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Review

Surveillance Strategies of Rodents in Agroecosystems, Forestry and Urban Environments

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Abstract: Rodents belong to the group of occasionally economically significant to very significant pests. Some species, especially synanthropic species, cause material damage in various ways. Successful and sustainable management of rodent control strategies requires different procedures such as prevention and rodent control measures. The present study gives an overview of the most common rodent species and methods for estimating the rodent population to assess the risk of economic damage that may occur due to rodents feeding in field crops, gardens, orchards, and young forest plantations, as well as contamination of stored food. As a prerequisite for effective integrated control of mice and voles, it is necessary to implement an adequate long-term monitoring system of these species, as they are primary pests. The integrated approach improves the treatment efficacy and reduces the treatment costs but also is considered ecologically friendlier compared to conventional measures. An integrated approach should provide an effective strategy for rodent management and control in all types of rodent habitats, from agricultural and forestry production fields to residential and public areas. By combining different preventive measures, it is possible to prevent the presence of pests, which will therefore result in a reduction of pesticide use.

Keywords: rodents; rodent control; forest crops; rodent in urban areas; mouse; vole; dormouse

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1. Introduction

Mouse-like rodents (Myomorpha) are a group of rodents that differ from other rodents in the arrangement of jaw muscles and the structure of molars. The most important feature of the upper and lower jaw of mouse-like rodents is the enlarged incisors. Lower incisors are usually longer than upper incisors. Their canine teeth are not developed. As a rule, rodent incisors do not have a root and grow throughout their life. Unlike them, molars have limited growth. There is an empty space between the incisors and the molars, called the diastema [1]. The medial and lateral masticatory muscles of the jaw in mouse-like rodents are shifted forward and follow the path through the animal's eye socket. No other mammal has a similar constitution of the medial masseter muscle. Key features of murine rodents are unique arrangement of jaw muscles used for chewing, unique structure of molars, jaw structure and musculature suitable for biting, one pair of incisors, and three cheek teeth on each side of the jaw [2].

Contemporary requirements in forestry and crop production requirements rely on sustainable, intensive management and administration to achieve optimal yields. In forests, this process begins with rapid regeneration of forests after logging, which ensures optimal number, distribution, and growth of young plants. In crop production, rodent control is critical for production profitability and achieving maximum yields. In the early stages of crop development, damage from mouse-like rodents can be an important factor limiting rapid regeneration and causing damage to young crops. In orchards, damage from rodents, especially from voles, occurs in the autumn and winter period when there is not enough other food and when the winter cover protects the voles from mammalian and bird predators [3]. In Europe, the common vole, *Microtus arvalis* (Pallas, 1788) is a significant pest of orchards, arable crops, and young forest plantations [4,5]. From another point of view, in order to preserve biodiversity, it is necessary to apply sustainable management of forest ecosystems in practice. Research shows that after clear-cutting of forests, application of pesticides, and removal of wood residues by grinding, negative impacts are created for the maintenance of most species in small forests [6].

Some rodent species, particularly synanthropic species, can cause wide spectrum of material losses in both agriculture and forestry, but also in storage facilities and households. Material damage could be expressed through economic loss and epizootiological effects [7–10].

Natural feeding activities of rodents, as well as their behavior (milling and digging holes in the ground), cause damage and thus a reduction in crop yields, damage to seeds and seedlings, damage to fruits, destruction and contamination of food for human and animal consumption, damage to building structures, and damage to technical equipment [11].

According to the World Health Organization (WHO) and the Food and Agriculture Organization (FAO), an estimated 5% of the food produced worldwide is destroyed and eaten by rodents. It is estimated that rodents destroy 33 million tons of food per year, which is enough to feed 130 million people [12].

The damage caused by rodents to crops can be enormous. Crop production in agriculture and forestry can suffer enormous damage due to the overpopulation of rodents. A large number of rodents leads to structural damage due to gnawing and digging, and the risk of transmitting zoonoses increases [13]. One recent example is an outbreak of human hantavirus infections in Germany in 2010, when more than 2000 people were infected [14]. This damage is usually caused by several harmful rodent species at the same time. Rodents considered pests on agricultural land, orchards and nurseries of forest seedlings include at least 40 species and almost as many subspecies [15–17]. In our country (Serbia), the following are pests of agricultural crops: common vole, European pine vole, European water vole (Northern water vole), Bank vole, Yellow-necked mouse, striped field mouse, European woodmouse, Black and Brown rat (Norway rat), hamster, Steppe (mound-building) mouse, European ground squirrel, and in some parts of Serbia, the Lesser blind mole-rat also occurs. The population density of these species varies depending on the season and year. In 2019, increasing or unusually high common vole densities have been reported from several European countries. This is highly important in terms of food production and public health [18].

As a rule, as population numbers fluctuate over the course of many years, occasional calamities occur, reflected in the amount of damage, which can reach the magnitude of a real disaster. In years of overpopulation, they cause considerable damage to forest seeds, saplings, and seedlings. The large number of species of small rodents, the insufficient knowledge of their life and reproductive cycles, and the numerous limitations in the choice of chemicals indicate the need to study and monitor the populations of these pests, to identify them reliably, and to find effective and environmentally friendly methods of controlling their populations.

To minimize economic losses, it is necessary to take timely preventive measures as well as rodent control measures. These measures must be based on scientific, professional, theoretical, and practical knowledge of the population biology and ecology of these species. Despite the emphasis on the harmful role of rodents in terms of economic importance to humans, we should also keep in mind their positive role in all ecosystems, primarily as predators in biological control of insect pests, but also in maintaining forest ecosystems as an important element in food chains [19–21]. Considering the possible negative effects of rodents, the aim of the work is to identify and monitor the number of rodents in agroecosystems, forests, and urban areas in order to determine the critical number of rodents in a timely manner and to implement timely and preventive measures to protect agricultural production and the health of people and animals through an integral control approach. This review focuses on the most important questions and answers that are essential for understanding the population dynamics of small rodents and indicates that rodent control as a pest is a long-term, science-based process of measures that in practice reduces the risks of pests and improves the pest management strategy.

Mouselike Rodents' Overpopulation in Nature

All rodent species mature sexually very quickly and usually have a short life expectancy and a polyestrial cycle. Female rodents have the ability to mate immediately after birth. Small rodents are not thought to have a precise mating season and mate throughout the year. As a result of this method of reproduction, combined with the constant availability of sufficient amounts of food and favorable climatic factors, overpopulation and disruption of the natural balance can often occur, resulting in a high density of rodent population in a given area, and occasional calamities [22,23].

Rodents hibernate mainly in their tunnels (burrows), which are characterized by a suitable microclimate. During winter, rodents rest and feed on stored food (hamsters) or they are active under the snow (mice and voles). A layer of snow only a few centimeters high protects rodents from freezing to death at a temperature of at least −6 °C, while a layer of 30 cm protects them from severe and prolonged frost and enables reproductive conditions. Rodent population density changes over a period of one or more years and depends on the factors indicated in Figure 1.

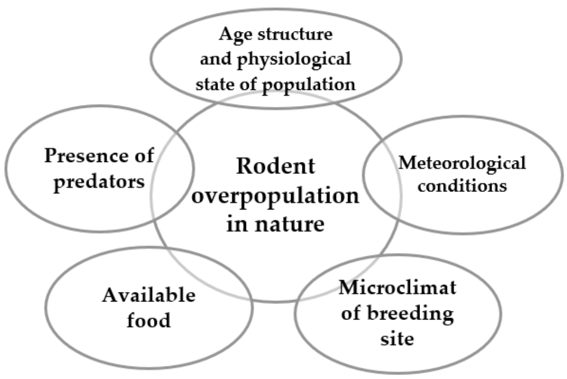

Figure 1. Meteorological factors and other factors that affect rodent overpopulation in nature.

In forest ecosystems, the main food sources are forest seeds, which have the greatest influence on rodent overpopulation. In years when forest seeds are abundant, rodent populations do not reach a maximum until the following year, after which they decline. It is also possible that the increase fails to occur due to numerous other factors. The abundant yield of forest seeds of English oak, beech, hornbeam, and maple provides an active winter for small rodents to continuously reproduce, resulting in the mass appearance of new populations that migrate in search of food and cause damage to shoots and seedlings.

In the winter following the autumn without forest seed yield, the average mortality of mouse-like rodents reaches 80% [24]. After a period of overpopulation, the rodent population usually remains below average. The number of rodents in the coming period depends on the sex ratio, intra- and interspecific structures, mortality rate, and meteorological conditions. The overpopulation of rodents also depends on the microclimatic conditions in the habitat, the presence of weeds, the intensity of available light, their activity, the duration of floods and fluctuations in the groundwater levels.

The increasing number of rodents in field crops is closely related to the applied agrotechnical measures in crop production. They migrate from arable land cultivated by deep tillage in the fall. Field mice and voles first colonize fields with alfalfa. Alfalfa provides good shelter and a good food source, including below- and above-ground plant parts, so overpopulation occurs quickly. Rodents in this case reduce the number of plants and can completely destroy the crop [25]. Therefore, rodent control in alfalfa should be carried out in winter. In small cereals, the presence of rodents depends primarily on the proximity of the alfalfa field, the proximity of canals, agrotechnical measures, and the proximity of non-cultivated areas, which are natural habitats of rodents. In recent years, the number of rodents recorded has been high, especially in fields where reduced (shallow) tillage was applied before sowing the small grains. Therefore, rodent numbers should be monitored in both winter and spring [26]. In many studies, rodent numbers are thought to be only partially reduced by natural predators. In forestry, for example, several methods should be used to monitor and control rodents. Several authors [24,27–30] point out that the maximum of rodent numbers occurs cyclically every 3–5 years. As a result of the continuous use of rodenticides, rodents could develop resistance to the rodenticides used. This type of chemical treatment of rodents cannot be considered the best option from the point of view of environmental protection.

In search of food, rodents migrate to areas where food is available in large quantities. Rodents are found everywhere, both in rural and urban areas-in fields, crops, forests, orchards, vineyards, stables, warehouses, buildings, etc. [31].

Economically, rodents belong to the group of occasionally significant to very significant pests. The greatest damage can be caused by the following rodent species, which belong to different families.

2. Family Cricetidae

2.1. Myodes glareolus (Schreber 1780)–Bank Vole

The body length is about 10 cm, the tail about 5.5 cm. The body mass is 17 to 20 g. The eyes and ears are small, the muzzle is blunt and round. The fur is dense, reddish-brown on the back, and yellowish-grey on the belly. It inhabits lowland deciduous forests of various species with dense low herbaceous vegetation.

Sometimes it occurs in temperate mountainous regions [32]. It is less present in mixed or coniferous forests and in higher mountainous regions. The vole is active at night, but also during the day when the habitat is covered with dense vegetation. The vole digs underground, branched tunnels that it uses for burrows and shelter. Although it does not hibernate, it often stores granular food in its shelter [33]. Unlike other voles, it is a good climber, so it spends about 10% of its activity in the treetops in addition to the ground and underground. The vole feeds mainly on plant food. It usually feeds on seeds, tree bark, roots, herbaceous plants, fungi and fruits, and to a lesser extent, on insects [34]. This vole eats the bark of the above-ground parts of the tree (up to 6 m high), but most often at the bases of branches and below the branches. The damage occurs in winter.

