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X. COMMENSAL RODENT CONTROL[1]

by

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Since 1970 the Vector Biology and Control Division of WHO has prepared, with the assistance of collaborators outside the Organization, a number of papers on vector control. The Expert Committee on Insecticides held in October 1974 (Technical Report Series No. 561) recommended that these documents - general reviews of the ecology and control of individual vector groups - should be continued and revised from time to time to provide workers with up-to-date, practical information on the particular subject. It was also recommended that there should be a feedback to the Organization. readers are therefore requested to write to Vector Biology and Control giving comments on their experience of the subject reviewed.

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[1] This brochure includes information on the house mouse, thus replacing WHO/VBC/70.215 (II. The House Mouse) which is now out of print.

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1. INTRODUCTION

With the sole exception of man, the most successful and abundant mammals on earth today are the commensal rats and mice. They would never have enjoyed this success without man's inadvertent help. Commensal rodents have taken advantage of human transport and trade routes and in this way they spread from their ancestral home in Asia moving outward as civilizations developed until they reached all continents of the world.

What are the commensal rodents? Commensal refers to the fact that these animals live at man's expense, invading his home, eating his food and damaging his commodities; they are also capable of transmitting diseases to man, who thus derives no benefit from the relationship. Some authors refer to commensal rodents as "synanthropic" (Kucheruk, 1965), meaning literally, living together with man. Three species of worldwide distribution are the most important of the commensal rodents: the Norway or brown rat (Rattus norvegicus Berk), the roof rat (Rattus rattus L.) sometimes called the ship or black rat, and the house mouse (Mus musculus L.). There are several other important commensal species of more localized distribution but this manual is solely concerned with the cosmopolitan species.

Man regarded his rodent commensals as little more than household pests until the very end of the nineteenth century. Then, when the role of the rat in the spread of plague was first clearly shown, man realized that commensal rodents were among his worst enemies and more attention was given to their control. The first example of a national rodent control campaign was that conducted in Denmark under the Danish Rat Law of 1908 (Zuchlag, 1920). Local authorities made bounty payments to members of the public for each dead rat produced but, although enormous numbers of Norway rats were killed over several years, little real progress was made towards their eradication.

The principles underlying modern-day rodent control technology are largely founded on the results of investigations carried out since 1940. The need to protect food supplies from attack by pests became imperative in Britain during the Second World War (1939-1945) and studies of commensal rodents were begun then at the Bureau of Animal Population, under the direction of C. Elton. The principal workers, D. H. Chitty and H. N. Southern, mainly concentrated on the biology, behaviour and control of the Norway rat; this pioneer research work was subsequently continued and extended by Barnett (1975). Other investigations were made in the United States of America, J. T. Emlen, D. E. Davis, R. L. Doty, C. P. Richter and J. B. Calhoun being particularly involved in studies of rats, both in the laboratory and the field. Parallel work on the house mouse, begun by Southern (Chitty & Southern, 1954) was amplified later by W. P. Crowcroft, F. P. Rowe, C. H. Southwick and other researchers. The scientific research begun 40 years ago continues to the present day. Control problems are exacerbated by human failings for when man attacks the rat he has also to fight his own habits and the neglect of the environment in which he lives. Man's indifference, ignorance and lack of attention to sanitation helps to sustain rodent populations and makes their control a more arduous task.

The literature dealing with the history, biology, behaviour and control of commensal rodents is scattered through hundreds of scientific and technical journals, bulletins and books. This is unfortunate because knowledge of such information is needed to formulate the most effective and broadest attack possible upon rodent populations. The aims of this manual are to assemble these diverse threads of biology and behaviour and to outline current control technology. Emphasis is placed on commensal rodent control in urban and village environments and in food storage areas. Indispensable guides to those wishing more detailed information are three recent bibliographies (Bibliography on Rodent Pest Biology and Control 1950-1959, parts I & II; 1960-1969, parts I, II, III and IV; 1970-1974, one volume) published by WHO/FAO.

2. CLASSIFICATION

Commensal rats and mice are members of the mammalian order RODENTIA. The outstanding characteristic of rodents is the adaptation of the incisor teeth for gnawing. The upper and lower jaws each bear a single pair of constantly growing incisors which become much enlarged to produce a very effective cutting tool. The additional incisors, canine and premolar teeth normally present in many other mammals are absent in rodents, creating a space between the incisors and the molars called the diastema (Fig. 1a). Rats and mice can draw the sides of the lips into this space, enabling them to dig and gnaw with the incisors without getting dirt, chips of wood or other material in their mouth.

The incisors are rootless and grow from a crown of persistent pulp. The outer surface consists of a thin layer of very hard enamel beneath which are thicker but softer layers of pulp and dentine. During gnawing the incisors become worn down and blunted, but the sharpness of their cutting edge is continually restored by the rubbing of the hard enamel front faces of uppers and lowers against the softer materials behind (Fig. 1b). Addison & Appleton (1915) first showed this by placing rats in a glass jar with only soft food to eat; their incisors wore down just as fast as those of rats given normal opportunities for gnawing. In mice, the upper incisors are characterized by a distinct notch on the wearing surface.

The Rodentia are divided roughly into three major groups: the Sciuromorpha (squirrel-shaped), Myomorpha (mouse-shaped) and Hystrichomorpha (porcupine-shaped). Commensal rats and mice are all members of the rodent family Muridae, a part of the Myomorph group (Table 1). Murid rodents are extremely successful and are the dominant species in most regions of the world, largely due to their high reproductive potential, their omnivorous feeding habits and their ability to adapt to and then exploit new situations rapidly.

The skull of a mammal is the most important diagnostic feature for purposes of taxonomic identification. Selected field characteristics of the skulls (dorsal view) of commensal rodents are given in Fig. 2. In Rattus norvegicus the temporal ridges are roughly parallel and extend back to the lambdoid crests. The brain case is narrow and flattened, and, in adults, the skull length is 43-54 mm. In Rattus rattus the temporal ridges are sharply bowed outwards and the flask-shaped skull is 38-44 mm long. In Mus musculus the temporal ridges are absent or, in older animals, only slightly developed; the skull is roughly flask-shaped and 20-22 mm long.

Rodents are sometimes characterized by their modes of locomotion and living habits. All commensal rodents are plantigrade, walking on the soles of their feet instead of their toes. Norway rats are somewhat fossorial in habit, that is, they are semi-specialized for digging in the ground and living in burrows. Roof rats, in contrast, are semi-arboral, spending less time on the ground than in climbing trees, shrubs and the upper parts of buildings. The foot pads of a climbing species such as the roof rat are modified to provide better traction and clinging power by the presence of numerous lamellae (scaly grooves and whorls), whereas a digging rodent such as the Norway rat has smooth foot pads. These differences are illustrated in Fig. 3.

3. CHARACTERISTICS, HABITATS AND DISTRIBUTION

3.1 Norway rat

The identifying characteristics of commensal rats and mice are summarized in Table 2 and Fig. 4. Norway rats are stocky, medium- to large-sized rodents, and, with the exception of some tropical living forms, the length of the sparsely-haired tail is shorter than that of the head and body. The snout is blunt, the ears relatively short and thick and the fur is coarse, being brownish-grey on the back and whitish-grey on the belly. The female has 12 mammaries, three pairs of pectoral and three pairs of inguinal.

TABLE 1. CLASSIFICATION OF RODENTS

(Adapted from Anderson & Jones, 1967)

Only selected Families, Genera, and species are given.

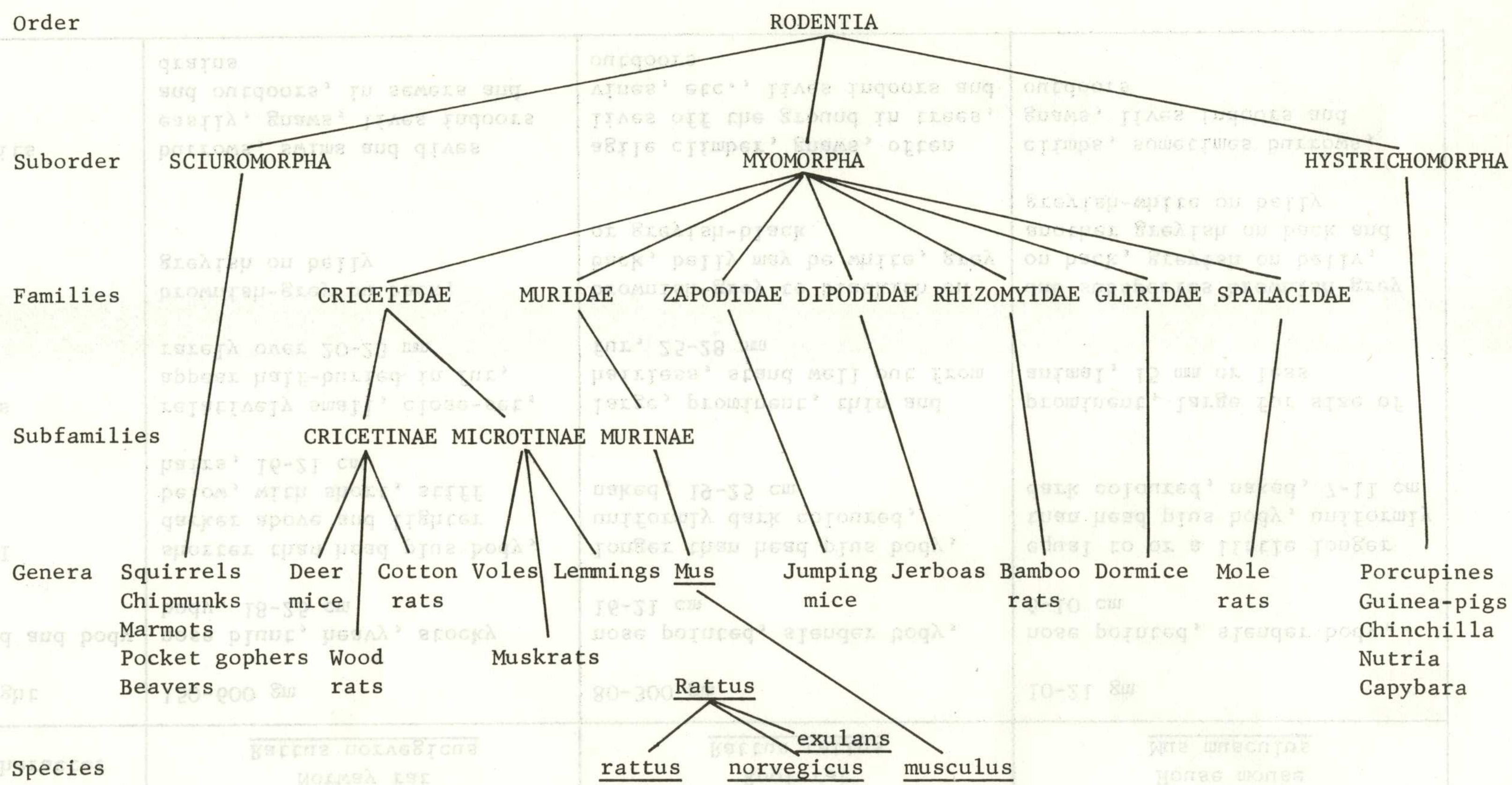

TABLE 2. FIELD CHARACTERS AND MEASUREMENTS OF COMMENSAL RODENTS

Character	Norway rat Rattus norvegicus	Roof rat Rattus rattus	House mouse Mus musculus
Weight	150-600 gm	80-300 gm	10-21 gm
Head and body	nose blunt, heavy, stocky body, 18-25 cm	nose pointed, slender body, 16-21 cm	nose pointed, slender body, 6-10 cm
Tail	shorter than head plus body, darker above and lighter below, with short, stiff hairs, 16-21 cm	longer than head plus body, uniformly dark coloured, naked, 19-25 cm	equal to or a little longer than head plus body, uniformly dark coloured, naked, 7-11 cm
Ears	relatively small, close-set, appear half-buried in fur, rarely over 20-23 mm	large, prominent, thin and hairless, stand well out from fur, 25-28 mm	prominent, large for size of animal, 15 mm or less
Fur	brownish-grey on back, greyish on belly	brownish-grey to blackish on back, belly may be white, grey or greyish-black	one subspecies brownish-grey on back, greyish on belly, another greyish on back and greyish-white on belly
Habits	burrows, swims and dives easily, gnaws, lives indoors and outdoors, in sewers and drains	agile climber, gnaws, often lives off the ground in trees, vines, etc., lives indoors and outdoors	climbs, sometimes burrows, gnaws, lives indoors and outdoors

The Norway rat is a gregarious species, and, under favourable conditions, colonies several hundred strong may develop. In general, individual colony members display intolerance towards those belonging to other colonies nearby. The Norway rat shows a strong tendency for burrowing, especially into soil banks or under secure coverings, such as concrete or rock piles. Inside buildings, it prefers living in wall and floor spaces and beneath piles of rubbish and debris and, outside, it is frequently found living near water, by drains, along ditches, streams, rivers and marshes and in sewer systems, cess pits and dockside structures. The Norway rat is essentially a temperate climate species and this is reflected in its rather patchy distribution (Fig. 5). It is more abundant and widely distributed in the northern than in the southern hemisphere, occurring across Asia, Europe and North America. The range of this species continues to expand due to changes in urban environments favourable to its habits and to occasional introductions resulting from sea traffic.

R. norvegicus is the common urban and rural rat of temperate regions of North America and Europe, living both indoors and outdoors. In urban areas, Norway rats frequently live in and around residences, in cellars, stores, warehouses, slaughter-houses, docks, and sewers. On farms they infest barns, silos, granaries, piggeries, poultry houses, stables and kennels. The open garbage dump is also a favourite habitat for R. norvegicus. Norway rat burrows are commonly found in hedgerows and banks and along streams, canals and drainage ditches. In the United States of America, Spain and Italy, R. norvegicus has been found living in rice fields.

In tropical areas, Norway rats are mainly found in coastal seaports, irrigated agricultural areas and river valleys; in towns and villages they occur in garbage dumps and other refuse, around cess pits, in sewer systems and storm drains. They are sometimes restricted to warehouses and dockside structures in port areas.

At the present time, the Norway rat is less well established in the tropics than the roof rat; whether this is because it is less well adapted to living in hot climates or merely because it is a more recent invader of tropical regions is not clear. In some areas of the Middle East, however, R. norvegicus has now begun to spread at the expense of R. rattus (Gratz, 1973b). In contrast, Walton et al. (1977) have indicated that the Norway rat in Rangoon, Burma has been displaced from the outdoor habitat by the larger and more aggressive bandicoot rat Bandicota bengalensis.

3.2 Roof rat

The roof rat, also known as the black or ship rat, is a moderate-sized, slender, agile rat. The black rat, which is a colour variant of the roof rat, has a slate-grey to black back and a dark grey belly. Although the brownish-grey and the black colour variants were earlier referred to as separate subspecies this is no longer considered to be valid (Bentley, 1959), both colour variants commonly occurring in the same litter. The snout is slender, the ears are large and thin and the eyes are prominent. The tail is unicoloured and generally longer than head and body length. The female has 10 mammaries, two pairs pectoral and three pairs inguinal although, on rare occasions, an extra pectoral pair is present. In the Asiatic region, other rats are present which are considered to be closely related to R. rattus, for example, R. jalorensis, R. argentiventer and R. diardi in Malaysia (Harrison, 1957). R. jalorensis is a white-bellied rat of woodland whereas argentiventer is a grey-bellied rat of grassland, including rice fields; diardi is essentially a dull-bellied house rat but it is less common on the east coast where it is replaced by jalorensis in village houses.

The roof rat occurs in small family groups in the wild, the individuals repelling members of nearby social groups; it does not live in as large colonies as R. norvegicus except under certain circumstances, when, for example, it is the sole rat species inhabiting a refuse site or a poultry house. The roof rat is at home indoors or out, depending on the climate. It is a semi-arboreal species, climbing shrubs, vines and trees in habitats ranging from riparian to tropical rain forest. R. rattus nests freely outdoors in tropical and subtropical areas, tending to choose sites, where possible, in the higher branches of trees and in the crowns of palms. It fills the niche of a squirrel in the maquis of southern France, Spain and Cyprus, feeding upon the seeds of Pinus halepensis. It is an orchard and plantation pest in many areas causing damage to citrus fruits, macadamia nuts, cocoa, coconut, sugar cane, date palms, carobod and avocado.

Indoors, R. rattus inhabits a wide variety of human structures, including residences, shops and large foodstores, warehouses, poultry houses, barns, markets, restaurants and grain elevators. It is still the most common rat found on sea vessels (Drummond, 1972), hence the alternative name "ship rat". It is not averse to living in close association with man in many cities and villages in tropical areas.

The roof rat is more extensively distributed than R. norvegicus. The ancestral home of this tropical and subtropical species is the South-East Asian mainland, southern China, parts of India, Indonesia and the Philippines (Schwartz, 1960), but roof rats are widely distributed in both the northern and the southern hemispheres (Fig. 6).

In North America, the roof rat is distributed in the southern United States of America from Virginia, Maryland and westwards in southern states as far as the Rio Grande Valley in Texas and New Mexico. On the Pacific coast, roof rats are found from Baja, California northward as far as the Queen Charlotte Islands of British Columbia and they occur inland in California, Arizona and in several dry Great Basin localities. R. rattus is common to all islands of the West Indies and it is also present in Central America.

In South America, roof rats commonly occur along sea coasts but they are rarely found more than a hundred miles inland except in south-eastern Brazil and along the Parana and Uruguay Rivers in Argentina, Uruguay and Paraguay. Roof rats are established far inland along the drainages of the Orinoco in Venezuela, and they are also common in the Guianas, excepting the highlands. In Ecuador, Peru and Chile their distribution is restricted to the fertile agricultural areas near the Pacific coast.

In Europe, the roof rat is generally distributed across continental areas, its range in the north extending to a few localities in Sweden and Finland. It is sparsely distributed north of 45° latitude and in northern parts it generally lives indoors; in more southern Europe the roof rat is also an outdoor-living species. In Turkey, roof rats occur on the coast but they are abundant only from Istanbul to Sinop; in Russia, they are found living in a few localities as far east as the Volga River.

In Africa, roof rats are commonly distributed across the continent south of the equator and on the island of Madagascar. They inhabit the Atlantic coast and extend inwards in lowland areas; in Egypt, they are found southward along the Nile Valley to the Aswan Dam.

In the Middle East, R. rattus is mostly confined to coastal areas in Syria, Lebanon and Israel. It is found in Iraq along the Tigris and Euphrates River Valleys, in the Caucasus and in Iran along the Caspian coast and inland on the Khuzistan Plains.

Roof rats occur over much of India, from the foothills of the Himalayas southwards. They are also common throughout South-East Asia, Indonesia, southern and eastern China, the Philippines, and Japan as far north as Honshu. In Australia, the roof rat is mainly restricted to the western and eastern coasts; it is also present in Tasmania and New Zealand.

R. rattus greatly extended its range in the Pacific islands during and following the Second World War (Smith, 1968). It is found on the majority of inhabited islands (Wilson, 1968; Williams, 1974) and on some atolls the roof rat is tending to replace the Polynesian rat, Rattus exulans, as the dominant species. While it is very numerous in the dense rain forest that covers most of the high volcanic islands, R. rattus has also adapted well to human habitation and cultivation and here it can be found in houses, stores and grasslands as well as in coconut, sugar cane, cacao and macadamia nut growing areas, and even mangrove swamps.

As stated earlier, R. rattus appears to have lost ground in some regions where it was once the most dominant rat but it has become more widespread in others. Bentley (1959, 1964) has documented the decline of R. rattus in Britain. Loosjes (1956), who reported on reduced numbers of R. rattus in western Europe generally (R. norvegicus now being the most prevalent), attributed the decline to recent changes in building methods rather than the failure of R. rattus to compete with the more aggressive Norway rat. Ecke (1954) concluded however that the Norway rat actively displaced the roof rat in rural areas of Georgia. The roof rat is not losing out everywhere; for example, in southern coastal and inland valleys of California, this species is becoming increasingly important in suburban residential areas and feral habitats (Brooks, 1966; Dutson, 1974; Jamieson, 1965).

3.3 House mouse

The house mouse is a small slender animal with prominent eyes and ears. It is very variable, especially in colour, and many different forms are recognized (Schwartz & Schwartz, 1943; Vinogradov & Argiropulo, 1941). The ancestral stocks are generally the smallest forms and they have a tail considerably shorter than the head and body, the pale grey or white underparts being sharply demarcated from the brown back. They exist almost entirely out of doors living in small family groups, usually comprising one adult male, several females and their sexually immature offspring. In winter, they store large food reserves in burrows or mounds made in fields (Naumov, 1940).

Several forms of M. musculus have evolved, living in close association with man and his dwellings. Commensal mice tend to be larger than the ancestral forms, the length of their tail being almost equal to that of the head and body and, in further contrast, the underparts are dark grey, shading almost imperceptibly into the brownish-grey back. The female has 10 mammaries, three pairs pectorally and two pairs inguinally. Commensal mice also tend to burrow less than the ancestral forms, making more use of existing crevices, and they are less inclined to store food. When conditions are favourable, however, commensal house mice may revert to a feral existence and live quite independently of man. The original range of the house mouse included the Mediterranean zone of Europe and North Africa and most of the steppe region of Asia as far east as China and Japan. It has since invaded or been carried to most parts of the world. House mice can exist in much drier habitats than can Norway rats and this may well account, in part, for their relatively wider distribution. Jackson (1972) has also referred to the increased prevalence of the house mouse in urban environments where rats have been systematically reduced through intensive sanitation and poisoning programmes. The house mouse is still extending its range to more remote areas; in comparatively recent years it has been reported for the first time on South Seymour Island in the Galapagos off South America (Eibl-Eibesfeldt, 1955) and on Guadalcanal, one of the Solomon Islands in the Western Pacific (Rowe, 1967).

At the present time the house mouse probably has a wider distribution than any other mammal apart from man, occurring in temperate, tropical, steppe and semi-desert regions. It habitually infests food storage and other premises in both urban and rural surroundings and it is also found occupying such varied habitats as cold stores, rice, sugar cane and cereal fields, garbage dumps, salt marshes and coal mines. In Alaska, mice have even been found in open tundra, far distant from human settlements (Brown, 1960). They frequent cereal growing areas in different parts of the world and when conditions are extremely favourable, populations increase inordinately, reaching plague proportion. Outbreaks of house mice have been recorded from California, where densities of 32 400/ha were estimated in 1926 (Piper, 1928). Similar irruptions have been reported in Russia and more recently in Australia (Newsome & Crowcroft, 1971).

4. SENSORY AND PHYSICAL ATTRIBUTES

Rats and mice are primarily nocturnal animals and need special skills in order to range freely, to locate food and cover, and to escape predators in darkness. Understanding how commensal rodents respond to their surroundings can help to explain their behaviour patterns and in turn lead to the improvement of control methods.

4.1 Sensory abilities

4.1.1 Smell

Rats and mice have a very keen sense of smell, continually moving their head and sniffing when active; they also leave odour trails for orientation during movements around their living quarters. Reiff (1952) has shown that urine and genital secretions contribute to the odour trails of rats, and that these trails are detected and followed by other rats. Odour is important to rats and mice in distinguishing between familiar and strange individuals (Bowers & Alexander, 1968; Rowe & Redfern, 1969) and both sexes make use of odour signals in detecting sexually active mates (Carr et al., 1965). In observations of confined colonies of wild Norway rats, Calhoun (1962) reported that receptive females left their scent on the ground, around burrows, against trees, posts and on rocks. Males quickly examined the marked points and used the scent trails in tracking the females to their burrows.

4.1.2 Touch

The sense of touch is highly developed in commensal rodents, aiding their movement along runways in darkness. The vibrissae, or whiskers, are in constant use during exploration, contacting floors, walls and nearby objects, thereby aiding orientation and warning the animal of voids or obstacles ahead (Vincent, 1912). The long guard hairs on the body are also extremely sensitive to tactile stimuli. Rats and mice tend to move in contact with vertical surfaces and to travel from one object to another along a definite route; the repeated use of the same routes leaves well-defined trails or runways. This behaviour, movement oriented by tactile stimuli, is called thigmotaxis (Barnett, 1975). Such tactile repetitive behaviour is predictable and is used to advantage in siting traps or poison bait.

4.1.3 Hearing

Rats and mice have an acute sense of hearing, and they are extremely sensitive to any sudden noise. Brown (1970) has recently shown that many rodents have a bimodal acoustic response. In addition to a peak of acoustic sensitivity in the "audible" range, he found a second peak that corresponds to the ultrasonic signals produced by the animals themselves. Rats can detect ultrasounds up to 100 kHz (Ishii et al., 1965), the response being greatest at about 40 kHz (Gourevitch & Hack, 1966); house mice hear up to 90 kHz, sensitivity being most acute at 20 kHz (Ralls, 1967).

Rats and mice are not only able to detect ultrasounds but have also been found to emit them at various intensities between 22 kHz and 90 kHz (Anderson, 1954; Sewell, 1967). Ultrasounds and echolocation have been used by blinded rats in learning to run a maze (Riley & Rosenzweig, 1957). Certain ultrasounds are also used for social communication. Sewell (1967) described three such vocalizations in the rat: a 22 kHz call emitted by defeated or supine subordinate males (subordination call), a 50 kHz vocalization that occurs during sexual mounting activities, and a 50 kHz pulse associated with aggressive behaviour. Rat pups five to 15 days old emit ultrasounds at 40-65 kHz when isolated from their mother (Noirot, 1968; Okon, 1972). It has been further found that lactating females will leave their nest and pups to investigate the tape-recorded ultrasonic calls of lost infant rats (Allin & Banks, 1972). Adult mice have also been shown to respond to the model calls of infants (Smith, 1976).

The ultrasounds made by Mus musculus, both adults and young, are of greatest intensity in the 70 kHz range (Whitney et al., 1971). As the authors point out, the upper limit of hearing in the domestic cat is just below 70 kHz. The ultrasonic signals made by mice would be rapidly absorbed in the air and also scattered by objects such as blades of grass; thus, although the signals might be detected by a cat situated a few metres distant, one further away would find them extremely difficult to hear and to locate.

4.1.4 Vision

The rat and mouse eye is specialized for nocturnal vision; it has high light sensitivity but poor visual acuity. Thus, rodents have the ability to recognize simple shapes and to detect motion in very dim light. Rats detect movements at distances up to 10 m and they can distinguish between simple patterns and objects of different sizes. The rat has good depth perception, up to about 1 m, and is able to gauge correctly the effort required for varying jumps. House mice can identify objects at least 15 m away (Hopkins, 1953).

Rats and mice, in common with most other rodents, are seemingly colour blind. Most colours are thought to appear to them as varying shades of grey, with yellow and green probably being the most attractive because they are revealed as very light grey. This fact is utilized in colouring poison baits bright yellow or green in order to repel birds but not rats. Since rats and mice are relatively insensitive to red light, it is possible to use a red-coloured lamp to observe them at night without greatly affecting their behaviour (Finley, 1959; Southern et al., 1964). Fall (1974) has also reported that wild Norway and roof rats maintained under continuous red light are more docile and easier to handle in the laboratory than those held under usual lighting conditions.

4.1.5 Taste

The sense of taste is highly developed in wild rats. Brooks (1969) reported that both laboratory and wild rats can discriminate between plain bait and the same bait containing as little as 2 ppm of an oestrogen. Similarly, Richter & Clisby (1941) found that rats detected and refused drinking-water containing 3 ppm of phenylthiocarbamide, a bitter, toxic compound. Even more striking is the observation that wild Norway rats are able to detect contaminants of warfarin at 0.25 parts per million (Bowerman & Brooks, 1972). This marked ability to detect extremely minute quantities of bitter, toxic or unpleasant substances has significant implication in practical rodent control involving the use of poisons for it can lead to bait refusal and sublethal dosing problems.

4.2 Physical abilities

4.2.1 Digging

The Norway rat is a burrowing animal and readily digs in the soil when given the opportunity. Burrows excavated for shelter and nesting rarely exceed 1/2 m in depth although this species digs 2-3 m through loose soil without difficulty. Burrow systems are often extensive with connecting tunnels and several exits (Pisano & Storer, 1948).

Roof rats will burrow in areas where Norway rats are absent but the systems are seldom extensive. House mice living in and around buildings only make shallow burrows when other harbourage is not available; those residing in open fields either burrow, live in mounds or utilize natural crevices.

The "L" shaped curtain wall, used to protect buildings against entry by burrowing rats (Jenson, 1965), takes advantage of the rat's habit of digging in close proximity to foundation walls. Having established contact with an external wall, a burrowing rat will not dig away from it to circumvent an obstruction at foundation level. This is an example of the use of predictable thigmotactic behaviour in designing and implementing a specific control technique.

4.2.2 Climbing

Commensal rodents are excellent climbers. Roof rats and house mice, probably because of their smaller size and slighter build, are generally more adept climbers than Norway rats but all three species can climb rough wood and masonry surfaces, walk on telephone and utility wires and descend head first down a rough surface. Norway rats can move up most pipes, inside or outside, without difficulty. Climbing is assisted by the prominent foot pads, the claws, and the tail which is used for support and balance.

4.2.3 Jumping

An adult Norway rat can jump vertically more than 77 cm (Hansgen, 1972). Jumping out and down from a standstill, it can cover a horizontal distance of about 2.4 m while dropping less than 4.6 m, and it performs even better from a running start (USPHS, 1949). Jumping from a standstill, the Norway rat can cover 1.2 m horizontally (Hansgen, 1972). Adult house mice can jump about 25 cm vertically.

4.2.4 Gnawing

Rats and mice readily gnaw through any material that is softer than the enamel of their teeth, the enamel registering 5.5 on the geologist's hardness scale. This includes most building woods, aluminium sheeting, soft mortar, poor quality concrete and asphalt (Tarzwell et al., 1953). Galvanized sheet metal and hardware cloth are generally impervious to attack by rats and mice and are used as rodent-proofing materials. Unless a material is very soft, rodents must be able to grip it with the incisors in order to gnaw. Neuhaus (1957) found that Norway rats were just able to attack smooth round objects 22 mm or more in diameter.

4.2.5 Swimming and diving

All three commensal rodents are good swimmers. Norway rats, especially, are excellent swimmers and divers, being semi-aquatic by habit, frequently living along streams and rivers, in marshy areas, sewer systems and other wet areas. Their considerable swimming ability was demonstrated by Richter (1958) who found that rats could swim for 50-72 hours in a tank of water at 35°C before they became exhausted.

Norway rats can remain under water for up to 30 seconds at a time and they readily penetrate the water seal in toilets, emerging into houses and buildings by this route. Roof rats also thrive in sewers in the absence of Norway rats (Brooks, 1963; Davis, 1955) and will emerge through water seals in the same manner. Both rats and mice swim by kicking the hind feet alternately, moving at about 1.4 km/h and 0.7 km/h respectively (Dagg & Windsor, 1972).

