Rodents

11

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Contents

Abstract

Rodents are the largest order under the class Mammalia with more than 2000 living species in 30 extant families and as high as 481 genera. Two-thirds of all living rodents belong to one single family, Muridae. Rodents are immensely diverse, ecologically, and they occupy any vacant places on Earth and eat anything. They are an important link in the food web and a number one vertebrate pest and also transform landscapes. Their adaptation is awesome; they adapt to any habitat, any food and any situation. Commensal rodents not only occupy the human habitation, causing economic losses to various stored products of human beings. They also act as vectors of numerous dreaded rodent-borne diseases in human beings. Rodent population dynamics depends on the availability of resources and environmental conditions. The assessment of rodent population

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in the wild is tricky as most of the pest rodents are nocturnal or subterranean. Pest rodents cause damage to agricultural crops, forestry, poultry industry, aviation and public health sectors. Being a mammal, rodents are extremely intelligent, and because of some limitation in their physiology, rodents are always suspicious. Neophobia and bait shyness are some of the traits which limit the use of rodenticides successfully. As one of the prolific breeders, rodents perform reproductive bounce after a successful control programme. Numerous management methods, viz. environmental, physical and chemical techniques, are being followed to contain the rodent population to a certain extent in a particular habitat.

Keywords

Rodent · Rat · Mouse · Diversity · Assessment · Management · Rodenticide

11.1 Introduction

Rodents (from the Latin *rodere*, 'to gnaw') are the quadruped mammals. They are one of the persistent vertebrate pests causing enormous damages to agricultural crops and storage facilities either by direct feeding or by indirect damages, viz. contamination, spillage, spoilage and hording.

Rodents are a dominant group of mammals and the order Rodentia, the largest order of mammals, comprising of 2277 species, 481 genera in 30 extant families (Wilson and Reeder 2005; Macdonald et al. 2015). Family Muridae has two-thirds of all living rodent species under Rodentia. Ecologically, rodents are incredibly diverse. Some species are entirely terrestrial or arboreal, whereas others never emerge out from underground burrows; some species are essentially aquatic, while others are specialists in living in extreme conditions of deserts. Majority of the rodents are omnivorous, while some have specialised food habits like feeding on only a few species of invertebrates or fungi. Size of the rodents also varies; some are very small (pygmy mice, weighing only 5 g), while others are robust (capybaras, the largest South American rodent having a body weight over 70 kg). However, all rodents share one common character, the highly specialised dentition for gnawing, despite their enormous morphological and ecological diversities. In general, rodents have a pair of ever-growing upper and lower incisors, followed by diastema (a gap in the dentition), and molars or premolars; no rodent has canine teeth. The characteristic gnawing helps the rodents to do self-sharpening of their incisors by grind against each other which wears off the softer dentine and makes the enamel edge as chisel blade-like. The gnawing habits and the powerful incisors help the rodents to survive in any environment and hold the key for their success.

Rodents occupy a wide range of natural habitats, including forests, grasslands, the agricultural landscapes and human habitations. They are the most important link in the food chain and food web as a primary consumer and prey for higher animals. The rodent stomach can vary from a simple sac in the dormice (Gliridae – the only rodents without a caecum) to the complex ruminant-like organ of the lemmings (*Lemmus* spp.).

Life history strategies can be short and prolific, as in the *r*-selected house mouse, *Mus domesticus*, or long with low fecundity as in the *K*-selected African spring hare, *Pedetes capensis*, which produces only one progeny each year. Rodent social systems include monogamous water voles (*Arvicola amphibius)*, polygynous wood mice (*Apodemus sylvaticus)* family groups of alpine marmots (*Marmota marmota)* herds of capybara (*Hydrochoerus* sp); and, a very unique among mammals, a blend of monogamy and communal denning in mara (*Dolichotis patagonum)*.

Rodent breeding systems include the single-sex litters of wood lemmings, *Myopus schisticolor*, and the manipulated sex ratio of coypus, where selective abortion of male-biased litters is done by female parents in poor environmental conditions (Gosling 1986). Naked mole rats, *Heterocephalus glaber*, are unique among mammals in the degree of their eusociality (Jarvis 1981) with only one breeding female within the group.

Added to the diversity within the order, there are special adaptations in many individual species and behavioural flexibility of individuals. Thus, brown rat, *Rattus norvegicus*, and house mouse (*Mus musculus*) can be found throughout the world, using their generalist body plan to feed and breed wherever humans go and their sophisticated behaviour patterns to avoid the most cunning and increasingly sophisticated attempts to eradicate them.

Brown rats and house mice, along with the roof rat, *Rattus rattus*, are known as commensal (‘sharing the table’; *mensa*: a table, in Latin) rodents, meaning that they are usually found in association with human habitation. However, as the word commensal implies no damage to the host, these rodents might more precisely be termed as kleptoparasitic. Because of the importance of the first two species in medical and experimental psychological research, knowledge of rodent biology is heavily biased on these commensal rodents.

Rodents generally have very acute senses of smell, hearing, touch and taste (Broadford 2015). Social odours play an enormous role in rodent biology, both through a direct impact on behaviour and through the physiological impact through primer pheromones (Johnston 2003). Functional odours are produced in the urine and faeces and in secretions from apocrine and sebaceous glands (e.g. flanks, prepuce, eyes). Scent marking plays an important role in territoriality in many species, and territoriality can affect rodent control.

Olfaction is also important in transferring information between individuals and can affect rodent control. Taste, mediating food preferences and recognition, affects the efficacies of poison baits. The inability of rodents to taste certain compounds at a concentration that is repugnant to humans (e.g. Bitrex® – denatonium benzoate) is used to ‘safen’ modern rodenticide baits.

Many rodents produce ultrasounds (i.e. sounds above the normal level of human hearing, 20 kHz), which are apparently relevant in courtship and aggression, in eliciting parental care, as alarm signals, and, possibly in echolocation. Sounds in the ‘audible’ frequencies are also used for these purposes. Hearing is often the first sense to detect the approach of a potential predator; the most extreme case is the middle ear of desert-living kangaroo rats (Dipodidae), which amplifies the movement of the eardrum 92 times, compared with 18 times in humans, meaning that their hearing is four times more superior than ours (Webster 1965).

Touch is a highly developed sense in many rodents: rats and mice with trimmed or removed vibrissae (whiskers) become subordinate when grouped with intact conspecifics. Tactile hairs are found all over the pelage (fur) and are important in ensuring that the rodent moves in close proximity to vertical surfaces, a behaviour that may limit the possible avenues of attack of predators. Closely related to the sense of touch is that of 'muscle awareness' or kinaesthesis, by which a rodent is aware of its physical environment through a combined memory of movement and touch. This is vital for quick escape from predation, where a rodent will run along a 'prerecorded' path at a great speed.

Another important adaptation of rodents is their ability to swim. The brown rat can swim for 72 h nonstop and has been known to enter houses through lavatory U-bends. Commensal rodents can climb brick walls with comparative ease. Other species are accomplished jumpers, with the African spring hare covering 2 m in a single bound. Flying squirrels have membrane on both sides of the body, and one species has been observed to use flapping movements to reach a point that was 1 m higher than its launch pad and to glide a horizontal distance of 135 m (Hanney 1975). A rat or mouse can generally enter any hole through which its head will fit, with young mice being able to enter a gap less than 10 mm high (Meehan 1984).

Rodents also play an important role as environmental engineers, aerating the soil by their extensive burrowing activities. They also change, for instance, the entire nature of the landscape (e.g. beavers). Rodents also help in the dispersal of seeds and, in some cases, aid in spread of pollen.

11.2 Rodent Anatomy

Like any other mammals, rodents share most of the characteristics of class, Mammalia. Rodents are homoeothermic, and body temperature is regulated by heat generated through metabolic processes. With the subcutaneous fat and fur all over the body and by regulating blood flow to the skin, panting and sweating, rodents regulate the body temperature. Rodents are viviparous like other mammals, and the young ones are fed with the mammary glands.

11.2.1 External Morphology

Rodent body has four positions or regions, viz. anterior (cranial), posterior (caudal), dorsal and ventral (Fig. 11.1).

Anterior (cranial) position: Frontal position or the front side of the rodent.
Posterior (caudal) position: Position towards tail or posterior end.
Dorsal side or dorsal position: Upper side of the body.
Ventral sides of rodent body: Under body surface or belly of the rodent.

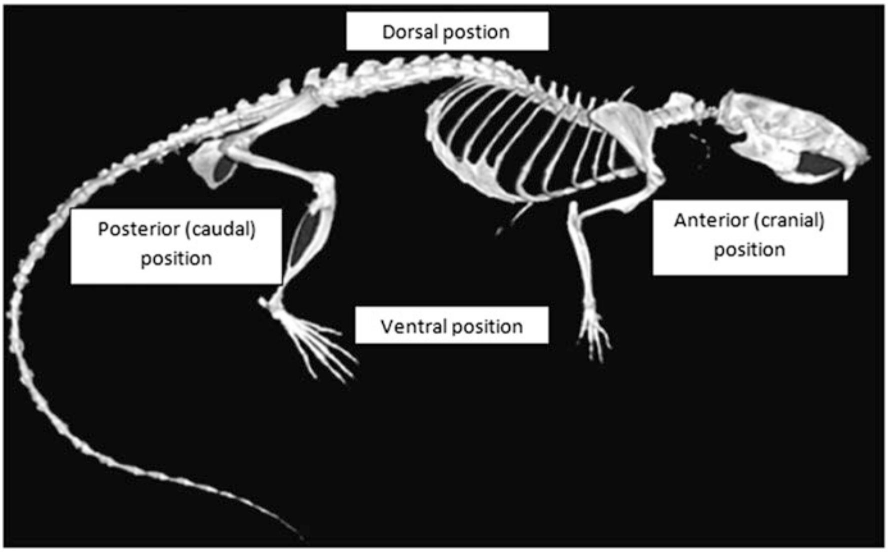


Fig. 11.1 Position of rodent body

Medial and lateral sides:
It is the middorsal longitudinal line passes from the anterior end to the posterior end of the body and divides the body into two-halves, the right and left.

Distal and proximal positions:

Depending on the position of the structures, it may be closer (proximal) and farther (distal) to the reference point.

Rodent body is generally covered with fur and is divisible into head, neck, trunk and tail (Figs. 11.2 and 11.3).

Head: Head is broader posteriorly and tapers anteriorly as a naked muzzle or snout. A pair of nostrils, shaped like inverted commas, is present above the mouth opening, which leads into nasal passages. Below the nostrils is the cleft upper lip, which exposes the two upper incisors. On the lateral sides of the head are large, paired popping eyes. Eyelids have very fine and short eyelashes; the nictitating membrane is reduced. The head bears a pair of external ear or pinna at its postero-lateral position. The mouth is subterminal and located beneath the nostrils and remains guarded by upper and lower lips. Long, stiff, bristle-like hairs, known as *pili lactiles* or vibrissae, are present on both sides of nostrils. They help the animal in measuring width of area through which the animal is to pass even in pitch dark.

Neck: It is a short connective between head and trunk. With the help of neck, the animal can bend its head in different directions.

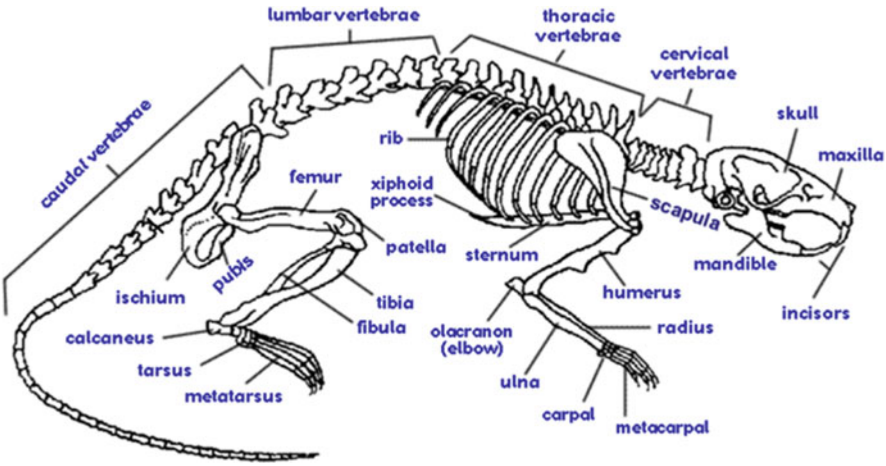


Fig. 11.2 Rodent skeleton

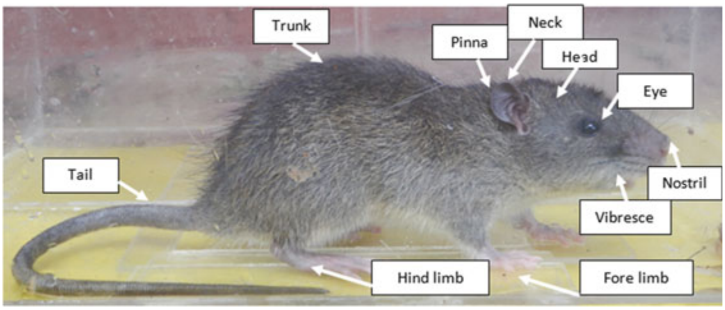


Fig. 11.3 External morphology of a rat: lateral view

Trunk: It is the major part of the body, which has two parts – anterior narrow but stouter thorax and posterior wider softer abdomen. The ventral surface of female bears six pairs of teats or nipples (three pectoral/thoracic and three inguinal/abdominal). The trunk bears two pairs of limbs, two forelimbs and two hindlimbs. Forelimbs are smaller than the hindlimbs. Five digits are present in each limb. The first digit is thumb or pollex, which is much reduced with a peculiarly flatted nail and two phalanges. Nail is keratinised structure occupying position above the distal phalanx of each digit. Typical walking pads, the tori, are present on the tips of digits, palm and the base of palm. These are also present on the feet, but palms and soles do not have hairs. Anus lies posterior-ventrally at the base of the tail.

Tail: It is long and cylindrical and tapering structure present above the anus. It bears overlapping scales and sparse hairs in between. Tail is used as a balancing organ for the animal while trotting or climbing or swimming.

11.2.2 Internal Anatomy

Rodent body is completely invested in fur-covered skin, and it consists of two layers, viz. the epidermis (outer skin) and the dermis (inner skin).

(a) **Outer skin:** It is made up of multiple layers of cells, called stratified squamous epithelium. It consists of five principal layers, viz. germinative layer or stratum germinativum, prickle cell layer or stratum spinosum, granular layer or stratum granulosum, clear layer of dead cells or stratum lucidum and the outermost layer of skin containing keratinised cell or stratum corneum. There are some layers of cells above the stratum lucidum, which constitute the stratum corneum. The cells of this layer contain keratin and have lost all other cell organelles, including nuclei.
(b) **Dermis:** It develops from the mesoderm of embryo. It is composed of dense fibrous connective tissue with blood vessels, lymph vessels, nerve fibres, pigment cells, etc.

Hairs, cutaneous glands and claws are formed from the skin. Major skin glands are sudoriferous glands (sweat glands), sebaceous glands (oil glands), mammary glands (modified sweat glands), meibomian glands (modified oil glands, present along the edges of the eyelids) and ceruminous glands (wax glands, present in the external auditory canal of external ear).

11.2.2.1 Digestive System

Alimentary canal, associated structures and glands constitute the digestive system.

Alimentary canal: It is a coiled tube having variable diameter at different positions. It begins at mouth and ends at anus. Various parts of the digestive system include the mouth, buccopharyngeal cavity, oesophagus, stomach, small intestine, large intestine and anus:

(a) **Mouth**: The mouth opens in the buccal cavity that is surrounded by the vestibule, which is a space between the lips, cheeks and teeth.
(b) **Buccopharyngeal cavity**: It is space enclosed by two jaws, and it consists of broader buccal cavity in the anterior region and narrow pharynx in the posterior region. Jaws bear teeth. The teeth are heterodont (different sets of teeth), thecodont (base of the tooth is completely enclosed in a deep socket of bone) and monophyodont (only one set of teeth develops in their lifetime). Each jaw carries two ever-growing incisors (growing teeth) and six molars. A sharp cutting edge is maintained due to the absence of enamel on the surface. A space called diastema occurs between incisors and molars due to the absence of canines and premolars. The dental formula of a typical rodent is (1/1, 0/0, 0/0 and 3/3) $\times$ 2 = 16. The middle of buccal cavity contains a muscular tongue. Taste buds occur on tongue as well as lining of buccopharyngeal cavity. Pharynx lies behind, and it is a common chamber for the passage of food and air.

(c) **Oesophagus**: It is a short tube situated dorsal to the trachea, and it leads into the stomach.
(d) **Stomach**: It lies on the left side behind the diaphragm. The curvature of the stomach is more on left side compared to right side. Oesophagus opens into the stomach through cardiac orifice/valve, and pyloric sphincter is present at the posterior, where it meets duodenum. Stomach contains goblet cells for mucus, oxyntic (parietal) cells for HCl and peptic cells for pepsinogen secretions.
(e) **Small intestine**: Stomach leads into small intestine, which can be differentiated into three parts: U-shaped duodenum, a straight jejunum and highly coiled ileum. Glands in the small intestine secrete intestinal juices or *succus entericus,* which contains lipase, nuclease, peptidase, lactase, sucrase and maltase enzymes to digest the food.
(f) **Large intestine**: It has three parts – caecum, colon and rectum. Caecum is slightly constricted about its middle. The constriction subdivides the caecum into two parts, the apical and basal portions. The apical portion contains a vermiform appendix. Caecum opens into the colon, the first part of large intestine which leads into rectum and finally opens outside through the anus.

Digestive Glands of Rodent Digestive System
(a) **Salivary glands**: Three pairs of salivary glands are present in rodents. They are:
  (i) Sublingual glands
  (ii) Submandibular glands
  (iii) Parotid glands
(b) **Liver**: Liver is located below the diaphragm in the upper and right side of the abdominal cavity. The liver of rat has four lobes (left, middle, right and caudate), and the spigelian lobe is a part of caudate lobe. The liver cells (hepatocytes) secrete bile which is carried to the duodenum by bile duct. Bile contains no digestive enzymes but helps in digestion of food in the small intestine. Gall bladder is absent in rats, like whales and horses.
(c) **Pancreas**: It is much diffused structure and is present between the duodenal loops. It secretes pancreatic juice, which contains digestive enzymes, such as trypsinogen (proenzyme), amylopsin and lipase. Islets of Langerhans of the pancreases secrete certain hormones, such as insulin and glucagon. Insulin converts glucose into glycogen in the liver and muscles.
(d) **Gastric glands**: These are found in stomach and secrete gastric juice containing digestive enzymes (e.g. pepsin) and hydrochloric acid which help in digestion of food.
(e) **Intestinal glands**: These are present in the small intestine and secrete intestinal juice containing digestive enzymes (e.g. maltase, sucrase, lipase, etc.) which help in digestion of food.

11.2.2.2 Respiratory System of Rodents

It consists of respiratory tract, two lungs and a mechanism for inspiration and expiration. Respiratory tract consists of nostrils, nasal chambers, internal nares (nostrils), glottis, larynx, trachea, bronchi, bronchioles and alveoli. The nostrils lead into the olfactory or nasal chambers. The two nasal chambers lead into pharynx through internal nares. Pharynx contains a slit-like glottis, which leads into voice box called larynx. Larynx passes into trachea and wind pipe which runs ventral to oesophagus. Trachea divides into two primary bronchi that pass into lungs.

