Management of the Common Vole in the Czech Lands: Historical and Current Perspectives

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Abstract: The integrated management of a serious agricultural pest, the common vole (*Microtus arvalis*), should be based on modern and empirically proven approaches. The aim of this paper was to map the historical development of the monitoring and control practices of the common vole in the Czech Republic (CR) territory. Published records of vole population outbreaks and heavy crop damage have been documented in the Czech literature since the turn of the 20th century, and even in crops planted in highly fragmented and diversified agricultural landscapes. In the CR, systematic state monitoring was introduced in 1955. In the 1930’s, there were more than 100 various rodent preparations against the common vole, which were formulated as smoke generators, gases, baits, dusts, toxic mushy mass, and insecticide sprays. Currently, there are only six preparations with three active ingredients registered in the CR. Zinc phosphide is the only active ingredient that has been used from the 1940s to the present, whereas anticoagulants were banned for vole control in 2011 owing to the high environmental risks. The poisoning of nontarget animals by rodenticides is not a new phenomenon tied to synthetic pesticides; poisoning by botanical extracts (strychnine) was documented more than 100 years ago. This review may provide both historical lessons for current practice and new incentives for future research.

Keywords: baits; IPM; landscape fragmentation; *Microtus arvalis*; rodent pest control; rodents; secondary intoxication; Stutox; zinc phosphide

1. Introduction

The common vole, *Microtus arvalis* (Pallas, 1778) (Rodentia, Cricetidae), is one of the pest rodents that commonly occurs throughout most of Europe, including the territory of the Czech Republic (CR) [1,2]. This rodent prefers dry treeless habitats with plant cover. The common vole is an herbivore that occupies open agricultural landscapes, where it inhabits various habitats, such as fields, fallow fields, and meadows, as well as ecotones, including stream banks, ditches, and railway embankments. Of the field crops, alfalfa and clover fields suit it best. Its main occurrence is situated at an altitude of about 200–600 m, but there are data on its occurrence up to 1600 m in the Czech mountains [1–4]. In the CR, the common vole mainly prefers moderately warm climatic regions, and these are inhabited by 79.52% of its population; the geographic areas where there is regular overcrowding of common voles correspond to these areas [1].

The population dynamics of *M. arvalis* are characterised by multiannual cycles that occur at intervals of 2–5 years [2,5–7]. In peak years, the population numbers can reach...
more than two thousand individuals per hectare [8]. This is one order of magnitude greater than other vole species. During population outbreaks, they cause significant economic damage to crops, both in the European Union (EU) [6] and the CR [9,10].

Traditionally, harmful pest rodents have been viewed as two distinct groups: either agricultural pests, or hygiene pests such as rats [11]. However, voles not only cause crop-feeding damage, but they are also competent hosts of larval *Ixodes* ticks, and significant reservoirs of many pathogens of medical and veterinary importance, such as the tick-borne encephalitis virus, *Anaplasma*, *Bartonella*, *Borreliia*, *Coxiella*, *Francisella*, *Rickettsia*, and *Salmonella* [12–15]. The increase in their population numbers allows for both the multiplication of disease vectors (ectoparasites) and the acceleration of the intensive circulation of the disease agent. In central Europe, the following zoonoses have been detected in common voles: tularaemia (*Francisella tularensis*), leptospirosis (e.g., *Leptospira grippotyphosa*), and, more recently, the increasingly important tick-borne encephalitis, borreliosis (*Borrelia burgdorferi*), toxoplasmosis (*Toxoplasma gondii*), Q fever (*Coxiella burnetii*), hantavirus (haemorrhagic fever), and alveococcosis (*Echinococcus multilocularis*) [14,16–22]. Therefore, the hygienic and medical aspects of the vole as a pest should be reflected in the risk assessment and the approval of pesticide bait products and control methods.

To minimise damage and health risks, multiple approaches to managing vole populations have been attempted. Usually, their control is carried out through nonchemical (i.e., mechanical and biological) and chemical (i.e., the application of rodenticide products) methods. However, the chemical control of voles, and especially with anticoagulant-based baits, has long been known to cause the poisoning of nontarget species [23,24]. As these cases were widely publicised, some of the media may have presented many issues simplistically and without historical context. Because of the increased emphasis on environmental issues over the last decades, the public may perceive the phenomenon of vole population outbreaks and the poisoning of nontarget organisms as a recent problem that is mainly tied to aspects of modern agriculture.

This paper provides the first historical review of the common vole management in the territory of the present CR and former Czech lands since 1850, including its economic importance, monitoring, and control. From 1850 to the present, the current Czech Republic (the regions of Bohemia, Moravia, and Czech Silesia) was, for most of the mentioned time, part of a geographically and/or politically larger territory: it had been part of the Austro-Hungarian Empire from 1867, an independent Czechoslovakia from 1918, and part of the German Reich (as the Protectorate of Bohemia and Moravia) from 1938. In 1945, Czechoslovakia was re-established as an independent state. However, in 1948, it turned into a satellite state of the Soviet Union: the Czechoslovak Socialist Republic, which was part of Comecon (the Council for Mutual Economic Assistance), which was a trade organization that brought together the socialist states of the Soviet bloc during the Cold War. The independence of Czechoslovakia was restored in 1989, but it was split into Slovakia and the Czech Republic in 1993, and both countries became members of the EU in 2004. This short political history shows that the CR has always been under the influence of various broader geographical and political entities, which must have also always largely affected the concurrent vole-management legislation and technology. Thus, due to these international influences, the authors believe that the presented review has a broader general significance than simply describing local trends that are exclusive to the CR itself.

The review provides evidence that vole population outbreaks, and the ensuing devastating crop damages locally approaching 100% of economic losses to crop production, are not solely associated with modern agriculture, as they were significant even in traditional cropping systems with highly diversified and fragmented agricultural landscapes. Furthermore, we show that the problem of nontarget animal poisoning is not an emerging environmental issue that is associated with the advent of modern synthetic chemical control, but that it has persisted from the very beginning of vole control. We highlight the complexity of effectively addressing the problem of vole management, which requires both a historical-experience perspective and unbiased modern scientific approaches. We
therefore map the history of vole management in the Czech lands by focussing on the major milestones of the development of the monitoring systems and methods of vole control. The authors of this review believe that the historical and current information gathered can provide both lessons for current practice and a starting point for formulating hypotheses for future research.

2. Materials and Methods

A search of the literature sources using ISI Web of Science and Google Scholar was used to find publications that studied common vole control and monitoring concerning the current or historical geographical territory of the current Czech Republic (CR). For the search of the historical resources regarding common vole management (mostly in the Czech language), the library system of the national Moravian Library’s digital library and the institutional library of the Crop Research Institute were used. A book monography by Kratochvíl [25], “Common vole (Microtus arvalis)”, was used as a valuable source of historical primary and secondary references. Finally, a literature search known as the “snowball process” was performed of the reference lists of eligible sources, in a similar way as described in [26]. The latter approach also assisted in the identification of relevant information hidden in the so-called “grey literature”. The key terms used to search the abovementioned databases and resources included, singly and/or in combination, sets of English, Latin, or Czech words that are relevant to common vole management (e.g., “common vole”, “Microtus arvalis”, “monitoring”, “control”, “baits”, “fumigation”, “zinc phosphide”, “anticoagulants”, etc.).

