THE DEMOGRAPHIC STRUCTURE OF *Microtus arvalis* AND *Microtus rossiaemeridionalis* (MAMMALIA, RODENTIA, CRICETIDAE) POPULATIONS IN AGROCENOSES FROM THE REPUBLIC OF MOLDOVA

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Abstract. The studies were carried out during 33 years (1986-2019) in various types of agricultural ecosystems and shelter belts all over the territory of the Republic of Moldova. The aim of the study was to elucidate the demographic structure of the populations of *Microtus arvalis* and *Microtus rossiaemeridionalis* in the agrocenoses of the Republic of Moldova. Standard methods were used to assess the number of small mammals, to determine their reproductive status and fecundity, and to estimate the number of colonies. During the study, we captured 1070 individuals of *Microtus arvalis* and 530 of *Microtus rossiaemeridionalis*. Significant differences were established between the species *M. arvalis* and *M. rossiaemeridionalis* regarding the number of adult and juvenile males, reproductive and juvenile females in both peak and depression phases, as well as between the density of the studies species in various types of agrocenoses: perennial herbs, cereal fields and shelter belts. The gender ratio in vole populations on cereal crops and perennial herbs at different densities depends on the populational phase. In young individuals, the dispersal is more intense, they mature faster, reproduce better and have higher survival rate in comparison with resident individuals of the same age.

Keywords: *Microtus* voles, colonies, density, sex ratio, age structure.

Rezumat. Structura demografică a populațiilor *Microtus arvalis* și *Microtus rossiaemeridionalis* (Mammalia, Rodentia, Cricetidae) în agrocenoze din Republica Moldova. Studiile au fost realizate pe parcursul a 33 de ani (1986-2019) în diferite tipuri de ecosisteme agricole și perdele forestiere pe tot teritoriul Republicii Moldova. Scopul studiului a fost elucidarea structurii demografice a populațiilor *Microtus arvalis* și *Microtus rossiaemeridionalis* în agrocenozele Republicii Moldova. Au fost utilizate metodele standard de evaluare a efectivului de mamifere mici, de determinare a stării de reproducere și fecunditate a acestora și de estimare a numărului de colonii. Pe parcursul cercetărilor au fost capturați 1070 indivizi de *M. arvalis* și 530 *M. rossiaemeridionalis*. S-au stabilit diferențe semnificative între speciile *M. arvalis* și *M. rossiaemeridionalis* în ceea ce privește numărul de masculi adulți și juvenili, femele reproductive și juvenile atât în fazele de vârf, cât și de depresie, precum și între densitatea speciilor studiate în diferite tipuri de agrocenose: ierburi perene, culturi de cereale și perdele forestiere. Raportul de sex în populațiile de microtine în culturile de cereale și ierburile perene la densități diferite depinde de faza populațională. La indivizii tineri dispersia este mai intensă, se maturizează mai repede, se reproduc mai intens și rata de supraviețuire este mai mare în comparație cu indivizii rezidenți de aceeași vârstă.

Cuvinte cheie: *Microtus*, colonii, densitate, structura de sex, structura de vârstă.

INTRODUCTION

The age and sex structure of micromammal populations are demographic indexes that characterize the population and represent one of the mechanisms of number regulation (STEIN 1953; KREBS 1966, BRYJA et al., 2005). These parameters are varying within large limits in relation to the variation interval covered by the development cycle of each species (BASHENINA 1962). In general, three ecological age groups are considered in the case of natural populations: pre-reproductive, reproductive and post-reproductive. Given the differentiation rates with which the metabolic processes occur, susceptibility to environmental pressure and fertility, it is necessary to define, within each age class, several subclasses to characterize the state of a population (LIDIKER 1973).

The voles (*Microtus arvalis* and *M. rossiaemeridionalis*) are common small mammals in open type and agricultural landscapes of Central and Eastern Europe (MITCHELL-JONES et al., 1999). They can display spectacular increases in population numbers, especially *M. arvalis* that is considered a major rodent pest in agriculture, causing significant and costly crop damages (JACOB & TKADLEC, 2010). The common vole is a particularly suitable species in order to study variation in demographic structure. It is characterized by colonial life mode, high reproduction rate and can reach in short time highest population densities, much above one thousand individuals per hectare in peak years (MUNTEANU et al., 1989; BRYJA et al., 2001). The vole populations are also known to fluctuate temporally and spatially (TKADLEC & STENSETH 2001), have variable age structure (JÁNOVÁ et al., 2003), and short generation times as a consequence of a female's ability to breed extremely early in life (TKADLEC & KREJOVÁ 2001).

