SOME GENERAL APPROACHES TO PALEARCTIC SYNANTROPIC RODENT CONTROL

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Abstract It has been shown that rodent extermination measures are most effective when carried out throughout an entire affected area, mainly during the calendar period that coincides with the diapause in reproduction. Efforts aimed at reducing a rodent population to an acceptable size must be proportional to how effectively the rodents resist damaging factors. There is a positive correlation between population complexity and resistance, which means that as many independent methods as possible must be devised to combat the main groups within the structure. The number of methods may be rigorously defined if the target groups have been identified. For each targeted (discriminatory) extermination method, we can expect rodents to exhibit a specialized adaptive mechanism, whereas we can expect a less specialized one for each nondiscriminatory method. The probability of reducing the number of synanthropic rodents at a controlled site is proportional to the effectiveness of the product and the vulnerability indicators of the population. The probability that the size of a synanthropic rodent population will be restored at a controlled site is proportional to the size of the living environment, the increase in population due to reproduction and immigration, and the rate at which reproductive groups are formed. It is inversely proportional to the size of the living environment at neighboring sites as well as the distance between the controlled facility and neighboring populated sites. Stable habitats are associated with more predictable results of extermination efforts.

Key Words Synanthropic rodents populations, independent extermination methods, target groups, restoration of number, size of the living environment

INTRODUCTION

Deep insight into the biological species, taking into account its annual and perennial population dynamics throughout its geographical range, makes it possible to control populations of problematic species of living organisms. This report considers some common approaches to managing populations of synanthropic rodents that pose risks to humans as well as the probability of success in using prescribed procedures and techniques, taking into account the situation in the hierarchy of the populations as well as population structures in terms of sex, age and phenotypes.

MATERIALS AND METHODS

We analyzed more than 700 works for this study. The author conducted original research on the Norway rat (*Rattus norvegicus*), detailing the methods and results (Rylnikov, 2008 a,b; Rylnikov, 2010). We determined the ages of the rats by dental wear. We propose methods for studying the natural diets of Norway rats, determining their fecundity, fertility, mortality, population sizes and mobility. We used methods for studying the effect of rodenticides on rats in laboratory and field conditions, along with statistical methods for processing the results of the experiments. We estimated the amount of rodenticide bait ingested and carried away on the body, taking into account gender, age and social status. For this purpose, in these forms we introduced markers to allow us to estimate

avoidance reaction and tolerance. We found the markers in the feces, teeth and bone tissues of the rats. Principles of the graph theory and the probability theory used.

RESULTS

<u>Estimation of the probability of discovering the control and exterminatory container (CEC). Within 1 day.</u> We shall examine Graph G , which depicts the preferred areas of motion of rodents – the line on the plane (usually along walls and partitions) and the areas of intersection, which we shall call crossroads are the graph vertices. We will also examine the smallest dominating set V of graph vertices G, which corresponds to the placement within its vertices of containers with minimal amounts of deratization agents. Their number will correspond to the domination number γ *(G),* where γ *(G)$\geq$r/(k$_{max}$+1)* (Melnikov, 2009). Let r_k be the number of vertices to the degree of k, k_{max} – the vertex of the highest degree and i – the degree of the vertex. Let C be the event "lands in vertex of the degree k within one day", A/C be the event "visits s CECs", located at vertices to the degree of k within one day", then $P(C)= k\times r_k/\Sigma(i+1\rightarrow k)\ i\times r_i$, and $P(A/C)= s/r_k$. Then $P(AC)=P(C)P(A/C)=(k\times r_k/\Sigma(i+1\rightarrow k)\ i\times r_i)\times(s/ r_k)= (s\times k)/(\Sigma(i+1\rightarrow k)\ i\times r_i).$

<u>Within t days</u> (the frequency of placing deratization agents may be considered at its optimum value when $P(AC_t)$ over 7 days is no less than 0.95). Let t be the time necessary to search for a CEC, then within t days the event "AC" will occur with a probability of $P(AC_t)=1-[1- P(AC)]^t$,where AC_t be the event "rodent comes into contact with the deratization agent".