The lungs are placed on either side of the heart in the thoracic cavity with a covering of visceral pleura. There are three lobes of the right lung and only one in the left. Each lung possesses a large number of alveoli, where gaseous exchange occurs between air and blood.

11.2.2.3 Circulatory System

Blood vascular and lymphatic systems constitute the circulatory system of rodents:

(a) **Blood vascular system**: Like other mammals, rodents possess closed and double circulation. Blood, heart and blood vessels constitute the vascular system.

Blood: The volume of blood is about 5–7 ml/100 gm body weight. The blood consists of blood plasma and three types of blood corpuscles, namely, red blood corpuscles (6–7 lakh ml^{-3}), white blood corpuscles (6000–10,000/ml^{-3}) and platelets. Mature RBCs are without nucleus. They contain haemoglobin (respiratory pigment). WBCs provide immunity and defence against diseases. The platelets help in clotting of blood.

Heart: The heart lies on the midline and is placed obliquely in the thoracic cavity, surrounded by pericardial cavity.

The heart has four chambers, viz. atrium (right and left) and ventricle (left and right). Blood flows from the right atrium to the right ventricle via the tricuspid valve (right atrioventricular valve) with three cusps of fibrous tissue. Blood flows from the left atrium to the left ventricle via the bicuspid or mitral valve (left atrioventricular valve). Well-developed arterial and venous system similar to other mammals is found in the rat. Only the left aortic arch is present and two precavae are present in the rat. Hepatic portal system is comprised of veins collecting blood from alimentary canal and supplying to the liver after branching in capillaries. The renal portal system is absent.

(b) **Lymphatic system**: Lymph vessels, lymphatic nodes and lymph constitute the lymphatic system. Lymph is a colourless fluid, which is similar to blood but lacks red blood corpuscles and blood platelets. Lymph is formed by lymph capillaries from tissue fluid. Lymph capillaries join to form lymph vessels. At places, lymph vessels bear lymph nodes. The latter contain minute channels where germs are entrapped by leucocytes. Lymph nodes also produce lymphocytes. Tonsils, a type of lymphatic node, are absent. Lymph vessels form lymph ducts of two types, right and thoracic. They also open into veins.

11.2.2.4 Excretory System

The excretory system of rodents includes paired kidney, ureters, a urinary bladder and urethra.

(a) **Kidneys**: There is a pair of dark red and bean-shaped kidneys. The right kidney is slightly higher in position. The kidney consists of outer cortex and inner medulla. A kidney has numerous microscopic functional units called nephrons. Each nephron is made up of a cup-shaped Bowman's capsule, proximal convoluted tubule (PCT), Henle's loop and distal convoluted tubule (DCT). The Bowman's capsule contains a meshwork of blood capillaries, the glomerulus. Filtration of metabolic wastes takes place in the glomerulus. Filtrate comes to the Bowman's capsule from the glomerulus and then to the other parts of the nephron.
(b) **Ureters**: There is a pair of ureters. Each ureter arises from each kidney. Ureters carry urine from the kidneys to the urinary bladder.
(c) **Urinary bladder**: It is muscular sac-like structure in which two ureters open. The urinary bladder is weak and stores urine temporarily, and hence the rats urinate very frequently. The urine thus discharged is useful to mark the territories in case of dominant animal.
(d) **Urethra**: In male, it carries both urine and semen. In female, it carries urine only. Thus, in male rat, there is only one urinogenital aperture to pass urine and semen. However, in female rat, both urinary and genital apertures are separate.

11.2.2.5 Nervous System

The nervous system is divisible into three main parts:

(a) **Central nervous system (CNS)**: The brain and spinal cord comprises the CNS; the brain is within the skull, while the spinal cord is within the vertebral column.

Brain: The brain is covered by three membranes or meninges. The innermost membrane is called pia mater, the next is the arachnoid mater (= arachnoid membrane) and outermost is the dura mater. The subdural space is present below the dura mater, and the subarachnoid space lies below the arachnoid mater. These spaces are filled with a fluid. The meninges are protective in function.

The brain is composed of two large halves or hemispheres. The cerebral hemispheres form the largest part of the brains. The medulla oblongata tapers posteriorly and is inserted into the spinal cord. The spinal cord is a long, tube-like, thick-walled structure that emerges out through the foramen magnum of the skull and passes through neural canal of vertebral column.

(b) **Peripheral nervous system (PNS)**: The cranial (12 pairs) and spinal (33 pairs) nerves arising from the brain and spinal cord, respectively, in rat constitute the PNS.

(c) **Autonomic nervous system (ANS)**: Involuntary actions are being coordinated by the autonomic nervous system. It consists of both sympathetic and parasympathetic nervous systems.

11.2.2.6 Sense Organs

Skin has tangoreceptors (receptors of pressure and touch), thermoreceptors (receptors of temperature), algesireceptors (receptors for pain) and rheoreceptors (receptors for current or vibrations). Gustatoreceptors (taste receptors) occur in the form of taste buds over tongue and posterior part of palate. Olfactoreceptors are located in olfactory epithelium present in nasal chambers. They perceive the sensation of smell. Smell is also perceived by a pair of Jacobson's organs present in the wall of buccal cavity of rat. Organs of sight are eye, while statoacoustic organs are ears.

11.2.2.7 Reproductive System

11.2.2.7.1 Male Reproductive System

A pair of testes, epididymis, vasa deferens, urethra, penis and spermatic cord (Raj 1984, 2015) constitutes the male reproduction organs in rat.

(a) **Testes**: A pair of testes is found in the scrotal sacs. Each testis is an elongated and ovoid body attached posteriorly to scrotal sac by gubernaculum. Testis of male rat descends in the scrotal sacs through inguinal canal when the animal is in between 30 and 40 days of its life. The inguinal canal remains open throughout life, but during sexually inactive period, the testes may be withdrawn into abdominal cavity.
(b) **Epididymis**: These are paired structures. Each epididymis is a mass of long narrow coiled tubule lying along the testis, which consists of anterior caput epididymis, middle corpus epididymis and posterior cauda epididymis. Epididymis stores the sperms.
(c) **Vasa deferentia**: There is a pair of vasa deferentia. A vas deferens arises from the cauda epididymis. Vasa deferentia carry sperms.
(d) **Seminal vesicles**: A paired structure, which is large and lobulated, except for the smooth tip where it is doubled back upon itself. They are not storehouses for sperms. Their secretion is alkaline and forms the bulk of seminal fluid (semen).
(e) **Urethra**: It is divided into three parts:
    (i) Prostatic urethra is surrounded by the prostate gland.
    (ii) Membranous urethra is the shortest portion and runs from the prostate to the bulb (base) of the penis.
    (iii) Penile urethra passes through the penis and opens at the tip of the penis as urinogenital aperture.
(f) **Penis**: It is a copulatory organ covered by a loose sheath, the prepuce. The penis of the rat has a bony process called the os penis (baculum).

Male Accessory Glands:

(a) Ampullary glands: The outer end of the vas deference near the entrance into the urethra is enlarged into ampulla, which contains ampullary glands to secrete mucus.
(b) Vesicular glands: These are branched glands, which originate from the vas deferens behind the ampulla.
(c) Coagulating glands: Closely applied along the minor curvature of the seminal vesicles and within the same sheath are the coagulating glands. The secretion of these glands serves to coagulate the seminal fluid (semen).
(d) Prostate glands: There are two prostate glands, whose secretion is rich in citric acid, lipid and acid phosphatase.
(e) Cowper's glands (bulbourethral glands): These are one pair, which originate from the urethra at the base penis. They produce a secretion during sexual excitement, which protects the sperms from traces of acids found in the urethra (as the urine also passes through the penile urethra).
(f) Prenuptial glands (glands of Tyson): They develop from the skin forming prepuce. They are modified sebaceous (oil) glands, which secrete peculiar odorous secretion.

11.2.2.7.2 Female Reproductive System

It consists of a pair of ovaries, fallopian tubes, uteri, a common vagina and a clitoris:

(a) **Ovaries**: Ovaries are paired small yellowish compact structures suspended in the body cavity by mesovarium.
(b) **Fallopian tubes** (oviducts or uterine tubes): There is one pair of convoluted fallopian tubes. Each fallopian tube begins with fimbriated funnel, which receives ova from the ovary. As the fertilisation is internal, it takes place in the dilated uppermost portions of the fallopian tubes.
(c) **Uterus** (womb): The uterus is a hollow muscular structure. The uterine horns are fused near the vagina. The wall of the uterus consists of outer covering of peritoneum (perimetrium), middle layer (myometrium) and the inner layer of simple columnar epithelium (endometrium). The embryo gets attached to the uterine wall through placenta. Embryonic development takes place in the uterus. Placenta provides the physiological connection between developing foetus and uterine wall (endometrium) of the mother.
(d) **Vagina**: It is a tubular structure, which extends from the uterus and opens outside as vaginal opening (= vulva). Penis of the male rat is inserted into the vagina during copulation. The vagina also helps to deliver the young ones at the time of birth.
(e) Clitoris: It corresponds to the penis of the male, but it is reduced in size and does not have any passage (it is solid structure). The clitoris is found anterior to the vulva.

Female Accessory Glands:

(a) **Vestibular glands**: These are small mucous glands, which open on the surface of the vestibule of the vagina.

(b) **Bulbourethral glands**: These are small glands, which are present in relation with the urethra.

(c) **Preputial glands**: There is one pair of large preputial glands near the tip of the clitoris.

11.3 Rodent Classification

Modern-day rodents are descendants of Paramyidae, insectivore-like ancestor, which arose about 60 million years ago in the late Palaeocene (Wood 1962). The genus *Aplodontia*, the American mountain beaver, is the most ancient surviving lineage of rodents. Great diversity exists in the contemporary rodents as they are very small to gigantic sizes.

11.3.1 Systematic Position

Kingdom:	Animalia
Subkingdom:	Bilateria
Infrakingdom:	Deuterostomia
Phylum:	Chordata
Subphylum:	Vertebrata
Infraphylum:	Gnathostomata
Superclass:	Tetrapoda
Class:	Mammalia
Subclass:	Theria
Infraclass:	Eutheria
Order:	Rodentia

Order Rodentia is divided into five major suborders (Plate 11.1–11.5) (Editors of Encyclopaedia Britanica 2020; Myers et al. 2020)**:**

1. Anomaluromorpha
2. Castorimorpha
3. Hystricomorpha
4. Myomorpha
5. Sciuromorpha

11.3.2 Suborder Anomaluromorpha

It consists of two families, viz. Anomaluridae and Pedetidae

11.3.2.1 Family Anomaluridae

Family Anomaluridae includes genera *Anomalurus*, *Idiurus*, and *Zenkerella*. Some of the members of this family have the gliding ability (e.g. pygmy and large anomalures) using the fur-covered membrane. Anomalures have slender bodies with large eyes, long limbs and dense silky fur. Large and pygmy anomalures are nocturnal, and they eat bark, oil palm pulp, insect, etc. A flightless anomalure, a rare species, feeds on termites (Plate 11.1).

11.3.2.2 Family Pedetidae

Commonly called as spring hare (*Pedetes capensis*), which lives in open arid habitats and cultivated area of southern and eastern Africa. Spring hare is about a size of a rabbit. It uses its long and powerful hind legs for jumping (2 to 3 metres, i.e. 6.6 to 9.8 feet, when the animal is alarmed). Apart from grass, the spring hares eat agricultural crops and even locust also (Plate 11.1).

11.3.3 Suborder Castorimorpha

11.3.3.1 Family Castoridae

Members include amphibious and one of the largest rodents, viz. beaver (*Castor* sp.) and giant beaver (*Castoroides* sp., now extinct). They weigh about 16–30 kg. Beavers are native to North America, Europe and Asia. Beavers live in aquatic habitat and construct dams forming ponds that quite often cover many hectares. By this way, they alter the landscapes in which they live, and beavers are referred to as ‘ecosystem engineers’. Beaver incisors are strong and massive and have orange outer enamel containing iron in place of calcium. Beavers are colonial animals, and they construct dome-shaped island lodges with plant parts plastered with mud to protect the nest from predators.

11.3.3.2 Family Heteromyidae

Includes kangaroo mice, kangaroo rats and pocket mouse which falls under 36 families and 4 genera.

Kangaroo mouse (Plate 11.1) is a jumping rodent predominantly found only in the arid zones of the western parts of USA. Large head, large ears, fur-lined external cheek pouches, short forelimbs and long hindlimbs are the characteristic features of kangaroo mouse. The cheek pouches are used to carry food to the nest. Kangaroo mice produce concentrated urine and dry faeces as they do not drink water; instead, they obtain it from the food they eat.

Kangaroo rats (Plate 11.1), like the kangaroo mouse, have large heads and eyes, fur-line external pouches alongside the mouth, short forelimbs and very long hind

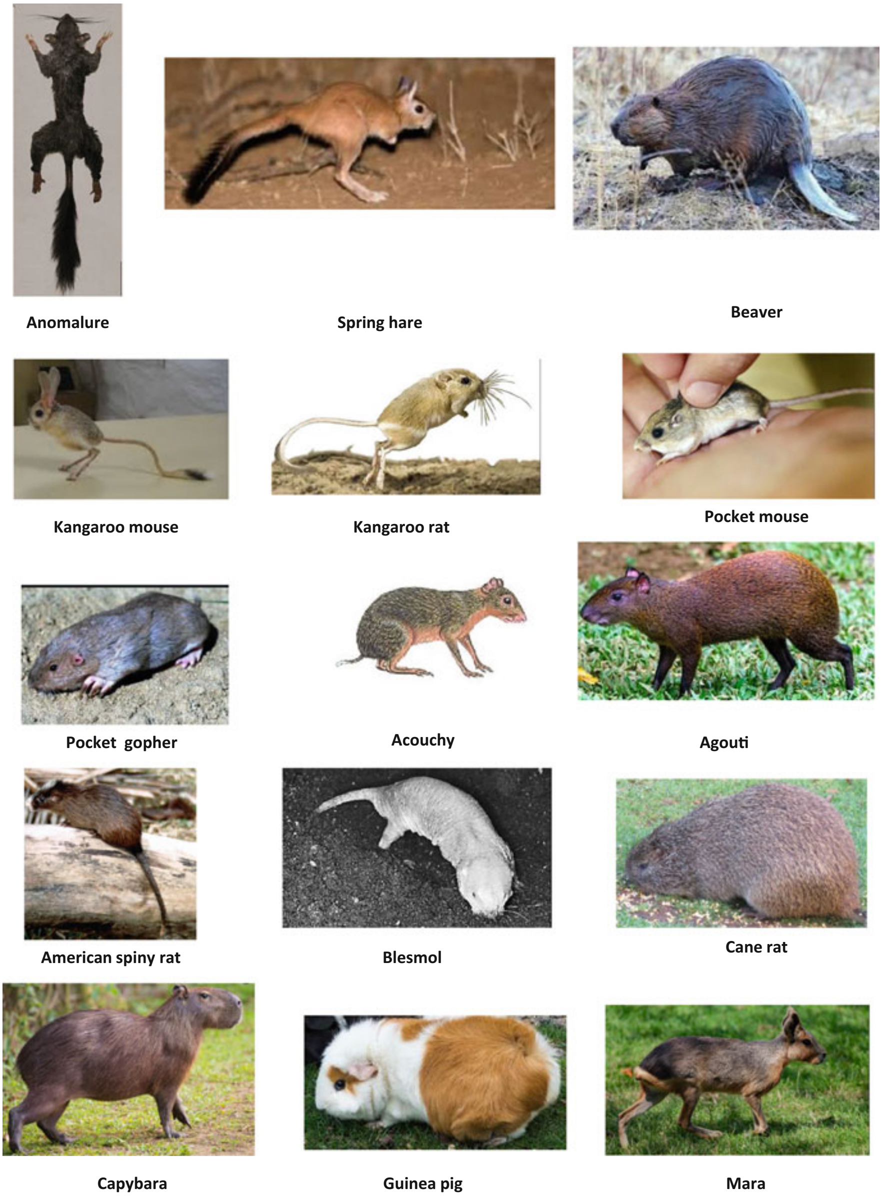


Plate 11.1 Rodent diversity

legs and feet. The tail has a characteristic tuft at the tip. Kangaroo rats can jump up to 2 metres (6.6 feet) using their hind legs. Like the kangaroo mice, kangaroo rats seldom drink water and get the same from their food. Kangaroo rats are night foragers and carry the food in their cheek pouches to the nest.

Pocket mouse (Plate 11.1) is an American rodent and has more than 36 species. Unlike kangaroo mouse, pocket mouse uses all four legs for the movement. Pocket mice consume many plant materials like seeds, nuts and succulent parts and carry the food in their cheek pouches.

11.3.3.3 Family Geomyidae

At least 38 species are present in this North and Central American rodent's family, and they are commonly called as pocket gopher. The 'pockets' are cheek pouches along the sides of mouth. Pocket gophers (Plate 11.1) are extensive burrowers that make shallow tunnels mainly using their forelimbs. One of the characteristic features of pocket gopher is that they can move backwards as fast as they move forwards. The pocket gophers feed mainly on plant roots and tubers.

11.3.4 Suborder Hystricomorpha

This suborder has 19 families.

11.3.4.1 Family Dasyproctidae: Includes Acouchy and Agouti

Acouchy is an antelope-like animal weighing about 1–1.5 kg (2.2–3.3 pounds), with a pencil-thin tail tufted at the tip (Plate 11.1), and is inhabitant of South America. Acouchys are terrestrial and nocturnal rodents with long, three-toed hind legs. When threatened, acouchys produce whistles similar to the ones produced by birds and hop a greater distance like the duiker, an African antelope. Acouchys eat seeds, nuts and other plant parts and also burry nuts in soil in their territories.

Agouti resembles a small forest-dwelling hoofed animal. It has an elongated body (Plate 11.1) and weighs up to 6 kg. The tail is very small and bald. The hindlimb toe has hoof-like claws. They are capable of jumping vertically up to two metres from a stationary position. Agoutis feed mainly on fruit, nuts and seeds; occasionally, they also feed on leaves, flowers, fungi and insects. Like acouchys, agoutis also bury nuts in the soil and disperse the seeds of many plants.

11.3.4.2 Family Echimyidae

American spiny rat (Plate 11.1) (18 genera, viz. *Proechimys,* terrestrial spiny rats; *Mesomys*, spiny tree rats; *Carterodon*, Owl's spiny rat; *Hoplomys*, armoured rat) is a nocturnal animal and has nearly 80 species. It is predominantly found in Central and South America. Like house lizards, the tail breaks off easily when pulled. They eat leaves and shoots of plants (bamboo in case of American bamboo rats), nuts, fruits, fungi and insects.

11.3.4.3 Family Bathyergidae

Blesmol is a burrowing naked mole rat with protruding incisors found in arid regions south of the Saharan deserts. Blesmols are colonial rodents living with nearly 300 individuals per colony. They appear to be without neck and external ears; however, they can sense the vibrations emanating from the ground. Underground roots, bulbs, tubers, other plant parts and occasionally invertebrates are the part of their diet. Blesmol is a prolific breeder and produces up to 27 pups per litre, which is the largest for any mammal.

