by one rat, a second rat approaching this passage would have an alternate route for attaining its goal. The goals in question at either end of the routes of travel were the source of food and the source of harborage.

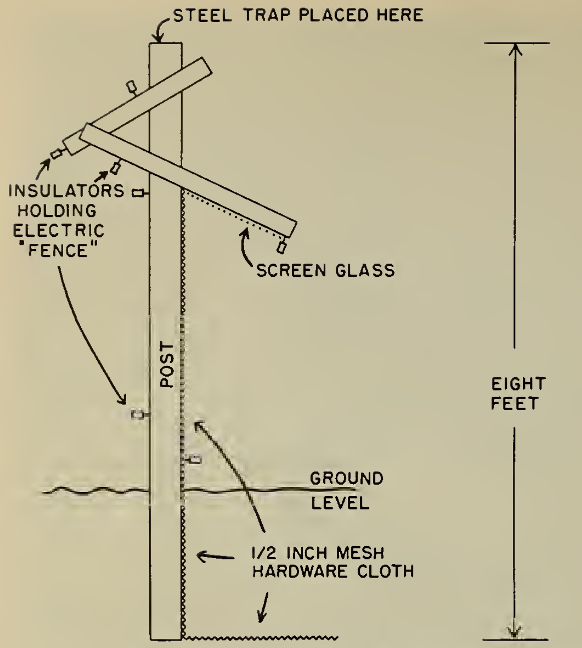

Figure 6.—Cross section of rat and predator-proof limiting fence. Both the overhanging screen glass shelf and the underground shelf of hardware cloth were directed into the pen.

In order to facilitate the systematic recording of data with reference to their place of occurrence, the following system as shown in figure 3 was devised. (1) The triangular areas were designated as Areas I to IV in a counterclockwise fashion starting with the south corner. (2) The passages through the outer of the two barrier fences were numbered from 1 to 4 in a counterclockwise fashion starting with the southwest passage between Areas I and IV. (3) The region between the Food Pen barrier fence and the second barrier fence was called the alley with the four segments of it being specifically called the South, East, North, and West Alleys. (4) The four passages through the Food Pen barrier fence were numbered from 5 to 8 in a counterclockwise fashion starting with the south passage. (5) In order to facilitate observations the Food Pen was always kept clear of any plant growth. Likewise a 3-foot wide path was kept cleared around the outside of the Food Pen and from the corners of the Food Pen toward the passages through the second barrier fence. The limitations of these pathways are shown by dashed lines in figure 3. The paths were numbered from 1 to 4 in a counterclockwise fashion beginning with the southwest path.

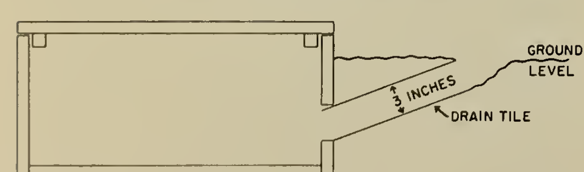

Figure 7.—Cross section diagram of the construction of the wooden harborage boxes.

3. *The Rats Introduced into the Pen*

The colony in the pen was begun with five pairs of rats (table 28; pp. 136–143), which were assumed to have been as genetically homozygous as it is possible to trap them in the wild state. This assumption is based on the following grounds. The rats were trapped in February 1947 on Parsons Island, a 150-acre tract in the Chesapeake Bay. A natural causeway connecting the island with the mainland was severed about 1900. Since this time the rats have been effectively isolated. The number of rats on the island has fluctuated widely both on an annual basis and on the basis of changes in agricultural practices. An experimental reduction by poison in 1923 was conducted by the Fish and Wildlife Service. A second experimental reduction was conducted in the spring of 1946 by J. T. Emlen and D. E. Davis, of the Rodent Ecology Project. Estimation of numbers: (a) prepoisoning, 670; (b) postpoisoning, 220. At the time of trapping in February 1947 surveys indicated that there were probably no more than 150 rats on the island. Under these circumstances of fluctuation in population size, it might be anticipated that considerable homozygosity would have been reached though gene drift (7). It is from this inference that variability of results in this paper are judged to arise from environmental conditions rather than from the hereditary variability among the rats.