<u>Estimation of the probability of contact with rodenticide bait.</u> If it is assumed that CECs are placed correctly and the probability of rodents coming into contact with the containers tends to 1, then at the next stage we must estimate the probability of the event $B(AC)_t$ "rodent ate bait and died". The probability the such event $P(B(AC)_t)$ will be equal to the product of $P(AC)_t \times P(B/(AC)_t),$ and $P(B/(AC)_t)$ is the probability that the rodent ate the bait, provided that it found the bait tray. The probability of the event $B(AC)_t$, according to data from field tests is less 0.9 (our data). $P(B/(AC)_t)=S^{i\ (-1/k)},$ and $S^{i\ (-1/k)}$ is the probability of a rodent being on a unit of the territory within the limits of its site depending upon the density of the population (S^i takes conventional values from 1 to 2 corresponding to an increase in the size of the site from a certain minimum value S^i_{min}). It is evident that the greater the value of $S^i,$ the lesser the probability of the rodent stopping at each point of its site. The probability of ingesting the bait will also decrease. $1/k$ is a degree value where $S^i,$ which describes the attractiveness of the bait or the bait tray as a whole ($0<1/k<1$). The probability $P(B/(AC)_t)$ rises with an increase in the attractiveness of the bait and tends to 1 with an increase of the value of $1/k$ even under conditions of a small number of rodents and a low frequency of placement of the deratization agent. The high level of attractiveness of the deratization agent will ultimately lead to a high rodent death rate. Therefore, the probability of taking the bait will be $P(B(AC)_t) = P(AC)_t\times S^{i(-1/\kappa)}.$ The probability of an animal receiving a moderately lethal dose of strong poison, according to data from laboratory and field tests during 30 days, does not exceed 0.7 (our data), and the probability of an animal receiving a moderately lethal dose of poison with a cumulative effect is 0.8-0.9 (our data).

<u>Estimation of the probability of capturing rodents using mechanical means (traps).</u> The desired probability is $P (H(AC)_t) =P(AC_t)\times P(H/AC_t),$ and $P(H/AC_t) = S^{i(-1/\kappa)}.$ The probability of full catching of Brown rats arc traps №0 is 0,9 for 30 days (our data).

<u>Estimation of the probability of the extermination of rodents at sharing of two conditionally independent method: rodenticide baits and traps.</u> $P(X/E)$ is the probability of the event "animal dies, provided that operator proficiency is sufficient". $P(X/E_1)$ is the probability of death under the conditions of the work of the rodenticide bait operator. $P (X/E_2)$ is the probability of death under the

conditions of the work of the trap operator. The event $B(AC)_t$ "rodent ate bait and died"− in essence reflects the qualification of the operator taking into account the changes occurring in population within the calendar year. Therefore, it is possible to accept that $P(B(AC)_t)= P(X/E_1)$ and $P(H(AC)_t)= P(X/E_2)$. The probability of the death of a rodent when using two comparatively independent methods – bait and traps may be estimated as follows: $P(X/E)=P[(X/E_1) \cup (X/E_2)]= P(X/E_1)+ P(X/E_2)− P[(X/E_1) \cap (X/E_2)]= P(X/E_1)+ P(X/E_2) − P(X/E_1) \times P(X/E_2)$. According to the addition theorem of probability, the probability of death of a rodent will be higher if at least one of the events occurs (either one, or the other, or both). The probability of death of rodents with combined use of anticoagulant rodenticide bait and traps simultaneously during 30 days is 0,98–0,99 (our data) . $P(X/E_1)$ and $P(X/E_2)$ are calculated taking into consideration the selective death of the young and mature. According our data, the Brown rats who ate two kinds of rodenticide baits, were more victims, than survivors. And also, with simultaneous application of rodenticide baits and coverings (dust or paste), more deaths amongst Brown rats were noted, than with separate applications (Rylnikov, 2010). Therefore, application of two and more rodenticide agents in the form of baits or coverings presented simultaneously is justified, though these events are more dependent, than simultaneous application of rodenticide baits and traps.