11.3.4.4 Family Thryonomyidae

Cane rat, genus *Thryonomys*, is relatively larger rodent weighing up to 7 kg with blunt muzzles and small ears. Their fur coat is brown, rough and bristly (Plate 11.1). Cane rats are swift and agile on land and swim very well. They feed on grass, agricultural crops, bark of plants and fruits. Cane rats are hunted for human consumption in Africa.

11.3.4.5 Family Caviidae: It Includes Capybara, Guinea Pig and Mara

Capybara is also called as ‘water hog’, and it is the largest living and semiaquatic rodent of Central and South America (Plate 11.1). Largest capybaras are the South American species which grow about 1.25 m long and weigh up to 66 kg or even more, and the smallest one is the Panamanian capybaras (27 kg). Capybaras are generally brown coated and have almost no tail but with small ears, blunt snouts and short legs. They are vegetarian and at times become pest on cultivated areas.

Guinea pig is a domesticated rodent in South America. It has large head with large eyes and short ears; the body and the limbs are short (Plate 11.1). Several breeds of domesticated guinea pigs exist based on the coat texture and hair length. Coat coloration is extremely variable ranging from white to black. Domestic guinea pigs are fairly large, weighing between 500 and 1500 g. Domestication of guinea pigs started in Peru for more than 3000 years, and now there exists no wild population of this animal.

Mara resembles hares; it has a blunt muzzle, large ears and prominent eyes. The legs are slender and long (Plate 11.1). The body is 45–75 cm long, and the weight ranges between 9 and 16 kg. Their front claws are sharp but have hoof-like hind claws. Their diet is generally any available vegetation in the habitat.

11.3.4.6 Family Chinchillidae Consists of Chinchilla and Viscacha

Chinchilla is a highly valued rodent for its soft and thick fur which is generally blue to brownish grey in colour (Plate 11.2). Chinchillas are hunted almost to extinction in the wild. However, they are commercially reared with various colours and kept as pets. Chinchilla has a compact body with large ears and eyes and bushy tail.

Viscacha resembles chinchillas and is an inhabitant of South America. They have dense soft fur. Their ears are very long and resemble long-tailed rabbits (Plate 11.2). They weigh up to 3 kg.

11.3.4.7 Family Abrocomidae: Chinchilla Rat

Chinchilla rat superficially resembles a chinchilla but is more rat-like with short limbs, large eyes and large, rounded ears (Plate 11.2). They are nocturnal animals and are agile rock climbers. Massive latrines are built by some species of chinchilla

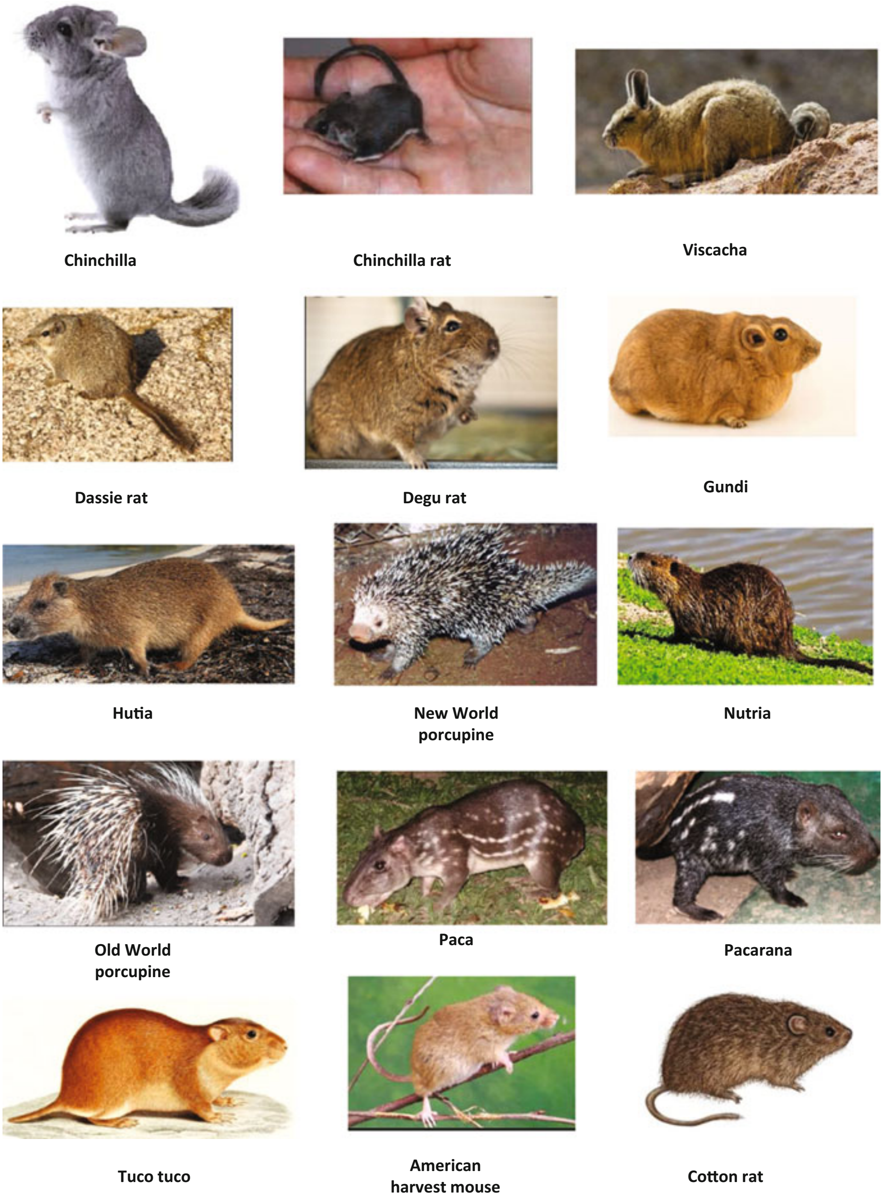


Plate 11.2 Rodent diversity

rat on rock crevices using their faeces, urine and other liquids which eventually become rock solid. Chinchilla rats feed mainly on vegetation.

11.3.4.8 Family Petromuridae: Dassie Rat

Dassie rat is a rock dweller of southwestern Africa. It has a squirrel-like body (Plate 11.2) and weighs 170–300 g. Dassie rat can flatten its body against any substratum and can squeeze itself into very narrow gaps. They feed on grasses, fruits and other plant materials. Dassie rat is very unique among the rodents as it can regurgitate the food for further chewing more like the ruminants do.

11.3.4.9 Family Octodontidae: Degu (Genus *Octodon*)

Degu is a small rodent endemic to central Chile. It prefers to live in open grassy areas near human habitation. Their head and eyes are large sized, but they have medium-sized almost hairless ears and black-tipped tails (Plate 11.2); some animals have pale neck band also. Long, comb-like bristles project over claws on the hind feet, which is a characteristic feature of degu. Their body weight ranges between 170 and 300 g. Degus forage on the ground and also on shrubs and trees. Many individuals live together in a common burrow complex which has nests and stores.

11.3.4.10 Family Diatomyidae: Diatomyid

Fossil evidences are available for Diatomyidae from early Oligocene (~32.5 million years ago) to the Miocene (~11 million years ago). Recent addition to this group is *Inopinatia balkanica*, from the early Oligocene of southeast Serbia (Dawson et al. 2006; Marković, et al. 2018).

11.3.4.11 Family Heptaxodontidae: Giant Hutia

An extinct group of large rodents once lived in West Indies.

11.3.4.12 Family Ctenodactylidae: Gundi (Multiple Genera)

Gundis have two rows of comb-like bristles on their hindlimb for grooming themselves. Larger eyes, blunt nose and short but rounded ears are the identifying characters of gundi (Plate 11.2). Unlike other rodent species, gundis do not make burrows or nests; instead, they use available crevices and caves to rest at night. They eat leaves, seeds, flowers and other plant materials. When threatened, gundis produce birdlike sharp whistling alarm calls.

11.3.4.13 Family Capromyidae: Hutia (Multiple Genera)

Hutia is a Caribbean rodent with 26 living and recently extinct species. Hutias have stout body, short limbs, smaller eyes, exceptionally long whiskers and very prominent claws (Plate 11.2). They are specialised tree and rock climbers and dwellers, and like the gundis, they do not excavate burrows. Hutias are active both on day and at night. Some of the species like the long-tailed Cuban hutias resemble tree squirrels and are nocturnal. Plant materials like leaves, stem, bark, underground plant parts and sometimes small vertebrates constitute hutias' diet.

11.3.4.14 Family Erethizontidae: New World Porcupines

Members are medium-sized animals weighing up to 18 kg, and body is covered with modified hairs called spines or hollow quills. Some species are entirely arboreal and have long prehensile tails and wide foot pads; however, the less arboreal species have shorter tails. New World porcupines are solitary nocturnal animals and shelter themselves in tree caves, rock crevices or among the tree root networks (Plate 11.2). These rodents ingest nuts, leaves, bark, roots, grass, aquatic plants, insects and small reptiles. By the way of stripping the bark, these rodents kill the trees. Mineral requirement is met from the bones and antlers on which these rodents gnawed upon.

11.3.4.15 Family Myocastoridae: Nutria (*Myocastor coypus*)

Nutria, also called coypu, is originally from South America (southern and central parts). Fur of this animal has tremendous commercial value. Nutria is an amphibious rodent with large body (weight ranges between 10 and 17 kg). Hindlimbs with five toes and webbing are adapted to lead amphibious life, whereas the forelimbs have no webbing, but all toes have very well developed claws (Plate 11.2). Nutria can remain underwater for nearly 5 minutes. It can also close its mouth while cutting the submerged vegetation without swallowing water. In general, the nutria prefers slow-moving water and feeds on a wide variety of aquatic vegetations. Occasionally, they feed on aquatic invertebrates also. Nutria lives in families of 10 to 15 individuals, constructing burrows and platform nests in river banks. Intentional and accidental introduction of nutria in North America and Europe facilitated the nutria to become one of the destructive pests on cultivated crops.

11.3.4.16 Family Hystricidae: Old World Porcupine (genera *Atherurus*, *Hystrix* and *Trichys*)

Old World porcupines are large animals which move slowly. They are primarily terrestrial animals. Their primary defence is their imposing spines or quills (Plate 11.2); *Hystrix* sp. rattles its quills for communication among the individual and warn their predators. There are three groups of Old World porcupines, viz. a tree-climbing long-tailed porcupine (*Trichys fasciculata*), brush-tailed porcupine (*Atherurus* sp.) and short-tailed porcupine (*Hystrix* sp.). Among the three, *Hystrix* sp. is the largest (nearly 30 kg body weight). They feed on many kinds of plant material and also carrion. They gnaw antlers and bones to get calcium and other minerals. Even though they are excellent diggers, they often shelter in caves and rock crevices.

11.3.4.17 Family Cuniculidae: Paca (Genus *Cuniculus*)

Paca is a terrestrial herbivorous rodent in South America. It has pig- or deer-like body which weighs between 6 and 14 kg, square head and a tiny tail (Plate 11.2). Pacas reside in rain forests and near water bodies. They are excellent swimmers and can stay underwater up to 15 minutes, at times. Pacas live in deep burrows (3 m) near water bodies. These rodents make peculiar growling sound using their cheeks. Pacas diet consists of fruits, leaves, fungi and insects; they are also coprophagous and absorb nutrients from fresh excreta.

11.3.4.18 Family Dinomyidae: Pacarana (*Dinomys branickii*)

Pacarana is a rare rodent found in tropical rain forests of Amazon river basin and Andes mountains in South America. It has a robust body (weighing 10–15 kg), large head and eyes and unusually long vibrissae (Plate 11.2). Pacarana produce a variety of vocalisations for communication apart from stamping its fore paw. While eating, pacanas hold their food in their forelimbs and while sitting on their hindlimbs.

11.3.4.19 Family Ctenomyidae: Tuco-Tuco (Genus *Ctenomys*)

Tuco-tuco is a fossorial rodent similar to pocket gopher (Plate 11.2), of central and southern South American origin. Tuco-tuco makes a characteristic alarm calls, hence the name. These rodents spend most of their lives underground. Their forelegs are exceptionally long and equipped with powerful claws suited for digging; they also use their tooth in excavation process. Tuco-tucos lead either solitary or semi-social lives feeding on vegetation, root, bark (considered as agricultural pest), invertebrates, small mammals, reptiles, toads and even birds.

11.3.5 Suborder Myomorpha

11.3.5.1 Family Cricetidae

It is the second largest mammalian family having nearly 608 species; it includes New World rats and mice, hamsters, lemmings and voles.

American harvest mouse: There are 20 species of American harvest mice found in southern Canada, USA, Mexico to northern South America. An adult harvest mouse barely weighs around 20 g (Plate 11.2). Harvest mice are nocturnal and use the runways of other rodents. At low temperature, these animals enter into torpor. They are herbivorous animals and also pests of forest trees and cultivated crops. Their diet consists of grains and seeds of various plants.

Cotton rat (genus *Sigmodon*) is found in southern and northern parts of USA and South America, respectively. They have S-shaped molar, hence the genus name, *Sigmodon* (literally means S-tooth). All species live in natural grassland habitats, and all are primarily herbivorous and inhabit cultivated fields. They are both nocturnal and diurnal in habit (Plate 11.2). Cotton rats lead a solitary life except during mating season. They eat seed and plant materials; thus, they can become serious agricultural pests.

Deer mouse (genus *Peromyscus*) is small rodent with conspicuous bulging eyes found in North and Central Americas. Deer mouse genus, *Peromyscus*, has 56 sub-species, and the body weight of different species ranges from 15 to 110 g. Fur is soft and colour varies from nearly white to grey, brown, reddish brown, to black, white underside (Plate 11.3), and all have white foot. The white-footed mice are nocturnal, and their reproduction depends on the availability of food. They are one of the preferred laboratory animals for the study on genetics, evolution, physiology and medicine. Incidentally, *P. maniculatus* is carrier of dreaded Hanta virus, plague and Lyme disease.

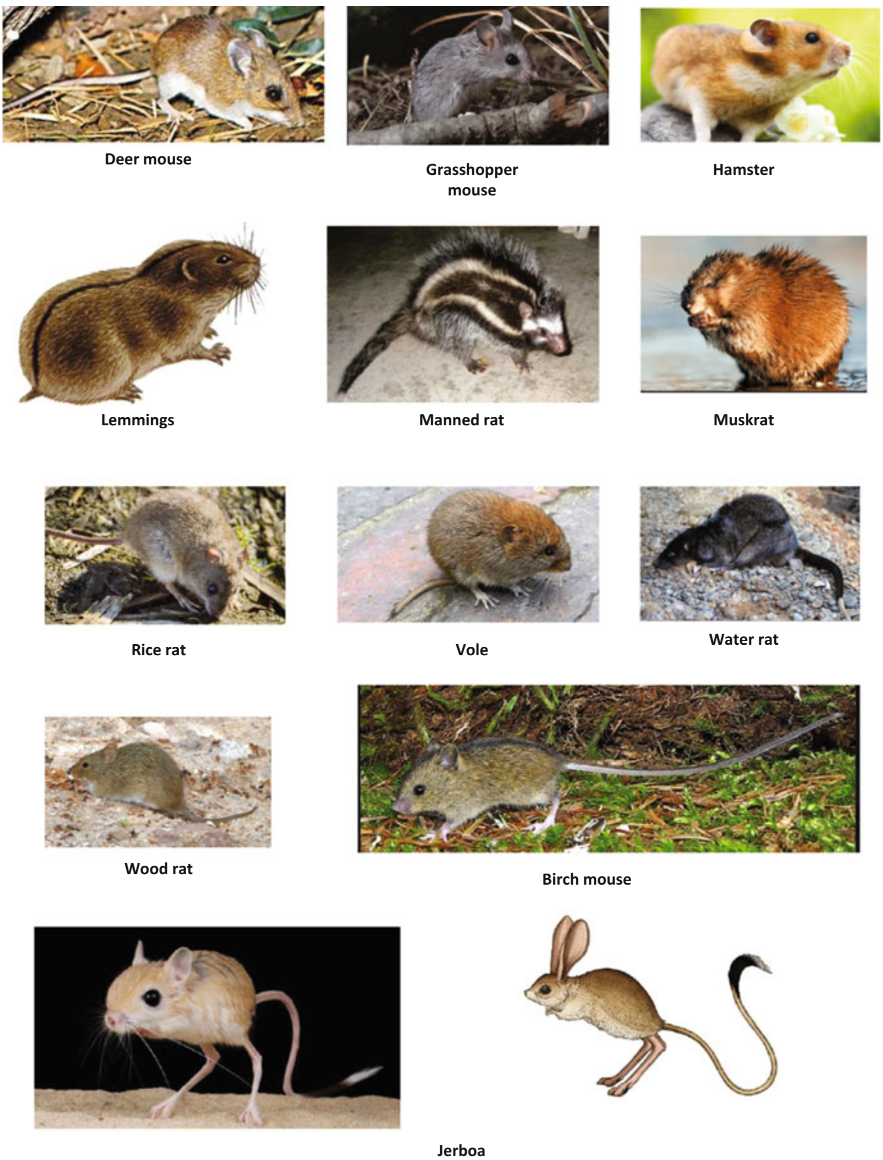


Plate 11.3 Rodent diversity

Grasshopper mouse (genus *Onychomys*) is a terrestrial, nocturnal, insectivorous and carnivorous rodent (Plate 11.3) adapted to semiarid and arid habitats; they are endemic to North America. Grasshopper mice mostly eat grasshoppers, other insects and arthropods like scorpions; they are also known for stalk and kill small rodents and snakes and eat them just like the larger mammalian predators. They use a variety of vocalisation to communicate, and the calls are used to distinguish species, sex and even the position in the hierarchy (immature and adults make different vocalisation); the howling calls these rodents make, like the miniature version of a coyote howl, can be heard over long distances.

Hamsters are popular house pets in many countries (e.g. golden hamster or Syrian hamster, *Mesocricetus auratus*) (Plate 11.3). Hamsters have silky fur, and the colour ranges from black to red depending on the species. They are solitary animals, and if put together, the animals show acute and chronic stress. Hamsters are omnivorous animals and consume seeds, grassy vegetation, invertebrates and even other small animals. Hamsters are known to carry food in their cheek pouches to their burrow.

Lemmings are small rodents and found only in the Northern Hemisphere. There are 20 species, some of which undertake large, swarming migrations. They have soft fur-covered rounded body with short legs and stumpy tails (Plate 11.3). Among the different species of lemmings, the wood lemming (*Myopus schisticolor*) and steppe lemming (*Lagurus lagurus*) are the smallest, weighing about 20 to 30 g. Lemmings are behaviourally different from other rodents as they aggressively behave towards predators. Some species of lemmings undertake migrations, and if the migration is not successful through a large water bodies, many of the migrating lemmings die *en route*, which leads to the popular notion, ‘suicidal lemmings’. They feed on almost any sort of vegetation like grass and mosses. Lemmings make extensive runway systems under the rock or snow and scamper along.

