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Changes in the rodent fauna (Mammalia, Glires) of the region of the Ukrainian Carpathians during the XIX–XXI centuries

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Changes in the rodent fauna (Mammalia, Glires) of the region of the Ukrainian Carpathians during the XIX–XXI centuries. — Z. Barkaszi. — The paper is devoted to the analysis of historical changes in the rodent fauna (superorder Glires) of the region of the Ukrainian Carpathians. The period from the 19th to the early 21st century is considered. Data on natural and artificial species dynamics due to extinction, introduction, re-introduction, invasion, and expansion are generalized. Brief characteristics of species involved into these events are given. It was clarified that new species appeared in the region in the result of expansion (*Castor fiber*, *Mus spicilecus*) and introduction (*Ondatra zibethicus*), while re-introduction of glacial relicts (*Lepus timidus*, *Marmota marmota*), which disappeared during the 19th century, as well as introduction of *Oryctolagus cuniculus* and *Myocastor coypus* were unsuccessful. In addition, two species vanished from the composition of the local fauna: the rare *Eliomys quercinus* and the ancient commensal *Rattus rattus*. A reconstructed checklist of the rodent fauna as of the early 20th century is presented and used in calculations of indices of fauna changes, checklists' ambiguousness, and of fauna rotation for a century. It was shown that quantitative changes of the local fauna for the last century are nonessential (the index of fauna rotation is 10.9 %) because the number of lost species was compensated by expansion and introduction.

Key words: fauna dynamics, expansion, introduction, invasive species, rodents, Carpathians.

Introduction

Biotic diversity appears in all levels of organization, from genes to ecosystems. One of biodiversity's essential features is that it changes dynamically in time and space due to emergence of new and disappearance of already existing components (e.g., alleles, genes, species, communities, entire ecosystems).

The most visible and available to investigate manifestations of biodiversity is the diversity of species. Changes in composition of communities and fauna in general, on both global and local scales, occur constantly, which is a regular process affected by several ecological factors. Obviously, modern dynamics of species and communities are hugely influenced by human activity both directly (extirpation and introduction of species, alteration of landscapes and habitats) and indirectly (climate change, modification of interspecific relations in ecosystems). Transformation of natural landscapes along with climate change contributes to dispersal and naturalization of alien species, some of which exhibit invasive features leading to competition or hybridization with indigenous species often displacing them from the composition of local communities. Upon such changes of fauna, protected areas with minimally disturbed natural biotopes might serve as shelters for indigenous species from displacement by invasive ones (Gallardo et al., 2017), thus proper maintenance and enlargement of the net of protected areas is extremely important for conservation of autochthonous components of fauna.

In addition to real changes in species composition, it is also important to consider another aspect, particularly the level of knowledge, i.e. what we know about species in general, and whether our knowledge is sufficient for our conclusions to reflect the real situation. With the development and emergence of different species concepts more and more new species were described, which were initially included into the Linnaean system of nature, and later into other, more sophisticated,

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taxonomic schemes. Most of the currently recognized species were described right in the 18th–19th centuries, and in the end of the 19th – at the beginning of the 20th century the general picture of 'visible' (recognized) species diversity was already known for many regions (e.g., Austria-Hungary (Mojsisovich, 1887; Paszlavszky, 1918), the Ukrainian SSR (Migulin, 1938) etc.). Later on, owing to new research methods, in particular biochemical, cytogenetic, and molecular genetic approaches, the 'hidden' or cryptic species diversity had been gradually discovered as well, and fauna checklists were complemented by new taxa (e.g., see Pavlinov, Rossolimo, 1987; Zagorodniuk et al., 1997). Obviously, those new species occurred earlier as well in the composition of fauna, but no criteria existed for their identification. In many cases, they 'appeared' due to division of Linnaean species, which often turned out to be superspecies or species complexes, into several taxa.

One of the basic issues of zoological science is to establish the fauna composition and to monitor its changes. This stage in research is necessary for effective population management, game husbandry, planning of conservation measures, etc. At the same time, to estimate the entire spectrum of animals of a given region, in particular the Ukrainian Carpathians as the object of the present study, is a complex task thus model groups are usually selected that are easily available to study and are characterized by relatively high species richness. As the most diverse group among mammals and terrestrial nonflying vertebrates in general, rodents are often used as model group.

The modern mammal fauna of the Ukrainian Carpathians is relatively rich in taxonomic aspect being represented by 82 species (Barkaszi, Zagorodniuk, 2016 a). The checklist of rodents sensu lato, i.e. superorder Glires[1] (order Leporiformes seu Lagomorpha + order Muriformes seu Rodentia) includes 29 species. Among them are species of different origin, in particular invasive and introduced ones.

Data regarding changes of the mammal fauna during the last centuries are known for the territory of Ukraine in general (Zagorodniuk, 2014), although separately for the region of the Ukrainian Carpathians a similar study is conducted for the first time. The aim of the present paper is to generalize data on changes of species composition of the rodent fauna of the region of the Ukrainian Carpathians for the 19th–21st centuries and to show the processes due to which its current state was formed. Additionally, based on the totality of available data, we aim to create a reconstructed fauna checklist as of the beginning of the 20th century and to compare it with the modern fauna composition in order to reveal the volume of its change for the past century.