2.2. Microtus arvalis (Pallas, 1778)–Common Vole

Microtus arvalis (Pallas, 1778) is a small rodent, about 10 cm long. The tail is short, 3 to 4 cm, and covered with hairs. The fur is short, yellowish-grey to greyish-brown on the dorsal side, whitish ventrally. The population dynamics of *M. arvalis* are characterized by multiannual cycles that occur at intervals of 2–5 years [35]. In peak years, the population numbers can reach more than two thousand individuals per hectare [36].

The ears are short and sparsely covered with hair. The legs are short, so that when it moves, it looks as if it is dragging the body on the ground. The vole always inhabits open habitats, meadows, pastures, farmland, and forest edges [37]. This species can also be found in nurseries, vineyards, and orchards. It is active during the day and digs underground burrows up to a depth of 20 cm. The vole is a good climber, a skillful and fast animal. In summer the vole eats the green parts of plants and in autumn and winter seeds and roots [38]. If there is not enough food, it bites the bark of trees and eats young seedlings. It is a potential pest of white and black pine, white ash, maple, field maple, sessile oak, English oak, fir, linden, hornbeam, Norway maple, spruce, and larch. Damage occurs at the root and base of the tree seedling, which is up to 15 cm tall. The tooth marks are asymmetric, about 1 mm wide, and the plants are cut off straight, below the ground.

2.3. Microtus subterraneus (Selys-Longchamps, 1836)–Common Pine Vole

The body length is 8 cm, the tail is 3 to 4 cm long. The coat is dense, brownish-gray, darker on the dorsal side and silver-gray on the ventral side. The eyes are extremely small and the ears are small and completely covered with hair. The limbs are short with well-developed claws suitable for digging. This species inhabits various habitat types. Loamy and slightly moist soils are suitable for the vole. This vole avoids sandy soils. It is commonly found near rivers, lakes, and ponds, wet meadows, and also in forests. It is a very fast species. This species digs underground burrows and rarely comes to the surface. The presence of this vole can be confirmed by an extensive network of burrows that end in openings and mounds. It is active throughout the year. It feeds on underground and above-ground parts of mainly herbaceous plants, tubers, bulbs, and green shoots. In the fall, it feeds on various seeds (often acorns), which it stores for the winter. It damages the roots of trees, the bark of the soil part of young seedlings, acorns and other tree seeds, and seeds and shoots of forest plants. The damage occurs mainly in winter.

2.4. Microtus agrestis (Linnaeus, 1761)–Field Vole or Short Tailed Vole

This species is characterized by similar morphological features as the field mouse. The body length is 9 to 12 cm, and the tail accounts for 1/3 of the body length. It has a compact body structure, the fur is dense and shiny, brown to gray-brown on the upper side of the body, and pale on the underside. The tail is sparsely covered with hair. The ears are short, also covered with hairs. *Microtus agrestis* (Linnaeus, 1761) usually inhabits moist habitats in open areas, such as meadows, riverbanks, and dams. It is also found in forests with dense, low vegetation [39]. The vole is mainly active during the day and hides at night in burrows it digs under the roots of trees. Its presence can be confirmed by trails on the ground and under vegetation, from which it regularly removes leaves, twigs, and blades of grass. It feeds mainly on herbaceous vegetation, seeds, and may feed on the bark and roots of young tree seedlings in winter. *M. agrestis* damages trees up to 20 cm above the ground. It also damages the tree parts below the ground and causes characteristic damage in winter.

2.5. Arvicola terrestris (Linnaeus, 1758)–Eurasian Water Vole

Arvicola terrestris (Linnaeus, 1758) is a relatively large species. The body length ranges from 12 to 20 cm and the tail from 6 to 10 cm. The body weight is from 70 to 250 g. The fur is dense, dark, gray-brown on the back, sometimes black, and on the underside of the body it is pale colored, gray-yellow to white. The ears are small, round and completely covered with fur. The vole inhabits the environment of freshwater streams and habitats near water bodies [40]. The vole is most commonly found along riverbanks, streams, and ponds. It prefers habitats with rich vegetation and can often be observed swimming and diving. In winter and during its breeding season, it may move to drier habitats in search of food, so it can be found in fields, gardens, orchards, and forests. During this time, it damages the roots of trees and may also feed on the bark of young saplings. It is mainly active during the day. The vole digs underground burrows at various depths, which in some cases can be >50 m. The underground burrows serve as a food supply. This species does not hibernate. It feeds mainly on roots, grains, various seeds, herbaceous and aquatic plants, tree bark, and fruits. It damages the roots of young seedlings and often destroys the entire root. In the place where the seedlings are cut at an angle, there are 3–4 mm wide teeth marks. The damage is caused during the winter.

2.6. *Ondatra zibethicus (Linnaeus, 1766)–Common Muskrat*

The muskrat is a large rodent with a body weight of 500 to 800 grammes. The length of the body without the tail is 35 to 40 cm, and the tail is about 25 cm long. The tail is scaly. The fur is dense, smooth and shiny, dark brown dorsally, grey-brown ventrally. The eyes are small. The head is very large, and the ears are almost invisible under the fur. The legs are stout with short feet, strong claws, and the hind feet are slightly braided for swimming. The muskrat is found exclusively near standing and flowing water, mainly on the shores of ponds, lakes, and canals. It defends its territory and often competes with the vole. This species digs in underground tunnels on the banks with an opening below the water surface. It is considered an excellent swimmer. The vole is mainly active during the day and does not hibernate, so it does not collect food stores for the winter. During the breeding season, the muskrat can cause damage by eating the bark of young trees. The damage occurs in winter when the other food species are not available.

3. Family Muridae

3.1. *Apodemus agrarius (Pallas, 1771)–Striped Field Mouse*

Apodemus agrarius (Pallas, 1771) is easily recognized by a black longitudinal stripe, 3 mm wide, that runs the length of the body across the back. Other than the dorsal side, which is reddish-brown, the fur on the abdomen is white to gray. The body length is about 10 cm, and the tail is shorter than the body (about 8 cm). The weight is about 25 g. The striped field mouse inhabits meadows and forest edges overgrown with bushes and shrubs. It is a typical steppe-and-meadow species and sporadically occurs in flooded deciduous forests. The species is active both during the day and at night. It does not hibernate, so it can be found in various habitats throughout the year. Digging underground burrows is specific to this species and it often burrows under snags and tree roots where it stores its food. It is a skilled climber, so it can also be seen in the treetops. The striped field mouse feeds on acorns, beech, chestnuts, and pinecones. Tooth marks on the broadside of seeds are an indication of the presence of this species [41]. This mouse eats cones by splitting the shells at the base to the axis of the cone from which it takes the seeds.

3.2. *Apodemus flavicollis (Melchior, 1834)–Yellow Necked Field Mouse*

The body length is about 11 cm, and the tail is 11.5 cm long. The body weight is about 25 g. The fur on the back is brown and on the ventral side is white. The hair around the neck is pale and yellow-brown. A complete band of yellow fur can be seen on the nape of the neck, a fairly reliable distinguishing feature from similar mice. It inhabits deciduous and mixed forests but is rarely found in open areas [42]. It is the dominant mouse species at higher elevations in oak woodlands and in all deciduous lowland forests. The species is active at dusk and at night. *Apodemus flavicollis* (Melchior, 1834) is a good climber and jumper. It is found in tree canopies at heights of over 20 m. Abandoned nests of birds and dormice, as well as tree hollows and burrows of moles, are used for shelter. It often burrows into the roots of trees. The main food is tree seeds, forest fruits, and rarely, insects. It is always found near the food sources [43]. It feeds on seeds and fruits of various tree species (oak and beech oaks, hazelnuts, chestnuts, and cones). In autumn it collects seeds and eats them over the winter [44].

3.3. *Apodemus sylvaticus (Linnaeus, 1758)–Wood Mouse, Long Tailed Field Mouse*

Apodemus sylvaticus (Linnaeus, 1758) is somewhat smaller compared to the other species. The body is about 9.5 cm long and the tail is about 9 cm long. The body weight is between 17 and 24 g. The fur is grey-brown on the dorsal side and grey-white on the ventral side. It inhabits all types of forest habitats, parks, agro-ecosystems and even sandy habitats. The species prefers areas with low vegetation [45,46]. It is mainly active at night. The wood mouse is a good and fast climber, often moving with large jumps. The wood mouse builds underground burrows and stores food in them. The main food is seeds (especially acorns) and fruits. It rarely feeds on buds and shoots of plants, as well as insects. The damage it does is similar to that done by other species of mice.

3.4. *Mus musculus* Linnaeus 1758–House mouse

Mus musculus (Linnaeus 1758) is spread all over the world. Adults has the head and torso length between 7 and 10 cm, the tail length is 7 to 12 cm, and the body weight is 20 to 25 g. Fur is dark gray on the dorsal side and light-gray to white on the stomach. In nature, this rodent feeds by seeds and fruits of all crops. It often consumes freshly sown cereals and hence causes enormous damage from the moment of sowing and afterward. *M. musculus* populations in residential buildings cause significant damage to households by eating and contaminating foods such as sugar, flour, biscuits, chocolate, butter, milk, walnuts, poppy seeds, and almost all types of meat and dairy products. In rural areas, it is almost inevitably present in food storages and barns for grain storage. It eats food intended for human and domestic animal consumption, making a food unusable due to its contamination with urine and feces. The house mouse partially or completely damages books, valuable papers, art objects (e.g., paintings), cardboards, plastic, and wooden packaging.

3.5. *Rattus norvegicus* (Berkenhout 1769)–Brown Rat

Rattus norvegicus (Berkenhout 1769), also known as the common rat, street rat, sewer rat, wharf rat, Hanover rat, Norway rat, Norwegian rat, and Parisian rat, is a widespread species. This species inhabits almost the entire territory of Europe. It is a relatively large animal compared to most rodent species. The adults' head and body length is between 20 and 25 cm, and the length of the tail is 16 to 20 cm. This rat species almost always lives in the direct proximity or in the animal stables (poultry houses, pigs farms, and calf stables), in storages of cereals and other plant and animal product storages, residential buildings, industrial facilities, ports, harbors etc. This rat is always present in garbage dumps. From the epidemiological point of view, the gray rat deserves special attention because it is a natural reservoir and carrier of a large number of pathogens which cause infectious diseases to humans and animals. In infections, transmission occurs directly, with the rat as a carrier of pathogens, or indirectly, through numerous ectoparasites. It prefers eating grains cereal products, meat and dairy products, and fruits and frequently eggs and nestlings, crabs, shellfish, fish, some species of amphibians, insects, lizards, etc. This rodent is one of the most important pests among small species of rodents.