5. BEHAVIOUR OF RATS AND MICE

The behaviour of commensal rodents is complex and not fully understood. For years experimental psychologists and animal behaviourists have studied the behaviour and learning ability of laboratory rats and mice, but little of this knowledge is helpful in explaining the behaviour patterns of the wild species. The behaviour of commensal rodents, because of their very wildness and fears, their high degree of sensory acuity and greater activity is often different to that of their domesticated cousins (Barnett, 1975; Lockard, 1968; Richter, 1969). Appreciation and understanding of the behavioural differences only emerged when unexplained phenomena, encountered during control operations, necessitated detailed studies of the wild species.

The patterns of rat and mouse behaviour of most significance in relation to their control, concern a complex balance of opposing reactions such as approach and avoidance, food consumption and rejection, and aggregation and aggression. These opposing behavioural traits operate within commensal rodent populations to ensure the survival of the individual or the population and they need to be fully understood in order to exploit control practices satisfactorily.

The three most important aspects of rat and mouse behaviour, bearing on practical rodent control, are orientation and movement in the living space, feeding behaviour and social behaviour.

5.1 Orientation and movement patterns

Wild rats and mice display a strong exploratory drive within their immediate home range. They constantly explore and re-explore known and new aspects of their environment; in a short time they come to know the topography thoroughly and they are able to move to shelter immediately (Barnett, 1975; Crowcroft & Rowe, 1963). During exploration they sniff and investigate objects within their range, tasting and sampling any foods or liquids that are encountered. The end result of this exploratory behaviour is to expose and familiarize them to a wide variety of situations.

In exploring their environment rats and mice go through a learning process. All the details of pathways, obstacles, hiding places, location of food and water are memorized and the actual muscular movements necessary, for example, to move down a runway and to take refuge are also learned. This is known as orientation using a kinaesthetic sense. This behavioural trait is easily demonstrated by covering an opening that rats or mice have been used to entering. When disturbed, they will repeatedly attempt to gain access to the opening, which their kinaesthetic sense of orientation has informed them should be there. Such detailed familiarity with the living space, the location of food and water, known runways, burrows and other places of concealment, greatly aids individual survival.

Inquisitive exploratory behaviour would quickly lead wild rodents into traps or result in their ingesting poison bait if it was not inhibited in some manner. Another behaviour pattern, opposite to exploratory activity, serves to protect them from their own curiosity. Thus, Norway rats will quickly detect but initially tend to avoid any strange objects that are encountered in a familiar environment. This behaviour, which has been called "new object reaction" or "neophobia" (Chitty & Southern, 1954; Barnett, 1958) is most easily seen in the case of rats living in an area with established runways. The use of a runway can be prevented, sometimes for days, by simply placing upon it an innocuous, but unfamiliar item, such as a block of wood. Other objects, such as a bait container or trap can produce the same effect. Morlan et al. (1952) observed that rats were reluctant to cross through patches of DDT dust on hitherto well-used runs and that they established new runways instead. "New object reaction" is also displayed by roof rats (Cowan & Barnett, 1975) but it is less evident in mice which become accustomed to traps and unknown food within a relatively short period of time.

The runways used by rats and mice in travelling between food and cover are often clearly visible and they can be used as a guide in placing bait stations or traps. Because of the reaction of rats to new objects, traps, baits and bait stations should be placed near, but not on runways. Here they will be found quickly and, after a short period, explored cautiously. To diminish the effects of neophobia in rat control operations it is common practice to place bait boxes or baited but unset traps in position for several days before poisoning or trapping operations are begun.

Rats and mice tend to have a limited home range when living in the presence of ample food, water and shelter. Norway rats living in residential areas in Baltimore and around farm buildings were found to reside for several months in an area 30-50 m in diameter (Davis et al., 1948). Brown (1953), in his study of farm mice, found that most individuals moved no more than 3-10 m daily and other work by Emlen et al. (1958) and Rowe & Swinney (1977) also showed that the indoor movements of mice are localized.

Similar studies have been made on roof rats in Pacific Islands and in Cyprus. Most individuals were recaptured within 15-50 m of the site of original capture (Kartman & Lonergan, 1955; Spencer & Davis, 1950; Watson, 1951), males moving longer distances than females.

Such limited movements occur under rather constant environmental conditions; seasonal or other changes in the environment may cause rats and mice to move much greater distances. Errington (1935) reported that Norway rats in Wisconsin moved considerably different distances in fields in the summer and winter months and, on arable land in Britain, individual rats have been found to make journeys of 0.5 km to farm buildings (Taylor, 1978).

Rowe et al. (1963) recorded significant movements of house mice from fields into the shelter of English corn ricks with the beginnings of cold weather in autumn and, as with rats, feral animals generally range much further than those individuals living indoors (Berry, 1970).

5.2 Foods and feeding behaviour

According to Jackson (1965), commensal rodents have taste patterns similar to that of man, and rats have been observed to select a nutritionally balanced diet when given the opportunity to choose from a wide range of different foods. The Norway rat is omnivorous, consuming waste foods, stored foodstuffs, growing crops and other food items. In the urban environment it acts as a scavenger, feeding, to a large extent, on human and animal refuse. Foods preferred by Norway rats are cereal grains and seeds, meats and fish, nuts, cooked eggs, and some fruits (Schein & Orgain, 1953; Shuyler, 1954). Garbage offers them a fairly balanced diet and also satisfies their water requirements. Among the cereal grains and seeds, some observers (Cornwell & Bull, 1967a; Crabb & Emik, 1946; Shuyler, 1954) found that Norway rats liked oats and maize best but others have reported that wheat (Barnett & Spencer, 1949) or barley (Eckart, 1936) are preferred. A previously unreported bait that Norway rats and roof rats find very attractive is hulled proso millet (Panicum miliaceum) (Brooks & Bowerman, 1973b; Barnett et al., 1975). Kahn (1974) found that R. rattus held in the laboratory preferred cereal flours to whole grains and that millet (Pennisetum vulgare), maize and wheat were chosen in that order.

The roof rat freely changes its dietary needs to utilize insects and herbivorous foods if necessary but, in general, it prefers grains, seeds, nuts and fruits. House mice were found to prefer whole canary seed, Phalaris canariensis, in laboratory tests, but oatmeal and wheat were also well accepted (Rowe et al., 1974a). Rats living in field situations can subsist on a variety of naturally occurring foods supplemented with field crops. In sugar cane growing areas of Hawaii, Kami (1966) found that roof rats lived on grass seeds, stalks, nuts and fruits when they lived in the gulches adjacent to the cane fields. Brooks & Barnes (1972) reported that Norway rats infesting rice fields in California lived on grass and weed seeds and tubers of Scirpus and Typha during the off-season.

Adult Norway rats eat about 25 g (about 10% of their body weight) of dry food a day (Chitty & Southern, 1954) and Schein & Orgain (1953) found that they consumed about 39-40 g of mixed garbage in a day. Norway rats require about 15-30 ml of water a day when feeding on dry foods, less when eating moist foods. Roof rats can live on cereals for relatively long periods without access to free water. Mice eat only about 3-4 g of dry food daily (Strecker & Emlen, 1953) and, although they normally drink about 3 ml of water daily, Chew & Hinegardner (1957) found that they can survive on as little as 0.3 ml. Later studies showed that house mice could survive for months without free water when they were given a diet of seeds (Fertig & Edmonds, 1969) and that they were also capable of subsisting on sea-water and laboratory chow (a standardized pre-mixed rodent diet), losing only about 20% of their original body weight. It is not surprising, therefore, that this species exists in arid regions and thrives in food stores in the absence of free water.

In general, rats have rather more regular feeding habits than mice and, when accustomed, tend to eat steadily on foods situated at known sites; mice are lighter and more intermittent feeders and generally more erratic in their feeding behaviour. Initially, however, both rats and mice sample new foods cautiously and in small amounts. Just as exploratory behaviour gives the rat experience of every feature of the environment, food sampling informs it of the kinds of nourishment that are available. By this means the rat learns not only where the foods are located but also acquires information on their attractiveness and relative nutritional value. When baits containing a quick-acting poison (see later section on Rodenticides) are used for the control of commensal and other rodents, it is common practice to lay unpoisoned baits for from four to eight days before poison baiting is begun. The adoption of this technique, commonly referred to as "pre-baiting", allows rats or mice to get well used to feeding at a known site and on a particular bait, so that when poison bait is laid they are likely to feed on it readily and rapidly (Doty, 1938; Chitty & Southern, 1954; Czyzewski, 1956). Use of the pre-baiting technique thus helps to ensure that a lethal dose of poison is taken before illness develops and feedings stops. Survivors are more likely to occur when acute poison baits are laid directly; having experienced the effects of a sublethal dose of the poison, the rodent may avoid eating more of the same poison bait for weeks or even months afterwards. This phenomenon, which is often called "bait or poison shyness", was clearly demonstrated in experimental studies conducted by Rzoska (1953).

The carrying of food to cover is another aspect of rat feeding behaviour that may be of importance in control programmes. Carrying is most likely to occur when bait in the form of large particles or pellets is used or when it is included in packets or sachets; it is generally prevented by utilizing finely ground bait. The motive behind this behaviour appears to be simply the withdrawal of food to a secure place to feed and not the storage of food as a protection against scarcity (Barnett & Spencer, 1951; Calhoun, 1962). The advantages and disadvantages of bait carrying in relation to practical control programmes are not well understood and additional study of this behavioural trait is needed.

5.3 Social behaviour

The natural social behaviour of Norway rats, roof rats and house mice involves territorial and hierarchical behaviour. Males of each species are territorial under conditions of low to moderate population densities. High ranking males often defend a system of burrows, runways or nest sites and a number of females that live in the immediate area (Barnett, 1975; Calhoun, 1962; Crowcroft, 1966; Ewer, 1971). Females which are in a late stage of pregnancy or nursing young will also defend the nest and its immediate environs.

In his study of Norway rats in an outdoor enclosure, Calhoun (1962) found that certain males dominated the most favourable places close to the food supply, established territories there, and controlled burrows containing several females. As the population increased, social competition forced lower ranking rats, especially males, into fringe areas. The frequent contacts between subordinate males in these areas led to the development of unstable social structures and normal territories were not delineated. Oestrous females were pursued and harassed by packs of males and the considerable stress experienced by them resulted in poor reproductive success. In this study however, and unlike in the field situation, confinement prevented any dispersal or immigration.

Ewer's (1971) observations of a free-living population of R. rattus in Accra, Ghana, showed that this species also has a definite social structure. A single dominant male was always present and at times a linear hierarchy was evident among the older males. Furthermore, there were usually two or three mutually tolerant, top-ranking females which were subordinate to the most dominant male but dominant to all other members of the group. Aggressive attacks were all directed downwards in the social scale but serious fights tended to be avoided. Attacked subordinates either fled or resorted to appeasement behaviour; the latter proved extremely effective when performed quickly and helped to stave off attacks even from the most dominant individuals. A group territory around the feeding place was defended by resident rats against strangers, both sexes aiding in defence. Females were most active in excluding strangers of the same sex because the resident males were inhibited in attacking females. The territorial boundaries were fixed but resident rats frequently explored beyond the territory limits and thus became familiar with a larger area. Although intruders were normally driven out, it was found that certain individuals of either sex occasionally succeeded in becoming included in the population.

Similar studies on house mice have shown parallel behaviour patterns. As house mice populations confined to a penned area increased in size, they displayed increased aggression; population growth became retarded because infant mortality was high as the result of nest destruction (Southwick, 1955a, b) or ceased, because adult females remained in a non-breeding condition (Crowcroft & Rowe, 1963).

Male mice are hierarchical, with certain males showing territorial behaviour and exclusively dominating small groups of breeding females. Thus a population can be divided into small breeding units, all the paternal genes coming from a few individuals (Reimer & Petras, 1967, 1968). Although there is generally little or no aggressive behaviour within a small family group of mice (one male, several females and young), introduced strangers are detected quickly, smelled intensively, and attacked vigorously, even by some of the young individuals (Rowe & Redfern, 1969). If contact with a stranger is lost, resident mice, particularly dominant males, carry out active searches until the stranger is detected again. As with rats, olfaction is known to play an important role in individual recognition in wild house mice (Bowers & Alexander, 1968). It seems probable that the low level of aggression in related mice is due to frequent mutual identification operating through recognized olfactory cues; strangers, which smell different, are quickly isolated and attacked (Archer, 1968).

Territorial behaviour, in both rats and mice, results in the dispersal, or spreading out of the population and, thus, in the full utilization of the effective living space and resources.

6. POPULATION CHARACTERISTICS

General laws governing the growth and decline of rodent populations have been formulated by Davis (1953) who studied discrete Norway rat populations living in urban areas. Changes in population size are dependent on the birth rate (natality), the death rate (mortality) and movement (immigration and emigration). The relative significance of each of these operating factors determines whether a particular population grows, declines or remains at about the same level. The extent to which each factor operates essentially depends on limitations imposed by the physical environment, predation and disease, and intraspecific competition.

6.1 Environmental resources

The important physical elements necessary to sustain commensal rodent populations are food, water and harbourage. Their abundance and distribution has a direct bearing upon how many rodents can be supported in a given environment. Commensal rodent populations thrive best when all three elements are abundant and in close proximity.

The main food sources for commensal rodents are stored foods and garbage in urban areas and, in rural areas, field crops, natural vegetation and seeds. Stored foods are available in grain mills, warehouses, port facilities, food processing plants, feed bins and corn cribs; waste foods and spilled grain are other important food sources. Warehouses containing food stored in bags or in bulk is particularly vulnerable to rodent attack unless they are protected. Improperly stored and handled garbage can do much to enhance rat problems in urban environments; in one study (Bureau of Community Environmental Management, 1972), there was poor garbage disposal and collection in 30-40% of all premises examined in deteriorated neighbourhoods.

Water is generally available to rodents in urban and rural environments but its supply can be a problem for Norway rats, particularly those living in well-structured warehouses or in areas with dry seasons. The Norway rat needs foods with a high moisture content or a supply of free water, and lack of water may restrict its distribution or increase. House mice, which utilize metabolic water more efficiently (Fertig & Edmonds, 1969), tolerate dry habitats without difficulty and the roof rat also withstands water deprivation better than the Norway rat.

Harbourage for rodents is usually abundant in both urban and rural areas. Rats and mice can usually penetrate deteriorated or faulty structures, cellars, basements, alleyways and street drains without difficulty and rats burrow in gardens, yards, river banks and the spaces between walls and fences. Apart from house refuse and debris, municipal garbage dumps, cesspits, old sheds, farm barns etc., vacant lots with weeds and debris, piles of wood and lumber, and heaps of broken concrete and bricks can also provide ideal harbourage for rats and mice.

6.2 Reproduction

Reproductive activity in commensal rats and mice is characterized by rapid sexual maturation, short gestation period, post-partum oestrus, polyoestrous breeding throughout much of the year and large litter size. These traits give commensal rats and house mice the potential for very rapid population growth and for quick replacement when their numbers are reduced by man's poisons, traps or by other means.

The results of reproductive studies of female commensal rodents are summarized in Table 3. This table, which gives straight unweighted averages of all values so that studies with very large or small samples would not bias the results unduly, enables interspecific comparisons to be made. An inverse relationship between the pregnancy rate and number of embryos produced per female is evident. R. norvegicus has the lowest average pregnancy rate but the highest average litter size; M. musculus, conversely, has the highest pregnancy rate but the lowest average litter size. Of the three species, the house mouse attains the highest annual productivity, about 45 young per female (Laurie, 1946). M. musculus achieves this relatively higher productivity through the combination of high incidence of pregnancy, short gestation period (19-20 days) and rapid sexual maturation.

TABLE 3. SUMMARY OF REPRODUCTIVE PATTERNS OF FEMALE COMMENSAL RODENTS
(ADAPTED FROM BROOKS, 1973 AND VARIOUS OTHER SOURCES)

	R. norvegicus	R. rattus	M. musculus
Age at sexual maturity	75 days	68 days	42 days
Gestation period	22-24 days	20-22 days	19-21 days
Average per cent. of adult females visibly pregnant (and range)	21.4% (10.7-34.8)	28.6% (12.9-48.8)	35.3% (19.8-50.5)
Average number of embryos per female (range)	8.8 (7.9-9.9)	6.2 (3.8-7.9)	5.8 (3.9-7.4)
Incidence of pregnancy	4.32	5.42	7.67
Production/female/year	38.0	33.6	44.5
Number of studies	15	18	11

Under conditions of optimum climate, surplus food, and abundant shelter, commensal rodent populations tend to breed throughout the year. These conditions are commonly found indoors in food stores, warehouses, farm buildings and ships. The breeding performance of rats and mice living outdoors in temperate climates, however, may be reflected in either a unimodal peak in activity during the milder spring, summer and autumn months or in bimodal peaks occurring in the spring and autumn. The reproductive pattern may also differ in the same population from year to year.

Male commensal rats and mice generally remain in breeding condition throughout the year although the testes may be retracted into the abdominal cavity during periods of cold weather giving the appearance that they are infertile. Even in very cold areas, a minor amount of breeding may take place throughout the winter months, although it is doubtful if the young are always raised successfully unless they are reared indoors.

Norway rats construct a neat nest of grass, waste paper, twine or other suitable materials in a separate chamber within a burrow system or in the natural spaces within buildings. Likewise, house mice build nests in wall and roof cavities, in stacks of food or cabinets, drawers, etc. Roof rats living outdoors often build nests in shrubs or trees, constructing them from twigs, leaves, grass and other plant materials.

The infants of all three species need constant maternal care for at least three weeks after birth. They are born pink and hairless and with the eyes and ears closed; at this stage they respond primarily to tactile stimuli and to body heat. The important stages of growth and development in the three commensal species are summarized in Table 4.

TABLE 4. GROWTH AND DEVELOPMENT OF COMMENSAL RODENTS

	Rattus norvegicus	Rattus rattus	Mus musculus
Gestation period	22-24 days	20-22 days	19-21 days
Birth weight	5-6.5 gm	4-5 gm	0.8-1.5 gm
Condition at birth	Hairless, pink	Hairless, pink	Hairless, pink
Ears open	3-4 days	6 days	3-4 days
Eyes open	16 days	14-15 days	11-14 days
Lower incisors erupt	10 days	10 days	9-10 days
Upper incisors erupt	11 days	11 days	7-8 days
Age at weaning	28 days	28 days	25 days
Weight at weaning	45-65 gm	30-40 gm	7-8 gm
Breeding maturity in females	75 days	68 days	42 days

6.3 Mortality factors

Studies of mortality in populations of wild rats and mice are difficult to carry out and consequently few in number. The actual cause of death is not as important as the death rate. Davis (1948), determined the death rate of Norway rats on a farm in Maryland and found that only about 5% survived 12 months and that females lived longer than males. Harrison (1951) who studied roof rats in peninsula Malaysia estimated that the probability of dying (the number of deaths in a group divided by the initial number in the group) was 0.97 per annum, a death rate similar to that found to occur in farm Norway rats. In later work, Harrison (1956) estimated monthly mortality in R. diardii populations (20% for males and 17% for females), the total annual mortality for both sexes being 98%. Mortality data in feral house mice on a small Welsh island (Berry & Jakobson, 1971) indicated a summer mortality of over 20% per month and an average life expectancy of about 100 days. The turn over of mice occupying farm buildings has also been found to be rapid, more than 50% of isolated populations disappearing within eight weeks (Rowe & Swinney, 1977).

Predation and disease can be prime causes of mortality in rodent populations. The main predator of rats and mice is man himself, using killing techniques such as poisons, traps, or gases. There is some disagreement as to the value of dogs and cats as predators of rats and mice. Jackson (1951) found that the presence or absence of city cats had no measurable effect upon rat populations. Davis (1957), however, concluded that cats on farms do have an effect upon rat populations, taking sufficient young rats to prevent the normal large population increase in the spring. Elton (1953) considered that cats helped to prevent the infestation of farm buildings but that they were ineffective against entrenched rat and mouse populations. Similarly, many other predators - owls, foxes, ferrets, weasels, mongooses and snakes, take their toll of rodent populations but they rarely exert a significant influence upon population size. The Norway rat is itself a predator of the house mouse but, even so, it is not uncommon to find both species occupying the same habitat.

Rodent parasites can be regarded in a similar manner; they can cause severe debility in rodents but, less commonly, death. The plague organism, Yersinia pestis, is often highly fatal in rats but other organisms, such as Rickettsia mooseri or Leptospira icterohemorrhagiae, produce few symptoms and are rarely fatal, although rats are known vectors of these organisms. Rats and mice in natural high density populations have been found with pulmonary infections, resembling pneumonia or bronchiectasis (Calhoun, 1962; Pearson, 1963). Infection generally occurs in older individuals subjected to severe stress.

Some types of Salmonella organisms may cause severe epizootics among rodent populations (Davis, 1953), but the effect is generally short-lived and populations recover rapidly. This is one reason why the use of such pathogens to control rats has not been widely adopted, another being the potential danger to non-target species, including man, from the serotype of those organisms which have been occasionally used in rat control campaigns. FAO/WHO (1967) has recommended against the use of Salmonella organisms as rodent control agents.

6.4 Population growth, competition and dispersal

A rodent population that has been reduced in size recovers slowly at first and then at an increasingly faster rate. As it approaches the capacity of the environment, the primary limitations being food, water and shelter, growth slows down and the population tends to level off. In an unchanged environment it might be expected that the population would remain at essentially the same level. In reality, however, such a population has been found to fluctuate somewhat around the carrying capacity of the environment (Davis, 1953).

There is considerable evidence from confined colony studies that rodents compete more fiercely for food, shelter and living space as the population density increases. At very high densities, rats and mice spend inordinate time and energy in aggressive attacks and in the defence of territories. Wounded individuals become relatively easy victims of disease and death. The reproductive performance of females can also be seriously impaired as the result of aggressive behaviour; nest destruction and desertion becomes particularly common with resultant high mortality in newborn and immature animals.

Profound physiological effects have been observed in crowded rat and mouse populations. Christian (1950) concluded that the function of the adreno-pituitary hormonal system was disturbed in rats under severe stress through overcrowding and hypothesized the operation of a negative feedback mechanism, whereby the birth rate fell and the mortality rate increased. While it is known, from studies of growing colonies of rats and mice held in close confinement, that populations tend to be self-regulatory under these conditions (Christian, 1956; Calhoun, 1962; Southwick, 1955b; Crowcroft & Rowe, 1963), there is little evidence that natural populations are much regulated in this manner. For example, reproduction was not found to be seriously inhibited in dense populations of mice inhabiting corn-ricks in Britain (Southwick, 1958; Rowe et al., 1964). Dispersal, which is prevented in confined population studies, is the more likely outcome when natural populations increase and marked competition occurs (Brown, 1960).

7. RODENTS AND HUMAN DISEASE

Rodent-borne diseases are known collectively as zoonoses, a term meaning "an infection or an infectious disease transmissible under natural conditions from vertebrate animals to man". Such diseases are numerous and only the most important ones are considered here.

7.1 Plague

The greatest and most fearful epidemic to descend upon man was the pandemic of the Black Death that originated in Asia and swept Europe and the Middle East from 1347 to 1350 A.D. At the height of this epidemic, thousands died daily and by the time it ended at least one-third of Europe's population had perished. Zeigler (1969) has given a graphic account of the terrifying nature of this epidemic as it moved from city to countryside across medieval Europe. This occurrence was of the greatest economic and social importance to Western man. Another two centuries would pass before Europe fully recovered from the catastrophe.

Human and animal plague within the last decade have been reported from several countries in South-East Asia, Indonesia, the USSR, Iran, Yemen, Libya, South and East Africa, Zaire and Madagascar, Equatorial Guinea, Brazil, Bolivia, Ecuador, Peru and western United States. During the period 1968-1977, a total of 28 042 human plague cases from 21 countries were reported to WHO, of which 1467 died. Of special interest is the recrudescence of human cases which appear after long years of quiescence. Such cases were seen in Indonesia in 1968 after an absence of seven years and in the focus on the Yemen - Saudi Arabian border where human plague appeared in 1969 after not having been found since 1952.

Plague is an acute febrile, highly fatal (when not treated) epidemic disease of man and rodents. It is caused by a bacillus, Yersinia (Pasteurella) pestis, and is characterized by inflammation and swelling of the lymph glands (buboes), septicaemia, petechial haemorrhages, and in some cases, secondary invasion into the lungs, causing pneumonic plague. Plague is primarily an infection of rodents, transmitted from rodent to rodent and from rodent to man by fleas. The principal flea vectors are several species of Xenopsylla. Man can also acquire the infection through direct contact with infected animal tissues. Pneumonic plague can result from direct human to human transmission.

Plague persists in rodent populations in many parts of the world in an enzootic (asymptomatic) form. In western United States the enzootic hosts are mice, especially deer mice (Peromyscus) and meadow voles (Microtus). Occasionally, plague is transmitted by fleas from these enzootic hosts to several species of plague-susceptible squirrels, chipmunks, wood rats, marmots and prairie dogs, which may then suffer epizootic plague and die in vast numbers. The enzootic and epizootic hosts of plague in tropical areas are not as well recognized as those in temperate climates and require further study before the complete transmission cycle is known.

Urban rat-borne plague remains a potential threat wherever commensal rat species come into contact with either the enzootic rodent species or the epizootic plague-susceptible rodent species in urban or peri-urban areas. The transfer of Y. pestis organisms from native rodents to commensal rats by exchange of fleas occurs rather easily. Once commensal rodents become infected, the risk to the human populace is greatly increased.

The recent war in Viet Nam, through its intensive disturbance of the ecology of human populations, led to a human epidemic of plague. Plague was recognized in several species of commensal rats living in human habitations and around the major ports and airfields. Strict rat and rat-flea control procedures were applied to cargo storage areas in Viet Nam and to containerized cargo in shipboard transit. As a result, plague was confined to Viet Nam and not carried to other parts of the world.

7.2 Murine typhus

Murine typhus is a rickettsial infection in man and commensal rodents of worldwide distribution. The causative organism is Rickettsia mooseri (sometimes also referred to as R. typhi). The mode of transmission is by infected flea faeces. The itch from a flea bite causes a person to scratch, and the flea faeces which were deposited on the skin while the flea was feeding are rubbed into the bite, thereby infecting the person. The principal flea vector is the oriental rat flea, Xenopsylla cheopis, although several other species of fleas are also believed capable of transmitting the rickettsiae. The infection of humans has been shown to be closely linked with the presence of commensal rats living in indoor urban environments and is less commonly seen in rural areas (Traub et al., 1978).

Murine typhus in man is characterized by sudden onset, marked by headache, chills, prostration, fever and general body pains. A spotted skin rash appears on the fifth or sixth day. The disease usually runs its course after about two weeks of fever unless treated promptly with antibiotics. Fatality is quite low, running about 2% for all age-groups but increases with age.

The distribution of this disease is worldwide, mainly in areas with warm climates and it is probably quite common wherever commensal rat populations are high, especially in seaport areas. Cases of murine typhus in the United States of America reached a peak in 1944 when more than 5000 cases were reported annually. At that time, the widespread use of DDT for rodent flea and rodent control along with environmental sanitation were credited with sharply reducing the incidence of the disease in the southern states. Since that time, the incidence of cases has remained low and in 1973 there were only 32 cases reported in the United States of America. In Israel, likewise, some 800 cases were reported yearly until 1952 (Gratz, 1973b) and then its incidence greatly declined following a DDT dusting campaign and has remained low despite the human population growth. The control of the disease, where it is a problem, is essentially that of killing the flea vector as in plague control, using techniques described in detail under the section Ectoparasite Control.

7.3 Leptospirosis

Leptospirosis, or infectious jaundice (Weil's Disease) is an important worldwide disease of man, commensal rodents, dogs, pigs and cattle. Rat-borne leptospirosis is caused by a spirochete, Leptospira icterohemorrhagiae, which lives in the rats' kidneys and is shed in the urine. Humans may contract the disease by swimming in contaminated water or from contact with moist soil containing infected urine. More frequently, however, people get the disease either by handling a sick animal or coming into contact with infected animal tissues.

Leptospirosis is a serious disease characterized by fever, chills, severe body pains, vomiting and conjunctivitis. Occasionally meningitis, jaundice, renal insufficiency and haemorrhages in the skin and mucous membranes are symptoms. The clinical illness may last up to three weeks but relapses can occur. Fatality is high, increases with age, and may reach 75% in cases with jaundice and kidney damage.

Rat-borne leptospirosis is generally considered to be the classical form of the disease but recently it has been found that there are more infections transmitted from cattle, swine and dogs than by rats. Leptospirosis is an occupational disease among persons involved in direct contact with infected animals, their tissues and soil or water contaminated with their urine. In Great Britain some occupational groups formerly associated with leptospiral infections are now seldom affected, such as sewer workers, fish cleaners and miners (Turner, 1973). In rice field workers in Spain and Italy, leptospirosis of rat-borne origin is still an important disease and it is spreading in certain port areas of the Middle East.

7.4 Salmonellosis

Salmonellosis is a collective term for the infection of man or animals with organisms of the bacterial genus Salmonella, and is known commonly as infectious food-poisoning. Salmonella organisms of several hundred different serotypes infect a variety of domestic animals, poultry, wildlife and rodents. Of concern here are the serotypes infecting rodents that are transmitted to man in contaminated foods or liquids.

Rats and mice are most commonly infected with S. typhimurium (S. aertrycke) or S. enteritidis and certain varieties of these two serotypes can cause serious mortality in commensal rodents. While they have been proposed as biological control agents, their use in rodent control has not been particularly successful (Laird, 1966) and there is considerable danger to man and domestic animals (Taylor, 1956).

Salmonellosis in man is characterized by acute gastroenteritis, abdominal pain, diarrhoea, nausea, vomiting and fever; dehydration, especially among infants, can also be severe. Rats and mice are capable of spreading the infection to man through infected faecal droppings and urine. Infection most commonly occurs as the result of contaminated foods or food preparation surfaces in bakeries, markets and restaurants. The house mouse probably plays a greater role than rats in the transmission of food poisoning diseases.

7.5 Lymphocytic choriomeningitis

Lymphocytic choriomeningitis (LCM) is a viral disease of animals, especially mice, transmissible to man. The disease often begins with an influenza-like attack; complete recovery may occur, or, after a few days of remission, meningeal symptoms suddenly appear. Patients with meningo-encephalitis show somnolence, disturbed reflexes, paralysis and anaesthesia of the skin. Most patients recover within a few weeks although the disease is occasionally fatal.

The reservoir of this disease is primarily the house mouse. When adult mice are infected with the virus they either die or recover after a short period, with or without showing signs of the disease.

The embryos of female mice which become infected during pregnancy are similarly affected and transmission can also occur during the first seven to eight days after birth. The young mice become tolerant to the virus; that is, the virus can be found in their blood and organs for as long as they live. They show no signs of illness nor do they produce antibodies, i.e., they carry the virus in a latent state. Their offspring also inherit this trait along with the virus, and so on indefinitely. The blood and organs of tolerant mice contain the virus in high concentrations, as does the urine, faeces and nasal secretions. This latent form of infection has great significance as a reservoir of the virus. Foci of infection in mice can persist for years within the limits of a city block, resulting in sporadic clinical cases.