3. Historical and Current Economic Importance of Voles in the Czech Republic

3.1. Economic Losses Caused by Voles in the Past

 Historical sources show how significant a pest the common vole was in the past. During population outbreaks, especially, a lot of information and advice on vole control appeared in the literature, such as in scientific journals [27,28], or in the daily press, where it was presented as information by experts [29] or the farmers’ own experiences [30]. One of the first detailed accounts of a vole outbreak dates back to 1857, when voles were reported to be so numerous in the Prague area that the farmers were deprived of whole crops of cereals, alfalfa, and clover [31]. The common vole was one of the major field pests in the first half of the 20th century, causing average damages of about CZK 50 million per year. This is 5% of all the damage caused by animal and plant pests to field crops [32]. As mentioned in Durdík [33], there were two ordinances that dealt with the control of voles: (i) the Decree of the Governor of the Kingdom of Bohemia of 16 March 1896, No. 42.914; (ii) the Regulation of the Governor of 11 April 1896, No. 59.267. These legislative documents may, among other things, be of interest in terms of comparing the historical and current competences of municipal authorities in the field of protective interventions against common voles. For example, the first legislative document (decree) obliged the mayor of the municipality to order measures in the event of an increased occurrence of the common vole on all the land in the cadastral of the relevant municipality. The second decree required landowners to tolerate these measures, and to cover the associated costs. Additionally, Anonymous [34] lists Government Regulation 78/26 Coll., on the control of field mice and voles. This regulation was an implementing regulation to Act 165/24 Coll., on the protection of crop products.

3.2. Current Economic Losses Caused by Voles

 Currently, the common vole is one of the most important pests of field crops in the CR, but it also causes significant damage to fruit and forest trees by bark gnawing. The damage depends on its population density and the time of year when the maximum population density is reached. The earlier in the season the peak is achieved, the greater the damage to crops. In peak years, it can cause damage up to CZK 1 billion (i.e., EUR
40 million), and especially to perennial forage crops (alfalfa, clover) and grassland, winter rape, and cereals [35].

Extensive damage is also caused to fruit trees, but the damage is only irregularly recorded. In 2006, the losses were estimated at CZK 280 million, which is more than EUR 11 million [36]. Damage to forest-tree species, and especially beech, is also significant and can reach CZK 145 million per year (i.e., almost EUR 6 million) [37]. Most of the damage to tree species occurs in the winter season, but, in recent years, probably due to climate change, significant damage has often been detected in the growing season [38].

The extent of the damage to crops is also considerable. For example, in the area of southern Moravia (the Znojmo region), crops of perennial forage and grassland can be damaged by 80–100% [35]. Plantations of forest-tree species (especially beech) can be damaged even by more than 80% [39]. Plantations of fruit trees on an organic regime (without treatment) can be damaged by more than 90% [36]. Little data is available regarding the extent of the damage to sugar beet in the CR. However, the estimates suggest that they may also be substantial. For example, the losses observed in winter 2019 were around 18 t/ha [40].

The lowland areas of southern and central Moravia, and central, western, and northwestern Bohemia, where vole abundance is highest over the long term, are most affected [9]. The significant damage and intense population dynamics in these areas are also related to the nature of the landscape. A limited number of field crops, such as alfalfa, rape, cereals, and sugar beet, are grown there in large soil blocks of 1 to 200 ha (average: 27 ha) in size, which is 10 times larger than usual in Europe [9]. Moreover, the expanding no-till sowing system has led to better vole survival in the spring period and an increased risk of damage [41].

Large areas of rape (canola), which have been increasing in the CR in recent decades [42], are of great importance, as the rape crop provides better support to voles in winter than cereal crops [43]. It presents a risk, and especially when grown close to winter cereals. Voles leave the rape when it matures and quickly colonise the cereals, causing considerable damage there [44].

Some of the vole population outbreaks are characterised by unusually high abundances and correspondingly severe damage. Such an outbreak was recorded in 2019, and it affected several countries in Europe [6]. In the CR, the total damage in that year was estimated at more than CZK 1.65 billion, or EUR 61 million, which is the highest estimate recorded to date. Voles had already increased in numbers above the threshold of economic damage in May, causing considerable damage not only to the perennial vegetation and rape, but also especially to cereals in the June preharvest period [44].

4. History and Present Status of *M. arvalis* Monitoring in Czech Lands

4.1. History of Vole Population Monitoring

The first attempts to monitor the population densities of the common vole in the territory of the current CR began to appear during the first half of the 20th century, although in a rather haphazard form. The information on vole abundances was based only on reports from farmers or voluntary observers interested in the issue, who had no special training (e.g., Inspector Siegel, Chief Financial Commissioner, or Mr. Šimek, Director of the School of Economics) [27]. Consequently, the information is scattered in various specialised journals, proceedings, and newspapers. Prášil [45] reported that common voles have been damaging crops since 1893, practically throughout the whole territory of the Czech Kingdom, and that increased population densities were also observed in 1901 and 1902, and especially in the southern part of Bohemia. To obtain an idea of the vole numbers, the farmers offered 1 penny for 10 captured individuals. Many farmers paid a total of CZK 100–150, corresponding to about 10,000–15,000 voles on their lands [45]. Farský [27] found that the information on vole abundance is related to the amounts of pesticides applied in individual years (Table 1). From 1893 to 1943, eight population outbreaks were documented (Table 2). The detailed monitoring of the occurrences of voles was summarised by Farský [27], who described the increased vole densities in Moravia from 1920 to 1924. In 1923 and 1924,
especially, the calamity occurrence of common voles covered 90% of the entire territory of Moravia.

Table 1. Usage of rodenticides between 1920 and 1924 [27].

| Year  | Toxic Mushy Mass and Pills (kg) | Strychnine-Prepared Grain (kg) |
|-------|---------------------------------|-------------------------------|
| 1920  | 2100                            | 18                            |
| 1921  | 3430                            | 302                           |
| 1922  | 0                               | 17                            |
| 1923  | 5000                            | 6127                          |
| 1924  | 2500                            | 2707                          |
| Total | 13,030                          | 9171                          |

Table 2. Literature documenting population outbreaks in the first half of the 20th century in the Czech lands.

| Year  | Reference                      |
|-------|--------------------------------|
| 1893  | Prašil [45]                    |
| 1901–1902 | Prašil [45,46]                |
| 1910–1912 | Anonym [47]; Bradáč [48]; Teichmann [49]; Horák [50]; Uher [30]; Kašpárek and Senft [51]; Humpál [52]; Mráz [53] |
| 1915–1917 | Straňák [54]; Straňák [55]; Řepa [56]; Batiš [57] |
| 1919–1925 | Jičínský [58]; Farský [59]; Anonym [60]; Farský [27]; Anonym [61] |
| 1927–1930 | Baudyš [62]; F.B.P. [63]; Anonym [64]; L.V. [65] |
| 1936–1940 | Sedláček [66]; Anonym [67]; Blattný et al. [68] |
| 1943  | Klúz [69]                      |

Various population indices have been widely used to monitor the relative population sizes of many pests and game species to aid their management. Estimates of the population density are the basic tool in vole population management, as many phytosanitary decisions critically depend on them. Population-density estimates are necessary for the quantitative forecasting of the population densities in the next year. They are indispensable to the decision on the efficacy of the control treatments. Population estimates are easily mapped to give farmers very useful information on the range of vole densities and the areas affected by the vole population outbreak. In agricultural practices, it was clear from the beginning of the 20th century that the abundance should be monitored by a uniform method. Initially, only the high-abundance areas, where the damage exceeded more than 25% of the winter crops, were monitored [70].

