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ESTIMATING SIZE OF HOME RANGE
OF *APODEMUS AGRARIUS* (PALL.)

(Ekol. Pol. 18: 1—12). An estimate was made of the home range size of
Apodemus agrarius (Pall.) using the method of calculating the number of traps. The
results were compared with the results obtained by a second generally employed method
of estimating home range size which is based on calculating the center of activity.
The two estimates were found to vary greatly.

INTRODUCTION

Determining the home range size of an animal belonging to an investigated
population is an important and interesting problem in ecological research.
Data from literature indicate that the size of this area depends on many
population and biocenotic factors (population organization, interspecies
relations, character of environment, etc.).

There are several methods used in estimating the size of the home range.
Among the most widely used is the method proposed by Hayne of calculating
the center of activity of the animal (center of gravity of capture points) as
well as the frequency of captures at a point which is at a given distance

from this center (H a y n e 1949). This method has been theoretically developed
by other ecologists by giving the random variable distance from the calculated
center of activity as the distribution function. A normal distribution was
taken as the distribution of this variable (C a l h o u n and C a s b y 1958,
H a r r i s o n 1958) or Pearson's distribution of type III for recapture radius
to which the appropriate transformation was applied (D i c e and C l a r k 1953).

It was stated that this method was applicable when the home range of
the investigated individual does not change during his presence in the area
under study and when there are at least 10 captures of the animal. The
assumption concerning one center of activity and the fixed home range has
been questioned in the works of S t i c k e l 1954, K a y e 1961, B r o w n 1962,
T a n a k a 1963 and others.

The method employed in this work allows to estimate the home range
size for few captures of mouse (more than 1). This method is independent
from shape of this home range. The obtained results have been compared
with the estimate arrived at through an analysis of the distribution of recapture
radius for the calculated center of activity.

METHOD OF COLLECTING AND ANALYZING MATERIAL

The investigation was conducted near the Field Station, Institute of
Ecology at Dziekanów Leśny near Warsaw. The investigated area is covered
by woods (*Pino-Quercetum* and *Carici elongatae-Alnetum* communities). The
animals were caught live in wooden traps using oats as bait. The CMR pro-
cedure, i.e., capturing, marking and releasing the animals at the capture
points was used. Traps were checked daily. The traps were arranged on
a rectangular area encompassing 4.7 ha.

The arrangement was in the form of a chessboard with each catch point
15 m from the next. Thus 210 traps were ranged in 15 rows with 14 traps
per row. Trapping lasted 43 days (Sept. 3 to Oct. 15). In the first period from
Sept. 3 to Sept. 14, each trapping point contained one trap, and in the next
31-day period (from Sept. 15 to Oct. 15), the trapping points contained two
traps.

Three species of rodents were caught: *Clethrionomys glareolus* (Schreb.),
Apodemus agrarius (Pall.) and *Apodemus flavicollis* (Melch.). Only materials
pertaining to *Apodemus agrarius*, in the period from Sept. 15 to Oct. 15, were
used for analysis. This choice was dictated by the abundance of the material.

192 mice were marked during the analysis period. Of these 82 were captured
at the periphery of the experimental plot (periphery: two outside rows of
traps) and 110 mice were captured in the interior of the plot.

In this estimate we have assumed, according to C a l h o u n and C a s b y

(1958) that the distribution of recapture radius is the normal function and also that the individual's home range is a circular area where radius R equals three standard deviations of the normal function (3σ). The probability of the animal's presence within this area ($R = 3\sigma$) is 0.9888 (Calhoun and Casby 1958). The probability of the animal's presence in the radial area where the radius equals 2σ is 0.8645. In accordance with the above the area of the home range is:

$$S = \pi R^2 \cdot d^2$$

where d is the distance between traps arranged in the grid of the experimental area.

The above method of estimating the home range has been compared with the method employed in this work.

