CDC

MANUAL 10

SELF-STUDY COURSE 3013-G

Vector-Borne Disease Control

Biological Factors in Domestic Rodent Control

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES

SELF-STUDY

BIOLOGICAL FACTORS IN DOMESTIC RODENT CONTROL

Harry D. Pratt
and
Robert Z. Brown

Revised 1976

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL AND PREVENTION

Contents

Man has been combating rats and mice across much of the earth for hundreds of years. His control efforts have taken numerous forms, and many have been the attempts to "build a better mousetrap." Building a better mousetrap, however, requires that one first know something about the mouse. It is no surprise that man's most successful methods for controlling rodents are based on a knowledge of the rodents themselves. The knowledge of the biology and habits of rats and mice is an important weapon to use in their control.

introduction

North American rodents include such native animals as the field and wood mice, wood rats, squirrels, woodchucks, gophers, porcupines, muskrats, and beavers. Some of these, such as the muskrat and beaver, are of considerable economic importance to man because of their valuable fur. Many native rodents cause tremendous damage to crops, stored foods, and agricultural lands. Native rodents act as reservoirs of many diseases transmissible to man, such as plague in the western United States, tularemia, tickborne relapsing fever, spotted fever or tickborne typhus, human babesiosis, and some types of salmonellosis and leptospirosis.

Rodents also include three imported species: the Norway rat (*Rattus norvegicus*), the roof rat (*Rattus rattus*), and the house mouse (*Mus musculus*). These three belong to the Old World family Muridae and are often called "murine rodents," as opposed to the New World rats and mice in the family Cricetidae (*48, 95*). The Norway and roof rats and the house mouse are frequently called "domestic rodents." Some persons object to the term "domestic rodents" because they feel that man does not purposely raise these animals as he does livestock. These authorities prefer the term "commensal rodents," which refers to the fact that "these animals live at man's expense, eating his foods, living in his house, and sharing with man their diseases, without contributing anything beneficial to the relationship." (*8*)

The three imported domestic rodents are far more destructive to man and his property than are the native rodents. One or more of these three are found almost everywhere that man lives. They inhabit his buildings and destroy his food and property. They endanger his health by carrying and spreading such diseases as plague, murine typhus, salmonellosis, leptospirosis, and rickettsialpox.

In rodent control, man is faced with two problems: controlling the **individual** rodent in any given situation, and controlling groups of individuals, or **populations.** It is one thing to trap and kill a rat or mouse in the pantry, quite another to control numbers of them in a large residential area. Although at any given instant man may be after a certain rat or mouse, he wants eventually to control populations of rats and mice over large areas. Because of the differences between the individual rodent and the population, this discussion is divided into two main sections. The first part deals with individual rats and mice, their identification, distribution, and life history. The second part deals with the characteristics of rodent populations and the principles of rodent control.

identification

The best single way to distinguish the rodents from other mammals is by the location and shape of their teeth. Rodents are called the gnawing animals and are placed in the order Rodentia because of their strong, well-developed front teeth or *incisors* (Figure 1). There is a single pair of these prominent incisors in both the upper and lower jaws. The incisors are separated from the molars by a decided gap. In North America the only similar tooth arrangement is found in the rabbits, hares, and pikas. These species have two extra incisors behind the front pair in the upper jaw. Because of these extra incisors the rabbits, hares, and pikas are placed in a different order of mammals, the Lagomorpha. (*48, 95*).

FIGURE 1. Incisor teeth of a Norway rat. These conspicuous teeth are found in all rodents. Note the long vibrissae or whiskers.

FIELD IDENTIFICATION

The introduced murine rodents have been associated with man for a long time and are known by many names. The Norway rat (Figure 2) is also called the brown, house, barn, sewer, or wharf rat. The different color phases of the roof rat (Figure 3) are called the black, alexandrine, and fruit or tree rats. The house mouse (Figure 4) is often simply called the mouse.

These three murine rodents may be distinguished from our native rodents by the character of their tails. The tails of murine rodents generally are more naked and scaly than those of the native rodents. The simplified key that follows compares the murine and native species.

*FIGURE 2. The Norway rat (*Rattus norvegicus*). Note the heavy body, blunt nose, small ears, and tail shorter than the combined head and body.*

*FIGURE 3. The roof rat (*Rattus rattus*). Note the slender body, pointed nose, prominent ears, and long tail.*

*FIGURE 4. The house mouse (*Mus musculus*). Small in size with delicate feet and tail. (Photograph courtesy Joe E. Brooks.)*

KEY TO RODENTS

1. Hind leg **not** two times longer than front legs; external fur-lined cheek pouches absent 2

   Hind legs two or more times longer than front legs; external fur-lined cheek pouches present 25

2. Tail (bones) longer than one-half body and head length. 3

   Tail (bones) length equal to or less than one-half that of head and body. 15

3. Tail almost naked, with fine scales and hairs 4

   Tail not scaled, not naked (although short hairs on some species make them appear so) 5

4. Adults less than 4 inches (10 cm) from nose to base of tail (Genus *Mus*) . . . . **House Mouse**

   Adults more than 6 inches (15 cm) from nose to base of tail. (Genus *Rattus*) . . . . **Norway and Roof Rats**

5. Tail with more or less distinct rings. 6

   Tail without definite rings. 7

6. Head short and thick, no neck; fur coarser; tail usually dark above and beneath (Genus *Sigmodon*) . . . . . . **Cotton Rat**

   Head long and slender, neck evident; fur finer; tail usually dark above, pale beneath (Genus *Oryzomys*). . . . . **Rice Rat**

7. Tail round in cross-section. 8

   Tail flattened from side to side; feet partially webbed (Genus *Ondatra*) . . . . **Muskrat**

8. Half of tail nearest body slender and round, not bushy. 9

   Entire tail bushy or fluffy 11

9. Whiskers reach to or beyond base of front leg (Genus *Neotoma*) . . . . **Wood Rat**

   Whiskers do not reach to base of front leg 10

10. Tail same color above and beneath (Genus *Reithrodontomys*). . . . . **Harvest Mouse**

    Tail bicolored, dark above and light below (Genus *Peromyscus*) . . . . . . **Deer Mouse**

11. Whiskers reach to base of front leg 12

    Whiskers do not reach to base of front leg 14

12. Tail as long as head and body (Genus *Sciurus*). . . . . **Tree Squirrel**

    Tail shorter than head and body. 13

13. Membrane present between front and hind legs (Genus *Glaucomys*) . . . . **Flying Squirrel**

    Membrane absent between front and hind legs (Genus *Neotoma*) . . . . **Wood Rat**

14. Stripes on cheeks (Genera *Tamias* and *Eutamias*). . . . . **Chipmunk**

    No stripes on cheeks (Genera *Citellus, Spermophilus,* and allies) . . . . **Ground Squirrel**

15. Tail round; feet not webbed 16

    Tail flattened from top to bottom; feet webbed (Genus *Castor*). . . . . **Beaver**

16. Tail slender and pointed with fine hairs 17

    Tail hairy, not slender and pointed, with a fluffy or brush-like arrangement of hair 22

17. Claws on front feet longer than on hind feet 18

    Claws on front and back feet about equal length. 19

18. Upper front teeth grooved. Found in Eastern U.S. (Genus *Geomys*) . . . . **Eastern Pocket Gopher**

    Upper front teeth without grooves. Found in Western U.S. (Genus *Thomomys*) . . . . **Western Pocket Gopher**

19. Tail with white tip (Genus *Onychomys*). . . . . **Grasshopper Mouse**

    Tail without white tip 20

20. Fur reddish on back contrasting with pale gray on sides (Genus *Clethrionomys*). . . . . **Redback Vole**

    Fur brownish on back and sides 21

21. Fur grizzled, tail over 1 inch long (Genus *Microtus*). . . . . **Field Vole or Meadow Mouse**

    Fur not grizzled, but thick and short, tail 1 inch or less (Genus *Pitymys*) . . . . **Pine Vole**

22. Crown of head dark or black with or without a few white hairs (Genus *Marmota*) . . . . . . **Marmot and Woodchuck**

    Crown of head same color as back 23

23. Feet dark brown or black (Genus *Marmota*). . . . . **Woodchuck**

    Feet same color as body fur. 24

24. Back tan or light brown color, hair lies close to body like that of a short-haired dog (Genus *Cynomys*) . . . . **Prairie Dog**

    Back dark brown or gray, hair soft like fur (Genera *Citellus, Spermophilus,* and allies). . . . . **Ground Squirrel**

25. Tail has definite brush of hair on tip **26**

Tail without definite brush at top (Genera *Zapus* and *Napeozapus*). . . . . **Jumping Mouse**

26. White markings on head (Genus *Dipodomys*) . . . . **Kangaroo Rat**

No white markings on head (Genus *Perognathus*) . . . . **Pocket Mouse**

The Norway rat, the roof rat, and the house mouse differ in many ways and hence are easily identified in the field. These differences are shown in Figure 5. Of particular importance are the differences between the tail lengths and ear sizes in the two rats. The long, slender, whip-like tail and the large, naked ears of the roof rat readily distinguish it from the Norway rat. The house mouse is much smaller and has finer fur than the rats. The major characteristics and average measurements of the three species are listed in Table 1.

Juvenile rats can be distinguished from adult house mice by the difference in body build. As in the young of many animals, juvenile rats have conspicuously large feet. This is especially true of the hind feet. The tails of young rats are much thicker than the tails of house mice. In addition, the head is much larger and the fur much fuzzier. Since most juvenile rats do not leave the vicinity of the nest or burrow until they are larger than the average adult mouse, the difference in size also aids in recognition.

The many unsuccessful attempts to cross-breed Norway and roof rats indicate that these two animals are distinct species. Hence there are no intergradations between the two.

FUR COLOR

There is a great range in fur color among the three murine rodents, and therefore color alone is not a good character for identification.

The Norway rat has grizzled reddish to grayish brown fur on the back and sides. The underparts are tinged gray to yellow-white. Black individuals also occur quite frequently. Smith *(80)* reports that in a rural area in Georgia as high as 25.4 percent of Norway rats trapped were black. He cites evidence that these black animals were not as aggressive as the more common brownish phase. In addition, white and white-spotted individuals occasionally occur. The white laboratory rat is the albino form of the Norway rat. It might be said that the albino rat and the albino house mouse used for laboratory purposes are truly domestic rodents.

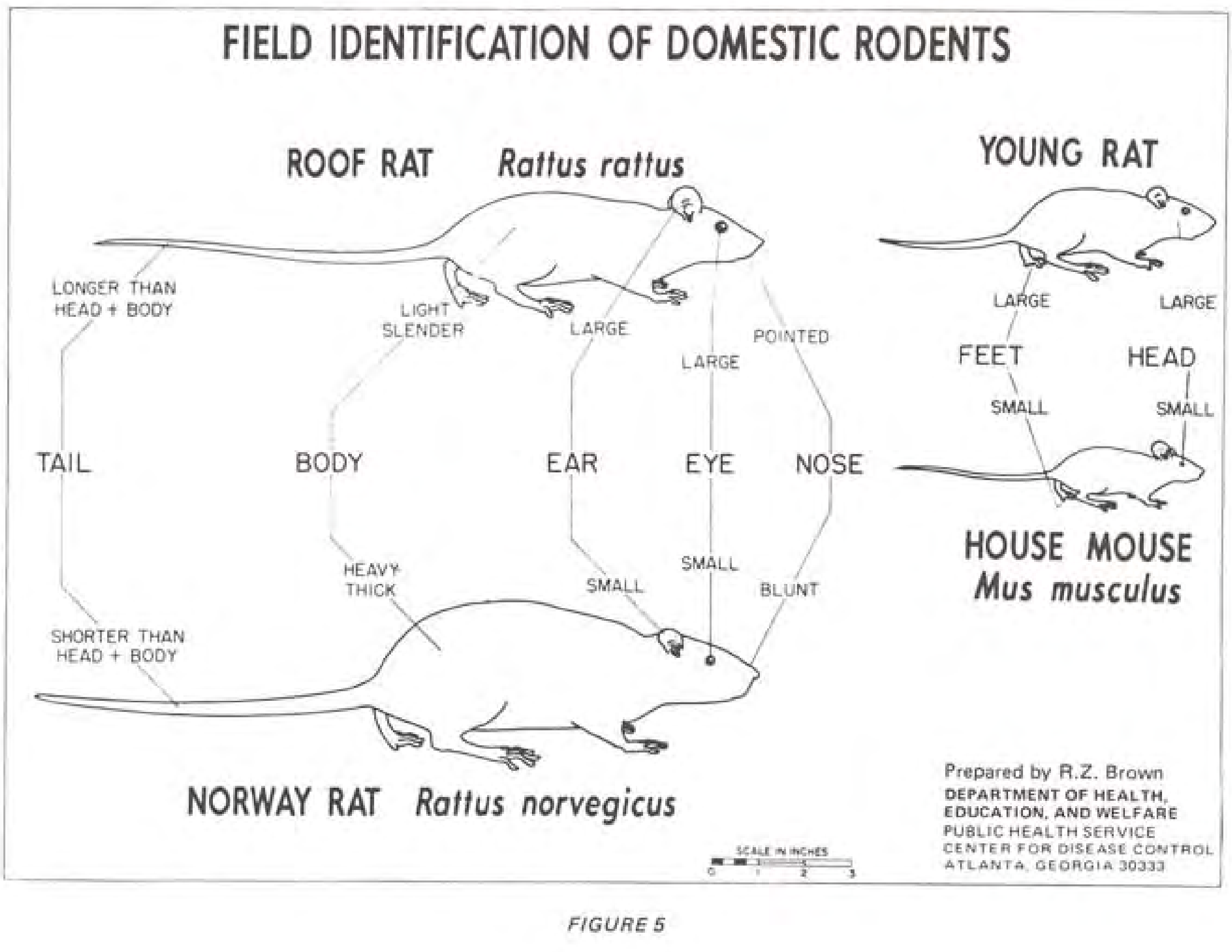

FIGURE 5

Three color phases of the roof rat occur in the United States, but every degree of intergradation occurs between them. *Rattus rattus rattus,* the black rat, is black to slate-colored on both the back and the belly. *Rattus rattus alexandrinus,* the alexandrine rat, has a tawny back, and an underside that is grayish white but is never clear white or lemon-colored. The hairs on the underside are always slaty at the base, except occasionally on the throat and chest where the hairs continue the same color to the base. *Rattus rattus frugivorus,* the fruit rat or tree rat (sometimes called the white-bellied or yellow-bellied rat), also has a tawny back, but its underside is white or lemon-colored. The hairs on the underside are white or buff-colored to the base. Usually there is no gray margin at the line of demarcation between the color of the back and the whitist belly. In populations of roof rats one of these color phases may, be more common than the others, depending somewhat on the degree of geographic isolation. However, all three color phases and intergradations among them often occur in single populations. Since the habits of the three color phases are very similar, these phases will be treated as a group and collectively called roof rats. (*8, 76, 92*).

The general color of the house mouse is grayish to brown. Occasionally, black or pale gray individuals occur. The underside may vary from white to dark gray.

Table 1. Charaeteristics and Measurements of Adult Murine Rodents

Species	Norway Rat *(Rattus norvegicus)*	Roof Rat *(Rattus rattus)*	House Mouse *(Mus musculus)*
Weight	10 - 17 oz. (280 - 480 gm.)	4 - 12 oz. (110 - 340 gm.)	1/2 - 3/4 oz. (14 - 21 gm.)
Total length (Nose to tip of tail)	12-3/4 - 18 in. (325 - 460 mm.)	13-3/4 - 17-3/4 in. 350 - 450 mm.)	6 - 7-1/2 in. (150 - 190 mm.)
Head and Body	Nose blunt; heavy thick body 7 - 10 in. (180 - 255 mm.)	Nose pointed; slender body 6-1/2 - 8 in. (165 - 205 mm.)	Nose pointed; small body 2-1/2 - 3-1/2 in. (65 - 90 mm.)
Tail	Shorter than head plus body, carried with much less movement, comparatively, than roof rat. Lighter-colored on underside at all ages. 6 - 8-1/2 in. (150 - 215 mm.)	Longer than head plus body generally moving whip-like, uniform coloring top and bottom at all ages and for all subspecies. 7-1/2 - 10 in. (190 - 255 mm.)	Equal to or a little longer than body plus head. 3 - 4 in. (75 - 100 mm.)
Ears	Small, close set, with fine hairs, appear half buried in fur. Rarely over 3/4 in. (20 mm.)	Large, prominent, hairless, stand well out from fur. Generally over 3/4 in. (20 mm.)	Prominent, large for size of animal, with some hairs. 1/2 in. (15 mm.) or less
Hind Foot	Usually over 1-1/2 in. (40 mm.) from heel to tip of longest toe.	Generally less than 1-1/2 in. (40 mm.) from heel to tip of longest toe.	Feet are shorter, darker, and broader than most wild mice. Generally less than 3/4 in. (20 mm.) from heel to tip of longest toe.

distribution

GEOGRAPHIC RANGE

Rodents of the murine group are most abundant in eastern and southeastern Asia. All evidence indicates that the Norway rat, the roof rat, and the house mouse are native to Asia and have spread from there throughout the world.