Maned rat (*Lophiomys imhausi*) is also called crested rat which resembles a porcupine and found in East Africa. Mane is the coarse, black and white banded hairs present on the head and extends beyond the tail base; when alarmed or excited, the mane gets erected (Plate 11.3). These rats are known to deliberately smear poisonous materials from plants on which they chew as a defence mechanism. The maned rat sits on its haunches when eating and manipulates food with its forelimbs. They feed on fruits, leaves and other plant materials; they also consume insect or meat, if available.

Muskrats (genera *Neofiber* and *Ondatra*) are large amphibious rodent; they are native to North America but found also in Europe and Asia. These rodents produce a musky substance from their perineal glands to mark their home ranges. These rodents also are called as musk beavers because of the flattened tail. Muskrats use their large semi-webbed hind feet as oars while swimming (Plate 11.3). They are very efficient swimmers (5 km/h) and divers (can stay submerged for up to 20 minutes). Muskrats consume various aquatic plants; occasionally, they also feed on aquatic animals and young birds. Muskrats usually live in groups and build nests to protect themselves and their offspring. These rodents are being hunted for their fur and meat.

Rice rats (genus *Oryzomys*) including about 120 species are small rodents (Plate 11.3) found in many environments, viz. coastal marshes, grasslands and rainforest of USA and South America. They resemble house rat but are smaller in size. An opportunistic feeder, they eat a variety of food materials like plant seeds, succulent parts of grasses, invertebrates, small vertebrates and even carrion.

Voles are also called as meadow mice. They resemble shrews, rats, mice and gophers; they are small-bodied rodents with stouter body and shorter but hairy tail found in the Northern Hemisphere. Voles live in a wide variety of habitats eating plants, nuts, fruits, dead animals, etc. Voles are known to griddle young trees which eventually kill the plant; they also eat roots until the plant is dead. However, the voles play a vital role through their burrowing activities to disperse soil nutrients in different soil layers.

The **woodland vole** (*Microtus pinetorum*) is one of the smallest voles weighing less than 35 g. It has brown dorsum and silvery underside. It is found in the apple orchards, dry fields and deciduous forests of eastern USA. Woodland vole inflicts heavy damage to apple orchards.

The **meadow vole** (*Microtus pennsylvanicus*), also known as the meadow mouse, has the widest distribution in North America. Meadow voles prefer grasslands, but they are found in forest areas also. These rodents dig shallow burrow, and nest is constructed with woven grass. Diet includes agriculturally important plant species, grasses and sedges; the meadow voles take insects and snails and, at times, carrion feeder.

Water rats are a group of not closely related semiaquatic carnivorous rodents (Plate 11.3). They live in burrows dug near the water bodies. They are expert swimmers. The animals feed on a variety of aquatic insects, crustaceans and small fishes. Their sensitive whiskers aid in locating the prey underwater.

Woodrats (genus *Neotoma*), also called packrats, are medium-sized North and Central American rodents (Plate 11.3). Middens (collection of various items includes bones, sticks, dry manure, shiny metal objects, etc.) are seen near their dwellings. Woodrats are generally solitary, nocturnal and active year-round. Normally, wood rats feed on green vegetations and some species, viz. Stephen's woodrat (*Neotoma stephensi*) thrive on juniper sprigs and *N. albigula* and *N. lepida* on cacti and yucca plants.

11.3.5.2 Family Dipodidae: Dipodid/Birch Mouse (Genus *Sicista*)

Birch mice are small, long-tailed jumping mouse-like rodents (Plate 11.3) found in Europe and Asia. They are nocturnal in general, but also seen in shallow burrows during daytime. They feed on seeds and insects and live in nests constructed out of woven ball of grass either in bush or crevices. Birch mice move around by leaping on the ground, but they use their tail for support while climbing on the tree.

Jerboas are hopping rodents of Europe, Asia and northern Africa found in grasslands and deserts. Jerboas resembles mouse but have short forelegs and extremely long hind legs for jumping; when alarmed, these rodents can leap up to 3 m. The tail is often tufted (Plate 11.3). Jerboa's dense fur colour usually matches the ground of the animal's habitat. In some species of jerboa, to regulate the temperature and moisture in their burrows, plugging the burrow entrances with soil is noticed; it also prevents the hot air getting into their burrow network.

Jumping mouse (genera *Eozapus*, *Napaeozapus* and *Zapus*) is a small (13–26 g), mouse-like rodent found in North America and China. These rodents have elongated hind legs for leaping when alarmed (4 m high) and have tail which is longer than the head and body (Plates 11.4) which is used as a balancing organ. They have soft and

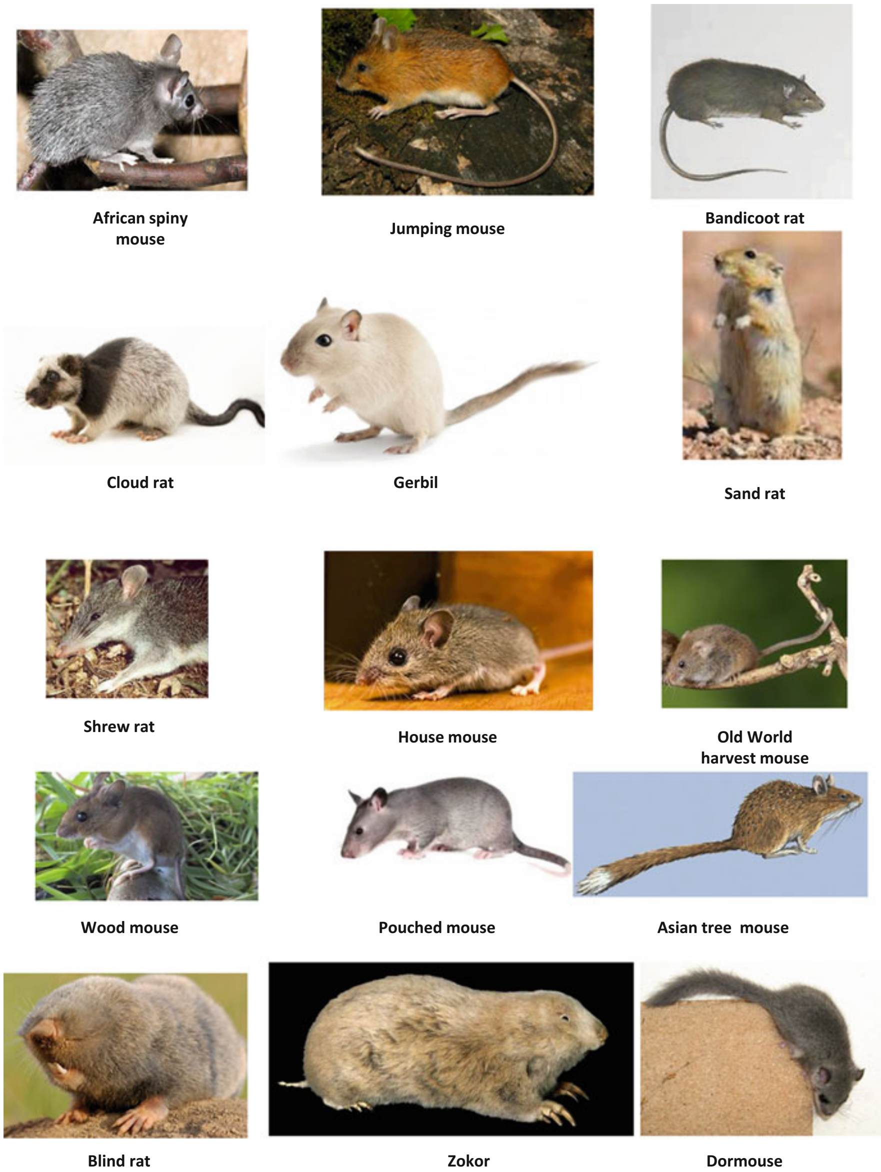


Plate 11.4 Rodent diversity

glossy fur, and the fur colour varies. Jumping mice are generally terrestrial but are agile climbers and swimmers. They feed on seeds, fruits, fungi, invertebrates and sometimes molluscs and small fishes, also.

11.3.5.3 Family Calomyscidae

Mouse-like hamster (living fossils) is a group of small rodents, found in rocky areas in desert regions of Central Asia.

11.3.5.4 Family Muridae

African spiny mice (genus *Acomys*), which originated from Africa, have unusually stiff hairs similar to spines on their coats, hence the common name. They have large eyes and ears and scaly tails (Plate 11.4). African spiny mice are social animals and are omnivorous; they eat plant materials like dates and also some odd diet like dried flesh and bone marrow of mummies in Egypt. They live in a variety of environment like rocky areas, savannas and dry woodlands; they occupy rock crevices, termite mounds or even other rodent burrows. Skin of these mice is brittle and can be easily torn (an escape mechanism from predators), which can be completely regenerated, a special trait that no other mammals possess.

Bandicoot Rat (Genera *Bandicota* and *Nesokia*)

Bandicoot rat is a commensal rodent, and there are five Asiatic species which depends on human habitations for their survival. They are found throughout the Indian subcontinent and Indochina. The larger bandicoot rat (*Bandicota indica*) that weighs up to 1 kg (Plate 11.4) is a robust blackish brown rat with a sparsely haired tail equal to the head-body length. These rats erect their hairs on their back and produce grunts when challenged. They cause extensive damage to masonry structures with their burrowing activities, and they are also very important carrier of many zoonotic diseases. These rats consume any household refuse, grains and vegetables and are serious pest on poultry.

The lesser bandicoot rats (*B. bengalensis*) or the Indian mole rats are one of the large rats in Southern Asia. They have dark brown or brownish grey body fur and weigh up to 350 g and measure up to 40 cm long including their brown tails which is shorter than the head-body length. The lesser bandicoot rat is found on the Sothern and Southeast Asia, Middle East and Africa. They produce pig-like grunts when threatened. They are extensive burrowers, and the elaborate burrows have numerous chambers and exit or bolt holes. They are very serious pest on agricultural crops; they store grains and other food materials in their nest. These rodents can burrow through even concrete cellars.

Savile's (*B. savilei*) bandicoot rats are solitary omnivorous animals found in the Indo-Malayan Realm (Myanmar, Thailand and Vietnam). They resemble more like the lesser bandicoot rat. They feed on grains, fruits and invertebrates and a serious pest on agricultural crops.

Short-tailed bandicoot rats (*Nesokia*) are of the size of the bandicoot rats with soft brown fur on the upper parts, lighter underpart and a short tail with scantily haired. They live in river valleys and irrigated crop lands in Asia and Africa. The rats make extensive burrow system which goes up to 60 cm deep and 9 m long; they push up mounds of soil to conceal the entrance and exit holes. Some species of *Nesokia* are excellent swimmer and live in natural marshes and build nests on reed platforms above water level. The diet of these rats includes grains, grasses, roots, fruits and vegetables.

Cloud rats (genera *Phloeomys* and *Crateromys*), also called cloud runner, are large, slow-moving endemic arboreal rodents of Philippine forests (Plate 11.4). They are nocturnal and herbivorous. Cloud rats have been hunted for their meat driving them to near extinction.

Gerbils (subfamily Gerbillinae), once known as desert rodents, are living in arid habitats and have more than 110 species. They are social animals, and a gentle and hardy gerbil, *Meriones unguiculatus*, is even kept as a popular house pet (Plate 11.4) in some regions. Most gerbils are nocturnal. Their hind legs are long, and they have large ears and eyes. When alarmed, the gerbils flee in running leaps. They are known to construct elaborate underground galleries, and the burrows of the great gerbil sometimes weaken embankments. In the wild, gerbils inhabit often harsh environments with little vegetations. They consume plant materials and insects and occasionally, like the Indian gerbil (*Tatera indica*), eat eggs and young birds.

Mouse (genus *Mus*) is a small rodent (about 5 inches long) having 38 species found worldwide (Plate 11.4). The subgenus includes spiny mice (*Pyromys*), shrew-mice (*Coelomys*), rice field and the house mice (*Mus*) and African mice (*Nannomys*). The common house mouse (*Mus musculus*) is native to Central Asia, and now it is a global commensal rodent.

Mice have a slender body, pointed snout, round small ears and scally tail which is equal to the head-body length. Fur colour varies among the species of *Mus.* Body weight of pygmy mouse (*Mus minutoides*) of sub-Saharan Africa is only 3 g, whereas the largest flat-haired mouse (*Mus platythrix*) of peninsular India weighs up to 18 g. Mice are nocturnal rodents and a few are specialised burrowers which live in grasslands. Basically herbivorous but mice adapt very well to human habitation and feed nearly anything digestible. Mice are prolific breeders producing up to 14 litters per year (1 to 12 offspring per litter).

Old World Harvest Mouse (Genus *Micromys*)

Old World harvest mouse (*Micromys minutus*) is the smallest of rodents (weighing less than 7 g) with semi-prehensile tail and lives in the Northern Hemisphere (Plate 11.4). These nocturnal rodents are good climbers and prefer to live among tall vegetation. They construct globular nests of grass suspended between branches and stems. These mice eat seeds and other vegetation in addition to insects and the eggs of small birds.

Old World Rat (Genus Rattus)

Rats (genus *Rattus*) or true rats originally belong to continental Asia. Brown rat, *Rattus norvegicus*, and the house rat, *Rattus rattus*, however, spread far and wide. These commensal rodents eat human food resources, damaging and contaminating stored grains and killing domestic poultry. They created havoc in island ecosystem driving endemic fauna to their extinction. Numerous zoonotic diseases have been spread by these rodents. However, the brown rat has been used in laboratories worldwide for medical, genetic and biological researches.

Rats in general have a slender body with pointed head, large eyes and prominent ears. The brown rat is bigger than the house rat, and its tail is shorter relative to the body length. The brown rat also has thicker furs and 12 pairs of mammae instead of 10 compared to the black rat.

Being a commensal species, the house rat consumes nearly anything digestible with particular preference to grain and fruits. However, the brown rat is basically omnivorous but prefers a carnivorous diet and even resorts to carrion feeding. Other tropical species, such as the rice-field rat (*R. argentiventer*) and Malayan field rat (*R. tiomanicus*), primarily consume the insects, snails, slugs and other invertebrates found in the habitats. Rats are prolific breeders, start reproducing within three months and produce up to 12 litters of 2 to 22 pups (8 or 9 is usual) per year.

Shrew rats (various genera, viz. *Chrotomys, Echiothrix, Rhynchomys, Archboldomys, Microhydromys, Pseudohydromys, Celaenomys, Mayermys, Melasmothrix, Neohydromys*) are carnivorous ground-dwelling rodents. They are endemic to the tropical islands of Philippines and New Guinea.

These shrew-like rodents have small eyes and long whiskers (Plate 11.4). The Sulawesi spiny rat is the largest shrew rat (weighs 220 to 310 g). Shrew rats of New Guinea are very small (*Microhydromys richardsoni*) and weigh only 9 to 12 g. Shrew rats always poke their noses through wet leaf litter and moss to locate their food, mostly the earthworms.

Water rats (genera *Hydromys*, *Crossomys* and *Colomys*) are amphibious carnivorous rodents (Plate 11.4). They swim with their long hind legs equipped with webbed digits and hunt food underwater with the help of highly sensitive whiskers.

Wood mice (genus *Apodemus*) are small-bodied rodents, native to Europe and northwestern Africa. Body weight of these nocturnal rodents ranges between 15 and 50 g and body length between 6 and 15 cm excluding the tail (Plate 11.4). If caught by tail, these rodents shed the tail which never regrows. Wood mice live in burrows and live in forests, grasslands and cultivated fields. They feed on seeds of oak and other trees, roots, fruits, insects, snails and hibernating bats.

11.3.5.5 Family Nesomyidae: Nesomyid (Genera *Beamys, Cricetomys* and *Saccostomus*)

African pouched rats (subfamily Cricetomyinae) have characteristic cheek pouches. All terrestrial nocturnal animals have grey to brown coats with white or grey under parts (Plate 11.4). These are the largest muroids (about 3 feet long including the tail) in the world. These are gentle animals and can easily be tamed and raised in captivity. They are nocturnal, colonial and omnivorous animals found throughout sub-Saharan Africa. They become invasive in northern America. Gambian pouched rats apparently have the calibre to detect land mine and tuberculosis.

The short-tailed pouched rats (genus *Saccostomus*) are small rodents and inhabit savannahs, steppe and cultivated lands in Africa. Their legs are short and adapted for digging to make their own burrows, but they also use cavities made by other animals, holes among tree roots and rock piles to nest. These rats usually inhabit natural grasslands and cultivated land. They primarily feed on seeds during wet periods but eat insects during drought. A characteristic feature of these rodents is that they go spontaneously into torpor with sudden variation in temperature.

The long-tailed pouched rat (*Beamys hindei*), also called as lesser hamster rat, is nocturnal and a nimble climber. They have medium-sized body (weighs up to 97 g) and have a scantily haired tail about as long as the head and body. It constructs burrows in soft sandy soil. This species lives in forest and open woodlands and is also found in fallow agricultural fields and feeds mainly on fruits and seeds.

11.3.5.6 Family Platacanthomyidae: Oriental Dormouse

Asian Tree Mouse (Genera *Platacanthomys* and *Typhlomys*)

Asian tree mice (genera *Platacanthomys* and *Typhlomys*) are small rodents found only in a few tropical forests of India and continental Southeast Asia.

The Malabar spiny tree mice (*Platacanthomys lasiurus*) are endemic to Western Ghats of India. Though they resemble dormouse, both are not closely related. The ears of the rodent are pointed at the tip. They are nocturnal, frugivorous and arboreal; they build nests in tree cavities and eat fruits and nuts. The hairs on the tail are long and white at the tip of the tail resembling a bottlebrush (Plate 11.4).

11.3.5.7 Family Spalacidae: Spalacid (Genera *Rhizomys* and *Cannomys*)

Bamboo rats are burrowing, slow-moving, nocturnal rodents endemic to Asia. Bamboo rats have a robust, cylindrical body, small ears and eyes and short stout legs (Plate 11.4).

Bamboo rats construct a simple burrow with single entrance and exit holes, a nest and a latrine chamber. To dig they use their incisor teeth and claws. *Rhizomys* species construct their burrows among roots of bamboo stands and line their nest with dried grass and shreds of bamboo. They feed on bamboo roots and also roots of sugarcane and cassava.

The lesser bamboo rat is a mole-like burrowing animal digs deep tunnels in the rocky ground of mountain area, forest floors and even gardens; mount of excavated soil is found at the entrance of the burrow hole. It feeds mainly on bamboo shoots, roots and other vegetation; it is also found in tea plantations.

Blind mole rats (genera *Nannospalax* and *Spalax*) are fossorial blind rats. Their small eyes are completely covered by a layer of skin. They have cylindrical body, short limbs and protruding incisor teeth (Plate 11.4) which is used for digging purpose; they possess a minute stub of a tail which may not be visible externally. Their diet includes roots, tubers and bulbs which they search 10–25 cm belowground, but occasionally they feed on aboveground seeds and green plant parts.

Zokors (genus *Myospalax*) are Asiatic fossorial rodents resembling mole rats with cylindrical bodies with short powerful limbs. They have long self-sharpening front claw. The tiny eyes are very sensitive to light and nearly hidden in furs (Plate 11.4). Zokors are efficient burrowers, and the main burrow is dug about 2 metres below the surface and is constructed with separate chambers for nesting, food storage and waste. They feed on roots, bulbs and rhizomes and occasionally leaves and shoots.