Since 1955, an index of reopened burrow entrances has been extensively used in central Europe to monitor common vole populations by the State Phytosanitary Administration of the CR. This index is based on the counts of reopened burrow entrances in five quadrats of a $10 \times 10$ m size. On the first day, all entrances are closed by trampling out. On the second day, the quadrats are checked for the number of reopened burrow entrances. The sum of the reopened entrances from all the quadrats is then multiplied by 20 to obtain the index of the common vole density per hectare.

Based on extensive research [25], the Ministry of Agriculture, Forestry and Water Management of the former Czechoslovak Socialist Republic issued a new norm of protection against the common vole in field crops [71]. According to this norm, effective from 3 March 1964 [72], vole population densities were classified into four categories: low, medium, high, and extremely high (Table 3). The method was re-evaluated in 1968–1970 by modifying the density category ranges (Table 4).
Table 3. Classification of the common vole densities evaluated per 1 hectare, according to the norm [71] effective from 1964.

| Season          | Low       | Medium   | High      | Extremely High |
|-----------------|-----------|----------|-----------|----------------|
| Spring (March)  | 0–5       | 6–25     | 26–50     | 51 and more    |
| Summer (July)   | 100–290   | 300–990  | 1000–5000 | 5100 and more  |
| Autumn (September) | 500–990 | 1000–2900 | 3000–10,000 | 10,500 and more |
| Winter (January) | 100–290  | 300–590  | 600–1000  | 1050 and more  |

Table 4. Modified density categories of the common vole in 1968–1970, according to a new evaluation. The norm [71] was replaced by a modified norm, effective from 1 March 1983 [2].

| Season of the Year | Low       | Medium   | High      | Extremely High |
|--------------------|-----------|----------|-----------|----------------|
| Spring (March)     | 1–40      | 41–100   | 101–200   | 201 and more   |
| Summer (July)      | 100–290   | 300–650  | 660–5000  | 5100 and more  |
| Autumn (September) | 500–990  | 1000–2000 | 2100–10,000 | 10,500 and more |
| Winter (January)   | 100–290   | 300–450  | 460–1000  | 1050 and more  |

The method of reopened burrow entrances was used in the period of 1964–1998. The method was published by the former State Phytosanitary Administration (currently the Central Institute for Supervising and Testing in Agriculture) and was also distributed as a leaflet. The observed common vole abundances were mapped and published annually in the “Overview of the occurrence of some harmful factors on the crop plants in the Czechoslovak Republic”. This index has been used to survey the common vole populations for many decades. Currently, it not only presents the main tool for management decisions, but it is also a primary source of long-term data for analysing the population dynamics [73]. Considering a sample size in terms of costs and benefits, it was concluded that five quadrats was a reasonable solution, combining the highest efficiency with the lowest possible cost [74].

4.2. Present Status of Vole Monitoring

As the method of reopened burrow entrances was time consuming (2 days) and relied solely on the counts from perennial foraging crops, the Central Institute for Supervising and Testing in Agriculture introduced a cheaper method based on the counts of active burrow entrances that takes just one day and is applicable to other crops as well. The new monitoring method has been implemented since 1 January 2000 (Table 5). It is based on the number of active burrow entrances (showing evidence of vole activity, such as food, fresh faeces at the entrance, vegetation eaten around, burrowing activity, and a smooth opening), as described by Zapletal et al. [2]. The active burrow entrances are counted along four 100 m transects, each 2.5 m wide, situated in different parts of the crop (Figure 1). The sum of the burrow numbers of four plots (1000 m$^2$) multiplied by ten is the burrow index (BI) per hectare. For good visibility of burrow entrances, the optimal height of the crop should be less than 15 cm.

Table 5. Classification of vole densities according to a new monitoring method based on counts of active burrow entrances [2].

| Season      | Low   | Medium | High     | Extremely High |
|-------------|-------|--------|----------|----------------|
| Spring      | 10–40 | 50–200 | 210 and more |
| Summer      | 10–200| 210–600| 610 and more |
| Autumn      | 10–400| 410–2000| 2010 and more |
who discriminated five basic groups: (1) mechanical methods (pouring, irrigation, etc.); (2) fumigation; (3) poisons; (4) predator protection; (5) unspecified “secret” means. Later, Blattný [32] divided these agents into four groups: (1) effective toxic agents; (2) natural enemies; (3) mechanical means; (4) natural physical measures. In general, the distribution of vole-control methods was very similar to what we have at present.

### 5. Methods of Controlling Common Voles

In the first half of the 20th century, many different means of vole control were used. One of the oldest categorisations of vole-control methods was suggested by Prášil [45], who discriminated five basic groups: (1) mechanical methods (pouring, irrigation, etc.); (2) fumigation; (3) poisons; (4) predator protection; (5) unspecified “secret” means. Later, Blattný [32] divided these agents into four groups: (1) effective toxic agents; (2) natural enemies; (3) mechanical means; (4) natural physical measures. In general, the distribution of vole-control methods was very similar to what we have at present.

#### 5.1. Agrotechnical Methods of Control and Landscape Management

The current strategy for the implementation of farming conditions in the EU ((GAEC) good agricultural and environmental conditions; standards aiming to achieve sustainable agriculture [76]) and the Czech Republic (DZES 7d: the national equivalent of GAEC) has a requirement for the fragmentation of large fields to reduce the size of one soil block to below 30 ha. The central idea of this strategy is to increase the heterogeneity and species diversity of the landscape by breaking up large monoculture blocks. In terms of the population dynamics of the common vole, it is even expected that this will lead to a reduction in the breeding intensity and average abundance.

**Figure 1.** The spatial pattern suggested for situating the sampling transects within the field with sizes (a) above and (b) below 20 ha [2].

The Czech Plant Protection Service collects data on common vole densities using the system of monitoring points, covering the whole territory of the CR (76 districts). Data are collected twice a year: in spring (February–May) and autumn (October–December). If needed, in times of common vole outbreaks, monitoring is extended to cover winter and summer as well.

In each district, proportionally to its size, 10 estimates should be performed per each 20,000 ha of the agricultural land. Crop fields should be larger than 5 ha. Fields larger than 20 ha can be sampled more times. Besides forage crops (alfalfa, clover, meadows, orchards), various other crops suitable for common voles are checked, such as cereals, rape, sugar beet, potatoes, and others.

Each estimation includes the district and location name, date of monitoring, GPS coordinates and altitude, crop (biotope), stage of crop development, field size (in ha), number of active burrow entrances, remarks for other relevant conditions (e.g., rodenticides), precrops, and so on. Detailed information on the monitoring of harmful organisms is available on the web, but in Czech [75].
Among the mechanical methods, several procedures to be directly applied by farmers were proposed, such as the use of traps, soil tillage (deep ploughing), threshing voles with a broom behind a plough, or drilling holes in an infested plot [45]. In addition, Blattný [32] also included watering burrows with water or liquid manure in the mechanical methods. A very interesting method that could be implemented, even today in organic farming, is to create ditches around fields, with dug holes at distances of 4–5 m, where voles are caught [59,62]. Recently, this method was extended by Schlötelburg et al. [77], who suggested a technique that combines mechanical and biological control by self-service traps that are inspected by avian and terrestrial predators. Such methods not only prevent the spread of voles from the infested field, but can also protect against reinfestation after treatment from the surrounding field.