Usually, in natural populations the proportion of individuals in different age classes change widely in time and space depending on environmental pressure (JÁNOVÁ et al., 2003; SÎTNIC, 2017). The age structure of vole populations may determine the reproductive rate of the population on the one hand, but it is also the resultant of reproduction and mortality (ADAMCZEWSKA-ANDRZEJEWSKA & NABAGŁO, 1977). For populations with considerable fluctuations in numbers this indicator may be of great importance in predicting numbers. The analysis of samples taken with certain frequency, followed by sex ratio and age structure analysis, allows to estimate the population size, variation of sex ratio depending on season and population phase and the distribution of individuals by age classes.

The aim of the paper was the multiannual study of vole populations' demographic structure, which will allow to emphasize some mechanisms of population functioning and of species number regulation, since the vole species are important pests for agriculture.

MATERIALS AND METHODS

The studies were carried out during 33 years (1986-2019) in various types of agricultural ecosystems and shelter belts all over the territory of the Republic of Moldova. The data were collected near the localities Cruglic (47°10'40" N 29°01'49" E), Sociteni (46°56'50" N 28°44'53" E), Horăşti (46°51'50" N 28°53'04" E), Boşcana (47°06'33" N 29°01'38" E) from the central part of the Republic of Moldova, throughout the year in cereal crops (wheat, barley, corn), fodder crops (alfalfa, clover), in pastures and in shelter belts. The standard methods of small mammal number assessment, of determination of their reproductive status and fecundity, and of colony number estimation were used (NAUMOV, 1956). In total 60,000 live traps and 38,300 snap traps were used for trapping small mammals. The traps were baited with bread pieces soaked with unrefined sun-flower oil, placed in lines at 5 m from each other, one trapping period lasted 4-5 days.

The study of spatial structure of vole populations, the activity of individuals, the surface of individual sectors were performed on marking sectors by capture-mark-recapture method (KREBS, 1966). Voles were caught with live traps, on 4 ha sectors, placed in lines at the distance of 20 m from each other and on 1 ha sectors – at 10 m from each other. The surface of individual sectors and the distance of vole individuals' movement were determined according to standard methods (NIKITINA, 1972). The number of studied populations was expressed as individual number related to a surface unit – the absolute density. During the study period 1600 vole individuals were captured and marked (1070 – *M. arvalis* and 530 - *M. rossiaemeridionalis*) and performed 5245 recaptures on the marking plots.

For the evaluation of demographic structure of the population, the following parameters were taken into account: density, share of males and females, overwintered females, reproductive females, juveniles one-two weeks old, non-reproductive adults, reproductive adults, as well as the growth rate of the population and the population phases (depression, peak). In order to emphasize the significance of differences between various parameters the Student test was used.

Ethical issues: due to the fact that the voles are the most numerous rodent species and reach very high densities in open type biotopes, being a pest species in agricultural landscape, the Ministry of Agriculture, Regional Development and Environment allows the capture of vole species by snap traps.

RESULTS AND DISCUSSIONS

On the territory of the Republic of Moldova the most favorable habitats for *M. arvalis* individuals are the perennial and cereal crops, and for *M. rossiaemeridionalis* are the shelter belts and insular woods, located near cultivated lands, thus the two sibling species are separated in space and use different ecological resources. The population number of both species in spring period is not always a definite criterion for prediction of autumn population number. When having good ecological conditions and a satisfactory physiological state, the voles can increase their density by several hundred times in short time periods (3-4 months), and, thus, become one of the most important vertebrate pests for agriculture. Usually, during the years of demographic explosion 2 peaks of number density are registered: the first, less pronounced, in July-August, and the second, well defined – in September-October. The availability of trophic resources is the main factor conditioning the beginning of breeding. The variation of breeding activity provokes the density oscillation and is decisive in maintaining population number (MUNTEANU et al., 1989; MUNTEANU & SITNIC, 1994). The age and sex structure of *M. arvalis* population in cereal crops and of *M. rossiaemeridionalis* in forest shelter belts at peak and depression phases is different (Figs. 1, 2).