11.3.6 Suborder Sciuromorpha

11.3.6.1 Family Gliridae: Dormouse (Various Genera, viz. *Graphiurus, Dryomys, Myomimus, Eliomys, Selevinia, Glirulus, Muscardinus and Glis*)

Dormouse (family Myoxidae) is a small-bodied nocturnal rodent found in Africa, Asia and Europe. Dormice have large eyes, rounded ears, short legs and hairy or bushy tails (Plate 11.4). They are known for their prolonged hibernation in winter. They have soft and dense reddish brown fur; dark stripe along the back and dark facial markings are seen on some species.

Dormice construct globular nests and also use abandoned nests of other animals. They feed on fruits, nuts, invertebrate like insects and spiders, bird eggs and nestlings and small rodents; they are even cannibalistic.

Desert dormice (*Selevinia betpakdalaensis*) are a rare nocturnal rodent of Central Asia. They live among the desert vegetations on which they climb efficiently. They are endangered rodents living in clay and sandy deserts in southern Kazakhstan.

11.3.6.2 Family Aplodontiidae: Mountain Beaver

Mountain beaver (*Aplodontia rufa*) is a North American rodent. Extremely short tail and smaller body size (body length less than 50 cm and body weight less than 2 kg) differentiates from the American and Eurasian beavers (genus *Castor*). Small rounded ears with white spots, small eyes and short limbs with five digits are the identifying characters (Plate 11.5) of mountain beaver. Mountain beavers are asocial animals having very acute tactile and olfactory senses but limited auditory function and vision. The rodents move very little from their burrows, and the burrow entrance is covered with wilted vegetations. Diet includes succulent vegetation and fern.

11.3.6.3 Family Sciuridae: Squirrel

Family Sciuridae has 50 genera and 268 species. Squirrels are small- to medium-sized rodents which have bushy tails. Closely related to dormouse and mountain beaver, squirrels, viz. ground squirrels, chipmunks, marmots, prairie dogs and flying squirrels, occupy a range of ecological niches worldwide.

Tree squirrels have slender bodies and muscular limbs. The bushy tail is equal or even longer than the head and body length. Large, strong, curved and very sharp claws enable the tree squirrels to traverse among the branches of trees with ease. Tree squirrels consume varied foods like nuts, berries, fruits, flowers, bark, plant sap, insects and other invertebrates, eggs of birds, baby birds, etc. Sizes of tree squirrels vary; Oriental giant squirrels (genus *Ratufa*) weigh about 1.5 to 3 kg, whereas the pygmy squirrels, the smallest being the African pygmy squirrel (*Myosciurus pumilio*) of the West African, weigh only 13 to 20 g. Fur colour varies in tropical species from white to black.

Chipmunks (genus *Tamias*) are small, striped, terrestrial red squirrels, which are active during day (Plate 11.5). Their body length ranges from 8 to 16 cm and tail length almost equal to the body length. Their eyes, ears and tail are prominent, but the claws are delicate in contrast to the tree squirrels. Chipmunks are well adapted to


Mountain beaver


Chipmunk


Flying squirrel


Ground squirrel


Suslik


Marmot


Ground hog


Prairie dog


Tree squirrel

Plate 11.5 Rodent diversity

exploit the resources of rocky terrain and forest under stories. They inhabit various forest types and make characteristic chipping calls. They are omnivorous animals that eat grass shoots, seeds, fruits, nuts, berries, flowers and fleshy plant parts, fungi, arthropods and sometimes carrion feeding. They store nuts and seeds for future use in their nest.

Flying squirrels (multiple genera) are the gliding squirrels (Plate 11.5). They glide by extending their limbs supported by flaps of skin up to 450 m (Giant flying squirrels *Petaurista sp.*). These are nocturnal squirrels that live in tree cavities or globular nests they make with leaves, shredded bark or mosses on high trees. They feed on plant materials like seeds, fruits, leaves, flower buds, nuts, pollen, ferns, plant sap, lichen, fungi, arthropods, small birds, eggs, snakes and even smaller mammals.

Ground squirrels are ground-dwelling diurnal rodents. They are gregarious squirrels and live in colonies in open areas and grasslands. They have short limbs with strong claws and moderately long tail. Coat colour varies widely among the species (Plate 11.5) which may be solid or pattern of colours. Most ground squirrels are omnivorous and feed on fruits, nuts, fungi and seeds; they eat insects, other arthropods, eggs, birds and even other rodents.

Tropical Ground Squirrels

Tropical ground squirrels are small social rodents and active year-round. These squirrels do not store food. Tropical ground squirrels are paler and have unringed tail. There are five genera (*Dremomys*, *Lariscus*, *Menetes*, *Rhinosciurus* and *Hyosciurus*) under this group, and they live in the forests of Southeast Asia. These squirrels eat more arthropods than that of nontropical ground squirrels. During the period with scarce food availability, these squirrels undergo aestivation for a brief period.

Marmots (genus *Marmota*) are relatively large ground squirrels weighing 3 to 7 kg, depending on the species. They are found in North America, Europe and Asia. Marmots are brown and have short but robust legs and strong claws for digging. Their coat colour may be brown or black or a mixture of grey and white (Plate 11.5). They eat grasses, berries, flower, roots of plants, lichens and mosses.

Prairie dogs (genus *Cynomys*) are herbaceous burrowing rodents of North America that closely resemble marmots (Plate 11.5). Prairie dogs are stout bodied with a short tail and weigh approximately 1.5 kg. Prairie dogs dig elaborate burrow systems with volcano-shaped entrances and live in colonies called as ‘towns’. The ‘towns’ may cover hundreds of hectares, the largest ever recorded being in Texas that stretches across 65,000 square km and contained whopping 400 million individuals. They forage on succulent vegetation, seeds and roots depending on the season.

11.4 Behaviour of Rodents

Depending on the family and species, rodents occupy a variety of habitats and exhibit a wide range of behaviour, habits and lifestyle (Buckle and Smith 2015). The rodents may be burrow formers (gophers, rats and moles), or they may be living entirely on trees (flying squirrels) or leading aquatic life and spend most of their time in water (capybara) or living in some of the challenging terrain like deserts (kangaroo rats and jerboas). Generally, many rodents lead a social life, living in large groups with a complex social setup and interacting with each other frequently; prairie dogs, naked mole rats and ground squirrels live in large colonies. There are many other rodent species that live in smaller groups, like the beaver, containing the adult male, female and their offsprings. Specific territories exist for each colonies, and breaching the territory leads to violent fighting. Within the territory, there are numerous animals, and the colonies are broken into smaller units. For example, the prairie dog towns are divided into certain neighbourhoods. Within these smaller units, they look after the young ones; cooperate building other nests, playing together, mutual grooming and communication among the animals take place. In contrast to the social living, some rodents are solitary (many desert species, porcupines, pocket gophers and pocket mice), live lonely and feed alone; only during breeding time, these animals are seen with the opposite sexes for a brief time. Some of these solitary species construct and live alone in their own burrow system except during certain periods; more than one individual in the burrow during the mating season or the female animals with her dependent offsprings may live together for a brief period.

Except a few cases, most of the rodents are active throughout the year. At very low temperature in the temperate regions, some rodent species (ground squirrels) may suspend the activities and hibernate for several months or aestivate for a brief period when there is a scarcity in food availability, as in tropical ground squirrels. Elaborate communication system exists among rodent species; they communicate with numerous sounds, characteristic odours and sights. The innate capacity to reproduce is one of the primary reasons for the success of rodents, and they produce large numbers of offspring in one go. The strategy is having a short gestation period (17 to 45 days), having multiple litters per year and thus producing large numbers (can be up to or more than 20) of highly dependent babies (e.g. mice, rats and pocket gophers). Another strategy is rodent having longer gestation periods (60 to 238 days), fewer litters per year (generally one to two) and having a relatively fewer number of offspring with reasonably good parental care. Depending on the species, the mating system varies in rodents; there are monogamous rodents where the male and female pair is together for multiple mating seasons seen as in Patagonian mara. Harem-based mating system exists in other species where one male mates with a set group of females for the mating season. However, many rodents are promiscuous, meaning they mate randomly. As rodents are prolific breeders, availability of food determines the copulation built up in crop fields and storehouses.

Table 11.1 Rodent species of economic importance

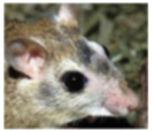
S. No	Family	Common name	Name of species
1	**Sciuridae**	Five stripped/Northern palm squirrel	*Funambulus pennantii* Wroughton
2		Three striped/Southern Indian palm squirrel	*Funambulus palmarum Linn.*
3	**Hystricidae**	Indian crested porcupine	*Hystrix indica* Kerr
	Muridae	**S.F. Gerbillinae**	
4		Indian desert gerbil	*Meriones hurrianae* Jerdon
5		Indian gerbil	*Tatera indica* Hardwicki
6		Hairy footed gerbil	*Gerbillus gleadowi* Murray
		S.F. Murinae	
7		House/black/ship rat	*Rattus rattus (Linn.)*
8		Soft furred field rat	*Millardia meltada (Grey)*
9		Norway rat	*Rattus norvegicus Berkenhout*
		S.F. Murinae	
10		House mouse	*Mus musculus* Linn.
11		Brown spiny mouse	*Mus platythrix* Bennett
12		Indian field mouse	*Mus booduga* Grey
13		Short-tailed mole rat	*Nesokia indica* (Grey and Hardwicke)
14		Lesser bandicoot/mole rat	*Bandicota bengalensis* (Grey)
15		Larger bandicoot/mole rat	*Bandicota indica* (Grey)

Rodents may be neutral or beneficial or harmful. As pest, rodents cause substantial damage and economic losses to human interests. Rodent pests may be in the field (field rats) or in the human habitation (commensal rats) (Tables 11.1, 11.2 and 11.3). Since they are prolific breeders, lots of efforts have been put forth to manage the rodent pests. Hereafter, mostly pest rodents are dealt with, unless or otherwise mentioned for management point of view.

11.4.1 Neophobia and Bait Shyness

Neophobia (neo = new, phobia = fear) is the fear of new things in rodents, has been a major issue encountered for at least four centuries in poison baiting of problematic rodents. The neophobic response can be one of the most important obstacles in the successful rodent management. Barnett (1958) defined neophobia as, 'the avoidance of an unfamiliar object in a familiar place'. The success of the rodent management programme depends on this behaviour of the rodents as neophobic rodents tend to avoid new foods and even foods previously eaten if they are placed on or in new objects or containers. The neophobic response varies between species, populations of the same species and even between individual animals. Female brown rats are considered to be highly neophobic which makes them difficult to trap or to attract

Table 11.2 Comparison of characters of selected field rats

Field rodents					
Species name	Body	Muzzle	Ear pinna	Tail	Faecal pellet
1. Lesser bandicoot rat and Indian bandicoot	 Heavy and thick body	 Blunt	 Small ear pinna, half buried in body	 Short tail; shorter than head-body (HB)	Bulky oval
Field mouse, *Mus booduga*	 Small, slender	 Small, pointed	 Small oval	 Shorter than HB, thin and naked	Qty: 50 to 75 pellets daily; size: ¼ inch long; shape: small with one or both ends pointed
Indian gerbil, *Tatera indica*	 Medium-sized body with big eye	 Pointed	 Large, prominent and stands out from the body	 Tuft of hairs at the tip	Oval at both ends

(continued)

Table 11.2 (continued)

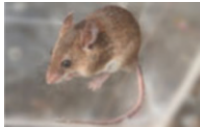
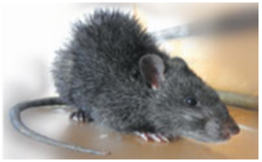
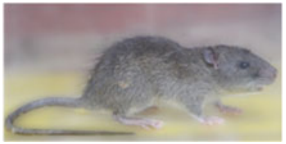
Field rodents					
Species name	Body	Muzzle	Ear pinna	Tail	Faecal pellet
Brown spiny mouse, *Mus platythrix*	Small and slender body	Small, flat and blunt	Large, fan shaped and stands out from the body	Naked, shorter than HB	Small elliptical

Table 11.3 Comparison of characters of commensal rats

Commensal rodents					
Species name	Body	Muzzle	Ear pinna	Tail	Faecal pellet
1. House rat	 Slender and medium-sized body	 Pointed	 Large, prominent and stands out from the body	 Longer than HB	 Black rats produce narrow cylindrical pellets with one or both ends that are pointed. Pellet colour varies with diet but is commonly a dark brown or black colour  Qty: 40 to 50 pellets daily. Size: ½” long. Shape: larger, curved, sausage-shaped with pointed ends. Found scattered

(continued)

Table 11.3 (continued)

Commensal rodents					
Species name	Body	Muzzle	Ear pinna	Tail	Faecal pellet
2. House mouse, *Mus musculus*	 Small, slender body	 Small, pointed	 Prominent, large for the size of the animal	 Longer than HB	 Spindle shaped and about ¼” size
Indian greater bandicoot rat, *Bandicota indica*	 Heavy and thick body	 Slightly pointed	 Thick, smaller for the size of the animal	 Shorter than HB	Oval and bulky
Brown rat	 Heavy and thick body	 Blunt nozzle	 Small, half buried in the fur	Shorter than HB	 Blunt and rectangular Qty: 40 to 50 pellets daily Size: ¾ inch long. Shape: larger, rectangular with blunt ends. Found in small groups

into bait stations. Generally, brown rats are exceptionally wary of unfamiliar food. Wild brown rats may even avoid a pile of wheat in an unexpected place and continue to treat it with great caution for more than a month. Moreover, when an individual rat has overcome its suspicion sufficiently to try the new food, it will only eat a small amount, perhaps 10% of its normal requirement. If it feels ill within the next 16 h or so, it will associate the illness with the ingestion of the novel food and refuse to eat it again. This phenomenon is known as aversive conditioning or 'bait shyness', normally encountered when using acute poisons (zinc phosphide). This is one of the major reasons for the success of anticoagulants as there is a delay of several days between ingestion of the bait and the onset of symptoms, thus preventing the bait toxicosis association and the development of bait shyness.

11.4.2 Feeding Behaviour

Rodent feeding behaviour varies with the species. Some rodent species eat the food from one point, whereas the others may have many feeding locations. For instance, mice may be taking food from different locations in a single foraging trip and the feed quite randomly. They exploit heavily a few feeding stations, but the sites vary from time to time. Due to the erratic feeding behaviour, the mice are considered to be one of the difficult rodents to trap or kill.

Norway rats sample the food before feeding is stabilised, and it cannot be a good indicator of food preference. Feeding stabilisation usually takes 1 or 2 days for these rodents. This sampling behaviour is seen both in young and adult brown rats; more sampling by young rats causes more spillage, but this habit leads them to food sources. The juveniles that are still suckling used to lick the paws and mouth of the mother to get the taste of the food the mother has taken. The feeding behaviour also varies among the rodents. For instance, the Norway rats hold their food in their front paws and eat them in a sitting position (Meehan 1984), whereas the mice dehusk the grain and eat.

Studies have shown the Norway rats use the trails made by other rats to find their food. Juveniles get the food cues from the mother during the nursing period which determines the dietary preference of the young rats at weaning. The juveniles observe keenly and imitate the adults while feeding and familiarise the food sources.

Mice and Norway rats prefer to feed under cover. Uncovered bait is being dragged to cover by Norway rats. This behaviour determines the success of bait stations, especially with the brown rat. Some rodent species store (hoard) food materials in their nest, and it influences the poison baiting programme. Brown rats start to hoard food after initial bouts of feeding. The hoarding depends on the type of food, number of feeding stations, distance between the source and the burrow, size of the group and sex; lactating females hoard more food than the males. Black or house rats hoard food as they do not like to feed far from their shelter.

Table 11.4 Home range of pest rodents

Sl. No.	Rodents	Home range m^2
1	*Funambulus pennantii*	65–61
2	*Rattus meltada*	88
3	*Rattus norvegicus*	459
4	*Bandicota bengalensis*	945
5	*Mus booduga*	1275
6.	Gerbils	1875

11.4.3 Home Range, Movements and Territoriality

Home Range and Movements

Home range is the space in which the rodent lives and moves on a periodic basis (Table 11.4). It is related to the territory of the rodent where it defends the area actively. Food, shelter, social effects, predation and infection determine the home ranges of rodents. Radio telemetry is used to understand the home ranges of rodents. Home range in rodent is important as it provides information on habitat utilisation and movements of rodents in a riparian habitat, which is important in the management of the species concerned. In case of mice, they tend not to move great distances. Ranges are sometimes exclusive, but often it overlaps both between and within the sexes as they also share the nest. The size of the home range of male range increases during the breeding season. Dispersal of young ones, search for food, seasonal cropping patterns and agricultural cycles determine the home range of a particular species of rodents. Home range decides the rodent movements or migration from a particular locality and their population buildup to a serious level warranting immediate control measures.

Territoriality

A territory is an area in space that is defended by an animal (by both male and female in the wild) and which contains resources (e.g. food, nest site or mates) for their survival. Territories are defended ritualistically, which minimises the need for life-threatening escalated aggression. Mice have a flexible form of territoriality. Dominant male rats aggressively defend their territory and guard a harem of females from mating by other males. Brown and roof rats used to travel 50 to 300 feet from their nests to look for resources and patrol their territory. If necessary, they can travel much farther from their territories. Normally, the patrolling is done by the dominant males during dawn and dusk time. However, the rats which are socially low-ranked individuals, who have been denied access to food by dominant rats during the night, are seen during daytime.

11.4.4 Rodent Responses to Bait Stations

Bait station is an important component in the management of pest rodents as it encourages the targeted species to sit comfortably inside and feed. It encourages the rodent to eat sufficient quantity of bait without transporting it to their burrows. Any material (wood, plastic or bamboo) and shape (cylinder is more preferred by the rats) can be used to prepare bait stations. The size of the bait station also matters; mice prefer small bait stations than large boxes or open trays for comfortable feeding. Among the various bait stations under no-choice and multi-choice conditions, house rat, *Rattus rattus*, preferred the black metallic bait stations followed by mud bait stations and showed no neophobia against these bait stations. Less bait consumption is observed when the food is offered openly (Sakthivel et al. 2013). Spacing between bait stations is also crucial for successful baiting; a spacing of 100 m is considered suitable for house rats.

11.4.5 Behavioural Resistance

Rodents tend avoid troubles, and some of behavioural characteristics of rodents make it difficult to control a rodent population especially those that had previous experience with poisoning. It is the learned behavioural characteristics which reduce a rat's tendency to eat palatable bait. It also includes the development of bait shyness and poison avoidance and enhanced neophobia. The neophobic response is more pronounced in rats that have survived. Enhanced behavioural resistance can be observed if alternative foods are available so that the rodents are not pressured to eat the poison baits. Poison avoidance behaviour, apparently heritable (physiological resistance), can also reduce rodenticide efficiency.

11.4.6 Rodenticide Resistance

Rodenticide resistance is the ability of rodents within a population to continue feeding on the rodenticide bait over a period of time, without being killed. Rats can be physiologically resistant to rodenticides, and this inheritable trait has been selected for over generations of exposure to the anticoagulant rodenticides, in commensal rodent species (Garg et al. 2017).