Material and methods

The methodological base of the present paper follows the research conducted by Zagorodniuk (2007, 2014) regarding the changes of the mammal fauna of Ukraine for the last three centuries. For correct further comparisons our analysis is based on an algorithm similar to that used in the above mentioned works, according to which the objects of analysis are four components of the general checklist of the rodent fauna, in particular 1) *basic fauna list*, including local indigenous species; 2) *adventive component*, including invasive and introduced species; 3) *lost component*, including extinct species; and 4) *phantom component*, including species listed by mistake or with no reason.

The analysis is based on data obtained by generalization of knowledge published by authors of the 19th–21st centuries. It consists of two parts presented in separate sections: 1) real species dynamics due to different bioecological events (extinction, introduction, re-introduction, expansion, and invasion); 2) analysis based on fauna checklists for different periods separately and compared to the former, i.e. reconstructed, state. In the first section, brief essays on species that were involved into each of those events are presented, particularly regarding knowledge about their distribution and state of population. In the second section, the fauna checklist is presented for different periods. The selected timeframes reflect the periods of taxonomic revisions and establishment of views on systematics. Additionally, in this section presented are the calculations of indices of fauna change and of fauna

[1] The author follows the latest taxonomic surveys on the mammal fauna of Ukraine (Zagorodniuk, Emelyanov, 2012) and the rodent fauna of the Eastern Carpathians (Barkaszi, Zagorodniuk, 2016 b).

checklist ambiguousness for each period, and the index of fauna rotation regarding the fauna's current state compared to the reconstructed one as of the beginning of the 20th century (Zagorodniuk, 2007, 2014).

Fauna changes due to species dynamics

Data analysis shows that the rodent fauna of the region of the Ukrainian Carpathians undergone changes due to dynamics of 10 species involved into such events as extinction, introduction, re-introduction, expansion, and invasion. Each event, as well as the species involved, are considered below. Since the interpretation of these events is rather diverse (see e.g., Colautti, MacIsaac, 2004), brief remarks are given in respective sections on how these events are considered in this review.

1. Extinction[2]**.** The Carpathian bow, in particular its Ukrainian part, represents the edge of geographical range of several mammalian species (e.g., *Eliomys quercinus* (Bertolino, 2016), *Sicista betulina, Microtus agrestis* (Barkaszi, 2017), etc.). Accordingly, populations of such species have relatively low abundance, they are totally or partly isolated from the main part of the range, and thus they are under a higher risk of extinction. For instance, one species of dormice (family Gliridae) — the garden dormouse (*Eliomys quercinus*) — has not been recorded in the region for the past 60 years.

- ***Eliomys quercinus.*** The species is widely distributed in Northwest Europe, most of the western Mediterranean islands, and also occurs sporadically in Central and Northern Europe (Perez et al., 2013; Bertolino, 2016). The Carpathians represent an edge fragment of the species' range, and the garden dormouse had been considered extremely rare in the region (Zizda, 2008; Głowaciński, 2011; Murariu, 2015) for many years. The species disappeared from large parts of Central and Eastern Europe (Bertolino, 2016). It was assumed that among the main causes of population decrease are the reduction of available feeding sources, overuse of pesticides, competition with *Rattus norvegicus* (Cristaldi, Canipary, 1976; MacDonald, Barrett, 1993), as well as inbreeding in small populations (Keller, Waller, 2002). However, the exact reasons of range contraction and population decrease of the species remain ambiguous (Bertolino, 2016).

  In Ukraine, reliable records of the species are known from 1965–1986, mainly from Polesia, particularly from Rivne, Zhytomyr, and Kyiv oblasts (Bezrodny, 1991). There is only a single record of the species from the Ukrainian Carpathians collected in 1957 (Dykyy, Zagorodniuk, 2005). The specimen is deposited in the Zoological Museum of Ivan Franko National University of Lviv. It is recorded in the collection catalogue (Zatushevskyy et al., 2010) as the following (translated from Ukrainian by the author of this paper, the specimen's inventory number is given in the Cyrillic original):

  > 2. ЗХ-С/т 2736. Case #6, Box #72. – [Ukraine], Zakarpattia oblast, Rakhiv raion. – Summer. – 1957. – juv. – Study skin.

  Records of the species in the region of the Ukrainian Carpathians had not been reported since 1957 and Korchinsky (1988) excluded the garden dormouse from the fauna checklist. Such point of view was followed later by Zagorodniuk et al. (1997). On the contrary, Bashta and Potish (2007) in their review on mammals of Transcarpathia (Zakarpattia oblast) without additional explanation considered the species again in the composition of the region's fauna. In our recent survey on the rodent fauna of the Eastern Carpathians (Barkaszi, Zagorodniuk, 2016 b), we considered *E. quercinus* a phantom species, although, since new findings of the species have not been reported, it should be considered extinct in the rodent fauna of the Ukrainian Carpathians.