7.6 Rickettsial pox

Rickettsial pox is a mild rickettsial infection of man and house mice, transmitted by the bite of the house mouse mite, Allodermanyssus sanguineus. The causative agent is Rickettsia akari. In man the disease is characterized by a papular lesion that develops first at the site of the infecting mite bite. About a week later, fever, chills and headache develop. Within two or three more days a varicelliform rash appears over most of the body.

In the summer of 1946 cases of this disease, until then unknown, occurred in housing developments in New York City. The symptoms were typical of an outbreak of chickenpox in adults. Investigation showed that the buildings were infested with house mice and their mites and the mode of transmission was soon discovered (Huebner et al., 1946, 1947). Rickettsial pox has also been reported from urban areas in Connecticut, Massachusetts, Pennsylvania and Ohio but no cases have been seen in the United States of America since 1969. Cases have been reported in the USSR, where commensal rats also may be involved in the natural cycle. In Equatorial and South Africa, cases clinically and serologically consistent with rickettsialpox are contracted in the bushveld, suggesting a wild rodent/mite natural transmission cycle.

7.7 Rat-bite fever

The wild Norway rat is notorious for biting the hand that feeds it. This is literally true since rats bite the hands or fingers of humans more frequently than any other part of the body. Scott (1965), conservatively estimates there are some 14 000 victims of rat-bite annually in the United States of America.

Rat bites occur most frequently in children under 12 years of age (Richter, 1945; Sallow, 1953). Two disease organisms may be transmitted to man as the result of a rat-bite: Spirillum minus, the causative infectious agent of sodoku and Streptobacillus moniliformis, causing a disease known as Haverhill fever. Tetanus is an ever-present possibility following a rat bite and the wounded victim should receive prompt medical attention and tetanus immunization if this has not been done within the past five years.

7.8 Rabies

One disease so extremely rare in commensal rodents that it hardly deserves mention is rabies. Bites of rats and mice seldom, if ever, call for rabies prophylaxis. Winkler (1972) summarized information regarding rabies and rodents in the United States of America and concluded that rabies in rodents is a rare phenomenon in that country. He considered that the circumstances of each rodent bite should be evaluated, however, since about four or five cases of confirmed rodent rabies are reported each year out of some 25 000 rodents examined. In areas endemic for rabies, every attempt should be made to capture, identify and examine those rodents inflicting bites. While Winkler's conclusion regarding rabies in rats and mice in the United States of America may be valid, much additional information needs to be obtained regarding the role of commensal rodents in other areas where rabies is endemic. In such areas rabies prophylaxis may still be justified when laboratory facilities are not available for the close examination of suspect rodents or other species.

7.9 Trichinosis

Trichinosis is a nematode parasite infection of man, rodents, swine and some other species. The causative agent is a nematode, Trichinella spiralis which occurs worldwide in rats and pigs. In man, the disease runs a rapid course of fever, gastrointestinal symptoms, muscular pain and eosinophilla. It is sometimes fatal.

Man almost always acquires the infection from eating infected raw or undercooked pork. In Europe, infection in man is much less common now than it was a century ago and in the United States of America, laws requiring the cooking of raw garbage for pig feeding have gone far in reducing its incidence.

Rats are infected by eating other infected rats or discarded pig trimmings around slaughter houses. Dogs, cats and other mammals develop the infection from eating infected rats. Pigs have been shown to contract trichinosis from infected rat faeces contaminating their food.

7.10 Other endoparasites

Rats and mice serve as hosts of numerous intestinal parasites some of which also infect man. For example, the two small tapeworms, Hymenolepis nana and H. diminuta can be transmitted from rodents to man. Infection occurs when food is eaten that has been contaminated by rat or mouse faeces containing the microscopic eggs of the tapeworms.

Another rat-borne parasitic infection is eosinophilic meningitis, a disease of the central nervous system in man caused by a nematode (Angiostrongylus cantonensis), the lungworm of rats. The disease is found in South-East Asia, Hawaii, Tahiti and many other Pacific islands. The rat is the reservoir for this nematode which is transmitted to man through intermediate hosts, such as raw or insufficiently cooked snails, land crabs and prawns.

Infection in man is marked by the onset of severe headaches, stiffness of the neck and back, and various morbid sensations. Temporary facial paralysis may occur but death is rare.

8. ECONOMIC IMPORTANCE

It is difficult to obtain accurate information on the losses of foodstuffs and the damage to structures caused by commensal rodents and the costs (money, time and labour) expanded in their control. Estimates sometimes are little more than expert guesses. Even though some of the estimates may seem exaggerated, there is common agreement that the damage and losses caused by rats and mice are substantial and that they can be ill-afforded in these times of rapid human population growth.

Several recent articles have reviewed the world-wide situation concerning rodent damage and losses to both growing crops and to foods stored after harvest (Hopf et al., 1976; Jackson, 1977; Taylor, 1972a, 1972b). All agree that the problems caused by rodents are most acute in the tropics and subtropics, and thus severely affect developing countries. The survey carried out by the Centre for Overseas Pest Research (Hopf et al., 1976) revealed, in broad outline, the major rodent problems in the tropical and subtropical regions of the world. Rice is the most frequently mentioned crop to suffer damage in all the areas where it is grown. Other crops, such as maize, sorghum, millet, oil palm, coconuts, groundnuts, cocoa, sugar cane and vegetables are also seriously at risk. Some selected examples of estimated food crop losses are given in Table 5. The information should be accepted with caution and used only as a guide to the possible magnitude and variability that might be encountered. Of the commensal rodents, R. rattus was by far the most frequently mentioned and widely distributed pest, followed by M. musculus. Least important, and then only locally, was R. norvegicus.

TABLE 5. ESTIMATED LOSSES OF FOOD CROPS DUE TO DAMAGE BY COMMENSAL RODENTS

Field crop	Area	Estimated damage or loss (%)	Source
Sugar cane	Jamaica	5	Taylor, 1972b
	Hawaii	4-40	Hilton, 1968
	Barbados	6	Taylor, 1972b
Rice	Philippines (average yearly)	10	Alfonso, 1968
	Philippines (outbreak year)	90	Townes & Morales, 1953
	Philippines (National survey)	2-18	Schaefer, 1975
	Java	40	Soekarna, 1968
	India	6-9	Srivastava, 1968
Coconuts	Tokelau Islands	30-40	Wodzicki, 1972
	Ivory Coast	10-15	Smith, 1967
	Tarawa	23	Smith, 1968
	Tahiti	27-47	Smith, 1967
	Fiji	5-13	Williams, 1974
	Jamaica	5-36	Smith, 1967
Cocoa	Solomon Islands	1-9	Wilson, 1968
Macadamia nuts	Hawaii	16	Erskine, 1968
Carob	Cyprus	3	Watson, 1951

Stored foodstuffs are particularly prone to rodent attack - the food items concerned varying from area to area largely in relation to the predominant, locally grown foods. Cereal crops constitute by far the largest proportion of stored commodities, and are therefore the most vulnerable. Most common are maize, rice, sorghum, millet, barley, oats, wheat and cereal products, such as flour, maize meal and semolina. Oilseeds and oilseed cakes are frequently attacked as well as groundnuts, cotton seed, sunflower seed, mustard seed, linseed, sesame, coconuts and copra. In some areas pulses (various dry food grain seeds of leguminous plants) are damaged as well as root crops, such as potatoes, yams, sweet potatoes and onions. Miscellaneous food items also consumed by commensal rodents include powdered milk, cocoa beans, bread and sugar. The most frequently attacked types of storage containers are sacks or bags, made of cloth, jute, sisal or plastic.

Much food loss occurs as the result of contamination, supplies being rendered unfit for human consumption by rodent hairs, faecal droppings and urine which are shed liberally as the animals forage nightly for their food. Additionally, organisms such as Salmonella bacteria (Smith, 1969) and Leptospira spp. (Alston & Broom, 1958), or protozoan parasites such as

Entamoeba histolytica (Neal, 1951) and Giardia muris (Conroy, 1960) are spread to man through rodent-faeces and urine-contaminated foods. In many countries foodstuffs for human consumption are inspected for rodent contamination and other filth. Past surveys in some areas of Britain (Kent, 1959) and in the United States of America (Harris et al., 1952) revealed that contamination of cereal grains was particularly common.

While damage to stored foods is widespread, estimates of damage are imprecise and poorly documented. The best information available is summarized by Hopf et al. (1976) and an extract is presented in Table 6. In all, some 245 replies to postal questionnaires were received from different parts of the world. As with growing crops, the major species concerned are R. rattus and, to a lesser extent M. musculus.

The amount of food lost through actual consumption by rodents is considerable. An average sized Norway rat eats about 20 to 25 g of food a day, or the equivalent of 7 to 9 kg in a year. Barnett (1951) found that small colonies of Norway rats (10 to 26 animals), each with access to a ton of sacked wheat for 12 to 18 weeks, contaminated 70% of the grain and caused a 4.4% loss of weight. The main monetary loss, however, resulted from damage to the sacks. Total losses from all causes were 18.2% of the total value of the wheat and the sacks.

Mice can cause serious losses to foodstuffs in markets, bakeries, mills, warehouses, animal feed stores, and corn cribs. House mice eat only about 3 g of food per day but because of their habit of nibbling and then discarding partially eaten foods, they destroy considerably more food than they consume.

Commensal rodents also damage man's structures through their burrowing and gnawing habits. Rats undermine the foundations of buildings, and cause settling in roads. Their burrows connecting sewers with the ground surface lead to excessive infiltration of storm water run-offs into sewers. Such burrows can cause the collapse of railway tracks (Pingale, 1966) and damage the banks of irrigation canals and rice field levees.

Rats and mice are known to gnaw electrical and telephone cables (Neuhaus, 1957) and plastic waterpipes. They damage bituminous fibre pipe creating fire hazards or causing disruption (Wolf, 1962). They will also attack the walls, floors, window sills and doorways of buildings as well as undermining the entire structure. The amount of structural damage due to commensal rodents has never been adequately assessed but repair and replacement costs can be substantial. Prevention of this type of damage alone would probably justify most of the commensal rodent control carried out in the world today.

In addition to the losses and contamination of foodstuffs and the costs of repairing human structures, account must be taken of the amount of money and labour expended in commensal rodent control throughout the world; again, no estimates of the amounts involved have ever been prepared.

TABLE 6. ESTIMATED DAMAGE AND LOSSES OF STORED CROPS AND OTHER FOODSTUFFS DUE TO COMMENSAL RODENTS IN TROPICAL AND SUBTROPICAL AREAS
(Hopf et al., 1976)

Area	Type of storage	Commodities attacked	% damage or loss
Brazil	Stacks, sacks, cribs	Rice, maize, beans	4-8
Bangladesh	-	Rice, pulses, grains	2-5
Egypt	Open and closed stores	Cereal grains	0.5-1
Ghana	-	Maize, rice, grain	2-3
India	Warehouses, sacked	Cereal grains	5-15
Korea	Sacks in houses and stores	Rice, barley	20
Laos	Stores	Rice, maize	5-10
Malawi	-	Maize, rice	1-7
Mexico	Granaries, sacks, cribs	Maize, rice, groundnuts	5-10
Malaysia (Sarawak)	Cribs	Rice	5-10
Nepal	Sacks	Maize	3-5
New Hebrides	Covered platform	Yams	10
Nigeria (Kaw State)	Temporary or closed stores	Pulses and groundnuts	3-5
Philippines	Warehouses, sacks	Rice, maize, legumes	2-5
Sierra Leone	Temporary cribs or sacks	Rice, maize, groundnuts	2-3
Solomon Islands	-	Yams	5
Thailand	Sacks, cribs	Maize, rice, copra	5
Turkey	Warehouses, sacks	Wheat, rice, maize, legumes	5-15
Tunisia	Warehouses	Cereal grains, legumes	6-8

9. COMMENSAL RODENT CONTROL

The control of commensal rodents is important to safeguard human health and to prevent economic and other losses. Most control work is directed towards preventing rats and mice from living in and around buildings in both urban and rural areas or eradicating populations that have already become established in them (Rowe et al., 1970; Brooks, 1973; Howard & Marsh, 1976). Thus, the usual control practices involve improvement in environmental sanitation, the protection of buildings by proofing measures and the use of poisoning, fumigation and trapping techniques. Sometimes good control can be achieved by employing one method only but effective and lasting results are more usually dependent on the application of different methods applied either in combination or in sequence.

9.1 Environmental sanitation

Environmental sanitation concerns the orderly management and maintenance of the environment. Basically, it entails good housekeeping, the proper storage and handling of foodstuffs and organic wastes and the elimination of harbourage for rodent and other pests. Commensal rodents are opportunistic and readily take advantage of man's abuse of the environment: in urban areas particularly, improvements in sanitation standards can do much to prevent the development of infestations. Poor sanitation generally results in waste foods and harbourage being abundant and easily available to rodents, and, in general, it creates conditions enabling their rapid establishment in the environment. Lack of proper attention to sanitation is thus a major reason for the continued presence of commensal rodents in urban areas.

Human food wastes, providing both food and water, can be a major cause of much rodent infestation. For example, Norway rats occupying residential areas are often largely maintained on accessible garbage. Food wastes in residential and commercial premises should be stored in covered rodent-proof containers of sufficient capacity to hold all wastes that accumulate between collections and any rooms or shelters used expressly for the storage of waste food should be similarly proofed and easily cleaned. On farms, the improper disposal of waste foods and refuse can encourage rodent infestations, but of even more concern is the often poor storage of farm crops and animal forage.

Wherever possible, all foodstuffs, whether for human or animal consumption, that are kept in dwellings, restaurants or elsewhere, should be stored in rodent-proof containers, such as glass or pottery jars, metal cans or bins, or in screened rodent-proof rooms. Warehouses, grain mills, port facilities, silos and corncribs are particularly vulnerable to infestation by rodents and bulk foods, such as flour, sugar, dried fruits and vegetables, cereal grains and meals, nuts, etc., are best housed in rodent-proof buildings. Large amounts of foodstuffs, such as cereal grains and groundnuts, are still retained, stored and transported in sacks made from burlap, jute, paper or plastic. Such packaging materials are easily penetrated by rodents and the replacement and re-bagging of spilled foodstuffs can prove costly. Bagged foods should be stacked on pallets in orderly rows. It is advisable to keep the stacks narrow - not more than 3-4 m wide - so that one can walk around and readily inspect them for signs of rodent infestation. Stacks should not be built into the corners of a building since they may become seriously infested before rodents are detected. It is also good practice to move stock-piled foodstuffs every two months whenever long-term storage is undertaken.

Almost any pile of debris, indoors or out, can provide rodents with suitable cover for nesting and breeding. Materials stored indoors, such as boxes, crates, sacked goods, machinery and lumber can create potential rodent harbourage; they should be properly stacked on racks or shelves and regularly inspected for signs of infestation. Access to water should also be prevented by ensuring proper drainage, attending to leaky taps and plumbing and emptying all sinks and other sources of unprotected water.

Harbourage for rodents outside buildings can exist in the form of improperly stacked lumber, bricks, abandoned appliances and other rubbish; unwanted materials should be removed to the nearest refuse dump and immediate steps taken to prevent the further accumulation of debris. Racks, raised approximately 1/2 m above the ground should be provided for materials that need to be stored outdoors. Weeds and brush growing near food stores provide other potential rodent harbourage and they need to be cut back and removed. Similarly, any tree branches enabling rodents easy access to roofs should be removed; this is particularly important in the case of R. rattus which often nests in dense vines and bushes. In general, the maintenance of a cleared area, as extensive as possible, can do much to deter rats and mice living outdoors from encroaching near food premises.

9.2 Rodent exclusion

Rodent exclusion is the technique of denying rodents access to buildings and food supplies. It involves the use of barriers, either mechanical, chemical, or other in order to keep rodents from penetrating an area or moving from one place to another.

9.3 Mechanical proofing

Mechanical proofing measures can effectively deny rodents access to food and harbourage inside buildings, food storage bins and ships. In practice, this entails having no openings into structures that rats and mice can penetrate. This is a difficult task since house mice can pass through a 12 mm aperture and very young rats through 14 mm openings.

Rodent-proofing of existing structures requires that foundations are solid with no holes or large cracks; that cellars are provided with concrete floors; that all openings at ground level or above are screened with 6 mm mesh hardware cloth or fitted with metal grills having equally small apertures; that all doors, windows and screens fit tightly and that all holes where pipes pass through exterior walls are sealed with cement or with sheet metal sheathing. Complete instructions on rodent-proofing are given in Scott & Borom (1965) and Jenson (1965). In the case of new food stores it is important to incorporate rodent proofing measures at the design stage.

The most significant benefits to accrue from rodent-proofing have been in relation to ships. After an intensive study of shipboard rat harbourage had indicated the practicality of rodent-proofing, Grubbs & Holsendorf (1925) virtually eliminated rats from a large ocean liner by implementing only minor structural improvements. Since then, ships have been designed and built with rat-proofing in mind and the number of rats on shipboard and the proportion of rat-infested vessels has declined sharply. Rat-proofing plans and directions for eliminating rats on ships are found in two United States Public Health Services Publications (1963, 1965).

The rat-proof construction of ships before and since World War II has gone far in preventing the spread of plague by shipping (Hirst, 1953), but a new problem has now arisen. Large volumes of cargo are now carried in standard-sized containers inside which rats and rat-fleas can survive for a period of weeks during transit. The transport of rats to United States of America ports in cargo containers from Viet Nam demonstrated this. Better rodent and rodent-flea control is required in international ports where containerized cargoes are handled aboard ships and inside the cargo containers themselves to reduce the risk of ship-borne plague.

9.4 Repellents

Repellents are chemicals that are noxious to rodents; their use in preventative measures is based on the extreme sensitivity of rodents to distasteful compounds and odours (Fearn & DeWitt, 1965). A number of compounds have been found to possess repellent properties but few have been employed successfully. Many of them are particularly odorous to man, besides being difficult to work with, and a long-lasting effect has also proved difficult to obtain.

Rodents frequently damage packaged materials, boxes, sacked grain and stored articles when seeking food and cover. Preventing their entry into buildings is the best method of eliminating such damage but alternative measures are being sought. One approach is to incorporate a repellent into packaging materials in order to inhibit rodent attack. Besides being effective in practice, a repellent should be stable, lack objectionable taste and odour and be essentially non-toxic. Naturally, it should not have any deleterious effect upon the packaged goods. Recent techniques have been used to develop a repellent-treated fabric held between two layers of polyethylene, protecting both the foods and the handler (Tigner, 1966). Results have been moderately successful in preventing rodent damage over a period of several months.

Repellents have also been used to protect agricultural crops, wiring and cables (Gutteridge, 1972). Among the most commonly used are thiram [bis(dimethylthiocarbamyl)disulfide], cycloheximide, tributyltin salts and tert-butyl dimethyltrithioperoxycarbamate (R-55 or Rotran). The latter compound has been utilized successfully in protecting buried telephone cables from rodent damage (Gutteridge, 1972) and this material has been further considered as an area repellent to force rats from treated burrows and to protect foodstuffs. However, Krishnakumari & Jackson (1973) found that R-55 had a short effect (25 to 96 h) against both Norway rats and house mice, failing to give complete protection to paper bags containing attractive foods, and similar results were obtained by Meehan & Cole (1974).

9.5 Ultrasound

The use of ultrasonic sound has been proposed as a means of preventing rats or mice from freely moving into a building or from one area to another (Pinel, 1972). Field and laboratory studies (Marsh et al., 1962; Sprock et al., 1967; Greaves & Rowe, 1969; Meehan, 1976b; Lavoie & Glahn, 1977) have generally failed to support these contentions however. These studies showed that ultrasound will not drive rodents from buildings or keep them from their usual food supplies and that it cannot be generated with sufficient intensity to kill.

Meehan (1976b) tested the repellency of four commercially-available ultrasonic generating machines against a population of wild Norway rats in a large outdoor enclosure. The animals were subjected to an uninterrupted beam of sound 0.5 m from where they were accustomed to feed. There was an initial and partial repellency for a day or so, but thereafter the feeding behaviour of the rats was unaffected. Meehan concluded that existing ultrasonic units are of little value in deterring the feeding activity of rodents or in dispersing populations and Lavoie & Glahn (1977) reached the same conclusions. Greaves & Rowe (1969) however, considered that carefully placed sound generators might well discourage rodents from invading premises having few access points.

There are several reasons for believing that ultrasound is unlikely to find wide application in rodent control; the generators are relatively expensive and the sound produced is extremely directional so that "shadows" result where rodents are not affected; ultrasound intensity also rapidly diminishes in air making for rather limited penetration and, furthermore, rodents appear to become rapidly conditioned to the sound waves produced.

9.6 Electrical barriers

Electric fences have been used on occasion, both to exclude and to enclose wild Norway rats and other small animals (Ryckman et al., 1953; Srinivasalu et al., 1971; Stains et al., 1961). Such fences can be rather easily set up, taken down and moved, and they can be effective in protecting stored foods. Their cost and maintenance is high, however, and their use has been largely confined to protecting small areas of experimental field crops.

9.7 Trapping

Traps, which are used to control rats and mice or for their capture for scientific purposes, were an early development in human culture (Fitzwater, 1970), the earliest versions being pitfalls and snares. Spring traps, the kind most commonly used in rodent control, were developed during the Middle Ages and refined through the centuries to the present-day versions (Lloyd, 1963).

Traps are the preferred method of killing or capturing rodents in situations where the use of rodenticides is considered undesirable, e.g. where poisoned animals dying in inaccessible areas could cause unwanted odour problems or where animals are specifically required for disease or other biological studies. Those most used against rats are the wooden- or metal-based snap-traps (break-back traps), the steel-jaw trap and the conibear trap (Fig. 7). Cage-traps of several designs are used to capture live animals (Fig. 7).

Rats, because of their neophobic reactions, tend to be wary of traps and are sometimes difficult to capture or control by this method. In campaigns against rats, traps should be placed near runs and at other locations where there are clear signs of rat activity. Trapping success can be improved by leaving the traps baited but unset for a few days. Even so, it is very difficult to remove entire populations in this manner because some individuals may show a tendency to avoid the traps.

Baits of proven acceptability include bacon, peanut butter, fresh or smoked fish, ground meat or bread for Norway rats and nuts, meat, apples, carrots, melon or bread for roof rats; those that dry out or spoil should be replaced immediately by fresh ones. Traps should be examined daily to remove dead rats, which should be buried or incinerated, and to re-set those that have sprung. Human odour does not affect trapability because rats, living in close association with man, are accustomed to it.

Unbaited traps consist of the standard snap-traps modified with an expanded trigger, the steel-jaw trap and the conibear steel trap. The expanded trigger consists of a 5 cm square of hardware cloth (wire mesh) or cardboard attached securely to the trigger mechanism. Unbaited traps are set directly in rat runways, in corners, near burrows and holes, on rafters, pipes, beams and in secluded areas (Fig. 8). Boards, boxes or other obstructions should be placed beside or immediately behind traps to encourage rats to run into them.

For economic or other reasons, traps are of little value in controlling large infestations of mice but they are useful in dealing with the odd individual or a small family group living in domestic premises, small stores or office buildings; they are also of use in helping to remove the survivors of poison treatments.

There are two kinds of mousetrap, the live-capture variety and the more familiar break-back or snap-trap. The former includes various single and multiple catch-traps. Although they can be highly efficient, live-traps do not have much practical use in large-scale mouse control, mainly because of their cost; they are principally used as research tools.

The effectiveness of snap-traps against house mice is largely determined by the sensitivity of the traps, their placement and the number of traps used. Newly-weaned mice weigh only about 5-6 g and, to prevent selective trapping of heavier animals, it is important to set the traps finely so that the least touch on the trigger releases the spring. Traps should be set close to walls and in other areas where active runs are evident; because of the limited range of movement of mice, the traps need to be closely spaced. For best results, they should be laid about 1 m apart and, wherever possible, so that the trigger mechanism lies at right angles across a runway.

It is possible to catch part of a mouse population using unbaited traps but baited traps are about twice as efficient. Fine or crushed cereal products, such as rolled oats, oatmeal and flour are usually dependable baits; other baits reported to give good results include cheese, peanut butter, pieces of fruit and meat, fish, bacon, bread and chocolate.

An abundance of food makes trapping somewhat less effective for mice. Before starting a trapping programme therefore as many sources of accessible food as possible should be protected or eliminated. No distinct advantage is gained by prebaiting and leaving mouse-traps unset for a few days. Some mice may become wary of traps left down for long periods however, and it is far better to carry out frequent trapping campaigns with a large number of traps laid out for a few days than to distribute traps sparsely over a wide area for several weeks at a time.

9.8 Fumigants

Fumigants are used to kill rodents and their ectoparasites living in inaccessible areas in buildings, ships or in burrows in the soil. Fumigants are quite dangerous, both to the persons using them and to other humans or animals in the immediate area. Experience and skill is required therefore in their application. Fumigants most commonly used against rodents are calcium cyanide (to produce hydrogen cyanide), methyl bromide, chloropicrin and aluminium phosphide (to produce phosphine). More rarely used are carbon dioxide, carbon monoxide and sulfur dioxide.

Fumigants having a molecular weight less than 29 tend to rise to the top of burrow systems when used in the soil. Factors that can be important in burrow fumigation are the moisture content of the soil and its particle size. Hydrogen cyanide, methyl bromide and hydrogen phosphide are extremely toxic gases and great caution must be taken to avoid inhaling them when fumigating burrows, confined structures, or commodities under gas-proof tarpaulin. Some characteristics of commonly used fumigants are given in Table 7.

TABLE 7. SOME CHARACTERISTICS OF RODENT FUMIGANTS

Fumigant	Chemical structure	Molecular weight	Physiologic action[a]	LD_{50} (rat) mg/litre	Inflammable
Hydrogen cyanide	HCN	27	C.A.	0.4	Yes
Carbon monoxide	CO	28	C.A.	(0.35% conc)	No
Hydrogen phosphide	H_3P	34	I.	0.8	Yes
Carbon dioxide	CO_2	44	S.A.	(20-30% conc)	No
Sulfur dioxide	SO_2	64	I.	1.6	No
Methyl bromide	CH_3Br	95	I.	3.6	No
Chloropicrin	CCl_3NO_2	164	I.	2.0	No

[a] C.A. = Chemical asphyxiant; S.A. = Simple asphyxiant; I. = Irritant.

9.8.1 Calcium cyanide, $Ca(CN)_2$, is most frequently used in outdoor operations (it should never be used near a building); it is greyish-white and available in a granular or powdered form. The granules or powder are blown or spooned into a burrow and hydrogen cyanide (HCN) is liberated when they come into contact with moist air or soil. Hydrogen cyanide is lighter than air and the gas accumulates in all the upper parts of the burrow network; thus all holes must be sealed quickly. Calcium cyanide is usually blown into burrows using a special commercially available pump, the hose being inserted into the burrow opening and soil packed around it. Five or six strokes are then made with the pump handle, the valve switched to "air" and about 10 more strokes applied to blow the powder further into the burrow system. Entrances into the treated burrow are then immediately closed with soil. Holes reopened in a day or so will indicate that some rodents have survived, and the burrow system should be retreated (Johnson & Bjornson, 1964).

Gassing with cyanide should always be done by more than one operator for HCN is quick-acting and a person working alone could be easily overexposed and rendered unconscious. Workers using calcium cyanide should carry ampules of amylnitrite as a first-aid measure in case of accidental poisoning. A broken ampule is held under the nose of the affected person for 30 seconds out of every two minutes and a physician should be called immediately. Death may result from a few minutes exposure to 300 ppm HCN.

9.8.2 Methyl bromide (CH_3Br) is an odourless, highly toxic gas used in general pest fumigation (Thompson, 1966). Methyl bromide canisters with valve and hose attached are used to fumigate rodent burrows in the same way as hydrogen cyanide. The hose is inserted into the burrow, soil is packed around it, and the valve opened for several seconds, releasing 15-30 ml of liquid methyl bromide into the burrow. The burrow is then closed and examined a day or two later. Methyl bromide should not be used near roots of trees or shrubs, as it is toxic to plants. Hazards associated with using methyl bromide in outdoor rodent control operations are slight if operations are conducted with care and precautions are taken to prevent the liquid material from getting in the eyes, mouth or on the skin. The wearing of gloves is not advised since any liquid penetrating them can become trapped and cause serious burns to the skin. Methyl bromide should not be used at low temperatures (below 2-4°C) as the liquid does not vapourize and the valve on the canister may freeze up.

9.8.3 Chloropicrin (CCl_3NO_2) sometimes known as tear gas, has been occasionally used to drive house mice out of grain storage areas (Tigner & Bowles, 1964). Mice die when subjected to a concentration of less than 32 ppm of chloropicrin. Chloropicrin, mixed with heavy motor oil, has been suggested as a burrow fumigant for rats and sometimes a small quantity is mixed with methyl bromide to provide an olfactory warning to the person using that gas. Over-exposure to chloropicrin produces severe sensory irritation in the lungs apart from severe lachrymation and this chemical is also a strong skin irritant.

9.8.4 Hydrogen phosphide (H_3P) also known as phosphine and Phostoxin, has been used as a fumigant against insects infesting stored products for many years. The gas is liberated from a highly compressed tablet composed of ammonium carbamate and aluminium phosphide.

When the tablet is exposed to moisture, it decomposes into hydrogen phosphide, aluminium hydroxide, ammonia and carbon dioxide. A tablet weighing 3 g, liberates 1 g of hydrogen phosphide. Hydrogen phosphide is a colourless, poisonous, spontaneously inflammable gas, slightly heavier than air, with a sharp garlic-like odour. The odour may not be a sufficient warning however to workers accustomed to the use of the gas. The prepared tablet is relatively safe to handle; it is not self-combustible but should not be exposed to open flame. Workers handling the tablets should wear gloves.

Hydrogen phosphide is sometimes used to fumigate burrows of R. norvegicus, Bandicota bengalensis and Nesokia indica in parts of the Middle East, India and elsewhere. Normally one to two tablets are placed into each burrow entrance and the openings are then closed with soil. The speed of liberation of the gas in burrow systems is dependent upon both soil moisture and temperature levels but it normally takes several hours to fumigate a burrow.

9.8.5 Carbon dioxide (CO_2) has been used to fumigate cold storage warehouses and corn-ricks against house mice (Chitty & Southern, 1954). It was found that CO_2 concentrations of 23% or greater killed wild house mice in less than two hours and that the gas was most easily and economically applied using solid CO_2 (dry ice). Dry ice has been proposed for fumigating refrigerated warehouses where low temperatures must be maintained (Thompson, 1959). The ice is crushed and distributed throughout the room; an electric fan is then used to disperse the gas. Approximately 2 kg dry ice/m^3 of space is needed to give a 15% concentration of gas over 24 hours.

9.8.6 Carbon monoxide (CO) derived from an automobile exhaust, can be used to kill rats in burrows. A flexible hose is attached to the exhaust pipe and the other end is inserted inside the burrow. All of the burrow openings are then sealed and the automobile engine is run for about five minutes. Precautions must be taken to ensure good ventilation of the automobile since carbon monoxide might be forced back into the exhaust system and leak into the vehicle.