11.4.7 Response to Odour

Olfaction in rodent communities plays a definite role in their feeding, social behaviour and reproduction. It decides the response of rodents to traps, baits and bait stations. The odour of preferred foods and urine of opposite sex, especially the male, may increase the investigatory behaviour of rodents. Rodents depend on urine marks as a cue to detect novel objects in their territories. The traces of odour left in traps affect the behaviour of other rodents. Rodent odour varies with sex, age and reproductive stage dominant male or female or subordinate individual. Trap catches can be increased with smearing rodent scent in traps as more mice are trapped in these compared to clean traps. Some other compounds (dimethyl sulphide and dimethyl disulphide) can also be used to improve the bait acceptance and trapping of rats (Veer et al. 2002).

11.4.8 Response to Repellents

Rodents are repelled by the addition of capsaicin, citronella oil, cinnanamide, tannic acid, eucalyptus oil, etc., to baits (Spurr et al. 2001; Singla and Kaur 2014a, b; Singla and Kaur 2017; Sachdeva and Singla 2018). Denatonium is used as a deterrent for rodent gnawing. Apart from chemical substances, high-intensity ultrasonic sound is also used to repel the rodents. For want of scientific evidences on the effectiveness and the practicalities of large-scale application of these devices, limit their use in the field.

11.4.9 Grooming

Rodents keep their body neat and clean when they are at rest by grooming. They lick their body parts to remove dirt. This character of rodents can be well exploited in rodent control operations. Poisonous dust like alpha-naphthyl thiourea and anticoagulant rodenticides can be laid on rodent runways or in burrow entrance collects on the animals and is ingested during grooming.

11.4.10 Responses to Traps

Trapping efficiency varies with the species involved and the type of traps used. All rodent species are not equally trappable. Among the pestiferous rats, brown rats are comparatively difficult to trap. Intrinsic factors and previous experiences of the individual rodent also count in the trapping efficiency. Sex (male or female) and age (adult, subadult or juvenile) also determines the levels of trappability. Extrinsic factors, viz. vegetation cover, temperature and precipitation, play an important role in the relative trappability of pest rodents.

11.5 Indicators of Rodent Infestation

Rodents colonise virtually any environment that supports life. Being largely nocturnal, it is very difficult to spot the actual organism, but they leave the signs of infestation. There exist a number of tell-tale signs that rodents leave in a particular habitat (ManiChellappan and Ranjith 2019).

11.5.1 Direct Indicators

Actual spotting of live or dead rodent pest is a direct indication of rodent infestation. Unless, or otherwise, there is a population explosion, live rodent pest cannot be seen during daytime.

11.5.2 Indirect Indicators

(a) Rodent track
(b) Gnaw marks
(c) Nests
(d) Holes and marks on food packages
(e) Droppings
(f) Smudges
(g) Noise

Rodent Track
Rats, especially, establish foraging paths and rarely stray from them. As a result, tracks are often the clearly visible signs to look for.

Gnaw Marks
One of the ways to identify the rodent infestation in an area is the signs of chewing or gnaw marks close to foraging paths. As black rats are agile climbers, gnaw marks can be seen in lofts, wires, cables or other items. Shredded paper or fabric pieces on high raised places or among the clutter indicate the presence of a mouse.

Rat Droppings and Urine Stains
Droppings and urine stains are other indications of rat activity. Rodent droppings and urine are often deposited along favoured travel pathways. Rodents usually deposit their excreta in particular locations where they are frequenting. They deposit as many as 40 faecal pellets per night. The shape and size of the droppings give a clue on the species involved; black rat droppings are black tapering on both sides like a spindle or a grain of rice.

Rub or Grease Marks
Rats travel on established runways which are against any vertical surface like a wall or any solid material. They often rub their fur and smear with their body secretions against these objects. Over a period of time, these smudge marks become an indicator of rodent activity

Rat Footprints or Tracks or Runway
Rats produce a four-toed front and five-toed back footprints. They are most easily seen in muddy or dusty locations.

Rat Nests
Rats build nest and construct burrows in their habitat, viz. agricultural field bunds, in cavity walls, lofts, attics, etc. Invariably the nest consists of shredded material like grass, bark, insulation, foam, fabric and many others. Shredded paper in the house indicates the presence of rats indoor.

Rat Holes
Bandicoot and brown rats are extensive burrowers that dig out soil, concrete and wooden structures for food and nesting. The size of the burrow hole, nature of the burrow entrance and type of nesting material used are species specific.

Rodent Noise
Rodents produce a variety of sounds, which are useful to communicate with other individuals of the same species; some are audible to human ears, and some are in the ultrasonic range. Rodents make squeaks, grunts (brown rats produce grinding noise with their teeth), alarm and distress calls, and these noises have numerous behavioural responses in the receiving individuals.

11.5.3 How to Spot a Rat Infestation Indoors?

Rodents invade any space which they feel comfortable and supply the basic requirements. Since rodents are active throughout the year, periodically checking for signs of their presence is mandatory. Once rats have invaded, it is only a matter of time before the population explodes. Thorough and regular inspection for rodent infestation is obligatory to reduce the population buildup in a particular area. The following are further signs of the presence of rat inside the building:

- Rat or mouse droppings in the waste bins
- Smudge or grease marks against beams, rafters, pipes and walls
- Rat droppings around pet food storage containers
- Squeaky noises just after dusk
- Burrows beneath the compost pile or garbage can
- Rats traveling along fences at dusk
- Damaged indoor or backyard plants
- Rat carcass
- Drowned rat from swimming pool or bath tub
- Rat nests behind boxes or in drawers in the garage
- Remnants of rat nests
- Feeding marks on fruits/nuts kept exposed

11.6 Rodent Population Density Assessment

In the pursuit of rodent management, it is very important to know the population and damage caused by a particular species in question. Conducting population and damage assessments may be considered: (i) to establish the economic status of pest rodents, (ii) to determine the geographical distribution of pests, (iii) to determine the effectiveness of control measures followed and (iv) to provide information for planning.

Methods of Population Estimations
Population estimation can be done in many ways; rodent census and trapping are the most widely used and time tested ones.

11.6.1 Census by Trapping

It is also called the Lincoln index method or capture, mark and release method (CMR) where the target rodents are captured by using live traps. It is a direct method of estimating the rodent population in the field. Live traps are set in a grid manner 15 m apart in 1 ha (54 traps/ha) to capture rodents; the trapped rodents are marked and then released back in the field. Recapturing will be done after a week to estimate population using the formula:

$$\mathrm{N} = \frac{\mathrm{Mn}}{\mathrm{m}}$$

where

N = Rodent population in the study area
M = No. of rodents in first trapping
n = No. of rodents in second trapping
m = No. of marked rodents trapped

More marked individuals in recapture indicate less population in the study area and vice versa.

11.6.2 Trapline or Index Method

Index of rodent abundance can be determined by this method. Population sampling can be done by trapping on a line or lines across the study area. Snap trap or back break trap can be used for the study. Five traps should be laid in a group, and each one represents one point, which is 10–15 m apart on the line. The trapline (parallel or diagonal) should represent the entire study area. Based on the catches, trap per cent index (I) is calculated to compare the population in different areas or seasons:

$$I = \frac{M}{Xt} \times 100$$

where

X = No. of traps used in trapline
t = No. of trap set nights
M = Cumulative number of rodents trapped

11.6.3 Trapping Method

Live traps (wire box) are used to estimate the population density of rodents. The traps are loaded with very attractive bait and lay at dusk and collected back in the next morning. The trapped rodents are classified and recorded. The efficiency of trapping (trapping index) and the relative abundance of each species are calculated as population density in the study area:

$$\text{Population density} = \frac{\text{No.of rodent species}}{\text{Total rodents captured}} \times 100$$

$$\text{Trap index (TI)} = \frac{\text{No.of rodent species}}{\text{Total rodents captured}}$$

11.6.4 Active Burrow/Live Burrow Count (LBC) Method

It is an indirect method to estimate the population of rodents in the study area. The presence of rodent dropping, footprints of rodents and food material at the entrance indicate the presence of live animal in the burrow. It involves closing of all the open burrows and opening of closed burrows on the first day. The 'live burrow count' on the second day gives the approximate rodent numbers. This can be done for four consecutive days every month. The per cent live burrow count (LBC) can be worked out as follows:

$$\text{Live Burrow Count}\,(\%) = \frac{\text{No.of active burrows}}{\text{Total number of burrows counted all over}} \times 100$$

11.6.5 Food Consumption Method

Population fluctuation of rodents can be estimated by the quantity of food consumed and calculated as follows:

$$\text{Total number of rodents} = \frac{\text{Daily food conumption from a bait station}}{\frac{1}{10}\ \text{weight of the dominant rodent in the study area}}$$

(Assuming rodent's food consumption is 1/10 of its body weight)

$$\text{Population density} = \frac{\text{Total food consumed in a month (g)}}{\text{Total food consumed over the year (g)}} \times 100$$

11.6.6 Footprint Method

Footprints on soft soil or dust can be used to calculate the rodent population in the study area. Count the number of footprints on a square unit and calculate the population as follows:

$$\text{Population density} = \frac{\text{Total no. of foot prints on randomly selected squares}}{\text{Total number of foot prints on the entire study square}} \times 100$$

11.6.7 Tracking Boards

A square or rectangular board or tile of approximately 25 × 25 or 25 × 12.5 cm on which 2–5 mm layer of dust is covered and smoothed which can be used as tracking boards to monitor rodent activities. Boards are laid out for rodent footprints near the rodent tracks or the area where the rodents are frequenting. Rodent activities are assessed based on the intensity of footprints on the tracking board (Rao et al. 2014).

11.6.8 Rodent Faeces Method

Rodent dropping is one of the vital signs of the rodent infestation and activity. Based on the physical condition of the faecal pellet, it is easy to ascertain whether the burrow is active or inactive; soft and shiny faecal pellet indicates the presence of the animal. Various sizes of rodent dropping of the same shape indicate the presence of different age groups of the rodent in that area. To estimate the rodent population, collection and counting of rodent dropping in a specified area ($3m^2$) is done at monthly interval. Using the following formula, the population of a particular rodent species can be calculated:

$$\text{Rodent population} = \frac{\text{Total no. of fecal pellets}}{\text{Total no.of fecal pellet of dominant rodent per day}} \times 100$$

$$\text{Population density} = \frac{\text{Total no. of fecal pellet in unit area in a month}}{\text{Total no.of fecal pelletn in a year}} \times 100$$

11.6.9 Census Baiting Method

Food consumption by rodents is used an index of their numbers in a particular habitat. Known quantity of food is offered in the infested area for about 24 h. After the exposure time, the remaining food is weighed. Again the bait stations are replenished with food and left for the next 24 h. The average daily food intake for 72 h is used to estimate the number of the rodents present in that area.

11.6.10 Other Alternate Census Techniques

(i) Rodent carcass rodenticide-treated area
(ii) Reduction in the rate of damage to the crop compared to the control plots

11.7 Rodent Damage Estimations

Rodents are persistent vertebrate pests that cause damage to agricultural crops, stored commodities and structures both by feeding and spoilage. Rodents cause immense damage to forest and plantation crops (Singleton et al. 2010; Buckle 2015). Analysis shows rodent damage is about 5–15% in rice and wheat crops alone.

The nature of rodent damage includes:

1. Direct feeding
2. Gnawing on bark of woody crops
3. Consuming seed on seed bed
4. Storing food resources in the burrow
5. Tiller cutting in cereal crops
6. Food spoilage by rodent waste
7. Soil digging and excavation
8. Damage to poultry
9. Spreading zoonotic diseases of public health and veterinary importance

11.7.1 Assessment of Rodent Damage in Rice

Rodents cause damage to rice crop at every stage of its growth:

1. Seed
2. Seedling
3. Tillering

4. Panicle and matured grain
5. Harvest
6. Postharvest and storage

Rice agroecosystems are particularly conducive to rodent infestation, and rodents are categorised as the key preharvest pest of rice in most of rice-growing areas. Grassland rats are well adapted to rice, and damage can occur right from sowing to harvest and beyond (Plate 11.6). Rat depredation in crops especially in rice could be a serious threat to food security of sizeable population of the world (Meerburg et al. 2009; Parshad 1999; Prakash 2018; Parshad et al. 2007; Rao 2003a, b). Assessment of rodent damage(s) in rice is as follows:

Preharvest Damage Assessment

Random fields are selected (five fields; six plots of 1 m^2 – four fixed plots and two variable plots), and using multistage random sampling technique, observations are taken at every stage of growth. Observations are recorded at fortnightly interval.

Rat damage in vegetative stage of rice crop – circular patches

Rat damage in vegetative stage of the crop – circular patches

Characteristic rat damage on rice tiller

Rat droppings contaminated stored rice

Plate 11.6 Rat damage in rice

Observation date/stage of crop	Affected plots (a)						Undamaged tillers (b)						Damaged tillers (c)					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

(i) **Philippine Method**
- Select a field at random.
- Select a plot at random (5–6 plots in a field).
- Select 10 rows of plants for observation.
- In each row, select randomly 10 hills at equal distance.
- In each hill, count rat cut tillers and other healthy tillers.
- Tabulate for 100 (10 rows x 10 hills) observations.
- Calculate damage incidence, $P = \frac{A \times C}{B + C}$.

  where

  A = Number of damaged hills
  B = Number of undamaged tillers in A
  C = Number of damaged tillers

(ii) **Diagonal Method**

Select a field at random.
- Select a plot at random.
- Select a diagonal.
- Start with first hill.
- Count cut and uncut tillers.
- Select next position on the diagonal.
- Repeat steps 5 and 6 until 25 samples at equidistance are taken.
- Calculate damage incidence (P):

$$P = \frac{A \times 100}{(A + B)}$$

where

A = No. of damaged tillers
B = No. of healthy tillers

Per cent vegetative loss can be calculated as

$$\%\text{loss} = \frac{a \times c}{b + c}$$

where

a = Number of affected plots
b = Number of healthy tillers
c = Number of damaged tillers

Damage at the time of tillering also contributes to the actual loss at the time of harvest as those tillers regenerate and produce poor-quality grains. Yield from such tillers is deducted from the total yield, and the yield loss can be worked out as follows (Raj 2018).

Total no. of plants N	No. of damaged plants $N1$	No. of healthy plants $N\text{–}N1$	Yield of grains from health plants (g) Y	Average yield in g $\frac{Y}{N-N1} \times N$	Loss in yield (g) $\frac{(y)}{(N-N1 \times N)-Y}$

Hoarding Loss Assessment

Rice field rodents store a large quantity of grains in their nest and cause severe preharvest losses. The loss assessment can be done as follows.

Observation date/stage of crop	No. of rat burrow	No. of burrow/ha	Food chamber			Nature of food store
			Without food (No.)	With food (No.)	Quantity	

$$\text{Food hoarding/ha} = \frac{\text{Average Amount}}{\text{Food stored}} \text{Average of number of burrow systems per ha}$$

(i) **Mean number of burrow systems per ha**

- (i) Select field at random.
- (ii) Count the number of burrow/ha.
- (iii) Count the number of burrow openings/systems.
- (iv) Dig out the burrow system and note the number of food chambers with or without hoarded food.
- (v) Measure the amount hoarded at least from 5–6 fields.
- (vi) Record data and calculate the average and hoarding losses/ha as follows:

Date/stage of crop	No. of burrow openings	No. of burrow systems/ha	No. of food chambers	Food eaten/intact	
			Without food	With food	Amount of food stored (g)

11.7.2 Assessment of Rodent Damage in Sugarcane

Sugarcane ecosystem, which is stable and undisturbed for nearly 3 years, provides ideal place for food and shelter for small rodents. Rats cause direct loss of cane by eating into the internodes of standing and lodged cane. This permits entry of insects and pathogens and also causes physiological stress. Damage may also come from the eating of growing tissues and of underground parts by fossorial rodent species. Loss relates to the proportion of damaged canes, and it is around 10–20% of its sugar content. The proportion of damaged canes is often high, up to 90% or more, with a significant proportion dying.

In the Indian subcontinent, sugarcane is an important crop subject to heavy rodent damage. The most common rodent pest is *B. bengalensis*, which has caused damage as high as 63% of canes in Andhra Pradesh (Rao 2003a, b). Other species damaging sugarcane in India are squirrels and porcupines (Srivastava 1992; Wood and Singleton 2015).

Damage caused by rodents to sugarcane is assessed similar to rice crop.

Date and crop stage	No. of affected plots (a)						No. of undamaged tillers (b)						No. of damaged tillers (c)					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6

$$\text{Loss} = \frac{(\text{a} \times \text{c})}{(\text{b} + \text{c})}$$

where

a = Number of damaged plots
b = Number of unaffected tillers
c = Number of affected tillers

11.7.3 Rodent Damage Assessment in Coconut

Coconut palms of all ages are being attacked by rodents, and the developing nuts damaged fall, prematurely (Plate 11.7). Since natural 'thinning out' takes place in coconut palms, assessment of actual losses is not straightforward. In India, Bhat (1992) showed losses varying between geographical locations (8.7% in Andhra Pradesh to 50% in the Lakshadweep Islands). The main species include various sub-species of *Rattus*, in particular *R. r. wroughtoni, R. r. rufescens* and Malabar giant squirrel (*Ratufa indica*) in mainland India (Rao et al. 1984; ManiChellappan and Vidya 2018) and *R. r. andamanensis* and *R. r. holechu* in the Andamans.

Nursery and young field palms may also be attacked by the ground-dwelling rodents, *B. bengalensis*, *B. indica* and *Tatera indica*. The porcupine, *Hystrix indica,* also attacks at this stage (Wood and Singleton 2015).

In a plantation, 10 palms out of 100 palms may be randomly sampled for nut damage once in a month. Care may be taken to count the freshly damaged ones. The damage can be worked out as follows:

Plate 11.7 Rodent damage in coconut

Rat damaged coconuts

Malabar giant squirrel damaged coconuts

Date	Number and stage of nut damaged	Remarks
	Tender/medium/mature	Rodent species

Select a block of plantation with 100–150 palms; identify and count the number of infested palms on the basis of freshly fallen damaged nuts near the palm base. Calculate per cent rodent-infested palms (RI) using the formula:

$$\text{RI }(\%) = \frac{\text{Number of palms with fallen nuts}}{(\text{Total number of palms})} \times 100$$

For assessing per cent nut damage, select 10 palms with fallen nuts in the same orchard and record the number of healthy and damaged nuts on the selected trees covering all branches:

$$\text{Nut damage }(\%) = \frac{\text{Number of damaged nuts}}{\text{Total number of nuts}} \times \text{RI}$$

11.7.4 Rodent Damage Assessment in Oil Palm

Rats gnaw the unripe bunches, even through to the kernels, leaving characteristic scarring and the ripe fruitlets detached from the bunch. Rats also feed on those detached fruitlets and often carry them away. A loss of about 5% to 10% yield is reported from oil palm plantations (Wood and Singleton 2015).

Young palms may be gnawed at the base by rats before they begin to fruit. The pests occasionally penetrate the bud and kill the palm, altogether. Hystricomorphs are conspicuous pests in the young plantations. In the Far East, the Malayan porcupine, *Hystrix brachyurus*, can destroy large numbers of palms, though this is usually confined to the locality near its habitat in secondary jungle or scrub.