2. Re-introduction. Re-introduction is considered here as releasing into a territory a certain number of individuals of a species to restore the population that formerly existed in this particular area (Frankham et al., 2002). The success of re-introduction is hugely depends on the scale of change of the

[2] Only natural extinctions are considered here. During the 20th century, the black rat *R. rattus* vanished from the composition of fauna due to displacement by its competitor *R. norvegicus*. This case is not considered in this section but taken into account for the respective period in calculations of indices of fauna changes (see further).

local ecosystem, i.e. on whether the newly emerging population would perform its former function in the ecosystem, and if it does so than re-introduction will have a positive effect such as restoration of some lost features of communities and biotopes (Zagorodniuk, 2006). In the region of the Ukrainian Carpathians, attempts to re-introduce two rodent species took place, which are described below.

- ***Lepus timidus.*** The current range of the species covers circumpolar regions of the tundra and taiga, while isolated populations also exist in the region of the Alps (Angerbjörn, Flux, 1995). It was a common species in the Carpathian Basin as well during the Holocene (Pazonyi, 2004), although due to changes in living conditions, mainly because of climate warming, and anthropogenic factors (habitat loss, overhunting, killing by dogs) it was gradually ousted to the upper forest zone and subalpine zone, and eventually disappeared from the region's fauna (Tatarinov, 1981).

  The presence of the mountain hare in the region can be traced to the mid-19th century (e.g., Zawadzki, 1840). It should be mentioned though, that the taxon *Lepus timidus* L. is mentioned in the fauna chapter in a monograph about the former Hungarian Máramaros county[3] (Kardos, 1876), but with a common name 'field hare' which in the Hungarian nomenclature corresponds to the taxon *Lepus europaeus* L. Such substitution of names of these two species occurs in other authors of that time as well, for instance in Czernay (1853) in his book on 'The Fauna of Kharkiv Governorate'. Consequently, there is a reason to suggest that in case of Máramaros and the Ukrainian Carpathians it is also about *L. europaeus*, which means that the mountain hare was absent in the region's fauna yet in the late 19th century.

  Nearly a century later, an attempt to re-introduce the mountain hare took place in order to enrich the mammal fauna of the Ukrainian Carpathians (Tatarinov, 1973). Upon this goal, in 1963, 45 mountain hares were released in Rakhiv and Perechyn raions, Zakarpattia oblast (Fig. 1). The hares became established and their number increased during the following five years, although the population was under a strong pressure of predators, including homeless dogs, and eventually was extirpated (Tatarinov, 1973; Turyanin, 1974). After 1968, there is no information available about the existence of hares in the Ukrainian Carpathians (Khoyetskyy, 2010).
- ***Marmota marmota***. The alpine marmot's geographical range currently covers the highlands of Western and Central Europe, in particular the Pyrenees, Alps, and Carpathians (Mann et al., 1993). Turyanin (1975) mentioned that, in the Eastern Carpathians, the alpine marmot occurred in the Chornohora massif and in the Maramureș Mountains. We can assume that in the second half of the 19th century gradual decrease of the population took place: Hanák (1853) reported on the observation of the marmot on the slope of Hoverla Mt., close to the spring of the Bila Tysa river, while in the late-19th century zoologists noted that the marmot occurs in the Eastern Carpathians only in the Rodna Mountains (Mojsisovich, 1887). On the contrary, Kolyushev (1957, 1964) suggested that the alpine marmot disappeared from the Chornohora later, during World War I. The species obviously vanished from the Rodna Mountains as well, because in 1973 it was re-introduced here and since has gradually increased its abundance (Szabo, 2010; Geacu, Dumitrașcu, 2017). An attempt to re-introduce the alpine marmot took place in the Ukrainian Carpathians as well (Fig. 2): in 1991, six individuals from Slovakia were released in the Carpathian Biosphere Reserve (Lugovoy, 2009), although, eventually, they did not get established (according to other sources (Zagorodniuk et al., 1997) only two individuals were released but both were males).

3. Introduction. Introduction is considered here as appearance of species in territories beyond their native geographical range, which is directly or indirectly due to human activity (Pyšek et al., 2009). Introduction can be either intentional (artificial settlement of animals to enrich the local fauna or because of economic interests such as in case of fur-bearing and game species) or unintentional (escaping from farms, accidental transportation with products and goods, etc.).

[3] Today is part of Ukraine and Romania.

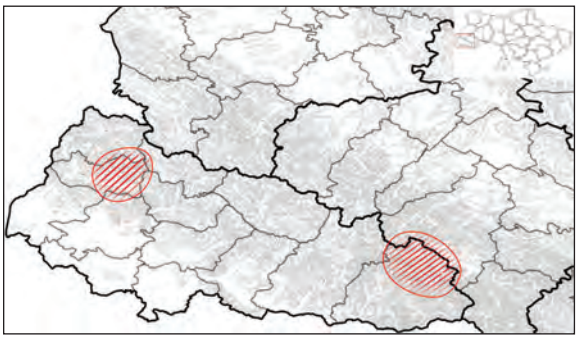

Fig. 1. Re-introduction sites of *L. timidus* in the Ukrainian Carpathians.

Рис. 1. Місця реінтродукції *L. timidus* в Українських Карпатах.