3.6. *Rattus rattus* (Linnaeus 1758)–Black Rat

Other common names of this rodent include roof rat, ship rat, house rat, the Egyptian rat, and Alexandrian rat. The head and body length of the black rat adult is 16 to 20 cm, with the tail 16 to 25 cm long. Body weight is usually between 160 and 240 g. The tail is poorly covered with hairs. Scaly rings between hairs are clearly visible (up to 260 rings). It builds nests in attics, cracks in the wall, treetops, or in treeholes. The black rat is an important pest of citrus plantations, i.e., lemons, oranges, and mandarins, but also vineyards, rice fields, and sugar cane plantations. This rodent is a carrier of pathogens which cause infectious diseases of humans.

The highest risk for pathogen transmission to humans and animals is related to the presence of house mice, black rats, and brown rats, and the most common transmission path is through contact with urine and feces [47].

4. Family Myoxidae

4.1. *Glis glis* (Linnaeus, 1766)–Fat Dormouse

Glis glis (Linnaeus, 1766) is a large rodent with a body length of 13 to 20 cm and a tail length of 11 to 15 cm. The weight is up to 150 g. The fur is dense and soft, gray on the back and white on the belly. The hair around the eyes is brown. The tail is also covered with dense fur. Typical habitats are deciduous forests dominated by beech trees. The species rarely inhabits oak woods and can also be found in orchards. The fat dormouse is nocturnal and lives mostly in trees. It builds shelters in tree cavities and uses other various burrows for the same purpose (sometimes the underground burrows). The dormouse also inhabits attics and rooms under the roof of buildings located in or near the forest. It hibernates from October to April. Suitable food is fruits, seeds, insects, bird eggs, and nestlings. The dormouse often damages the bark of young trees and their buds, causing the trees to weaken and rot. This dormouse eats the bark of a variety of tree species. The damage usually occurs on older trees and on the higher parts such as the tree crown, but most often under the branches. The damage can be detected from autumn to spring.

4.2. Muscardinus avellanarius (Linnaeus 1758)–Dormouse or Common Dormouse

Muscardinus avellanarius (Linnaeus 1758) is a smaller species than the previous one. Its body length is between 6 and 9 cm, and the tail length is between 5.5 and 7.5 cm. The tail is covered with hairs that are shorter compared to those of the dormouse, so the tail of the dormouse looks narrower. The fur is dense, yellowish-brown on the back, and lighter on the ventral side. It inhabits mainly deciduous forests with a lot of hazel and shrub vegetation. The activity is registered at night. In the treetops and shrubs, the dormouse builds a spherical nest (similar to a magpie's nest) in summer. It hibernates from October to April, spending the winter on the ground or underground as well as in the treetops. The species gathers granular food for hibernation. It is predominantly an herbivore. The main food is hazelnuts and other seeds and fruits. Plant shoots and insects are less often on the menu. The dormouse damages the fruits and seeds of trees. It also feeds on young shoots and buds and sometimes eats the bark, similar to other dormouse species. The damage is caused in autumn and early spring.

4.3. Dryomys nitedula (Pallas, 1778)–Forest Dormouse

The body length is about 110 mm. The tail is almost as long as the entire body and is covered with soft fur. The weight is between 18 and 34 g. The fur is dense and soft. The dorsal side of the body is greyish-brown. The shins are yellowish-white in color. A black band surrounds the eye and extends to the small ear. The whiskers of the forest dormouse form a bushy tuft about 10 mm long. There are six pads on each paw. The species is found in mountainous regions up to an altitude of 3500 m in forests with bushy vegetation. *Dryomys nitedula* (Pallas, 1778) is a very skilled climber and often jumps from branch to branch, reaching up to two meters. There are usually only two or three adult woodland dormice per hectare. This species builds temporary nests in bushes and on lower tree branches, while it builds a nest for its offspring over 7 meters above ground. Similar to the nests of other dormouse species, the wood dormouse builds a spherical nest with an entrance facing the tree.

The main food sources are fruits of about 20 different tree and shrub species, including apricots, apples, cherries, plums, sour cherries, pears, peaches, blackberries, etc. After completing hibernation in spring, the forest dormouse eats small invertebrates and nestlings. It feeds on fruits and seeds. Sometimes it damages the bark of conifers and fruit seedlings.

5. Family Sciuridae

Sciurus vulgaris Linnaeus, 1758–Eurasian Red Squirrel

The body length of an adult squirrel is 18 to 25 cm, and the tail is 14 to 20 cm long. The weight is between 200 and 220 g. Depending on the season, the squirrel's fur can be reddish-brown in summer and reddish-gray to brown with a dominant gray color in winter. The tail is covered with long hairs. In fall and winter, tufts grow on the tops of the ears and remain there until spring. The red squirrel inhabits dry forests with tall trees that have a dense canopy. The species avoids high humidity and strong daylight. It is commonly found in spruce, pine, and mixed coniferous and deciduous forests. This squirrel is both diurnal and nocturnal but is most active at dusk and dawn. *Sciurus vulgaris* (Linnaeus, 1758) builds its shelters in three-holes or in the crown of trees. The outer part of the shelter is made of willow mesh and resembles a bird's nest. The squirrel climbs and jumps from tree to tree. It feeds on the seeds of forest trees. The squirrel also bites the bark of older trees. The damage often occurs in the tree crown. Besides the bark, deeper layers of the wood can also be injured.

6. Family Castoridae

6.1. *Castor fiber Linnaeus, 1758–European Beaver*

Castor fiber (Linnaeus, 1758) is the largest rodent in the Europe. Body length is 70 to 90 cm, and the tail length is between 30 and 40 cm. Body mass is usually up to 35 kg. Fur is dense red-brown colored. The tail is flattened, hairless, covered with scales. The toes of the hind paws are webbed for swimming. It inhabits the coastal areas of slow-flowing rivers and lakes, river tributaries, and flooded deciduous forests. Beavers inhabit all types of freshwater habitats surrounded by forests and bushy vegetation. It has nocturnal activity. During the day, it hides in burrows which builds on the water using the branches of felled trees. In order to keep the same water level around its shelter, beavers build dams and constantly adjust and upgrade them. Dams can be 150 to 200 m long, 2 to 3 m high, 4 to 6 m wide at the base and 1 to 2 m at the top. This beaver swims and dives well, and can stay under water for up to 2 min. It damages older trees by feeding with bark, and often bites and knocks down the whole tree; afterwards it feeds on leaves and green shoots and uses the branches as material for its dams. This species prefers to eat willow, poplar, birch, and ash, but sometimes also oak.

6.2. *Important Note*

Apart from the above mouselike species, other animals, by size and morphology similar to rodents, could also be sampled by in forest ecosystems. Those species belong to the order Insectivora and the family Soricidae, and they are mainly similar by size to the mice. They hide under fallen branches and near stumps. They look like mice. Their snout is long and pointed, and the jaws are full of small sharp teeth (approximately 20 in the upper jaw and 12 in the lower jaw, with the tooth formula of common shrew (*Sorex araneus* Linnaeus 1758) 3133/1113, and the mouse 1003/1003). Shrew teeth have dark tips and the bite is poisonous. It has submaxillary glands that secrete toxins, which further flow along the incisors. Bites can kill mice and but also other smaller animals, while to humans it causes pain at the place of the bite. Pain can last for several days. Poison excreted by water is similar to venom produced by cobra. Additionally, these poisons have a strong odor that repels predators.

Characteristic of the shrew’s feeding behavior is that they have to eat constantly, in short intervals, due to its very fast metabolism (daily intake often exceeds even twice the body weight of shrew). They eat almost everything that is digestible, such as fruits and vegetables, insects, and young mouselike rodents. Therefore, they are considered as very useful members of forest communities [48].

7. Damage, Consequences and Benefits of Rodents

In trems of of agricultural production, forestry, medical and veterinary importance, the damages, consequences, and benefits caused by rodents are classified into four groups.

7.1. *Direct Damages Caused by Rodents in Agricultural Production and Forestry*

7.1.1. Damages to Crops and Vegetables

It has been determined that a single rat can eat about 100 stalks of rice 4–6 weeks old per day. This causes more damage than consuming mature grains. In the Philippines, the estimated value of rice lost to rodents was 67 million USD. Rodents also cause a lot of damage to sugar cane plantations in Indonesia, ranging from 2 to 100% lost. Over 12% of mature grain is lost in so-called ‘mouse years’. Among other important pests, we should mention the hamster (*Cricetus cricetus* (Linnaeus 1758)), which damages fields of wheat and other cereals, fields of peas, vetches, broad beans, potatoes, beets, and other crops [12,49]. Young plantations of forest trees can be damaged by more than 80%, and organic plantations of fruit trees by more than 90%, in case of overpopulation by common voles [50].

Considering the damage caused by rodents, lesser blind mole-rats (*Spalax leucodon* Nordmann 1840) should also be mentioned. This species can cause the damage of vegetables production by eating onions, garlic, potatoes, carrots, as well as bulbs and tubers of different flower species. Damage to bark and roots in orchards and forest plantations can also occur during the summer. In the Czech Republic, traces of the common vole (*M. arvalis*) were registered on 24% of the trees in one orchard, while in another orchard, 15% of damage was observed on the roots of the examined trees as a result of the feeding of the water vole (*Arvicola amphibious*) [51].

7.1.2. Damage and Contamination in Food Intended for Human and Animal Consumption

Food used for human and animal consumption is frequently damaged or contaminated by synanthropic rodent species such as the house mouse and the brown rat [8,52]. Apart from these rodents eating large amounts of food, high amounts of food are wasted due to damage of packaging and wrapping material or contamination with feces, urine, and hairs. While searching for food and water, rats and mice pollute water in drinkers and diet in feeders of domestic animals [53]. Contamination by the hairs of rats and mice has been particularly frequent in stored grains and corns. In grinding the contaminated corns and grains, all the impurities are transferred to food intended for people and domestic animals [54]. American regulations for export allow 10 rat pellets (small particles that originates from rats, e.g., feces) per kg of corn, 2 rat pellets per kg of wheat, and 1 hair of rat or mouse per kg of flour [55].

7.1.3. Damage of Buildings, Riverbanks, and Railway Embankments Accompanied by Accidents and Fires

Due to the natural need to use (reduce) their constantly growing incisors, rodents, but especially rats, need to gnaw non-food items such as electrical installations or packaging [56]. Searching for food, they often dig under the foundations of stables and other buildings [57].

There are well-known examples from Hungary during 1976–1977 when gray rats caused short circuits and fires in three modern farms by chewing electrical insulation. Most likely, this was caused by the overpopulation of this species during 1970, when their number was estimated at over 2 million gray rats in Budapest alone [58]. This city had to invest over ten million dollars a year to reduce and control their numbers. In spite of the efforts that have been made to control commensal rodents, these animals are still causing serious problems in many towns and cities around the world [59].

It is believed that 1/4 of fires of unknown origin are caused by rodent activity. In 1995, the World Health Organization published a statement claiming that rodents had caused damages equivalent to 75 billion dollars in value [12]. The presence of rodents is especially dangerous if they settle and overpopulate in the embankments where they make their shelters and holes, into which water easily penetrates due to changes in the water level. The last case was recorded in 2014 on the Velika Bačka Chanal between towns Kula and Vrbas, when the embankment almost burst and water flooded human settlements and fields with crops.