4. *Objectives of the Investigation*

The central objective of the investigation was to determine the manner and extent to which social interactions might influence population growth. However, the nature of the experimental situation presented the opportunity for simultaneously investigating several subsidiary aspects of the biology of the rat. These include.

1. Growth and life span of the individual.
2. Reaction of the rats to the physical components of the environment.
   a. Orientation responses to those components of the environment which serve as cues.
   b. The effect of meteorological conditions and related factors which may alter intensity or periodicity of activity.
3. Investigation of population dynamics irrespective of the social factor.
4. Systematic recording of all types of behaviors and other variables with the expectation that these might lead to a better understanding of the rat as a species.

5. *Experimental Procedure and the Gathering of Data*

Once the colony was initiated, every effort was made to interfere as little as possible with the daily routine of life which the rats established. It was intended that such changes as might occur in the colony should be brought about by the activity of the rats themselves.

Observational techniques: The objective was established that, in so far as possible, all observations should pertain to known individuals and not to just rats in general. This required the permanent marking of individuals so that whenever handled each rat could be recognized, and it required the occasional marking of individuals so that they could be recognized at a distance without hampering their normal activities. The former was accomplished by inserting numbered light weight alloy fingerling fish tags in the ear lobes of the rats. It was found advisable to place a tag in each ear since occasionally the ear would become infected and the tag lost. Since two tags were rarely ever simultaneously lost, it was possible through this procedure to maintain a continuous identification of the individual. The tags utilized were obtained from the National Band and Tag Company, Newport, Ky. I have also used with success on other rodents similar tags produced by the Salt Lake Stamp Co., 43 West Broadway, Salt Lake City 1, Utah. The problem of sight identification was finally solved by using a commercial cosmetic depilatory, Nair. Spots of hair could be removed from the locations shown in figures 8 and 9. Sexes were differentiated by removing the hair from the top of the head on females. During the warmer months of the year, when the testes were descended into the scrotum,

PELAGE MARKING CODE

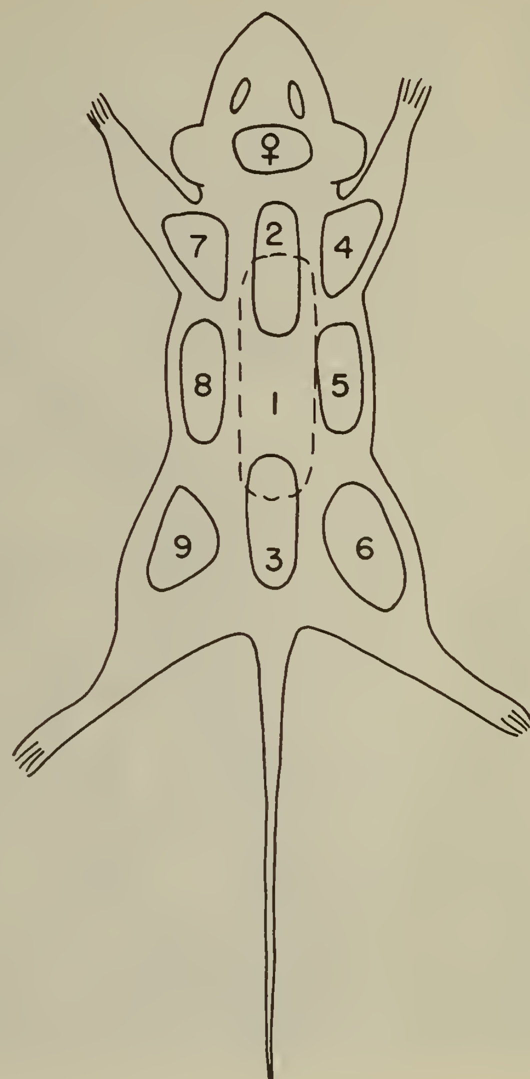

Figure 8.—Code for the pelage marking of rats. The pelage was removed from no more than two locations on a single rat. Sexes were indicated by removing a spot from the head of the female. See figure 9 as an example of marking.

males could be distinguished by this character irrespective of pelage marking. It was found advisable never to remove more than two spots on a single animal (other than on the head). This pelage marking system provided 43 combinations for each sex (table 1).