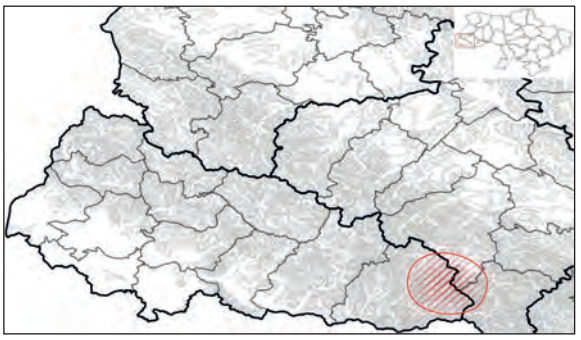

Fig. 2. Re-introduction site of *M. marmota* in the Ukrainian Carpathians.

Рис. 2. Місця реінтродукції *M. marmota* в Українських Карпатах.

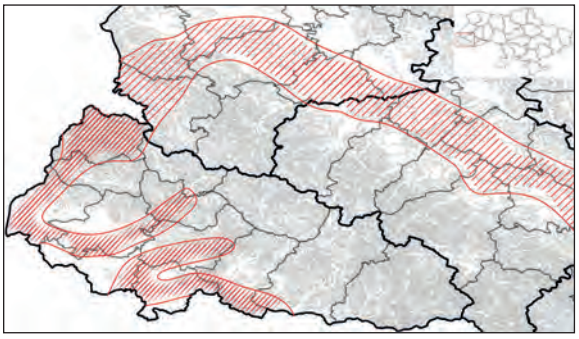

Fig. 3. The current distribution of *C. fiber* in the region of the Ukrainian Carpathians.

Рис. 3. Сучасне поширення *C. fiber* в регіоні Українських Карпат.

Fig. 4. The record locality of *M. spicilegus* in the region of the Ukrainian Carpathians.

Рис. 4. Місця знахідок *M. spicilegus* в регіоні Українських Карпат.

In the region of the Ukrainian Carpathians, during the 20th century three species of rodents were intentionally introduced, but only one became naturalized.

- ***Ondatra zibethicus***. The native range of the species covers almost the entire territory of North America (Musser, Carleton, 2005). In 1905, a few individuals were released in the Czech Republic where a population emerged and the species rapidly dispersed in all directions (Sokolov, Lavrov, 1993; Brzeziński et al., 2010). Besides, in the early 20th century muskrats were kept in fur farms, and animals that escaped also gave rise to new populations (Okarma, 2011).

  Muskrats that appeared in the region of the Ukrainian Carpathians in the 1910s–1920s (in Prykarpattia from Poland, while in Zakarpattia from Czechoslovakia) were derivatives of West European populations (Kolyushev, 1953; Turyanin, 1959). In addition, attempts to introduce muskrats into the region were made in the 1950s as well (Tatarinov, 1973).
  According to Bashta and Potish (2007), in the modern fauna of the region of the Ukrainian Carpathians, the muskrat is a common and occasionally even a quite abundant species of lowland and piedmont areas. It is a little studied species of the region, although we can assume that its population is probably in decline here, just as in some other European countries (Skyrienė, Paulauskas, 2012).
- ***Oryctolagus cuniculus.*** The centre of origin of the European rabbit is in the Western Mediterranean region, particularly the Iberian Peninsula and Northwest Africa (Nowak, 1971). Its introduction as a game mammal species started in Silesia in the 1860s (Solarz, 2011). In the 1960s, to enrich the local game mammal fauna, rabbits were released in several regions of Western Ukraine, in particular in Lviv, Ivano-Frankivsk, and Chernivtsi oblasts (Tatarinov, 1973). The animals were transported here from Odesa and Kherson oblasts (Southern Ukraine) and released in the territory of several

raions. However, the attempt to naturalize the species failed and yet in the 1970s no rabbits were revealed in these areas. Besides, Bashta and Potish (2007) referring to personal reports noted that in the 1970s unsuccessful attempts to introduce the European rabbit took place in Berehovo and Irshava raions, Zakarpattia oblast as well.

- ***Myocastor coypus.*** The native geographical range of the species covers the Patagonian region of South America (Bertolino, 2009). The coypu was introduced in all continents but Australia and Antarctica, and in most of the regions instead of being a valuable industrial species it became a pest thus programmes on the coypu's eradication have started in many regions of introduction (Carter, Leonard, 2002).

  In Ukraine, the coypu was introduced in 1948 when 59 individuals were released in Kherson oblast for semi-free breeding to obtain its highly valued fur (Khoyetskyy, 2010). Coypus have been kept in special fur farms and individuals spotted in natural habitats are usually specimens which escaped from such farms (Smagol, 2007).

  In the region of the Ukrainian Carpathians coypu farms existed in Lviv, Ivano-Frankivsk, and Zakarpattia oblasts (Tatarinov, 1973; Malyarchuk, 2015). Data on distribution of the species in natural habitats of the region are absent. Lately, the coypu has been kept as pet so sightings of single individuals, which are regularly reported in mass or social media, presumably are concerned with escaped animals. Besides, semi-aquatic mammals (coypu, muskrat, beaver, and otter) look quite similar in the water and their distant identification is often challenging even for professional zoologists (Zagorodniuk, 2012). Hence, reported 'internet identifications' are often incorrect[4] and they should be carefully verified.