7.1.4. Damage to Textile, Leather, and Other Items

Mice, especially rats, due to their need to constantly sharpen their incisors, damage a wide range of objects made of natural and artificial materials (wood, leather, fabrics, plastic insulation, nylon bags, building materials, valuable and precious museum collections, antiques, books in libraries, etc.) causing large damage, which exceeds the damage caused by diet.

7.1.5. Damage to Other Animal Species

The presence of gray rats in poultry farms can cause a stress to the poultry and thus reduce egg-laying capacity. This rodent can sometimes attack chickens, and frequently it feeds on eggs. There have also been cases of gray rats attacking newborn piglets, young rabbits, and hares. Just 10 days after rat extermination at one farm, an increase in lactation of cows of approximately 15% was recorded [48]. In Great Britain, rats have destroyed some colonies of seabirds. Rats caused eradication of the marsh frog from Ireland. After the introduction of the gray rat on the Galapagos Islands, the field snail was exterminated.

On one island in Denmark, the breeding of certain species of seabirds has stopped as a result of the presence of rats in the same habitats. Similar cases have been reported on other islands in the country [12,60]. Gray rats also attack humans [61]. In North America, 600 cases of human attacks and bites by rats are registered annually, and mainly the victims are babies, children under 9, and older people [62].

7.1.6. Damage to Seeds, Fruits and Seedlings in Nurseries, Orchards and Forestry Production

As predominant herbivores, rodents feed on different parts of plants and thus damage seeds, seedlings, tree bark, roots, and buds. In some cases, rodents can reduce the success of afforestation by feeding on sown seeds. While mice feed more often on seeds, voles damage the roots and bark of trees, especially young seedlings, which leads to physiological weakening and dying of trees. The wood mouse seriously endangers areas where natural seed rejuvenation is expected. This rodent also destroys sown seeds of agricultural crops [63]. The yellow-necked field mouse also causes significant damage to nurseries and forest crops by eating sown seeds of newly sprouted shoots and the bark of young trees, and can devastate large fields of cereals.

Voles also cause great damage, especially in Central America and Europe. In Denmark and Finland, for example, the main pest of forest plantations is *M. agrestis*. Rodent bark-gnawing is common during winter in times of low or unavailable food supply [64,65]. In Sweden, *A. terrestis* is a more significant pest compared to the gray rat and the house mouse. This rodent damages young fruit trees, plantations of poplars and willows, and often causes great damage to the crops. The biggest danger for young forests is *M. agrestis*-vole of meadows that damages the roots of woody plant species. In East Africa, it is estimated that damage from small rodents in plant nurseries and young forests can reach up to 80% of the young, planted shoots. In Australia, in 1971, about 100,000 pine seedlings were destroyed by mouselike rodents, which accounted for 5% of the total plantation. Lesser blind mole-rat can cause great damage in gardens by eating onions and garlic, potatoes, carrots, flower bulbs, tubers, and the root system of fruit trees, but also, in plant nurseries, it can damage the roots of oak, acacia, elm, etc. From the economic perspective, higher damages are recorded in deciduous than in coniferous forests, and mostly, the highest damage is registered on trees 2 to 15 years old [66,67]. Increased population density of rodents in forests correlates with the presence of dense low vegetation, which provides to the rodents natural protection from predators.

7.2. Rodent Danger to Human and Animal Health

Historically, rodent-transmitted diseases have the highest impact on human health. Rats and mice are responsible for more human diseases and deaths than any other group of mammals. Some species of pest rodents are vectors and hosts of various infectious pathogens dangerous to human and animal health, which results in negative health and economic outcomes. Small rodents play an important role in the epizootic cycles of maintenance and circulation of various pathogens, such as bacteria, viruses, rickettsia, and protozoa. The most important role is reflected in the maintenance and transmission of zoonoses in areas marked as natural foci of particular disease. All human and animal diseases caused by the transmission of pathogens that are permanently maintained in the body of rodents and that are transmitted by direct contact or through hematophagous arthropods (some species of ticks) can be classified as follows (Table 1).

Table 1. Diseases transmitted by mouse-like rodents [48].

Bacterial Diseases	Virus- and Rickettsia-Caused Diseases	Parasitic Diseases
Tularemia	Foot-and-mouth disease	Trichinosis
Brucellosis	Rabies	Leishmaniasis
Leptospirosis	Lymphocytic choriomeningitis	Coccidiosis
Listeria	Hemorrhagic fever	Protozoan-induced toxoplasmosis
Tuberculosis	Rickettsia	Fungal dermatomycoses
Plague		
Salmonellosis		
Borreliosis		

Due to rodents' great mobility while they are searching for food and likelihood of making contact with humans and domestic animals, either directly or by its urine and feces, spread of infectious pathogens can be very fast, and thus the vectorial capacity of rodents is very difficult to estimate. At the end of the 19th century, the outbreak of plague and cholera were recorded. Outbreak was recorded later as well (e.g., in India in 1994). Cases of trichinosis and hemorrhagic fever with renal syndrome, known as "mouse fever", are occasionally registered in our country.

In recent years, many studies have been conducted to precisely define transmitting and maintaining paths of *Borrelia*, responsible for Lyme disease in humans and animals. Different genospecies of *Borrelia* in Europe are associated with different hosts and reservoirs. *Borrelia afzelii* spirochetes were isolated from various rodents: *A. silvaticus*, *A. flavicollis*, *A. agrarius*, and *M. glareolus*. Voles are suitable hosts for the developmental stages of hard ticks and are significant reservoirs of many pathogens of medical and veterinary importance, such as tick-borne encephalitis virus, *Anaplasma*, *Bartonella*, *Borrelia*, *Coxiella*, *Francisella*, *Rickettsia*, and *Salmonella* [68,69].

Striped field mice are numerous in areas close to human settlements, which makes them even more important and dangerous hosts in circulating and maintaining pathogens [70]. Some authors believe that each rodent, as a potential host, develops a different infection mechanism. This is due to the fact that *Apodemus* spp. maintain a low level of Borrelia infection, but Borrelia is effectively transmitted to ticks, while on the other hand, in *M. glareolus*, infection is quickly detected and spirochetes are easily isolated [71]. However, a small percentage of Ixodidae species feed on this species of vole. This is in accordance with the observations of Kurtenbach et al. [72], who demonstrated that *M. glareolus* develops a specific immune response against both pathogens and ticks. It is an important role of other small mammals to maintain the cycle of *Borrelia* spp. in nature. Confirmed hosts of Borrelia spp. in Sweden are M. agrestis and R. rattus, and in urban areas of Germany, *R. norvegicus* is a confirmed host [73]. The same author found that in the endemic areas of Germany and France, two species of dormice, G. glis and Eliomys quercinus (Linnaeus 1766), can be hosts for Borrelia. Studies have shown that over 95% of tick larvae that feed on dormice will be infected with *B. burgdorferi*. The Eastern gray squirrel, Sciurus carolinensis (Gmelin 1788), in Great Britain and Eurasian red squirrels in Switzerland contribute to the maintenance of spirochetes in nature [74,75]. According to the available annual reports of infectious diseases in Serbia, a total of 144 cases of tularemia were reported in 2015, but with no fatal outcomes [76]. In the same year, 32 cases of leptospirosis were reported, and the natural sources of infection were rats, mice, and voles.

Infected animals transfer bacteria into the environment by excreted urine. Humans become infected through injuries of the skin or through the mucous nose membranes, mouth, or eyes. In 2015, ten people got infected and two of them died from hemorrhagic fever with renal syndrome (Hanta virus). During 2016, 63 cases of leptospirosis with one fatal outcome were reported. Hemorrhagic fever virus infected 14 people and 2 had fatal outcome, while tularemia affected 13 people with no fatal cases. In the EU / EEA countries, in 2016 the incidence rate of leptospirosis was 0.17/100,000 inhabitants. In total, 783 cases and 16 deaths were registered, mostly in Portugal and Slovenia [46]. In EU/EEA countries 2190 cases of Hantavirus infections were reported in 2016. The highest incidence rate was registered in Finland with 30.31/100,000 inhabitants [77]. In 2017, 28 human cases with Hanta virus infection were reported in Serbia (25 cases in Central Serbia and 3 in Vojvodina Province). In the period from 2008 to 2017, the highest incidence rate was recorded in 2014, when an outbreak was reported. In 2017, 23 cases of tularemia were registered in Serbia, all in central Serbia. In 2017, Lyme disease was the most significant arthropod-borne disease in Serbia. In that year, a total of 544 cases of Lyme disease cases were reported, of which 540 patients were reported in central Serbia, and 4 in Vojvodina. Lyme disease was reported through the whole year, with the highest frequencies in June and July [76].

According to the World Health Organization (WHO), it is estimated that about 75% of new diseases that have been reported in the human population in the last 10 years are caused by infectious agents of animal origin or products of animal origin. Hence, monitoring and control of harmful rodent species is considered as a significant measure for the protection of human and animal health. Deratization measures are obligatory not only for epizootiological and epidemiological reasons, but also to prevent enormous damage that certain species of rodents cause to the agricultural and forestry production.

7.3. Fear and Anxiety of Rodents

A small percentage of the human population has a fear of mice and rats known as murophobia. Some species of rodents, most often mice and rats, cause disgust in humans. Synanthropic rodents, mice and rats, are particularly repulsive to people. Humans have an objective fear of rodent bites, mainly as a result of experiences when these animals were attacking humans during famine, war, and natural disasters. Synanthropic rodents have a negative impact on the tourism of any country [55].

The bite of rats or other small rodents can cause zoonotic diseases called rat-bite fever [78]. This disease manifests after the wound has healed. The infection agents of this disease are two species of bacteria *Streptobacillus moniliformis* and *Spirillum minus*, which are both regularly present in the oral cavity of rodents [79]. Young children bitten by rats during sleep are most often affected [80]. Therefore parents, but especially young ones, have develop a non-objective fear for all species of rodents.

8. Identification of the Rodents and Other Mammals Presence Based on Their Tracks

According to the different types of damages on plants caused by rodents, it is possible to identify what species of rodent is present there [48]. Traces which can help to identify presence of rodents are footprints, feces, food debris, and damage to seeds and parts of trees and roots. Animal footprints are observed only in specific occasions. The footprints are most often observed on soft and moist soil and on the ground after rain and snow (Figure 2). Traces of mice and rats can also be seen when the animals move over surfaces covered by dust, especially in warehouses, barns, and food storage buildings.

Figure 2. Rodent tracks in snow.

When it comes to smaller mouselike rodents such as voles and mice, it is difficult to assess the type of feces, because the size and shape of the feces is similar to the feces of other small mammals (weasel, shrew, squirrel, etc.). In that case, it is good to follow other clues.

Traces of the feeding of some rodent species can also be found on the plants along standing water and the water streams. Rodent feces can also be found. In such situations, based on the size of the feces, it can be determined whether it is a vole (smaller) or a muskrat (much larger).