Among the various farming practices (vegetation height, mowing, mulching, harvesting, and ploughing), only ploughing can suppress common vole populations [41,78]. Hence, the currently preferred no-tillage farming may enhance common vole infestation [9].

The way to achieve fragmentation is to implement breakaway strips. From the vole perspective, there is a risk that, if grassed, the strips may accommodate the common vole, which, in turn, may lead to an increase in its abundance, with subsequent migration to the surrounding stands. Scientific evidence shows that vole numbers in agricultural landscapes can be significantly affected by linear strips of vegetation, which induce a field-margin effect with higher vole numbers and, thus, have higher potential for damage to adjacent crops [79,80]. This is because these field-edge habitats provide relatively stable conditions for voles in agricultural areas [78,81,82]. The vegetation at field edges, either in the form of linear strips of seminatural vegetation or nonlinear habitats, such as perennial forage, fallow fields, and ruderal, represents key habitats for vole distribution [83]. As a result, it plays a role in damage occurrence as refugia, from which voles disperse into crops [79]. However, some crops, and especially rape (canola), also exhibit edge- or field-margin effects [44]. In the CR, the influence of the field-margin effect has not yet been practically studied. Given the planned introduction of measures to reduce the size of soil blocks using vegetation strips, this issue is completely new.

Similarly, very little can be found on the effect of the size of the area sown and the structure of the landscape. While the effect of the plot size on the abundance dynamics has not yet been studied at all, the lack of landscape heterogeneity has been credited as a decisive influence on the emergence of cyclic population dynamics in France [84]. There is a need for further research in this field.

5.2. Biological Control
5.2.1. Mammalian and Avian Predators

In the past, as well as in recent decades, there has been a strong interest in understanding the role of natural enemies in small-pest-rodent population dynamics, and the involvement of such knowledge in practical pest control [85–87]. Blattný [32] provided one of the first published lists of the natural enemies of the common vole, which included not only cats, dogs, weasels, foxes, buzzards, owls, crows, jackdaws, and ravens, but also vipers. More than a decade later, Balát et al. [88] documented that the common vole is an important food source for more than 66 bird species. Grulich [89] found that at least 21 mammal species were feeding on common voles in Czechoslovakia. Although the effect of raptors was considered beneficial, it was not considered effective enough for vole biocontrol in the 1950s [25], nor in the 1990s [90]. The only more recent work that deals with the use of raptors to control voles in the CR is that by Machar et al. [91], which focussed on the importance of the installed perches for the abundance of raptors during two vole outbreaks. The densities of some raptors were found to be lower in fields without installed perches than in fields with installed perches. Unfortunately, there is little research documenting the potential of predators to control, or at least suppress, vole populations.
5.2.2. Microbial Methods

The use of bacteria to control common voles has been studied since the 1880s, and has been published in several scientific papers, especially by Löffler (Loeffler), Mechnikov, Danysz, Ivaščenko, Gamaleu, Bahr, etc. [25]. Since 1890, various bacterial cultures have been used to control common voles in many countries (e.g., Germany, Denmark, etc.). The pathogens of the microorganisms *Salmonella enteritis* and *Salmonella typhimurium* were most often used under various names, such as *Bacillus Löffleri*, Danysz culture, Merežkovsky culture, Ratin culture, etc. [90]. In 1890, Löffler discovered that the typhus bacteria were the cause of the mass death of these pests, and, as early as 1892, the preparation was successfully used to control outbreak voles in Thessaly (Greece) [32,46].

In Bohemia, the first-mentioned uses of Loeffler’s bacillus for the control of common voles date back to 1895 and 1897, and, since 1902, this product has been used extensively [46]. In the early years of the use of these preparations, many authors praised them in terms of the safety for nontarget organisms. Prášil [46] stated that typhus only destroys voles and is harmless to other animals. Mráz [53] recommended the use of typhus preparations as the safest means of controlling voles. Kašpárek and Senft [51] recommended controlling rodents with bacterial preparations as the most effective ones, which cause fatal diseases in mice and voles, but are nevertheless harmless to other animals, which was experimentally proven. In 1942, Blattný pointed out certain disadvantages and problems that the use of bacterial cultures brought into the control of voles. The bacteria used in the Loeffler preparation were shown to be compatible with the bacterium *Enteritidis breslauense*, which contaminates meat and causes enteric infections in humans. Similar problems were found with other preparations, and, for hygienic reasons, their use was banned until the preparation of pure cultures was resolved. Kratochvíl et al. [25] drew attention to the risks of using bacterial cultures for humans, especially children, and livestock, especially calves and piglets. For these reasons, the use of bacteria in the CR has been prohibited by law. As mentioned by Zejda et al. [90], for the reasons given above, the use of bacterial preparations for the control of voles has also been banned by the World Health Organization.

5.3. Chemical Control

The chemical method of controlling the common vole is based on various toxic chemicals (poisons), which enter the body through the lungs in the form of gases or vapours, or orally in the form of various admixtures in baits. Historically, some methods were based on the toxic contamination of the fur or skin by dusts or by toxic greasy and sticky (mushy) mass. The chemical methods of vole control are commonly divided accordingly. Grulich [92] divided the chemical control of voles into three basic groups: (1) poisons that enter the body through the lungs in the form of gases or vapours; (2) poisons that enter the body orally in the form of baits; (3) poisons that contaminate the fur. The formulations have included smoke generators, gases (fumigants), toxic baits (grain/pellets), toxic mushy mass (spread on stalks or twigs), dusts, and sprays.

Over the history of vole chemical control, a great variety of active substances/ingredients have been used, or at least tested under field conditions. They include, among others, strychnine preparations, sodium arsenate, calcium arsenate, calcium arsenite, arsenic oxide, sodium fluorinate, sodium fluorosilicate, barium carbonate, zinc phosphide, calcium phosphide, aluminium phosphide, phosphine, alphanaphthylthiourea, phosphorus, anticoagulants (e.g., bromadiolone, brodifacoum), and insecticides (dichlorodiphenyltrichloroethane (DDT), toxaphene, endrin, etc.) [25]. Sulphur dioxide (SO$_2$) was the main active substance for smoking. Apart from solid particles, the burning process also produces invisible gases (CO$_2$, CO, SO$_2$, etc.) that may, depending on the concentration and length of exposure, have some insecticidal action. Smoke generators produced by pyrotechnic formulations consist of ready-to-use pyrotechnic combustion mixtures (dusts, granules) containing registered synthetic or natural compounds [93]. They are ignited to produce a defined volume of dense white or grey smoke and toxic gases. Some combustions of pyrotechnic fumigation cartridges containing sodium nitrate (NaNO$_3$) and charcoal-carbon (C) produce toxic carbon
monoxide (CO), along with gaseous nitrogen (N\textsubscript{2}) and solid sodium carbonate (Na\textsubscript{2}CO\textsubscript{3}). Such cartridges are mainly used for the control of pest vertebrates in burrows [93–95].