9.8.7 Sulfur dioxide (SO_2) is a colourless, non-flammable gas with a strong suffocating odour. It is intensely irritating to the eyes and to the respiratory tract. Sulfur dioxide was formerly used to fumigate rat-infested ships but now it is mainly used in the preservation of fruits and vegetables. Sulfur, mixed with potassium nitrate (saltpetre) and a small amount of tallow constitutes the so-called "smoke ferrets"; the smoke produced on burning has been used to force rats to bolt from their burrows when they can be killed by force (Hovell, 1924). This method can also be used for the rapid collection of live rats, needed for laboratory and other experimental purposes, such as the examination of ectoparasites. The use of SO_2 as a general burrow fumigant is not recommended however.

9.9 Rodenticides

Most measures to control commensal rodents depend on the application of poisons (or rodenticides) incorporated in either bait, powder or water. These are usually classified either as chronic (multiple dose, slow-acting) or acute (single dose, quick-acting) compounds. General accounts of compounds of both kinds have been given by Gutteridge (1972) and Greaves (1971). Of particular importance are the anticoagulant poisons since these slow-acting compounds are now regarded as first choice rodenticides against commensal rodents in most control operations. Acute rodenticides still have a part to play but they are principally and most effectively employed in situations demanding a rapid reduction of high-density populations.

9.9.1 Anticoagulants

The various anticoagulant rodenticides have a similar physiological action in that they disrupt the mechanism that controls blood-clotting and cause fatal internal haemorrhages to develop. Their action is cumulative and most of them need to be ingested over a period of several days to be effective. Anticoagulants possess two main advantages over acute rodenticides. First, they are readily accepted by commensal rodents when they are included in bait at low concentration so that sublethal dosing and bait-shyness problems do not normally arise. Secondly, primary and secondary poisoning hazards to non-target species are reduced and if accidental poisoning of man or animals does occur, an effective antidote, vitamin K, is available. Even so, the utmost care should be taken in their application.

The anticoagulants presently in wide-scale use are either hydroxycoumarin derivatives or indandione compounds. They are white, creamy or yellow, fluffy powders or crystalline solids in the technical state. Most are odourless but not necessarily tasteless. Pival (pindone) has a slightly mouldy, acrid odour suggestive of tobacco. All are virtually insoluble in water, although the sodium or calcium salts of most of them are water-soluble and made available for the preparation of liquid baits. Chlorophacinone and bromadiolone are made available as mineral oil-soluble concentrates. All are chemically stable either in concentrate or in prepared bait form.

The anticoagulants have been particularly successful in controlling Norway rats. The roof rat is rather less susceptible to anticoagulant poisoning and house mice can be highly variable in their response (Rowe & Redfern, 1965). Recommended dosage levels for anticoagulant rodenticides are given in Table 8. In general, pigs are about as susceptible to anticoagulants as are rats; cats and dogs are moderately susceptible and chickens, rabbits and horses are the least susceptible.

TABLE 8. RECOMMENDED DOSAGE LEVELS FOR ANTICOAGULANT RODENTICIDES (CONCENTRATION IN FINISHED BAIT IN %)

Anticoagulant	R. norvegicus	R. rattus	M. musculus
Brodifacoum	0.001	0.005	0.01
Bromadiolone	0.005	0.005	0.01
Chlorophacinone	0.005-0.01	0.005-0.01	0.01
Difenacoum	0.005	0.005	0.01
Diphacinone	0.005-0.01	0.005-0.01	0.0125-0.025
Fumarin	0.025	0.025	0.025-0.05
Pival	0.025	0.025	0.025-0.05
Warfarin	0.025	0.025	0.025-0.05
Coumatetralyl	0.03-0.05	0.03-0.05	0.05
Isovaleryl-indandione	0.055	0.055	-

There are about 12 anticoagulants in current use in various countries throughout the world (Bentley, 1972). Ten of these are considered here, including the three so-called "second generation" anticoagulants difenacoum, brodifacoum and bromadiolone.

9.9.1.1 Warfarin

Warfarin [(3-a-acetonylbenzyl)-4-hydroxycoumarin] was the first anticoagulant to be developed as a rodenticide (in 1950) and it has had the most widespread use. In the case of Norway rats, Bentley & Larthe (1959) and Hayes & Gaines (1959) both concluded that Warfarin was not excelled by the other anticoagulants available at that time.

Different Warfarin preparations have been found to vary significantly in acceptance to Norway rats and roof rats (Bowerman & Brooks, 1972; Krishnamurthy et al., 1971) and there is some evidence that small quantities of contaminants produced during manufacture can impair palatability. Other observers have evidenced some measure of unacceptability at the 0.05% level (Bentley & Larthe, 1959).

The sodium salt of Warfarin is available as a 0.5% concentrate. The salt is dissolved in sufficient water to make a final concentration of 0.05 mg/ml. In contrast to highly purified Warfarin incorporated in bait, sodium Warfarin solution can be detected by rats and sugar is usually added to mask the taste.

"Prolin" is a variant of Warfarin made by adding an equal concentration of sulfaquinoxaline to prepared bait. Sulfaquinoxaline is a bactericide which inhibits vitamin K - producing bacteria in the rodent gut. Field trials of "Prolin" however have not confirmed that the addition of sulfaquinoxaline improves the efficacy of Warfarin bait.

9.9.1.2 Fumarin

Fumarin, also known as Coumafuryl [3-(a-acetonylfurfuryl)-4-hydroxycoumarin] is a whitish or cream-coloured material supplied as a 0.5% concentrate in corn starch. It has been shown to be equally as effective and palatable as Warfarin and a water-soluble salt is used in preparing liquid baits.

9.9.1.3 Coumatetralyl

Coumatetralyl [3-(a-tetralyl-4-hydroxycoumarin] also known as Racumin, has been widely used against all three commensal species. Greaves & Ayres (1969) compared the efficacy of coumatetralyl and Warfarin and found that coumatetralyl at 0.05% and 0.005% was about as toxic and at least as palatable as Warfarin at 0.005%. Lund (1972a) reported that coumatetralyl at 0.03% and 0.05% was extremely well-accepted by Norway rats and better than Warfarin at 0.025%. Greaves & Ayres (1969) also found that coumatetralyl, at 0.05%, was about as toxic to Warfarin-resistant Norway rats as 0.005% Warfarin is to normally susceptible individuals. Lund (1972b) however did not find that coumatetralyl was effective against Warfarin-resistant rats in the field in Denmark. Rowe & Redfern (1968b) considered that coumatetralyl was at least as effective as Warfarin against the house mouse.

9.9.1.4 Difenacoum

Difenacoum [3-(3-p-diphenyl-1,2,3,4-tetrahydronaph-1-yl)-4-hydroxycoumarin] a recently introduced anticoagulant, is a close relative of coumatetralyl. It was discovered as a result of the search for alternative rodenticides to combat the anticoagulant-resistant rat problems in the United Kingdom (Hadler & Shadbolt, 1975). Probably because of the novel structure of the molecule, difenacoum is toxic to Norway rats resistant to Warfarin or other anticoagulants.

Recent reports upon the efficacy of difenacoum, both in the laboratory and field, indicate it to be an excellent rodenticide when used against Norway rats including Warfarin-resistant populations (Bull, 1976). It is also highly toxic to R. rattus and M. musculus. In trials against confined colonies of Warfarin-resistant wild mice, difenacoum gave 88.9% and 97.0% mortality when it was offered in bait at 0.005% and 0.01% respectively for 21 days in the presence of unpoisoned food (Rowe & Bradfield, 1977).

Field trials of difenacoum on farms in England and Wales gave excellent control of Warfarin-resistant Norway rat populations on 19 farms when used at 0.005-0.01%. No difference in effectiveness was evident and the lower concentration is recommended for field use (Rennison & Hadler, 1975). Redfern & Gill (1978) have recently reported however on a single population of Warfarin-resistant Norway rats that proved difficult to control with difenacoum.

9.9.1.5 Pival

Pival /2-pivalyl-1,3-indandione/ also known as pindone, is a fluffy yellow powder with a slightly acrid odour; the sodium salt (Pivalyn) is a grainy powder with only a trace of odour. Pival is only slightly soluble in water; the sodium derivative is soluble up to 0.1 mg/ml, but nevertheless it precipitates, unless a chelating agent is added, when it is used with many natural waters.

Pival is available as a 0.5% concentrate in corn starch. Recently, a new 2.0% concentrate has been developed. The sodium salt is made available in sachets, each containing sufficient ingredient to poison a litre of water. Pival has a generally good record of performance against all three species of commensal rodents. Hayes & Gaines (1959) found it was as effective as Warfarin against roof rats and house mice, but less so against Norway rats. At normally used field concentrations, Rowe & Redfern (1968a) found pival to be less acceptable to house mice than either Warfarin, diphacinone or chlorophacinone.

9.9.1.6 Diphacinone

Diphacinone /2-diphenylacetyl-1,3-indandione/ is a pale-yellow, odourless crystalline material. It is practically insoluble in water but the sodium salt is soluble. Diphacinone is supplied as a 0.1% concentrate in corn starch and the sodium salt as a 0.106% concentrate mixed with sugar for use in either cereal or water bait. The concentrate is added to bait (1:19) to give a final concentration of 0.005% of diphacinone.

Gates (1957) reported that diphacinone is considerably more toxic to rats, mice, dogs and cats than is Warfarin. Hayes & Gaines (1959) however considered that this anticoagulant was about as good as Warfarin against Norway rats. Bentley & Larthe (1959) found diphacinone, at a concentration of 0.0125%, to be the most effective of the anticoagulants they tested against roof rats.

9.9.1.7 Isovaleryl-indandione (PMP)

PMP /2-isovaleryl-1,3-indandione/ was developed by the United States Fish and Wildlife Service, but it has not found wide use. The calcium salt, used in preparing cereal or other baits, is supplied as a 1.1% concentrate, which is diluted to give a final 0.055% concentration. Water baits are prepared from the sodium salt. In addition, a tracking powder containing 2.18% PMP has been made available. PMP, included in bait, has a rather poor record however, attributable to palatability problems (Hayes & Gaines, 1959) and it performs best in dust form.

9.9.1.8 Chlorophacinone

Chlorophacinone /2(a-p-chlorophenyl-a-phenylacetyl)-1,3-indandione/ also known as Rozol, has been found to be more toxic to Norway rats and house mice than is Warfarin (Lund, 1971; Rowe & Redfern, 1968a). It is made available as a 0.28% concentrate in mineral oil, which is diluted in bait to give a 0.005% concentration. A 0.2% tracking dust, for use against Norway rats and house mice, is also marketed.

9.9.1.9 Brodifacoum

Brodifacoum /3-(3-/4'-bromobiphenyl-4-yl/-1,2,3,4-tetrahydronaphth-1-yl)-4-hydroxycoumarin/ is a new anticoagulant, closely related to but more toxic than difenacoum. It appeared first under the code names WBA 8119 and PP 581.

Brodifacoum, even in small doses, is a highly toxic compound, more so than most acute rodenticides. Thus, it is more hazardous to non-target species than previous anticoagulants. Its extreme toxicity suggested the possible use of brodifacoum as a "one shot" poison, i.e. applied in the manner adopted employing acute rodenticides. Field trials against Norway rats have so far failed to support this contention (Rennison & Dubock, 1978); its use in conventional anticoagulant treatments however (baiting until feeding ceased) resulted in complete control when it was included at either 0.002, 0.001 or 0.005%. The authors recommend the use of brodifacoum at a field concentration of 0.005% against Norway rats.

Brodifacoum gave complete kills of both Warfarin-resistant and non-resistant Norway rats when it was used in the laboratory at a concentration of 0.0005% in bait for two days, or at 0.001% for one day. At 0.005% complete kills of Warfarin-resistant R. rattus were obtained in two-day feeding tests and resistant house mice were found to be similarly susceptible (Redfern et al., 1976). In pen trials, using Warfarin-resistant mice given alternative food, brodifacoum at 0.002, 0.005 and 0.01% in cereal bait gave kills of 98.6, 98.4 and 100% respectively and, overall, brodifacoum performed better than did difenacoum (Rowe & Bradfield, 1976).

9.9.1.10 Bromadiolone

Bromadiolone [(hydroxy-4'-coumarinyl-3')-3-phenyl-3-(bromo-4-biphenyl-4')-1-propanol-1)] code-named LM-637, is another new, potent hydroxycoumarin-derivative. Laboratory tests have shown that bromadiolone is highly toxic to rats and mice (Lund, 1977; Marsh, 1977). Marsh (1977) found that bromadiolone was acceptable to Norway rats at a concentration of 0.005% in bait and extremely effective against this species (LD_{50} less than 2 mg/kg). In further laboratory tests, bromadiolone, at 0.005%, was also found to be highly effective against roof rats and the treated bait was well-accepted. House mice proved to be relatively less susceptible to bromadiolone.

9.9.2 Acute rodenticides

Rodenticides of the acute-acting type, which have been used in commensal rodent control are allocated in three hazard-in-use categories:

(1) compounds that are highly toxic and extremely hazardous to man and animals;

(2) compounds that are both moderately toxic and hazardous to man and animals, requiring considerable care in use;

(3) compounds of relatively lower toxicity that are the least hazardous to man and animals.

The main characteristics of the compounds reviewed are outlined in Table 9. Apart from zinc phosphide, few are used to any marked extent in rodent control at the present time. Only one, norbormide, shows some measure of specific toxicity to the genus Rattus, particularly to R. norvegicus, and each of the compounds described has some disadvantage or another, either in relation to toxicity, acceptability, safe usage or secondary poisoning hazards. Regulations governing their use tend to differ in different countries and it is mainly for this reason and for historical reference purposes that compounds not now recommended as rodenticides in some countries, or even no longer available, are also included.

9.9.3 Extremely hazardous rodenticides

9.9.3.1 Arsenic trioxide

Arsenic trioxide, As_2O_3, when chemically pure, is a white, finely divided powder, practically insoluble in water and chemically stable in air. The impure compound has a rather bitter acid taste. The rate of absorption of arsenic trioxide in affected animals is directly related to particle size. Particles measuring 6-9 mu in diameter are the most toxic and are rapidly absorbed by rodents.

Early field trials reported by Chitty & Southern (1954) indicated that 85-100% kills of Norway rats could be expected in poison treatments carried out after adequate prebaiting. Arsenic treated bait is also relatively effective against roof rats but not against house mice. The poison is normally included in moist or dry bait at 3%.

TABLE 9. SOME CHARACTERISTICS OF ACUTE AND SUBACUTE RODENTICIDES (ADAPTED FROM BROOKS, 1973)

Poisons	Lethal dose mg/kg[a]	Per cent. used in baits	Species effective against Rn	Rr	Mm	Acceptance in baits	Solubility - water - oil	Hazard to man	Antidote	Restrictions
Alpha-chloralose	300	4.0			x	Fair	Neither	Moderate		
ANTU	6-8	1.5	x			Fair	Neither	Moderate		Not recommended (WHO 1973)
Arsenic trioxide (micronized)	13-25	1.5	x	x	x	Fair	Water	Extreme		Not recommended (WHO 1973)
Calciferol	40	0.1	x	x	x	Good	Oil	Moderate	Procine calcitonin	
Castrix (Crimidine)	1-5	0.5	x		x	Poor	Oil	Extreme	Sodium pentobarbital	
Fluoroacetamide	13-16	2.0	x	x	x	Good	Water	Extreme		
Norbormide	12	1.0	x			Poor	Oil	Low		
Phosacetim	20-30	0.25	x	x		Good	Oil	Extreme	Atropine, Pralidoxine	Not recommended (WHO 1973)
Red squill	500	10.0	x			Fair	Water/oil	Low		
Scilliroside	0.42	0.015	x			Fair	Water/oil	Moderate		
Silatrane	1-4	0.5	x		x	Fair	Oil	Extreme		
Sodium fluoroacetate	5-10	0.25	x	x	x	Good	Water	Extreme		
Strychnine	6-8	0.6			x	Poor	Water	Extreme		
Thallium sulfate	25	1.5	x	x	x	Good	Water	Extreme		Not recommended (WHO 1973)
Pyrinuron	5-12	0.5-2.0	x	x	x	Fair	Neither	Moderate	Nicotinamide	
Zinc phosphide	40	1.0	x	x	x	Fair	Oil	Moderate		

[a] LD_{50} for R. norvegicus.

Arsenic trioxide is a slow acting poison, death occurring in rats from a few hours to several days after poisoning; corrosion of the gastrointestinal lining results in haemorrhage and shock. It is also toxic to man, domestic animals, and birds. A slight degree of safeguard is present, particularly in cats and dogs, because arsenic poisoning causes vomiting. Since arsenic can be absorbed through cuts or breaks in the skin, gloves should be worn in preparing or handling baits. The use of arsenic trioxide as a rodenticide is not recommended by a WHO Expert Committee (1973).

9.9.3.2 Crimidin

Crimidin (2, chloro-4, dimethylamino-6, methylpyrimidine), also called castrix, was developed in Germany in the 1940s. It was further evaluated in the United States of America; partly due to its extreme toxicity (oral LD_{50} of 1-5 mg/kg to Norway rats) but more importantly because of the availability of sodium fluoroacetate and warfarin, it was never accepted commercially. It has had rather limited use outside Germany and Denmark.

Crimidin is a quick acting poison and the symptoms shown are typical of central nervous stimulation (Dubois et al., 1948). Following oral dosing, convulsions occur after a latent period of 15-45 minutes; seizures occur intermittently, terminating in death or in complete recovery when sublethal dosing occurs.

Crimidin is toxic to dogs and cats as well as to rodents. It has been reported to be acceptable to rats at concentrations of 0.25-1.0% in bait. The 1% concentration killed all Norway rats in two hours and the lower concentrations were lethal in less than 12 hours (Dubois et al., 1948).

Vitamin B6 has been shown to be an effective antidote against crimidin poisoning in rats and dogs, even when given after convulsions have started. The availability of this antidote places crimidin in a unique class, along with phosacetim, among the highly toxic rodenticides.

9.9.3.3 Fluoroacetamide

Fluoroacetamide was first proposed as a rodenticide by Chapman & Phillips (1955) on the grounds that it was safer to manufacture and handle than sodium fluoroacetate. The onset of effect was also found to be slower than in the case of sodium fluoroacetate, leading to rats ingesting many times a lethal dose before poisoning symptoms developed (Bentley & Greaves, 1960). In field trials against Norway rats in sewers, fluoroacetamide at 2% in bait proved to be more successful than sodium fluoroacetate, used at 0.25% (Bentley et al., 1961).

Fluoroacetamide is effective against all three commensal rodent species. In practice, however, its use has been largely confined to treating rats living in sewers (Bentley et al., 1961). Rohe (1966) found that fluoracetamide at 1% in bait gave good control (99 and 100%) in two trials against R. rattus in sewers. The poison was incorporated in paraffin wax blocks containing rolled oats and 5% sucrose. Ophof & Langveld (1969) reported that the application of fluoroacetamide treated bait on several farms in Holland resulted in the eradication of anticoagulant resistant Norway rat populations.

Although fluoroacetamide is less toxic than sodium fluoroacetate it is used at a higher concentration in bait; hence, it is just as hazardous to domestic animals and man and subject to the same restrictions in use.

9.9.3.4 Phosacetim

Phosacetim, also known as Gophacide [OO-bis-(p-chlorophenyl) acetimidoyl-phosphoramidothioate], is an organophosphorus compound; it has been found effective against deer mice and pocket gophers as well as commensal rodents (Gutteridge, 1972). Baits containing phosacetim at 0.25-0.5% were found to give generally effective control of Norway rats and house mice but less satisfactory results were obtained against roof rats (Schoof & Maddock, 1968).

Phosacetim is highly toxic to rats and mice, the LD_{50} being approximately 20-30 mg/kg. Its high dermal toxicity to rats (25 mg/kg), indicates that it is readily absorbed through the skin. It is slow to act when ingested in bait and thus, advantageously, the onset of symptoms is delayed. Although atropine sulfate has been proposed as an antidote for phosacetim poisoning a WHO Expert Committee (1973) recommended against its use because of possible delayed neurotoxic effects.

Laboratory evaluations of phosacetim against R. norvegicus and M. musculus suggested that it would be more effective against mice than rats. At a 0.3% concentration, phosacetim appeared sufficiently palatable and slow-acting in mice to prevent sublethal dosing and the development of bait-shyness. In field trials against urban infestations of house mice, seven of eight populations were successfully controlled using 0.1% phosacetim in medium oatmeal. Phosacetim, at concentrations of 0.1-0.25%, proved to be as effective as 3.0% zinc phosphide against this species (Rowe et al., 1975). For various reasons, phosacetim is no longer available for use.

9.9.3.5 Silatrane

The compound 5-p-chlorophenyl silatrane has been proposed as a rodenticide because of its low dermal toxicity and because, in time, it hydrolyzes into non-toxic products in prepared baits (Beiter et al., 1970).

Silatrane is an odourless, white powder, stable up to its melting point of 230-235°C. It is soluble in benzene, chloroform, and related organic solvents, but only slightly soluble in water. In the presence of water and weak acids it hydrolyzes rapidly. Greaves et al. (1974b) found that silatrane had an acute oral LD_{50} of approximately 3 mg/kg for laboratory rats and mice; it is very fast-acting, oral doses causing death in both rats and mice within five minutes.

In laboratory feeding tests against wild rats and mice, the optimal concentration of silatrane was found to be 0.5%. In comparison with other rodenticides silatrane was found to perform better than norbormide and as well as zinc phosphide; it was not as effective, however, as thallium sulfate, fluoroacetamide or sodium fluoroacetate.

Field trials conducted in urban premises infected with house mice in Britain showed that silatrane (0.5%) was as effective as zinc phosphide (3.0%) (Rowe et al., 1974b). In contrast, comparative field trials of silatrane (0.5%) and zinc phosphide (2.5%) against Norway rats living on farms showed that silatrane was, in most circumstances, significantly less effective than zinc phosphide (Rennison, 1974a).

Greaves et al. (1974b) in considering safety-in-use, remarked that silatrane appears to be at least as toxic to non-rodents as are other rodenticides. While the risk of secondary poisoning hazards are diminished, there remains the risk of accidental primary poisoning through the direct ingestion of bait. Only where poison bait has sufficiently broken down in the field would this risk be significantly less. Silatrane has recently been withdrawn by the manufacturers.

9.9.3.6 Sodium fluoroacetate

Early work on the monofluoroacetate compounds was done in Poland (Pattison, 1959) and one of the compounds discovered subsequently, sodium fluoroacetate, was assigned the laboratory code number 1080. Sodium fluoroacetate is a white odourless powdery salt which is essentially tasteless and highly soluble in water. It is chemically stable in air but exhibits some instability in water with solutions becoming less toxic in time.

Sodium fluoroacetate is highly toxic to rats, mice, domestic animals, birds and primates (Chenowith, 1949; Ward & Spencer, 1947). It is fast-acting, producing symptoms in rats in 30 minutes or less and causing death in one to eight hours (Lisella et al., 1970). Rats apparently do not detect sodium fluoroacetate in bait and by the time poisoning symptoms occur, a lethal dose has usually been consumed (Gratz, 1973a). In surface treatments, sodium fluoroacetate is preferably used in water since cereal or other highly toxic baits may be displaced by rats and prove difficult to recover. It has been mainly used at a concentration of 0.025% in water or solid bait.

The use of sodium fluoroacetate should be restricted to sewers, ships, and other structures where the complete control of poison treatments and the environment is possible. It has been used, for example, in feed mills at weekends, situations where the treated premises were locked, patrolled, and all bait stations readily accounted for. Excess poison bait, bait containers and rat carcasses should be disposed of by incineration or deep burial.

9.9.3.7 Strychnine

Strychnine, an alkaloid, is a white, crystalline compound insoluble in water. The sulfate is slightly soluble in water; both the alkaloid and the sulfate have a bitter taste. Strychnine and its salts are highly toxic to all mammals. Dieke & Richter (1946b) give an LD_{50} of 4.8 ± 0.4 mg/kg for wild *R. norvegicus*. Strychnine produces violent muscular spasms, poisoning symptoms often appearing within a few minutes, and death, due to paralysis of the central nervous system, generally occurs in half an hour or less.

Strychnine is not effective against Norway rats which find its bitter taste objectionable (Howard et al., 1968) but it has been used for the control of house mice, the poison being applied to oats or canary seed. Its use is not recommended in most countries owing to its high toxicity, the very rapid and violent death it causes, and its stability which can give rise to secondary poisoning problems in other animals.

9.9.3.8 Thallium sulfate

Thallium sulfate, Tl_2SO_4, is a white crystalline material, stable in air and baits, and soluble in water. It is odourless and tasteless when chemically pure and rodents readily accept it in bait. Thallium sulfate has both advantages and disadvantages as a rodenticide. Its ready acceptance in bait and its very slow action are distinctly advantageous attributes. However, treated bait being odourless and tasteless, can be easily eaten accidentally by most birds and mammals, including man. Other disadvantages concern its solubility, cumulative effect, and hazards associated with secondary poisoning. It is readily absorbed through cuts and wounds on the skin and rubber gloves should be worn when thallium sulfate is handled and mixed in bait or water.

Thallium sulfate is highly toxic to Norway rats and most other mammals. It is very slow-acting in relation to the other rodenticides and although death can occur in 36 hours it may be delayed up to six days (Dieke & Richter, 1946b). Thallium sulfate has been used at a 0.5-2% concentration in food or water baits. Field trials showed it to be a very effective rodenticide; Doty (1945) provided comprehensive data on its efficacy in the field. Despite its proven efficacy and acceptability to rodents, however, the use of thallium sulfate is prohibited, on safety grounds, in many countries. A WHO Expert Committee (1973) has recommended against its use.

9.9.4 Moderately hazardous rodenticides

9.9.4.1 Alpha-chloralose

Alpha-chloralose is a narcotic drug used in the control of mice (Cornwell & Bull, 1967b). It acts by retarding the metabolic processes, death resulting from hypothermia. It is most effectively employed at external temperatures below 16°C (Boocock & Tiffin, 1969). According to Cornwell (1970), poisoning symptoms occur in mice within 5-10 minutes, and feeding usually ceases after 20 minutes, sometimes leading to inadequate intake of bait and sublethal poisoning. For this reason, studies of the micro-encapsulation of alpha-chloralose have been undertaken (Cornwell, 1970).

Alpha-chloralose is not recommended for use against rats. Against house mice, at 4% in bait, its use is recommended in indoor environments only, because it is hazardous to birds.

9.9.4.2 ANTU

ANTU, the abbreviation for alpha-naphthyl-thiourea, is a greyish-white fine powder; it has a bitter taste, not discernible to all people. Insoluble in water, it is highly toxic to adult wild Norway rats, dogs and pigs (Anderson & Richter, 1946; Dieke & Richter, 1946b). ANTU is a rather slow-acting compound, rats dying up to 48 hours after its ingestion from an over-production of fluid in the lungs, and death results from drowning or pulmonary oedema.

ANTU is effective against adult Norway rats only, young R. norvegicus, roof rats and house mice being much less affected (Dieke & Richter, 1946a). Rats which take a sublethal dose of ANTU can develop a tolerance to subsequent doses as high as 50 times the normal lethal dose. This tolerance can persist for up to six months and, for this reason, ANTU should not be used against the same rat population more than once during this period.

ANTU has been used at a 1-2% concentration in cereal, fish or ground meat baits and has also been incorporated in dust (20% ANTU and 80% pyrophyllite). Extensive field trials using directly laid poison bait were carried out in Baltimore, and in other tests the dust was laid in burrow openings and on runways. Good results were obtained by either method (Richter & Emlen, 1946). Chitty & Southern (1954) reported poor control, however, when ANTU baits were laid directly although excellent kills were achieved when poisoning was done after prebaiting.

A WHO Expert Committee (1973), noting the potential induction of bladder tumours in man caused by 2-naphthylamine (a 2% impurity in ANTU) has recommended against the use of ANTU.

9.9.4.9 Calciferol

Calciferol (Vitamin D_2, activated ergosterol) has been used to control both susceptible and anticoagulant-resistant house mice and Norway rats. It is a white crystalline material, slightly soluble in vegetable oils and very soluble in organic solvents such as acetone, chloroform and ether. Claciferol is unstable and it degrades into less toxic products in the presence of sunlight, air or moisture.

Calciferol is a common dietary supplement in homogenized milk, infants' diets, animal feedstuffs and vitamin pills. When taken in toxic amounts, calciferol promotes the absorption of calcium from the gut and from bone tissue. This results in a very high level of calcium in the blood and it is deposited in the lungs, cardiovascular system and kidneys. Death occurs in rats four to eight days following feeding on calciferol bait and is thought to be due to renal failure (Lund, 1974).

The acute oral toxicity of calciferol for M. musculus is 15.7 mg/kg and for R. norvegicus about 40 mg/kg (Greaves et al., 1974a). The chronic oral toxicity over three days for each species is 8 mg/kg and 11.5 mg/kg respectively. Calciferol is palatable to both rats and mice at a 0.1% concentration in bait. Treated bait is generally well accepted for the first two or three days but poisoning symptoms then occur and feeding and drinking virtually stop, the animals crouching and becoming apathetic (Greaves et al., 1974a).

Calciferol treatments are conducted in a similar manner to those involving the use of anticoagulants. Field trials carried out with 0.1% calciferol bait against Norway rats living on farms on a warfarin-resistant area in Denmark were reported successful in most cases (Lund, 1974), even though alternative foods were abundant. Rennison (1974b) also reported successful control of R. norvegicus on farms using 0.1% calciferol with or without 0.025% warfarin. The one failure was attributed to reasons other than the use of calciferol.

The combined use of 0.1% calciferol and 0.025% warfarin on whole canary seed was reported by Rowe et al. (1974c) to be effective against M. musculus. In six field trials against house mice infesting farm buildings 97-100% mortality was obtained.

Calciferol is toxic to many mammals, including man, but its slow action allows adequate time for antidotal measures. Cortisone (Verner et al., 1958) and procine calcitonin

(Buckle et al., 1972) have been used as antidotes in calciferol poisoning. There may be a primary poisoning hazard to birds, as reported by Greaves et al. (1974a).

Calciferol can be usefully employed against individual anticoagulant resistant Norway rat or house mouse populations, but its high cost tends to preclude its use in large-scale rat poisoning operations. Because of its subacute action, there is a possibility that sub-lethal dosing and consequent bait shyness may develop; prebaiting is recommended, therefore, in situations where alternative foods are abundant.

9.9.4.4 Pyrinuron

(Pyriminyl), 1-(3-pyridylmethyl)-3(4-nitrophenyl) urea, also known as RH-787, Vacor and DLP-787, is a relatively selective rodenticide. It is reported to be highly toxic to Norway rats, less so to house mice. Various other mammalian species, apart from cats, were found to be less susceptible; Peardon (1974) reports an LD_{50} for cats of 62 mg/kg.

Pyrinuron is relatively slow-acting, taking several hours to kill rats or mice. Peardon (1974) has stated that pyriminyl does not produce bait-shyness but there is need of more specific information on this aspect. Pyriminyl is a light creamy-yellowish powder, odourless and apparently tasteless. It is insoluble in both oil and water, is chemically stable and has a good shelf life. Pyrinuron is marketed as a 2% ready-mixed bait for use against both rats and mice. However, it was found in laboratory trials that better kills of Norway rats were obtained when it was included at 0.5% in bait. Pyrinuron is also available at 10% in dust for the treatment of house mice.