Muskrats often leave damaged mollusks shells next to damaged plants. Food remains are in close vicinity to each other, and traces of teeth are most often found on the trunks and branches of shrubs and trees. Due to its adaptability, the muskrat is considered to be a potentially invasive species and a strong competitor to the water vole. When this species overpopulates, it can cause disastrous damages [12].

Damage from rabbits and hares during the dormant period of vegetation can be seen at a height of up to 70 cm, and traces of deer and roe deer can be found at higher altitudes. Damage caused by mice and voles on the bark of the tree, branches, and roots is identifiable by the form of longitudinal lines, and young plants are often damaged.

Damage on coniferous plants by rodents is most easily recognized on cones. Mice and water voles properly tear off the seed shells from the axis of the cone, and the squirrel bites so that irregular long fragments of these shells remain around the axis of the cone [81]. Damage to the nuts is interesting because the dormouse makes a hole in the hazelnut and empties the contents without removing nut from the branch. The squirrel first makes a small hole, then pushes the incisors in the hole to make a biger crack.

The field mouse makes a large hole at one end of the hazelnut, and the outer edge of this hole on the shell has numerous traces of incisors. A water vole makes a similar hole, but there are no traces of teeth. Water voles and other voles always make holes laterally on the walnut shell [55].

Larger mounds of soil on the surface indicate the presence of moles, while smaller mounds, different in size, indicate the presence of water voles. Large mounds made of seeds and soil indicate the presence of the mound-building mouse, *Mus spicilegus* (Petényi 1882). The winding paths visible on the grass and connected with the entrance into holes indicate the presence of voles [82]. In autumn, all species of rodents eat the fruits of trees. Sometimes these fruits have very hard peesl. On such fruit, specific traces of teeth are clearly visible. Mice leave damage on the wider part of acorns, leaving clear tooth prints, while voles make lateral holes on fruits.

On the fruit of the beech, the field mouse and the wood mouse bite outer parts, but the inner part remains. Oak and beech seeds are particularly important for the diet of mouse-like rodents. Population density of all rodent species is directly proportional to the yield of these trees, because the availability of large amounts of high-calorie food boosts their reproduction. Along with high increases in the rodent population, their significance as pests in forestry is growing, not only for seeds, but also for the bark and roots of trees.

At ground level, the bark of young trees is damaged by the field mouse *M. arvalis*. Unlike this species, the vole *M. glareolus* climbs on trees and nibbles tree parts high above the ground, often below the canopy at the base of the branches. Vole *M. agrestis* causes damage to the bark up to 20 cm high, sometimes damaging the deeper layers of the tree. Voles and mice leave longitudinal lines on the trees, while transverse traces on the branches are left by dormice [56]. Damage is seen high in the canopy, often at the top of the canopy of older trees. The damaged surfaces are ring-shaped. Additionally, if deeper layers of the tree are damaged, that indicates damage from a squirrel. Dormice and squirrels damage bark, twigs, and buds. Sometimes, near rivers and lakes, the species *C. fiber* damages tree bark. This species can bite and knock down a tree. Smaller trees or branches are used to build dams and are used for food.

Sometimes it happens that rodents bite the roots of tree (especially in the winter) and when digging burrows. Damage to the roots is mainly caused by *A. terrestris*, and it more frequently selects the roots of young trees. The tooth prints of this species are 3 to 4 mm wide. The root of the seedling can be completely cut and gnawed with a diagonal cut, on which traces of incisors can be seen. The species *M. arvalis* can also damage the root, but this species makes a straight cut with traces of incisors in different directions, approximately 1.6 mm wide.

The damage created by rodents is different from damage caused by other mammals and birds. Many species of woodpeckers trap nuts in the forks of trees to make opening holes in them easier.

When coniferous species (for example spruce and pine) are damaged by woodpeckers and some other species of birds, shells are only torn off without visible traces of teeth, which is characteristic of mice and vole feeding. The presence of the vole *M. arvalis* is recognized by the presence of holes (2–4 cm in diameter) and numerous trampled paths on the soil. Some laboratory research shows that it is possible to track rats *Rattus ratus*, *Rattus norvegicus*, and the house mouse *Mus musculus* using fluorescent non-toxic baits. As a result, a fluorescent excrement in the form of pellets is formed that can be easily detected [83].

9. Methods for Estimating Rodent Population Density

The fundamental rules for rodent control are:

Rule 1. Measures must be maintained during each reproduction cycle.

Rule 2. Prevention is always preferable to chemical treatments.

Rule 3. Immediately after determining rodent presence indoors, treatment should be carried out.

Rule 4. In fields and forests, treatments are carried out after the threshold exceeds a standard value.

There are three basic quantitative methods for estimating the population density of small rodents: orientational-indirect, relative, and absolute. They are often used in combination, especially when it comes to small mammals. Indirect or orientational methods rely on some rodent tracks, such as counting active holes on a given surface to determine an action threshold or tolerance limit (action threshold: the level at which a pest causes sufficient damage to warrant public health attention and intervention [84]).

The application of absolute methods, such as census or total catch (collecting of all specimens from one location), is often time-consuming and technically demanding (both preparation and execution). Therefore, relative methods are frequently used to determine the relative number of one population or a quantitative index of population density. Absolute abundance is defined by the number of individuals of a certain species per unit area, while the relative abundance is expressed as the percentage of caught individuals in relation to the number of traps set up for the selected area or transect. The methods should be chosen in accordance with the objectives of the study, and they must be clearly defined at the very beginning. Ecological methods that can also be applied in the practice of small rodent control are the estimation of the population density of small mammals using trapping nets and remote sampling methods [85,86]. There are often discrepancies between the data obtained by trapping small rodents and actual population densities. More recent research focuses on a method to estimate population density from capture and recapture data of a captive population and does not depend on trap layout [87]. Different types of traps are given in Figure 3.

Figure 3. Rodent traps.

T-rex mark traps for mice are very often used to catch rodents. This trap can be used an unlimited umber of times without weakening the trigger mechanism, which reacts to 1 g of rodent body mass. They can be washed, disinfected, and stored after use.

In order to determine relative numbers of rodents, sampling should be conducted at least 2–4 times a year in spring and autumn, aiming to implement preventive and timely control measures [88,89]. The following methods are usually applied: population density index, transect method, sampling trap method, square method, and animal marking Lincoln Index.

To determine relative number or density index of populations of rodent species, primarily small mammals, only the active part of the population is sampled [90]. Hence, the methodology must be adapted to the specific characteristics of the target species in terms of site selection, trap placement, the radius of animal movement, the duration of the sampling, the choice of the adequate trap type, the selection of baits, etc. Therefore, all methods used for estimating rodent density can be divided into three groups.

9.1. Methods for Estimating Rodent Numbers in Agricultural Production

In agricultural production, mainly in crop production, the assessment of the rodent numbers is carried out indirectly by determining the thresholds of active holes per unit area. In natural conditions, rodents inhabit meadows, embankments, and other uncultivated fields, etc. Cultivated land with crops provides a significant source of food, frequently resulting in the overpopulation of rodents. For this reason, it is necessary to identify the present rodent species and to estimate the population size according to certain criteria in a timely manner. In agricultural production, the most damage is caused by the vole *M. arvalis*, the most widespread Eurasian species [91]. The threshold for this vole is 1–2 active holes per 100 m^2, and it is classified as category II (Table 2).

Table 2. Estimation of the population density of vole *M. arvalis* [55,56].

Category	Population Density	Criteria
I	very low number	<10 holes/ha
II	**low number**	**10–500 holes/ha**
III	medium number	500–5000 holes/ha
IV	high number	5000–20,000 holes/ha
V	very high number	20,000–50,000 holes/ha
VI	calamity	>50,000 holes/ha

The presence and activity of all three above given species of the genus *Apodemus* are determined by their optimal air temperature. Occasionally, they are considered economically significant pests. These mice are easily distinguished from voles. They have elongated ears and long hind legs, which allows them to move in jumps, unlike voles.

Particularly important is the determination of the presence and the number of all field mice on time, both in the field crops and in the fields where the production of field crops is planned [92]. Accurate estimation of abundance is based on the sampled individuals and detailed analysis of the genitalia, while in practice, the abundance is mainly estimated by counting the number of active holes per unit area, using the following scale (Table 3).

Table 3. Estimation of the population density of field mice [55,56].

Category	Population Density	Criteria
I	very low number	<10 holes/ha
II	**low number**	**10–50 holes/ha**
III	medium number	50–500 holes/ha
IV	high number	500–2000 holes/ha
V	very high number	2000–10,000 holes/ha
VI	calamity	>10,000 holes/ha

Chemical control is, based on the threshold, carried out when 10 to 50 active holes per hectare are counted (category II). If the number of rodents is below this level, control measures are not recommended. Similar criteria can be applied to areas where afforestation is planned. The greatest amount of economic damage in agriculture can be caused by the hamster, species *C. cricetus.* Hamster populations should be monitored at the beginning of winter and during the spring. Hamster can transport many kilograms of different grains to their shelters in preparation for the hibernation period. In the dens, there are two to five storage areas where up to 50 kg of food is stored. Their brood is far below surface, up to 1.5 m underground. Large, bare surfaces with openings up to 10 cm in diameter indicate the presence of this species. In favorable years, they cause great damage to both winter and spring crops. Hamster control should be conducted, at the latest, by the end of April, and the number is determined based on the number of dens per unit area. The threshold is three inhabited dens per hectare (Table 4).

Table 4. Estimation of the population density of hamster [55,56].

Category	Population Density	Criteria
I	very low number	<0.2 dens/ha
II	**low number**	**0.2–1 dens/ha**
III	medium number	2–5 dens/ha
IV	high number	6–20 dens/ha
V	very high number	21–50 dens/ha
VI	calamity	>50 dens/ha

Rodent control treatments should be performed according to estimated thresholds. Chemical control of rodents should be carried out in accordance with rodenticide manufacturer recommendations. The majority of rodenticides are applied by inserting baits into active holes; afterwards, the holes should be filled. The highest efficacy for rodent control was shown in zinc phosphide and bromadiolone treatments [93].

9.2. Methods for Estimating Rodent Numbers in Communal Hygiene Practice

In communal hygiene, which is regulated by law for the protection of the human population from infectious diseases in our country, it is stated that preventive deratization and disinsection are general hygienic–epidemiological measures, which must be regularly carried out in human-populated places in order to protect human health from infectious diseases [12]. Pest control consists of the mechanical, physical, biological, and chemical measures aimed to reduce the rodent population to a biological minimum.