4. Expansion. Expansion is considered here as a natural process of gradual dispersal of species to relatively short distances and enlargement of its geographical range in a certain direction (Głowaciński et al., 2011). Expansion often follows introduction of an alien species and it is caused by biotic factors (in particular, growth of population abundance, migration, generalist features of species, etc.). Expansion is not a mass event as, for instance, invasion, and it usually stops when suitable (but not necessarily free) niches are unavailable for the species. Populations established in the result of expansion either became stable allochthonous components of local communities or gradually became extinguished.

In the region of the Ukrainian Carpathians, there is a current expansion of two rodent species, namely the Eurasian beaver and the mound-building mouse.

- ***Castor fiber.*** The Eurasian beaver is a common species of the Palearctic. Its abundance by the end of the 19th century, due to overhunting, decreased to ca. 1,200 individuals. Since that time, owing to re-introduction programmes and further natural expansion, the beaver is recovering its range and abundance (Halley, Rosell, 2003).

  In the region of the Ukrainian Carpathians, the species probably disappeared in the 19th century — there are no exact data, although it presumably happened by the 1860s. In the neighbouring countries, for instance in Romania the beaver was last spotted in 1824 (Filipaşcu, 1969 as cited in Fülöp, Márk-Nagy, 2012), while in Hungary in 1865 (Bajomi et al., 2011). The beaver's reappearance in the region of the Ukrainian Carpathians has been observed since the 2000s (Potish, Bashta, 2005). It has been considered that the first beavers emigrated from neighbouring countries (Poland, Slovakia, and Hungary) in the result of expansion of re-introduced populations (Bashta, Potish, 2012). Therefore, the species may be considered in the status of a local invader, which is currently represented in lowland and mountain areas (Fig. 3) of both Zakarpattia (Bashta, Potish, 2012;

[4] For instance, a video showing a coypu in Ivano-Frankivsk city, which was posted on Youtube on 4 January 2018 by Valerii Priyatkin (https://goo.gl/FZWwbG), is really shows a coypu, presumably escaped from a private house. On the contrary, 'coypus' sighted in the Latoritsia river in Mukachevo city actually were muskrats (https://goo.gl/SLR768).

Koval, 2015; Barkaszi, 2016) and Prykarpattia (Buchko, 2010; Vikyrchak, Ploshchanskyi, 2017). The growth of beaver populations in the entire northern part of the Carpathian Basin, as well as their merge, which would increase genetic diversity, can lead to the full recovery of the species in the region (Čanády et al., 2016).

- ***Mus spicilegus***. The mound-building mouse is a common species in the steppe rodent fauna occurring mainly in agricultural lands (Unterholzner, Willenig, 2000). It is a sibling species of *M. musculus*, although it clearly avoids human proximity. It is distributed in areas adjacent to the region of the Ukrainian Carpathians, in particular in western Podolia and eastern Bukovina in Ukraine (Smirnov, 2010; Smirnov, Malyk, 2011), in eastern Slovakia (Čanády et al., 2014), eastern Hungary (Bihari, 2003), and in Transylvania, Romania (Benedek, 2007).

  The first 'colonies' (mounds) of the species in Zakarpattia (Fig. 4) were recorded in 2005–2007 (Bashta, Potish, 2007). Regarding the appearance of *M. spicilegus* in Zakarpattia, it is presumably due to range expansion, the northern edge of which runs along adjacent lowland regions (Čanády et al., 2014). It should be also mentioned that the distribution range of the mound-building mouse in Zakarpattia coincides with the range of *Mustela eversmanni* and reconstructed range of *Spermophilus citellus* (Zagorodniuk et al., 2010).

5. Invasion. Invasion is considered here as rapid, aggressive dispersal of a significant number of individuals of a species to notable distances beyond its native range. The process of invasion is accompanied by a rapid, explosive increase of abundance leading to significant changes in the state of autochthonous ecosystems (Głowaciński et al., 2011). Invasions usually occur when isolation barriers (geographical or/and ecological) disappear or when natural landscapes are violated. Some ecological factors such as the absence of natural enemies, parasites, and diseases, sufficient amount of feeding resources, high reproductive potential of the species can also contribute into the success of invasion. In addition, synanthropy can also promote the process of invasion, when human commensals rapidly disperse through the net of settlements, agricultural and urban lands.

In the fauna of the region of the Ukrainian Carpathians, three rodent species occur, which are traditionally considered invasive. All of them are synanthropic, and two species — the black rat and the house mouse — are ancient commensals of humans Genovesi et al., 2009). Brief descriptions of all three species are given below.

- ***Mus musculus.*** The house mouse is represented in the region by the Linnaean *Mus musculus* unlike Southwest Europe, where *M. domesticus* is distributed (Lever, 2009). The presumed centre of origin of the species is considered to be in areas located south and southeast of the Caspian Sea, particularly in Iran and Turkmenistan (Cichocki, 2011 a; Suzuki, Aplin, 2012). The exact migration routes of the species are still not clarified. It is considered that the main factors contributing to the dispersal of the house mouse presumably were the development of trade and of crop storage systems (Cichocki, 2011 a).