The rat is quite a nocturnal animal. This presented a problem in making adequate observations. Fortunately, there was considerable activity during at least the half-hour before sunset. Even after sunset there was sufficient light to permit

676-768 O—63——2

Figure 9.—Example of pelage marking, male pelage code No. 18. This male is examining a burrow entrance through which a female in estrous has just passed. Rarely do males follow the estrous female into the burrow. Photograph by U.S. Army Signal Corps.

TABLE 1.—*The 43 pelage marking combinations possible when no more than two patches of fur are removed as shown in figure 8.*

1	14	15	16	17	18	19	
2	23	24	25	26	27	28	29
3	34	35	36	37	38	39	
4	45	46	47	48	49		
5	56	57	58	59			
6	67	68	69				
7	78	79					
8	89						
9							

observations for another half-hour or 45 minutes. A similar situation existed in relation to sunrise. Thus, it was possible to get some good observations during at least an hour and a half both in the early evening and at daybreak. Since the activity of the colony was initiated at least by 6 p.m. regardless of the time of sunset, the period available for observation was much longer during the warmer months of the year (see pp. 112–135). Observation during any time of the night was facilitated by suspending lamps in certain portions of the pen. Four 250-watt lamps were suspended over the

Food Pen, two over the burrow system which developed in the South Alley, and two which flooded Path 1 and portions of the West Alley. Practically all observations of free ranging rats were made from the tower just outside of the pen above the base of Path 1. The rats never appeared to be disturbed in the slightest by these lights. The use of a moving spot light had to be discontinued since it did disturb the rats sufficiently that they would cease their activities and enter their harborages. During April and part of May 1949, when the activities of the rats were filmed by the U.S. Army Signal Corps (*8*), it was possible to make rather extensive observations of rats at several places in the pen from blinds whose platforms were only 6 feet above the ground. At times there were as many as five 2,000-watt lamps flooding a rather limited area. After a short period of adjustment the rats would enter these brightly lighted areas without any hesitation and proceed with their normal activities.

Whenever any considerable noise accompanies the observation, it is necessary to drown it by broadcasting a continuous nonsense sound tract. This was found to be the effective solution of obscuring the distracting noises occurring at the time of the filming. Within a day or two after first using this nonsense sound-tract broadcast, no further disturbance to the normal activities of the rat could be discerned.

About once every 6 weeks (see fig. 10) the attempt was made to capture every rat in the pen. The main device used in the capturing of the rats was a simple box trap (*9*) (fig. 31). The most effective baits used were sunflower seed, a horse-feed mixture (oats, cracked corn, and alfalfa impregnated with molasses), oranges cut in eights, garbage, and sections of sweet potato. The trapping usually was more effective when the bait was merely thrown into the back of the trap and not placed on the trigger. Rats were removed by allowing them to run into a cloth sack which was held over the opening to the trap as the door was removed. With adult rats it is best to elevate the trap by setting it on a neighboring trap. This allows the sack to hang downward, and the rats run into the sack. With juvenile rats it is frequently necessary to tilt the door end of the trap upward, while at the same time holding the attached sack also extending upward. The entering of the sack from the trap is an escape behavior which is positively geotropically oriented in adults, but negatively oriented in juveniles. During these periods of