Currently, there are only six preparations registered in the CR [96]. In contrast, before the Second World War, more than 100 rodenticide vole-control agents were used in central Europe (including the Czech lands), manufactured by small producers or drugstores [92]. According to Kác [97], 31 poisonous traps were on sale under various names in Czechoslovakia by 1948. This was very similar to what was documented for the historical use of insecticides in stores [93]. These small producers had limited opportunity to keep stable standard/defined compositions of these products. Research institutes have contributed little to studying this problem [25].

In the second half of the 20th century, there were great changes in central Europe, which were also reflected in the control of voles. The effectiveness of vole-control products had begun to be tested. Ineffective or very toxic preparations were removed from the market or from registration [25]. Out of all the active ingredients, only zinc phosphide successfully passed the tests, whereas most of the others (including anticoagulants) were used only for a limited time in the CR.

5.3.1. Research and Preparation Used in the Early 1900s

The work of Farský [27,98,99] is considered a basis of the early Czechoslovak scientific literature on common vole control. He experimentally tested the efficacy of the control methods in the laboratory and under field conditions. Kratochvíl [25] noted that his results became an inspiration for the following works by Traut and Semenov [100,101]. For example, Farsky [99], among other things, found that all dough pills, formerly very widely produced and used, spoiled very soon, and were rejected by voles as food. He even warned that: “Farmers are not advised to use the pills or any preparations at all which are recommended by various firms. It is very often a mere gimmick whose sole purpose is to pull money out of the farmer”.

The spectrum of chemicals used to control voles worldwide was much wider during the first half of the 20th century, and it included substances such as zinc phosphide, red squill/plant sea onion (extract from Drimia maritima, Asparagaceae), strychnine (an alkaloid from the seeds of Strychnos nux vomica, Loganiaceae), thallium sulphate, phosphorus, and arsenic [97]. However, many of them have been withdrawn for their unacceptable effects on human health and wildlife, such as arsenic and white phosphorus. As stated above, very few of the substances (zinc phosphide) can still be found in practice today [102,103]. However, they may be used in some other countries, such as strychnine in Australia [104]. The commonly used substances included strychnine-coated grain (wheat or dehusked oats), arsenic and phosphorus mushy mass, phosphorus pills, bran pills, barium pills, or a mixture of quicklime and flour [70]. Other substances used in the form of mushy mass, which contained zinc cyanide, white phosphorus, phosphorus dissolved in carbon disulphide, white arsenic, or sodium arsenates [28], were applied to the stalks or twigs, which were inserted into the burrows of voles [28,32,105]. As bait, pieces of bread soaked in a 25% solution of Chilean saltpetre (sodium nitrate = alkali metal nitrate salt) were used [30]. A specific method of controlling voles was to smoke burrows using various substances, such as sulphur or carbon disulphide [28], or sulphur dioxide [27]. As indicated above, many early active ingredients used to control not only common voles, but also synanthropic rodents in general, were of plant origin. The most common poisons were glycosides from the plant sea onion (red squill), as well as extracts of autumn crocus or thistle, black hellebore, white sneezing root, or some poisonous fungi [32]. Tyburetz [106] comprehensively dealt with sea onion for use in rodent control. In addition to the history of individual glycoside discoveries, he also described the toxicity and other important information. The toxicity data are interesting, stating that the lethal dose of sea-onion tissues for mice is 0.01 g/kg of body weight, while it is 40–50 g/kg for dogs and 30 g/kg for chickens. He concluded that all species of birds are tolerant to the poison and tolerate it without harm.
5.3.2. Research and Preparation Used in the 1940s–1950s

Grulich et al. [92] described practical experiences and experiments concerning the eradication of the common vole in the former Czechoslovakia. At this time, five groups of rodenticide formulations were used: smoke generators (smokes + gases), toxic baits, toxic mushy mass, and toxic insecticide sprays. However, it was gradually accepted that the versatility, efficacy, and cost-effectiveness of the baits are the main prerequisites for them to become a successful method of controlling harmful rodents, including voles. The work of Grulich [92] demonstrated that, during this period, both commercially mass-produced rodenticides and homemade rodenticides were still being produced. Because in the 1940s and 1950s, there was not only a high proliferation of vole-control products, but also and especially, an increase in published research, this subchapter is for the sake of clarity and is divided according to the individual formulations.

Cartridge Generators of Smoke and Gas

In the former Czechoslovakia, two types of the original smoke-generating cartridges, Neragen and Druchema, were developed and commonly sold. After ignition, the smoke, containing mainly sulphur dioxide (SO\textsubscript{2}), was blown into the vole burrows. Special devices were constructed to facilitate the handling of the cartridges, and to prevent the gas from dispersing into the area outside the burrows. Grulich et al. [92] tested the gas-penetration rate and efficacy. The efficacies of the two field experiments were up to 80%; the penetration rate (in an artificial hole with a diameter of 4.5 cm and a length of 2.5 m) was 2 min per distance of 2 m. The unsuitability (efficacy vs. applications costs) of this method of controlling common voles was pointed out 30 years ago by Farsky [99]. Because even in the world literature, there is no information concerning the practical experimental evaluation of the use of smoke bombs on common voles, we present the following translation of the whole paragraph from the unique Czech paper by Grulich [92] on this topic: “The gas had a lethal concentration only up to a distance of 4–5 m from the entrance through which it was blown into the burrow. In the vole burrows, the gas progresses much more slowly than in a mole hole. With the high number of common voles there, an average of 2 cartridges were consumed on an area of 64 m\textsuperscript{2}. Thus, to treat the area of 280 ha would have required the consumption of 75,000 cartridges and 1800 working days (200 people would have to work in this orchard for more than a week). The gas seeps very quickly into the ground so that after a short time (1–2 min) the concentration of gas inside the burrows decreases. It is very difficult for the gas to penetrate into blind corners or remote areas of the burrow. One cartridge burns for an average of 12 min. It takes 2–3 min to poison a colony. Therefore, only 4–6 colonies with side passages can be poisoned with one cartridge. Common voles can survive in any overlooked and non-treated burrows, so workers must apply smoke cartridges very carefully. With the relatively high price of the cartridge and the relatively low efficiency, the productivity of the work is very low.”

Toxic Baits

Among the active ingredients for baits, hydrogen phosphide, zinc chloride, zinc phosphide, thallium sulphate (cumulative poison), alphanaphthyl urea, chemically pure strychnine, Castrix (crimidine), arsenic compounds, and sodium fluoroarsenite were used or tested [92]. Zinc phosphide was the most used chemical in Czechoslovakia during the 1950s. According to Martelli [107] and Sorauer (quoted in Sachtleben [108]), this poison was first used in Italy. Later, it became widespread and was used in the former Soviet Union, West Germany, and the German Democratic Republic. As the major advantages of zinc phosphide, Grulich [92] listed the following properties: low cost; low repellency to rodents (either by taste or smell), but rather attractive [109,110]; low lethal dose in common voles (75–150 mg/kg live weight) [110]. The lethal dose for common voles and other harmful rodents was easily achieved when applied on the surface of the bait food. Due to its high effectiveness, it has been recommended by several authors (Farský [100], Dvořák [111], Marković [112], Raška [113], and Zbirovský and Myška [114]). Two ready-to-use com-
mercial baits, Azena and Nera-grain, were introduced on the market in Czechoslovakia. Nera-poisoned wheat was composed of 3.8% technical zinc phosphide (containing about 70% of $\text{Zn}_3\text{P}_2$) in a stabilised oily vehicle, applied to wheat [115].