In pen and field trials involving prebaiting, Rowe et al. (1978) found that pyriminyl, at 2% in bait, was about as effective as zinc phosphide against house mice. However, neither of these poisons proved to be as effective in controlling mice as either calciferol or brodifacoum.

Recent evidence has indicated that pyrinuron has some apparently unforeseen toxic hazards to humans and its future is uncertain. It must be regarded as a hazardous compound and great care should be exercised when handling and placing baits. Since domestic cats are also quite susceptible to pyriminyl, every effort should be taken to protect them when carrying out control treatments.

9.9.4.5 Zinc phosphide

Zinc phosphide is a fine-greyish black powder with a definite garlic-like odour and strong taste. It is a good general rodenticide that has been widely used for several decades to control a number of rodent species. Although fairly stable in air and water, it degrades in the presence of dilute acids liberating highly toxic phosphine gas.

Zinc phosphide is moderately fast-acting; death may occur in less than an hour, most rats dying from heart failure accompanied by liver and kidney damage (Schoof, 1970). It is used at 1-1.5% in cereal, fish, meat, vegetable or fruit baits; sometimes a fat or oil is used as a binder.

The characteristics that make zinc phosphide attractive to domestic rodents (odour, taste and colour) apparently make it unattractive to other mammalian species. It has a generally good record of safety in use (Hood, 1972) although it is toxic to man and domestic animals, especially chickens. The technical powder can be easily inhaled so a dust mask should be worn when mixing bait; gloves should also be worn when applying fresh baits.

Cases of primary and secondary poisoning of domestic animals and wildlife have been reported. The degradation of zinc phosphide bait laid outdoors under varying conditions has been studied and different conclusions drawn. Physical erosion may account for most of the decrease in the toxicity of weathered baits, for recent studies have shown that when baits are protected from rainfall over an extended period, the degradation of zinc phosphide is very slight (Guerrant & Miles, 1969).

In field trials against Norway rats, zinc phosphide has been found to be rather less effective than thallium sulfate, sodium fluoroacetate and fluoroacetamide, but more so than norbormide (Rennison et al., 1968; Schoof, 1970). Overall, however, zinc phosphide is recommended as an acute poison against commensal rodents (Gratz, 1973a).

9.9.5 Minimally hazardous rodenticides

9.9.5.1 Norbormide

Norbormide, /5(a-hydroxy-a-2-pyridylbenzyl)-7-(a-2-pyridylbenzylidene) norborn-5-3n3-2, 3-dicarboximide/, is a selectively toxic rodenticide. It is very toxic to *R. norvegicus*, less so to *R. rattus*, and essentially non-toxic to a number of other common mammals and birds, including some primates (Roszkowski, 1965).

The LD_{50} of norbormide to Norway rats is in the range of 9 to 12 mg/kg (Greaves, 1966; Roszkowski et al., 1964). Its mode of action appears to be that of a vasoconstrictor, poisoning symptoms occurring about 15 minutes after dosing and death from 40 minutes to 4 hours later. In *R. rattus*, the LD_{50} is considerably higher, 52 mg/kg according to Roszkowski (1965). Doses as high as 1000 mg/kg proved to be non-toxic to house mice, coypu, deer mice, cats, chickens, dogs, ducks, foxes, geese, ground squirrels, rhesus monkeys, pigeons, sheep, swine and turkeys.

The results of field trials, using norbormide at 0.5 and 1.0% concentrations, proved disappointing. Maddock & Schoof (1967), using 1% norbormide, obtained 75-100% control of Norway rats in only 11 of 33 treated premises and Rohe (1966) failed to kill roof rats in sewers using 1% norbormide incorporated in paraffin wax baiting blocks. Rennison et al. (1968) also failed to control *R. norvegicus* adequately when using 0.5 and 1.0% norbormide treated bait on pig and chicken farms. Radova et al. (1968) and Beveridge & Daniel (1966) however both reported favourable results using norbormide. Norbormide has been found to have several shortcomings as a rodenticide. It appears to be unpalatable to some rats even at a 0.5% concentration in bait (Greaves, 1966; Ogushi & Tokumitsu, 1970) and some Norway rats seem to withstand significantly high doses of norbormide. Greaves (1966) reported that one rat survived after consuming 154 mg/kg of norbormide and Ogushi & Tokumitsu (1970) similarly found that survival occurred up to 147 mg/kg. Roszkowski (1965) observed a two-fold decrease in susceptibility in rats previously exposed to sublethal doses of norbormide. The combination of variable palatability, significant physiological tolerance and fast action reduces the usefulness of norbormide as a rodenticide.

Attempts, only partially successful, have been made to improve the efficacy of norbormide by microencapsulating the compound in order to enhance palatability and to delay the onset of poison symptoms.

9.9.5.2 Red squill

Red squill is derived from the bulb of the onion-like plant, *Urginea maritima*, which grows mainly in the Mediterranean area. The bulbs of the squill plant are sliced, dried, and ground to a fine reddish powder. Squill keeps well if stored in a tightly-capped can or bottle but it slowly loses its toxicity when exposed to air. A method of stabilizing the powder has now been developed whereby squill is formulated to give a minimum LD_{50} of 500 mg/kg for Norway rats. Squill has been used as a rat poison since the Middle Ages, its toxicity depending on the presence of a glycoside, named scilliroside. It kills by a digitalis-like action which causes heart paralysis and is moderately slow-acting, death occurring within 24 hours.

Red squill powder has a bitter taste and severe vomiting occurs when it is ingested. Despite the bitter taste, squill is fairly well-accepted in bait by Norway rats, at least initially, but it should not be used at concentrations exceeding 10%. Red squill is not effective against roof rats but it has been incorporated in dust for house mouse control. Red squill exhibits a differential toxicity to male and female Norway rats, females being about twice as susceptible (Crabtree et al., 1939). Rats consuming a sublethal dose of the poison tend to become bait-shy and the effects have been found to last as long as a year (Chitty & Southern, 1954).

Field trials reported by Chitty & Southern (1954) showed that only about 75% of rat populations were killed when squill was used in damp bait. Koren & Good (1964) considered the use of red squill to be cheaper and more effective than anticoagulants because of labour savings. More recent laboratory and field trials showed that the stabilized scilliroside is a highly effective rodenticide against Norway rats when used at a concentration of 0.015% in cereal bait (Maddock & Schoof, 1970).

Red squill is considered to be a relatively safe compound to use because it acts as its own emetic in animals capable of vomiting and because of its bitter taste. The powder is extremely irritating to the skin however and rubber gloves should be worn during bait preparation; powdered squill is also capable of causing violent and persistent sneezing and a mask should be worn when large amounts are handled.

9.10 Chemosterilants

Increased attention has been given recently to the possible application of reproduction inhibitors or chemosterilants for the control of rodents, a concept different to that using rodenticides. Investigations have been conducted with both steroidal and non-steroidal compounds that are capable of producing temporary or permanent sterility. This approach, known as biogenetic control, involves breaking the chain of reproduction at any one of several vulnerable links to produce, at best, permanently sterile animals. The presence of sterile rats or mice in a population exerts pressure on the fertile animals to maintain the birth rate. Theoretically such sterile animals would continue to occupy territory and exclude immigrants but not contribute to the birth rate; under these conditions, the birth rate would tend to fall below that of the death rate and the population would gradually decline towards extinction. Relevant aspects concerning the application of chemosterilants for rat control purposes have been reviewed recently by Knipling & Macquire (1972) and a general review of the use of chemosterilants has been provided by Marsh & Howard (1973).

A number of steroids have been evaluated against female rats. Mestranol, the first proposed chemosterilant of the estrogen type, was shown to be ineffective in field trials against Norway rats (Marsh & Howard, 1969), apparently because it induced strong bait-shyness upon repeated exposure. Quinestrol, a longer-acting estrogen than Mestranol, was used successfully in a short-term field trial against Norway rats (Brooks & Bowerman, 1971) as the result of laying a different bait-base each time it was applied. Even so, bait-shyness was not fully overcome.

Gwynn (1972a, 1972b), using a seemingly palatable anti-estrogenic material in water baits offered to Norway rats daily, was able to show effective inhibition of reproduction in trials against rats living in pens and infesting a cattle-feed yard. The practical value of a chemosterilant that needs to be taken daily however is questionable.

The male Norway rat has been effectively and permanently sterilized using alpha-chlorohydrin (Bowerman & Brooks, 1971; Ericsson, 1970). The acceptance of treated bait can be improved by microencapsulating the compound (Ericsson et al., 1971). Field trials of alpha-chlorohydrin against high density rat populations indicated that although 80% of the adult males were rendered sterile, pregnancy rates were not reduced owing to the promiscuous breeding of females. However, Andrews & Belknap (1975) found that a smaller sewer rat population treated with alpha-chlorohydrin (U-5897) failed to recover afterwards as did a Warfarin-treated population. Male chemosterilants of this type might be best used therefore against low density rat populations, and possibly in combination with an estrogen.

The most successful use of an estrogenic steroid /3-cyclopentyl ether of 17 a-hexa-1'3'-diynyloestra-1, 3.5, (10)-trien-17 B-01/ (BDH 10131) against a population of wild Norway rats living on a garbage dump has been reported by Rowe & Lazarus (1974). The rat population numbering some 500-1000 animals was prebaited for three weeks with a cereal bait before it was treated for six days with the same bait containing 0.05% BDH 10131.

The treated population and an untreated one from another dump were sampled by removal trapping at four to ten week intervals. Pregnant females were regularly trapped at the control site but none were recovered from the treated dump until 26 weeks after treatment. Twelve weeks after the end of the treatment and throughout the remainder of the study year, the number of young rats declined at the treated site although they continued to comprise about 30% of the control samples. Six months after the treatment, the rat population was only 75% of that at pretreatment and this decline continued until the colony was almost eradicated.

The future of suitable chemosterilants in the field of rodent control is uncertain. They would probably be best used in conjunction with environmental management practices and in combination with more conventional killing techniques. Chemosterilants have an advantage over rodenticides in that they pose less immediate hazard to humans, pets or domestic animals. Some, such as the alpha-chlorohydrin, are specific to rats whilst others are reversible in effect.

The major disadvantage of chemosterilants is that rodent populations treated in this manner decline rather slowly; meanwhile, damage, contamination and disease problems have to be accepted. Most of the chemosterilants investigated so far have been found to produce marked bait-shyness making repeated baiting difficult, if not impossible. Those of the estrogen type particularly are also highly potent compounds, and they may cause harmful side-effects at high dosage levels; as yet, the potential hazards of chemosterilants to humans and domestic animals have not been sufficiently evaluated.

9.11 Rodenticide application techniques

9.11.1 Food baits and additives

The chemical control of rodent infestations is most commonly accomplished by the use of poisoned baits. Selection of acceptable baits is an important element in a successful rodent control programme and a thorough knowledge of the rodents and their food preferences is needed in order to achieve the best kill in poison baiting operations. Sometimes this information can only be satisfactorily gained in the field by offering a population a variety of food items over a period of several days.

Bait materials most commonly used for the control of rats and mice are fine or crushed cereals followed by meats, fish, nuts, fruits or vegetables. Liquid baits are also used, especially in arid climates or in areas lacking accessible water. Cereal-type baits have found the widest use because they are generally preferred by rodents; they are most easily mixed with powdered or liquid poisons; and because of their low moisture content they also tend to keep well, both in the store and the field. Contrary to some belief, rats and mice prefer fresh, palatable foods. If perishable baits are used, they should be laid in the early evening to ensure their freshness overnight - the period of greatest rodent activity. Most baits are exposed in bait containers which provide a secure place where rodents can become accustomed to feed; their use also helps to prevent other animals from gaining access to poison bait. Examples of several kinds of bait containers are shown in Figs. 9 and 10.

Various additives and attractants are frequently used to facilitate the preparation or to improve the efficacy of baits. Vegetable oils and sweeteners are commonly added to improve bait palatability: the addition of 5% sugar or 3-10% vegetable oil in a cereal bait will generally increase acceptance if the bait itself is palatable. Dexide, a carbohydrate with flavour, has been reported to improve the palatability and consumption of anticoagulant baits (Schisla et al., 1970). Artificial flavourings of several kinds have been proposed as attractants (Hulbert & Krumbiegel, 1972), but their efficacy is doubtful. Coloured dyes or pigments are frequently added to rodent baits as warning agents to deter humans or birds from feeding on them and a dye, preferably blue or black, should be added to any bait that could be mistaken for human food. Chlorazol Sky Blue (0.05% by weight) is recommended by Drummond (1972) and Alkali Fast Green, Aqua Green, Methylene Blue and Monastral Green have been reviewed by Howard & Marsh (1974). Lampblack and Nigrosine Black are also sometimes used. When colouring bait no more dye should be added than is necessary.

Other additives are used on occasion, either as bait preservatives or to protect baits from deterioration. Paranitrophenol and dehydro-acetic acid have been included as mould inhibitors in cereal baits used in sewers (Larthe, 1957) but such additives tend to reduce the palatability of bait. Paraffin has been mixed with bait materials to moisture-proof them for use in sewers or in warm, humid tropical environments (Marsh & Plesse, 1960).

9.11.2 Water baits

Rats and mice drink water daily if it is available to them. In habitats where access to water can be restricted or in hot, arid areas, water baits are a relatively cheap and efficient means of controlling both rats and mice. For example, mice living in such warm places as bakeries and in large food stores containing bagged cereals, flour or animal food-stuffs where free water is normally absent, can be readily drawn to poisoned water bait (Rowe & Chudley, 1963).

Water-soluble salts of anticoagulants are used most commonly in water baits; each is normally employed at the concentration of the compound that is recommended for use in solid bait and their acceptability is improved by the addition of between 5 and 10% sugar.

Many types of liquid bait dispenser are manufactured but a bottle, a small tin lid or plastic dish, can be substituted. The bottle is fixed to a wire loop and nailed to the wall. The common chicken fount has been found particularly convenient for use in large food storage areas where permanent water baits are established. Anticoagulant water baits can also be placed alongside poison bait in large containers. In this way, rats and mice can be encouraged to consume approximately double the amount of anticoagulant they would ingest from feeding on bait alone.

Poisoned water baits should be placed at floor level only. There are disadvantages in their use - contamination of the solution with dust, loss of water through evaporation resulting in an increase in the concentration of active ingredient, moulding of the water solution and the risk of accidental spillage. It is important therefore to inspect and replenish water baits regularly.

9.11.3 Anticoagulant poison treatments

When anticoagulant poison treatments are carried out against rats or mice there is no need to prebait. It is essential to survey the infested area first and to record the sites to be baited. Baits should be set out under cover and protected from the weather and other animals. Adequate protection can usually be devised from materials at hand, such as bricks and planks, but bait containers are sometimes required or preferred. If it is found necessary to employ bait containers, these should be put down for 4-10 days before baiting begins.

It is extremely important to maintain surplus anticoagulant bait throughout the entire poisoning operation. When a large enough amount is used initially, i.e. 25-50 g for mice and 200 g or more for rats at each baiting point, and further liberal quantities are replenished as necessary, the intervals between successive visits can be lengthened. Even so, if the infestation is large, the baits should be checked every 1-2 days, at least during the early stages of a treatment, and more bait added as necessary. When no more bait is being consumed, generally after about 2-3 weeks, the excess bait should be removed and all dead rats or mice recovered and burned or buried. All obvious rodent traces should be removed and a survey made for fresh traces a few days later. If new traces are found, a different palatable bait should be tried. In treating rats it is not normally necessary to change the anticoagulant at the same time although this can be done if another one is at hand. In the case of surviving mice, it is best to adopt another control method, either by using an acute poison in a different bait or by setting traps.

Typically, a treatment against rats involves surveying the infested areas and laying about 200 g of anticoagulant bait at or near sites where rat traces are found. Each site is then revisited on the second, fourth and seventh days of each seven-day cycle. The baiting sites where feeding is active are recorded on appropriate data sheets and the schedule of visits is continued until no more bait is consumed.

9.11.4 Acute poison treatments

When using an acute poison, it is equally essential first to survey the infested area thoroughly and to number the baiting points to be used. Poison bait is generally better accepted and an improved kill obtained by laying prebait for a few days beforehand. The bait laid should be the same as that used later in the poison treatment. Small amounts of prebait, about 50-100 g for rats and 10 g for mice, should be placed wherever traces of rodents are found - close to burrows, nests and runways, in order to encourage feeding on the bait before other food sources are reached. For mice, which tend to feed erratically, it is best to place small amounts of bait close together (about every 2 m). Baits should be set out under cover, using containers where necessary, in a similar manner to that employed in conducting anticoagulant treatments.

After prebait has been laid, the sites should be examined every one to two days and more bait added when necessary. At sites where all of the bait has been consumed, it is best to lay down twice the amount previously used. The amount of prebait consumed can help to give a rough indication of the number of rats or mice present and the amount of poison bait required. As a general rule, only half as much poison bait is needed at each site as was eaten on the last day of prebaiting. Prebaiting usually achieves its purpose in four to eight days; at the appropriate time all uneaten prebait should be removed and the acute poison bait laid. The poison baits should be maintained for one or two nights. During the poison treatment, the area should be disturbed as little as possible, particularly during the first night the poison bait is laid.

At the end of the treatment period, the uneaten poison bait and any dead rodents should be collected and disposed of by incineration or deep burial. Burrows should be filled in, all obvious traces of rodents removed and, a few days later the area re-examined for fresh traces. At sites where rodents appear still to be active, a different prebait should be laid down and, if any is eaten in a day or two, a second poison treatment should be conducted, involving a different poison to that used previously.

9.11.5 Poison dusts

The application of a poisonous dust can be useful in getting rodents to consume a poison in those situations where acceptance or other baiting problems arise. This control method relies upon rodents inadvertently coming into contact with the poisonous dust when it is laid in areas they frequent. The dust sticks to the rodents fur and feet and is ingested by them during normal grooming behaviour. Such dusts usually contain a considerably higher concentration of a poison than that used in food baits because contaminated rats or mice consume considerably less poison during grooming (Gutteridge, 1972).

There are advantages using this control technique; affected rodents do not suspect the source of illness resulting from ingestion of the poison and neither do they tend to avoid normal travel routes. Furthermore, they have no need to change their normal feeding habits. There are disadvantages in their use, however; the risk of contaminating food supplies and other species precludes the use of dusts in situations where these problems could arise. Poisonous dusts are also rather uneconomic to use since excess dust must necessarily be laid even though only a small amount will be consumed.

Poisonous dusts should be fine enough to stick to feet and fur, yet not so light as to become airborne; they can be applied in several ways, as patches on runways or other areas frequented by rodents, around the openings and on the floors of bait containers or blown into burrows, between walls or into other spaces occupied by rodents (Marsh, 1973). They can also be applied inside plastic or cardboard tubes, placed on runways or alongside walls.

It is usual to lay poisonous dust in isolated patches about 5 cm wide, 1/2 m long and about 3 mm thick - inside buildings - along walls, in corners and in other areas not in close proximity to foodstuffs. Further applications should be made as necessary during the course of a treatment. The patches should be examined and smoothed every few days to determine whether they are still being crossed by rodents.

Although DDT dust was extensively used at one time for the control of mice its use is now banned in most countries and alternative compounds are being sought. In Europe, the anticoagulants and γ-BHC (Meehan, 1976a) have been used the most, even against rats in refuse dumps. The successful use against mice of anticoagulant dust surrounding similarly poisoned water bait has been reported (Rowe & Chudley, 1963). Of the acute poisons described earlier, ANTU and red squill have been occasionally used in this manner and zinc phosphide and pyrinuron have also been incorporated in dust form (Marsh & Howard, 1977). In most situations however hazard considerations preclude their usage.

9.12 Anticoagulant resistance

Warfarin was introduced as a rodenticide in 1950 and it soon became more commonly used than the acute poisons then available. In 1958, however, Norway rats infesting a rural area of Scotland, between Edinburgh and Glasgow, were found to be remarkably resistant to both Warfarin and diphacinone (Boyle, 1960); the affected area has increased and Warfarin-resistant rat populations in Scotland now cover about 6400 km^2 of countryside (Brodie, 1976). Two years later, Lund (1964) reported the discovery of anticoagulant resistant rats in the Jutland peninsula of Denmark in an area which later involved over 9000 km^2 (Lund, 1972b). Anticoagulant resistant rat populations were also discovered in the Welsh-English border counties of Montgomeryshire and Shropshire and in other parts of England (Drummond, 1970). On the Welsh-English border, areas with resistant rats were found to expand radially at the rate of about 4.6 km/year, some 3100 km^2 of agricultural land being concerned. In 1968, a smaller resistance area in Kent, England, covered at least 500 km^2 of land (Greaves, 1971).

Other Warfarin-resistant rats discovered in a rural area of the Netherlands in 1966 were quickly eradicated using the acute rodenticide, fluoroacetamide (Ophof & Langveld, 1969).

The first reports of anticoagulant resistant Norway rats in the United States of America came from a rural area in Johnson County, North Carolina, in 1971 (Jackson & Kaukeinen, 1972). The area concerned covered some 100-140 km^2 and at least twelve farms were involved. Other resistant rat populations in rural areas of the United States of America were found in New York and Idaho (Brooks & Bowerman, 1973a; Brothers, 1972). A national survey to detect Warfarin-resistance in rats infesting urban areas of the United States of America has been carried out since April 1972 by two cooperating laboratories at Bowling Green, Ohio and Troy, New York. Resistance has been detected in rats taken from 20 out of 46 cities (Jackson et al., 1973, 1975a & b), the most extensive area and the one with the highest frequency of the resistance trait was in the Lawndale district of Chicago, Illinois.

Resistance has also been found in the roof rat in Liverpool, England (Greaves et al., 1973) and further investigation showed that resistance in this species was fairly widespread in Britain (Greaves et al., 1976b). The same problem has been encountered in California (Jackson et al., 1975a & b), and there is reason to believe that resistance may be increasing in *R. rattus* in other areas of the world.

Cases of anticoagulant resistance in mice were confirmed in England (Rowe & Redfern, 1965), and later in the United States of America (Jackson et al., 1975) and Sweden (Lund, 1977). House mice have been found to show great individual variation in response to Warfarin poisoning, so-called normal populations requiring 22 days feeding on 0.025% Warfarin before 95% mortality is obtained (Rowe & Redfern, 1965). The genetic mechanism of resistance in the house mouse has been shown to be due to a major dominant gene (Wallace & MacSwinney, 1976) and in the Norway rat it is determined, in most cases, by a single dominant autosomal gene (Greaves & Ayres, 1967; Pool et al., 1968). Breeding experiments carried out with Warfarin-resistant and susceptible *R. rattus* in Britain have indicated that inheritance in this species has a multifactorial basis (Greaves et al., 1976a). In susceptible rats, Warfarin acts by inhibiting vitamin K oxide reductase, thereby blocking the synthesis of the blood clotting factors of the prothrombin complex and causing internal bleeding. In resistant rats the biochemical conversion of vitamin K takes place even in the presence of the anticoagulant (Bell & Caldwell, 1973).

Anticoagulant resistance in rats and mice is heritable being passed from generation to generation; it is not due to the development of physiological tolerance as the result of the ingestion of small quantities of poison bait. In most of the cases studied in detail, individuals found to be resistant to Warfarin have also been shown to be resistant to other anticoagulants, both hydroxycoumarins and indandiones, with the notable exception of some of the second generation anticoagulants. Resistance arises in rodent populations whenever the gene concerned is present or appears spontaneously and when intensive anticoagulant poisoning programmes have been carried out over a period of years. The anticoagulant acts as a selective agent, susceptible individuals being killed leaving the resistant ones to produce resistant offspring.

A laboratory testing procedure to detect and/or confirm anticoagulant resistance in rodents has been outlined by WHO (1975) and this method has been used extensively in the United Kingdom, Denmark, and the United States of America. In suspect cases such laboratory confirmation remains the ultimate proof of genetic resistance in rodents. Drummond & Rennison (1973) have described a field procedure that is applicable for the detection of resistance in R. norvegicus. The method involves keeping a record of rat activity at each baiting point for the duration of a treatment. A linear decrease in activity as the treatment progresses, plotted on a logarithmic scale, indicates a normal susceptible population. Values consistently falling outside the upper 95% confidence limit are sufficient cause to suspect anticoagulant resistance and to call for confirmation by laboratory test. Although the method as given is for Norway rats, it is probable that the test procedures can be adapted to cover most other rodent species.

The containment of anticoagulant resistant rodent populations has proved to be difficult. Attempts made against R. norvegicus in England-Wales and in Denmark failed, resistant rats being discovered outside the containment area (Greaves, 1970; Lund, 1972b). Countermeasures must be taken immediately to prevent the resistance trait from spreading into nearby susceptible populations. Potentially valuable new rodenticides for the control of anticoagulant resistant rats and mice are calciferol, difenacoum, brodifacoum and bromadiolone. Further field trials of these and other promising rodenticides will show whether or not they will be wholly successful in controlling anticoagulant resistant populations. Periodic poisoning with acute rodenticides, is an alternative solution to the resistance problem when it arises.

9.13 Sewer rat control

The control of rats in sewers requires more specialized methods than those used against rats living on the surface. For one thing, environmental control is next to impossible and sewer rat populations are usually accessible only at manholes or street drains unless the sewer system is large enough to be worked. Sewer rats are rarely seen and the operator must largely rely upon signs of droppings or evidence of feeding activity at manhole ledges to indicate their presence and relative abundance.

The Norway rat is the most common inhabitant of sewers throughout the world but in its absence, the roof rat may appear. Roof rats have been reported to invade sewers on occasion in Britain (Davis, 1955) in California (Brooks, 1963; Mackie, 1964), and in Iran and Iraq (Wichmand, 1969). Rat populations living in sewers and drains in a city serve as underground reservoirs for surface infestation since they can usually penetrate the surface, establish new colonies there, and reinfest homes, shops, factories and other establishments.

The control of sewer rats is not difficult but operations can be arduous and they need to be well organized. Maps should be obtained of the sewer system, showing the location of all manholes, the direction of flow of the sewage and the location of pumping plants. Unfortunately, such maps are not always available or sufficiently detailed because sections of sewers were laid down long ago and their true locations not known; they are essential, however, in order to record survey results properly and to oversee poisoning programmes effectively. Pumping plants usually act as barriers to the movements of rats and they can be a helpful guide in deciding how to subdivide a sewer system for treatment purposes.

Surveys should be carried out in order to assess those manholes showing evidence of rat infestation and to map the distribution of rats within the total system. If necessary, the initial survey can be done concurrently with the first poison treatment in order to save manpower. Evidence of rat activity may be found from droppings on the manhole benchings; burrows and live or dead rats may also be observed around manholes. If the presence of rats is in doubt, it is best to lay small amounts of bait (about 30-50 g) and to examine them two to three days later to find if feeding has occurred. When possible, surveys are best done during the dry season, several weeks or a month after the last heavy rains, as storm water can flood manholes and sweep away the signs left by rats. Not every manhole in a system needs to be surveyed, a 10-20% sample of all manholes usually being sufficient to determine the extent of an infested area.

A vehicle, preferably a truck or van, equipped with warning flashing lights, is required to transport men and equipment, including pick-axes or tools for lifting manhole covers. Battery-operated searchlights or floodlights that operate from the vehicle may also be needed to inspect manholes. Heavy leather gloves are desirable for each worker and it is also useful to have clipboards at hand for holding maps and data sheets.

Poison baiting is the only practical means of controlling rat populations in sewers. Normally, bait is laid on manhole ledges but in large accessible sewers it can be placed along their length on available ledges or on specially installed trays. Baits that have given best results are various cereals, ground horse meat or fish, canned cat food, and peanut meal. While cereal grains tend to mould quickly, meat-type baits decay even more rapidly and so they are primarily recommended when a quick kill with an acute rodenticide is desired. The use of paraffin-wax block baits has been suggested to partially overcome moulding problems when anticoagulants are employed (Brooks, 1962; Marsh & Plesse, 1960). When cereal grains are mixed with paraffin in this manner and exposed in sewers, the blocks quickly hydrate, swell and break apart. A new bait using waste frying grease and an oil-soluble anticoagulant has been reported to be highly stable and very effective in sewer rat control (Sipaila, 1975).

Anticoagulant baits have proved useful in treating sewer rats. Several visits are normally required for effective control since a surplus of bait must be maintained at each manhole during the treatment. Bentley (1960a) recommends a 1-4-8 days baiting schedule when sewer rat infestations are heavy and a 1-8-15 day sequence otherwise. At least 1/2 kg of bait should be placed initially at each baiting site. At points where all the bait is consumed, the amount laid should be doubled.

The most efficient and easiest poisons to use in sewers are sodium fluoroacetate (1080) and fluoroacetamide (Bentley et al., 1961), although zinc phosphide has been used on occasion. They should be applied in dry or oily cereal bait in preference to damp bait, because the latter must be handled with extreme caution. Workers should wear rubber or plastic gloves during the preparation and laying of poisoned bait; their hands should be kept away from their mouths until thoroughly washed with soap and water.

Prepared bait can be spooned into polyethylene plastic bags in approximate 100 g amounts and the bags then sealed. An alternative method using anticoagulants is to mix the bait ingredients into hot, melted paraffin and to mould the mixture into approximate 100 g bait blocks, using one part of paraffin to two parts of mixed bait.

In treating a sewer system the truck is parked near a manhole, the flashing lights are turned on to warn traffic and the cover is removed; the chamber is then inspected for evidence of rats. When poisoning for the first time, it is advisable to treat each manhole in turn regardless of the presence or absence of rat signs. Information is recorded on the location of the manhole, its condition (wet, dry, flooded, blocked) and whether rats were present or not.

A plastic bag containing bait or, alternatively, a paraffin bait block is then tied to a length of flexible wire and lowered into the manhole until it rests on the manhole ledge. If no ledge is available, the bag should be hung above the flow of sewage. The wire is secured to the rungs of the manhole ladder or tied to a stout nail driven into the side of the manhole. Baits are tied in place in this manner in order to prevent rats from pulling them into the sewage flow.

Generally, three men can inspect and bait a minimum of 50 manholes a day and a trained crew can treat about 12 000 manholes annually. A single treatment each year is the minimum degree of control that should be exercised and two treatments a year will give a much longer lasting reduction of the rat population.

When sewer systems are treated regularly, a reduction in the number of infested manholes should occur in time. However, some areas may always show evidence of rats, certain sections of sewer appearing to be chronically infested. Effort can then be concentrated on these problem areas, leaving the cleared areas for annual inspection and treatment as required.

9.14 Village rodent control

Control of rodent populations in villages is complicated by the constant infestation from surrounding field crop areas or adjacent vegetable gardens by native or commensal rodents. Large-scale reduction of the rodents living in and around the village structures frequently leads to invasion of the village habitat by field rodents. Invasion may also occur on a seasonal basis due to harvesting of crops. Thus, control methods in villages must take account not only of resident rodents but also of potential invaders. Control treatments may have to be scheduled according to the cropping and harvesting practices.