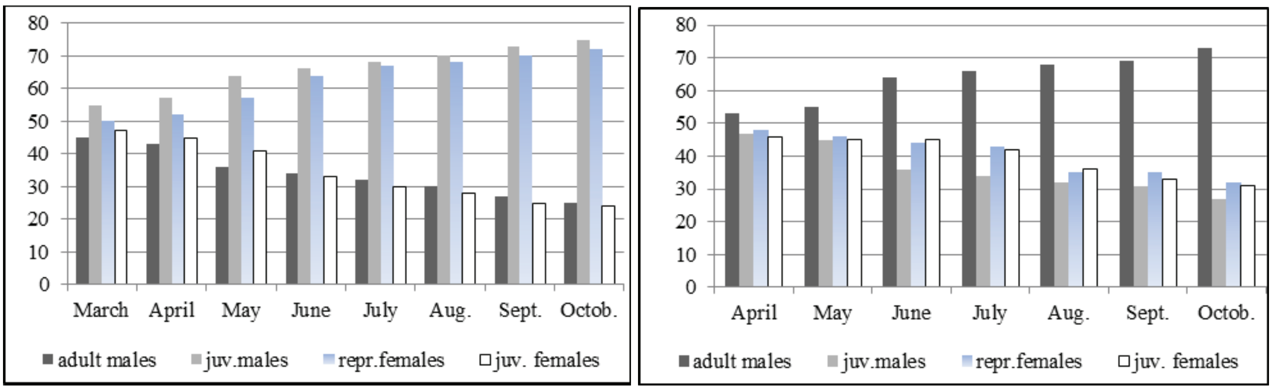

Figure 1. Sex and age structure of *M. arvalis* population at peak (left) and depression (right) phases of number density in cereal crops (considering males -100%, females-100% without non-reproductive females).

At the peak phase in both species an increase in the number of reproductive females was registered towards autumn. Significant differences were established between the number of adult and juvenile males, reproductive and juvenile females of the studies species in the peak (t=2.78, 2.96, 3.08, 3.27) and depression phases (t=3.12, 3.28, 3.07, 3.10).

The sex structure and the dynamics of mammal populations correlate with the processes of optimal density maintenance (KREBS, 1966). The dynamics of this structure represent one of the adaptation and regulation mechanisms of population number. According to the hypothesis of negative correlation the prevalence of females occurs under stable optimal conditions, while the increase in the male rate represents an index of unfavorable ecological conditions (BRYJA, 2005). The females in vole populations dominate during the reproductive period. This process recorded in autumn period can be explained as preparation of the population for breeding during winter period, which precedes the peak phase. The obtained data regarding the sex ratio in vole populations on cereal crops and perennial herbs at different densities allow to emphasize a dependence of sex ration on the phase of number density. Therefore, in *M. arvalis* populations inhabiting cereal fields in depression phase years the proportion of males increases from March (34.5%) till July (57.2%, t=2.74), after what it remains at a relatively stable level, while in the peak phase years the male number decreases significantly (t=3.05) from 22.3% in March to 16.7% in June (Fig. 3).

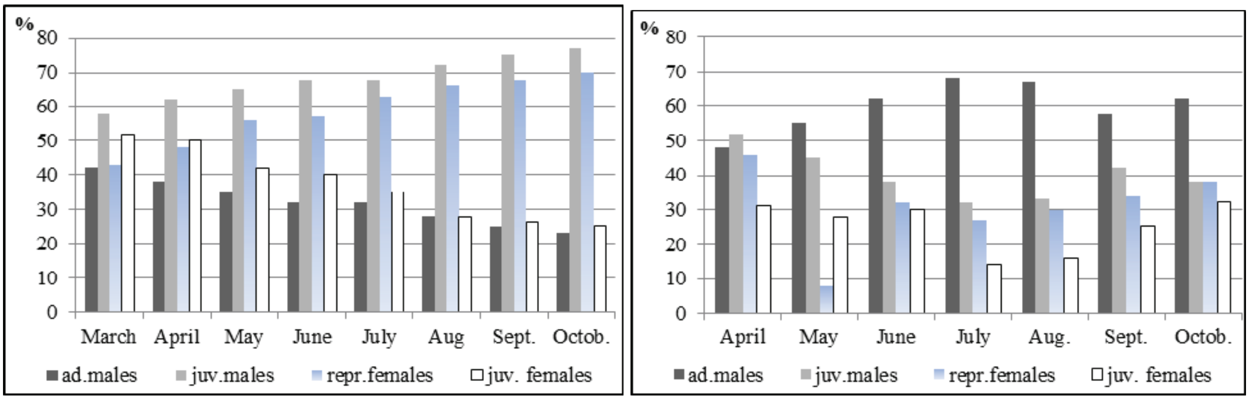

Figure 2. Sex and age structure of *M. rossiaemeridionalis* population at peak (left) and depression (right) phases of number density in forest shelter belts (considering males -100%, females-100% without nonreproductive females).

The male ratio of *M. arvalis* in the perennial field at the peak phase is lower than that of females, decreasing from March (41.9%) to October (28.4%, t=2.86) (fig. 3B), in opposite to other studies, where each year until May, males were usually more numerous than females (BRYJA et al., 2005). The males of *M. rossiaemeridionalis* significantly (t=3.11) increase their number in shelter belts at depression phase from March (52.8%) to October (72.5%), while at the peak phase their number decreases significantly (t=2.78) from 46.7% in March to 30.8% in June Fig. 3).