▪ **House Mouse:** The ancestral home of the house mouse probably was in the grassy borderland of Iran and Russia. From this area the house mouse followed the trade routes into the Mediterranean region and then into western Europe. From there man carried it to the New World during his early explorations. Because the mouse is so small and requires so little food, it has spread much farther than the rats. Today it is found from the tropics to the arctic regions all over the world. In North America it is found throughout the United States, southern and western Canada, and the Alaskan coastal regions and Aleutian Islands. It probably has the widest distribution of any mammal except man.

▪ **Roof Rat:** The roof rat is a native of Southeast Asia. It followed the caravan routes across India into the eastern Mediterranean region and entered Europe about the time of the Crusades. During medieval times it was the common house rat in Europe during the outbreaks of plague known as the Black Death. In the European area the roof rat has two distinct color phases: the black rat of Western Europe, and the brown alexandrine rat common around the Mediterranean. When this species was carried to the Americas, however, this situation changed. These introductions into North America began well before 1750, and roof rats were well known throughout the French, English, and Spanish colonies. Here the color phases from all parts of Europe were dumped together in the same ports, where they interbred freely. As a result, today in North America all the color phases can crop up in one population. Often a single litter of young roof rats will contain both black and brown animals. (*8, 76*).

▪ **Norway Rat:** There is evidence that the Norway rat is a later, more highly developed species originating in or near the center of origin of the *Rattus* group. This comparatively late comer is adapted to the dry, grassy plains of Central Asia (*47*). It is characteristic among mammals that the most advanced species of a group are found closest to the center of origin, where they replace the more primitive forms. So it appears to be with the rats. As the more highly developed, more aggressive Norway rat spread outward from Asia, the more primitive roof rat disappeared over much of its original range.

The Norway rat first appeared in Europe in the 1700's. It spread so rapidly that the Europeans called it the "Wanderatte" or migratory rat. Soon after the Norway rat reached Western Europe, it was carried to the New World. Here it quickly began spreading outward from the seaports, especially along the east coast of North America.

The present distribution of the Norway and roof rats appears related to two factors, competition between the two species and the reaction of both to different climates. When the aggressive Norway rat and the roof rat compete for the same areas, the Norway rat frequently becomes dominant, and the roof rat soon disappears. Only under special conditions do both species live in the same area. In one eastern seaport, roof rats live in the top of a grain elevator and Norway rats live in the bottom. This is probably because roof rats are better climbers than Norways. It is generally only in such situations as these that roof rats are found living in Norway rat territory.

As the spread of the Norway rat approaches tropical regions, the picture is altered by its reaction to the warmer climate. It appears that the Norway rat is definitely an animal of the temperate climates. In its original range in Asia it is restricted to temperate regions (*47*). It is found in the tropics only in seaport areas. On the other hand, the roof rat is most common today throughout the tropics. This is true both in its native area and in areas where it has been introduced. In these areas roof rats commonly inhabit regions quite far removed from man's activities.

While it appears that warmer climate has slowed the advance of the Norway rat, it has by no means stopped it. In southwestern Georgia, Ecke (*31*) found that from 1946 to 1952 Norway rats overran 1,000 square miles of country where the roof rat previously had been dominant. This is a gradual advance of 20 miles overland in 6 years in relatively warm climate. Today in this area the roof rat has largely disappeared, and the Norway rat is dominant. The importance of information of this kind cannot be overemphasized. Knowing what species one is likely to be dealing with in future years is of obvious value in rodent-control planning.

The present distribution of the three murine rodents in the United States is shown in Figure 6. The roof rat is confined mostly to the warm southern States and along the Pacific Coast into western Canada. It is found only sporadically in the northern part of the continent. The Norway rat and the house mouse are found throughout the United States and southern Canada. In the West, their distribution extends along the coast well into the main part of Alaska. Distribution of all three species is quite scattered in the arid and mountainous regions of the West.

ENVIRONMENTAL DISTRIBUTION

Within their geographic range, the rats and mice are distributed sporadically and are only abundant in certain environments. This distribution is due to differences in the suitability of the various kinds of available environments and reflects differences in the habits and needs of these three species.

▪ **Norway Rat:** Throughout most of its range in North America, the Norway rat is closely associated with man and his buildings. This applies even in rural areas where the bulk of the Norway rats live in fields and depend on man's crops. There are persistent reports that, when the crops are harvested, these rats shift their activities to farm buildings. This is especially noticeable in the fall of the year. Errington (*37*) found that in south central Wisconsin in summer Norway rats were

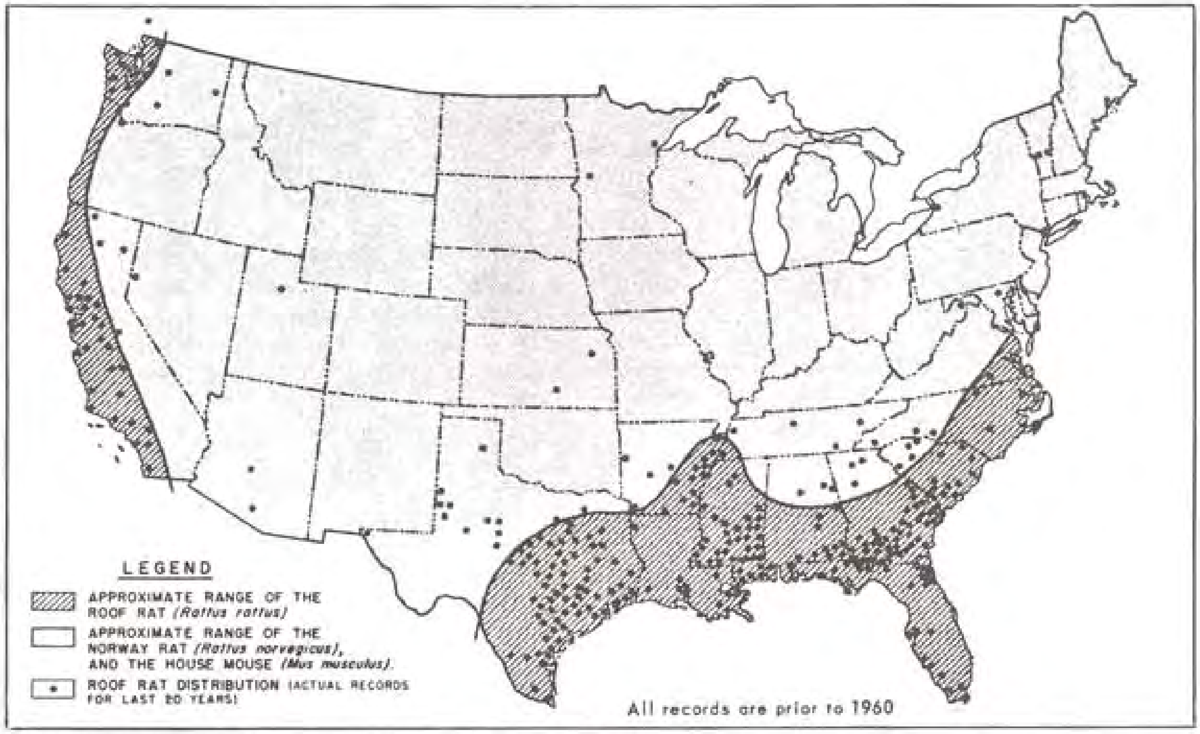

FIGURE 6. Distribution of murine rodents in the United States.

widely distributed in fields. In winter, however, they either left the fields or became very localized around especially good food sources such as shocked corn. By spring those that remained in the field appeared to have been annihilated; but, with the coming of warm weather, the fields were repopulated by rats and mice from farm buildings, dumps, and other spots with year-round infestations.

There are areas within the range of the Norway rat where only a few individuals, or none, occur. This is especially true in the mountainous and arid regions of the West (*93*). The survey by Harmston and Wright (*46*) indicated that Norway rats are found in or near most of the larger centers of population in five Rocky Mountain states. These rodents have followed highways and streams and become firmly entrenched at garbage dumps, at food processing plants, and at farms where adequate food, water, and harborage are available. However, infestations are often separated by many miles because the lack of human habitations and the arid countryside make it difficult for the rats to spread.

In certain situations, however, Norway rats can survive quite independently of man. These situations are usually closely associated with wet areas and shorelines. For example, Norway rats live quite apart from man in coastal marshes in Maryland, the Carolinas, and along Lake Erie. They depend on those foods that are washed up on the shores or that can be secured from the marsh plants and animals. A similar situation exists on Adak Island in the Aleutians. Introduced Norway rats not only feed on debris along the shores but are seriously endangering native bird populations by destroying eggs (*75*). There is ample evidence of the great reduction or even extinction of many island bird species by introduced rats. In the interest of conservation alone, great care should be taken to prevent such introductions.

- **Roof Rat:** Information on the local distribution of roof rats within their geographic range is less satisfactory. They seem to be less dependent on man than does the Norway rat except in the most adverse portions of their geographic range. In tropical regions, roof rats commonly live in the forests away from human habitation. They have been trapped in the Everglades National Park at a distance of 7 miles from any occupied structure (*102*). In the Pacific Northwest they are found living in wooded areas (*7, 20*).

The majority of rural rats in many parts of southeastern United States are roof rats. Worth (*102*) reports that the fruit rat color phase (*R. r. frugivorus*) in Florida is especially inclined to lead an outdoor existence, being a serious pest in the citrus groves. In California roof rats are widespread in both urban and rural areas. They are often found in citrus groves and sewers (*8, 69*).

- **House Mouse:** The house mouse has the widest distribution of the three murine rodents. Also, it appears to be the least dependent on man over most of this range. It has been taken in Nova Scotia from runways of meadow mice in midwinter (*77*). Linduska (*61*) reports that in Michigan some house mice leave the fields in late fall but others remain away from habitations all winter. In some areas in the southeastern United States house mice are more abundant than any other species in cultivated and recently abandoned fields. They have been captured in open tundra in Alaska miles from any human settlement. In and around buildings, of course, house mice occupy a great variety of places. There is even a report of house mice living 1,800 feet underground in a coal mine (*32*). Apparently they fed on scraps from the miners' lunches and on the feed for the mine ponies.

life history and behavior

Information on the life history and behavior of the three murine rodents suggests a great similarity in their birth, development, and general activity. Facts on any one species are sporadic and incomplete. Because of this, these phases of their biology are treated as a unit rather than by species. In this way a more coherent idea of the rodent's life may be gained (*8, 29, 50*).

BIRTH AND DEVELOPMENT

The life of the average rat or mouse is fairly short, and the young mature rapidly. The young of the Norway rat and the roof rat are born on an average of only 22 days after mating. The house mouse requires even less time, producing young on the average of 19 days after mating. In addition, female rats and mice can mate within 48 hours after they have borne young. It is possible, then, for females to be producing young almost continuously. Fortunately for control efforts, several things act to slow this reproduction. Mating is not always successful, or is not even attempted immediately after young are born. Then, too, if a female is nursing young and is also pregnant, birth of the new litter may be delayed by as much as a week. The length of this delay depends on the number of nursing young and the size of the unborn litter.

Young rats and mice enter this world none too gently, and birth is precarious at best. Large litters are the rule, and in the confusion at birth some of the newborn may be killed and eaten. Birth is usually preceded by a flurry of nest building. Although the female remains quiet, she is very nervous and may be disturbed by intrusions. It has been observed in nesting studies that among house mice disturbances to the nest by other individuals may cause litter destruction either by the mother or by other mice (*9, 82, 83, 84*). Often when a rat or mouse nest containing young is disturbed, the mother will move the young to another place. Many litters thus moved probably do not survive. Communal nesting or the use of a single nest by two or more female mice with litters is a frequent and apparently normal occurrence in nature (*19, 64, 82, 90*). Southwick (*82*) found, however, that in communal nests containing litters of different ages that the litter born first showed the highest survival. In any event, although large numbers of young rats and mice may be born, many of them die or are killed before they are weaned (Figure 7).

Those young rats and mice which survive the accidents at birth grow very rapidly although they are virtually helpless. They have almost no control over their own body heat or temperature (*2*) and may become very cold when left untended for a period of time in cold weather. Infant Norway rats can survive a body temperature as low as 34° F. An adult rat is killed under most circumstances when body temperature reaches 59° F. The growing rat slowly acquires the ability to control its own body temperature until at about 73 days of age it can maintain a high temperature even under cold conditions (*2*).

FIGURE 7. Norway rat with litter of young. (Photograph courtesy of Joe E. Brooks.)

Newborn rats and mice are helpless in many ways. Their eyes and ears are not open, they are hairless, and their legs are small and poorly developed. They move about by a combination of wriggling and paddling. In the Norway rat the ears open in about 3 days, but no signs of hearing can be detected until 12 days of age. In contrast, young mice may be sensitive to sound at only 4 days of age although they too respond very little until 11 days of age (*97*). During this early period mice and rats respond largely to heat and touch, although they probably have some ability to smell. In all three species fine hair appears on the body in about a week. They open their eyes at about 12 to 14 days of age. At this time the already active youngsters enter a period of intense investigative behavior. They begin to take excursions out of the nest, often as a result of following the mother when she leaves. For about three weeks the young depend on the mother for food but begin to take solid food in the middle of the third week. At the end of this period they can live away from the mother if forced to. Mice can actually survive on solid food as soon as the eyes are open although they normally do not begin to take such food until a few days later (*36*). In the wild, the mother rat or mouse may feed her litters until they are 4 to 5 weeks old. By this time their activity is essentially adult except for sexual behavior and fighting. These latter activities appear later and at the same time, in rats at 2 to 3 months of age, and in mice when they are about 2 months old (*4*).

GENERAL ACTIVITY

Young rats and mice gradually become familiar with their surroundings, undergoing a "training" period in company with their mother. Their first trips away from the nest are often by accident. Nursing young, clinging to their mother's nipples, are sometimes dragged from the nest as she leaves. Later they may follow her for a short distance when she leaves the nest. This habit of following increases until finally they regularly accompany her as she goes about her normal activities. During this period they learn their home area by associating with and imitating their mother. However, there is no evidence that she consciously tries to teach them. They learn by imitation and experience, part of the latter being gained when they accompany each other on forays. By the time the youngsters are 3 months old they are very active and are completely independent. This level of activity remains high until they are about 9 months old, when old age overtakes them and they slow down.

There appear to be certain daily patterns of activity among the rats and mice (*13*). Studies on the laboratory rat suggest that there are two such major patterns, one superimposed on the other. When food is abundant, the rat shows the greatest activity during the first half of the night. A number of studies reported by Calhoun showed that the rat becomes most active at or shortly after dusk and that this activity continues until about the middle of the night. The house mouse shows a similar pattern of nocturnal activity, and in addition shows a second lesser activity peak starting well after midnight and lasting until dawn. This latter may also be the case with many rats. Superimposed on this nocturnal activity are short periods of restlessness and activity occurring every few hours throughout the day and night, these shorter activity periods are related to periodic stomach contractions in the rat.