There is no effective way of rodent-proofing the open type of house common to many areas in the tropics, and it is thus virtually impossible to keep rats and mice from seeking harbourage in residences and shops. In village environments in Africa, southern Asia and the Pacific area, a great many of the structures are infested, perhaps by more than one species of commensal rodent. Under these conditions, it becomes vitally important to provide rodent-proof containers for stored foods and to take all measures to see that food wastes are disposed of either by burial at a central disposal site, by recycling wastes in the form of compost or as an energy source.

Where possible, all harbourages indoors should be removed by cleaning out trash and rubbish and eliminating dark, covered areas. Shops and food storage structures should be rodent-proofed where practicable. If complete rodent-proofing is not feasible, then at least the area where foods are to be stored should be made rat-proof by the use of sheet metal and wire mesh.

Outdoors, it is important to keep vegetation low or eliminate it from areas adjacent to structures. Ideally, a vegetation-free perimeter zone at least 50 m wide should be maintained around the village to discourage invasion of field rodents.

Grains can be stored in bulk in silos or storage containers utilizing locally available materials. The silo should be constructed upon a base of hard-packed stones to deter burrowing rodents, its sides made from upright poles woven with split bamboo, if available, and plastered with mud, straw and clay to make a sturdy seal. After filling with grain, the top is sealed in the same manner and provided with a cover to shed rains. If such silos are made air-tight and kept plugged, grains may be stored there for several years.

For home storage, split bamboo is woven into large cylindrical baskets and then covered with mud inside and out. According to Jackson (1977) the high density of the bamboo deters gnawing and effectively keeps rodents out. If the tops are covered with mats and sealed with mud, protection is reasonably good unless the seal is broken. For additional references to traditional grain storage methods see the reviews by Hall (1970) and Hyde et al. (1973).

In the carrying out of treatments to eliminate rodents from the village using poisoning methods previously described, it is essential to survey the entire village area for signs of rodents. Plots of vacant land, out-houses, latrines and refuse heaps as well as houses and stores must be included. Full records of the survey findings and of each treatment (amount of poison bait used, length of treatment, labour and transport costs, etc.) should be made so the success and cost can be assessed.

Besides poisoning treatments, traps can be used to deal with small infestations, especially in those areas subject to repeated invasion by rodents. The traps should be used in adequate numbers and maintained in good operating condition. All buildings and places frequented by rodents should be trapped, paying particular attention to latrines, cooking houses, food stores, nearby undergrowth and piles of rubbish.

9.15 Ectoparasite control

In areas where rodent-borne disease transmission to humans is known to occur, it is vital not only to control the rodent populations but also their fleas and other ectoparasites in order to help prevent disease transmission. When rodents are killed through trapping or poisoning campaigns, their ectoparasites are left without hosts and they may, by chance or by design, select man as a temporary host. Murine typhus is present in rat populations in many cities, towns and villages in tropical and subtropical areas around the world and plague is still a threat in cities and in the countryside in Brazil, Burma, Peru, Ecuador, Indonesia and Viet Nam. In any of these areas ectoparasite control should be a mandatory exercise carried out before or concurrent with rodent control. Even when the presence of disease is merely suspected, albeit not confirmed in a commensal rodent population, ectoparasite control should be carried out first.

Ectoparasites carried by rodents or present in their nests can be killed by blowing insecticidal dust onto runways, or into rodent burrows, cavities or other areas where rodents are living; by using insecticide-treated bait-boxes in which rodents become contaminated with dust when they come to feed on anticoagulant poison bait (Barnes & Kartman, 1960; Clark & Cole, 1968, 1974); by applying a space fumigant (cyanogas) to burrows; or by using plastic resin strips of dichlorvos in containerized cargoes aboard ships.

The simplest methods involve the treatment of burrows and the use of insecticide in bait-boxes containing anticoagulant bait. The five to seven day delay in the death of anti-coagulant treated Norway rats (even longer in roof rats and house mice) is advantageous giving ample time for any ectoparasites to be killed.

9.16 Hazard and safety precautions

The main hazards to persons either directly or indirectly concerned with rodents and their control concern the contraction of rodent-borne diseases and the risk of accidental poisoning. The need to maintain a high standard of personal hygiene at all times is stressed. Rodenticides handled carefully and sensibly should present no risk to other animals or people, including the operator himself. By observing the following precautions hazards can be kept to a minimum, both under laboratory and field conditions:

(1) Protective clothing should be worn in animal rooms; when it is impracticable to wear gloves in handling rodents, an antiseptic barrier should be used.

(2) No eating, drinking or smoking should take place when live and dead rodents or poison baits are handled.

(3) All cuts and abrasions on hands and arms should be covered before starting work; any rat or mouse bites should be reported and medical advice sought.

(4) During the preparation of poison bait, protective clothing, rubber gloves and, if necessary, a dust mask should be worn; non-disposable gloves need to be washed with soap and hot water after use.

(5) Poison bait should be prepared in a well-ventilated room designated for that purpose only, and care should be taken not to breathe in or absorb any poison.

(6) All poisons (pure chemicals, concentrates and prepared bait) should be clearly labelled POISON and held in a locked cabinet in a room which should also be kept locked when not in use.

(7) Containers with poisonous contents should be clearly labelled with the name of the active ingredient, its concentration etc. and empty containers should be thoroughly washed before re-use or disposal.

(8) Poison bait should be transported in a container having a well-fitted lid; it should not be handled directly and containers should be used, if necessary, to prevent animals other than rodents from reaching the bait. Bait containers need to be weighted down in situations where livestock could otherwise move them.

(9) When poison baits are laid, the occupier of the land or premises should be told their whereabouts - so that children, livestock and pets can be kept away.

(10) Poison bait should not be laid where the excess cannot be picked up in order to prevent any later danger. A record should be kept of the number and location of baiting points.

(11) If solid or liquid baits are laid above ground or at floor level, care should be taken to prevent their accidental spillage and the contamination of foodstuffs. Poisonous dusts should not be put in places where rodents might carry dust on their feet and fur, to food or food preparation surfaces.

(12) After treatment all uneaten poison bait should be picked up; any rat or mouse bodies should be burned or deeply buried. A check should be made that all baiting points have been accounted for.

(13) If any poison is absorbed or illness is suspected in relation to rodent control work in the laboratory or in the field, medical advice should be sought immediately; when accidental poisoning occurs, an attempt should be made to induce vomiting until medical attention arrives.

10. ORGANIZATION OF CONTROL PROGRAMMES

Experience has shown that large-scale rodent control programmes, invariably involving the use of anticoagulant treated bait, are best carried out by governmental or municipal authorities. This is because they should be done on an area-wide basis covering, for example, a whole village, a group of towns in a county or province, or a large portion of an entire city, and because various governmental authorities are concerned with public health, housing, sanitation, wastes and sewage disposal. Piecemeal programmes do not diminish rodent populations and related problems to any significant extent. Responsibility for an organized control programme rests with the local government but that for improvements in sanitation, food storage and rodent-proofing generally lies with the landowner and/or occupant. There is a growing and commendable tendency, however, to involve inhabitants in control programmes and to have them participate on a self-help basis.

10.1 Surveys

In any community, careful planning must precede the start of a rodent control programme. As a basis for planning operations the nature and extent of rodent infestation needs to be known. A survey should therefore be carried out to determine the particular rodent species present, the proportion of premises that are infested, the environmental conditions or cultural practices that are helping to sustain infestation levels, the severity of the problem in relation to the economic losses incurred and any factors of public health importance. An initial survey also provides basic information on which the progress of a programme towards established goals can be measured.

A survey in the case of a small village or town could be comprehensive, entailing the inspection of every premise, residence, food store and industrial site. This approach becomes impractical in the case of large cities, however, and it is more usual to survey houses, shops, markets, etc. sampled at random. Various methods used in carrying out such sample surveys are given in Annex II.

Information from the survey should be transferred to a large-scale map showing both the surface properties and the sewer system in detail. When the incidence of rodent infestation is mapped in this manner, certain areas are found to be more heavily infested than others; the total area involved can then be subdivided and a priority assigned to each depending upon the severity of the problem.

10.2 Staff and operational needs

Local conditions, particularly those affecting the availability of funds and manpower, can influence the organization and staffing of rodent control programmes. Myllymaki (1975) who dispensed with laboratory and some other facilities, showed that a comprehensive programme could be implemented rationally and without additional hired staff provided that existing resources were utilized to the best advantage. In conducting long-term rodent control programmes in major urban areas, however, it is preferable to recruit and train permanent staff. The overall supervisor of the programme should be a professional or semi-professional public health or sanitation specialist having a good knowledge of rodent control techniques and how best to use them in the local situation. Good organizational and administrative abilities are needed and the person concerned must be able to deal effectively with other local departments and programmes in the community.

A team leader is essential to direct and supervise the work of field staff, to arrange the daily schedule of activities and to handle reports, records and public complaints. A store, with keeper, to oversee the safe-keeping and supply of rodenticides, traps, weighing and other equipment is also necessary and room should be set aside for the mixing and packaging of bait. Field workers are needed to conduct surveys, carry out control operations and to pin-point sanitary and structural deficiencies. A pick-up truck or van is required to transport a field team together with its equipment and it is also useful to have a small motorcycle available. Ideally, provision should be made for a small, well-equipped laboratory to enable the maintenance and testing of live rodents and for conducting flea insecticide susceptibility tests. A laboratory assistant and a laboratory attendant are necessary to carry out such investigations.

Safety clothing and equipment is needed for certain activities. Gloves, respirators, and occasionally, gas masks, are required for persons handling or mixing poison baits or using fumigants. Steel-toed shoes are the best footwear for personnel treating rats in sewers and clipboards and hand-torches are very useful items in field work.

10.3 Carrying out the programme

After the initial survey has been made, the staff recruited, and the necessary facilities acquired, the operation of the programme should be planned. Based upon the survey results, the areas of highest priority need to be selected and the frequency of control treatments decided upon. Surface and sewer infestations should be dealt with simultaneously whenever possible, the overall strategy being to attempt to gain area-wide control.

On the basis of the survey results, the programme supervisors should set specific goals to be attained, e.g., to reduce the incidence of rodent infestation from that revealed by the initial survey to a certain level in a given time period. Only by setting such goals can the progress of a programme be adequately determined and evaluated. Priorities and goals should be set realistically, consistent with the number of staff available and the financial budget.

The organization of a programme involves the timing of various aspects of the control operations, such as rodent extermination, removal of food and harbourage sources, rodent-proofing and community health education and it can vary according to local conditions and whether rodent-borne diseases are, or suspected to be, present in the area. If plague or murine typhus is an additional problem, the control of rodent fleas should precede or accompany other control measures.

Field staff should be organized in teams; ideally one field leader and a small number of operators (2-5) would make up one team. Each team should be assigned to a specified district within the area selected for comprehensive control. Flexibility is important, however, and a team assigned to cover a certain area should be available to move to another one if necessary.

As far as possible, the areas selected for rodent control operations should lie adjacent to one another so as to reduce the likelihood of reinvasion occurring from untreated areas. Each team should carry out rodent control measures in their area on a premise by premise basis until the entire area has been treated and all rodent activity has ceased.

It is stressed that good record keeping is essential to ensure the best direction of activities. Records should be kept of all poison bait placements and on all surveys and follow-up treatments. Infestations uncovered during field operations should be mapped. Special data sheets are required for survey and control work and suggested record forms are shown in Annex III.

10.4 Maintenance of control

Large-scale rodent control operations, particularly in the initial stages, can be demanding in relation to the effort required to achieve satisfactory results and their value can be eroded rapidly unless they are continually followed-up. Emphasis is placed on sustained improvements in sanitation, assessment of changes in infestation levels by means of repeated surveys and the use of permanent anticoagulant bait stations to reduce the chances of reinfestation.

After carrying out comprehensive rodent control measures, an evaluation of the success of a programme is needed together with an assessment of any changes in control methods or timing that are required. This necessitates a resurvey of the area, again on a random sampling basis. Appraisal is then possible on the effectiveness of the campaign and the progress made toward stated goals. Areas and activities in need of improvement are most easily spotted by repeated surveys, allowing strategies and priorities to be adjusted. Comprehensive surveys of the entire area should be made at least once a year, in addition to the random sample surveys, in order to fully identify new or reinfested premises and necessary environmental improvements.

In Finland, Myllymaki (1975) found that reinfestation of a residential area cleared of rats was minimal when strict attention and supervision was given to environmental sanitation. Thus, after field teams have concentrated on rodent extermination activities, they should strive to effect environmental improvements. Improper storage of food wastes should be pointed out to the occupant or landowner and attempts made to secure metal containers with tight fitting lids for all premises. Harbourage on the premises should be removed, either directly by the field personnel or by arrangement with the landowner/occupant. Food stores should be proofed against rodents by the property owner. Improvements in sanitation should be encouraged by widespread and intensive publicity campaigns in the press, on the radio or on television, if available, and in schools. Handout brochures should be given by field staff to householders at the time of the initial visit. Placards and posters displayed prominently in the neighbourhood area during the operation of control measures can also help to inform the public of the benefits to be derived from improvements in sanitary conditions.

In West Germany and England particularly (Steiniger, 1960; Telle, 1966a, 1966b, 1969; Drummond et al., 1972, 1977), an additional strategy, based on the use of permanent anticoagulant baiting stations, has been employed to maintain urban areas free from rats. It is essential to identify all routes by which immigration can occur and those sites where invading rats are most likely to settle. Immigration mostly occurs along riversides, ditches and embankments, and bait stations containing anticoagulant bait need to be placed along all suspected routes to intercept rats and prevent them from becoming established. The bait stations need to be capable of holding about 500 g or more of anticoagulant bait; they also need to be checked frequently, at least every one to two months, and bait added as necessary. Records should be kept of rat activity at the stations, which should be protected from interference as much as possible. It is stressed that such permanent baiting must be sustained to ensure a low level of rat infestation and that complete eradication, even with persistent effort, may take considerable time.

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ANNEX I

GLOSSARY OF TERMS

ACUTE - acting quickly and severely; reaching a crisis rapidly.

AGNOSTIC BEHAVIOUR - actions, including threats, that result in withdrawal or submission of an opponent.

ANTIBODY - a chemical produced in a living organism in response to a foreign substance entering the organism.

ANTIGEN - a foreign substance which produces an antibody response in an organism.

ARBOREAL - pertaining to living in trees, as with many squirrels and most monkeys; having a tendencey to live or move in trees.

BIOMASS - the total weight of all living organisms in a sample or per unit area.

BIOTA - all the living organisms in an area; the flora and fauna of a region.

BIOTIC - relating to life; biological.

BIRTH RATE - the number of births per individual in some given time interval.

BLASTOCYST - the animal body which develops from cleavage of the fertilized egg.

CARNIVORE - an organism (animal) that eats other organisms (animals); contrasted with herbivore.

CHRONIC - acting over a prolonged period; continuing over a long duration.

COMMENSALISM - the living together of two species, usually with benefit only to one; sharing the same food; used to distinguish species that depend on man for food.

COPULATION - coitus; the union of male and female reproductive organs.

CREPUSCULAR - an animal that is active during the twilight periods of dusk and dawn.

DEATH RATE - the number of deaths divided by the average population.

DENSITY	- the number of organisms (animals or plants) per unit area.
DIASTEMA	- a space between adjacent teeth; e.g. the space between incisors and molars in rodents.
DIGITIGRADE	- walking on the digits with the wrist and heel bones held off the ground; contrast with plantigrade.
DISPERSAL	- spreading or moving out from a point.
DIURNAL	- an animal active during the daylight hours; opposite of nocturnal.
DORSAL	- pertaining to the back or upper surface.
ECOLOGY	- the study of the interrelationships between and among organisms and their environment.
ECOSYSTEM	- the biotic community and its non-living environment as an interacting system.
ECTOPARASITE	- a parasite that lives on the external surface of an animal, e.g. fleas, lice, mites, ticks.
EMIGRATION	- movement out of an area.
ENAMEL	- an extremely hard outer layer on the crown or outer surfaces of the tooth, consisting of calcareous compounds and a small amount of organic matrix; usually white, but can be brown, red or yellow in rodents.
ENDEMIC	- referring to a group of organisms confined and indigenous to a certain region.
ENDOPARASITE	- a parasite that lives within its host; e.g. nematodes, cestodes.
ENVIRONMENT	- the physical and biological characteristics of a certain region.
ENZOOTIC	- a disease affecting or peculiar to animals of a specific area or limited district.
EPIDEMIC	- the occurrence in greater numbers than usual of a pathogen, parasite or pest; a disease that affects a large number of organisms and spreads rapidly.
EPIZOOTIC	- a disease attacking a large number of animals simultaneously or prevalent among a group of animals.

FAUNA - a collective term for all the animals in a given region or geological time period.

FLORA - a collective term for all the plants living in a given region or geological time period.

FOSSORIAL - pertaining to life under the surface of the ground; living in burrows or holes in the ground.

FUMIGATION - any process by which animals, especially arthropods and rodents, are killed by the use of gaseous agents.

GENITAL - pertaining to the external sex organs or the area of the external sex organs.

GENUS - (plural, genera) a taxonomic category within a family, consisting of one or more generally similar species.

GESTATION PERIOD - period of embryonic development in the uterus between fertilization and parturition.

GRANIVORE - an organism (animal) that feeds primarily on grains and seeds.

GUARD HAIRS - the outer coat of coarse, protective hairs in most mammals.

HABITAT - the physical place (home) where an organism lives.

HERBIVORE - an organism (animal) that eats plants; contrast with carnivore.

HIERARCHY - a social rank order of animals; dominance hierarchy.

HORMONE - chemical substances released into the blood by the endocrine glands to stimulate and coordinate distant organs; bodily growth, metabolism and sexual functions are largely regulated by hormones.

HOST - the animal parasitized by a parasite or disease organism.

IMMIGRATION - movement into an area.

IMPLANTATION - the embedding of the blastocyst in the uterine epithelium.

INCIDENCE OF PREGNANCY - the number of times pregnancy occurs in a given time period.

INCISOR - the most anterior of the four basic kinds of teeth found in mammals:, usually chisel-shaped and used for cutting or gnawing.

INGUINAL - related to or located in the groin area (lower abdomen and thigh area).

INSECTICIDE - any chemical substance used for killing arthropods and other insects whether applied as powder, liquid aerosol or as a "paint" spray; residual action is usual; larvicide generally means those insecticides that kill immature stages; adulticides, to designate those applied to kill mature or adult forms.

INSECTIVORE - any member of the mammalian order Insectivora; a primitive insect-eating (insectivorous) group; for example, moles, hedgehogs and shrews.

INTERSPECIFIC - within or amongst members of different species; contrast with intraspecific.

INTRASPECIFIC - within or among the members of the same species.

KINAESTHESIA - the sensation of bodily position; presence or movement resulting chiefly from stimulation of sensory nerve endings in muscles, tendons and joints.

LATERAL - located away from the midline; at or near the side(s).

LD_{50} - the dose of a chemical that will cause death to 50% of a group of animals during a given period of time.

LIMITING FACTOR - a factor in least supply for growth or other process; the ecologic influence which limits or controls the abundance and/or distribution of a species.

LOGISTIC EQUATION - a model of population growth described by a symmetrical S-shaped (sigmoid) curve with an upper asymptote.

MAMMARY GLAND - milk-producing gland unique to mammals.

MANDIBLE - the lower jaw.

MARKING - the behavioural process by which a mammal intentionally leaves an indication of its presence in its environment; usually accomplished by deposition of scent gland secretions.

MOLAR - any check tooth situated posterior to the premolars, used primarily for grinding; one of the four kinds (incisors, canines, premolars and molars) of teeth in mammals.

MORBIDITY - the condition of being diseased.

MORTALITY - the process of removal from a population by deaths.

NATALITY - the process of addition to a population by births.

NEOPHOBIA - the fear or avoidance of unfamiliar objects in a familiar environment.

NICHE - the unique ecological role or way of life of an organism in its ecosystem; where it lives and what it does in the community.

NOCTURNAL - pertaining to night time, the hours without daylight; in particular, pertaining to animals that are active at night; opposite of diurnal.

OLFACTORY - perception by the sense of smell.

OMNIVORE - an organism (animal) that eats both plant and animal food; an animal that eats all kinds of food.

OVARY - the female gonad or reproductive glands; the organ of egg production.

PANDEMIC - epidemic (disease) over an especially widespread geographic area.

PARASITE - an organism which derives its nutrition by competing with its host, often with deleterious results to the host, or by feeding upon its tissues.

PARTURITION - the process by which the embryo separates from the uterine wall and is born.

PATHOGEN - an organism which causes disease.

PECTORAL - pertaining to the breast or chest area.

PENIS - the organ which the male mammal inserts into the vagina of the female for the purpose of insemination.

PESTICIDE - a chemical substance used to kill species regarded as pests by man; an agent that kills pests.

PHEROMONE - a substance secreted by an animal that influences the behaviour of other individuals in the same species.

PLACENTA - the vascular organ with which the embryo is attached to the mother's uterus.

PLANTIGRADE - the foot structure in which the digits and the wrist and heel bones touch the ground while walking; contrast with digitigrade.

POPULATION	- a group of individuals of a single species.
ppm	- parts per million.
PREDATOR	- an organism that kills and eats another organism (prey).
PREVALENCE OF PREGNANCY	- the number pregnant divided by the number of females examined.
PREY	- animals killed and eaten by predators.
PROMISCUOUS	- mating system in which males and females are not restricted to one sexual partner.
RECRUITMENT	- the additions to a natural population usually from young animals entering the "adult" population.
RESERVOIR	- any humans, vertebrates, arthropods, plants, soil or inanimate matter in which an infectious agent normally lives and multiplies, and on which it depends primarily for survival and reproduces itself in such a manner that it can be transmitted to a susceptible host.
RODENT	- any of various animals of the mammalian order Rodentia, such as a mouse, rat, squirrel or beaver, characterized by large constantly-growing incisors adapted for gnawing or nibbling.
RODENTICIDE	- a chemical substance used for the killing of rodents (and sometimes other forms of small mammals), generally through ingestion.
RUNWAY	- a worn or otherwise detectable pathway caused by the repeated usage of mammals.
SCAVENGER	- an organism (animal) that feeds on dead animals or other decaying organic matter.
SCROTUM	- the pouch of skin in which the testes are situated outside the abdominal cavity.
SEPTICEMIA	- a systemic disease caused by pathogenic organisms or their toxins in the bloodstream.
SIGMOID CURVE	- an S-shaped growth curve (e.g. the logistic curve).
SIGN	- any indication of an animal's presence, e.g. footprints, fecal droppings, burrows, runways, gnawings.
SKULL	- the skeleton of the head; includes the cranium and the mandible.

SPECIES	- groups of interbreeding natural populations that are reproductively isolated from other such groups.
SYMBIOSIS	- the living together in intimate association of two diverse types of organisms.
SYNANTHROPIC	- meaning living together with man.
SYSTEMIC	- refers to the entire body of an organism.
TACTILE	- perception by the sense of touch.
TEAT	- a protuberance of the mammary gland in which numerous small ducts empty into a common collection structure that opens to the exterior through one or more pores.
TERRITORY	- a defended area.
TESTIS	- the male gonad; the organ of sperm formation.
THIGMOTAXIS	- movement of an organism in response to direct tactile contact with a surface.
UNDERHAIR OR UNDERFUR	- fur, wool and velli; hair types that serve primarily for insulation.
UTERUS	- in most female mammals, a muscular expansion of the reproductive tract in which the embryo and fetus develop; opens externally by way of the vagina.
VAGINA	- the portion of the female reproductive tract that receives the male's penis during copulation.
VECTOR	- an organism (often an arthropod) that transmits a pathogenic virus, bacteria, protozoan or fungus from one organism to another.
VELLI	- a very fine, short type of underhair.
VENTRAL	- pertaining to the under or lower surface.
VIBRISSAE	- long, stiff hairs of the face and snout that serve primarily as tactile receptors.
ZOONOSES	- infections or infectious diseases transmissible under natural conditions from vertebrate animals to man, or from vertebrates to other vertebrates.

URBAN RODENT AND SANITATION SURVEYS

Rodent surveys conducted in urban areas, whether in cities or villages, play an essential part in programme planning, indicating the severity of the problem and its causes and showing those areas in most need of attention. The information provided by repeated surveys is used to check the progress of programmes and to keep the public informed of community environmental problems and developments.

There are five distinct phases in an urban rodent survey:

1. Random selection of the premises to be surveyed
2. Preparation of survey forms and itineraries
3. Inspection of the selected premises, both inside and outside
4. Preparation of maps, graphs and tables that summarize the results
5. Preparation of a report analysing the rodent problem together with any sanitary deficiencies and recommendations for their improvement.

Sampling premises

Two methods are in general operation:

1. To use randomly selected city blocks and to survey all the premises in each block chosen; this method, commonly used in the United States of America, works best where urban areas are laid out in a regular grid pattern

2. To conduct a monthly survey of rats and mice, as done by local authorities in England and Wales under the guidance of the Ministry of Agriculture, Fisheries and Food. Premises are selected at random, using the local rating or tax lists. This method has the advantage of obtaining specific addresses for subsequent inspection. Both methods require the use of random numbers for the determination of sample size and the selection of numbered premises within the survey area.

Sample size

A guide to the number of premises that need to be inspected is given below:

Number of premises in the survey area	Minimum number of premises to be inspected
10,000 or more	500
between 3,000 and 10,000	450
less than 3,000	435

It is emphasized that these are minimum sample sizes required to ensure reliability of the survey results. Such sampling will provide data that has a 95% probability of being correct with from ± 4 to 5% error. If greater reliability is desired, for example ± 2%, the sample sizes will have to be 3 to 4 times greater than those listed above.

Numbering the premises

The allocation of premises is done using random numbers. Where detailed lists or postal addresses are available, all premises (or blocks) in the survey area are simply numbered sequentially from 1 onward. When no lists or addresses are available, the following procedure may be adopted:

(i) Obtain a detailed map, large scale (1:5000)
(ii) Divide the survey area into kilometre squares (1000 x 1000 m). Number each square from 00, 01, 02.. etc. proceeding from left to right and top to bottom
(iii) Divide each km^2 into 100 hectares (100 x 100 m). Number each hectare in each km^2 from 0 to 99 (not 1 to 100 to avoid 3-figure numbers) as in (ii).
(iv) Divide each hectare into 25 squares of 400 m^2 (20 x 20 m). Number each 400 m^2 in each hectare from 1 to 25.
(v) Each 400 m^2 square now has a reference number composed of 6 figures. The first two digits refer to the km^2 reference, the second two digits refer to the hectare in that km^2 and the last two digits to the 400 m^2 in that hectare. The premise potentially to be surveyed is the one closest to the centre of the 400 m^2.

With all the premises, blocks, or 400 m^2 now referenced, proceed to the random number selection method.

Random number selection

Random selection of reference numbers of premises (blocks or 400 m^2) will provide an unbiased sample. Tables of Random Numbers are used, and the reference numbers are picked as follows:

METHOD OF SELECTING REFERENCE NUMBERS AT RANDOM

	METHOD	EXAMPLE (15000 PREMISES)
(i)	choose any page in the tables at random	
(ii)	without previous inspection e.g. by closing the eyes and pointing with a pencil, pick a two figure number on the page (*)	23 05 62* 26 81 99
(iii)	read from the same line of the table a number that is one digit larger than the total number of premises (blocks or hectares). Obtain this number by reading the numbers immediately to either or both sides of the two digit (*) number selected, including it as a digit pair in the larger (-) number.	23 05 62* 26 81 99
(iv)	divide this number (-) by the total number of premises (blocks or hectares) Multiply the total number of premises (blocks or hectares) by the decimal fraction of the first product. Use 3 to 4 figures of the decimal.	622681 ÷ 15000 = 41.5120 (first product) 15000 x .512 = 7680 (final product)
(v)	round the final product of (iv) to a whole number. This is the reference number of the first premise (block or hectare). Make 3-figure numbers up to 4- figure with a leading zero e.g. 326 to 0326, similarly 26 or 0026.	premises (or block) No. 7680 or km^2 No. 76 hectare No. 80 in that km^2 (see note b for 400 m^2 ref).
(vi)	continue selection of initial random number pair by going up and down random number table from first figure chosen. Repeat (ii) to (vi) until desired premises (block or hectare) sample size is reached.	66 12 *77 03 44 11 23 05 *62 26 81 99 09 33 *41 77 50 00

If reference numbers for blocks or premises obtained in this manner do not provide a large enough selection without overlap, use more figures in the decimal fraction multiplier of (iv). To obtain the final pair of figures for the 400 m^2 reference in the map grid method, choose any number in the table without prior inspection (e.g. by pencil, with the eyes closed) and take the first number between 1 and 24. The premises to be inspected is the one nearest to the centre of the 400 m^2.

Survey forms

Survey forms, according to their design, can provide basic or very detailed and complex information. It is recommended that survey forms should be designed to obtain the following minimum information:

a) precise location of the inspection premises (street address or numbered squares of hectares within km^2)

b) premises type (residence, commercial, food and non-food, warehouse storage, vacant ground or other)

c) condition of structure (good repair or deteriorating)

d) type of construction materials (concrete, brick, wood, sheet metal, thatch)

e) number of occupants (of residence or residence/commercial)

f) presence or absence of:
- stored foods
- waste foods
- water
- harbourage
- cess pits or surface latrines
- rodents or rodent signs indoors or outdoors
- species of rodents present

g) residents' complaints (pests present, rodent damage and rodent bites)

Suggested survey forms are given in Annex III.

Survey operation

An inspector should be equipped with a supply of survey forms, clipboard, pens, personal identification (an official letter or badge) and a hand torch. After contacting the resident, a short interview should be conducted to obtain the information for items e) and g) on the survey form.

Having received permission to carry out an inspection, the inspector should proceed around the exterior of the house or structure, observing sanitary deficiencies together with evidence of rodents and noting them on the survey form. Rodent signs must be observed at close range to determine if a premise is currently infested. (The signs of use in assessment are discussed in detail in Annex IV.) In particular, a search should be made for active runs or burrows in the land underneath the building and elsewhere, fresh damage, droppings, and any other evidence indicating outdoor infestation.

The inspector should then examine the interior of the building to determine if it is infested. Using a torch, all rooms should be checked for rodent signs, especially kitchen, bathroom and latrine areas. Although residents are often very helpful in pointing out evidence of current or past rodent infestation, they often confuse rats with mice. Before leaving the premises, the survey form should be checked to make certain that all of the items listed have been covered.

Sometimes permission to inspect is refused or residents are unavailable at the time of inspection. Under these circumstances, a similar type of property in the same street or road should be inspected instead; at best, the substitute should be the address nextdoor. If the chosen property is a large institution such as a hospital, factory, school or hotel it should be included in the survey but for practical reasons the inspection of such premises can be restricted to kitchens, waste food storage areas and other likely sites of infestation.

Summarizing the survey data

The premises is the basic unit for assessing infestation rates and for evaluating sanitary deficiencies. Infestation rates, indoors and outdoors, are easily tallied from the survey forms. The data should be further subdivided according to premise type and condition, or by location within a certain zone or ward within the city. Sanitary deficiencies can be similarly rated per given number of premises. The deficiencies can then be examined in detail to see if there is any obvious correlation with rodent infestation and to ascertain those environmental improvements that are likely to have impact in reducing population levels. The mapping of infested premises helps to reveal areas having the highest infestation rates and the most severe sanitary deficiencies, and allows priorities to be assigned to the control programme.