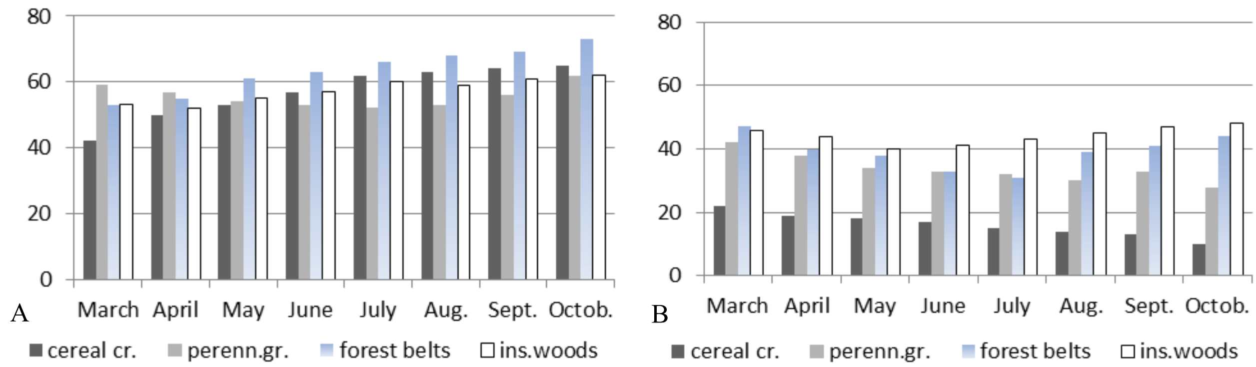

Figure 3. The male ratio (%) in *M. arvalis* population in cereal crops and perennial fields and in *M. rossiaemeridionalis* populations in shelter belts and insular woods at depression (A) and peak (B) phases of number density.

Along with the increase in the *M. arvalis* population density up to 150 individuals/ha, a decrease in the male proportion was registered in cereal crops (t=2.62) and in perennial herbs (t=2.74). In the cases of higher density of the population the male ratio increases (Fig. 4). The same process was registered for *M. rossiaemeridionalis* in forest shelter belts – the minimum value of male number was recorded at the density of 125 individuals per hectare (Fig. 4). For this species the multiple linear regression reflects a decreasing of male ratio in insular woods up to a density of 110 individuals/ha. The figures below indicate the regression equations which describe the correlation between the population density and male ratio.