The major pattern of nocturnal activity breaks down, however, when the individual is hungry. In one experiment mentioned by Calhoun, the amount of available food was cut below the daily needs of caged rats and mice. They quickly shifted their peak of activity to the period when the food was added to the cage. Even when it was added during daylight, they were most active at feeding time. These habits of laboratory rats appear to hold true in the field. For example, workers in the Bureau of Animal Population in England studied Norway rats in simulated natural surroundings. They found a period of high activity just after dark when the rats came out for food. In another study they did not put out enough feed to go around. In as few as 5 nights they could get all the rat feeding to occur in the first hours after dark (*91*). There is some conflicting evidence from the field on house mouse activity. On a Maryland farm more house mice were trapped during daylight hours than at night. It is possible that this daytime activity was related to the absence of cats and other enemies on the farm. Then, too, much of this daytime activity was in the relatively dim interior of barns (*9*).

Knowing where the rats and mice are likely to go is important in such control procedures as rat-proofing. They like to use regular paths or runways, especially along walls or objects that present a vertical plane. When a rat or mouse wants a piece of food, it will run under and behind things until it gets as close to the food as it can. Then, if the food is in the open, a short dash is the only exposure to danger. The farther away from runways that traps or baits are placed, the less is the likelihood that they will be visited.

REACTION TO STRANGE OBJECTS

Rats and mice very often carefully avoid strange objects, even strange food. This habit contributes greatly to their ability to survive even in the most dangerous environments. Strange objects may be dangerous or even deadly. It is to the rodent's advantage to investigate them very cautiously. Interestingly, his "strange-object" reaction has led to many stories about the "wily" and "highly intelligent" rat. The answer to a great number of these stories is that the rat recognized the trap only as a strange object to be avoided, not specifically as a trap. Probably one of the reasons that the last few rats or mice in a building are so difficult to kill is that these survivors have the strongest reaction to strange objects. Hence they avoid all new attempts to kill them.

Several studies have been made which show the effect of strange objects in the rodent's environment. During experiments with wild Norway and roof rats, changing the shape of the feeding tray was enough to cause feeding to drop almost to nothing (*4*). This reaction would sometimes persist for several nights. Lights left on at night in a normally dark room, or unfamiliar noises, also caused a decided drop in feeding. Even changing the location of a familiar object caused avoidance and a lowering of general activity (*4*). On the other hand, complete removal of a familiar object commonly had no effect, even to the extent that rats ran around the place where the object had been rather than taking the shorter route opened to them by removal of the object. These studies also point out that rats may avoid new food for several days. This is an important fact in poisoning operations. When the rat or mouse first begins to take a new food, it may only take "token" amounts. If these amounts contain a sublethal dose of poison, they may make the animal sick and thus strengthen the avoidance reaction. This is the biologic basis for the use of unpoisoned bait, or **prebaiting**, before the poison is added. The feeding studies also indicate that hunger causes the avoidance of strange objects to break down more quickly.

In environments where "strange objects" appear regularly, however, rats and mice may show little or no evidence of the avoidance reaction. This is particularly true in such places as in warehouses where a constant turnover in harborage and food is occurring. Rats feeding on garbage are accustomed to new foods and may accept anything edible.

CLIMBING

One should not underestimate the climbing ability of rats and mice. Roof rats and house mice are notoriously good climbers, and even the Norway rat can climb very well if it has to. There are records of Norway rats having crossed wide city streets by walking telephone wires. This use of wires is common among roof rats and house mice (Figure 8).

Rats and mice can climb the vertical walls of most brick buildings. This is understandable for the smaller house mouse, but even the larger rats climb well. They can climb any vertical surface on which they can get a claw hold. By means of a fingernail test of the surface of the average brick building, it can be seen how easily a rodent could hang on. Stucco is often rough enough to permit ready climbing. Vine-covered walls are perfect runways, and since the vines afford concealment thev can be used by day or night. Smooth surfaces can be

FIGURE 8. Roof rat running along cable.

climbed if there is a pipe, a corner, or something else against which the rat or mouse can brace its back. Rats have been found using both the outside and inside of rusty 3-inch pipes placed against walls. Nailheads or screwheads placed too close together can serve as steps for rodents to climb. Rats have crossed sheet metal flashing by catching the top edge with the claws of their forefeet and swinging across overhand. When improperly installed, sheet metal guards have failed to stop rats. Even the rat guards used on ship mooring lines are seldom installed properly and therefore do not prevent crossings.

In rodent control work, however, it is necessary to draw a line between the possible and the probable in rodent climbing. For example, it is possible for rats to climb most types of vertical walls, but the chance of rats climbing these walls without supporting wires or pipes is quite remote. It is well to remember that rats and mice do not climb at every opportunity. They work only as hard as is necessary, and only when they are driven by hunger or lack of shelter, will they try the feats mentioned above. This greatly simplifies the necessary precautions against rat entry and reduces ratproofing costs.

JUMPING AND REACHING

Rats can reach as much as 13 inches along smooth vertical walls; therefore a safety factor must be added to rat guards to make certain that the rodents do not pass. The distance which should be completely clear of possible holding points is 18 inches. Rats can be expected to make a standing high jump of nearly 2 feet. With a running start and a bounce against the vertical surface two-thirds of the way up to give them a boost, rats can jump a little more than 3 feet. Under these conditions even the much smaller house mouse can jump more than 2 feet high. Jumping out and down from a height of 15 feet, a rat can cover a horizontal distance of 8 feet. It can do even better with a running start (*16*).

SWIMMING

All three domestic rodents are good swimmers. This is especially true of rats. They have been known to swim as far as half a mile in open water. Rats which were placed in a tank swam for hours. When they circled the tank and could not escape, they dove repeatedly and searched the bottom for an exit pipe. Norway rats can dive and swim under water as long as 30 seconds at a time. Rats that live in sewers have been known to follow lateral lines into buildings. They swim through floor drains without hesitation. They also swim the water seal in toilets and enter buildings by this route. In one building believed to be completely ratproofed, it was impossible to eradicate the rats. Although the basement, the roof, and the outside were inspected repeatedly, no means of entry could be found. Then a close observer noticed a rat trail entering a false floor. When the floor was ripped up, a roughed in toilet outlet was exposed. Rats had gnawed through the closed lead service pipe and had by-passed all the ratproofing by traveling through the sewer line (*8, 10*).

Norway rats are seimaquatic by habit. They are frequently found along the margin of streams, in marshy places, in sewers, and in rice fields. In many cities, infestations of rats are often associated with sewers or burrow systems along waterways. Usually sewer rats are Norway rats, but, in some areas where Norway rats are absent, roof rats thrive in sewers (*3, 5, 8, 69*).

In many large cities, rats use the older sewer systems as regular highways. Anyone responsible for ratproofing inspection should be familiar with the layout of the major sewer lines in the area to be ratproofed. Information is especially important on small trunk lines which were abandoned but not removed when larger mains were laid. This is very important in cities where the first sewers were made of wood.

The following report by Cottam (*17*) well illustrates the rat's familiarity with water.

"An example of the Norway rat's adaptability was recently brought to my attention at the U.S. Fish Hatchery Station in Leetown, West Virginia. Despite the fact that several buildings and food storage bins are kept reasonably free of rats from 50 to 200 yards distant, a surprisingly large colony was found living in earthen banks adjacent to the fish ponds and stream courses where concentrations of fish are kept. The spawn, fingerlings, and adult fish — primarily of species or varieties of trout and bass — are fed horse meat daily as well as other prepared foods that are equally acceptable to the rat colony. Undoubtedly bits of food accidentally dropped on the bank in feeding operations accustom the rats to that type of diet. It is obvious that an inadequate food supply occurs on the land, and the rats have learned to obtain it from the water. In their competition for food, the young and small fish at all hatcheries concentrate in enormous numbers when food is thrown into the water. Consequently, food is available for a very short period only. The rats as well as the fish have learned this. Therefore, at this hatchery these normally nocturnal rats have synchronized their feeding time to correspond with the feeding of the fish. When food is thrown into the water, the rats have no hesitancy in competing for it. They swim well and rapidly. After the food in the water is consumed, they then seek tidbits inadvertently dropped on the bank.

"Apparently low temperature is no serious deterrent to the rat's aquatic activity. On the day of my visit, December 10, 1947, the temperature was considerably below freezing, and an unpleasant sleet and snow storm was in progress; even so, a dozen rats were observed in the water, and part of their runway extended through small areas of the stream. While omnivorous rats avidly consume all kinds of fish food, it was a surprise to find that they are not at all averse to preying on young fish. On a number of occasions the rats have been observed catching the fingerling fish and taking them into their ditchbank runways or burrows."

NESTING AND HARBORAGE

Rats and mice will nest wherever safety can be found close enough to food and water. Holes or burrows in the ground may be used for hiding and nesting outdoors. In buildings, rats and mice use double walls, the space between floors and ceilings, closed-in spaces around counters, or any place hidden from view that enemies cannot reach. The more rubbish that is piled around, the more objects that are stacked in corners or closets, the greater is the number of hiding and nesting places. Williams (*96*) found a rat nest with live young in it in a space hollowed in the ice around a brine pipe on a ship. Laurie (*58*) tells of thriving mouse colonies in English cold storage warehouses where the temperature was never higher than 17° F. The mice ate the meat stored in the cold rooms and used feathers from stored birds or fur from stored rabbits for nesting material. Sometimes they made deep holes in the meat and lined these meat nests with parts of the bags that were used to cover the meat. These mice were larger than mice from elsewhere in England and were very successful at raising their young.

Roof rats will sometimes build large closed nests in trees much as squirrels do. This is the case, for example, in Hawaii and Florida.

Generally rats and mice build their nests in hiding places that are relatively quiet. They gather whatever soft material is nearby, or tear up paper and cloth to line the nest. Rat nests generally are bowl-shaped and about 8 inches in diameter. Occasionally they are completely roofed over. In addition to cloth and paper, such materials as grasses, excelsior, small twigs, and other soft materials may be used. Mouse nests are similar to rat nests but are smaller, about 5 inches in diameter. Normally they are completely covered, and entrance is through a small hole in one side. Nest-building activity is greatest just before young are born and at the start of cold weather.

In addition to disclosing nesting sites, a careful search may reveal hidden resting and feeding places that are safe from enemies. Here rats and mice can eat or rest undisturbed in places usually found somewhere between the food supply and the nest or burrow entrance. To these spots the mice and rats carry or drag food to eat it, and they leave behind feces, food wrappings, and scraps. The ideal condition, of course, is harborage such that runways, too, can be concealed. Too often this condition is found around man's dwellings and business places.

BURROWING

The three murine rodents differ considerably in their tendency to burrow. This habit is most highly developed in the Norway rat. As an adaptation to burrowing, the ears of this species are small, and hairs in the ear openings keep dirt out. The roof rat is more adapted to a life of climbing, and burrows only in areas where Norway rats are absent. Its burrow system is seldom extensive. House mice burrow where other harborage is not available. In and around buildings mice seldom have trouble finding cover, but in open fields they burrow well and extensively. As previously mentioned, in the South, house mice living in burrows in the fields are among the most common mammals.

Calhoun (*13*) made a detailed study of over 50 burrows of Norway rats. He found that the greatest depth to which the Norway rat dug a burrow was about 15 inches (460 mm.). Each burrow system consisted of a series of tunnels about 2½ to 4 inches (64 to 110 mm.) wide to accommodate the passage of a single rat connecting a series of nests, food caches, and bolt holes. He reported that in some burrow systems there was a dominant male with a harem of several females apparently living in harmony and raising their young communally.

Pisano and Storer (*67*) dug into 34 Norway rat burrows in poultry yards in California and found that all but one were no more than 3 feet long. Most of these burrows were 1 foot or less in depth, and the deepest went down only 18 inches. This deepest burrow was part of an old ground squirrel burrow. Several of the burrows had blind side passages, and all had one or more "bolt holes." The bolt holes are used as escape exits in times of trouble. They may be left open but are often covered with loose vegetation or plugged at the exit with loose dirt. An alarmed rat can easily burst through the loose plug and escape. The short, shallow burrows are primarily for shelter and nesting. Sometimes much longer tunnels are made, especially where rats and mice are searching for food. There are reports of tunnels under sidewalks running the length of a city block. Rats also have been known to dig downward to a depth of 5 or 6 feet, usually through soft earth or fill around foundations (Figure 9).

Because of a peculiarity in rat-burrowing habits, rodent control workers have developed the L-shaped curtain wall to protect buildings from rat entry under

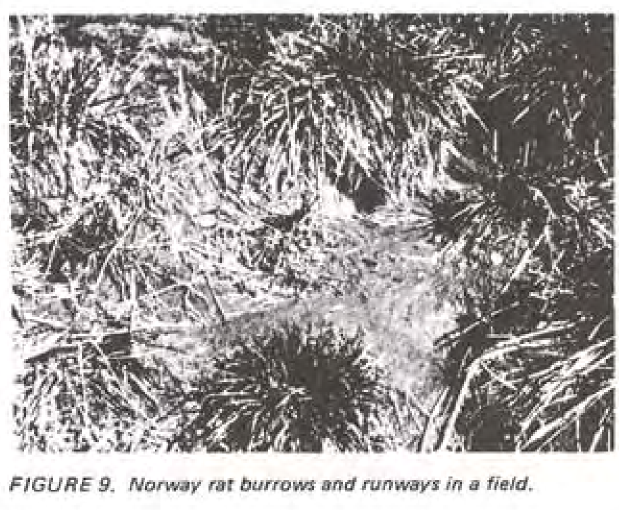

FIGURE 9. Norway rat burrows and runways in a field.

the foundation walls. When rats and mice attempt to burrow under a wall, they often begin a short distance away and burrow at an angle toward the wall (Figure 10). Usually they reach it before they are 18 inches deep, and upon reaching it they may follow it downward. Most important, once they reach the wall they will not dig away from it to go around an obstruction. Therefore the rat can be stopped by extending a wall downward 24 inches below the ground surface, with a horizontal lip projecting 12 inches out from the base. When the rats hit this block, they almost always stop digging. This curtain wall has a twofold value; it precludes the possibility of rat infestations that result in the spread of disease and the loss of foodstuffs; and it prevents the burrowing which results in undermining of walls and their possible subsequent collapse.

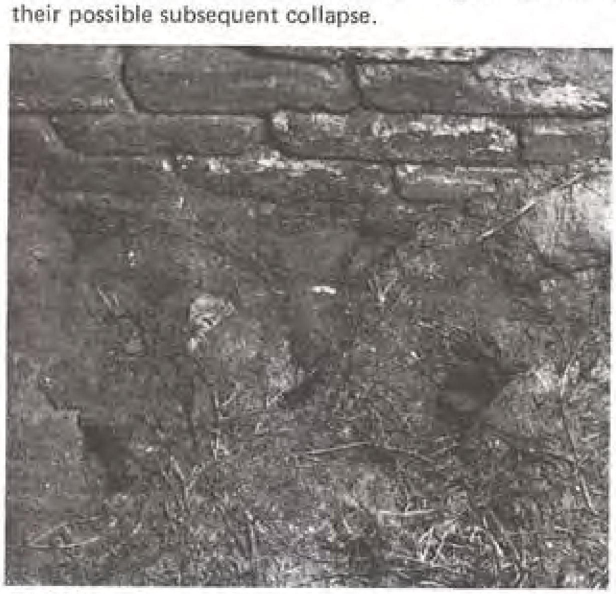

FIGURE 10. Norway rat burrows by a foundation wall.

GNAWING

Nature seldom has provided an animal with a more effective cutting tool than the rodent's front or incisor teeth. Young rats and mice begin to gnaw as early as the second week of life. Throughout their lives the teeth keep growing rapidly. In adult laboratory rats, the average growth for upper incisors is 4½ inches a year, and the lower incisors grow 5¾ inches. The growth rate in wild rats probably is similar. This fast growth allows continuous gnawing without wearing out the cutting edge of the teeth. It may, however, cause trouble. Sometimes rodents are found with a front tooth broken and the one in the opposing jaw very long. This bears out the idea that the grinding action of the opposing teeth helps keep the teeth short. It is believed that the hard enamel on the front of the rodent's incisors wears away the softer dentine on the back of the opposing tooth and thus helps keep the tooth sharp. It is difficult to see how gnawing, as such, could keep the teeth sharp, although this idea still persists. It would be like a chisel that grew sharper the more it was used (*1*).