  The house mouse currently is a common species in the region of the Ukrainian Carpathians. In the warm period of the year a part of population moves from human buildings to agricultural lands (Tatarinov, 1973). Mountain regions are not an exception. According to Tatarinov (1973), the house mouse is uncommon in forests and meadows, which suggests that the dispersal of the species might be contributed by disturbances of natural landscapes, particularly their transformation for agricultural purposes.
- ***Rattus rattus***. It is believed that the black rat was the first mammalian species that 'associated' with humans in Southeast Asia, which considered to be the centre of origin of the species (Aplin et al., 2011). To determine the exact time and route of migration of the black rat is a complex issue due to repeated appearance and disappearance of the species in colonized regions, although it is considered that the invasion of the species into Europe took place during the Bronze Age (Cichocki, 2011 c). According to another point of view, the black rat dispersed from India to Egypt during the 4th century BC, and therefrom to Europe along trade routes (Lever, 2009).

In the current fauna of the region of the Ukrainian Carpathians, the species is absent and likely it was displaced by the brown rat *R. norvegicus.* Although, it should be mentioned that melanistic individuals of *R. norvegicus* trapped in the region had been considered earlier as *R. rattus*. However, later it was clarified that in Ukraine populations of the black rat remained in areas where *R. norvegicus* is absent or not abundant, in particular in Polesia and in the Crimean southern coast (Zagorodniuk, 1996; Tovpinets, Evstafiev, 2008).

- ***Rattus norvegicus.*** Northeast Asia, in particular the region of southern Siberia and eastern China, is considered the most likely centre of origin of the brown rat (Long, 2003). According to a widely accepted view, the species invaded Europe through Russia in the 18th century and the main wave of the invasion occurred at this time (Lever, 2009; Cichocki, 2011 b). Although, there are a few reasons to consider this view mistaken, because the species most likely dispersed into Europe from northern and southern coastal regions. This is evidenced by results of detailed mapping of dates of the specie' first records in different regions of Europe (Zagorodniuk I., unpublished data).

  As Strautman and Tatarinov (1949) stated, the brown rat appeared in the region of the Ukrainian Carpathians after World War I dispersing from the northern to the southern slopes. This belief is entirely corresponds to the accepted concept on the species' dispersal from the east to the west of Europe. However, the brown rat was listed for the fauna of the region much earlier, in particular by Zawadzki (1840) for Galicia and by Kardos (1876) for Máramaros County, moreover in the latter case along with *R. rattus*. Therefore, the viewpoint about post-war dispersal of the species in the region is rather controversial, and apparently the brown rat appeared in the region yet in the 19th century. In the modern fauna of the region, the brown rat is a common species, quite abundant in some areas, although it occurs only close to human settlements (Bashta, Potish, 2007). In the mountains, it is distributed up to 1,400–1,500 m a.s.l., as well as on poloninas (subalpine meadows) at livestock farms (Tatarinov, 1956; Bashta, Potish, 2007). Apparently, the dispersal of the species is contributed by its ecological features (omnivory, high reproduction rate, capability to rapid adaptation) and anthropogenic landscape disturbances, particularly by expansion of the area of agricultural and urban ecosystems.

Fauna 'changes' due to taxonomic revisions and misidentifications

Obviously, the modern views on the taxonomic structure of the orders Muriformes and Leporiformes differ from those on the verge of the 19th–20th centuries. Several species were first described for the region's fauna right in the early 20th century, while later attention was focused on taxonomic heterogeneity of some species, which eventually turned out to be species complexes.

To analyse the changes in the checklists of the fauna, three potential time periods were distinguished, which correspond to periods of taxonomic revisions and establishment of views (in the 1920s, during the 1930s–1980s, since the 1990s).

The checklist of the first period is a reconstructed one. To reconstruct the checklist of the mammalian fauna for the first period (in the 1920s), taxonomic surveys of Polish (Zawadzki, 1840; Pietruski, 1853), Hungarian (Severinus, 1779), and Austro-Hungarian (Mojsisovich, 1887; Paszlavszky, 1918) authors were used. These contributions cover, respectively, the territory of Galicia and Bukovina and the entire Hungarian Kingdom, thus the chorological criterion was used when selecting species for the local fauna (into the checklist were included only the species which ranges cover the region of the Ukrainian Carpathians and such coverage likely did not change sufficiently during the 18th–19th centuries).

For the checklist of the second period (during the 1930s–1980s), the survey by Korchinsky (1988) on the rodent fauna of the Ukrainian Carpathians and separate publications on introduced species were used, while the checklist of the third period (since the 1990s) was based on the checklist of the mammal fauna of the Carpathian Biosphere Reserve (Zagorodniuk et al., 1997), of the vertebrate fauna of Gorgany Natural Reserve (Kyseliuk, Godovanets, 2000), and of the rodent fauna of the Eastern Carpathians (Barkaszi, Zagorodniuk, 2016 b).

The corresponding checklists are presented in Table 1. Taxa names are given according to the current nomenclature (Zagorodniuk, Emelyanov, 2012).