This second method is based on the assumption that the home range is a fixed one with defined boundaries which may shift depending on different ecological situations. Within this fixed area whose size is S units square there are r traps which constitute part of all the traps regularly set (at intervals of d metres) in the experimental area. It is accepted at the same time that the home range of the studied individual is located entirely within the experimental area. Moreover the assumption is made that the animal does not show an inclination for any of the r capture points of his home range and thus it treats them with a uniform probability equal to $\frac{1}{r}$. Captured n times in a given period the mouse may "reveal" k capture points among r points located in his home range with the probability:

$$P_{n,k} = \binom{r}{k} \frac{1}{r^n} \cdot (-1)^k \sum_{v=1}^{k} (-1)^v \binom{k}{v} v^n \tag{1}$$

The expected value is given as:

$$E\left(X_n\right) = r\left[1 - \left(\frac{r-1}{r}\right)^n\right] \tag{2}$$

With the known mean value $E\left(X_n\right)$ for the given n (number of captures) the value r may be calculated from equation (2), and, multiplying it by the square of the distance between traps we arrive at the following estimate of the home range size:

$$S_1 = r \cdot d^2$$

When the mouse systematically avoids certain points in his home range (for enviromental reasons) this value will be an underestimation. Since the value $E(X_n)$ is unknown, we assume its estimate on the basis of samples $(\bar{x}_n)$. Let N_n be the number of animals captured at least n times. In the course of n successive captures each of these mice "reveals" a given number of points of its r home range points. For the entire group of mice comprising N_n individuals we calculate the mean number of "revealed" points $(\bar{x}_n)$ and accept it as the estimate of the value $E(X_n)$. From equation (2) we calculate value r for the given n as well as value $\bar{x}_n$.

If the empirical frequency does not agree (for estimate r) with the probability values as given in equation (1), we may consider the "truncated" distributions for the given values of the variable X_n, and in this way uniform groups may be distinguished with respect to value r.

ANALYSIS OF MATERIAL

When the mice are captured in the interior of the experimental area, the size of the home range is estimated on the basis of 3, 4, 5 and 10 captures.

If the home range of a particular mouse belonging to a given group (comprising N_n mice) does not change during the time of its presence on the investigated area, the home range size estimate on the basis of n number of captures should be equal to the estimate obtained for the number of captures less than n. Thus the home range size estimate may be made for any number of captures (more than 1) provided there is a sufficient number of animals. This type of analysis makes it possible not only to estimate the home range size on the basis of a small number of captures but also to verify the hypothesis of the invariability of the home range size during the time of the individual's presence on the investigated area (more precisely, depending on the number of captures). To obtain this type of information, the home range size has been evaluated separately on the basis of 3, 4, 5 and 10 captures and thus separately for each group of individuals which have been captured at least 3, 4, 5 and 10 times.

An analysis was made of the distribution of the number of "revealed" points (distribution of the variable X_n) during n captures ($n = 3, 4, 5$ and 10) for these selected groups of animals. The obtained empirical data are shown in Table I where n is the number of captures, k — the number of "revealed" points (value of the variable X_n in n captures), $N_{n,k}$ — the number of individuals which in n captures "revealed" k points of the home range. For these empirical sequences the mean number of "revealed" points $(\bar{x}_n)$ was calculated and their corresponding values r were found. The obtained values are shown on Table II. For value r (corresponding to mean $\bar{x}_n$) the theoretical

Distribution of number of "revealed" points

Tab. I

k \ n	3		4		5		10	
$N_{n,k}$	$N_{3,k}$	$N'_{3,k}$	$N_{4,k}$	$N'_{4,k}$	$N_{5,k}$	$N'_{5,k}$	$N_{10,k}$	$N'_{10,k}$
1	4	2	0	0	0	0	0	0
2	29	34	14	8	10	4	1	0
3	48	45	24	36	13	24	1	0
4			30	24	28	30	2	1
5					13	6	6	5
6							7	12
7							5	9
8							3	2
9							4	0
10							0	0
N_n	81	81	68	68	64	64	29	29

n — no. of captures.
k — no. of "revealed" points,
$N_{n,k}$ — no. of mice who "revealed" k points in n captures,
N_n — no. of mice for which there were at least n captures,
$N'_{n,k}$ — no. of mice (theoretical) who ' revealed" k points in n captures.