Rats and mice will gnaw almost anything. Some of this gnawing may be only to keep the teeth short, for some of it seems to serve no other purpose. This would explain why many holes are gnawed much larger than necessary. It will also explain random cutting of furniture legs and counter posts. To get to food, rats and mice gnaw any material with a gnawing edge that is softer than the enamel of their teeth. This includes such things as wood, paper board, cloth sacks, lead pipes, cinder block, asbestos, and aluminum. They have pierced concrete used for ratproofing before it had time to harden and have even gnawed through sun-dried adobe brick. Roof rats are even better at gnawing than are Norway rats.

FOOD HABITS

• **Foods Eaten:** The Norway rat and the house mouse originally came from grain-producing regions in Asia where their diets probably consisted largely of this sort of food. Knowledge concerning the type of country in which the roof rat originated is more obscure.

The standard poison bait for rats and mice consists of yellow cornmeal and an anticoagulant rodenticide. In some cases, the addition of oatmeal, grain, oil, and sugar increases acceptance. Anticoagulant-water baits often are more attractive to rodents if they contain a small amount of sugar. Nevertheless, all three species have become adapted to a very wide range of foods. Schein and Orgain (*74*) found that Norway rats feeding on mixed garbage preferred such foods as meats, grain and grain products (such as oatmeal), cooked eggs, and potatoes. On the other hand, they showed very little desire for such foods as raw beets, peaches, onions, celery, cauliflower, and green peppers. There appeared to be an actual aversion to highly spiced foods.

The choice of food is determined largely by the environment where the rat or mouse is living. For example, citrus fruits are not preferred by rats and mice, but in Florida, the roof rat is considered a serious pest in citrus groves (*102*). Apparently there is very little other food to choose from in this area. Their method of feeding is so characteristic that by simply observing the eaten fruit one can determine the presence of the rats and their abundance. When opossums, raccoons, and chickens eat the fruit, they mutilate it and leave a ragged edge on the rind, whereas roof rats gnaw a symmetrical round hole into the fruit and eat the pulp and seeds. In one case rats were seen feeding on manure at a farm where other food sources were few.

Rats appear fond of eggs also and may employ ingenious methods to secure them. Langeveld (*57*) tells of Norway rats stealing eggs by gnawing a small hole in the shell, inserting their teeth, and carrying the egg away. If the hole was too big, the egg was eaten on the spot. There has never been any reliable confirmation of the old story of one rat lying on its back holding an egg in its feet while another towed the carrier by its tail.

On occasion, house mice feed extensively on insects. Calhoun (*12*) found that 45 percent of the food eaten by house mice living in open fields consisted of insects, principally beetles and caterpillars. Mice have also been found eating pea weevils. They cracked open the infested peas, ate the weevils found inside, and discarded the cracked pea (*60*). An extreme example of the carnivorous habits of mice occurred on a pigeon-raising farm.

The mice actually gnawed the backs of helpless live young birds, and although the birds did not die, their value for marketing was destroyed.

▪ **Foods and Growths:** Differences in the nutritive value of available foods produce obvious differences in the sizes of rats and mice. When Davis (*22*) compared farm rats and city rats, he found the city rats to be much bigger. The farm rats ate only corn, commercial horse feed, and fresh manure; the city rats, on the other hand, had a well balanced diet of garbage. When farm and city rats were given the same diet, they grew at the same rate, indicating that most of the difference in size was due to difference in diets. Rats in the corncrib were bigger than the other farm rats. House mice on the same farm were only one-half as large as mice trapped in laboratory animal rooms at a nearby university.

▪ **Amount Eaten:** Knowing how much food and water rats and mice need is valuable in control work. For example, it helps in determining the amount of poison to put into bait material. Since rats and mice need only limited amounts of food and water, enough poison must be used so that normal feeding will give them a lethal dose. The average adult rat eats about one ounce of dry food a day. Schein and Orgain (*74*) found that the average Norway rat ate about 1-1/3 ounces of mixed garbage a day, but since the garbage was moist, the rats probably had to eat more to get the equivalent of dry food. Rats drink 1/2 to 1 ounce of water a day when eating dry foods, less when eating moist foods. Mice, because of their small size, need less food than rats. They eat an average of only 1/10 ounce of dry food a day (*90*) and take an average of 1/20 ounce of water in each drink (*33*).

In studies on water consumption Chew and Hinegardner (*14*) found that mice normally consume 3/10 of an ounce of water per day. They could survive on as little as 3/100 of an ounce per day! This extremely small water requirement may be responsible for the persistent belief that house mice can live without water. This opinion appears to be false, for this same study showed that complete lack of water is lethal. It should be remembered that very small amounts of water are often present even in very dry areas. Both rats and mice have been observed licking the dew from grass in otherwise waterless areas.

In cold weather mammals normally eat more to maintain body heat. In the very gregarious mice, however, huddling to keep warm cuts down trips to food sources, and food consumption is decreased (*4, 89*).

▪ **Feeding Habits:** The feeding habits of rats and mice are sufficiently different to make some differences in their control. All three species have regular eating habits. These are determined by differences in the species, in the amount and kind of food, and in the dangers involved in securing it. Rats usually begin searching for food a little after sunset each day. However, mice are small and hard to see, and may come out during the day whenever possible. They all treat food much the same way, once it has been found. Usually they carry it to a hiding place before eating it. If the food is in small pieces, it is carried to cover a bit at a time; larger pieces are dragged to cover. If the pieces are small enough, occasionally they are eaten on the spot. Usually, however, rats and mice will eat in the open only if they are starved, if no enemies are around, or if the pieces are too big to move to cover (*4*).

Anyone who has ever watched both rats and mice actually feed will be struck by the differences between the two. Rats are fairly steady eaters. Mice are nibblers, taking a bit here and a bit there. Hence, in efforts to poison mice a great many baits should be put out quite close together to make sure that the mice nibble enough to kill them.

Some light may be shed on the old question of the type of bait to use for control work by Young's (*103*) work on laboratory rats. He found that rats become satiated on one food and will no longer work to obtain it, although they will work to some extent to get at other foods. Using a bait quite different from food already available to the rat or mouse may increase the probability of the bait being eaten. Perhaps the best way to solve this problem, however, is to make several different baits available. The one taken the most readily will most likely be best for poison baiting.

senses

How well the rodents know the world they live in depends on the keenness of their senses. Their reactions to control efforts are the direct result of their perception. Knowing what things rats and mice can detect is of obvious value to persons attempting to destroy them.

TOUCH

Touch is one of the first senses useful to rats and mice while in the nest. It is also important throughout life, especially since most often they operate in the dark. In addition to the normal ability to feel, such as man has in his hands and feet, the rodents have highly sensitive whiskers, or **vibrissae,** and guard hairs (Figure 1). At the base of each whisker is a complex nerve net to provide a high degree of sensitivity. The guard hairs are longer hairs scattered throughout the rodent's fur. Apparently they are more sensitive to touch than are the shorter fur hairs covering the body. Rats and mice seem to prefer running along walls or between things with which they can keep their **vibrissae** or guard hairs in contact. Since they repeatedly use these same routes, this habit leads to the formation of trails or runways. This tactile repetitive behavior is so well-known that control workers use it as a guide as to where to best set traps or baits so rodents will find them.

VISION

Vision is not as well developed in rats and mice as in humans. The eye of rats and mice is specialized for nocturnal vision. It has high light sensitivity but poor visual acuity. Therefore, the rodent can detect motion and recognize simple shapes in very dim light. The Norway rat can recognize motion at distances up to 30 feet and can distinguish between simple patterns and objects of different sizes (*8*). Mice can distinguish objects at least 45 feet away (*49*).

Rats and mice are apparently color-blind. If rats are tested with different colors, they respond to brightness but not to color. This can be helpful when using poisons for control. If there is danger that human beings might accidentally eat the bait, a bright warning color can be added. As in color-blind human beings, colors appear as different shades of gray to the rodents. Yellow and green are among the most attractive since the rodent probably sees them as light gray. Cornmeal bait, colored green to deter people from eating it, remains attractive to rodents. Unfortunately, birds soon learn to eat the colored bait if it is exposed over extended periods. Rats and mice are relatively insensitive to red light. A red-colored lamp can be used in a darkened room to observe their activities with minimum disturbance of their behavior (*8*).

SMELL

Rats and mice have a keen sense of smell. However, little detailed information is available on how this sense of smell governs their activities. Of course, rats and mice readily follow rodent body odor, especially that of the opposite sex. The smell of rodent urine helps to induce rodents to enter new wooden bait boxes. There is much confusion in the literature, however, on the value of attractant and repellant odors. Oil of bergamot, for instance, is listed as having both of these qualities. It is a good rule, though, that any odor used to attract rodents has to be strong enough to carry some distance. It must also overcome competition from other odors in the area. *There is little need to worry much about the odor of man on traps or baits.* After all, rats and mice live so close to man that his odor is an everyday experience to them.

TASTE

Usually rodent taste patterns parallel those of man. If man will eat the material, in general the rodents also will do so (*53*) The sense of taste varies considerably among the three domestic rodents. Mice will eat grain baits containing strychnine, whereas rats seldom do. It is well known that red squill bait is so bitter that mice and roof rats rarely accept it. Norway rats eat red squill bait when it is first used in an area, but they soon associate sublethal doses with pain and refuse to eat later baits containing this rodenticide. Barnett (*4*), reporting English studies, pointed out that Norway rats very rarely refuse new bait materials after they have investigated them. However, if poison in a bait makes them sick, they soon become "bait shy" for this material, not because they recognize the poison but because the bait mix made them sick. Some field men believe that rodents eat decayed food only if they have no other food, and not because they are unable to taste it. For this reason, experienced workers insist on fresh bait and often add a preservative to baits that are likely to decay.

Brooks (*8*) believed that the sense of taste in rats is highly developed. He reported that laboratory and wild Norway rats can discriminate between plain bait and the same bait containing as little as 2 parts per million of an estrogen. In other experiments he reported that wild rats could detect contaminants of warfarin anticoagulant rodenticide at 250 parts per billion. "This unusual ability to detect extremely minute quantities of bitter, toxic, or unpleasant substances is what leads to bait refusal, sublethal dosing, and bait shyness." (*8*)

Hulbert and Krumbiegel (*51*) experimented with the addition of half an ounce to an ounce of food-flavoring concentrates per 100 pounds of standard warfarin-yellow cornmeal bait. Four of the five flavors showed a significant improvement in the overall acceptance of the warfarin-cornmeal baits: butter-vanilla, roast beef, coconut, and maple. Commercial producers of rodenticides often add artificial flavors such as apple, fish, meat, or cheese to make their products more attractive.

HEARING

Rats and mice can recognize noises readily and can locate them to within a half foot. Since many rodent activities are carried out in darkness, this acute sense of hearing is of great importance to them. Loud noises cause them to try vigorously to escape. Rodents produce two types of sounds that have been tested for rodent control: biosonics which are mimics of, or recordings of, natural sounds; and ultrasonics which are high frequency sounds above and in the higher range of human hearing. Many attempts have been made to produce ultrasonic sound generators which would drive rodents from buildings and produce audiogenic seizure which cause death. Brooks (*8*) has summarized much of the research (*42, 62, 66, 86*) in this field as follows: "Ultrasound will not drive rodents from building or areas; will not keep them from their usual food supplies, and cannot be generated intensely enough to kill rodents in their colonies. Ultrasound has several disadvantages: it is expensive, it is directional and produces 'sound shadows' where rodents are not affected, and its intensity is rapidly diminished by air and thus of very limited range." However, at some locations ultrasonic devices have reduced, but not eliminated, the number of rodents present. Additional evaluation of these devices is desirable. Biosonics, mimics or recordings of rodent distress and alarm sounds, played back with good acoustics at low intensity may play an important role in future rat and mouse control programs.

BALANCE

Rats and mice have an excellent sense of balance. This can be shown easily by tossing one into the air. Almost invariably it will land on its feet. This sense develops very early, and newborn young can right themselves. It should be remembered that rats and mice sometimes can fall two or three stories without being injured. Rats have been known to enter buildings apparently by dropping through open skylights. Mice have fallen from the fourth floor of a building to the pavement below with no apparent injury (*16, 45*).

identification of rodent signs

Often it is necessary to inspect an area to determine the extent of rat or mouse infestation. Usually rodents leave characteristic signs of their activities behind them. Proper interpretation of these may yield much valuable information to one familiar with these signs. Often the species present, the degree and location of the infestation, and the habits of the animals may thus be determined. It is always desirable to observe as many signs as possible before making a decision as to the presence and degree of any rodent infestation (*34*).

LIVE OR DEAD RODENTS

The most positive proof of infestation, of course, is to see a live rat or mouse. However, because these rodents generally are nocturnal and secretive in their habits, live animals seldom are seen. As a rule, it is only in very heavy infestations that rats and mice show themselves when humans are present. They are especially secretive if there is much human activity in the area.

Dead animals may indicate either a current or a past infestation. If the carcass is dried or reduced to a skeleton, it may mean only a former infestation. If many recently dead animals are found, inquiries should be made concerning the use of poisons in the area. If poisons have not been used, there is the possibility that an epidemic disease such as plague is present among the rodents. If disease is suspected, the dead rodents should not be handled with bare hands. If possible they should be placed in cloth or paper bags to prevent the escape of fleas and other ectoparasites and should be held for examination by specialists to determine the cause of death.

SOUND

The various noises made by rats and mice may give clues as to their presence and location. These noises are rarely heard unless the area is otherwise quiet. Upon entering an infested building, if one stands still to allow the sound of his own entry to subside, rat and mouse activity may be resumed. The sounds of running, gnawing, and scratching may be heard, especially from double walls and floors. Various squeaks and churring noises are also produced. The squeaking may accompany fighting and may occur intermittently for several minutes. Also, youngsters in the nest make faint squeaking noises.

DROPPINGS

Presence of rat and mouse feces is one of the best indications of an infestation. All three animals commonly produce quantities of droppings, as does the American cockroach (*Periplaneta americana*) (Figure 11). These droppings may be a key to the species present and its relative abundance. Norway rat droppings are the largest, ranging up to ¾ of an inch long and ¼ inch in diameter (Figure 12). They vary in shape from having bluntly rounded ends to being spindle-shaped in appearance. Roof rat droppings generally are smaller and more regular in form. The ends are usually quite blunt. House

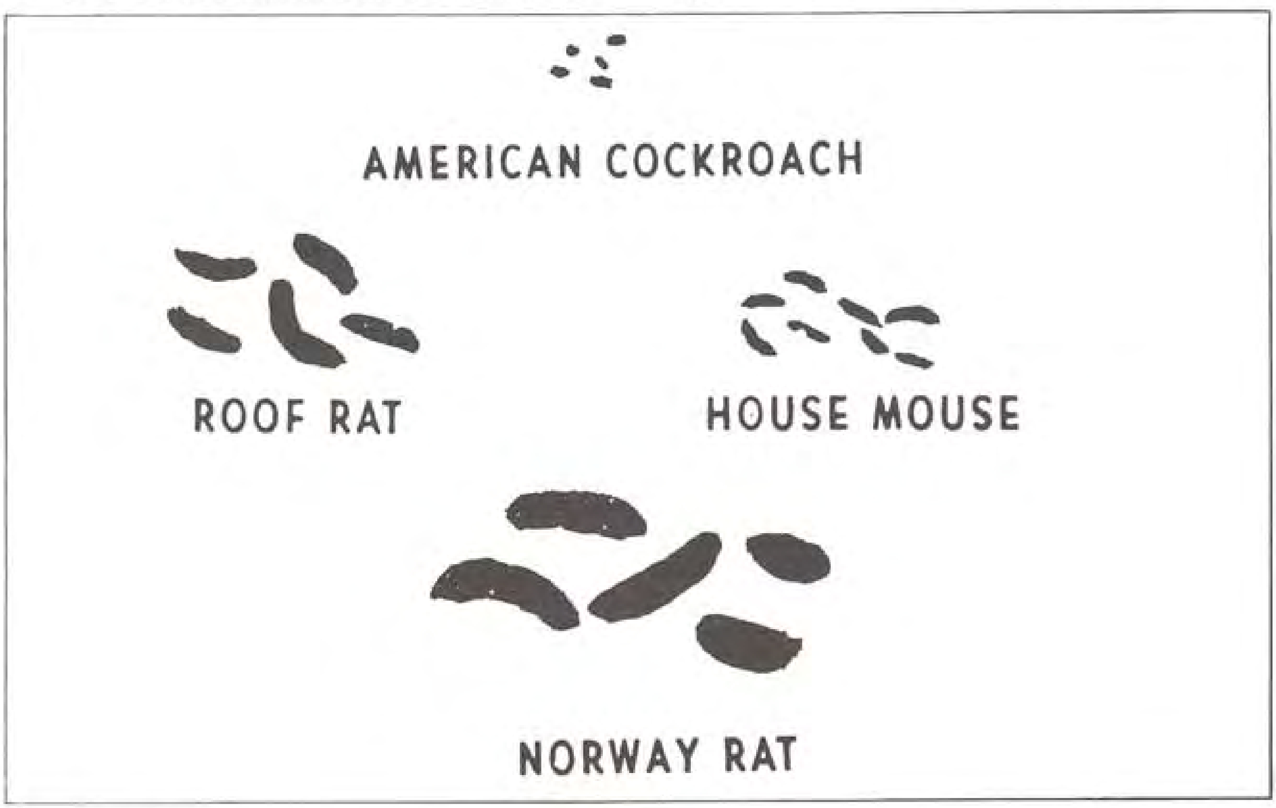

FIGURE 11. Relative size of droppings of murine rodents and the American cockroach (Periplaneta). *(Shown actual size.)*

mouse droppings are very small, averaging only about 1/8 of an inch long. They are pointed at both ends, and may be easily distinguished from those of *P. americana*. Cockroach droppings are much smaller than those of mice and have blunt, almost squared-off ends (Figure 11).