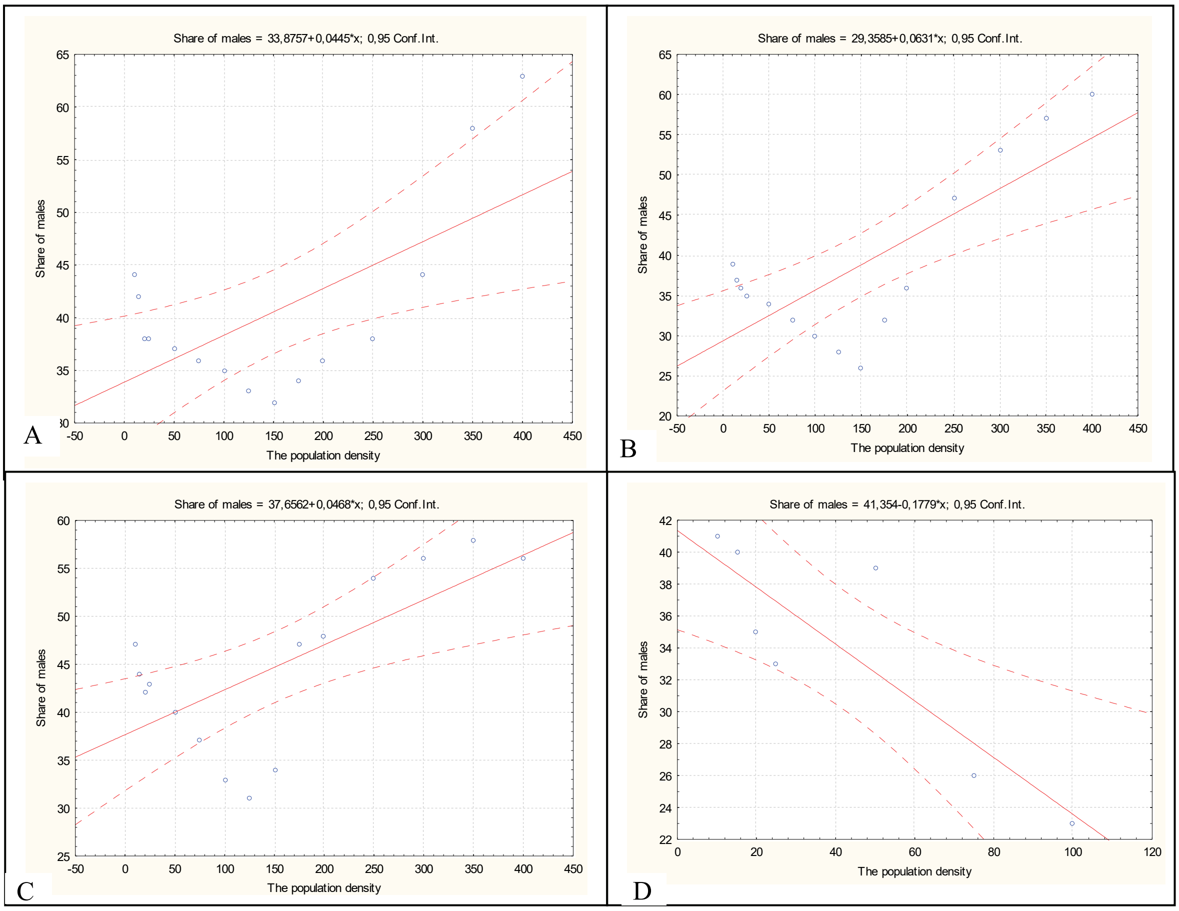

Figure 4. The correlation between the male ratio in *M. arvalis* populations in cereal crops (A) and perennial herbs (B) and in *M. rossiaemeridionalis* populations in shelter belts (C) and insular woods (D) and population density (%)

The variation of age structure can be the cause, but also the effect of populational processes. In common voles *M. arvalis* females mature earlier than males, and therefore, more females than males are recruited to the adult population in early summer (BRYJA et al., 2005). The modification of reproduction intensity, which correlates with the density variation cause changes in population age structure. Usually, during the number growth phase the individuals develop and maturate faster than in peak and number decreasing phases. Significant differences were registered between both sibling species regarding the number of overwintered adults (t=2.81) and adult yearlings (t=3.16), as well as between the juvenile individuals' (t=3.22) number (Fig. 5).

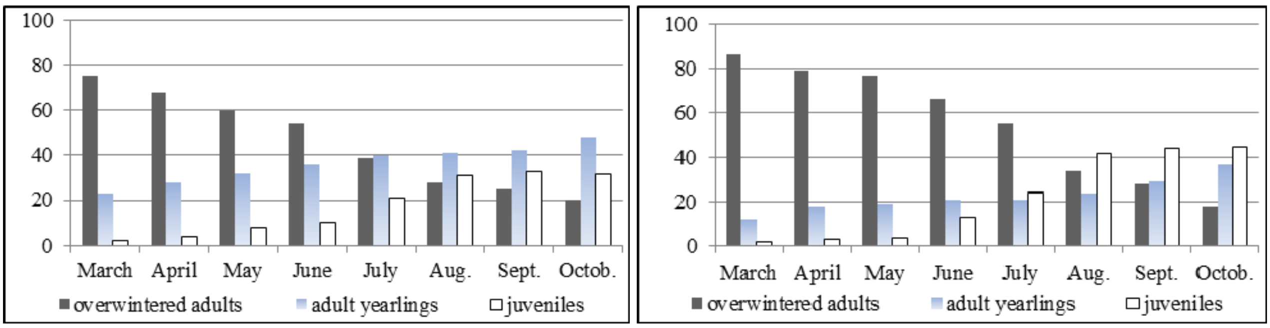

Figure 5. The age structure (%) of *M. arvalis* (left) and *M. rossiaemeridionalis* (right) generations

In most cases, the cereal crops were inhabited since winter and in May already 2-3 generations were registered. In *M. rossiaemeridionalis* populations, toward the end of summer and in autumn months, the juveniles have a significantly (t=2.9, t=2.6) higher proportion than those from *M. arvalis* population. By comparing the age structure of the *M. arvalis* population from cereal crops in the peak phase and in the depression phase, a gradual elimination of overwintered individuals can be noticed in May–July with a single difference: the elimination occurs more intensely in the *M. arvalis* population. Therefore, in years with peak phase in both species, the overwintered individuals as well as the first three generations reproduced intensely and the population age structure became complex. In opposite, during the depression phase the generation number decreased at least by 1–2, the age structure became simplified. In the phase of depression exit in April the *M. arvalis* population was formed by overwintered individuals and the first generation appeared only in May, which constituted 32%, while in *M. rossiaemeridionalis* it constituted 27.1%. In September the adult proportion of overwintered *M. arvalis* decreased to 32.5% and that of *M. rossiaemeridionalis* – to 35.6%. The juvenile ratio oscillated within the period of reproductive cycle, but also within the phases of population cycle.