Grulich [92] claimed that industrially manufactured baits have the following advantages. First, they reduce the danger to workers in the manufacture of the bait on the cooperative or state farm. Second, there is no need to train special workers. Third, there is no need to obtain special permits to purchase and handle poisonous preparations. However, Grulich [92] tested the commercial formulation and found that the efficacy was not that high (57–70%). The observed common voles frequently dug the Azena toxic grains out of the burrows, and the grain was then rolled for a long time in front of the burrow exits. His study revealed that the grain was not fresh, and its quality was low (almost zero germination). Moreover, the long storage of the grain further deteriorated the quality of the finished poison bait, and the bait lost palatability and efficacy. Therefore, he proposed and developed a procedure for making fresh baits with zinc phosphide. The prepared bait can be used within two days after it has been made. The bait was produced by inserting grain into the pickling drum with the appropriate dose of vegetable oil and, after the oil dried, poison was added. The bait was transported in a paper bag, which was placed in a protective jute bag. It was required that the production of the bait be managed by a responsible manager (a plant health officer of the machine and tractor stations of the district), who passed a test in the handling of poisons and was authorised.

Toxic Greasy and Sticky Materials (“Mushy Mass”)

Grulich [92] claimed that the control of common voles with poisonous pastes, saps, and greasy sticky materials—called “mushy mass”—was highly recommended by several concurrent authors (e.g., Markovič [112], Turček [116], Sviridenko [117]). In Czechoslovakia, two commercial products, Antimur and Moratox, were available in the 1950s. Antimur contained 10% of technical zinc phosphide in a stabilised fatty matrix, with the addition of a filler. The effect of poisoning by poisoned straws or wands inserted into burrows depended, to a large extent, on several factors, summarised by Grulich [92] (based on Farský [99]) as follows: “1. Greased straw or wand must be inserted into all the exits from the burrows used because voles would only use an exit that was not poisoned. 2. Voles must get a full lethal dose when cleaning their fur. 3. If the grease is covered with a layer of dirt when engraving new burrows, it ceases to be dangerous to voles. This method of poisoning voles is not highly effective. Its disadvantages certainly include great labour. The worker has to be bent over while working and the straws are inserted very slowly. Therefore, the manufacturer himself recommends using poison traps only in closed rooms (warehouses, crèches, etc.”).

Dusts and Ashes

In this historical period, several authors (Grulich [92], Sviridenko [117], Falkenstein and Vinogradov [118]) reported the possibility of using toxic dusts and ashes to control voles. Calcium arsenate or zinc phosphide (+50% ash) were reported as active substances. The dusting of burrows was carried out with conventional handheld dusters; the dust was blown into the burrows (0.5–1 g of dust per burrow) through a special nozzle at the end of the duster tube. The voles were poisoned by the dust while walking through burrows and while cleaning their fur, when the poison entered their digestive tracts. In addition to this method, plugging vole burrows with plugs of hay or straw that had been dusted with toxins was recommended [112]. The voles emerging from the burrows became contaminated with the powdered poison incorporated into the hay. In the opinion of Grulich [92], this method was too laborious and could only be used on a small scale.

Spray and Dust Insecticides

Surprisingly, in the 1950s, not only in Czechoslovakia, but also in some other European countries, rodents were also controlled by some spray or dust insecticides with toxaphene
or endrin. This trend started with the observation by Kratochvíl et al. [25] that even small rodents perished when harmful insects were killed in the forest by strong doses. According to him [119,120], emulsions of toxaphene at a dose of 4–6 kg/1 ha were highly effective in killing the field vole (*Microtus agrestis*). A dose of powdered toxaphene at 30 kg/1 ha (9 kg of a pure substance) and endrin at 20 kg/1 ha (2 kg of pure active substance) had a similar rodenticide effect.

Grulich [92] carried out the experimental control of the common vole with the German preparation Lepit-Endrin (manufacturer Schering A. G., Bertin-West). On the one hand, the efficacy was close to 100% in most cases, and, in some cases, even when the weather was rainy after spraying. On the other hand, trials with the powder formulation of toxaphene did not achieve satisfactory efficacy. After application with the hand duster “Pulvis”, at a rate of 25 kg of 10% toxaphene per ha, the efficacy was only 16%, and, at an increased rate of 25–40 kg of toxaphene per ha, the efficacy was only slightly higher (38%). The difference in the efficacy between these two preparations was likely caused by the fact that the emulsion of Lepit-Endrin dried on the plant surface and, consequently, was washed off very slowly [92]. Thus, its effect on voles was long lasting. Even during the inspections 14 days after the treatment, Grulich [92] found that individual voles on the marginal strips of the poisoned plots, which had immigrated from the neighbouring untreated plots, were dying after eating plants treated by the insecticide emulsion. Grulich [92] argued that insecticide sprays made it possible to carry out eradication on large areas in a short period of time, with considerable savings in human labour, and without the need to train large numbers of citizens, which are conditions that are considerable disadvantages when laying zinc phosphide or other baits.

5.3.3. Preparations Used from the 1960s Onward

Several new acute active rodenticide ingredients have been further examined for use against common voles [102], from the 1960s up to the present time (Tables 6 and 7). Nevertheless, all of them were banned because of their ecological or public health risks. For instance, endrin was widely used in the 1950s, but its large-scale use was restricted after recommendation by the International Conference on Rodents and Rodenticides in Paris in 1965 [90]. It is important to note that all of the tested active substances (both acute and anticoagulants)/products mentioned in Table 6 were developed/tested for surface broadcast application.

The use of acute poisons decreased after the introduction of anticoagulants in the 1950s. Anticoagulants are rodenticides with a delayed mode of action, which favoured them over acute compounds. They stop blood coagulation resulting in fatal haemorrhage, which occurs within 4–12 days after bait consumption. Another advantage to the delayed intoxication manifestation is the availability of treatment in the case of accidental poisoning. Besides their huge worldwide application against commensal rodents [121], anticoagulants were also introduced for field rodents and have been used simultaneously with phosphine gas products for decades [122]. Because of their persistency in the environment and non-negligible risk of primary and secondary nontarget intoxication (e.g., [123,124]), anticoagulants have been restricted for plant-protection application over time. Currently, although some of these active substances are still approved for use against field rodents (common voles) in the EU and other European countries (e.g., Serbia [125–127]), most national authorities have banned the use of anticoagulant products for these purposes [6].

In the CR, the only anticoagulant preparation used was Lanirat Micro (PROST a.s; CR), which is based on bromadiolone as an active substance (0.005% of bromadiolone + 99.995% of attractants and binders). It was registered as a granulated feeding bait, designed for the control of common voles in broadcast application in crops, including orchards and vineyards. The dosage was 5–10 kg/ha, depending on the crop type and the vole population density. The baits were manually spread (protective clothing and gloves were required) directly onto the area infested by common voles, or were applied by specialised equipment, which allowed for precise dosing and the spreading of the baits over the infested area. To
The treatment procedure in forest stands allowed only manual application to the rodent box stations (1 station per 100 m²) at an initial dose of 50 g per station (dose 5–10 kg/ha). However, there is only one publication that partly evaluates its efficacy under field conditions [91]. Its registration was terminated in 2011 on the basis of environmental safety reasoning, and probably also as a consequence of an incident of the secondary intoxication of black-headed gulls in 2010 [128].