It is important to be able to determine the age of rat and mouse droppings. This information is necessary in deciding whether an area is currently infested. Fresh droppings are soft enough to be pressed out of shape and often have a glistening, moist appearance. The color varies according to the kind of food eaten, but usually it is black or nearly black. Within a few days, depending on climatic conditions, droppings become dry and hard. Later the surface becomes dull, and with great age they assume a grayish, dusty appearance and may crumble easily when pressed with a stick. The appearance of the surface alone, however, may be misleading. Droppings may be black and shiny and still be hard and crumbly. Old droppings dampened by rain or other moisture may appear fresh, but when crushed they do not have the putty-like consistency of fresh droppings.

The quantity and sizes of fresh droppings found in an area may give an indication of the number of animals present. Fresh droppings mean that at least one rat or mouse is present. Since only rarely are Norway and roof rats found occupying the same area, presence of several sizes of fresh droppings means that several ages of rats are present and that reproduction probably is occurring. This often is the case in extensive infestations. Droppings are most numerous along runways, near harborage, in secluded corners, and near food supplies. In contrast, the burrows and nests, especially, are usually very clean and have no droppings. Rats and mice have actually been observed carrying feces from nests and burrows.

The number of rodent droppings found in any area depends not only on the amount of rodent activity but also on how often floors are swept and how rapidly stored goods are moved. The absence of droppings may not always mean that no rodents are present, for droppings are present irregularly in infestations. Sometimes they are abundant, sometimes scarce. On the other hand, the presence of old droppings, even in quantity, does not mean that the area is currently infested.

RUNWAYS, TRACKS, AND RUB MARKS

Since rats and mice generally occupy only a limited area, they may use the same pathway many times. Out of doors or on earthen floors these runways may appear as clean-swept, well-packed earth paths 2 to 3 inches wide. In dusty areas, runways may consist of tracks made in dust by passing rats or mice (Figure 13). Occasionally, even the wavy line of a dragged tail may be seen. In many areas rats and mice leave dark smears or rub marks when rubbing against objects as the result of natural oils and dirt on their bodies.

Outdoors, runways are easily seen in dense vegetation such as lawn grass, and even on bare earth they may be conspicuous. However, the location of runways usually reflects the rodent's generally secretive habits. Most often they are found along walls, under boards, behind stored objects and accumulated litter, and in similar places. It is important to search such places carefully.

Rat and mouse runs in or on buildings are often marked by more or less extensive rub marks. These may be found around gnawed holes, along pipes and beams,

FIGURE 12. Norway rat droppings on basement restaurant counter.

on the edges of stairs, along walls, or anywhere else that the rodent is likely to travel. Swing marks made by rats passing under floor joists along a beam generally indicate the presence of roof rats (Figure 14). Norway rat runs are more often near the floor. House mouse runs, on the other hand, may be anywhere. They are the most difficult to locate because they are small and often very faint. It is especially important to search behind vertical pipes near walls for evidence of rub marks. Small vertical pipes and columns are a favorite means by which rats and mice change floors.

Tracks may be found anywhere along rat and mouse runs, both outdoors and inside. Tracks are more clearly seen by side illumination from a flashlight than by direct light from above. Especially good places to find tracks are in dust in little-used rooms and in mud around outdoor puddles. Rat tracks are fairly large (Figure 13). The hind foot of a walking Norway rat may leave a print 1½ inches long. Running, the prints are ¾ to 1 inch long. Roof rat prints are about the same size. Mouse footprints are conspicuously smaller, rarely being even ½ an inch long, and are much closer together. It is often said that the long, wavy marks left by a dragging tail indicate old rats or mice. This is difficult to demonstrate, however, and may be open to question.

The age of a rat or mouse run may often be determined. A fresh run over earth will generally be hard-packed and free of dirt and litter. Heavy use may even give it a shiny appearance. Dusty cobwebs across a run usually mean that it is no longer used. Fresh rub marks and smears are soft when scratched. Old marks are brittle and may flake off. Tracks found outdoors generally are fresh because wind and rain would quickly erase them. The age of tracks indoors is more difficult to estimate, and they may appear fresh long after having been made. If the dust is thin enough, one may determine their age by pressing a finger lightly into the dust near the track and observing the color. Fresh tracks should show about the same color as the finger mark, while old tracks will be different in color and have less sharply defined edges. Knowing the speed with which dust is laid down may be helpful. In a dusty flour mill where there is a heavy deposit every day, visible tracks are probably quite fresh. In the still air in the unexcavated area beneath a building, tracks persist for a long time. A very helpful procedure is the use of a fine dust for tracking. Any fine powder like pyrophyllite or flour may be dusted on a suspected runway and inspected later for footprints. The powder should be spread smoothly to a depth of no more than 1/8 inch.

By tracing rat and mouse runs, the harborage, the food and water supply, and the means of entry into buildings may be revealed. This information will greatly facilitate control measures.

GNAWING

Recent gnawings through wood can be distinguished by the fresh, light-colored appearance of the gnawed surface and the presence of small chewed pieces or cuttings in the vicinity. The edges of the gnawed area become darkened in a few days, and small cuttings are soon scattered or swept away (Figure 15). Another

FIGURE 13. Typical rat tracks in dust.

FIGURE 14. Roof rat "swing marks" under floor joints on an overhead beam indicate runway.

FIGURE 15. Rat gnawing in corner of wooden door.

method of determining the age of gnawed openings is by noticing the sharpness of the bitten edges. A freshly gnawed opening has sharp edges which scratch the animals as they pass through. They will stop and nibble at the offending edge, so that, as the openings become older, they acquire well-rounded edges. Evidence of recent gnawing is one of the most reliable signs for determining the presence of rats and mice.

The extent of damage to materials may be an indication of the degree of infestation. One must be careful to determine whether the gnawing was done by one or more species. A mixed infestation of rats and mice may be present, and damage done by mice may be ascribed to the rats. When recently delivered materials are damaged, it may be assumed that the infestation is a current one. In this case the extent of damage may be a very reliable index to the number of animals present.

BURROWS

Norway rats prefer to live in the ground. Their burrows are easy to recognize and relatively easy to find. They occur along the outside walls of buildings, around outbuildings, and in dirt basements. Away from buildings, burrows can be found in embankments, hedgerows, and under heavy growths of brush and bushes. When burrows are found in the absence of Norway rats, they may have been made by roof rats, although this is not a common habit of the latter. House mice living in and around buildings seldom burrow. However, those living in fields or near farm buildings very commonly burrow. Their holes are much smaller than those of rats, averaging about 1 inch in diameter. Rat holes, on the other hand, average around 3 inches in diameter (*13*).

Often the age of rat and mouse burrows may be determined by how well worn they appear. Holes in current use are free of dust and cobwebs and may have a slick, beaten-down appearance. Fresh earth pushed out of the entrance in a fan-shaped pattern also indicates recent use.

Burrow systems generally are shallow and often complex. Several holes may lead to the same system, some of them partially hidden by debris. It is necessary, therefore, that a careful search for all holes be made before such measures as burrow gassing are attempted.

NESTS

Rats and mice generally conceal their nests very well. They may be found in such places as piles or boxes of stored material, between double walls, under floors, and in hollow trees. (For a detailed description of nests see page 11.) The nests of both the house mouse and the Norway rat are almost always well hidden. The roof rat, on the other hand, may build large ball-shaped nests in trees and dense bushes.

It is very difficult to determine the age of an empty nest. If it feels warm to the touch, it may mean only that the hand which tests it is cold. Fleas found in a nest may have survived away from rodents for several weeks or even longer. Only if young are found, if a rodent is seen leaving the nest, or if other evidence is present, may one determine the age of the nest. These conditions, coupled with the rarity with which they are found, make nests a very unreliable rodent sign.

FEEDING STATIONS AND FOOD SCRAPS

The habit of dragging food to safety before it is eaten may contribute evidence of a rat or mouse infestation. Often an animal will have one or more favorite feeding stations. These may be located under stored materials or debris or behind materials leaning against walls. These stations may be recognized by the gnawed bones, food wrappers, seed hulls, and other debris that has accumulated around the spot. In addition, food particles too large to be pulled into burrows or feeding stations may be found at the entrance to these places. The rat or mouse drags the food to the hole and feeds on it by poking only its head out of the hole. The freshness of the food scraps may be a guide to how long ago the activity occurred.

MISCELLANEOUS SIGNS

Urine stains, hairs, or the characteristic odor of rats and mice may occasionally be encountered during infestation surveys.

At best, urine stains are uncertain signs. On some materials these stains show clearly in normal light; on other materials they are revealed by use of an ultraviolet light. Such a light is portable and may be added to the inspector's equipment. The difficulty in ultraviolet identification, however, lies in the fact that materials other than rodent urine fluoresce under the rays of this lamp. Accordingly, the fluorescent check, which in most cases can be made quite rapidly, must be supported by other evidence of rodent infestation even when fluorescence is found.

Rat and mouse hairs may be found lodged around entry holes to buildings, in their feces, and in contaminated foodstuffs. These hairs, when examined under the microscope, show definite characters which distinguish them from hair of other animals. However, special preparation and detailed analysis often are necessary for proper identification. Because of the time and study involved, it usually is better to rely on other rodent signs for information.

In heavy rat or mouse infestations a peculiar musty odor may be present. This is especially true in poorly ventilated places such as basements. Unfortunately it is not possible to give an adequate description of this odor; it must be encountered for its peculiarity to be appreciated. It rarely persists for long after the rodents have been exterminated.

rodent population characteristics

Man can start in the laboratory with a single pair of Norway rats and produce more than 1,500 rats by the end of the year! If this happened in nature, the world, instead of going to the proverbial dogs, would long ago have been overrun with rats. To be sure, occasionally there are reports of very high populations. An outbreak of house mice in a dry lake bed in California where grain was grown reached the staggering size of almost 70,000 per acre (*44*). Gunderson (*43*) reports the killing of an estimated 4,000 rats on three acres around a farmyard in one poisoning campaign. Clearly, however, these are exceptional cases. The average rat or mouse population very rarely approaches anything near these numbers.

The answer to why rodent populations generally stop growing before they reach tremendous sizes lies in the factors controlling this growth. Thanks to much recent work on animal populations, considerable information on population growth and its control is now available. This will be reviewed briefly in the following sections.

A population may be defined as a group of individuals occupying a particular place. Being a group, the population has certain characteristics of its own in addition to those of its individual members. As a result there is much to learn about populations which cannot be discovered by studying selected individuals alone. A population behaves like a separate unit or entity. It even shows such characteristics as birth, growth, maturity, and death much as does an individual. When referring to a population, the events happening to its individual members are commonly translated into rates. Hence a population exhibits a mortality rate, and an emigration rate. The value of a study of a population and its rates of change lies in the fact that the rodent population is the most important unit dealt with in any general control program.

Typical examples of distinct populations are rats concentrated around a feed mill or contained within a city block. Often the reason for the isolation of one population from another is some physical barrier. Around a feed mill the barrier may be the great distance to another food source. In the city block the surrounding streets are the barrier. To be sure, rats occasionally are seen crossing streets. Compared to their normal daily activ. however, these excursions are rare. This makes the city block a convenient unit in which to study rat populations.

POPULATION CHANGE

Each city block has a certain ability to support rodents. This ability or capacity is related to the food, harborage, living space, and other "necessities of life" needed by the rodent. Clearly this capacity to support rodents varies greatly from block to block. In any case, however, the final size of a rodent population cannot be greater than this capacity. When rats or mice are introduced into a block for the first time, their population immediately begins to seek the capacity of this new environment. The population grows slowly at first. As it becomes larger, however, it grows faster and faster. Finally, as it nears the capacity of the environment it slows down. When it stops growing and "levels off," it has reached an equilibrium with the environment. As long as the rodents' environment is not changed, there will be no change in the capacity of the environment to support rats; as long as the capacity of the environment does not change, the rodent population will remain at essentially the same level.

Under actual conditions, a population at equilibrium does show variations in size. Figure 16 shows a Norway rat population in a Baltimore city block that has reached equilibrium at a little over 100 rats. Notice that although the size shows many variations, it always comes back to the same level. These fluctuations above and below the average level are due to the timing of the forces affecting the population. A householder's poisoning efforts may cause a temporary drop in the level; several litters of young may cause a temporary rise in the level (*25*).

A rodent population can be likened to a cork floating in a tub of water. The cork can be held under water, but when it is released, it pops to the surface. It can also be held above the water, but when it is released, it falls back to the surface. Now look at an actual rat population. Figure 17 shows a Norway rat population that was poisoned repeatedly from 1943 to 1947. Just like the cork, each time the pressure of the killings was removed, up came the population. The rat population at equilibrium was approximately 125 rats. Poisoning procedures gave only temporary relief because the capacity of the environment remained unchanged (*25*).

What actually happens when the capacity of the environment is changed also can be seen in Figure 17. From 1943 to 1947 the capacity of the block to support rats was not changed. Each time the poisoning stopped, the population came back to about 125 rats. Now look at 1948 and 1949. By an intensive sanitation program in this block, the capacity of the environment was changed. The graph shows that the population level went down and stayed down. Therefore, to change the level of a rodent population, it is necessary to change the capacity of the environment to support rodents.

FACTORS AFFECTING POPULATION SIZE

Having examined population change, it is necessary to look into the various factors responsible for these changes. First, these factors must be recognized. Then, by changing their effect or by taking advantage of their peculiarities, rodent population control can be achieved.