The vole family is characterized by different structure types: simple (female with its offspring), complex (female, new offspring and a part of previous offspring) and large family (female and several litters). On the colony territory one male was registered, seldom – 2 males. The male can live separately in a gallery, but it doesn't stay in it permanently, often attending different females. Males were captured in the females' gallery together with its juvenile litters. The sex ratio (male: female) in colony groups varies in alfalfa crops from 1:1 to 1:3.5. A smoother sex ratio was registered in both species in the years of number density depression. The low male number in the maximum reproduction period represents a favorable condition for the numerical growth of population. Group territoriality occurs in voles, based on common colony territory protection. The group's mode of life was recorded at peak phase, when the social blocking occurs, while the solitary life mode was recorded at the growing phase, the colonies being located some distance away from each other. Each female occupies a certain sector of the common territory.

In the growth phase adult males use the whole territory of colony group, being caught on their individual sectors, as well as on female sectors. Juvenile voles inhabit on the sector of mother-female, living in its gallery or separately. The young individuals and the non-reproductive females move not only within their territories, but also in other parts of colony territory. In general, during the peak phase all available types of agrocoenoses were intensely colonized, which means that vole diffusion was very rapid. The structure of *M. arvalis* colonies in perennial herbs and of *M. rossiaemeridionalis* colonies in shelter belts at peak phase of population density number is presented below (Fig. 6).

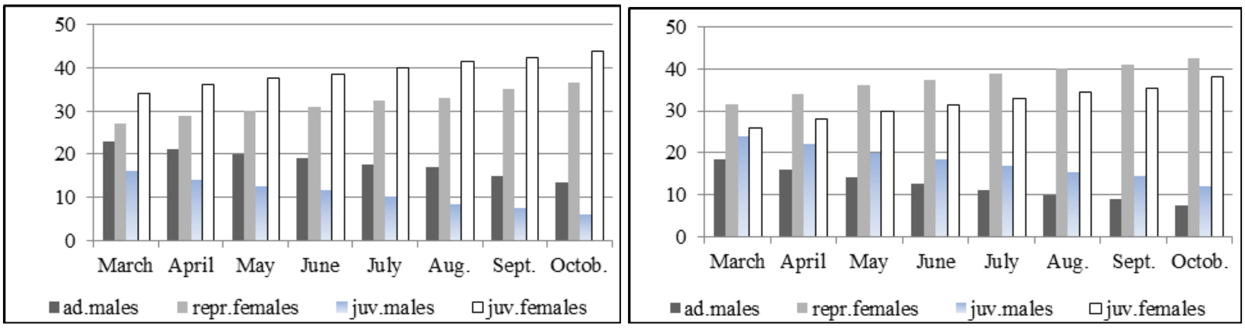

Figure 6. The sex and age structure of *M. arvalis* (left) in perennial herbs and of *M. rossiaemeridionalis* (right) colonies in shelter belts in the peak phase of number density

In summer months the colony number increased, as individuals born in that year inhabited new sectors. In the mark-recapture sector, the colony number of *M. arvalis* individuals is significantly higher (t=2.98) than in *M. rossiaemeridionalis* individuals. As for the age groups, it was established that the number of juvenile males and females, of adult males and reproductive females represented significant differences (t=3.58, t=3.14) between the both studied species. In *M. rossiaemeridionalis* groups the colonies were placed more compact with a mean distance between the colonies of 7±1.5 m, while in *M. arvalis* groups the mean distance between colonies is of 12±2 m. The surfaces of individual sectors as well as the distance of individual movement in males and in females increased from spring to summer.

The populations of *M. arvalis* and *M. rossiaemeridionalis* sibling species have a labile structure depending on season, number density phase, growth etc. (MEYER et al., 1972). Both species show high tolerance to anthropogenic pressure and were the most abundant species in the studied ecosystems transformed by human economic activity. When cohabiting, common and East European voles demonstrated different territorial distribution and circadian activity, which can be considered an adaptation to avoiding competitive interactions of ecologically similar species (TIKHONOVA et al., 2006). The data collected during many years regarding the number of voles in agrocoenoses prove that the sibling species showed different patterns of population structure.

The peculiarities of vole number density in agrocoenoses are significantly different from those registered in natural biotopes. In the conditions of the anthropogenic landscape, the tendency of the two vole species toward cyclicity can be observed, but it is diminished by human activity. As result, the individual number increases each 4-5 years, but the peak phases aren't similar.

The demographic structure of these sibling species depends a lot on the population density (MUNTEANU et al., 1989; MUNTEANU & SITNIC, 1994). The regression analysis between the density dynamics and reproductive female ratio (reproductive intensity) showed a significant negative correlation (Fig. 7). This correlation between demographic structure and reproductive intensity can be observed during the whole breeding period, with r=-0.875 for *M. arvalis* and r=-0.729 for *M. rossiaemeridionalis*, therefore the recorded fluctuations of the species occur in opposite directions.