Estimation of the probability of death among young and adult rodents from rodenticide bait. Probabilities $P(H(AC)_t)$ and $P(B(AC)_t)$ will differ for rodents of different age groups. The probability of $P(F_{sad})$ and $P(F_{ad})$, of events F_{sad} "death of young" and F_{ad} "death of mature", that a young or mature rodent will approach the bait is equal to the occurrence of that age group among others in the population or alternately a share in comparison with the other group. The events (F_{sad}) and (F_{ad}) are mutually exclusive. The share of the youngest age group in summer will reach 0.6, but in winter it will drop to zero in the mid- and northern latitudes or to 0.1-0.2 in the southern latitudes depending on the share of breeding females (our data). For simplification of designations, we wil accept event $B(AC)_t$ "rodent ate bait and died" as being equivalent to event D. The events (D_{sad}/F_{sad}) and (D_{ad}/F_{ad}), that a lethal dose of the bait will be eaten by a young rodent (event "D_{sad}") upon the condition that it is a young or mature rodent that approaches the bait ("D_{ad}") upon the condition that it is a mature rodent that approaches the bait. We will consider the events "D_{sad}" and "D_{ad}" to be independent, although this may not be the case. For example, mature rodents that approach the bait may emit warning sounds following contact with the poisoned bait, release glandular secretions or simply urinate or defecate on the bait, thereby warning other rodents of danger. Under the condition of independence of the events "D_{sad}" and "D_{ad}", $P(D/F)= P(D_{sad}/F_{sad}) + P(D_{ad}/F_{ad})− P(D_{sad}/F_{sad}) \times P(D_{ad}/F_{ad})$.

Estimation of the probability of freeing an area of synanthropic rodents. Freeing an area is defined, firstly, by the proficiency of the operator, which may be called an a priori component of success and be calculated by the percentage of areas that have been fully freed, from the number of areas that are under maintenance. Secondly − the dynamic component − the adequacy of the tactics of applying methods in relation to the given population grouping of rodents taking into account adaptive reactions and behaviour and physiology in the given calendar period of the year. An inference system may be applied to them using Bayes' formula:

$P(E/X) =P(X/E)P(E)/ P(E)P(X/E)+P(X/\bar{E})P(\bar{E})$ – Bayes' formula (Vinogradov, 1977).

$P(E)$ is the a priori probability of the event "operator is adequately proficient". $P(X)$ is the probability of the event "rodent dies". $P(E/X)$ is the probability that the "operator is adequately proficient upon the condition that the rodent dies". We shall assume that this probability is equal to the probability "the area is freed". $P(\bar{E})$ is the a priori probability of the event "operator is not adequately proficient". $P(E)=1- P(\bar{E})$. $P(X/E)$ is the probability of the event "rodent dies, upon the condition that the operator is not adequately proficient". The value $P(X/E)$ will tend to unity upon the condition that control methods are placed in the required quantity and in accordance with the distribution of the animals and their mobility, the absence of an avoidance reaction to the control method (event X_1) – no less than 95%; the absence of resistance (event X_2) – no less than 95%; $P(X/E)$ – the conditional probability associated with seasonal specific behavioural features as a whole and mobility of rodents in particular,

this value will therefore be subject to seasonal changes. As opposed to this, $P(E)$ is not subject to seasonal changes. $P(X|\bar{E})$ is the probability of the event "rodent dies upon the condition that the operator is not adequately proficient in order to free the area" and

$P(X|E)=1 - P(X|\bar{E})$. The death rate may be calculated using the formula $d_i =1- l_i$ and will be approximately (as a proportion): *winter* – **0.90**, *spring* – **0.30**, *summer* – **0.50**, *autumn* – **0.70**.