Fresh fruit damage in oil palm is worked out by counting undamaged and damaged fruits in each palm by the formula:

$$\text{Fresh fruit damage }(\%) = 100\left(\frac{\text{a}}{\text{b}}\right)$$

where

a = No. of palms with fresh fruit damage and
b = No. of palms assessed

11.7.5 Rodent Damage Assessment in Cocoa

Rodents bore into the cocoa pods, and large-bodied species can take whole beans, while small ones may feed only on the mucilage that surrounds the beans. The proportion of holed pods can be very high, and they become increasingly susceptible to damage as they ripen (Plate 11.8). The damage is compounded by ensuing fungal infection, and affected pods are all lost. Cocoa grown under coconuts is susceptible to attack by both rats and squirrels. Persistent widespread damage to cocoa is likely near to borders with crops that support rat, viz. oil palms or rice, where losses may reach even 100%. Heavy losses can occur in India by Western Ghats squirrel,

Plate 11.8 Rodent damage in cocoa

. Rodent damaged cocoa pods

Funambulus tristriatus, the south Indian palm squirrel (*F. palmarum*) and black rat, *Rattus wroughtoni* (Bhat 1992; Baco et al. 2010).

Since rodent damage is restricted to ripe pods, it may be categorised as healthy or undamaged, scratched and freshly bitten pods. Per cent pod damage is calculated as:

$$\text{Cocoa pod damage } (\%) = 100\left(\frac{b+c}{a+b+c}\right)$$

where

a = Number of unaffected pods
b = Number of pods with scratches
c = Number of freshly bitten pods

11.7.6 Rodent Damage Assessment in Groundnut, Soybean, Pineapple and Cardamom

Squirrel *Funambulus pennant* is reported to remove 25% of planted groundnut seeds in India, and the summer crop may be left unplanted. A strong relationship of rat activity to the suitability of the surrounding vegetation is noted. All stages of soybean in India are subject to damage, mainly by *Millardia meltada* and also by *R. rattus* and *B. bengalensis*.

Up to 16% of ripening pineapples are damaged by *Bandicota bengalensis* and *R. rattus* in Bangladesh in a range of study plots. In commercial plantings in India, cardamom seed capsules are damaged by a range of fossorial rodents, gerbils and squirrels (Srihari and Chakravarthy 1992), in particular *B. bengalensis*. Seed capsules may be emptied, over 12% in the worst cases. The plants too can be damaged, especially in the young stages.

11.7.7 Rodent Damage Assessment in Store

The problems caused by rodents in stores are wide ranging. Broadly, losses may be attributed to the following:

(a) Direct consumption of food
(b) Food contamination and damage
(c) Structural damage
(d) Disease transmission
(e) Source of reinfestation of adjoining areas
(f) Cost associated with control operations

Many estimates lie in the range 1–10% and invariably include total losses due to consumption as well as spillage, damage and contamination, resulting from rodent activity (Smith and Meyer 2015). Some estimates are that up to ten times as much food is lost as a result of spillage and contamination as is lost to direct rodent consumption.

11.8 Rodent-Borne Diseases

Rodents are carriers of many zoonotic diseases to human and animals. These diseases can be categorised into two (Fig. 11.4): (i) transmission of pathogen through rat bite and excreta and (ii) transmission through intermediate arthropod vector (rat flea, ticks or mites) (Meerburg et al. 2009) (Tables 11.5. and 11.6). Over the last millennium, it has been estimated that rat-borne diseases may have taken more lives than all of the wars ever fought (Battersby 2015).

Rat-bite fever is caused by the casual and active rat bites and scratches, while the bacteria in rat urine causes leptospirosis (Fig. 11.5). Lymphocytic choriomeningitis

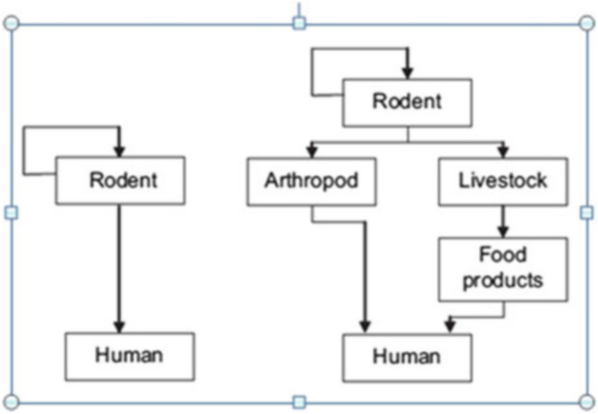


Fig. 11.4 Transmission of rodent borne disease to human

Table 11.5. Major rodent-borne zoonotic diseases

S. No.	Causative organism	Number of diseases
1.	Bacteria	19
2.	Virus	22
3.	Sprozoea/protozoa	3
4.	Zoomastigophorea	3
5.	Cestoda/flatworm	3
6.	Nematoda	6
7.	Lobosea/amoeboid eukaryotes	1
8.	Conoidasida/alveolates	1

(LCMV), a viral infectious disease, is transmitted through the saliva and urine of rats. Rat flea bite transmits plague, one of the most historically dangerous diseases. The Black Death is widely thought to have been an outbreak of bubonic plague that transmuted into the pneumonic form.

Rats also are a potential source of allergens. Rat droppings, flakes of skin (dander) and rat hairs can cause allergic reactions.

11.9 Management of Pest Rodents

Being herbivore, the choice of food for rodents is unlimited. No crop is spared by these small vertebrates at any stage of its growth. The extent of crop damage depends on the rodent species involved, location and stage of crop, rodent population level and availability of shelter. Devastations have been well documented in food crops, pulses, oilseeds, plantation crops, fruit orchards, grasslands and forestry plantation crops. Surge in rodent population leading to outbreak may be due to prolonged dry

Table 11.6 Overview of different pathogens that may be transmitted by rodents

Disease	Agent	Carrier/ reservoir	Population at risk	Chance	Human health	Economy
Hantavirus pulmonary syndrome	Virus, Bunyaviridae	Carrier	2	1	3	1
Haemorrhagic fever with renal syndrome (+ other haemorrhagic fevers)	Virus, Bunyaviridae	Carrier	2	2	2	2
Nephropathia epidemica	Virus, Bunyaviridae	Carrier	1	1	1	1
Crimean-Congo haemorrhagic fever	Virus, Bunyaviridae	Reservoir	1	1	3	1
Borna disease	Virus, Bornaviridae	Reservoir	1	1	1	2
Omsk haemorrhagic fever	Virus, Flaviviridae	Reservoir	1	1	1	1
Kyasanur forest disease	Virus, Flaviviridae	Reservoir	1	1	1	1
Apoi virus disease	Virus, Flaviviridae	Unknown	Unknown	Unknown	Unknown	Unknown
Tick-borne encephalitis	Virus, Flaviviridae	Reservoir	2	1	3	1
Powassan encephalitis	Virus, Flaviviridae	Reservoir	1	1	1	1
Lymphocytic Choriomeningitis virus (LCMV)	Virus, Arenaviridae	Reservoir	1	1	1	1
Lassa fever	Virus, Arenaviridae	Carrier	2	2	3	2
South American arenaviruses (Junin, Machupo, etc.)	Virus, Arenaviridae	Carrier	2	2	3	1
North American arenaviruses	Virus, Arenaviridae	Carrier	1	1	Unknown	Unknown
Colorado tick fever	Virus, Reoviridae	Reservoir	1	1	1	1
Venezuelan equine encephalitis	Virus, Togaviridae	Reservoir	2	2	2	2
Western equine encephalitis	Virus, Togaviridae	Reservoir	1	1	1	1
Hepatitis E	Virus, Caliciviridae	Reservoir	1	1	1	1
Cowpox	Virus, Poxviridae	Reservoir/ carrier	1	1	1	1
Contagious viral animal diseases (classical swine fever, foot and mouth disease)	Virus, Picornaviridae (FMD); Flaviviridae (CSF)	Reservoir?	0	1	0	3
Leptospirosis (Weil's disease)	Bacteria, Spirochaetes	Carrier	2	2	3	2

Lyme disease	Bacteria, Spirochaetes	Reservoir	3	2	1	2
Tick-borne relapsing fever	Bacteria, Spirochaetes	Reservoir	2	1	1	1
Scrub typhus	Bacteria, Alphaproteobacteria	Reservoir	2	1	3	1
Murine typhus	Bacteria, Alphaproteobacteria	Reservoir	3	1	1	1
Sylvatic epidemic typhus	Bacteria, Alphaproteobacteria	Reservoir	1	1	1	1
Queensland tick typhus or spotted fever	Bacteria, Alphaproteobacteria	Reservoir	1	1	1	1
Rocky Mountain spotted fever	Bacteria, Alphaproteobacteria	Reservoir	1	1	3	1
Rickettsialpox	Bacteria, Alphaproteobacteria	Reservoir	2	1	0	1
Bartonella illnesses	Bacteria, Alphaproteobacteria	Reservoir	2	2	1	1
Disease	Agent	Carrier/ reservoir	Population at risk	Chance	Human health	Economy
Human granulocytic anaplasmosis	Bacteria, Alphaproteobacteria	Reservoir	2	1	1	1
Q-fever	Bacteria, Gammaproteobacteria	Reservoir	3	2	3	2
Salmonellosis	Bacteria, Gammaproteobacteria	Carrier	3	1	1	3
Tularemia	Bacteria, Gammaproteobacteria	Carrier	2	1	3	1
E. coli 0157/VTEC	Bacteria, Gammaproteobacteria	Carrier	2	1	3	2
Plague (Yersinia pestis)	Bacteria, Gammaproteobacteria	Reservoir	2	2	2	2
Campylobacteriosis	Bacteria, Epsilonproteobacteria	Carrier	3	1	1	3
Rat-bite fever and Haverhill fever	Bacteria, Fusobacteria	Reservoir	2	1	3	1
Listeriosis	Bacteria, Bacilli	Carrier	3	1	3	2
Toxoplasmosis	Parasite, Sporozoea	Reservoir	3	2	2	3
Babesiosis	Parasite, Sporozoea	Reservoir	3	2	1	1

(continued)

Table 11.6 (continued)

Disease	Agent	Carrier/ reservoir	Population at risk	Chance	Human health	Economy
Cryptosporidiosis	Parasite, Sporozoea	Reservoir	3	2	1	3
Chagas disease	Parasite, Zoomastigophorea	Reservoir	3	1	3	2
Leishmaniasis	Parasite, Zoomastigophorea	Reservoir	3	2	3	2
Giardiasis	Parasite, Zoomastigophorea	Reservoir	3	2	1	2
Taeniasis	Parasite, Cestoda	Reservoir	1	1	1	1
Rodentolepiasis	Parasite, Cestoda	Reservoir	1	1	1	1
Echinococcosis	Parasite, Cestoda	Reservoir	2	1	3	1
Schistosomiasis	Parasite, Trematoda	Reservoir	3	2	1	3
Human fascioliasis	Parasite, Trematoda	Reservoir	3	1	1	3
Brachylaimiasis	Parasite, Trematoda	Reservoir	1	1	2	1
Alariasis	Parasite, Trematoda	Reservoir	1	1	0	1
Echinostomiasis	Parasite, Trematoda	Reservoir	1	1	0	1
Trichinosis	Parasite, Nematoda	Reservoir	3	2	1	2
Capillariasis	Parasite, Nematoda	Carrier	3	1	1	1
Angiostrongylosis	Parasite, Nematoda	Reservoir	2	1	3	1
Toxocariasis	Parasite, Nematoda	Carrier	1	2	0	2
Baylisascariasis	Parasite, Nematoda	Carrier	1	2	1	2
Aelurostrongylosis	Parasite, Nematoda	Reservoir	0	0	0	0
Amoebic dysentery	Parasite, Lobosea	Reservoir	3	1	3	1
Neosporosis	Parasite, Conoidasida	Reservoir	0	1	0	2

Reservoir: rodents harbour disease-causing organisms and thus serve as potential sources of disease outbreaks, but always via a vector (tick, sand fly, etc.)
Carrier: rodent that shows no or limited symptoms of a disease but harbours the disease-causing agent and is capable of passing it directly onto humans
Population at risk: focal = 1, regional = 2, more than 2 continents = 3
Chance: chance of contracting the disease (all pathways, not only via rodents): small chance = 1, moderate chance = 2, high chance = 3 Human health: mortality without treatment <5% = 1, 5 to 10% = 2, >10% = 3. No mortality = 0
Economy: losses in terms of morbidity combined with other losses (e.g. in animal productivity): small losses = 1, moderate losses = 2, huge losses = 3

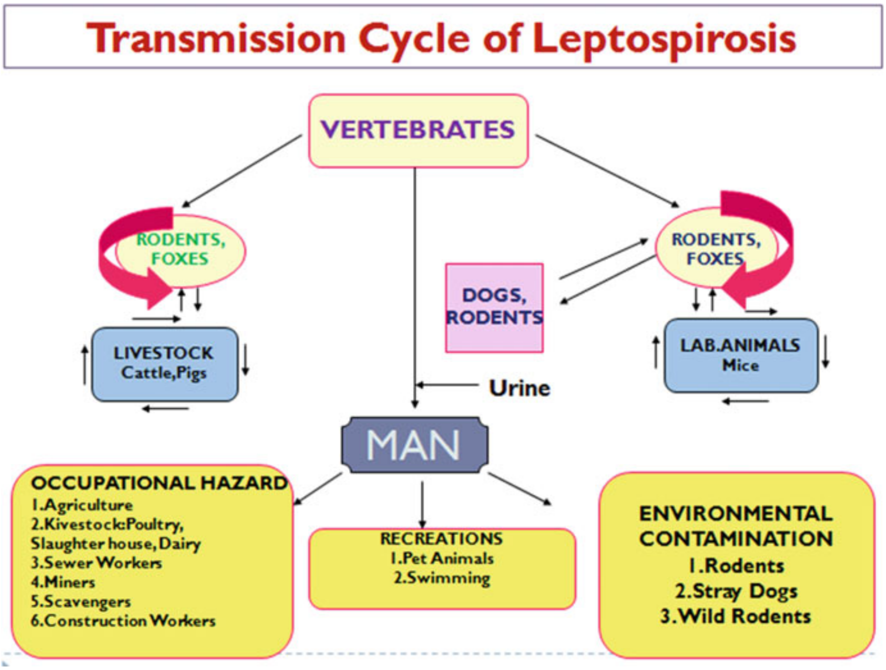


Fig. 11.5 Transmission cycle of leptospirosis

spell followed by heavy rains, failure of monsoon in preceding years, flash flood and bamboo flowering (in certain places).

A very well-planned strategy is required for an effective and cost-effective rodent management programme on any scale; meticulous planning is required to have long-term effective population reduction. Survey, different control methods (ecological, physical, mechanical, biological and chemical), record keeping, monitoring and review are some of the essential elements of an integrated rodent pest management (IRPM) programme (Rao 2019).

11.9.1 Survey

Prior to the full-scale practical management programme, it is essential to know the extent of infestation to be treated, identification of the targeted species, the activity pattern of the targeted species, sheltering materials, available food sources, nontarget risks and target sites are known from the initial survey. The survey also aims to identify the rodent species through indirect evidences of rodent activities. New technologies of survey include the options based on electronics and information technologies (real-time data recording with motion detectors) enabling constant remote monitoring.

11.9.2 Environmental Management

The presence of rodent infestation indicates suitability of that habitat which provides everything to the rodent to survive, viz. food, water they need and shelter to live, move around and breed successfully. Unavailability of these factors lowers the carrying capacity of that habitat that in turn reduces the level of rodent activity. For an effective programme, these factors are critical, and modifications of some of these key factors ensure no reinfestation in the same area in the near future once the control measures are withdrawn.

(i) **Cultural practice:** An ecological technique to create stress among the native rodent pests by manipulating the habitat. It involves low cost and just modification in crop husbandry practices, like deep ploughing, removal of wild vegetation and refuse of previous crops.

(ii) **Harbourage removal**: rodents are wary of open places, and they require some sort of cover for their movement, foraging, etc. Removing the potential harbourage makes the target rodent species vulnerable.

(iii) **Rodent-proofing at home**
- Mending damages in ventilator screen, around foundation and on walls in time
- Tight-fitting cover for the crawl spaces
- Repairing all gaps and crevices around the inlets
- Rat-proofing of windows with screens
- Tight-fitting doors

(i) **Use of Repellents**

Capsaicin and denatonium have repellent property and prevent rats from gnawing objects. Other compounds added to bait to reduce palatability are cinnanamide and tannic acid (Spurr et al. 2001; Singla 2013).

(ii) **Use of Antifertility Agents**

A host of chemicals with antifertility effect on pest rodents have been identified, and some of these are anti estrogen V-ll, diphenylmethane derivatives, metepa, tepa, tetradifon, furadantin, colchicine, etc.

(iii) **Use of Antifeedant and Antifertility Compounds**

This is one emerging area in rodent pest management. They include a host of chemicals with antifertility effect on pest rodents that have been identified, viz. anti-estrogen V-ll, diphenylmethane derivatives, metepa, tepa, tetradifon, furadantin, etc. (Tripathi and Chaudhary 2005), and many plant products with antifeedant and antifertility properties have been identified (Singla 2013).

(iv) **Trunk Banding**

Trunk banding with a galvanised iron or zinc or self-adhesive polyethylene sheet of the size 2 × 2 feet is wrapped around the coconut palms at a height of 6 feet that reduces damage to nut by palm-climbing rats.

(v) **Electronic Rat Repellents**

Devices which produce unfamiliar frequencies apparently scare the rodents. However, like other vertebrates, rats accustom to the electronic resellers.

(vi) **Electric Fencing**

Low volt current passed along the metal cable that protects the agricultural fields or plots from the marauding rodents. It is an efficient deterrent against not only rodent but also against other vertebrate pests. Animals that experienced the shock try to avoid the area fenced.

11.9.3 Rodent Population Control

Rodent pest management is always tricky and needs prior scientific knowledge about rodents. Rodent trapping is one of the direct methods of controlling rodent population and can be done in two ways: (i) kill trapping and (ii) live trapping. There are many methods available by which pest rodents are either caught or killed at once.

11.9.3.1 Physical Control

Physical control techniques include live and kill trapping, ultrasound, electromagnetic fields, shooting, etc.

Various kinds of traps (Plate 11.9a, b) are used to remove rodents from their habitat. Trapping also provides details about the species composition and population density of the rodent pest and hence is useful in monitoring purposes. Trapping is considered as the safest killing method around human habitations. Traps can be used for a prolonged period, cost-effective and safe but more labour intensive. Both intrinsic factors concerned with the target species like the species, previous experience and age of the rodents and the extrinsic factors like temperature, cover and moisture determine the efficiency of the traps (Drickamer et al. 1999; Davis et al. 2003).

Plate 11.9a Rodent live traps

11.9.3.1.1 Live Trapping

(i) **Use of Live Traps**

Live traps are not always preferred in the large-scale rodent management programmes as it involves killing of trapped rodents subsequently. However, for conservation purposes and monitoring of rodent population, live traps are being used. In multiple-catch live traps, as many as 20 rodents can be trapped.