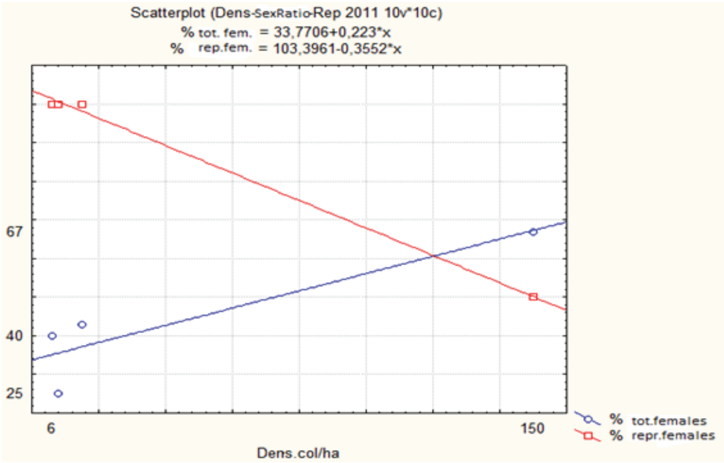

Figure 7. Dependence of the vole population density on demographic structure and reproductive intensity.

The field vole species are dominant species in arable land, and their relative abundance can reach, in peak years, 50–80% from all small mammal species. Taking into account their high reproductive potential they are considered a potential agricultural pest, reaching densities >3000 individuals/ha (TRUSZKOWSKI, 1982) and damaging up to 90% of the potential crop field (TERTIL, 1977). Therefore, the prognosis of the number development of vole populations in immediate perspective is of high importance for agriculture. For this purpose, the parameters of population size dynamics and the individual survival function are correlated within a model, considering all the individuals of certain population living in a time interval as the same event (cohort). The survival function expresses the graduate decrease of the individual number in a cohort and, after analysing the survival of individuals (Fig. 8), its decrease during a year period was registered.

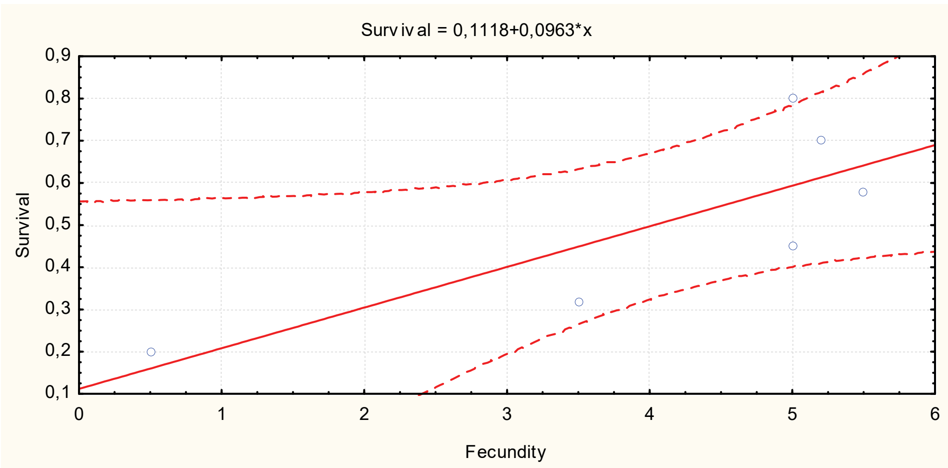

Figure 8. The dependence of individual survival on fecundity.

It was established that fecundity grows gradually till a maximum value and then it decreases. The numerical growth of the population is predicted by the multiple linear regression model: $l_x = 0.1118 + 0.0963*m_x$, which represents the dependence between the specific survival (l_x) and fecundity *(*m_x).

The phase of number growth succeeds in the 1st phase after the improvement of living conditions in refuge stations and outside them, this being a premise for survival growth, for increasing the group density and, therefore, for stimulating the dispersal. Outside the refuge stations the favourable conditions ensure the survival and breeding intensity of dispersed individuals. At this phase the groups are formed by 2-3 colonies, which don't overlap. By the end of summer – beginning of autumn the density increases to 80-100 colonies per hectare, and subsequently up to 200-300 colonies/hectare. The survival increases from 33.7±5.4.0% in September to 58.6±6.3% in October, while the number of reproducing females from late summer generation (67.4±8.2%) overpasses the breeding female number from spring generation (35.1±3.6%). At the peak phase of population number, the sexual maturation of young females is suppressed and a negative correlation between the density of reproductive females and intensity of sexual maturation was emphasized (PUSENIUS & VIITALA, 1993; BOONSTRA, 1989).