Rodent control in facilities and protected areas is carried out immediately after determining rodent presence. The presence of mice and rats indoors is determined through the presence of feces or urine using UV lamps [55]. Detection of rodent feces is the most reliable confirmation of the presence of mouse-like rodents in certain areas or confined places. The shape and size of the feces can often indicate the type of rodent, and the following methods are used for assessment:

9.2.1. Method of Marking the Animals (Lincoln Index)

This is used mainly in the quantitative analysis of small mammal populations. The procedure consists of marking the collected individuals, releasing them at the place of sampling and re-collecting. The population density $\boldsymbol{N}$ is calculated from the ratio of recaptured marked to simultaneously collected unmarked individuals (Equation (1)).

$$\boldsymbol{N} = \frac{\mathbf{N1} \times \mathbf{N2}}{\mathbf{N3}} \quad (1)$$

where **N1** is number of marked and released individuals in first collection, **N2** is total number of collected individuals in second collection, and **N3** is number of marked collected individuals caught in second collection.

9.2.2. Placebo Bait Method

The number of rodents can be estimated by accurately measuring amounts of food offered to rodents in several places within the facility or in an open area. The remaining amount of food after every 24 h should be measured. To obtain precise data on daily consumption, and thus the number of individuals of a certain species, it is required that trial baits are available to rodents for at least 5 consecutive days. The formula for calculating the number of rodents based on the amount of eaten food has the following form (Equation (2)):

$$\boldsymbol{N} = \frac{\mathbf{H}}{\boldsymbol{h} \times \boldsymbol{n}} \tag{2}$$

where $\boldsymbol{N}$ is number of present rodents, H is total amount of eaten food in grams, $\boldsymbol{h}$ is average daily rate of food required by specific species of rodent in grams (brown rat requires 28 g and the house mouse requires 6 g), and $\boldsymbol{n}$ is number of days when the rodents had the offered diet.

Data on the amount of food offered to rodents in the form of baits could be interpreted also in another way. Food consumption is monitored for at least seven days. Rodents, especially rats, need some time to get used to the new food in order to consume it. This usually happens in 5 to 7 days. The number of individuals is obtained when the maximum amount consumed during 24 h is divided by the average amount that one animal eats. For this assessment, it is necessary to make certain corrections, because some species of mouse-like rodents accumulate food in their underground burrows, as well as the fact that animals consume other food besides the offered baits [94].

9.3. Methods for Estimating Rodent Numbers in Forestry Practice

In coniferous and especially deciduous forests, the risk of damage caused by rodents increases in some years. Damage can occur to the seeds, i.e., annual yield, or to the stems and roots of young plants. Damage to the seeds of deciduous species is primarily caused and attributed to mice, while damage to the root and stem is most often caused by voles (Figure 4).

Figure 4. Damage to the trunk and root of the oak *Quercus rubor* (Source: Archive of Vojvodina) [48].

The level of potential damage depends on many factors; therefore, the population changes of rodents are very difficult to precisely estimate.

For that reason, in forests grown with beech and oak, it is necessary to conduct long-term monitoring of rodents in order to obtain data on quantitative and qualitative representation of population, to determine the threshold, and to predict the potential population increase. To obtain accurate information about the rodent populations in an area, it is not enough just to estimate the number of rodents. The population age structure and the sex ratio should be continuously monitored. The rodent sexual index (ratio of females and males) indicates the population reproductive potential of a certain species at a given locality. This directly indicates possible population density changes. Sexual index is calculated by formula (Equation (3)):

$$\boldsymbol{SI} = \frac{\boldsymbol{f}}{\boldsymbol{f} + \boldsymbol{m}} \tag{3}$$

where $\boldsymbol{f}$ is number of females of certain species, and $\boldsymbol{m}$ is number of males of certain species.

According to the sexual index, we can determine which sex dominates in the population (the higher the value of the sexual index, the higher the number of females in relation to the total number of individuals), and consequently the reproductive potential of the population, because rodents are polygamous animals [95].

Age groups (age stages or classes) are an indicator of the growth of the population because these groups are closely related to births and deaths. According to Petrović [96], body weight is directly proportional to the age of rodents and can accurately determine the age structure in populations of these small mammals. Voles are divided into five age groups. Based on body weight, body length and tail length, specimens of water vole *A. terrestris* are classified into five age groups. First age group is juvenile or pre-reproductive (weight < 19 g, body length < 30 mm, and tail length < 10 mm), second group is early reproductive phase, third is medium reproductive, fourth is late reproductive (weight 19–120 g, body length 30–160 mm, and tail length 10–80 mm), and fifth is post-reproductive (weight > 120 g, body length 100–200 mm, and tail length 40–105 mm).

Myodes glareolus specimens can also be classified into five age categories, where the first age group is juvenile or pre-reproductive (weight < 17 g, body length < 50 mm, and tail length < 15 mm), second early reproductive, third middle reproductive, fourth late reproductive (weight 17–25 g, body length 45–120 mm, and tail length 10–80 mm), and fifth is post-reproductive (weight 15–25 g, body length 90–130 mm, and tail length 40–85 mm).

Age groups of mice are classified into seven categories. The mouse species *A. agrarius* and *A. flavicolis* are characterized by similar parameters. They are classified as follows: the first and second group consists of juvenile individuals with tail length 20–97 mm, third, fourth, and fifth reproductive units are early, middle, and late reproductive stage with weight 19–34 g, body length 89–106 mm, and tail length 89–108 mm, sixth and seventh post-reproductive individuals are early and late post-reproductive stage with weight 22–40 g, body length 98–120 mm, and tail length 97–116 mm.

Wood mouse, *A. sylvaticus*, is classified as follows: the first and second groups consist of juvenile units of early and late pre-reproductive stage with weight 2–20 g, body length 40–87 mm, and tail length 20–97 mm; third, fourth, and fifth are reproductive units of early, middle, and late reproductive stages with body weight 17–32 g, body length 89–106 mm, and tail length 89–108 mm; sixth and seventh are post-reproductive units of early and late post-reproductive stage with weight 20–38 g, body length 98–120 mm, and tail length 97–116 mm.

In forestry, snap (killing) traps are mainly used for safer analysis of caught individuals and to reduce the risk of bites. Also, in forestry, the presence of rodents can be determined based on the number of active holes or damage to the young plants and twigs that serve as baits.

The advantage of these methods in relation to hunting is that they require less labor and time, but do not give an accurate insight into the number of rodents. The reproduction of rodents is reflected by the the damage to the tree and seeds, bark, and roots of young plants, and if not controlled, the natural process of reforestation, especially pedunculate oak, would be disabled, because seeds and young shoots are the most endangered.

Less damage occurs in forests consisting of beech, ash, and poplar. Apart from direct damage, consequential damages occur in terms of high costs of control and procurement of seeds and seedlings for the renewal of plantations. In forests, several methods can be applied: method of sampling area, transect method (sampling line), least squares method, Y method, method of active holes, method of setting plant shoots as baits, and method of water vole holes counting.

The methods must be adjusted based on the environmental conditions and age of the plantations. According to Wenk [97], the first two methods (method of sampling area and transect method) are mainly used to estimate the number of rodents in European forests.

9.3.1. Method of Sampling Area

In forestry, when estimating the number of rodents on the young of pedunculate oak or other species, at least three hunting areas should be selected where the sampling will be carried out. One sampling area consists of five tree rows and each contains 10–20 snap (killing) traps (Figure 5). The distance between the rows is approximately 6 m, and the traps are 2 m away from each other. Sampling should be conducted where the vegetation is more dense because these parts of forests provide shelter to the rodents.

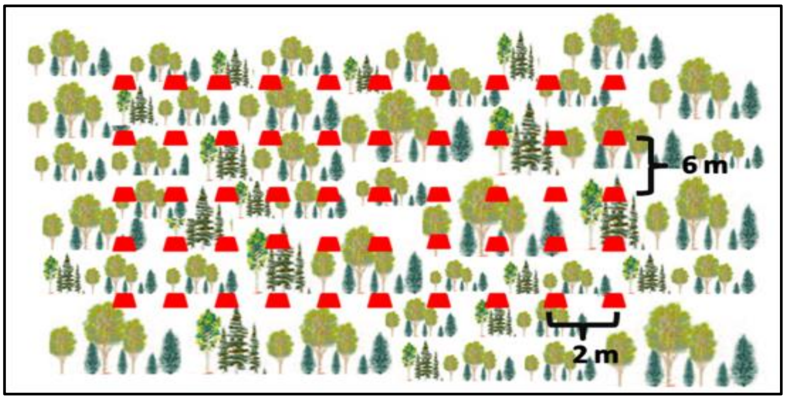

Figure 5. Sampling area with five rows of trees. (Red symbols represent traps for mouse-like rodents).

All traps (50–100 traps) should be inspected 24 h and 48 h after setup. The number of rodents is expressed through relative abundance and abundance index.

9.3.2. Transect Method (Sampling Line)

This method is used in young forests of pedunculate oak and other species. The snap traps are set up in a line with a distance of 2 m. The transect line should follow the configuration of the terrain and include as many different habitat types as possible (Figure 6).

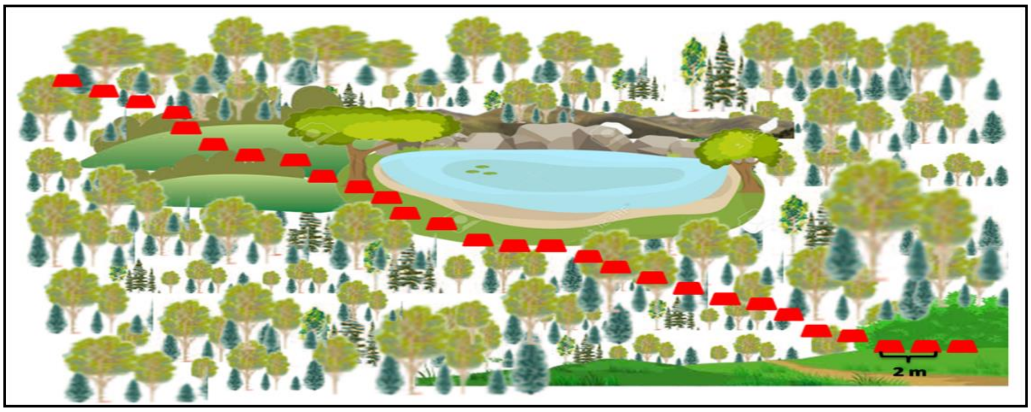

Figure 6. Sampling line.(Red symbols represent traps for mouse-like rodents).

Both methods described above should include 100 traps per method. If the sampling is carried out in smaller area, data obtained with 50 traps are also considered representative. Traps should be inspected 24 h and 48 h after setup.

The relative number of rodents ***RB*** (%) is calculated by the formula (Equation (4)):

$$\boldsymbol{RB}\ (\%) = \frac{\sum \textbf{rodents}}{\textbf{number of traps}} \tag{4}$$

Criteria for treatment:

- Relative number < 20%: no need to apply control measures
- Relative number 20–30%: control measures can be applied
- Relative number > 30%: protection measures should be applied

The abundance index for small rodents using the method of sampling area or transect method can be expressed separately for voles and especially for mice. Since all species of voles are herbivores and can cause vast damage to oak forest offspring by feeding on roots and bark, the abundance index should be calculated either for all species of voles or separately for only one species.