Taking into account the fact that the death rate of rats at built-up, inhabited areas is formed from two components – natural and involuntary death, we shall accept that $P(X|E)=d_i$. The desired probability will be greater, the higher the a priori proficiency of the operator ($P(E)$ equal to 0.5, 0.7 and 0.9), which is a limiting factor in relation to the increase in the probability of freeing the area. When $P(E)=0.5$, the proficiency of the operator has almost no influence on the probability of freeing the area. The a priori proficiency of the operator will have the least influence on the results of freeing the area in December when the natural component of the death of common rats is at its highest. The trend for the probability of freeing an area lies behind the trend for the probability of the death of common rats (Fig 1, left).
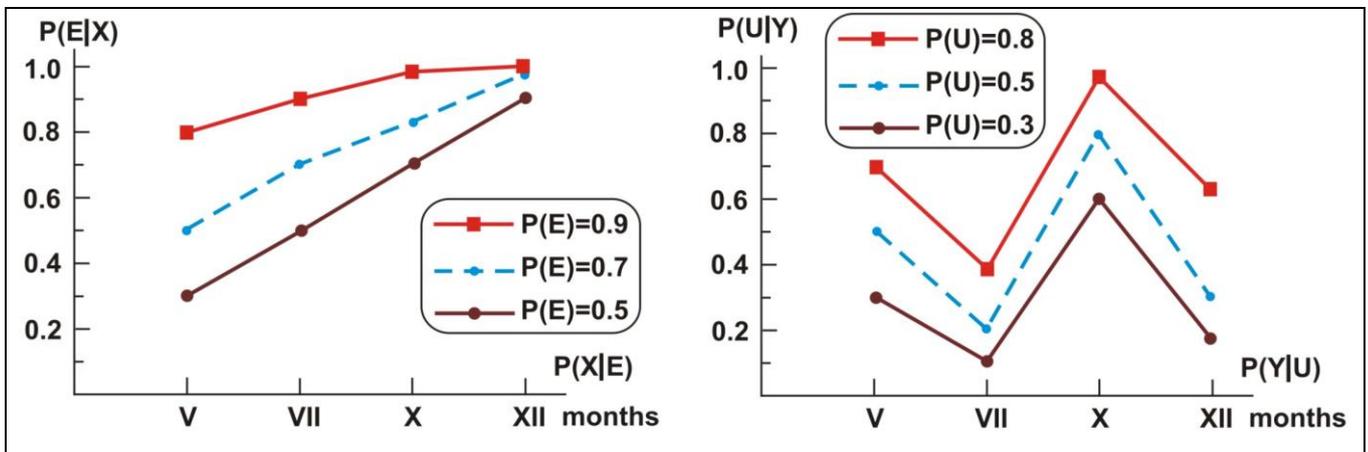

Fig. 1. Probability of freeing an area of common rats (left); probability of a recovery of the population of common rats (right).

Estimation of the probability of the recovery of the population of synanthropic rodents in the area. The a priori component of the speed of recovery of the rodent population is the capacity of the living environment of the controlled site and the dynamic component is the increase in population due to reproduction and immigration. This is all true under the condition that the action of the extermination methods was completed or reduced to a minimum. If extermination methods are operating effectively, the populating of a site by rodents may be slowed down for the period that the rodenticides are in effect. In this model it is necessary to also introduce a probability of rodents surviving at a controlled site: in winter – only due to surviving residents with minimal values of immigration and reproduction components; in spring (when the young come to the surface) – due to the young joining the active part of the population; in summer – due to the young joining the active part of the population and their dispersal; in the autumn (during the autumn-winter migration) – due to immigration from undeveloped land (our data);

$P(U|Y)=P(U)P(Y|U)/((P(U)P(Y|U)+P(\bar{U})P(Y|\bar{U}))$ – Bayes' formula (Vinogradov, 1977),

where $P(U)$ is the a priori probability that the area "has a sufficient capacity for the living environment for the common rat" (this value is calculated as proportion of the composite score (K_i) which characterizes the favourability of the living space in a given area to the composite score, which

characterizes the maximum level of favourability of a living space – K), i.e. $P(U) = K_i/K$. Where U is the event "the area does not have sufficient living environment capacity for common rats", Y is the probability that the event "rodent arrives at the area" takes place, which is formed from three components: Y_1 – the arrival of immigrants Y_2 – the arrival of young, Y_3 – surviving residents, upon the condition that the capacity of the living environment favours this. We shall proceed from the assumption that event Y takes within one month. One month is a sufficient period: 1) for the appearance of young on the surface; 2) for immigration; 3) for the survival of a part of the common rat population under the conditions of its extermination. $P(Y/U)$ is the probability that the rodent appears at the area under the condition that the capacity of the environment is sufficient for it to inhabit the area. The arrival of a rodent at the area does not mean that it will settle in the area. $P(U/Y)$ is the probability that the "area has sufficient environmental capacity for the habitation of rodents provided that event Y took place". We shall take this probability as being equal to the probability "rodents have settled in the area". $P(\bar{U})=1-P(U)=1-K_i/K$, and $P(Y|\bar{U})$ is the probability that event Y took place, upon the condition that the area does not have a sufficient environmental capacity for the habitation of common rats. For the characteristics of this last conditional probability, factual statistical data may be used on the percentage of areas, in which rodents have not settled for the period of one month, and $P(Y|\bar{U})=1-P(Y/U)$. Experimental information on the probability of the appearance of common rats in the area is obtained by a calculation of the relation of the population of common rats of a subsequent record to a previous record at rice fields of the Krasnodar Territory from December 1981 to June 1982 (our data). Therefore, the greater the a priori probability of the sufficiency of the capacity of the living environment, the greater the probability that rodents will settle in the area. If $P(U)$ is greater than 0.7 and $P(Y/U)$ is greater than 0.3, then $P(U/Y)$ will be greater than 0.5; the area will be prone to the actual settlement of rodents (Fig 1, right).