Table 1. **Checklists of the rodent fauna of the Ukrainian Carpathians for different periods**
Таблиця 1. **Списки родентофауни Українських Карпат за різні часові проміжки**

Taxa	in the 1920s	1930s–1980s	since the 1990s	Current status	Comments
Leporidae					
Lepus europaeus	N*	N	N	native	
Lepus timidus	E	(A)	–	extinct	extinct, unsuccessful re-introduction
O. cunniculus	–	A	–	absent	unsuccessful introduction
Sciuridae					
Sciurus vulgaris	N	N	N	native	
Spermophilus citellus	N	N	N	native	
Marmota marmota	E	(A)	–	native	extinct, unsuccessful re-introduction
Gliridae					
Glis glis	N	N	N	native	
Muscardinus avellanarius	N	N	N	native	
Dryomys nitedula	N	N	N	native	
Eliomys quercinus	N	F	E	native	extinct
Castoridae					
Castor fiber	E	–	A	invader	re-appeared due to range expansion
Sicistidae					
Sicista betulina	N	N	N	native	
Sicista subtilis	–	F	–	absent	misidentified
Spalacidae					
Salax graecus	N^{REC}	N	N	native	
Nannospalax leucodon	–	F	–	absent	misidentified
Muridae					
Micromys minutus	N	N	N	native	
Apodemus agrarius	N	N	N	native	
Sylvaemus sylvaticus	N	N	N	native	
Sylvaemus flavicollis	N	N	N	native	
Sylvaemus uralensis	S^{REC}	S	S	native	sibling of *S. sylvaticus*
Mus musculus	A	A	A	alien	ancient human commensal
Mus spicilegus	–	–	A	alien	appeared due to range expansion
Rattus rattus	A	A	E	alien	ancient human commensal
Rattus norvegicus	A	A	A	alien	relatively recent human commensal
Cricetidae					
Cricetus cricetus	N	N	N	native	
Cricetulus migratorius	–	F	–	absent	misidentified
Arvicolidae					
Ondatra zibethicus	–	A	A	alien	successfully introduced
Myodes glareolus	N	N	N	native	
Chionomys nivalis	N	N	N	native	glacial relict, restricted to highlands
Terricola subterraneus	N	N	N	native	
Terricola tatricus	S^{REC}	S^{REC}	S	native	sibling of *T. subterraneus*
Arvicola amphibius	N	N	N	native	
Arvicola scherman	N	N	N	native	
Microtus oeconomus	–	F	–	absent	misidentified
Microtus agrestis	N	N	N	native	
Microtus arvalis	N	N	N	native	
Myocastoridae					
Myocastor coypus	–	A	–	alien	unsuccessful introduction

* — for explanation see Table 2, index 'REC' denotes reconstructed species statuses.

For quantitative interpretation of the state and level of change of the fauna, the respective indices proposed by Zagorodniuk (2007) were used with some modifications. Five parameters are proposed to characterize the state and change of fauna, such as the following:

- *basic fauna composition*, B — includes native local species (N), as well as sibling species (S) the presence of which was confirmed relatively recently;
- *full list of species*, T — includes every species that have ever been mentioned for the fauna of the region, i.e., native (N), sibling (S), alien (A), extinct (E), and phantom and misidentified or unreasonably included into the checklist species (F);
- *volume of fauna change*, C — includes extinct and alien/new species;
- *index of fauna change*, I_C — the relation between the volume of fauna change and basic fauna composition;
- *index of checklist ambiguousness*, I_P — depends on the number of sibling and phantom species.

Data on the number of species of each category, the content of categories and indices, as well as obtained results are shown in Table 2.

Table 2. **The number of species belonging to different categories during different periods and faunal change indices**
Таблиця 2. **Число видів різного статусу за різні періоди та індекси зміни фауни**

Statuses / Indices	in the 1920s	1930s–1980s	since the 1990s
N, N^{REC} native species	21	20	20
A, alien invasive/introduced/re-appeared species	3	6	5
S, S^{REC} sibling species	2	2	2
F, phantom species	0	5	0
E, extinct species	3	0	2
T, total species (N+A+S+F+E)	29	33	29
B, basic fauna composition (N+S)	23	22	22
C, volume of fauna change (A+E)	6	6	7
I_C, index of fauna change [(C/2)/B]*100 %	13.0	13.6	15.9
I_P, index of checklist ambiguousness [(S+F)/T]*100 %	6.9	21.2	6.9

To estimate the level of change of the current fauna compared to its reconstructed state the index of fauna rotation (IFR) proposed by Zagorodniuk (2014) was used. The index is calculated by the following formula:

$$IFR = [(E + A) / 2] / N_{ini} * 100\ \%.$$

The parameter N_{ini} in the formula denotes the initial/reconstructed basic fauna composition (N, N^{REC}, S^{REC}), which in this case corresponds to the checklist 'in the 1920s.' When calculating this index, the number of extinct (E) and alien/new (A) species corresponds to the number of species that vanished and appeared during the last period, i.e. 'since the 1990s' (see Table 1). Under such circumstances, the IFR is

$$IFR = [(2 + 3) / 2] / 23 * 100\ \% = 10.9\ \%.$$

The obtained result shows nonessential quantitative change of the current fauna compared to its reconstructed state in the early 20th century, i.e. the disappearance and appearance of species for the past century is practically balanced.