- **Population Forces:** Davis (*25*) points out the three population forces that determine the size of a rodent population at any given time. These are: **reproduction, mortality,** and **movements.** Reproduction will tend to increase the population; mortality will tend to make it smaller; and movements, on the other hand, may work in either direction. Movements **away** will decrease the population, movements **toward** will increase the population. The relative balance of these population forces determines whether a population is growing, shrinking, or staying the same. When all of these forces exactly

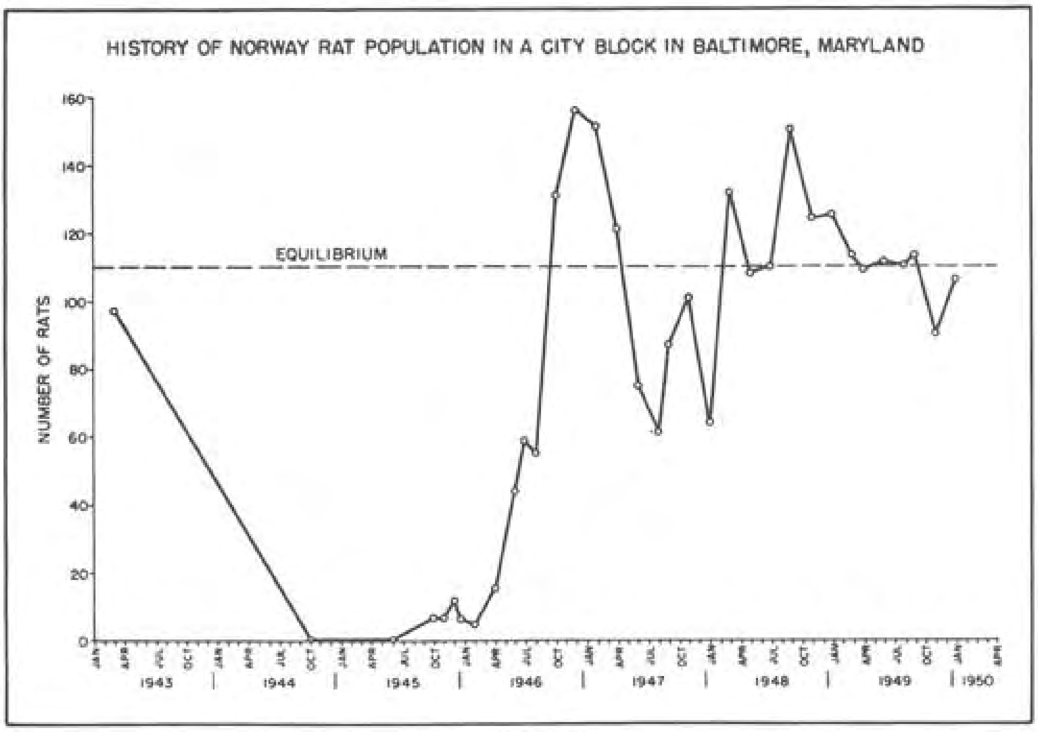

FIGURE 16

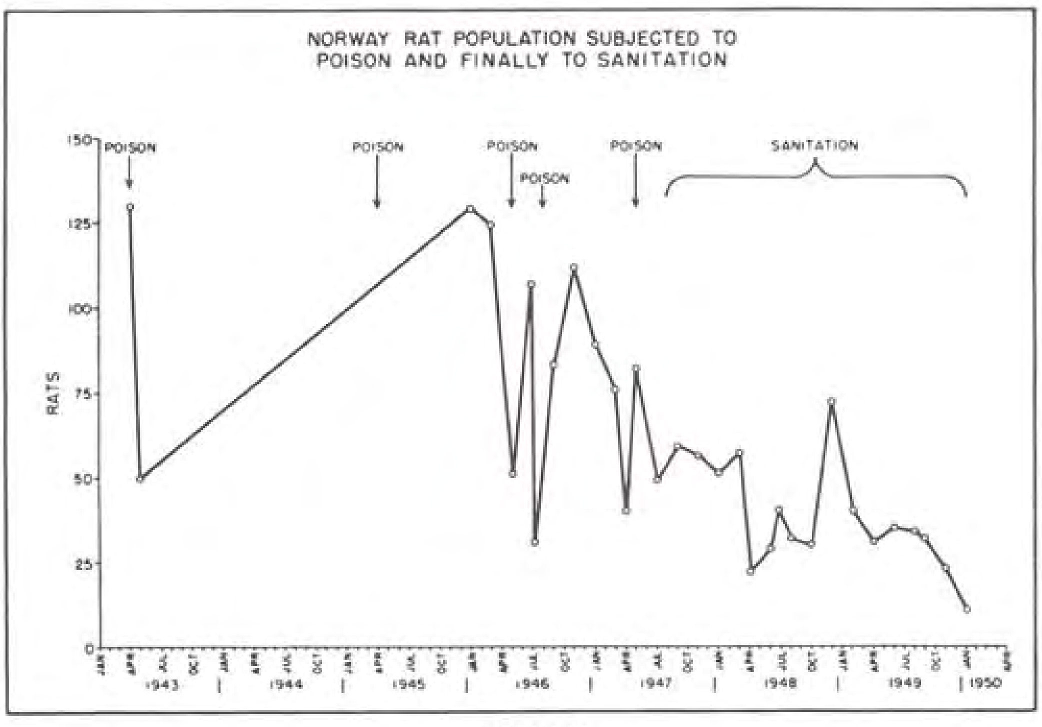

FIGURE 17

equal one another or "cancel out," the population is at equilibrium, and for all practical purposes has stopped growing.

1. Reproduction. Rats and mice breed all year round, but this breeding follows different patterns. Three main patterns are recognizable: a. Two breeding peaks (spring and fall); b. One breeding peak (usually in spring); c. No definite peak (same level of breeding all year).

In the areas where rodent breeding has been studied, the pattern of two peaks is commonest. In a review of the subject, Davis (*25*) reports two breeding peaks for both Norway and roof rats from many different locations. Brown (*9*) found a spring and fall increase of young in a rural house mouse population. It is possible that this reflected two breeding peaks although this was not clearly indicated. Smith (*78*) working in Mississippi also found definite spring and fall breeding peaks for house mice. In contrast to Brown's studies in a colder climate, Smith found some breeding during the winter. It is difficult to generalize about rat and mouse breeding seasons. For example, Davis reports Norway rat populations showing a single spring peak in 1943-45. In the same areas in 1947-49, there was an early summer peak and a fall peak. Perhaps the most useful information to be gained is that, in general, breeding is at a minimum during the coldest season and may also decrease during the hot season.

This knowledge of rodent breeding seasons may help plan the timing of control programs. For example, when rat populations in city blocks and markets in Baltimore, where a single spring breeding peak occurred, were reduced by killing in the spring, they returned to the original level in about 6 months. On the other hand, when the populations were reduced in the fall, they took 12 months to return to normal; just twice as long. Thus it appears that the best time to strike at a population is when breeding is at a minimum. In general, a rat-killing campaign would be most successful, in terms of how long the results last, if carried out in winter. The next best choice would be summer, and the next, fall. On the average, the winter choice gives the greatest chance of killing when breeding is low. The spring choice gives the least chance.

The importance of reproduction as a population force among rats and mice is suggested by the figures in Table 2.

The data on reproduction in Table 2 are based on studies of thousands of rats and mice from Asia, Europe, and North America (*8, 25*).

Rats and mice have the potential for very rapid population growth because of rapid sexual maturation, short gestation period, and large litter size. Norway rat populations in English grain ricks often increase at the rate of 35 to 45 percent per month (*59*). One wild house mouse population in an English wheat stack was found to increase from less than 50 to over 2000 in 6 months (*84*).

In most environments, however, conditions are not ideal, and many young rats and mice are lost between birth and weaning. This is very important, for an accurate and useful definition of rodent reproduction emphasizes that the animals that survive weaning and live on to reproduce are the really important individuals. To point out the effect of preweaning losses in one Norway rat population, 45 young were born to the average breeding female during a year, but only about 20 were believed to have been weaned (*25*). In this case each female rat was putting only 20 young into the population in a year. Figures for the roof rat and the house mouse are not available. However, they are believed to be similar. In all three species the number of entire litters killed or abandoned and the individual youngsters killed in surviving litters is quite high.

2. Mortality. In general, as rat and mouse populations increase in size, the mortality rate also goes up. It continues to increase until the population reaches equilibrium and ceases growing. During this period of equilibrium, the mortality which occurs, coupled with the number of animals leaving, balances those animals added by reproduction and movements. Reliable information on death rates among rodents is hard to obtain. There are some estimates available, however. In one study of survival on a farm, only about 5 percent of the rats lived for 1 year (*21*). In another case, for every Norway rat alive at the end of a year, over 16 rats were estimated to have died during the year (*25*). This figure included all rats from birth on. Looking only at the older juveniles and adults, between 2 and 3 of these rats died during the year for each rat alive at the end of the year. Davis estimates the average life of a wild Norway rat after weaning to be about 6 months.

As is true with so many animals, female rats and mice appear to live longer than the males (*9, 25*). This may be related to the greater aggressiveness and range of movements of the males. These subjects will be dealt with in more detail later.

3. Movements. It appears that under most conditions movements are less important in determining the size of rat populations than either reproduction or mortality. Just as most other animals, rats and mice usually spend their lives in a very limited area. Only when it is necessary will they move any distance.

The limited area in which animals live is called their **home range.** The size of this home range naturally depends on the condition of the area. An important factor in the extent of the home range is the nearness of food, water, and hiding places. A rat or mouse is safest when it remains in this home range because it is familiar with the escape routes and hiding places. When a rat escapes near the place it was caught, it usually disappears quickly. On the other hand, if it escapes on unfamiliar ground, it usually takes longer to find a hiding place.

The home range of rats and mice is no larger than is necessary to provide the necessities of life. In Baltimore, Norway rats seldom ranged more than 100 to 150 feet. In Hawaii, roof rats living in open areas tended to remain within a diameter of 200 feet (*85*). Brown (*9*) found that house mice living in and around a barn had much smaller home ranges. Of all the mice captured in live

Table 2. Data on Reproduction of Female Domestic Rodents

Species	Number of Young per Litter	Number of Litters	Number of Young Weaned per Year
Norway Rat	8 - 10	3 - 7	About 20 (18-56)
Roof Rat	4 - 8	3 - 9	About 20 (12-47)
House Mouse	4 - 7	3 - 11	About 30-35 (23-57)

Adapted from *8, 25.*

traps more than once, over 97 percent had moved less than 50 feet. Over 79 percent moved no more than 30 feet. In buildings in Wisconsin (*104*), 90 percent of the mice moved no more than 30 feet, and 70 percent moved no more than 10 feet. The importance of an understanding of how limited home ranges affect control measures can be seen from another study conducted in Wisconsin (*35*). The deadly poison 1080 was distributed at 30-foot intervals in a house mouse infestation. After an initial reduction, the population restabilized itself at a lower level although the poison was still available. The authors pointed out that mice in these colonies had a cruising radius of only about six feet and hence only a small fraction of the population was exposed.

This does not mean, however, that some individuals do not move greater distances. Some rats regularly move hundreds of feet between food and harborage when necessary, and King (*56*) records a house mouse moving 113 feet in its home range. By the same token, however, some move only a few feet. A rat living under an open garbage can near a leaky spigot has all it needs right there!

Under certain environmental conditions, population movements have great significance. In the extensive Wisconsin studies on house mice, populations were provided with an excess of food in one case and with limited daily food in another case (*89, 90*). In the population with excess food, very little strife was noted; and the rate of movements away from the colony was consistently low. In the other colony, however, a high rate of migration occurred when the population grew large enough to consume all available food each day. It is important to note that in the colonies from which mice migrated, reproductive rates were high; whereas in the colony confined to a limited area, reproduction dropped sharply when all available space was filled by mice.

Rats will migrate from flooded fields, and both rats and mice are known to leave houses in rural areas in the spring and return in the fall. Presumably they spend the summer in the fields. If a rodent is released in a strange area, this has the same effect as changing the animal's environment. The result is often extensive wandering. Creel (*18*), 1915, released in one place marked rats captured from many parts of New Orleans. It is not surprising that some were recaptured as far as 4 miles away. Unfortunately, this work has led many to believe that rats normally wander great distances.

▪ **Limiting Factors:** The rates of reproduction, mortality, and movement control the size of a population at any given time. The question remains, however, as to what controls the relative importance of each of these three factors. What decides whether the reproduction will be high or low; or if more rodents will die than are being born? The factors controlling this balance are the factors which really determine the **size** and **rate of change** in a population. These may be called the **limiting factors.**

The limiting factors may be divided into three major headings: **physical environment; predation;** and **competition.** The way in which these three factors are manipulated determines the degree of rodent control that man achieves and the duration of his results.

1. Physical Environment. The physical environment can be conveniently divided into three main parts: **food and water, harborage,** and **climate.**

a. Food and water. The size of a rodent population is limited by the food and water available. Information on these requirements as well as on eating habits already has been summarized in the section on "Food Habits," page 12. Most important to rat and mouse population sizes is the quantity and distribution of these essentials in any area.

The two chief sources of rodent food in urban areas are stored products and garbage. In rural areas a third important source is crops, such as grain in the fields and fruit in orchards. Other sources exist, such as sewage or flotsam washed up on shorelines, but these are of very minor importance.

The greatest quantities of stored products are found in warehouses and port facilities. Here, the type of container, the way in which the product is stored, and the length of time it is stored all affect the accessibility to rodents. Food stored in cloth or paper containers, placed on floors, and remaining in quantity for long periods may support tremendous rodent concentrations. This is often the case in rural areas where huge populations exist on farms and around grain elevators. Often spillage alone is sufficient to maintain large numbers of these animals. Food stored in local retail outlets and homes is of less importance because it is in smaller quantities. Generally it can support only a few rats. However, food stored in homes is of especial importance in maintaining generalized infestations of house mice.

Garbage must be considered as the chief source of food for rats and for some mice, especially in urban areas. Rodent populations in residential areas are almost always maintained on improperly stored garbage (Figure 18). Food handling establishments contribute great quantities of both garbage and edible food. A very important concentrated food supply is available on open garbage dumps. In rural areas, inadequate garbage storage and improper disposal on farms may contribute to a large rodent population.

FIGURE 18. Improper storage of refuse provides abundant food for rodents.

In addition to the quantity available, the distribution of rodent food in the local area affects population size. Studies on Norway rats were carried out by Orgain and Schein (*63*) in a Baltimore city block where **locations** of food were limited. Their results indicate that not all rats in the area had complete access to the food. Although a number of rats were trapped at the feeding areas, the consumption of food showed only a momentary decrease. They believe that when the "primary" rats were removed, "secondary" rats had freer access to the food. If the food had been more widely distributed, competition at the sources would not have been so intense. More rats could then occupy the same area.

Water is generally available in residential areas but may be a serious problem for rodents in warehouses. Often, although food is in tremendous excess, only a limited amount of water is available. Under these conditions, the size and location of the rat population may be limited by the water sources. House mice often live in homes, apartments, warehouses, or barns with an abundance of dry food but little or no free water. In such situations mice can remain isolated for generations in bags of stored grain or flour. Most foods contain some water. House mice have been shown capable of using this water in food as "metabolic water." (*39*).

b. Harborage. Harborage, especially in residential areas, is often no problem for rats and mice. This is most certainly true for the small house mouse. As mentioned in the section on Nesting and Harborage, page 11, rats and mice are able to utilize a great variety of structures and materials for harborage.

An important item in the prolonged maintenance of rodent populations is the existence of "potential" or alternate harborage. Orgain and Schein (*63*) report the results of a harborage "cleanup" in which board fences and trash piles were removed and some broken concrete was repaired. The rat population fell to about one-half its previous level. However, in 5 months the population had regained its original size. The rats remaining after the "cleanup" had become established in new nesting areas and among refuse which previously had not been occupied. The habits of the population, not the capacity of the block, had been altered.

c. Climate. In some respects the domestic rodents, because they are closely associated with human activity, are more independent of climate than other rats and mice. Their food supply is provided by man and so does not change markedly with the seasons. Even their harborage may be heated in indoor infestations. These factors have undoubtedly had much to do with their extensive geographic range. Nevertheless, climate apparently does play a part in their existence. The Norway rat appears to be primarily a temperate climate species, while the roof rat is most abundant in the tropics. Climatic effects may be indirect, such as tropical areas providing better habitats for roof rats (*8*).

More direct effects of climate may be seen in studies by Smith (*79*) and Schiller (*75*). Working in southern Georgia, Smith believed that a sharp decline in Norway rats in rural areas over a period of 9 years might have been the result of a severe 6-year drought in the area. This drought caused a serious drop in corn and peanut hay production, both important rodent foods. Working at the other extreme in Nome, Alaska, Schiller found that during the winter a very high percentage of rats living outdoors had frostbite, particularly of the ears, tail, and feet. In some cases this was fatal.

2. Predation and Parasitism. Predation is the preying of one species on another. This usually involves seizure of the prey for purposes of devouring it.