DISCUSSION

Key population indicators such as spatial structure, composition in terms of age, gender, genotype, fertility, mortality, migration activity, and ultimately, population dynamics may differ significantly in different parts of the geographical range, in different phases of population dynamics and in different seasons.

The tendency of rodents to sinanthropy as typical sinanthropes, like agrophiles, is more pronounced closer to the border of their geographical range, namely, in the far north and in arid and mountainous areas (Kucheruk, 1990; Kucheruk, 1994; Khlyap, Warsawskii, 2010), from summer to winter, as well as from the habitats having the best living conditions to those having the worst (Okulova, 1994; Shilova, Kalinin, 1994). This is associated with less favorable habitats for synanthropic and agrophilous rodents in unimproved areas and the desire to use refuges with constant microclimates and accessible food supplies. In the core area (optimum) of the species' geographical range, the population density is not only higher, but also more stable, whereas along the periphery it fluctuates in a wide range. The population cycles are determined mainly by density-dependent mechanisms in the optimum of the habitat and by exogenous factors (food, weather) and competitors along the periphery. Moreover, the population cycle lasts four years, the largest sustainable population being observed in the third year, particularly in summer (Puzachenko, 1995; Zhigalsky, 2002; Ivanter, 2008). It is possible in northern latitudes to limit rodent control measures to buildings (two cycles per year), and in middle latitudes to buildings and their adjoining grounds (four cycles per year), especially in summer. In southern latitudes, it should be done in buildings (monthly and year-round), and in unimproved areas (2-3 times every winter - our data; Karaseva et al, 1990; Okunev et al, 2010).

In the Palearctic, the diapause of breeding occurs from autumn until early spring, getting longer and longer as one goes from south to north. In the reproductive period, there is a remarkably high

proportion of younger age groups in the population contributing to diversity within the population, as well as migration activity associated with the dispersal of the young. As we and other authors have shown, the age groups within a single species of rodents have varying physiological resistance to the same active ingredient of rodenticide and different food preferences with respect to the components of the edible basis of rodenticide baits. Sex and age differences in the sensitivity of rodents to the active ingredients of rodenticides, reactions to rodenticide baits and traps reduce the risk that the population group as a whole will die. The resistance of populations to poisons and mechanical devices is largely determined by intrapopulation heterogeneity (Rylnikov, 2008 a,b; Shilova, Tchabovsky, 2009). Different versions of the functional organization of the population of different species of rodents, depending on the ratio between the settled and migratory parts, largely explain the resistance of intrapopulation groups and their cooperation to ensure a coherent response of the population to damaging factors (Shchipanov, 2000). According to Puzachenko, in such cases, the biological system becomes more complex, increasing its moment of inertia and consequently resistance to damaging factors (Puzachenko, 1992). The population of synanthropic rodents is least stable during the diapause of reproduction in winter. Rodents concentrate in areas with favorable microclimatic and feeding conditions (mainly heated aboveground and underground sites, transportation, landfills, etc.). Their migration activity and fertility are low, mortality is high, there is a lack of food and vitamins, and the age structure is simple, with a predominance of older animals. The resistance of a population of synanthropic rodents will be higher in the calendar period of the year coinciding with the time of active reproduction for the following reasons: the proportion of immigrants is high, birth rates are high, and the age structure of the population is complex with animals of all ages. Mortality is relatively low. To this we must add that during the period of diapause, extermination efforts are not only more efficient, but also more economical provided that they are carried out only in areas populated by rodents. Since the ratio of age groups is seasonally-dependent, the use of particular products and methods must obviously be directed simultaneously at these age groups (Rylnikov, 2008 a, b).