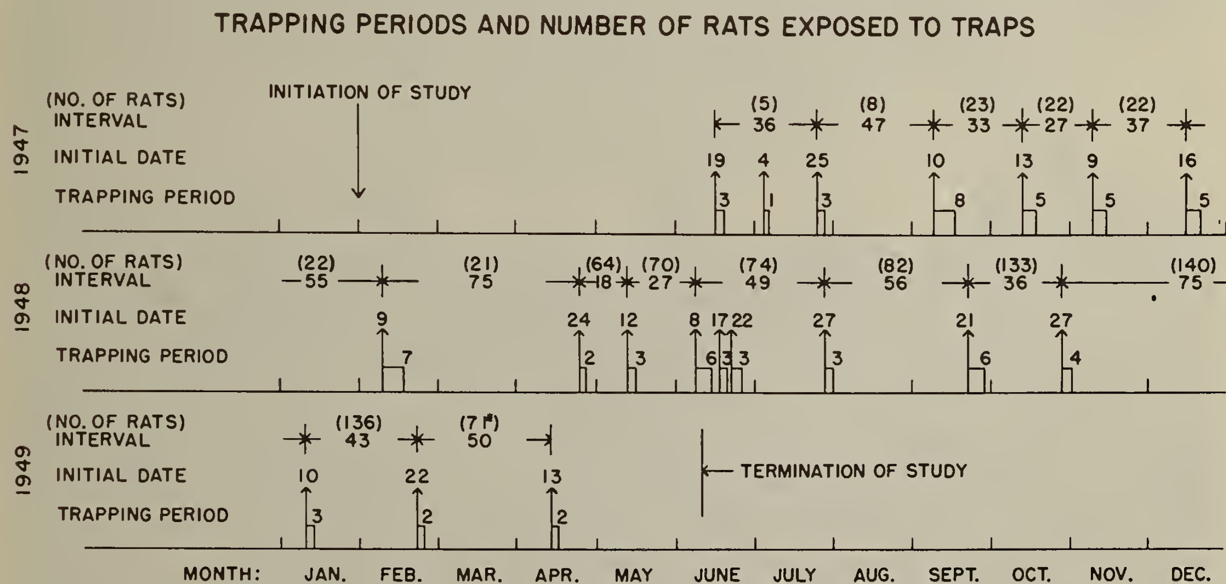

Figure 10.—Trapping periods* and number of rats exposed to traps. The number of rats exposed to traps was calculated as the number of rats 30 days or more of age at the beginning of one trapping period which lived through the following trapping period. This figure is shown in parenthesis above each trapping-period histogram. The interval in days between adjacent periods of trapping is indicated by the figures between the arrows. The duration of each trapping period in days is shown immediately to the right above the respective histograms.

*The April 1949 trapping period was the only time of trapping when all rats were not exposed to traps. At this time traps were set only in the north quadrant of the pen. It was estimated that only 60 percent of the 119 rats were exposed to these traps.

capturing the rats, all individuals were also removed from the artificial harborages. This was done by placing a cloth sack over the end of the drain tile leading from the harborage box. Upon opening the lid of the box the rats usually ran out into the sack. The third technique utilized in capturing the rats was the excavation of burrows. A drain tile with a cloth sack attached was inserted into each exit from the burrow system (see fig. 11). Then the excavation of the burrow began at the center of the burrow system. As it was excavated, the open ends of tunnels were kept plugged with other cloth sacks. By this process the rats in a burrow system were gradually encouraged to leave. To do so necessitated their passage through the drain tiles into the attached sacks. This procedure was mainly resorted to only during the December–January 1948–49 period and at the termination of the colony. The burrows in the alleys were only disturbed at the end of the study. While the rats were still in the sacks, each would be grasped just back of the head with the thumb and index finger of the right hand, while at the same time pressing its body down with the remainder of the hand. Then the left hand was inserted in the sack and a gradual exchange of the rat made from the right to the left hand. If one is careful, there is little danger in being bitten, even by the larger rats. When only identification of the rat was required it was immediately released, but if other observations were necessary, the rat was anesthetized before further handling.

Routine observations made usually included:

1. Weight in grams.

Figure 11.—Technique for capturing rats at the time of excavating burrows. Here the burrow emanated from the harborage box through a hole gnawed through its wall. Drain tiles with cloth sacks attached were inserted into each burrow exit. As the burrow is being excavated wads of cloth were inserted into the tunnels. Gradually the rats were forced to leave the burrow and enter the sacks as the tunnels were excavated.

2. Total length (tip of nose to tip of tail), and tail length in mm.
3. Sexual condition:
   a. For males: Whether or not the testes were descended into the scrotum.
   b. For females:
      Whether or not the vagina was perforated;
      Whether or not embryos could be palpated;
      The condition of the nipples.
4. The size and number of wounds.
5. The character of the pelage.
6. Date and location of capture.

Observations from the tower were kept chronologically. The contained data were transferred at a later date to cards (fig. 12) so that every observation pertaining to each individual rat was filed chronologically under its eartag number. The front of each card contained a list of some of the possible topics which might designate the behaviors described on the reverse side of the card. By placing checks in the appropriate places, later sorting of the data was facilitated.