Results of analysis of distribution of number of "revealed" points

Tab. II

n	3	4	5	10
$\bar{x}_n$	2.5432	3.2352	3.6875	6.2100
r	$5 \leqslant r \leqslant 8$	$6 \leqslant r \leqslant 9$	$6 \leqslant r \leqslant 7$	$8 \leqslant r \leqslant 9$
χ^2		10	8.97	4.84
$\chi^2_{0.05}$		3.841	3.841	3.841

n — no. of captures,
$\bar{x}_n$ — mean no. of "revealed" points,
r — point estimate of home range.

numbers $N'_{n,k}$ were calculated by multiplying the probability $P_{n,k}$ by N_n. It appears that for $n = 4, 5, 10$, $\chi^2_{emp.} > \chi^2_{0.05}$, thus the estimated r is not a good estimate for the entire group of animals (N_n) with an appropriate number of captures (Tab. II). In order to obtain the homogeneous groups with regard to value r (home range size) the "truncated" distributions designated for certain values k were examined (Tab. III). And so for the group of mice with 4 captures the distribution of 3 and 4 "revealed" points were analyzed, and for the group with at least 5 captures the analysis pertained to the group which "revealed" 3, 4 and 5 points of their home range. Among individuals

Analysis of "truncated" distributions of number of "revealed" points

Tab. III

k / $N_{n,k}$	n = 3		n = 4		n = 5		n = 10	
	$N_{3,k}$	$N''_{3,k}$	$N_{4,k}$	$N''_{4,k}$	$N_{5,k}$	$N''_{5,k}$	$N_{10,k}$	$N''_{10,k}$
1	4	2	0	0	0	0	0	0
2	29	34	14	4	10	1	1	0
3	48	45	24⎤	25	13⎤	10	1⎤	0
4			30⎦	29	28	28	2	2
5					13⎦	16	6	6
6							7	10
7							5	5
8							3⎦	1
9							4	0
10							0	0
N_n	81	81	68	58	64	55	29	24
$(r, k_1 k_m)$	$5 \leqslant r \leqslant 8$		10		10		8	
$N_{n(k_1 k_m)}$			54		54		24	
$N_{n(r, k_1 k_m)}$			58		55		24	
$\dfrac{N_{n(r, k_1 k_m)}}{N_n} \cdot 100$			85%		86%		83%	

n — no. of captures,
k — no. of "revealed" points,
$N_{n,k}$ — no. of mice who "revealed" k points in n captures,
N_n — no. of mice for which there were at least n captures,
$N_{n(k_1, k_m)}$ — no. of mice who "revealed" a number of points no less than k_1 but no more than k_m
(r, k_1, k_m) — home range size estimated on basis of r group of mice who "revealed" points $\leqslant k_1$ but $\geqslant k_m$,
$N_{n(r, k_1, k_m)}$ — no. of mice whose home is (r, k_1, k_m),
$N''_{n,k}$ — no. of mice (theoretical) for (r, k_1, k_m) who "revealed" k points in n captures.

with 10 captures, the group of mice which "revealed" 3 to 8 captures was taken for analysis.

The value r was estimated for those specified groups of mice and a calculation was made of how many among all the mice (N_n) have the same home range size as those which had been designated for analysis through "truncated" distribution.