Survey report

The results of an initial survey can be used to establish programme aims and the future surveys carried out later permit the programme supervisor to evaluate the success of the control strategy and the progress made towards fulfilling the aims. The result of each survey should be summarized in tabular form, the results analysed in comparison with past surveys, and a report made on the need for change in the direction or the continuation of the programme undertaken.

INSTRUCTIONS FOR USING THE MULTIPLE PREMISES FORM

a. At the preselected premises, enter on the form the premises reference number (the randomly chosen number on the premises listing) and the street address of the property.

b. Check off the "premises use" category by marking an X in the appropriate column. Each premise must fall into one of six categories. Other covers properties such as hospitals, schools, hotels or factories.

c. When contacting the occupants for permission to inspect the premises, ask how many persons live on the property.

d. Determine whether the premises is in good repair or is deteriorating and mark G (good) or D (deteriorating).

e. Rodent food

A mark (x) is entered for each category that is positive. No mark is entered if no evidence is found of that deficiency.

Waste foods. Mark this if household food wastes are found scattered on the ground, are in a container with no cover, or are stored in a container providing access to rodents.

Animal feed. Mark this if household wastes are placed as food for animals, or if animal feed is available in excess and accessible to rodents.

Stored foods. Mark this if stored foods, either for human or animal consumption, are accessible to rodents.

Household drain or cess pit. Mark this if it is evident that rats or mice are harbouring or feeding on food wastes or watering at the household drainage or cess pit area.

f. Rodent harbourage

Household rubbish. Mark this if household rubbish (junk, debris, old clothing, bags, cans, boxes) is lying about on the ground or inside the structure.

Wood on ground. Mark this if wood or lumber is lying about on the ground or against a wall.

Holes in walls or burrows. Mark this if there are obvious holes in exterior or interior walls that could afford harbourage for rats or mice. Mark this is there are obvious burrows in the soil.

g. Rat signs

Outside. Mark this if obvious signs of active infestation are seen outside living quarters or shop areas, such as burrows, droppings, runways, gnawings, live or dead rats.

Inside. Mark this if obvious signs of active rat infestation are found inside the structure.

h. Mice signs

Outside. Mark if obvious signs of mice are seen outside living quarters or shops.

Inside. Enter any items of special interest not covered elsewhere on the form.

ANNEX III(A). RODENT AND SANITATION SURVEY FORM (MULTIPLE PREMISES)

CITY, TOWN OR VILLAGE ____________ DISTRICT ____________ BLOCK ____________

DATE ____________ INITIAL OR RE-SURVEY ____________ INSPECTOR(S) ____________ PAGE ____ OF ____

	PREMISES INFORMATION								Rodent food				Rodent harbourage			Mouse signs				REMARKS
REFERENCE NO. ADDRESS	RESIDENTIAL	COMMERCIAL, FOOD	COMMERCIAL, NON-FOOD	WAREHOUSE STORAGE	VACANT GROUND	OTHER	NO. OF OCCUPANTS	STRUCTURE CONDITION	WASTE FOODS	ANIMAL FEEDS	STORED FOODS	HOUSEHOLD DRAIN OR CESS PIT	HOUSEHOLD RUBBISH	WOOD ON GROUND	HOLES IN WALLS OR BURROWS	OUTSIDE	INSIDE	OUTSIDE	INSIDE	

ANNEX III(B). RODENT SURVEY FORM (INDIVIDUAL PREMISES)

PREMISES

REFERENCE NO. ______________ HOUSING TYPE ______________ BLOCK ________ DISTRICT ________

CITY OR TOWN ______________________________ STREET ADDRESS ______________________________

DATE ______________________________ INSPECTOR(S) ______________________________

RODENT SPECIES PRESENT	SKETCH MAP
R. norvegicus	
R. rattus	
M. musculus	
O ACTIVE HOLE	
X FRESH DROPPINGS	
— FOOTPRINTS	
≠ GNAWINGS	
WATER	
EDIBLE REFUSE OR WASTE FOOD	
HARBOURAGE	
RESIDENTS COMMENTS	
Rats present ________	
Mice present ________	
Damage ________	
Rat bites ________	
No. occupants ________	
Others ________	

ANNEX IV

SIGNS OR TRACES OF RATS AND MICE

Droppings

Droppings, the most frequently observed sign of rodent infestation, may be found along runways, near shelters or other places rats and mice frequent; generally, they are most common at sites where rodents feed, and they are often found in association with food particles. Those of the house mouse can generally be identified by their smaller size and roof rat droppings tend to be somewhat smaller and to have more rounded ends than those of Norway rats (Fig. 11). Fresh droppings are shiny, moist and soft in texture whereas old ones are dull, dusty, dry and hard.

Runways

In moving about from the nest or burrow, rodents tend to use the same routes or 'runs' regularly, especially when visiting feeding and drinking sites. Indoors, these runs are often revealed as black, greasy 'smears' or 'rubmarks' left when oil and dirt on the rodents fur is rubbed off on overhead pipes, along beams and around holes made in metal, wood, or brickwork. Smears may persist long after the runs have become disused. Runways are most visible outdoors next to walls, along fences, under bushes and through low-growing vegetation, where continual traffic has prevented plant growth. Runways should be traced for their entire course since they can help show where rodents are entering a building, harbouring or feeding. Those that are dusty or covered in cobwebs indicate that rodents are no longer using them.

Tracks

Rodent footprints or tail marks can often be found in dusty surfaces. The tracks of the 5-toed rear foot are more commonly seen than the 4-toed front feet but both may be present. When moving slowly over flat surfaces the tail may be dragged, leaving a clear line. Rodent tracks are most readily observed by side illumination, often being evident from one angle but not from another. Footprints are well seen in muddy areas. Sharply outlined tracks indicate recent activity because tracks tend to become obscured quickly by dust deposited over them. Confirmation of rodent infestation indoors can be obtained by laying smoothed patches of flour or talc about 30 cm long and 10 cm wide, along suspected runways on floors, shelves and beams and examining them a day or two later for signs of footprints.

Gnaw marks

Rats and mice gnaw at the fabric of buildings, food containers, sacks, cartons, etc. Toothmarks on food and other materials, as well as the size of discarded particles, can also provide information on whether rats or mice are present.

The results of gnawings are indicated by the presence of wood chips around baseboards, doors, basement windows and frames, kitchen cupboards, furniture, clothes, stored materials, around pipes in floors and walls, and wherever rats or mice have attempted to enlarge a crack or enter a building. The chippings of recently attacked wood are light in colour, whereas older ones are dark.

Burrows

Unlike nests, burrows are readily observed and those in current use are fairly easily discerned. Burrows are usually most evident along the outside walls of buildings, in dirt floors, and around the outbuildings of a residence. Apart from buildings, burrows may be found in embankments, hedgerows, fills, and under any heavy growth of brush, bushes, etc. A fresh mound of soil in front of a burrow indicates that it is in current use. Active and inactive burrows can be checked by covering the entrance holes lightly with soil and determining those that are re-opened 1-2 days later; this procedure entails more than a single visit to a premises however.

Visual sightings

Occasionally, rodents may be seen moving during a survey, particularly if their cover is disturbed. Night observations with a powerful flashlight are often helpful. Sometimes undecomposed rodents are found to indicate recent infestation.

Miscellaneous signs

Rodent odour, urine stains, rodent nests and the foods stored by rodents may be found during a survey. Odour is not a very reliable sign in the case of rats but that left by house mice is easily recognizable. Urine stains show up best under ultra-violet light. Rat or mouse nests are not readily found since they are normally built in the most protected places.

ANNEX V

MIXING BAITS

1. Baits should always be mixed according to directions. Never put more poison in baits than the recommended amounts as this will (1) decrease acceptance by the rodents and (2) will increase the danger to man and other animals.

2. The dry ingredients of the bait formulation should be mixed first. The poison (as the technical or concentrate material) then should be mixed with the liquid or moist part of the bait formula and this mixture blended with the dry ingredients. Bait should be thoroughly mixed so that the toxicant is distributed uniformly throughout the mass. Poor mixing will result in poor kills and the risk of creating a bait shyness.

3. When handling pure technical powders or concentrates of poisons, the person doing the weighing and mixing of the ingredients should wear gloves and a dust mask or respirator. It is best to do this under an exhaust hood.

4. All bait ingredients and poisons should be weighed accurately on balances of the proper capacity. For small mixtures, a balance accurate to 0.1g and a capacity of 1kg should be adequate. For large mixtures, a balance accurate to 10g and a capacity of 100kg would be needed.

5. Calculating the bait formula:

(a) When using a technical ingredient, such as zinc phosphide, calculations are straight forward. To prepare a 2% concentration of finished bait, simply add 2kg of zinc phosphide to 98kg of bait ingredients. To mix a 0.5% concentration of pyrinuron, simply add 0.5kg of pyrinuron to 99.5kg of bait ingredients.

(b) When using concentrates, the rule to remember is to divide the % of the concentrate by the final concentration desired. The answer obtained will be the total number of parts of bait ingredients needed. Simply subtract one part for the concentrate and the remainder will be the bait ingredients.

Examples: (try these on your pocket calculator)

(1) a 0.5% concentrate, final mix to be 0.025%

$$0.5 \div 0.025 = 20$$

mix 1 part concentrate with 19 parts bait.

(2) a 0.1% concentrate, final mix to contain 0.002%

$$0.1 \div 0.002 = 50$$

mix 1 part concentrate with 49 parts bait.

(3) a 3% concentrate, final mix to contain 0.015% poison

$$3 \div 0.015 = 200$$

mix 1 part concentrate with 199 parts bait.

(4) a 20% concentrate, final mix to contain 0.025% poison

$$20 \div 0.025 = 800$$

mix 1 part concentrate with 799 parts bait.

(c) Now, since one may not want as little as 20kg as in (1) above, or as much as 800kg as in (4), simply decide the amount desired, say 100kg, and either multiply or divide as necessary to obtain the proper formula. In example (1) above, simply multiply by 5, using 5kg of concentrate and 95kg of bait ingredients (5 x 19 = 95).

In example (4), to prepare 100kg, divide 100kg by 800, giving the answer 0.125kg, or 125g. To prepare the bait, mix 125g (0.125kg) of 20% concentrate with 99.875kg of bait ingredients. This will give a final concentration of 0.025% active ingredient.

FIG. 1a. SKULL OF RATTUS NORVEGICUS SHOWING DENTAL CHARACTERISTICS.

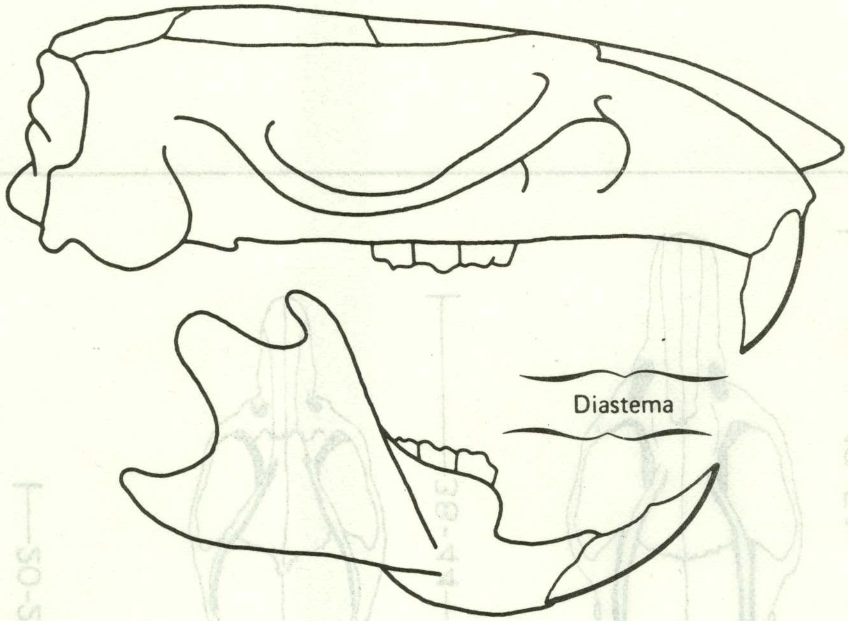
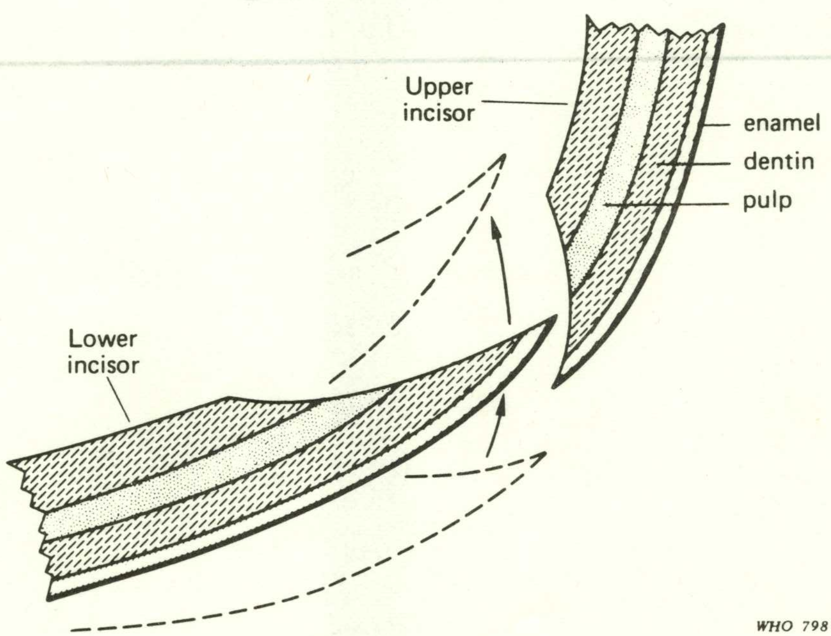
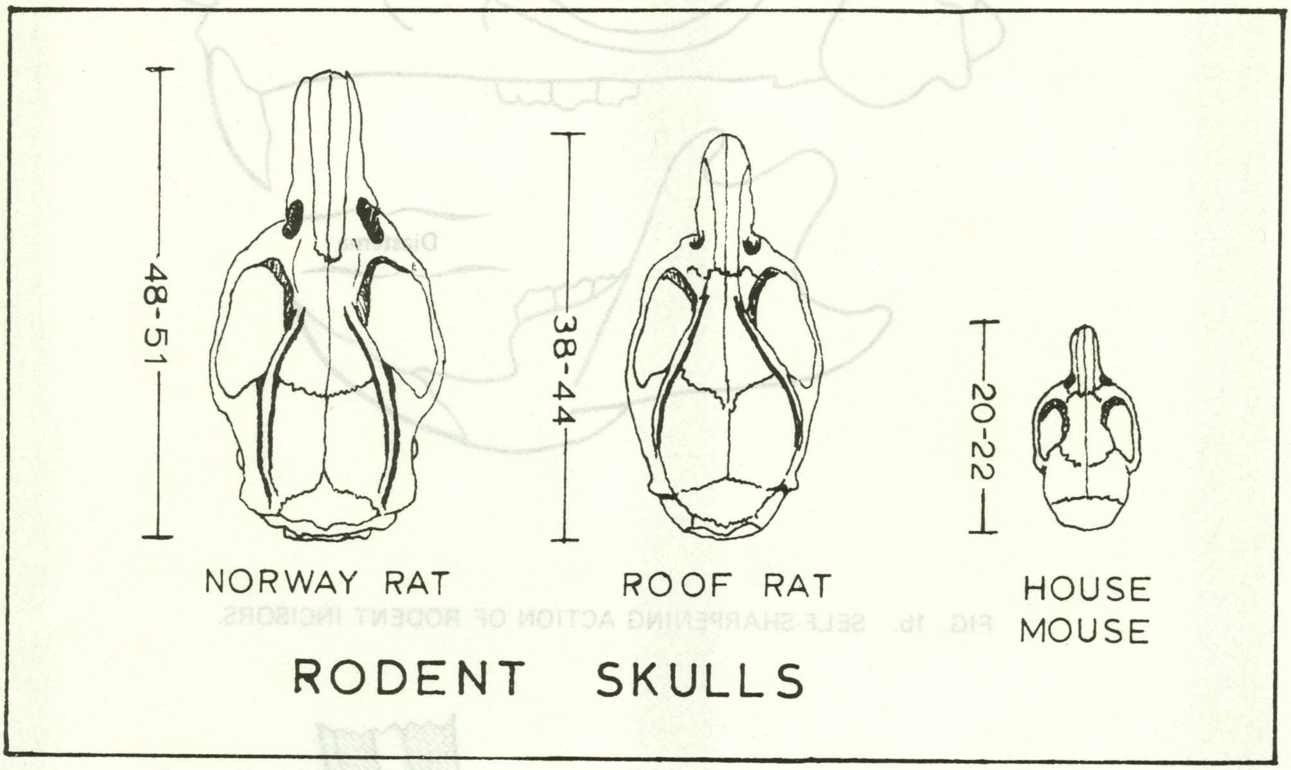


FIG. 1b. SELF-SHARPENING ACTION OF RODENT INCISORS.



WHO 79879

FIG. 2


48-51
38-44
20-22
NORWAY RAT
ROOF RAT
HOUSE MOUSE
RODENT SKULLS

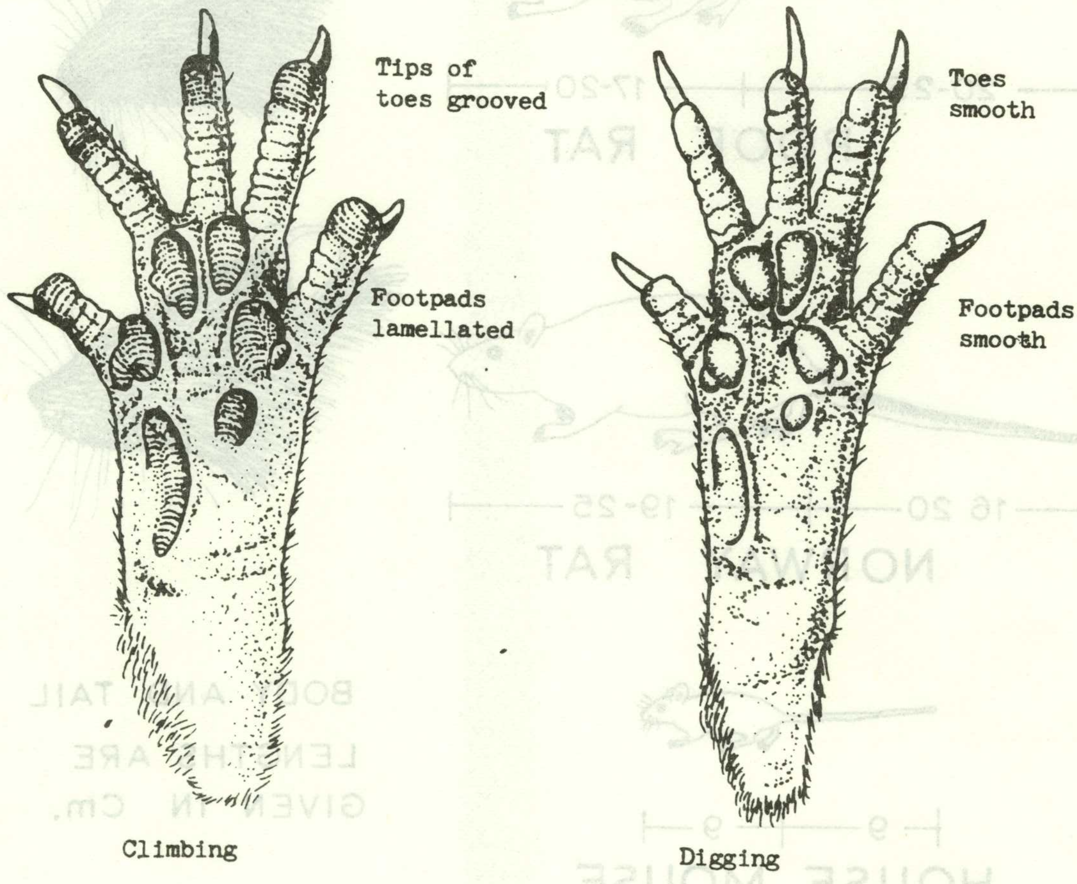


Fig. 3 Left hind foot of Rattus rattus diardi (left) and Rattus argentiventer (right) showing differences in footpads and toetips in foot adapted for climbing and digging. (Redrawn from Musser)

IDENTIFICATION OF RATS AND MICE

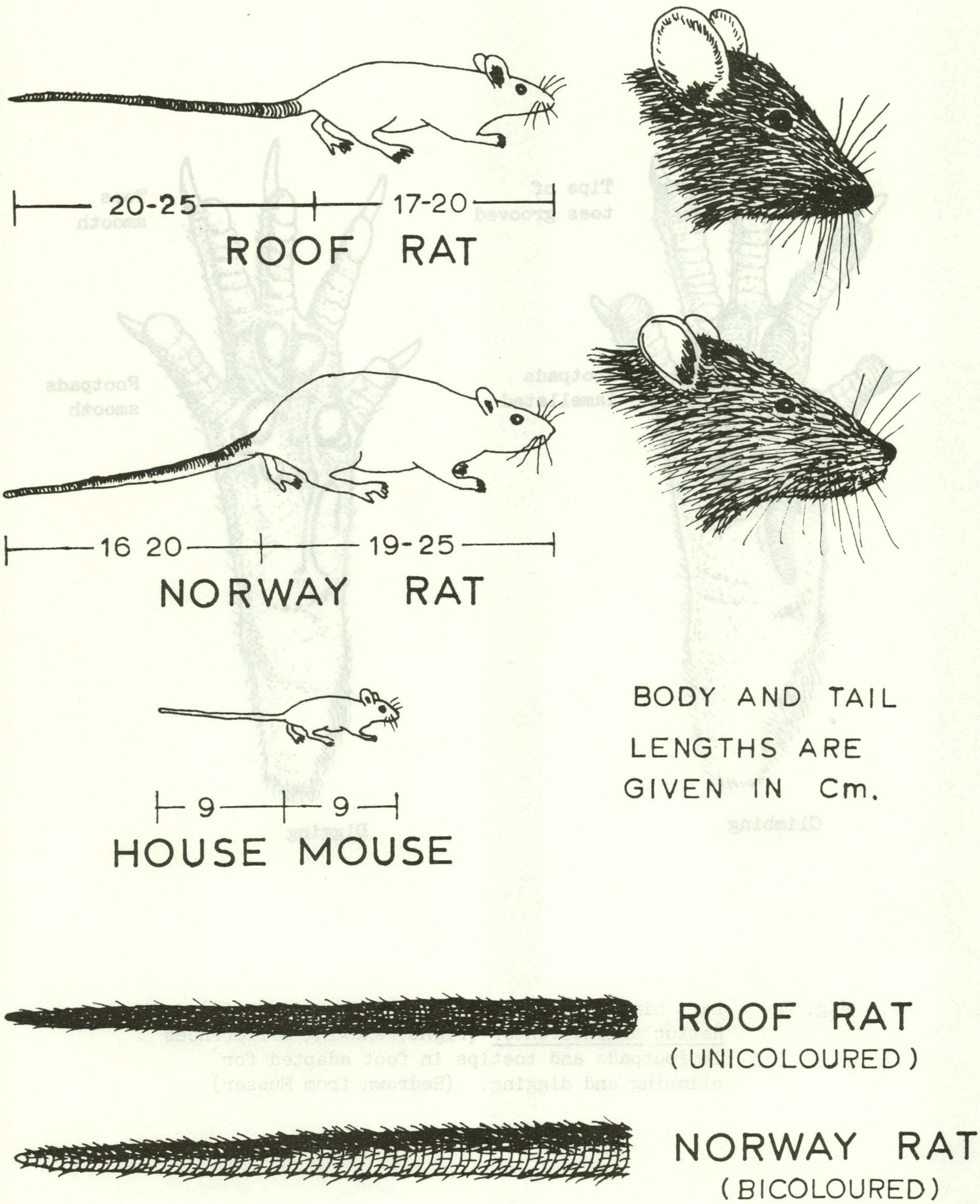


FIG. 5

DISTRIBUTION OF RATTUS NORVEGICUS

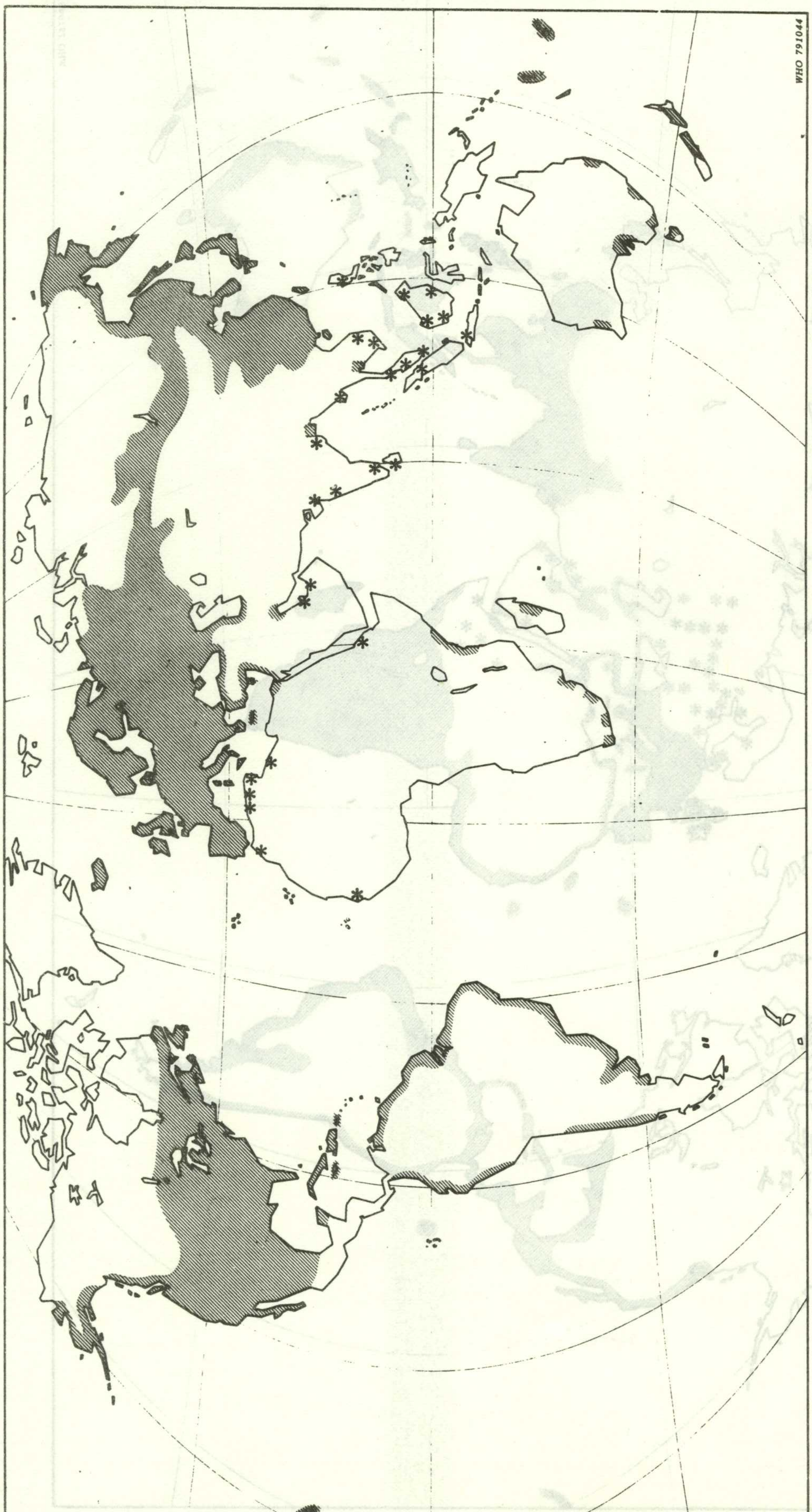


FIG. 6

DISTRIBUTION OF RATTUS RATTUS

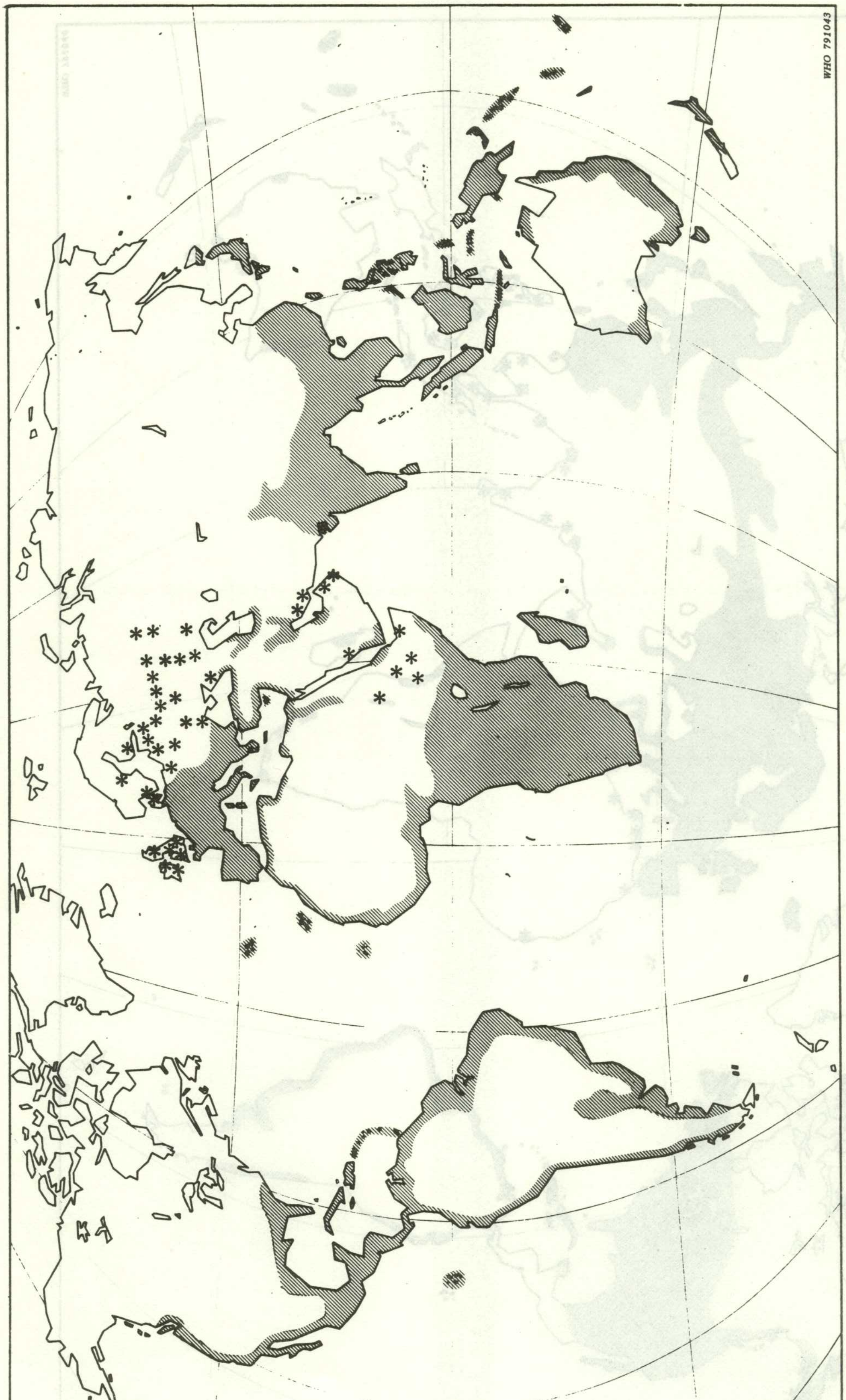
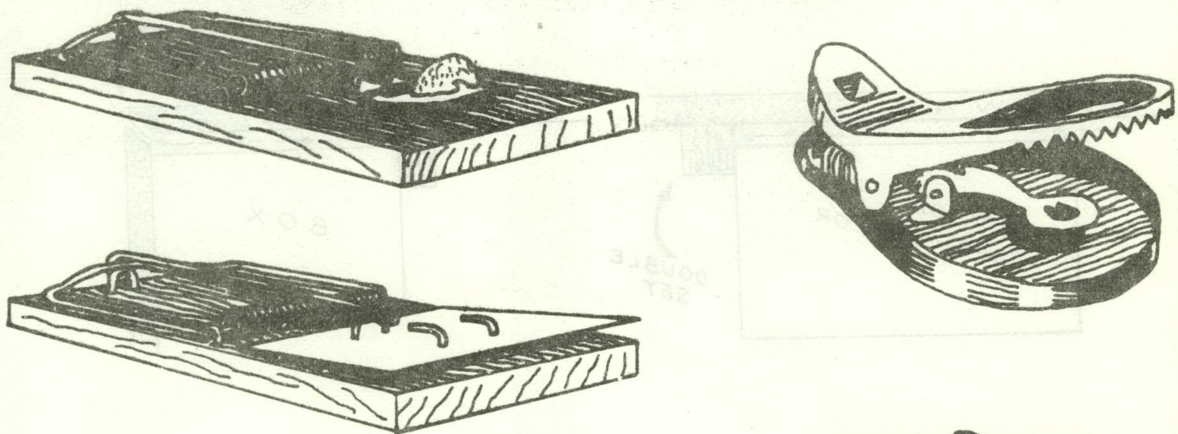
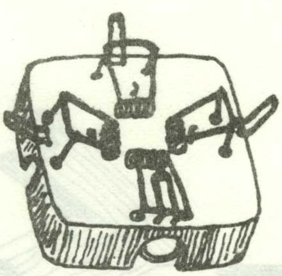
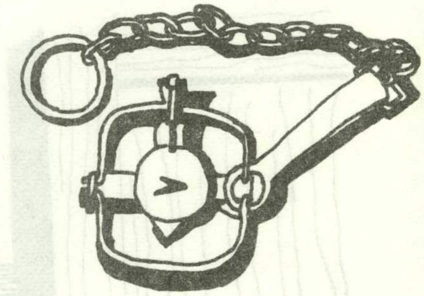