Many animals prey on rats and mice. The most conspicuous of these is man. Although the trap, poison, or gas actually does the killing, these are only the tools of man's predatory activities. Other predatory animals include cats, dogs, foxes, ferrets, hawks, owls, and snakes. Since parasites and disease organisms also adversely affect the rodents' welfare, they are included under predation.

Much of the information being collected about predation suggests that its intensity should depend on the density of the population. For example, the higher the rat population, the more rats that will be killed by cats. When the population density is low, it is much more difficult for cats to find and kill rats; and they generally turn to more abundant foods. This in turn allows the rat population to increase again.

Little is known about the effect of predation on mortality in rodent populations. Existing evidence indicates little more than a temporary effect in most cases. The fact that man has been killing rats and mice for centuries and is still plagued by them is ample evidence of this. Jackson (*52*) found that in residential areas the presence or absence of cats had no measurable effect on the number of Norway rats. The cats ate about 25 to 30 rats a year. On the basis of data available on rat reproduction, Jackson concluded that cats ate only about 20 percent of the rats that must die anyway to maintain a stationary population.

In contrast to this, Davis (*26*) found that cats living on a farm ate enough rats to prevent the expected upsurge in the rat population in the spring. It was apparent that the farm cats were eating rats even when cat food was present. The presence of normally predatory animals may serve also to increase the rat or mouse populations. One of the common sources of food for rodents in residential areas is food left out for dogs. In the Baltimore studies, the largest rat caught (over 1½ lb.) was trapped under a doghouse. Often dog and cat owners proudly assert that their pets keep the rodents killed off. It appears rather that these pets keep the rodents out of sight, in places where the dogs and cats cannot reach them. The only substantial effect on a rat population by pets seems to be to limit its spread to new areas. This, of course, is related to the dangers inherent in occupying a strange area because of unfamiliarity with hiding places and enemies. In this sort of situation, a dog or cat may keep an area free **after** the rodent population has been eradicated by other means.

The predatory activities of hawks and owls vary with the species of bird, the abundance of rodents and other prey, and the individual bird's habits. Because of the difference in size between rats and mice, only the larger species of hawks and owls are serious enemies to rats. On the other hand, mice are taken by almost all species. Even among the larger birds, mice are more frequently taken. The great horned owl (*Bubo*) in north central United States may occasionally take many Norway rats (*38*). These workers found that in this area the rats overwintering in the fields suffered heavy losses. Although a few owl families fed heavily on rats, in general, rat eating was light. Near Philadelphia, barn owls (*Tyto*) and short-eared owls (*Asio*) ate a small but regular number of house mice (*65*).

Norway rats were common in the area but were not taken often. In almost all of the above owl studies, a very much higher percentage of native rodents than of murine rodents was taken by the owls.

The role of pathogens in limiting rodent populations has been studied to some extent. Some disease organisms, such as the bacterium *Yersinia pestis* which causes plague, are highly fatal to rats. Others such as *Rickettsia typhi*, the agent of murine typhus fever, produce few symptoms and are rarely fatal. The spirochete *Leptospira icterohaemorrhagiae* which causes Weil's disease in man has been found in almost 50 percent of the Norway rats examined in Baltimore (*24*). Apparently it had no effect on the population of Norway rats and was equally prevalent in increasing, stationary, and decreasing populations. In the same study, *Salmonella* bacteria were found in 4 percent of the rats; and the roundworm *Capillaria* was found in 94 percent of them. Neither of the latter two appeared to affect the populations. However, *Salmonella* may cause sharp epidemics among rodent populations (*25*). The effect appears to be temporary. The many attempts to use *Salmonella* to control rats and mice have had little long-range value. In Alaska Schiller (*75*) found that several Norway rats taken in the winter had severe pulmonary infections and concluded that this disease contributed significantly to winter mortality. The causative organism was not identified.

3. Competition. Competition may be between two or more species, or it may be among members of the same species. Among the rodents it takes various forms and is one of the most important factors limiting their populations. The competition is generally for food and water, nesting sites, harborage, and other aspects of living space. Male rats and mice also compete for females in heat and ready for mating. The intensity of competition depends on the density of the population as is the case with predation.

Among the rats and mice, competition between the species is most intense between Norway rats and roof rats (Figure 19). This, as has been shown, has led to the replacement of the roof rat by the Norway rat over large areas. Competition between rats and mice is harder to define. Venables and Leslie (*94*) found a partial separation between Norway rats and house mice in grain stacks. The house mice occupied the lower parts of the stacks and the rats were found above. High populations of both species were found in the same stacks. Brown (*9*) found little evidence of competition between the same two species on a farm. The mice were so small and agile that they could easily avoid rats. In addition, their size made it possible for them to enter food bins closed to the rats. Competition between house mice and deer mice (*Peromyscus maniculatus*) was tested by King (*55*). He found that the house mouse was far more aggressive and was capable of driving the deer mice out of natural situations where these two species encountered each other. On the other hand, Caldwell (*11*) found that wild house mice were at a disadvantage in competition with oldfield mice (*Peromyscus polionotus*), both for food when population densities were high, and when the two species were confined together in an enclosure. Probably dominance and survival among domestic and wild rodents is determined by many factors as well as by species differences.

Competition among members of the same species is very closely associated with the social organization of a population. A definite social order exists among rats and mice (*4, 13, 84*). This social order is determined largely by fighting, and the most aggressive animals are dominant (Figure 19). The weight and age of an animal have some effect, but aggressiveness and experience are most important. As a result the members of a population have different social rank, this being separate for males and females. The social order among the males is the most conspicuously and most rigidly maintained. The social rank of an animal is very important because it affects its reproduction, longevity, and movements.

Calhoun (*13*) studied the effect of social order in Norway rats. He found that in general the farther away a rat lived from the food supply, the lower its social rank. Dominant rats living close to the food grew more rapidly and attained a higher social rank. Those animals living at a distance had to pass near the burrows of the more dominant animals to get food and often were attacked as

FIGURE 19. Fight between Norway rat and roof rat (on left).

they passed. This was especially true of juveniles, and their behavior became very cautious and retiring. This lower social status was passed on to later generations. Smaller adults were forced away from the food, and their young, born in these peripheral areas, grew slowly. Females in fringe areas showed less tendency toward self-isolation, burrow construction, and nest-building necessary to successful rearing of young. This made them even more vulnerable to the onslaughts of more dominant animals. Calhoun also found that although all female rats mated about the same number of times, those more distant from food raised much fewer litters. Of 12 litters born near the food supply, 10 were weaned. In the same number born at a distance, only 1 litter was weaned.

In the same studies it was found that high ranking rats had fewer wounds from fighting than did low ranking ones. Although these wounds did not often cause death, they permitted infection and weakness. In this way the lowest ranking animals are in most danger from predators such as cats, dogs, and man. Among house mice, Brown (*9*) found that fighting became very intense if space was limited. Low ranking male mice were often killed in a prolonged series of fights.

Barnett (*4*) reported that the cause of death in intraspecific fighting among Norway rats was exhaustion rather than wounding. For that reason death could occur without detectable external damage. Most of the injuries that he found were superficial and on the ears, tail, and neck.

Competition affects movements in a population by forcing animals to disperse from an area. The aggressive activities of dominant animals may drive lower ranking animals into peripheral or alien areas. The reaction of resident rats and mice to alien animals is another result of competition. A rat or mouse on strange ground is fair game for the attacks of any of the rodents already living there. This disadvantage, as might be imagined, makes the death rate much higher for alien animals. Davis (*23*) reports that the Norway rat population in several city blocks went down when alien rats were introduced. He believes this is the result of social turmoil set up by the newcomers. In this type of situation, the strife tends to lower reproduction, and the population decreases. This suggests that even when large-scale movements are forced, many of the possible consequences are nullified by the rodents' social relations.

Competition for space in a limited area may contribute heavily to infant mortality and even reduce fecundity among mice (*9, 83, 84*). Fighting and overcrowding result in excessive cannibalism and desertion of young. Southwick found that highly dominant mice may prevent subordinates from feeding freely. In these populations fewer males and females were in breeding condition.

A recent and very intriguing discovery is that the pituitary-adrenocortical system is affected by the increased stress in high rodent populations. It has been suggested that the progressive enlargement of the adrenal cortex in the rat and the concurrent reduction in reproduction may be very important factors in the limiting of populations through intraspecific competition (*15*). Considerable research is currently being conducted to clarify this relationship.

PRINCIPLES OF POPULATION CONTROL: A SUMMARY

The most important fact in rodent population control is that each environment can support only a certain number of animals. When the growing population of rats or mice reaches this capacity of the environment to support them, then the population ceases to grow. As long as no radical changes are made in the environment, the upper population level remains roughly the same. Records exist of rat populations remaining at the same level for several years. On the other hand, if the capacity of the environment is changed, there will be a corresponding change in the rodent population. A permanent change in the capacity of the environment produces a permanent change in the number of rats or mice.

Rodent population size is the result of the forces of reproduction, mortality, and movements. The reproductive rates of rats and mice are generally high. However, similarly high death rates cause a rapid population turnover, and the life expectancy of an individual animal is quite short. Rats and mice have a limited home range. Hence, under normal circumstances, movements are of little importance as a population force. However, when the environment is altered and the necessities of life are reduced, large-scale movements may occur. The rats or mice engaged in these movements have a high death rate due to exposure to enemies in unfamiliar surroundings.

The balance of the forces of reproduction, mortality, and movements is determined by three so-called limiting factors. These three factors are the physical environment, predation, and competition. They control the rate of each of the primary forces and, ultimately, the upper level of population growth. The physical environment consists of the available food, water, and harborage, and the climate. Predation is largely by man, cats, dogs, and birds of prey but diseases are caused by many parasites. Unlike the effect of the physical environment, the intensity of predation varies with population size. As the population grows, predation increases. When the population is low, little predatory activity occurs. Competition has the same relationship to the density of the population as has predation. It is most intense at the upper population level. Competition may be between species or among the same species. The former is important over a long period of time and may result in one species replacing another. Competition among members of the same species is of more immediate effect and is one of the most important of all limiting factors. The relation of limiting factors to population forces is shown in Figure 20.

Obviously, all of the various categories of limiting factors are not of the same value in a given population. In any given instance, only one of these factors is actually limiting the population. The others may be either absent or in excess. For example, Brown (*9*) found that house mouse populations stopped growing although excess food and water was available. The limiting factor was space. So many mice used the same nests that normal reproduction stopped. In a city block there may be plentiful harborage but little food. Here food may be the limiting factor. A rat population in the block will not be reduced by changes in the available harborage until enough of it has been removed to replace food as the limiting facor. In this block a much more efficient attack would have been to work directly on reducing the food supply. This would have had an immediate result on the rat population. For the most efficient rodent control, effort should generally be concentrated on reducing the limiting factor or intensifying its effect.

The most nearly permanent control can be achieved by alterations of the physical environment of rats and mice. Although it is quite possible for man to use predation, this factor is generally difficult to maintain over a long period. The high cost of labor involved and the problem of periodically repeating poisoning campaigns are a good demonstration of why a program based on predation may be ineffective. Alteration of the rodents' environment usually improves man's own environment and fits in with desirable changes in land use. The removal of unsightly piles of junk, lumber, and rundown buildings improves the appearance and living standards of an area. At the same time it destroys much rodent harborage. Placing garbage in tight-fitting ratproof containers not only destroys rodent food sources but also helps reduce flies. Once the environment has been altered, the effects of predation and competition are intensified. The rodents' enemies find it easier to run them down and kill them. Rats and mice compete violently for the remaining food and harborage. As a result, the rodent population goes down. For the most nearly permanent rodent control, man should *So Change the Physical Environment That the Level of Predation and Competition Is Increased.* This in effect, lowers the capacity of the environment to support rats and mice.