At fairly regular intervals detailed surveys of the pen were made on enlarged field maps to show the locations of all changes in the environment made by the rats. In addition, the surfaces of the burrows were mapped in even greater detail. Particularly detailed maps were always prepared of trails following snowfalls, since these presented good records of orientation responses. A photographic record was made of all pertinent alterations to the environment produced by the rats.

.............: Ear Tag	Card number :.............
.............: Date (Handled)	Sex :.............
.............: Age in days	Date born :.............
.............: Weight in grams	Litter Number :.............
.............: Body in mm.	Mother :.............
.............: Tail in mm.	Birthplace :.............
.............: Wounds	Place today :.............
.............: Body/Tail	Sexual condition :.............
.............: Weight/Body	
.............: Growth Index	Pelage condition :.............

Behavior Notes Recorded On Reverse Side

.............: Competitive	Food storage :.............
.............: Play fighting	Food acquisition :.............
.............: Psychol. drubbing	Water :.............
.............: Nose touching	Elimination :.............
.............: Sparring-tumbling	Sexual behavior :.............
.............: Chase	Rolling :.............
.............: Territorial	Following :.............
.............: Vocalization	Copulation :.............
.............: Manual abiliity	Homosexual :.............
.............: Orientation	Mother-young :.............
.............: Nest building	Among young :.............
.............: Burrow building	Adults-young :.............
.............: Aggregations	Inter-adult :.............
.............:	.... :.............
.............:	.... :.............

Figure 12.—Sample of 5- by 8-inch card onto which all data was either recorded or later transferred. Details of the observation were recorded on the back of the card.

6. *Acknowledgments*

This study was made possible by a grant from the International Health Division of the Rockefeller Foundation to the School of Hygiene and Public Health of the Johns Hopkins University for the founding of the Rodent Ecology Project. This project was placed in the general supervision of the Department of Parasitology, which was headed by Dr. W. W. Cort.

I am in great debt to the extensive knowledge of the biology of the wild Norway rat and the techniques of study established by Dr. Curt P. Richter, Dr. John T. Emlen, Jr., Mr. Allen W. Stokes, and Dr. David E. Davis before my arrival at Johns Hopkins. Without that as a basis it would have been impossible to conceive of the present problem and to proceed with its analysis. Once the problem was decided upon, its prosecution was greatly enhanced by the freedom permitted me by Dr. David E. Davis, who was directing the general program of the Rodent Ecology Project during these years.

Once the problem of investigating a free-ranging population of rats under semicontrolled conditions was conceived, it then became necessary to secure a suitable location for the establishment of the colony. During my association with the Johns Hopkins University I lived at the edge of a small suburban community north of Towson, the county seat of Baltimore County, Md. Surrounding this community there were several hundred acres of semiforest and forested land. That portion immediately adjoining my residence was owned by the late Mr. John O'Donovan of Dulaney Valley Road. He granted permission for the establishment of the experimental setup in a partial clearing

only a hundred yards from my house. I am certainly indebted to him for this consideration. Without the close proximity of the study area to my place of dwelling it would have been impossible to conduct effectively this study which required such irregular hours.

During the initial phases of the study considerable difficulty was met in constructing recorders, which would efficiently record each time a rat passed by. This was finally solved through the donation of four electronic rattraps by the L. F. C. Corporation of New York City. The circuits of these were modified to eliminate the electrocuting mechanism. Then, whenever a rat passed through the beam of light projected on the photoelectric cell, a circuit was completed which activated a pen on a tape recorder.

During April and May of 1949 the U.S. Army Signal Corps made available a photographic crew and the necessary accompanying facilities for the detailed filming of the behavior of the rat. Major W. C. Lown had supervisory control of the general operations, while Lt. Strickland directed the actual field operations. The crew consisted of six movie camera operators, one still photographer, one sound technician, two electricians and two prop men. The immediate purpose of these films was to obtain certain desired footage for its integration in a series of films on the biology, control, and epidemiology of the rat which was being jointly prepared by the U.S. Army and the U.S. Public Health Service. However, the facilities of the camera crews were made available for the recording of all obtainable details of the activities of the rats, irrespective of their use in the projected series of films. I have had the opportunity of examining this extensive footage frame by frame. This detailed examination has been a greatly facilitated proper interpretation of rat behavior. I am indebted to the Signal Corps for making available for this publication several of the included still photographs.