Rodents exhibit four main adaptive mechanisms (neophobia, aversion, tolerance and resistance), which reduce the impact of particular rodenticides on them. Some of these adaptive mechanisms are mutually exclusive. For example, neophobia rules out the possibility of any of the other adaptive mechanisms being observed. Aversion and tolerance are dependent but mutually exclusive adaptive mechanisms; the development of one of them virtually rules out the possibility that the other will form. It is well known that first-generation anticoagulants cause cross-resistance to second-generation anticoagulants in rodents (Macnicoll, 1988; Rylnikov, 2008 a, b; The RRAC Seminar in Lyon. 2008). Furthermore, the use of anticoagulant rodenticides and high-potency rodenticides or rodenticide baits and rodenticide coatings can be called conditionally independent, because the consequences caused by the latter can affect the behavioral responses of rodents to the former through the avoidance reaction (aversion) to the individual components of the rodenticide baits. It is well-known that if a rodenticide has food ingredients (sugar, vegetable oil, etc.), a conditioned reflex can be produced against it. Products that act upon the digestive and respiratory systems, as well as chemicals and mechanical devices, are more independent. When rodents adapt to the above-mentioned products and devices, we observe a reduction in their effectiveness; the population remains stable while fertility is moderate. We believe that along this path we can expect growth in the population towards the 'k' strategy. Mortality among rats increases when we effectively overcome their neophobia, aversion and resistance to rodenticides. Female fecundity increases, and puberty comes earlier, when density-dependent mechanisms are triggered. As a result, the population is preserved, but at higher cost. We believe that homeostasis can be maintained by using the 'r' strategy. It is well-known that the upper limit to the population size depends on the size of the living environment. In a stable living environment, the results of efforts to regulate morbidity will obviously be more predictable.

CONCLUSION

■ For effective control, the entire area occupied by a rodent population must be taken under control. ■ The most effective extermination efforts are those carried out mainly in the calendar period that coincides with the diapause in reproduction. ■ The required intensity of efforts directed towards attaining the necessary level of specific mortality is proportional to the resistance of the populations. ■ The more complex the population structure, the more numerous must be, if possible, the independent methods of acting upon the main groups of this structure in order to destroy it. ■ The number of ways of acting upon the population can be rigorously defined if the target groups have been identified. For each specialized (discriminatory) extermination method, we can expect the rodents to exhibit a specialized adaptive mechanism with relatively low energy expenditures, whereas for each nondiscriminatory method we can expect a less specialized adaptive mechanism with higher energy expenditure. ■ The probability of reducing the number of synanthropic rodents at a controlled site is proportional to: the effectiveness of the poison (whether a lethal dose of the active substance is administered taking into account individual, age and other intrapopulation variability) or mechanical device (its triggering mechanism) as well as population vulnerability indicators (high mortality, low fertility, low migration component, relatively uniform age distribution). ■ The probability that the number of synanthropic rodents will be restored at a controlled site is proportional to the size of the living environment at the site (or in the area), the increase in population due to reproduction and immigration, the current size of the population at neighboring sites (in neighboring areas), the average rate of migration during the current season, the current size of the population at the controlled site (in the controlled area), and the rate at which interpopulation reproductive groups are formed. It is inversely proportional to the size of the habitat at neighboring sites (in neighboring areas) and the distance between populated neighboring sites and the controlled site. ■ Stable habitats are associated with predictable results of extermination efforts.

It is therefore possible to estimate the desired probability of freeing the area (site) from rodents and the probability of repeat settlement under conditions of a certain procedure of applying methods, means and techniques taking into account the structure of the population under examination and its position within the population hierarchy. Relative values obtained on the basis of calculations, experimental information and approaches suggested by us to manage the rodent population are, from our point of view, sufficient for the desired goal − to seek an optimal method of controlling the chosen biological system. The information received may be applied in training programmes and also in artificial intelligence systems (expert systems).

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