(ii) **Sherman Traps**

Sherman traps are standard live traps used worldwide. It is a box trap with collapsible arrangement and can be safely handled. These traps are used to trap

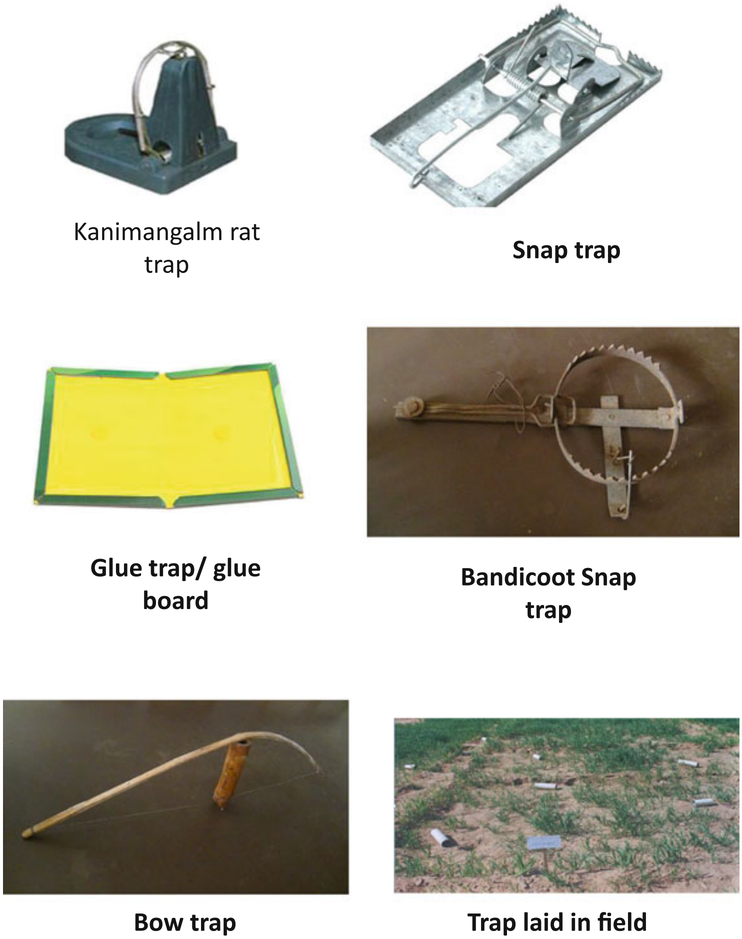


Plate 11.9b Rodent kill traps

rodents for population studies, collection, teaching, mark-recapture-release programmes, etc.

(iii) **Box Trap**

Wooden, plastic or metal box traps are widely used in household to capture the commensal rodents using attractive bait materials.

11.9.3.1.2 Use of Kill Traps

(i) **Snap Trap (Break Back Trap)**

Traps are made up of either wooden or tough plastic or metallic one. Efficiency of the trap can be increased by pre-baiting the rodents for 1 or 2 days; any fried material or a piece of coconut meat can be used as a pre-bait material. Care should be taken as it inflicts wounds if not properly handled and hence is not safe for kids and pets when used indoors. These traps can be used in the fields either linearly or diagonally.

(ii) **Bow/Arrow Trap**

These are fabricated from bamboo in the shape of arrow or bow. These are very effective against rice field rodents and used in Tamil Nadu, Andhra Pradesh, northeastern states of India. It needs some skill to use these traps.

(iii) **Glue Board/Glue Trap**

Sticky material is used to trap small rodents like mouse, and these traps work with the same principle of flypapers. Like the live traps, the trapped animal has to be killed which makes these traps less attractive for large-scale rodent control programmes.

(iv) **Electrocution Trap**

Rodents are killed by electrocution, and these are expensive traps. These traps require frequent checking for dead rodents. Though the traps are excellent in getting the problem rodents, these traps have some inherent drawbacks. Trapping is usually not practical if rodents are numerous, affected areas are too large, traps are costly or reinvasion is rapid. If traps are used, the intensity of efforts needs to be related to the numbers and activity of rodents and compared with the level of crop damage. Usually, trapping has proven to be so labour intensive that little benefit is achieved or efforts cannot be maintained because farmers lose interest, when local rodent activity is low before crops are susceptible. Still, in some special situations, for example, experimental fields of deepwater rice (Islam and Karim 1995: Huan et al. 2010), trapping has been used effectively to manage rat damage.

Trap barrier system: Trap barrier system is an eco-friendly rodent management method. It has been proved successfully in managing rice field rats (Singleton and Bell 2002; Rao and Kishore 2010)

Indigenous Methods to Kill Rodents

Numerous local methods are being used to kill rodents at home and in the agricultural fields. This indigenous technical knowledge (ITK) of rodent control includes the use of leaf and bark of *Gliricidia* mixed with rice.

Barn owl in the natural habitat

Artificial nesting site for the barn owl

Inverted coconut petiole perch for barn owl

T-perches for barn owl

Plate 11.10 Barn owl – rodent biocontrol agent

11.9.3.2 Biological Methods

Encouraging natural predators of problematic rodents is gaining importance as acute rodenticide causes secondary poisoning in nontargeted organisms. The role of barn owl in the management of rodents in rice fields and coconut plantations is immense (Neelanarayanan 1996; ManiChellappan et al. 2019; Roulin 2020). Barn owl is encouraged to breed artificial nesting sites established in the crop fields that are of immense value in managing field rats (Plate 11.10). Owls are encouraged in agricultural fields by providing T-perches (@ 25/ha) and inverted coconut petiole (@50/ha).

11.9.3.3 Chemical Method

For vertebrate pest management, naturally occurring compounds (cyanide and strychnine) have been used a number of years, globally; the same is true with zinc phosphide. Most of the research on rodenticide happened between 1940 and 1990. Sodium fluoroacetate is the salt form of fluoroacetate. Fluoroacetate is the toxic component of 1080 (developed in the 1940s), which occurs naturally in some poisonous plants. Anticoagulant rodenticides can be broadly classified in acute and subacute blood anticoagulants and fumigants (Endepols et al. 2015). Time and method of application of these rodenticides play an important role in getting desired effects on the rodent pest management (Chaudhary and Tripathi 2005, 2019).

11.9.3.3.1 Acute Rodenticides

These are the substances that cause death of rodents within a shortest time of exposure to the rodenticide either from a single dose or from multiple doses for a short period. Acute rodenticides cause death as a result of:

- Paralysis of central nervous system
- Respiration failure
- Cardiac irregularities
- Gastrointestinal irritation and haemorrhage
- Destruction of red blood cells
- Destruction of kidney and liver tissues
- Blocking of citric acid oxidation
- Hypothermia

Alphachloralose is an acute toxicant which induces hypothermia and death when used as baits (2–4% of the active material). However, the use of this compound is restricted due to its bird toxicity.

Zinc phosphide is another most widely used acute rodenticide throughout the world since 1911 (first used in Italy). Clinical signs of poisoning appear within 15 minutes after the ingestion and death within 3–12 h. Zinc phosphide reacts with the HCl in the stomach and releases phosphine which causes respiratory and heart failures which leads to death. It is effective against both urban and field rats (2%). At higher concentrations, it is less acceptable to rodents. Its garlic-like odour appears to be attractive to rodents unless bait shyness has developed, whereas this smell tends to repel higher animals.

Sodium fluoroacetate (1080) occurs naturally in the seeds of *Dichapetalum braunii* that contain levels of fluoroacetate up to 8000 mg/kg. It is very effective against many vertebrate pests. Clinical symptoms of poisoning appear within 30 minutes of its consumption, and death occurs within 24 h by inhibiting the energy production from tricarboxylic acid (Krebs) cycle.

Other acute rodenticides include norbormide, thallium sulphate, strychnine and red squill.

11.9.3.3.2 Subacute Compounds

These compounds are with delayed action. There are two compounds under this category – bromethalin and cholecalciferol.

Bromethalin: It is a single-dose rodenticide developed in the 1970s and predominantly used as bait against commensal rodents. It is used in baits (@ 0.005 or 0.01%)

Cholecalciferol (vitamin D3): It is used in baits (0.1%) for the control of rodents. It causes hypercalcaemia by mobilising calcium from bones, and death occurs within 3–7 days. It has low secondary poisoning on nontarget species like birds. Low doses of cholecalciferol are being added to anticoagulant-containing baits to increase their effectiveness.

11.9.3.3.3 Chronic Rodenticides or Blood Anticoagulant Rodenticides

Anticoagulants interfere with the blood clotting mechanism in the target species, rupture fine blood capillaries and cause internal haemorrhage, leading to death. Used in very low concentration, these rodenticides cause death after several days, and hence the development of bait shyness to anticoagulants is remote.

Anticoagulant rodenticides fall into two groups, first- and second-generation anticoagulants, and these rodenticides cause internal haemorrhage and death.

First-generation rodenticides: It includes warfarin, chlorophacinone and diphacinone that are multidose anticoagulants. Death occurs after ingesting the bait for a period of several days.

Warfarin: It is a hydroxyl coumarin compound first introduced in 1947; warfarin interferes with the blood clotting factors in the target animal and leads to death.

Diphacinone: It is an indane-dione class compound having comparatively more toxicity to rats and mice.

Chlorophacinone: It is similar to diphacinone but with more toxicity.

Coumatetralyl: It has more toxicity than warfarin and can be used in multiple ways, viz. tracking powder or bait, wax block or paste for rodent control.

Second-generation anticoagulants: It includes brodifacoum, bromadiolone, difenacoum, difethialone and flocoumafen which are single-dose anticoagulants and have greater affinity for vitamin K-epoxide reductase. However, the field use of second-generation anticoagulants has resulted in reports of adverse effects on wildlife.

Though the second-generation anticoagulants are used widely against commensal and to a certain extent field rodent management, their persistence on rodent's body than do the first-generation anticoagulants is one of the environmental concerns. They may pose potential hazards to predators and scavengers, which may consume poisoned rodents. Hence, proper disposal of dead rodents and application of these rodenticides as per the label directions may reduce the secondary poisoning in nontarget animals.

11.9.3.3.4 Fumigant Rodenticides

Fumigants are used to manage rodent in situations where the use of other rodenticides is either ineffective or impractical. Fumigant rodenticide application requires extreme care as the poisonous gases emanating from the compounds are deadly.

Aluminium phosphide: This is one of the most widely used fumigant, which releases phosphine (PH_3) gas when it reacts with moisture. It is used in storage to manage insects and rodents. It is available in either pellets or tablets and for burrow fumigation. After insertion of the fumigant pellets/tablets into the burrow, the burrows are closed with moist soil that results in the production of phosphine that becomes toxic to the rodents in the burrow.

Cyanogas: It is an alternative to acute rodenticide which is normally delivered into the burrow using a fumigator.

Carbon dioxide (CO_2): It is very effective against commensal rodents like mouse. Research shows that rats become unconscious in 25 seconds when exposed to 100% CO_2. Carbon dioxide offers many benefits as a fumigant. First, the gas is heavier than air, so it naturally sinks into the burrow. Second, it is noninflammable. Finally, it offers a greater margin of safety for the applicator than other fumigant gasses.

Ignitable gas cartridges: Ignitable gas cartridges are one of the burrow fumigants. The USDA-APHIS manufactures two gas cartridges, which contain sodium nitrate and charcoal as active ingredients that when lit produce toxic carbon monoxide gas, which kills the occupants of the burrow.

Smoke: Hand-operated centrifugal blower-type burrow fumigator using ignited straw as the source of smoke is being used in the rice-growing areas in India for burrow fumigation. The effectiveness is almost near to the aluminium phosphide fumigation (Reddy et al. 2005).

Estimates showed that burrow fumigation costs five to ten times more than toxic rodent baits; the benefit of burrow fumigants, however, is that they lack residual toxicity and have no secondary poisoning on other animals that reoccupy the treated burrows or feed on carcasses killed by the fumigants. Fumigants will be an appropriate method after the rodent baiting programme to deal with the residual rodent population still holed up in the burrows.

Bait Placement and Bait Stations

Rodenticides are highly toxic and must be handled according to the directions. These rodenticides can be used as bait, contact toxicant or fumigants. To improve the safety and effectiveness, bait stations are recommended. Keeping bait stations in places frequented by the rodents or near the burrows and harbourage improves the effectiveness of both the bait and bait stations. Both oil and sugar in the bait increases its attraction to the rodents. Leftover bait and carcasses of poisoned rodents should be properly disposed of.

11.9.3.3.5 Other Control Methods

Flooding the burrows of field rodents is an effective method. Using a water hose, water can be pumped into the burrows to kill the inhabitants.

Rodenticide Dust or Tracking Powder

Grooming behaviour is exploited to manage rodents in certain situations. Tracking powders like alpha naphthyl thiourea (ANTU), chlorophacinone, diphacinone, zinc sulphide, coumatetralyl, etc., are some of the tracking powders used in the rodent management. By placing these rodenticide powders in or near the rodent runways and burrows, rodents pick up the toxicant on their body. While grooming action, the chemicals get into the system. If properly used, rodenticide powders are safe to nontarget organisms.

11.9.3.3.6 Rodenticide Evaluation

New rodenticides are evaluated for their toxicity on rodents in laboratory.

Oral Toxicity

Determination of oral LD_{50} (mg/kg) is done by oral administration of technical grade and by stomach intubation technique.

Baseline Susceptibility

Susceptibility of rodents to rodenticide can be studied by plotting log days feeding against probit mortality. Then the Lethal Feeding Period (LFP) to kill 50% of the experimental rats can be determined.

No Choice Feeding Tests

In No Choice Feeding experiments, rodenticide at different doses mixed with bait is given to individually caged rodents to record the number of days taken from the initial feed to death of the rodents.

Choice Tests

Along with rodenticide laced food, plain food is also provided to the caged rodents to see if it is acceptable to the animals and mortality days to death are recorded.

Experiments are conducted to know the effectiveness of the rodenticide in field conditions based on live burrow count (before and after the poison baiting) and crop damage index.

11.9.3.3.7 Warning on the Use of Rodenticides

Pesticides are poisonous. Always read and carefully follow all precautions and directions provided on the container label.

Pets and Rat Control

Rodent control methods and materials are equally affecting the pets (dogs and cats) as well. Secondary poisoning of pets and wildlife is possible if they eat rodenticide-poisoned rats. It is always better to keep pets away from the leftover bait and dead or dying rodents.

11.9.3.3.8 Rat Control Campaign

It involves meticulous planning and neat execution. The campaign should be conducted during (i) preharvest stage of the crop and (ii) nonbreeding period (Fig. 11.6). Residual rodent population if not controlled would contribute to their population (Chaudhary and Tripathi 2005; Raj and Naik 2015). The operations include precontrol, control and postcontrol operations. The initial rodent populations are estimated by live burrow count and damage index. The difference of precontrol

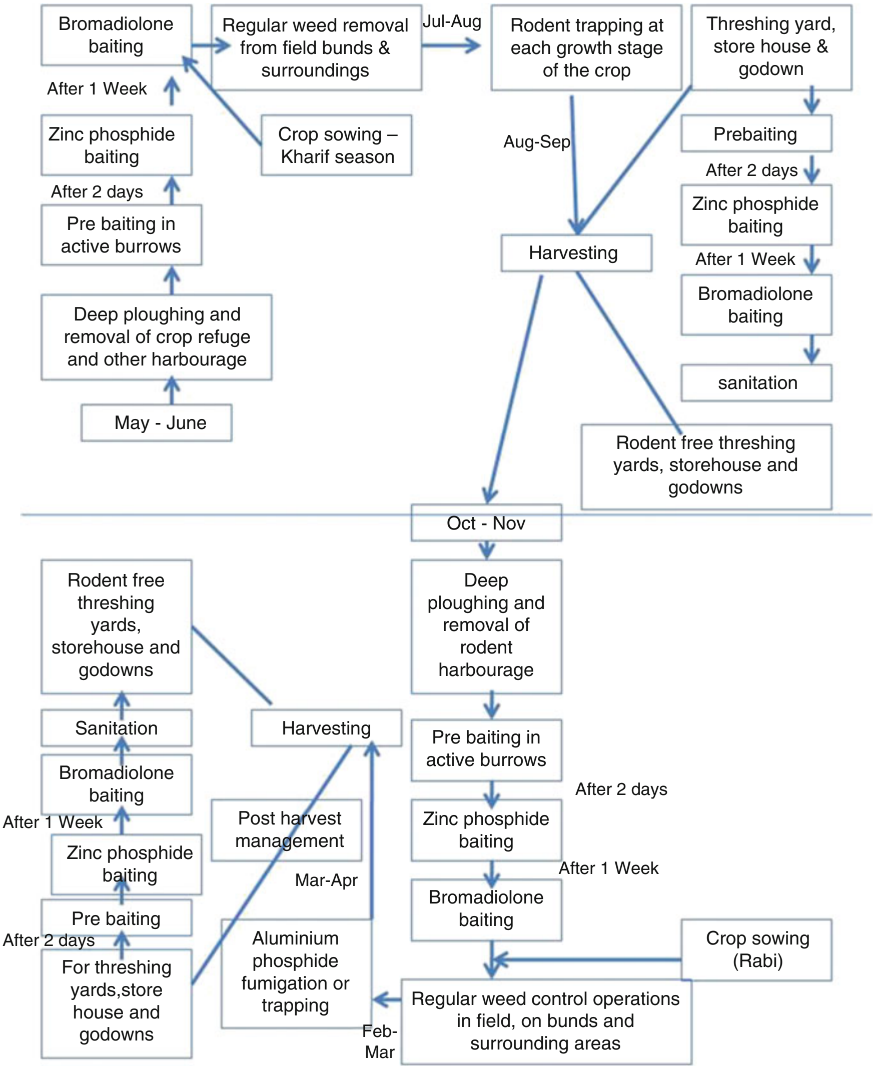


Fig. 11.6 Integrated management schedule for pest rodents

and postcontrol figures gives per cent success of the operation. In store/warehouses, godowns and poultry units, the food consumption index during precontrol and postcontrol censuses would give the control success.

11.9.4 Monitoring and Review

Monitoring and review are the essential component of rodent control programme with the following essential data:

- Personnel responsible for rodent control programme and place of the programme
- Environmental risk analysis
- Rodenticide used in the campaign
- Bait placement map
- Quantity of rodenticide used
- Important dates of all operations
- Bait consumed and bait station used
- Number of dead rodents
- Records of monitoring
- Details on leftover baits
- Rodent disposal
- Completion of the campaign

All these data should be analysed so that progress of the control programme can be easily known.

11.10 Conclusion

Rodents pose major threats to crop production, sometimes strikingly obvious, sometimes more cryptic. Awareness of their biology can improve the prospects for their management. Since rodents are highly evolved mammals, they avoid trouble by trap and poison avoidance, bait shyness/aversions to acute poisons, resistance or cross-resistance to rodenticide, etc. Therefore, an integrated approach based on the biology, ecology and ethology of the target rodent pest species *vis-a-vis* control measures which are cost-effective and socially acceptable is to be evolved. Sound knowledge on population ecology of the species concerned, behaviour of the pest, damage threshold of the pest on crops, state of dominance of the pest, human interference, etc., plays a vital role in the successful planning and implementation of rodent management programme, so that the outcome is more sustainable with more favourable economics. Therefore, understanding their bioecology is the prerequisite to have a long-term and sustainable rodent pest management programme.

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