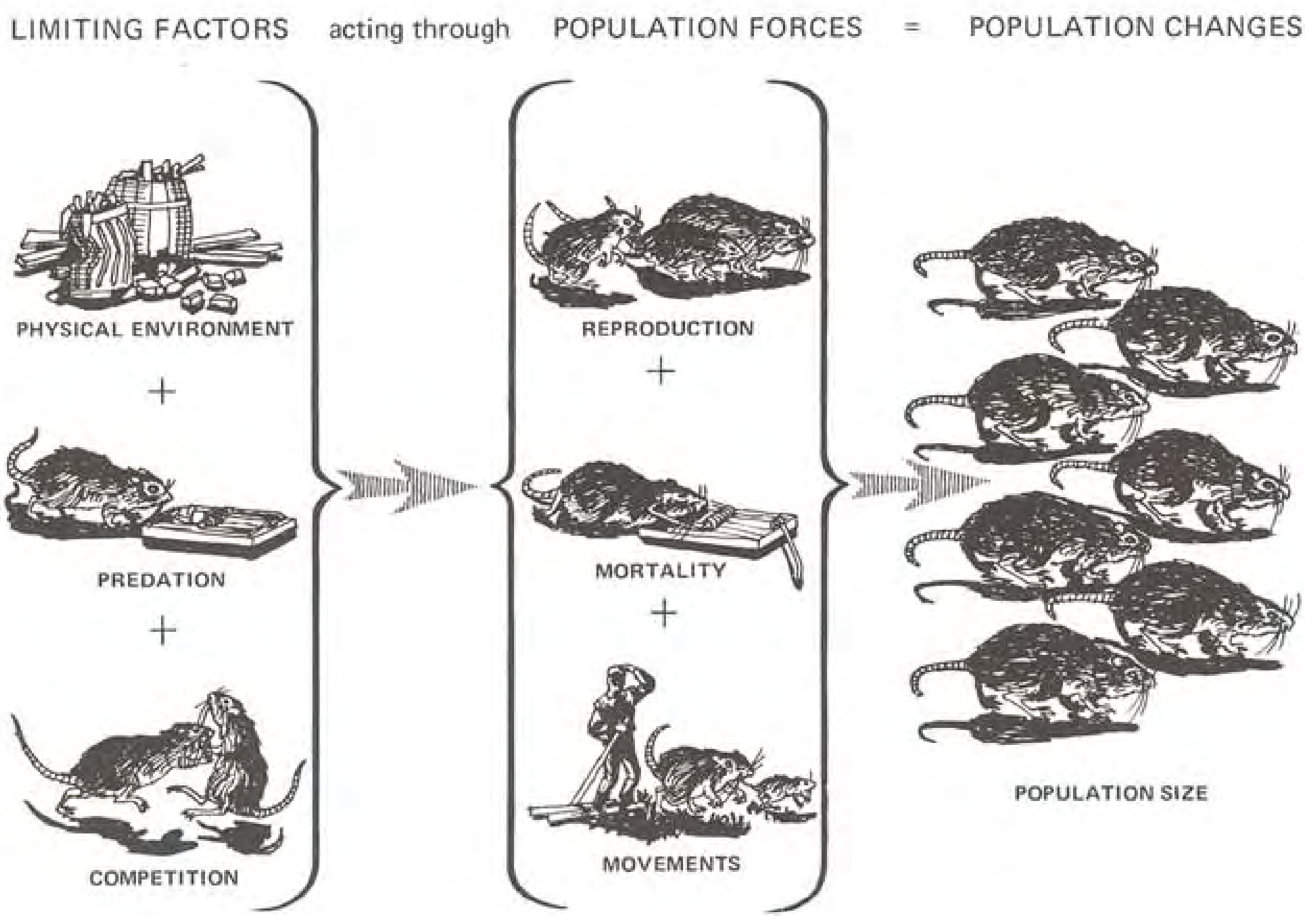

FIGURE 20

selected references

1. Addison, W. H. F. and J. L. Appleton. 1915. The structure and growth of the incisor teeth of the albino rat. J. Morph. *26*: 43-96.
2. Adolph, E. F. 1957. Ontogeny of physiological regulations in the rat. Quart. Rev. Biol. *32* (2): 89-137.
3. Barbahenn, K. R. 1970. Notes on the ecology of sewer rats in St. Louis. Proc. Vert. Pest Control Conf. *4*: 19-22, Sacramento, Cal.
4. Barnett, S. A. 1963. The Rat, A Study in Behaviour. Aldine Publ. Co., Chicago, Ill. 288 p.
5. Beck, J. R. and P. W. Rodeheffer. 1965. Cause and control of sewer rats. Public Works *96*: 116-118.
6. Berry, R. J. 1970. The natural history of the house mouse. Field Studies *3* (2): 219-262.
7. Brooks, A. 1947. The brown rat, *Rattus norvegicus,* in British Columbia. Canadian Field-Nat. *61* (2): 68.
8. Brooks, J. E. 1973. A review of commensal rodents and their control. Critical Reviews in Environmental Control *3* (4): 405-453.
9. Brown, R. Z. 1953. Social behaviour, reproduction, and population changes in the house mouse (*Mus musculus* L.). Ecolog. Monogr. *23* (3): 217-240.
10. Brown, R. Z. 1960. Biological Factors in Domestic Rodent Control. U.S.P.H.S., Pub. 773, Part II. 32 pp.
11. Caldwell, L. D. 1964. An investigation of competition in natural populations of mice. J. Mammalogy *45* (1): 12-30.
12. Calhoun, J. B. 1941. Distribution and food habits of mammals in the vicinity of Reelfoot Lake Biological Station. J. Tenn. Acad. Sci. *16* (1): 177-185 and *16* (2): 207-225.
13. Calhoun, J. B. 1962. The Ecology and Sociology of the Norway Rat. U.S.P.H.S. Pub. 1008. 288 p.
14. Chew, R. M. and R. T. Hinegardner. 1957. Effects of chronic insufficiency of drinking water in white mice. J. Mammalogy *38* (3): 361-374.
15. Christian, J. J. and D. E. Davis. 1956. The relationship between adrenal weight and population status of urban Norway rats. J. Mammalogy *37* (4): 475-486.
16. Communicable Disease Center. 1949. Rat-Borne Disease Prevention and Control. C.D.C., P.H.S., Federal Security Agency, Atlanta, Ga. 293 p.
17. Cottam, C. 1948. Aquatic habits of the Norway rat. J. Mammalogy *29* (3): 299.
18. Creel, R. H. 1915. The migratory habits of rats with special reference to the spread of plague. Pub. Health Rep. *30* (23): 1679-1685.
19. Crowcroft, W. P. 1954. Aggressive behaviour in wild house mice (*Mus musculus* L.) Ministry of Agriculture and Fisheries. Infestation Control Division, Res. Rep. *35*: 13 p.
20. Dahlquest, W. W. 1948. Mammals of Washington. Publ. Univ. Kansas Mus. Nat. Hist. *2*: 1-444.
21. Davis, D. E. 1948. The survival of wild brown rats on a Maryland farm. Ecology *29* (4): 437-448.
22. Davis, D. E. 1949a. A phenotypical difference in growth of wild rats. Growth *13*: 1-6.
23. Davis, D. E. 1949b. The role of intraspecific competition in game management. Trans. 14th North American Wildlife Conf.: 225-231.
24. Davis, D. E. 1951. The relation between the level of population and the prevalence of *Leptospira, Salmonella,* and *Capillaria* in Norway rats. Ecology *32* (3): 465-468.
25. Davis, D. E. 1953. The characteristics of rat populations. Quart. Rev. Biol. *28* (4): 373-401.
26. Davis, D. E. 1957. The use of food as a buffer in a predatory-prey system. J. Mammalogy *38* (4): 466-472.
27. Davis, D. E. 1972. Rodent Control Strategy. *In* Pest Control: Strategies for the Future. ISBN O-309-01945-1. Nat. Acad. Sci., Washington, D.C. pp. 157-171.
28. Drummond, D. C. 1971. Rodents and biodeterioration. Int. Biodetn. Bull. *7:* 73-79.
29. Drummond, D. C. 1972. Biology and control of domestic rodents. *In* Vector Control in International Health, World Health Organization, Geneva, Switzerland, pp. 46-69.
30. Ebeling, W. 1975. Urban Entomology. Univ. Cal. Press, Richmond, Cal. 695 p.
31. Ecke, D. H. 1954. An invasion of Norway rats in southwestern Georgia. J. Mammalogy, *35* (4): 521-525.
32. Elton, C. 1936. House mice (*Mus musculus*) in a coal mine in Ayrshire. Ann. Mag. Nat. Hist. *10* (17): 553-558.
33. Emlen, J. T. and J. F. Crow. 1951. A test for increased resistance in a chronically poisoned mouse population. Amer. J. Hyg. *54* (1): 71-75.
34. Emlen, J. F., A. W. Stokes, and D. E. Davis. 1949. Methods for estimating populations of brown rats in urban habitats. Ecology *30*: 430-442.
35. Emlen, J. T., H. Young, and R. L. Strecker. 1958. Demographic responses of two house mouse populations to moderate suppression measures with 1080 rodenticide. Ecology *39* (2): 200-206.
36. Enzmann, E. V. 1933. Milk-production curve of albino mice. Anat. Rec. *56*: 345-358.
37. Errington, E. V. 1935. Wintering of field-living Norway rats in south central Wisconsin. Ecology *16* (1): 122-123.
38. Errington, P. L., F. Hammerstrom, and F. N. Hammerstrom. 1940. The great horned owl and its prey in north-central United States. Iowa Agr. Exp. Sta. Res. Bull. 227, pp. 757-850.
39. Fertig, D. S. and V. W. Edmonds. 1969. The physiology of the house mouse. Scientific American *221* (4): 103-108.

40. Food and Agriculture Organization/World Health Organization. 1969. FAO/WHO Regional Training Seminar on the Control of Rodents of Agricultural and Public Health Importance. Bureau of Plant Industry. FAO/WHO An:TCR 69/1. Manila, Philippines. 227 p.

41. Food and Agriculture Organization/World Health Organization. 1973. Bibliography on Rodent Pest Biology and Control, 1950-1959. Part I, 1-210; Part II, 211-448. Food and Agriculture Organization of the United Nations and World Health Organization, Rome, Italy.

42. Greaves, J. H. and F. P. Rowe. 1969. Responses of confined rodent populations to an ultrasound generator. J. Wildlife Mgmt *33*: 409-417.

43. Gunderson, H. 1944. Notes on a heavy Norway rat population. J. Mammalogy *25* (3): 307-308.

44. Hall, E. R. 1927. An outbreak of house mice in Kern County, California. Univ. Cal. Pub. Zool. *30*: 189-203.

45. Hamilton, W. J. 1928. The height from which rodents may fall. J. Mammalogy *9* (1): 65-66.

46. Harmston, F. C. and C. T. Wright. 1960. Distribution and control of rats in five Rocky Mountain states. Pub. Health Rep. *75*: 1077-1084.

47. Harrison, J. L. and J. R. Audy. 1951. Host of the mite vectors of scrub typhus. II. An analysis of the list of recorded hosts. Ann. Trop. Med. *45* (3 & 4): 186-194.

48. Hoffmeister, D. F. and C. O. Mohr. 1957. Fieldbook of Illinois Mammals. Natural History Survey Division, Manual No. 4, Urbana, Illinois. 233 p.

49. Hopkins, M. 1953. Distance perception in *Mus musculus*. J. Mammalogy *34* (3): 393.

50. Howard, W. E. and R. E. Marsh. 1974. Rodent Control Manual. Pest Control *42* (8): A-U.

51. Hulbert, R. H. and E. R. Krumbiegel. 1972. Synthetic flavors improve anticoagulant type rodenticides. J. Environ. Health *34* (4): 407.

52. Jackson, W. B. 1951. Food habits of Baltimore, Maryland, cats in relation to rat populations. J. Mammalogy *32* (4): 458-461.

53. Jackson, W. B. 1965. Feeding patterns in domestic rodents. Pest Control *33* (8): 12, 50.

54. Jackson, W. B. 1972. Biological and behavioral studies of rodents as a basis for control. Bull. Wld. Hlth. Org. *47*: 281-285.

55. King, J. A. 1957. Intra- and interspecific conflict of *Mus* and *Peromyscus*. Ecology *38* (2): 355-357.

56. King, O. M. 1950. An ecological study of the Norway rat and the house mouse in a city block in Lawrence, Kansas. Trans. Kans. Acad. Sci., *53* (4): 500-528.

57. Langveld, D. W. 1953. Ratten en eieren (Rats and eggs). Lavende Natuur *56* (12): 221-225.

58. Laurie, E. M. O. 1946. The reproduction of the house mouse (*Mus musculus*) living in different environments. Proc. Roy. Soc., Ser. B., Biol. Sci. *133* (872): 248-281.

59. Leslie, P. H., U. M. Venables, and L. S. V. Venables. 1952. The fertility and population structure of the brown rat (*Rattus norvegicus*) in cornricks and some other habitats. Proc. Zool. Soc. London *122* (1): 187-238.

60. Linduska, J. P. 1942. Insect feeding by the house mouse. J. Mammalogy *23* (2): 212-213.

61. Linduska, J. P. 1950. Ecology and land-use relationships of small mammals on a Michigan farm. Game Div., Dept. of Conservation, Lansing, Mich., 144 p.

62. Marsh, B. T., W. B. Jackson, and J. R. Beck. 1962. Use of ultrasonics in elevator rat control. Grain Age *3* (11): 27-31.

63. Orgain, H. and M. W. Schein. 1953. A preliminary analysis of the physical environment of the Norway rat. Ecology *34* (3): 467-473.

64. Orr, R. T. 1944. Communal nests of the house mouse (*Mus musculus* L.). Wasmann Collector *6*: 35-37.

65. Pearson, O. P. and A. K. Pearson. 1947. Owl predation in Pennsylvania, with notes on the small mammals of Delaware County. J. Mammalogy *28* (2): 137-147.

66. Pinel, J. P. J. 1972. High-intensity, ulatrsonic sound. A better rat trap. Psychol. Rep. *31*: 427-432.

67. Pisano, R. G. and T. I. Storer. 1948. Burrows and feeding of the Norway rat. J. Mammalogy *29* (4): 374-383.

68. Reimer, J. D. and M. L. Petras. 1968. Some aspects of commensal populations of *Mus musculus* in southwestern Ontario. Canadian Field Nat. *82*: 32-42.

69. Rohe, D. L. 1966. Survey methods for roof rat populations in sanitary sewers. Calif. Vector Views *13*: 75.

70. Rowe, F. P. 1966. Economic importance of the house mouse (*Mus musculus* L.) WHO Seminar on Rodents and Rodent Ectoparasites, Geneva, Switzerland, October 24-28. WHO/VBC/66.217: 21-25.

71. Rowe, F. P., E. J. Taylor, and A. H. J. Chudley. 1963. The numbers and movements of house mice in the vicinity of four corn ricks. J. Animal Ecol. *32*: 87-97.

72. Rowe, F. P., H. Wichman, and M. Lund. 1970. The house-mouse. WHO/VBC/70.215. 43 pp.

73. Rowe, F. P. and R. Redfern. 1969. Aggressive behaviour in related and unrelated wild house mice (*Mus musculus* L.). Ann. Appl. Biol. *64*: 425-431.

74. Schein, M. W. and H. Orgain. 1953. A preliminary analysis of garbage as food for the Norway rat. Amer. J. Trop. Med. Hyg. *2*: 1117-1130.

75. Schiller, E. L. 1952. Ecology and health of *Rattus* at Nome, Alaska. J. Mammalogy *37* (2): 181-188.

76. Schwarz, E. 1960. Classification, origin, and distribution of commensal rats. Bull. Wld. Hlth Org. *23*: 411-416.

77. Smith, R. W. 1940. The land mammals of Nova Scotia. Amer. Midland Nat. *24*: 213-241.
78. Smith, W. W. 1954. Reproduction in the house mouse, *Mus musculus* L., in Mississippi. J. Mammalogy *35* (4): 509-515.
79. Smith, W. W. 1957. Factors influencing the decline in commensal rat infestations in a rural area of southwestern Georgia. J. Mammalogy *38* (2): 270-271.
80. Smith, W. W. 1958. Melanistic *Rattus norvegicus* in southwestern Georgia. J. Mammalogy *39* (2): 304-306.
81. Southwick, C. H. 1955a. The population dynamics of confined house mice supplied with unlimited food. Ecology *36* (2): 212-225.
82. Southwick, C. H. 1955b. Regulatory mechanisms of house-mouse populations. Social behaviour affecting litter survival. Ecology *36* (4): 627-634.
83. Southwick, C. H. 1969. Reproduction, mortality, and growth of murid rodent populations. *In* Indian Rodent Symposium, Calcutta, India, December 1966, pp. 152-176.
84. Southwick, C. H. 1969a. Population dynamics and social behavior of domestic rodents. *In* Biology of Populations: The Biological Basis of Public Health, B. K. Sladen and F. B. Bang (Eds.). pp. 284-298.
85. Spencer, H. J. and D. E. Davis. 1950. Movements and survival of rats in Hawaii. J. Mammalogy *31* (2): 154-157.

86. Sprock, C. M., W. E. Howard, and F. C. Jacob. 1967. Sound as a deterrent to rats and mice. J. Wildlife Management *31* (4): 729-741.
87. Storer, T. I. (Ed.). 1962. Pacific Island Rat Ecology. Bishop Museum Bull. 225. 274 p.
88. Strecker, R. L. 1954. Regulatory mechanisms in house-mice populations: The effects of limited food supply on an unconfined population. Ecology *35* (2): 249-253.
89. Strecker, R. L. 1955. Food consumption of house mice at low temperatures. J. Mammalogy *36* (3): 460-462.
90. Strecker, R. L. and J. T. Emlen. 1953. Regulatory mechanisms in house-mice populations: The effect of limited food supply on a confined population. Ecology *34* (2): 375-385.
91. Thompson, H. V. 1948. Studies of the behaviour of the common brown rat (*Rattus norvegicus* Berkenhout). I. Watching marked rats taking plain and poisoned bait. Bull. An. Behaviour *6*: 26-40.
92. Tomich, P. Q. and H. T. Kami. 1966. Color coat inheritance of the roof rat in Hawaii. J. Mammalogy *47*: 423-431.
93. Tryon, C. A. 1947. Entrance and migration of the Norway rat into Montana. J. Mammalogy *28* (2): 188-189.
94. Venables, L. S. V. and P. H. Leslie. 1942. The rat and mouse populations of cornricks. J. Animal Ecol. *11* (1): 44-68.
95. Walker, E. P. (Ed.). 1975. Mammals of the World. Third Ed. Johns Hopkins Press, Baltimore, Md. Vol. 1, 1-644; Vol. 2, 645-1500.
96. Williams, C. L. 1932. Rat infestation inspection of vessels. Pub. Health Rep. *47* (14): 765-800.
97. Williams, E. and J. P. Scott. 1953. The development of social behaviour patterns in the mouse in relation to natural periods. Behaviour *6* (1): 35-65.
98. World Health Organization. 1974. Ecology and Control of Rodents of Public Health Importance. Wld. Hlth. Org., Tech. Rept. Ser. No. 553, 42 pp.
99. World Health Organization/Vector Control. 1966. Seminar on rodents and rodent ectoparasites. Wld. Hlth Org., Vector Biology and Control, Geneva, Switzerland. WHO/VBC/66.217, 222 p.
100. World Health Organization/Vector Biology and Control. 1968. Seminar on the Ecology, Biology and Control of Ticks and Mites of Public Health Importance. Wld. Hlth Org., Vector Biology and Control, Geneva, Switzerland, WHO/VBC/68.57, 275 pp.
101. World Health Organization and Food and Agriculture Organization. 1971. Bibliography on Rodent Pest Biology and Control. 1960-1969. Part I, 232 pp.; Part II, 242 pp.; Part III, 267 pp.; Part IV, 206 pp. World Health Organization, Vector Biology and Control, VBC/71.9,9a, 9b, and 9c. World Health Organization and Food and Agriculture Organization of the United Nations, Geneva, Switzerland.
102. Worth, C. B. 1950. Field and laboratory observations on roof rats, *Rattus rattus* Linnaeus, in Florida. J. Mammalogy *31* (3): 293-304.
103. Young, P. T. 1944. Studies of food preferences, appetite, and dietary habit. 1. Running, activity preference. J. Comp. Psychol. *37* (6): 327-370.
104. Young, H., R. L. Strecker, and J. T. Emlen. 1950. Localization of activity in two indoor populations of house mice, *Mus musculus*. J. Mammalogy *31* (4): 403-410.