Table 6. Active substances tested for control of common voles in Czechoslovakia during 1957–1977 [90].

| Active Ingredient | Chemical Category   | Mode of Action | Formulation          | Product                  |
|-------------------|---------------------|----------------|----------------------|--------------------------|
| camphechlor       | organochlorine      | acute          | dust, liquid         | Melipax Spritzmittel     |
| endosulphan       | organochlorine      | acute          | liquid               | Thiodan 35 EC            |
| disulfoton + thiometon and O,O-methylethyl-S-(2 ethylthioethyldithiophosphate) | organophosphate + organothiophosphate | acute          | liquid               | Developmental preparation |
| demeton           | organophosphate     | acute          | liquid               | Systox                   |
| thiometon         | organothiophosphate | acute          | liquid               | Intration                |
| dimefox           | organophosphate     | acute          | liquid, grain        | Terrasytam              |
| disulfoton        | organophosphate     | acute          | grain                | Di Syston                |
| zinc phosphide    | anorganic           | acute          | grain, pellets       | Niva zrna, M-Köder, Arrex E, Grazinn pellets, developmental preparation |
| calcium phosphide | anorganic           | acute          | pellets              | Polytanol                |
| aluminium phosphide | anorganic         | acute          | pellets              | Delicia Gastoxin        |
| crimidine         | convulsant heterocyclic compound | acute          | pellets              | Castrix Pellets        |
| scilliroside      | botanical glycoside | acute          | grain                | Rascil                   |
| carbofuran        | carbamate           | acute          | liquid               | Furadan 75 WP           |
| alpha-naphthyl thiourea (ANTU) | organic synthetic compound | acute          |                    | Dirax                    |
| endrin            | organochlorine      | acute          | liquid               | Endrin 20                |
| chlorphacinone    | anticoagulant       | chronic        | grain, pellets       | Developmental preparation, Delicia pellets |
| chlorphacinone + scilliroside | anticoagulant + botanical glycoside | chronic        | grain                | Developmental preparation |
| warfarin          | anticoagulant       | chronic        | pellets              | Neratox                  |
| difenacoum        | anticoagulant       | chronic        | pellets              | Ratac                    |

Table 7. The active ingredients and commercial preparations/formulations for control of the common vole registered in the CR in 2021/2022.

| Preparation       | Active Substance  | End of Sale                            |
|-------------------|-------------------|----------------------------------------|
| Arvalin Forte     | zinc phosphide    | 30 April 2025                          |
| Delicia Gastoxin  | aluminium phosphide | 31 August 2023                      |
| Polytanol         | calcium phosphide | 2 March 2021 (end of sale) and 2 September 2022 (end of use) |
| Ratron GL         | zinc phosphide    | 30 April 2025                          |
| Ratron GW         | zinc phosphide    | 30 April 2025                          |
| Stutox II         | zinc phosphide    | 30 April 2025                          |
Nevertheless, anticoagulants are still widely used for human health purposes (as biocides) against commensal rodents (house mice and rats), both in the EU and the CR, although there has been a long-term effort to replace these products by increasing legislative regulations (e.g., [12,129,130]).

Currently, only plant-protection products and no biocides are registered against the common vole on agricultural land in the CR. Only three active ingredients and six commercial preparations/formulations are currently registered for the control of the common vole (Table 7). All of the registered preparations are acute rodenticides containing zinc phosphide, calcium phosphide, or aluminium phosphide as the active substances. These products cause the death of the rodent shortly after the ingestion or inhalation of the released active substance (hydrogen phosphide). Aluminium phosphide tablets are injected by a special applicator exclusively into burrows or corridors, where they release hydrogen phosphide (which, unlike baits, acts as a respiratory poison).

From the historical and current surveys of preparations, we can see that vole control has been dominated by products that release phosphine gas in both the CR and other countries and the EU [122].

In earlier bait formulations, zinc phosphide dust was applied on the grain-bait surface. Modern pelleted bait formulations homogeneously incorporate zinc phosphide dust throughout the pellet food matrix. The latter technological approach reduces the attractiveness to birds and retards the commonly occurring rapid degradation of this active ingredient by humidity, thereby increasing the bait efficacy. Due to the importance of zinc phosphide baits, the subsequent chapter briefly describes the case history of the development of the original Czech bait that is based on this active ingredient (Stutox).

6. Stutox—A History of the Original Pelletised Bait in the Czech Republic

The structure of Czech farmland, which is composed of many small fields separated by grassy banks of unploughed soil, has changed dramatically with the rise in collectivistic ideology and the transition to communal farming shortly after World War II. By aggregating the fields, the traditional means of plant protection administered by hand quickly turned out to be less applicable to a new agricultural landscape that was characterised by vast fields often exceeding 100 hectares in size. It was soon clear that the entire process of bait administration must be mechanised by surface broadcasting over the whole area of the field. At the same time, it was also clear that a new broadcast bait formulation had to be developed to replace the traditional grain-based baits with long-term persistence in the environment and great potential for hazard to ground-feeding seed-eating birds. In 1978, to resolve this issue, the Institute of Vertebrate Research in Studenec, the Czechoslovak Academy of Sciences, proposed a new formulation of pelletised bait for broadcast purposes called Stutox® [131]. It contained 5% zinc phosphide as an active ingredient, together with other components, such as cereals, dry alfalfa, and milk. To a certain extent, it can be regarded as a perfected successor of a former bait, Grazin, which was introduced early in the 1970s [132]. The recommended dose of Stutox was 5 to 10 kg per ha.

Stutox® was produced by dry pelletisation, with no bonding agent inside. When placed on moist ground, the pellets quickly absorbed water and decayed within 3 to 4 days while losing their attractiveness to voles [133]. The limited exposition time was perceived as a drawback that could potentially reduce the efficacy of the treatment, and not as an advantage for wildlife application. Consequently, the bait was enriched by a small amount of the natural clay montmorillonite to augment the endurance of the pellets under field conditions [134]. The innovated broadcast bait was labelled Stutox-I, and it was in use until 2018. Towards the end of this period, the bonding ingredient was omitted.

Since 2018, Stutox-I has been replaced by Stutox II. Because the registration process of this bait took place in Germany, the composition and application of the bait had to adhere to specific German criteria for zinc phosphide baits. First, the bait concentration of zinc phosphide was halved to 2.5%. Second, instead of surface broadcasting, zinc phosphide baits were now approved solely for application into the vole burrows or by using bait
stations, which strongly limits its use in large fields. This caused a serious management problem to the current vole-control practice, which became obvious during a huge vole population outbreak in 2019 [6]. Being under great pressure from farmers and nature conservation activists, the Central Institute for Supervising and Testing in Agriculture had to issue a one-time permission for Stutox II, allowing farmers to administer the bait by surface broadcasting. This permission-based approach has continued to be used until the present, which is far from optimal. As a result, the entire process of effectively controlling voles in large fields by broadcasting Stutox II pellets has become more complicated in the CR than ever before, thus reflecting the general decreasing trend in the availability of chemical-management options for common voles across the EU over the last 10–15 years [6]. However, the Czech authorities should be aware that EU legislation does not prescribe the placement of bait into burrow openings. The commission-implementing regulation (EU) for zinc phosphide, No. 540/2011 of 25 May 2011, stipulates that it can be authorised only as a rodenticide in the form of ready-to-use baits placed in bait stations or target locations. This regulation is presently still in effect.