Discussion

Quantitative changes in the rodent fauna and changes in fauna checklists. The obtained results show that the basic composition of the rodent fauna by the number of species changed nonessentially during the 20th century, and, respectively, the volumes of fauna change (C) and indices of fauna change (I_C) for the corresponding periods are also relatively low (see Table 2). The largest number of listed species is for the second period (during the 1930s–1980s), although, as we can see, it is not

because real changes in the fauna but ambiguousness of the checklist itself (I_p = 21.2 %) due to a significant amount of phantom species, most of which (*Sicista subtilis*, *Nannospalax leucodon*, *Cricetulus migratorius*, and *Microtus oeconomus*) were included unreasonably.

Among the reasons of including these species into the fauna checklist apparently is the different comprehension of the geographic volume of the 'region' of the Ukrainian Carpathians and of 'adjacent' territories. However, the mentioned species are distributed relatively far from the Ukrainian Carpathians thus there was no reason for later authors to include them into their checklists. Therefore, the real species richness of rodents in the beginning and the end of the 20th century is practically the same (23 and 22 species in the basic fauna composition, respectively) and only the qualitative composition of fauna changed owing to losses and additions of species. It is also supported by the low value of IFR (10.9 %).

On the other hand, changes in the fauna checklist of the region during the 20th century are also related to the development of the cryptic biodiversity concept and description of respective sibling species. For instance, the first record of the pygmy field mouse (*Sylvaemus uralensis*) in the region of the Ukrainian Carpathians was reported in 1980 (Polushina, Voznyuk, 1980), which belongs to the *tauricus–sylvaticus–uralensis* cryptic species complex of mice. A few years later, the first record of the Tatra pine vole *Terricola tatricus* was reported as well, which is a sibling species of the European pine vole *T. subterraneus* (Zagorodniuk, 1988). Obviously, these species had occurred here before but they were identified by zoologists as their siblings. The presence of these species was first suggested and especially recognized only after morphometric, and later cytogenetic and biochemical, research.

The causes of changes in the rodent fauna and further prospects. Real changes in the composition of the rodent fauna of the region of the Ukrainian Carpathians were related to species dynamics caused mainly by anthropogenic factors. Only the extinction of two glacial relicts — the mountain hare and the alpine marmot — has climatogenic component related mainly to landscape alterations and shifts in temperature regimes (see Przybylak et al., 2005). This is indicated by unsuccessful attempts to re-introduce these species, in particular the mountain hare, in case of which re-introduction failed due to the shift between the time of appearance of the snow cover and of the change of fur colouration, as well as due to strong pressure of predators including free-ranging and herding dogs.

Regarding the alpine marmot, it probably was not abundant in the region's fauna anyways since it is restricted to higher elevations. Thus, for instance, its re-introduction in the Rodna Mountains had more chances to succeed compared to Chornohora.

Hence, these species could not recover their populations and take their former niches in ecosystems of the region, which resulted in repeated disappearance of these two relict species.

Unlike the mountain hare and alpine marmot, the Eurasian beaver vanished because of overhunting for its fur and castoreum (Salvesen, 1928), i.e. mainly due to anthropogenic reasons. The reappearance of the beaver in the region is the result of natural expansion of populations re-introduced in the neighbouring countries (Poland, Slovakia, and Hungary). Therefore, in the current fauna of the region the beaver can be considered as a local invader.

Recent extinction concerns two rodent species such as the black rat (*Rattus rattus*) and the garden dormouse (*Eliomys quercinus*). The black rat disappeared from the fauna of the region because of strong competitive pressure by the brown rat (*Rattus norvegicus*). Meanwhile, in the extinction of *Eliomys quercinus* such chorological factors as high level of range fragmentation and related range edge effects probably played an important role.

Mainly unsuccessful introductions of entirely alien to the local fauna species are obviously due to not only ecological features of these species and anthropogenic factors but also the relatively high stability of ecosystems of the region in general. The appearance and dispersal of species new for the region of the Ukrainian Carpathians occurred in areas where natural biotopes are disturbed, particularly in places of drainage systems, channels, ponds (*Ondatra zibethicus*), agricultural lands (*Mus spicilegus*), and even more so near human settlements (*Rattus norvegicus*). These non-indigenous

species are distributed mainly in the lowland parts of the region, where there is a higher level of habitat disturbance compared to mountains. According to literature data (Tatarinov, 1956), the brown rat, as well as other commensals of humans, dispersed into the mountains through the net of human settlements and farm buildings.

In general, non-indigenous species usually occur in the mountains in unprotected territories where the influence of human activity is clearly expressed. On the contrary, animal communities in protected areas are more stable against the appearance of new elements. The only exception in the Ukrainian Carpathians is the Eurasian beaver that gradually extends its range in the Uzhanskyi National Park, which is located in the mountain part of the region. Apparently, it is because the beaver is an ecosystem engineer and it is capable to transform biotopes according to its own needs. The dispersal of this species, when the amount of water is sufficient, is prevented only by large-scale physical barriers.

Regarding prospects of appearance of new species in the rodent fauna of the region, the most probable and expected are discoveries of sibling species. First and foremost it concerns the East European vole *Microtus levis*, which is part of the sibling species complex *Microtus* ex gr. *arvalis*. Natural dispersal of new rodent species into the region, in our opinion, is quite unlikely at the present time.

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