FIG. 7

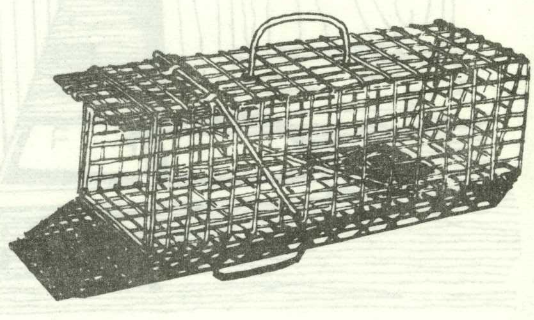
BREAK-BACK TRAPS

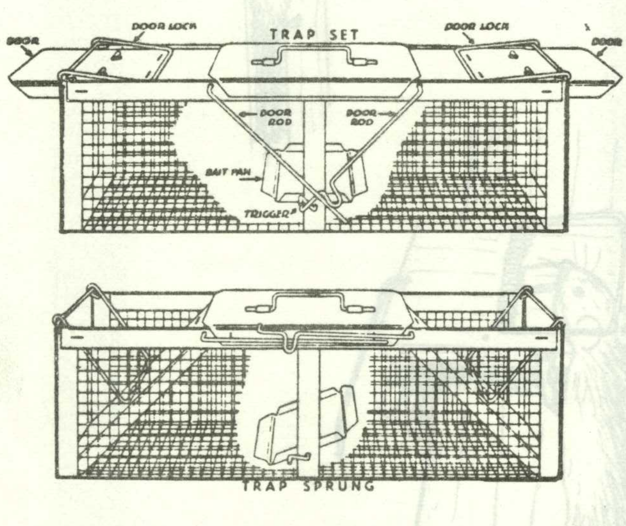


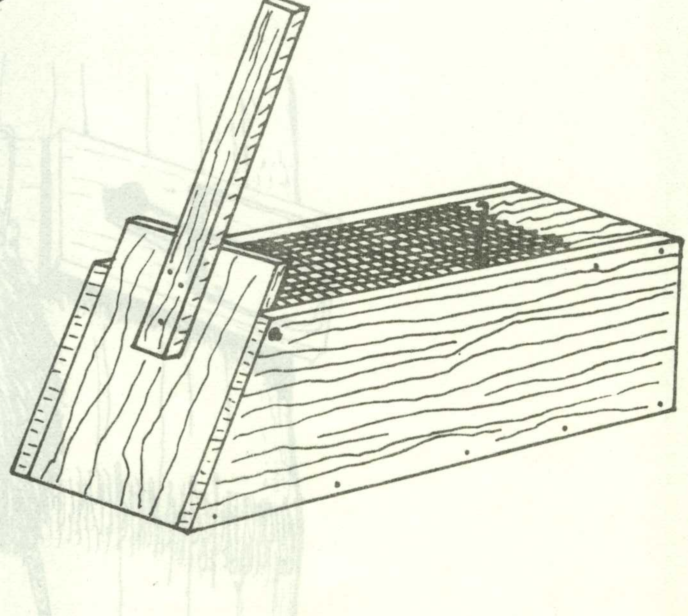




CHOKER TRAP







LIVE TRAPS

FIG. 8

TRAP SETTINGS

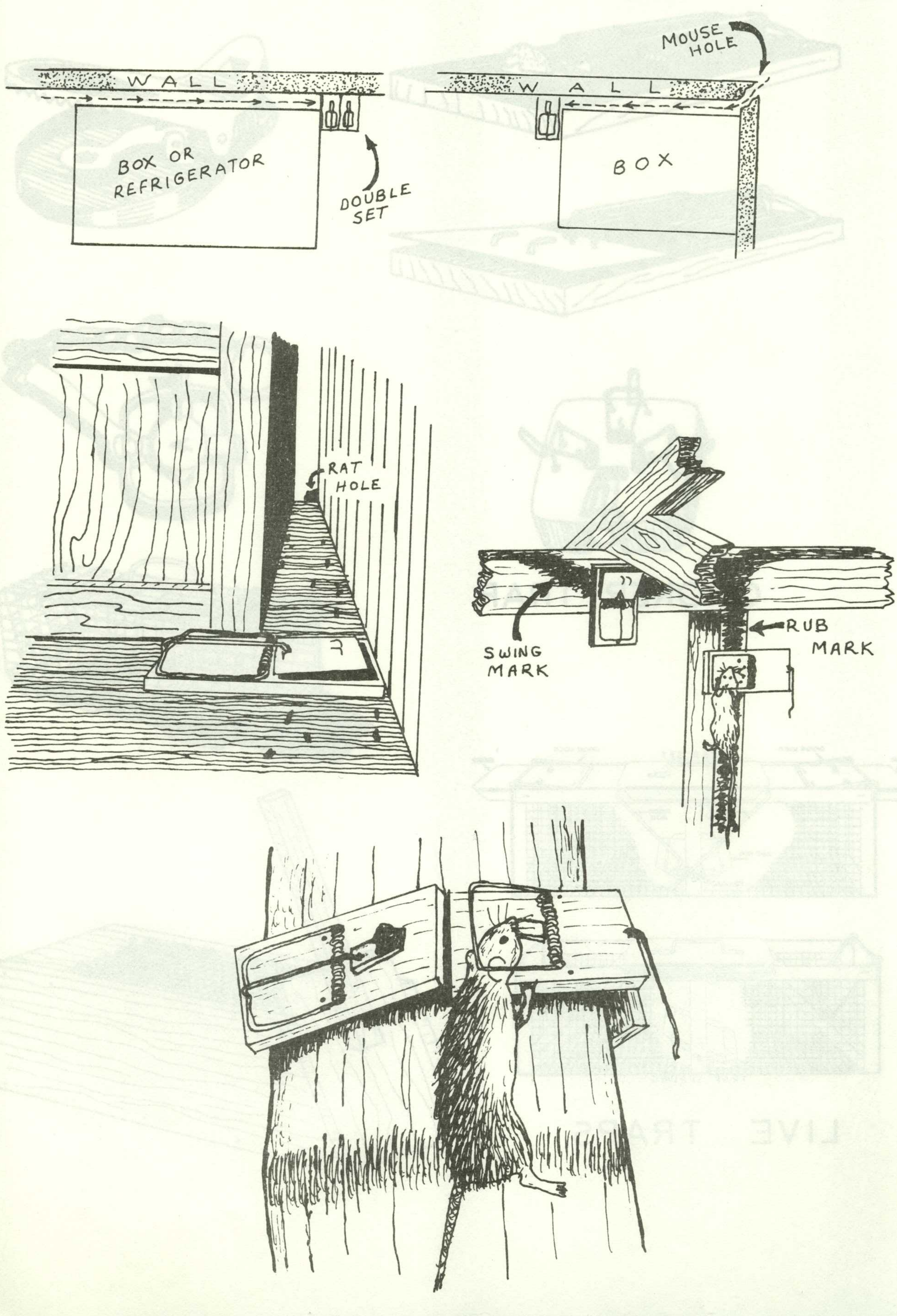


FIG. 9

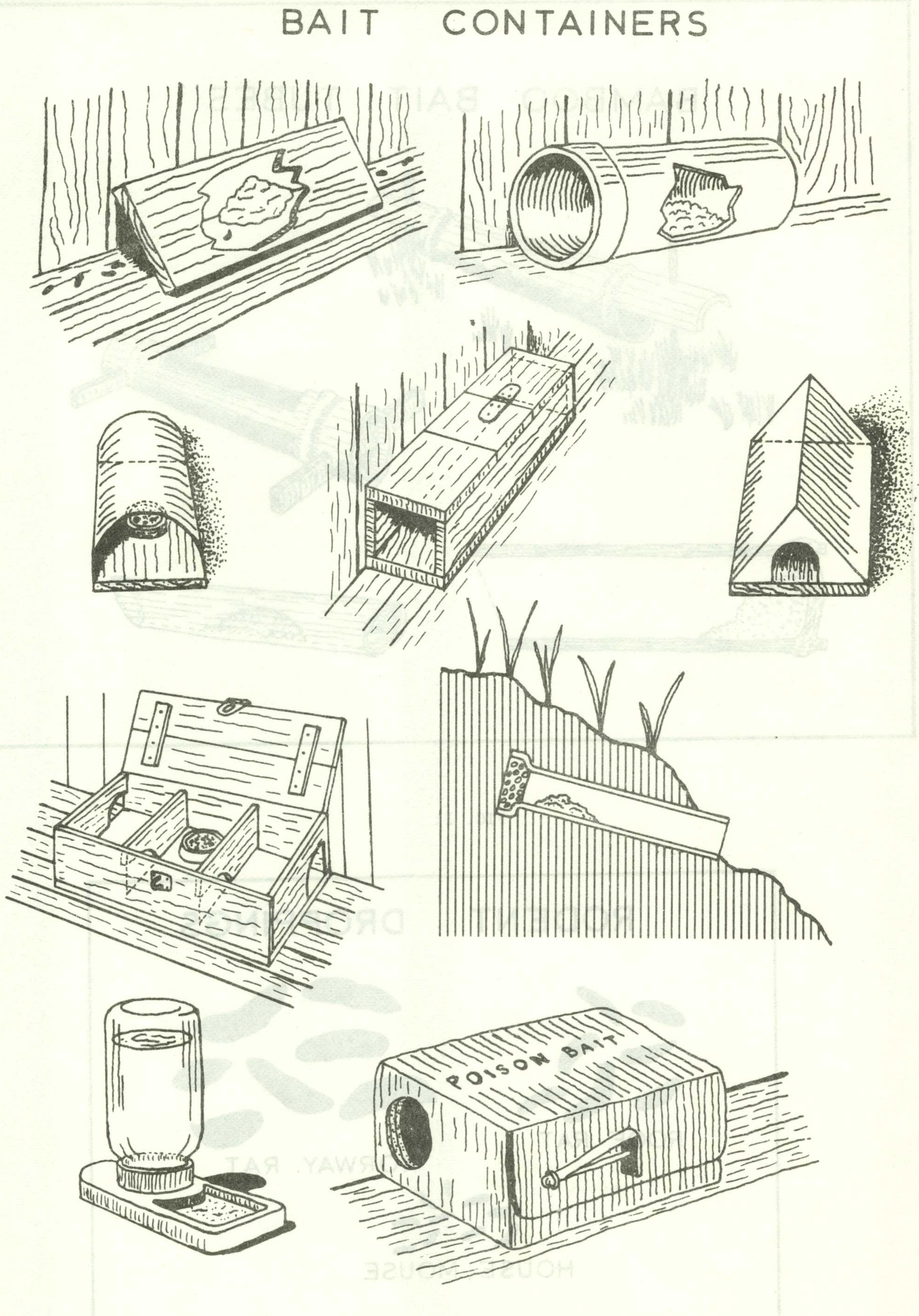


FIG. 10

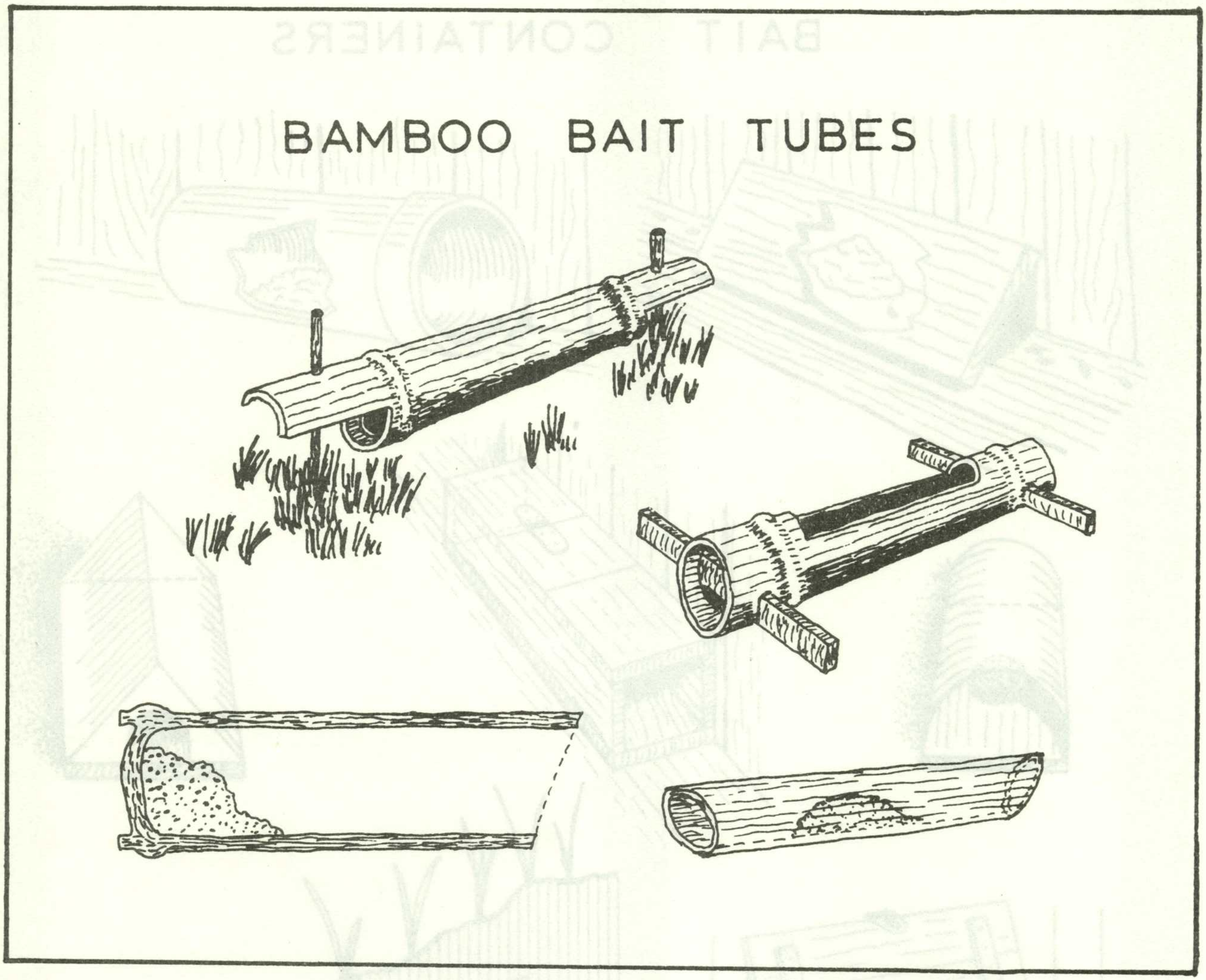
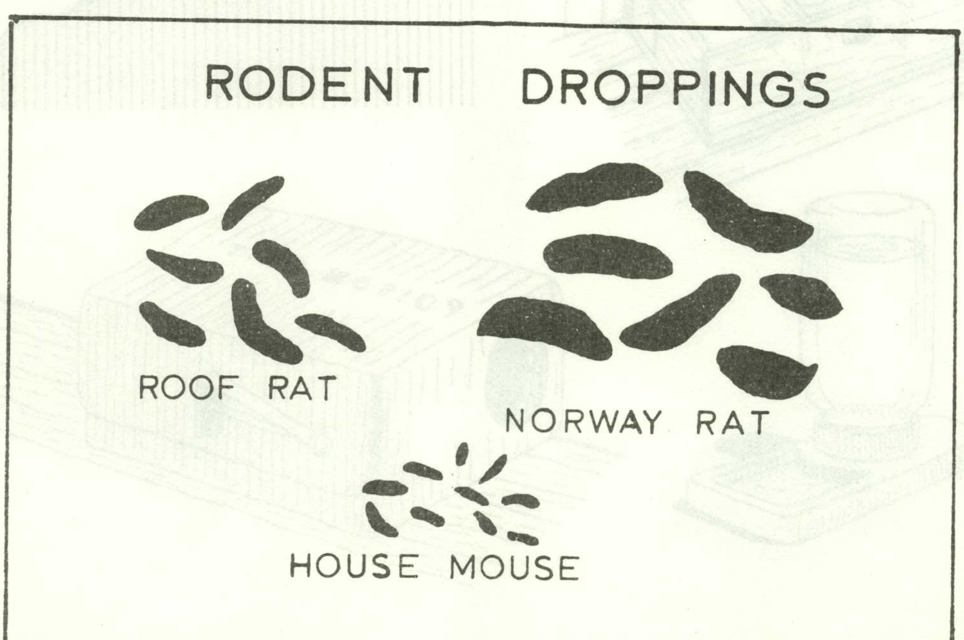
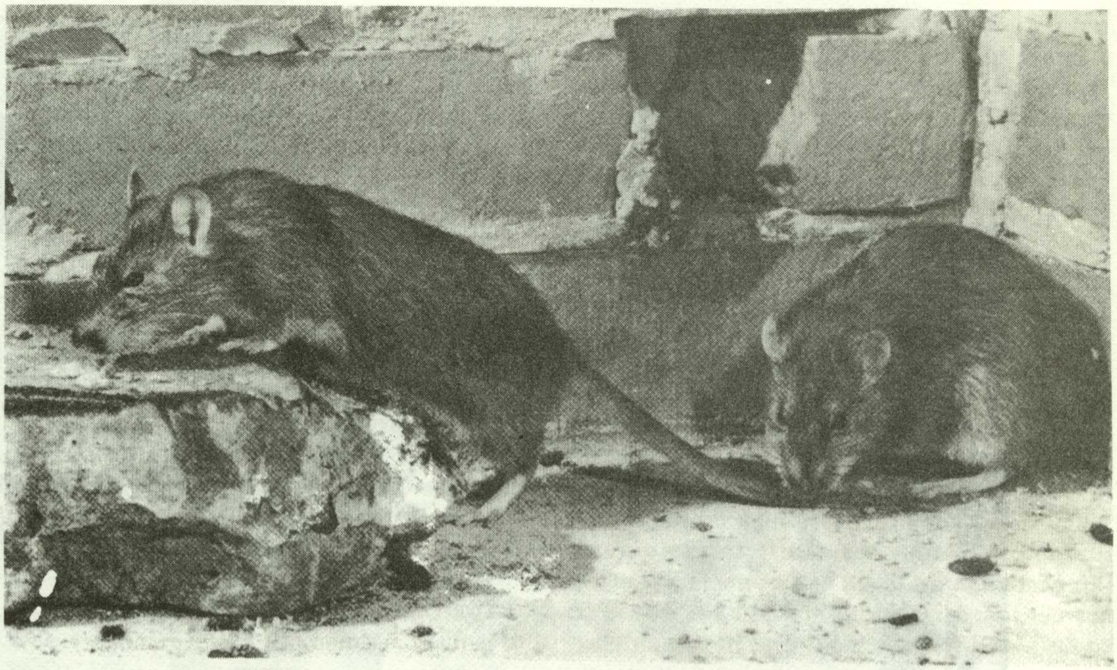

BAMBOO BAIT TUBES

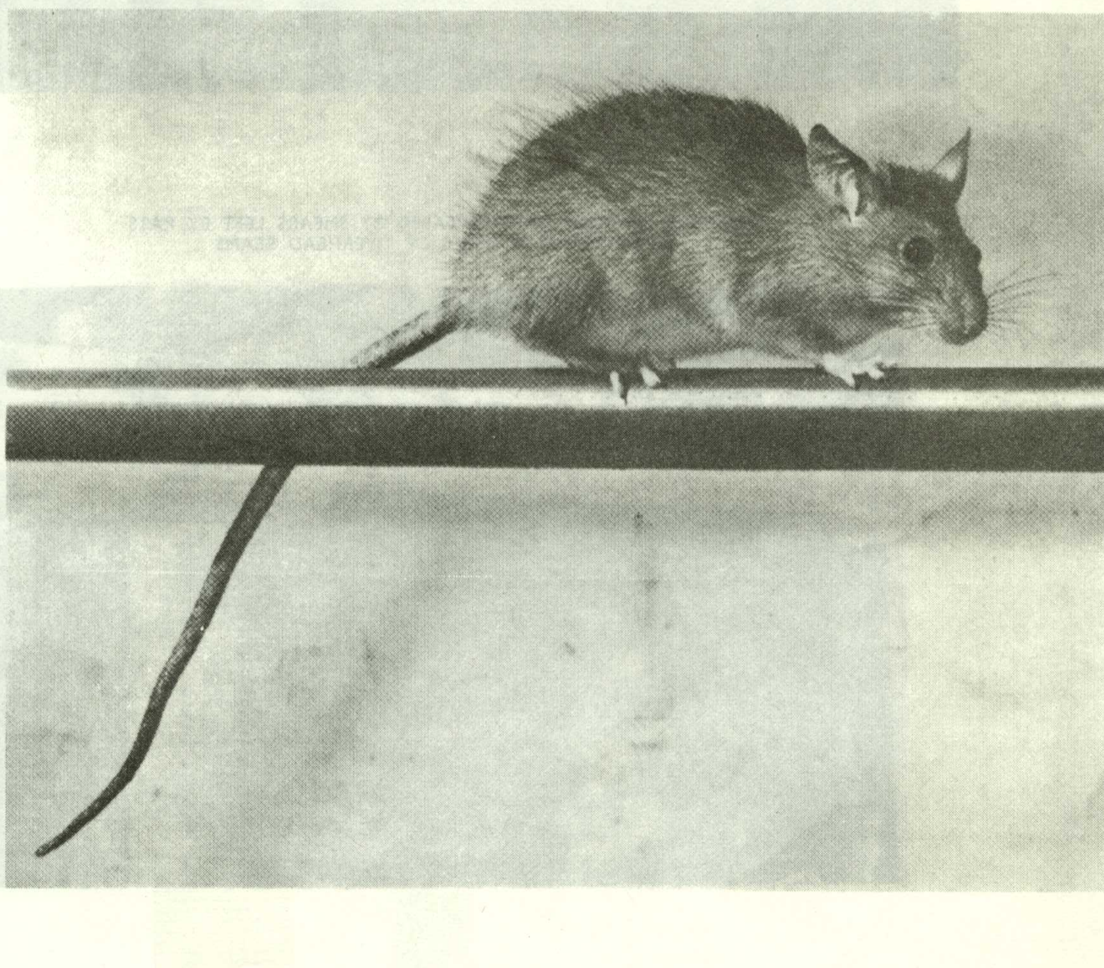
FIG. 11


RODENT DROPPINGS
ROOF RAT
NORWAY RAT
HOUSE MOUSE

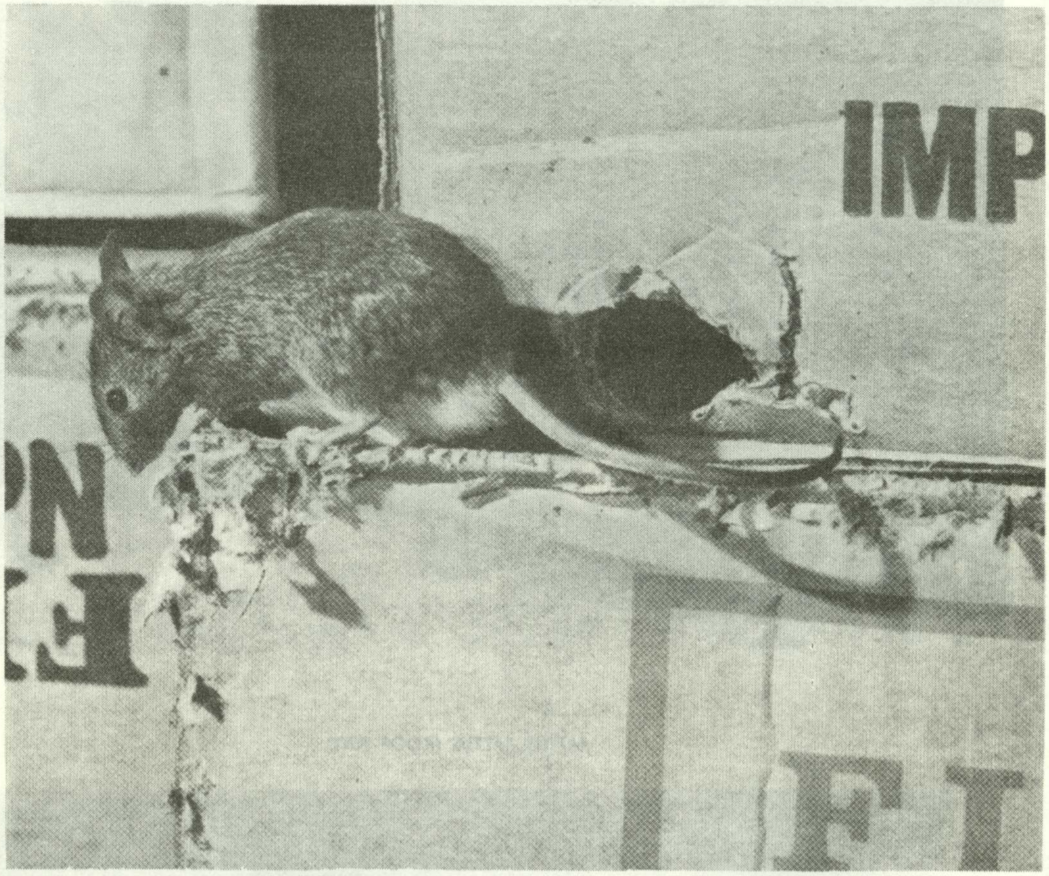
RATTUS NORVEGICUS (NORWAY RAT)



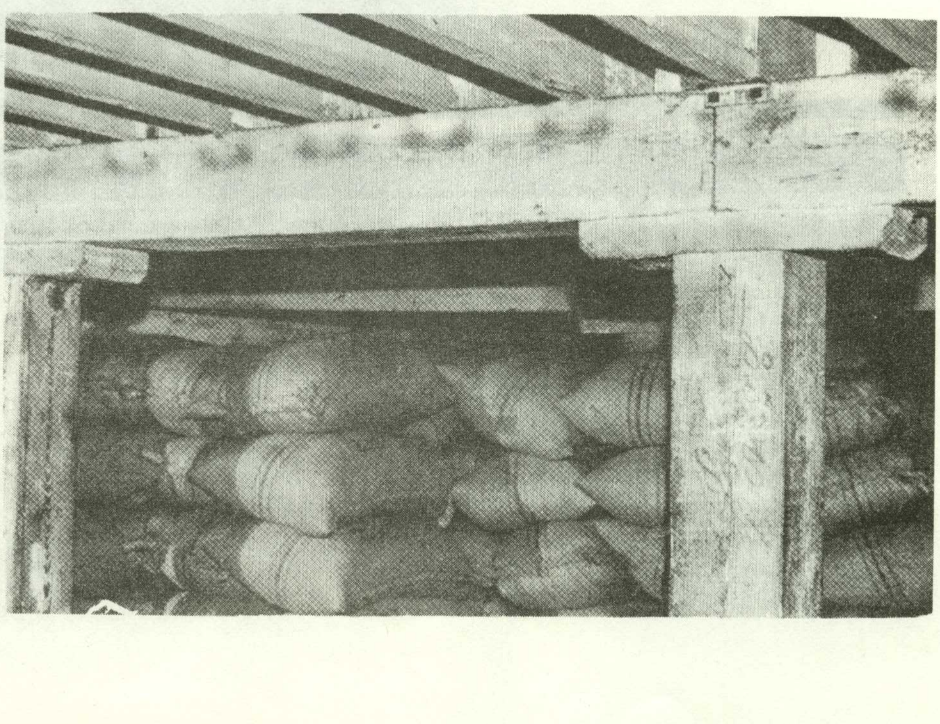
RATTUS RATTUS (ROOF RAT)



MUS MUSCULUS (HOUSE MOUSE)



PRESENCE OF ROOF RATS REVEALED BY SMEARS LEFT BY RATS
NEGOTIATING A SERIES OF OVERHEAD BEAMS



FOOTPRINTS OF NORWAY RAT IN MUD

= = =