The field tests with Stutox® carried out over 10 years (1978–1986; n = 29) revealed the high efficacy of broadcast application, which ranges from 82 to 99%, with an average of 91.7% [135]. For the whole period of use, it kept a very good safety record, with no mass poisoning of wildlife animals observed. This can be partly attributed to the favourable chemical properties and biological effects of zinc phosphide itself [136,137], and partly to the fast disintegration of the bait pellets under field conditions, which, in comparison with grain baits, markedly reduces both the exposure time and the attractiveness to nontarget species, especially birds. Thus, the primary poisoning hazards are low, despite the non-selectivity of the active ingredient to all forms of life. The risk of secondary poisoning to scavengers and predators from eating poisoned voles is low, primarily because most animals avoid consuming the stomachs and intestines of poisoned voles, where almost all the zinc phosphide residues occur [13,138]. Zinc phosphide is a simple inorganic chemical substance that decomposes in moist soils to natural compounds, such as zinc salt and phosphate anion; therefore, no environmental contamination is expected [136]. All of the favourable properties given above resulted in the widespread use of zinc phosphide baits against field rodent pests all over the world [121].

7. Ecological Aspects of Chemical Control
7.1. Surface vs. Subsurface (Burrow) Bait Applications in History and at Present

For the earlier toxic rodenticides, rodenticide baits were recommended for application into burrows [59]. During the 1940s–1950s, most methods were also targeted for application into burrows [92]. With the adoption of zinc phosphide (considered, for many decades, to be relatively safe) during the 1960s–1990s, baits were mainly applied on the surface using modern mechanised application machines [90].

Currently, based on the registered label, baits are applied either in burrows or inside the rodenticide stations. Bait application directly onto the soil surface is allowed only with the exemption permit issued by the Central Institute for Supervising and Testing in Agriculture. In the influential Czech agronomic journal for practitioners, Zapletal and Obdržálková [139] complained that changing the application of zinc phosphide baits from a surface-free to an inside-burrow or bait-station one (all the advantages of Stutox), both in terms of its ecological suitability and farmer-acceptable application technology, have been seriously compromised.

There has been continuing public and expert debates about which method of bait application is effective and economically acceptable, and yet has the lowest side effects on nontarget organisms, in the CR [140]. Recently, the debate has been notably accelerated by the announcement of an exemption for the method of application by broadcast to the soil surface of the rodenticide Stutox II, with the active ingredient zinc phosphide (2.5%). The application methods and risks of the previous variant of this product, Stutox-I (5 %), have been discussed in detail in the past by experts from the State Phytosanitary Administration
(now the Central Institute for Supervising and Testing in Agriculture), and by researchers from Palacky University in Olomouc [2,102,141].

7.2. Chemical Vole Control and Primary or Secondary Poisoning of Nontarget Animals

Currently, there is great interest in assessing the potential of rodenticides (notably, anticoagulants and zinc phosphide) to cause secondary poisonings of nontarget vertebrates in the EU [142,143], as well in the CR [144,145]. The widespread media coverage of this problem often gives a false impression that the primary secondary poisoning of nontarget animals by vole baits is a new phenomenon that is linked mainly to modern agriculture and newly introduced chemical products. However, this perception is far from the reality. In the Czech lands, there is ample evidence of nontarget animal poisoning, and especially of livestock, such as horses [45], that dates back to the beginning of the last century.

Nontarget poisonings were mainly associated with inorganic or botanical (strychnine) baits when presented using grain baits. Many authors were aware of the primary and secondary poisoning hazards to ground-feeding birds and the natural enemies of voles more than 100 years ago [53,59,146]. For this reason, Farský [59] recommended the application of these preparations to the burrows.

At present, most rodenticide baits are produced in a pelletised form, through which the issue of primary poisonings due to long persistence in the field and attractiveness to grain-eating birds was strongly reduced. However, secondary poisoning hazards still exist for anticoagulant rodenticides. In the experiments of Beklova et al. [147], in which the pheasants poisoned with bromadiolone were then offered to caged foxes, the residues of the toxicant in the livers of foxes were low; however, tests of the blood coagulation showed the prolongation of the prothrombin time and activated-partial-thromboplastin time. Recently, anticoagulant chlorophacinone residues in the livers of poisoned common voles, ranging from 82 to 3800 ng/g, were found after large-scale application in Spain, which poses a risk to predators/scavengers [148]. The large-scale surface application of anticoagulant grain baits in Spain resulted in the mortality of grain-eating pigeons and many other vole-eating avian predators [149]. Moreover, in the CR, Mazánek et al. [128] reported a case of mass seagull poisoning by bromadiolone bait in 2010. Although there are no anticoagulant baits registered as plant-protection products in the CR, the anticoagulants may still be used in outdoor conditions for commensal rodent control. Recently, Frankova et al. [150] demonstrated, under laboratory conditions, that some of the used baits may be more attractive for common voles than zinc phosphide baits. For example, in the tests, a food-bait component of Norat ATG (20% wax) for synanthropic rodents proved to be the best-accepted bait by the common vole.

8. Concluding Remarks

The importance of the eruptive common-vole-population dynamics in the CR goes much beyond the economic losses in agriculture. The common vole is well known for its epidemiological significance as a host of several pathogens that cause serious infectious diseases in humans. Its effective evidence-based population management may thus be beneficial to several spheres of human society.

Common vole outbreaks, and the associated extensive economic damage to crops, were common, even in the highly fragmented and biologically diversified agricultural landscape of the historical Czech lands between 1909 and 1930. Thus, devastating common-vole-population dynamics are a manifestation of the innate live-history features of the common-vole biology, and specifically its high reproductive rate, rather than the result of modern farming approaches based on advanced mechanisation and the high use of chemicals.

Occasional accounts of vole calamities were common in the 19th century, but the modern systematic monitoring of the common vole was not started until 1955. Before World War II, more than 100 rodenticide vole-control agents were commonly available in central Europe. In contrast, there are, at present, only six preparations registered for vole control in the CR. Zinc phosphide has been used to control voles for almost a hundred years,
and it is one of the most effective and safest rodenticides in the CR and Europe to date. No anticoagulant baits are currently registered in the CR due to the environmental hazards to nontarget animals. However, further research on the risk of rodenticide treatments to wildlife is needed.

The current strategy, to increase the biodiversity in the Czech agricultural landscape by fragmenting the large soil blocks, sets new goals for the population management of the common vole in a structurally changed landscape. In terms of the population dynamics of the common vole, the transition from a coarse-grained to fine-grained landscape may affect both the breeding intensity and the average abundance. However, evidence is lacking, or even contradictory, as the breakaway strips may accommodate voles. This, in turn, may lead to an increase in the vole abundance, with the subsequent migration to surrounding stands. There is a need for further research.

We also need to improve the monitoring and predictive abilities of the vole management system by building up predictive time-series models to forecast, in advance, the coming population outbreaks as a regular part of the warning system. We know of only one forecasting system implemented in Europe. This is particularly astonishing if the long-term data on vole population densities stored in electronic databases are fully accessible to experts. Despite these great challenges, there is little support from society and state authorities to encourage research in this field. We hope that this historical review of vole control in the Czech lands provides useful lessons for current practice, and that it becomes instrumental for further research on the population management of voles.

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