In this case, the species of mice should be neglected, because they feed mainly on various types of seeds. In practice, it is easiest to distinguish mice from voles based on the length of the tail and legs (Figure 7). The abundance index for voles is calculated with following formula (Equation (5)).

$$\mathbf{I} = \frac{\mathbf{100\ LKN} \times \mathbf{\Sigma\ vole}}{\mathbf{modified\ LKN}} \tag{5}$$

where **LKN** is total number of traps x number of nights, **BZSDUG** is the number of traps with other species of rodents including species that accidentally enter the trap, and **BAZBU** is the number of traps with zero specimens collected. Modified **LKN** = 100 **LKN-BZSDUG–BAZBU**.

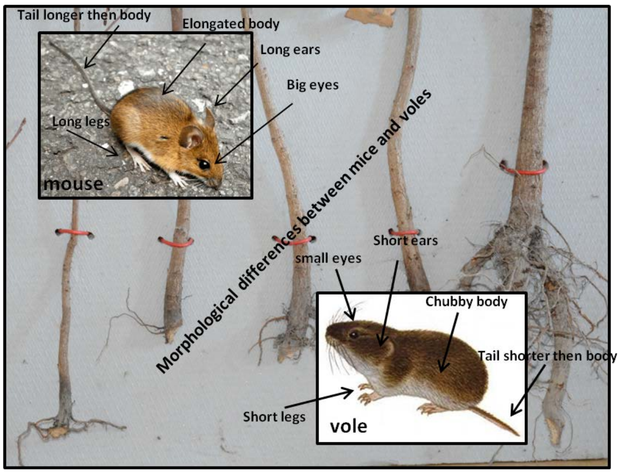

Figure 7. Morphological differences between mice and voles.

Criteria for control method application

The percentage of rodent species, voles in this case, that can potentially do damage to offspring and seedlings was calculated via the abundance index. If the presence of one species of vole (e.g., field voles) is registered with a minimum of 5% per 100 traps, control measures are recommended. If more than one species of voles with a share of at least 10% has been registered, treatment is also recommended.

9.3.3. Method of Counting Active Holes

In the initial phase of afforestation of agricultural or other open areas which are inhabited by field voles, it is required to determine the population size of voles. The method is very similar to the one described for crop production, but the criteria for control measures are different. Four parcels of 250 m^2 should be selected. In those parcels, all visible holes should be filled with soil, and after 24 h, all active (open) holes should be counted.

Criteria

- Threshold of active holes in forest is 2–3 active (open) holes/250 m^2 ($\geq$8/1.000 m^2);
- Threshold in orchatds is 8 active holes/250 m^2 ($\geq$32/1.000 m^2).

9.3.4. Method of Setting Plant Shoots as Baits

Every rodent species has some preferred diet, and that type of diet can be successfully used as bait. Knowing the biology of the species, this method can be applied to meadow, field, and forest voles. The ideal bait is young apple shoots up to 1 cm in diameter and up to 60 cm long. On grassy areas, shoots are pricked at about 10 cm at a 2 m distance and should be inspected daily for 14 days.

Criteria

- If there is damage on >20% of shoots by the second day, control measures should be carried out.

9.3.5. Method of Counting Water Vole Holes

The water vole is a species that bury all entrances and exits of its shelters. If the habitat is rich in grass and other vegetation, it is very difficult to detect this species. When the holes are found, they are marked and opened with a spatula or a small shovel. After 48 h, holes should be checked again to determine if they are closed. Open holes indicate that a vole is present, but it is not possible to estimate their number.

9.3.6. Least-Squares Method

In cases when certain quantitative and qualitative characteristics of rodent populations such as age structure, sex, birth rate, and health status should be determined, the least-squares method is recommended. Two traps are placed in defined square fields (sampling places). The square consists of 16 × 16 m with a distance of 15 m, which practically means that 512 traps have been set up on the area of 5.76 ha. The animals are collected for 5 days.

9.3.7. Y Method

Rodents are collected with the help of specially designed cylindrical vessels. The traps are arranged at a distance of 5 m in three Y-shaped directions. The animals fall into a hunting trap, after which they die, and the collection lasts 5 days. This method also has many disadvantages; for example, the procedure to set up traps is time-consuming because traps need to be buried in the ground.

10. Identification Keys for the Most Damaging Species of Rodents

In order to identify the type of rodent, morphological characteristics should be observed. Since a large number of characteristics are used to identify rodents, only those that are most important for the rodents as pests in forestry are presented below [16]:

(a) Body length (measured on ventral side from the end of the muzzle to the anal opening)
(b) Tail length (measured from base to end without distal hairs)
(c) Paw length (measured from the end of the heel to the end of the longest toe without claw)
(d) Number of toes (front and back paws)
(e) Claw shape (blunt, sharp, retractable, non-retractable)
(f) The cuticle between the fingers (exists, does not exist)
(g) Pads on the feet
(h) The shape of the tail and its coverage with different hair shapes
(i) Ratio of body and tail length
(j) The shape of the lateral and predial protrusions on the skull
(k) Formula and structure of teeth (incisors, canines, premolars, and molars)
(l) Diastema-toothless (distance without teeth between incisors and molars)

10.1. Identification Key for Family Muridae, Subfamily Murinae: Mouse-Like Rodents

Body with head longer than 130 mm, upper molars longer than 5.5 mm.

(a) Tail shorter than body, ear straightened, toes connected by cuticles, dorsal region gray, abdominal region whitish (*R. norvegicus*)
(b) The tail is longer than both body and head, the ear reaches the eyes, the fingers are free, the dorsal region is black, the abdomen is dark gray (*R. rattus*)

Body and head together shorter than 130 mm, upper molars shorter than 5.5 mm.

(a) Body and head longer than 70 mm, ears longer than 1/3 of the head, dark longitudinal stripe present on the back, females have four pairs of breasts (*A. agrarius*)
(b) The dorsal region is brown or reddish. It always has a small yellowish to brown chest pattern. The foot is shorter than 23 mm, the length of the upper molars is <3.9 mm (*A. sylvaticus*)
(c) There is a large colored pattern on the chest, feet longer than 23 mm (*A. flavicollis*).

10.2. Identification Key for Family Muridae, Subfamily Arvicolinae (Microtinae): Voles

Small animals with body length shorter than 200 mm.

(a) Body length 120–180 mm. The length of the tail exceeds half of the body length. The ventral region is dark, the number of pads on the feet is five, the number of breasts is eight (*A. terestris*);
(b) Body length is less than 120 mm. The length of the tail does not exceed $\frac{1}{2}$ of the body length. The eyes are extremely small. The number of pads on the feet is five. Behind the fourth interdigital pad there is only one tarsal. Females have four breasts (*Pitymys subterraneus*);
(c) The eyes are big, the number of pads on the feet is six, females have eight breasts. The dorsal region is rusty-colored (*Myodes glareolus*);
(d) The dorsal region is gray or gray-brown, the length of the tail corresponds to 1/3 of the body length, the foot is 14 to 17.3 mm long (*M. arvalis*);
(e) The dorsal region is gray or gray-brown, the tail length is 1/3 of the body length, the foot length is 18.8–20 mm (*M. agrestis*);
(f) The fur is brown, the ventral abdominal region is lighter than the dorsal, (yellowish brown), the body length without tail is 35–40 cm, the tail is long, flattened, and covered with scales, eyes small and round, ears are small and hidden in dense fur, hind legs with strong claws (*O. zibethicus*).

10.3. Identification Key for Fam. Gliridae: Dormice

Nocturnal species, whiskers are very developed, some species have a black spot on the face.

(a) There is no black stripe between muzzle and ear, fur is gray-brown, tail along the entire length overgrown with dense hairs longer than 1.5 cm, upper teeth longer than 5.5 mm, on the mandible-lower jaw, there is no opening in the processus angularis (*G. glis*);
(b) Orange-brown fur, tail overgrown with sparse hair shorter than 1 cm, upper dentition shorter than 5.5 mm, on the mandible there is an opening in the processus angularis (*M. avellanarius*);
(c) The black stripe is extended behind the ear, in front of the tip of the tail there is a black colored area, and on the top of the tail is a white tuft; the upper dentition is longer than 4.6 mm (*E. quercinus*);
(d) The black stripe ends before the ear, the tail on the dorsal side is equally colored, the upper dentition is shorter than 4.6 mm (*D. nitedula*).

10.4. Identification Key for Fam. Sciuridae: Squirrel

(a) Eyes and ears normally developed, tail partly covered with hairs, in the lower jaw on each side are four hind teeth (one premolar and three molars), hind leg length is >3 cm, in the upper jaw on each side are five hind teeth (two premolars and three molars). The most common species in our country is the red squirrel (*S. vulgaris*).

11. Integrated Rodent Management (IRM)

Integrated rodent control is a long-standing, science-based decision-making process that reduces risk caused by pests and improves the conventional pest management strategy. The goal of integrated control of rodents is to prevent the presence of pests by combining a series of preventive measures, and on the other hand, to reduce pesticide use to a minimum. Pest control by applying IRM is a precisely planned control program, which includes a combination of biological, mechanical, physical, and chemical measures, continuous surveillance, and monitoring. The integrated approach does not exclude the use of rodenticides but enables efficient and responsible use of these agents in case of rodent overpopulation. Many studies and prediction models in the world show that the best reduction of rodents and protection from them is achieved when chemical control is combined with appropriate modifications of the rodent habitat [98–100]. The modern strategy of rodent control, protection of natural resources, and protection of human and animal health must be based on the application and implementation of several different activities. These activities include changing the conditions of their habitats, monitoring of the presence of potential predators, and targeting the use of the least-toxic rodenticides. An integrated approach should provide an effective strategy for rodent management and rodent control in all areas of agriculture, forestry, and communal hygiene. The integration of all measures aims to optimization in achieving the effects of treatments with a cost effective and environmentally friendly measures. The most important instructions should be based on recommendations given by WHO, ECDC, and FSC [77,101,102] organizations. In order to form an effective program of integrated control of rodents as primary pests, it is necessary to establish an adequate long-term monitoring system of these species based on integrated approach (Figure 8), which would provide a high level of forest protection efficiency, environmental protection, and cost efficiency.

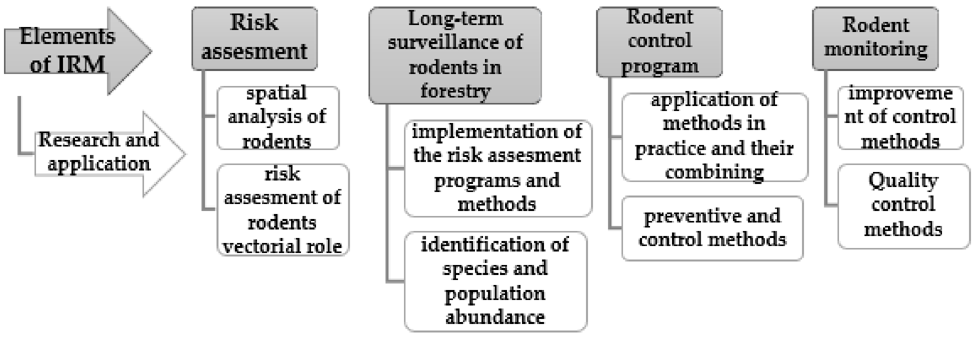

Figure 8. Elements of an integrated rodent management (IRM).