An important aspect in density regulation is the dispersal of individuals, which is one of the main mechanisms of population number density regulation. For vole species, the dispersal is more evident in the growth and peak phases than in the depression phase. The dispersal ratio does not depend only on population density, but also on the age of individuals, social structure, cohort character and biotope peculiarities. Thus, the dispersal is more intense in young individuals; they maturate faster, reproduce and survive better in comparison with resident individuals of the same age. The vole dispersal in various agrocoenoses can be explained by the mechanisms of relations between the individuals, but also by the state of the biotope and cycle period. Usually, in spring with the increase of breeding activity, the individuals migrate from winter refuge stations in adjacent sectors with favourable food and shelter conditions. The multiannual observations of vole individuals on marking sectors allow to separate them in two categories: resident individuals (sedentary), recaptured more than 3 times during 2-3 mark-recapture periods, and migrant individuals, caught just one time.

The information regarding the migration at peak and depression phases in cereal and perennial crops proves that at peak phase the ratio of *M. arvalis* migrants is higher than the ratio of *M. rossiaemeridionalis* migrant individuals in shelter belts, the difference being significant from March till July (t=2.66, 2.95, 2.72, 3.12, 3.38). It was emphasized that in shelter belts the migrant ratio increases from March to July at peak phase and decreases during the same period in the depression phase. The ratio of *M. arvalis* migrants in perennial crops is higher than the ratio of *M. rossiaemeridionalis* migrant individuals in insular woods, the differences being significant from March till June (t=3.12, 2.91, 3.58, 3.87). At the depression phase the proportion of migrant individuals is significantly lower than at the peak phase in both species during the same period (t=4.78, 3.65, 3.21, 4.08). The share of *M. arvalis* migrant males at peak phase in cereal crops is significantly higher than the share of *M. rossiaemeridionalis* migrant males in shelter belts between March and June (4.22, 3.34., 3.78, 4.79), while at depression phase the opposite process occurs also with significant differences (t=3.12, 3.85, 4.37, 3.91).

According to Lidiker's hypothesis (1973) the supersaturated dispersion occurs at a minimum density or at the growth phase until resource depletion. Usually, the individuals susceptible to density increase disperse. The saturated dispersion during maximum number phase is characterized as migration individuals that are in excess or are "social outcasts", among which juvenile, subadult and very old individuals dominate. This hypothesis was confirmed by our experiences. Therefore, in the autumn of 1988 the voles were in a peak number phase in perennial crops. Afterwards, the dispersion in adjacent cereal crops started. This process was observed in the second half of autumn and in December, when the vole density of the cereal crops was about 200 col./ha. The colonies were uniformly distributed throughout the field, with no evidence of aggregation, at a distance of 3-5 m from each other, being connected by paths. The widest colony groups were placed at 10-20 m from the wheat crop edge, where the voles migrated from the adjacent alfalfa crop and where their density reached 350 col. /ha. In February 1989 among the voles dispersed from cereal crops the females dominated (64.7±4.5 %), while among migrants from shelter belt and from alfalfa the males were dominant (56.7±6.8 % and 58.3±4.7%). The massive dispersion in late autumn from perennial to cereal crops coincided in time with the peak phase. The termination of perennial grasses vegetation process and their damage, as a result of vole activity, have undermined the food supply, while in adjacent wheat crop the food sources were abundant. This dispersion type is similar to that described by LIDIKER (1973), but in our case among migrants prevail the individuals that breed earlier than the remained residents.

CONCLUSIONS

Significant differences were established between the species *M. arvalis* and *M. rossiaemeridionalis* regarding the number of adult and juvenile males, reproductive and juvenile females in both peak and depression phases, as well as between number density of the studies species in various agrocoenoses types: perennial herbs, cereal fields and shelter belts. The sex ratio in vole populations on cereal crops and perennial herbs at different densities depend on the phase of number density.

In the years of peak phase, the age structure in both species become more complex –overwintered individuals reproduce intensely, as well as the first 3 generations. In the depression phase the generation number reduces by at least 1-2, with a simplification of the age structure. During the number growth phase, the individuals develop and maturate faster than in peak and decreasing phases. Significant differences were registered between both sibling species regarding the number of overwintered adults (t=2.81) and adult yearlings (t=3.16), as well as between the juvenile individuals' (t=3.22) number

The increase in the density of *M. arvalis* population up to 150 individuals/ha conditioned a decrease of the male proportion in cereal crops and in perennial herbs, for a higher density, the male ratio increases. The same process was recorded for *M. rossiaemeridionalis* in shelter belts – the minimum value was registered for a density of 125 individuals/ha, while in insular woods – for a density of 110 individuals/ha. At the growth phase, adult males use the whole territory of colony group. The juvenile voles inhabit on the sector of mother-female, living in its gallery or separately. In *M. rossiaemeridionalis* the colonies are placed in a more compact manner with a mean distance between the colonies of 7±1.5 m, while in *M. arvalis* the mean distance between colonies is of 12±2 m.

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