Risk assessment is the first step required in a rodent control program. Rodent species identification, distribution, and behavior contributes to the risk assessment objectives, but also provides an understanding of the transmission cycles of pathogens in which rodents participate. Long-term pest control is achieved by monitoring all relevant factors related to the rodents' vectorial role in the transmission and maintenance of different pathogens, but also monitoring of specific factors that contribute to the maintenance of rodent populations in forest ecosystems and indicate where to apply control measures. In many European countries, there is a clear need for better rodent control in forestry, which would provide better risk assessment. The control program includes a series of individual or combined indirect or direct measures aimed to prevent rodent overpopulation (e.g., preventive measures, biological control, and chemical control). In practice, rodent monitoring is carried out by constant sampling from nature and monitoring the occurrence and maintenance of rodent populations in different ecological conditions, which enables a successful integrated program of forest protection.

Control of rodent populations is very complex, and it must be done professionally and in a timely manner. Unprofessionally performed procedures during rodent control can have long-term and unforeseeable consequences for humans and all untargeted animal species [103]. Regarding the damage caused by rodents, it is necessary to implement rodent management in order to control or reduce its population.

Preventive measures are aimed at removing wild vegetation, which is an optimal habitat for rodent development. Comprehensive hygiene control in storage facilities and warehouses is also necessary in order to remove the conditions that enable rodent survival.

Mechanical methods include different types of traps. They are mainly used to determine rodent population size.

Biological methods are a natural mechanism for maintaining balance in nature. Predators or microorganisms are used as biological control agents to reduce rodent populations. Some of them are several species of bacteria. The natural enemies of rodents are snakes, cats, dogs, weasels, martens, and birds. The best natural predators of rodents are snakes. However, snakes are not selective to the rodents and can not be used in practice. Also, owls are very good rodent hunters, but their range is limited to nests [103].

Chemical measures are most often used to control rodents in agriculture and forestry, and pesticides used to control rodents are called rodenticides. Rodenticides are most often used in the form of baits in solid, liquid, or powder formulations, depending on mode of action and the biology of target rodents. The most efficient mode of action of rodenticides is via digestive tract, and much less effective is the inhalation route [104]. Among the most important rodenticides are anticoagulant rodenticides (first and second generation) and zinc phosphide. Only three rodenticides are registered in Serbia: bromadiolone, difenacoum (second-generation anticoagulants), and zinc phosphide. However, according to the current pesticide application policy of FSC, all three active substances are on the "FSC Highly restricted list" [105]. This means that if the forest owner decides to apply any of these rodenticides in certified forests, their efficiency and economy, or impact on environmental and social values, must be explained in detail in the provided forms [106].

It is necessary to explain whether non-chemical methods (biological or mechanical) or less-toxic rodenticides from "FSC Restricted list" were used. Since there are no rodenticides on the "FSC Highly Restricted List", in the case when rodents' population is high, the application of rodenticides from the "FSC Highly restricted list" is inevitable. Anticoagulants and zinc phosphide are the most commonly used rodenticides globally [107,108]. However, due to their persistence, bioaccumulation, and potential danger to the environment and the public health, they are in conflict with the regulations of the European Union. Anticoagulants and zinc phosphide fulfill the criteria for restrictions, and there have been long-term research and development efforts to find alternative, effective, and safer rodenticides. However, substances that would replace anticoagulants and zinc phosphide have not been found yet, which has resulted in new approvals for the use of these rodenticides. Decision of European Commission 2018/1260 to use zinc phosphide has been extended to 30th of April 2021 [109].

The European Union established various programs to diminish the threat of the rodenticides by replacing those which are now in use with novel environmentally friendly procedures for rodent control. These procedures also include restrictions on the continuous use of certain rodenticides. The European Commission accepted the recommendations of the European Chemicals Agency (ECHA) for the reclassification of currently used anticoagulant rodenticides (European Commission Regulation 2016/1179). Based on this regulation, all available anticoagulant rodenticides must be used in reduced doses of (<30 ppm). Before this restriction, all anticoagulant rodenticides contained 0.005% or more of the anticoagulant dose (50 ppm). Novel commercial rodenticides with low doses represent an important shift in the practice of rodent control, because their use reduces the environmental impact and decreases anticoagulant residues in the environment. On the other hand, the low concentration of the active substance in the product may require the consumption of several baits during one feeding and/or multiple visits to the feeding site due to the estimated lethal dose for target rodent. There is also a reasonable concern for poor efficiency in resistant populations [110].

Rodenticides are needed for the protection of human and animal health, for the protection of food supplies, for the prevention of damage to installations, for the protection of crops in fields, forest protection, etc. Due to their wide use, the rodenticides zinc phosphide, bromadiolone, and difenacoum are approved for use in the European Union and other countries. The largest number of rodenticides is registered for use in agricultural production. In some countries of the European Union, such as Germany and Austria, zinc phosphide has been registered for use in forestry [111]. However, in some countries, such as Croatia, the use of rodenticides is allowed only for use on non-agricultural land [112], while only calcium phosphide is registered for agricultural production [113]. In Serbia, out of the three active substances registered for rodent control, only difenacoum is registered for use in forestry. A long-standing problem related to the use of pesticides in forestry is the limited number of registered compounds for use in forests. It is obvious that chemical companies are not interested in registering pesticides that would be licensed for use in forestry. However, respecting the Law on Forests (Official Gazette of RS, No. 30/2010, 93/2012, 89/2015 and 95/2018-other law) and the Law on Plant Health (Official Gazette of RS, No. 41/2009 and 17/2019), forest owners are obliged to implement protection and improvement of plant health and to implement measures to prevent the introduction, detection, and spread of pest organisms. Therefore, in order to implement integrated protection, forest owners use all rodenticides available on the Serbian market. Exceptions are the protected areas where Ratak Forst (difenacoum) product is allowed, but only after the consent of the Ministry in charge of environmental protection in Serbia.

12. Forest Protection and FSC Standards

FSC (Forest Stewardship Council) is an independent, non-profit, non-governmental organization founded with the aim of promoting responsible forest management worldwide. Forest certification is a process by which the certification body, as an independent third party, provides a written guarantee (certificate) that a product, method, or service complies with certain requirements of the standard. It is one of the most flexible tools that can be used to adapt forest management to modern concepts of sustainable management. There are several forest certification systems in the world, and FSC is one of the most well-known. FSC certification proves that the product originating from the forest was not created by uncontrolled use of forests. In addition, chain of supervision (Chain of Custody, or CoC certificate) can be certified, i.e., the entire production process from forest production to the final product and marketing. The public company "Vojvodina šume" received the FSC certificate in 2008 and hence became an internationally recognized company with the guarantee that its forest resources are managed in a sustainable manner. According to the FSC standard, "Vojvodina šume" is obliged to use an integrated pest management system in order to reduce the pesticide application in certified forests. Protection measures planning and application of pesticides should be performed according to the relevant national legislation and according to the requirements of the FSC policy.

FSC is applicable in almost all forestry areas of mechanical and chemical wood processing. Wood could be FSC-labeled after validating the whole system via inspections that verify the quality of wood product. The label with the FSC logo represents a reliable link between the responsible production and rational use of wood, to the cutting of forests that are under the strict expert control, to the final wooden products.

The FSC standard is based on many criteria and indicators defined in 10 major principles. This standard describes how the forest should be managed in order to fulfill economic, environmental, social and cultural requirements. Therefore, with the FSC certification of forests, "Vojvodina šume" is obliged to apply pesticides in accordance with the requirements of the FSC Pesticides Policy (FSC-POL-30-001 V3-0 EN and FSC Lists of highly hazardous pesticides FSC-POL-30-001a EN, May 2019). FSC gave a list of prohibited pesticides, the use of which are not allowed in FSC-certified forests. Pesticides that are on the "FSC Highly restricted list" and "FSC Restricted list" can be used in FSC-certified forests by filling the ESRA form (Environmental and Social Risk Assessment template). In that case, preference must be given to active substances that are on the "FSC Restricted list". The new policy aims to reduce the use of pesticides in certified forests and to encourage the use of alternative methods that will be effective and less harmful to the environment [106]. When using pesticides in certified forests, precaution measures must be taken to prevent and diminish the negative impact of pesticides on the environment and human health [102].

13. Evaluation of Rodent Control Measures (Treatment Quality Control)

After the number of rodents is determined by one of the given methods and chemical treatment has been carried out, it is necessary to determine the reduction (percentage) of rodent populations, i.e., the efficiency of chemical treatment. The treatment is considered efficient if the reduction of rodents is ≥70%. The Henderson–Tilton formula is used to calculate the efficacy of the applied control measures.

Henderson–Tilton Formula

Number of rodents collected by traps should be determined before the chemical treatment. Sampling is carried out for 2–3 days. The same procedure should performed on the control site (which will stay untreated). After two to three post -treatment, the rodent sampling should be repeated to evaluate the efficiency of performed measures. Efficacy is calculated by the formula [114] (Equation (6)):

$$\boldsymbol{M}\% = \mathbf{100} \times (\mathbf{1} - \frac{\mathbf{T1} \times \mathbf{C1}}{\mathbf{T1} \times \mathbf{C2}}) \quad (6)$$

where ***M*** is efficiency in %, **T1** is number of rodents in treated plot before treatment, **T2** is number of rodents in treated plot after treatment, **C1** is number of rodents in control plot before treatment, and **C2** is number of rodents in control plot surface after treatment.

Reduction of the rodent population as calculated by Henderson–Tilton's formula could also be estimated by using the number of active holes or the eaten amount of non-poisoned baits.

14. Conclusions and Future Perspectives

The control of synanthropic and hemisynanthropic rodent populations is extremely difficult and complex. Rodent surveillance and control programs should be carried out continuously every year. These programs should be performed as long-term continuous research and monitoring of occurrence and all other relevant parameters of the rodent population. Rodents are reservoirs and vectors of a large number of pathogens (viruses, bacteria, rickettsia, protozoa, and helminths) that are dangerous for human and animal health. In cases of overpopulation, rodents cause great economic damage by destroying and contaminating food intended for human and animal consumption. By taking into account the above-mentioned methods and techniques for sampling, monitoring, and controlling rodents, highly efficient rodent prevention can be achieved. Depending on the available knowledge on the pests, integrated rodent management and surveillance should be applied in all areas at risk of rodent damage, such as agricultural, forest, and public areas.

Rodenticides should be used in a way that protects public health, agricultural production, and the environment. Integrated rodent management optimizes the strategy against the rodent pest populations and aims to reduce costs and to protect the environment. The most important recommendations and guidelines are provided by international organizations such as WHO and ECDC and should be followed when a rodent control plan is created. The goal of integrated rodent management is to combine different control methods in order to achieve a higher level of efficiency, sustainable management, cost reduction, and environmental protection.

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