Let us indicate by $N_{n(k_1, k_m)}$ the number of animals among all N_n mice

which "revealed" at least k_1 points but no more than k_m among r capture points. Then let $N_n(r, k_1, k_m)$ represent the number of mice which have the same home range size (r) as all the mice belonging to group $N_n(k_1, k_m)$ and let $P'_n(k_1, k_m)$ represent the probability that individuals having r points home range size will "reveal" not less than k_1 but not more than k_m capture points. Then the number of mice who have the same home range as the mice belonging to the specified group is calculated by the equation:

$$N_n(r, k_1, k_m) = \frac{N_n(k_1, k_m)}{\sum\limits_{k=k_1}^{k_m} P_{n,k}} = \frac{N_n(k_1, k_m)}{P_n(k_1, k_m)} \tag{3}$$

If all the mice (N_n) would have a uniform home range size then the size $N_n(r, k_1, k_m)$ from equation (3) should be equal to N_n.

The analysis of the "truncated" distribution (Tab. III) showed that these values are not identical. In the group of 68 individuals which had at least 4 captures, 58 mice (85%) had a home range size of 10 points whereas the remainder of the mice had a smaller home range. Among 64 animals which had at least 5 captures, 55 mice (86%) had a home range equal to 10 points and the remainder had a smaller home range. The group of mice which had at least 10 captures was also not uniform with respect to r. Among 29 individuals, 24 mice (83%) had a home range equal to 8 points. A very small number of mice had a home range different from those estimated on the basis of the specified groups and it was not possible to make an exact determination of the size of their home range.

Employing the method based on calculation of recapture radius through determination of the center of acivity (Calhoun and Casby 1958), the home range for each animal is estimated separately and this requires that the number of captures on the basis of which the calculation is made should equal at least 10. And thus, to employ the above method for the species discussed in this work, a group of individuals was selected which had a minimum of 10 captures. The center of activity and recapture radius for each of the mice belonging to this group were estimated after which the home range area was calculated according to Calhoun and Casby (1958), accepting the size $R = 3\sigma$, and for comparative purposes the home range area was calculated for the radius $R = 2\sigma$. To simplify the entries, the size 15 m² was accepted as the basic unit in expressing home range size. Then the number of points "revealed" by each mouse was calculated and, by accepting this number as an estimation from an one-element sample of the unknown mean value $E(X_n)$, the home range size (r) was estimated. The greater the

Home range size of *Apodemus agrarius* estimated by employing center
of activity method and also number of home range capture points method

Tab. IV

Mouse No.		No. of captures	Home range size in area units (15 m²)		
			center of activity method		no. of catch points method
			$4 \pi\sigma^2$	$9 \pi\sigma^2$	r
70		12	18.4	41.4	12—15
71		21	139.0	313.2	10
179			20.4	45.9	12—15
196			8.0	18.0	5—6
141		12	3.6	8.1	9—11
210		11	20.4	45.9	4
215	♀♀	13	23.2	52.2	14—18
222		12	24.4	54.9	9—11
228		10	1.6	3.6	2
239		10	11.6	26.1	8—9
240		12	13.6	30.6	9—11
54		13	62.4	140.4	5—6
103		19	25.2	56.7	17—20
21		14	62.8	141.3	13—15
115		10	58.8	132.3	29
117	♂♂	12	41.2	92.7	12—15
125		19	3.6	8.1	10—11
151		15	20.0	45.0	27—37
155		15	2.0	4.5	5
157		12	35.2	79.2	9—11
148		11	21.2	47.7	7—8
185		17	27.2	61.2	20—24
192		19	18.8	42.3	15—17
243		13	14.4	32.4	5—6
245		12	70.8	159.3	9—11
212		11	62.0	139.5	7—8
227		11	12.8	28.8	10—15
235		12	30.4	68.4	5—6
148		11	21.2	47.7	7—8

size of the home range of the studied animal the greater is the error in this
type of calculation. Where the home range is small ($r < 8$) we may accept
the arrived at estimate as sufficiently good. It appears from Table IV that
the home range which is calculated by employing the center of activity method
is several times greater than the home range calculated by the method of
counting capture points. This obtains both in cases where $R = 3\sigma$ and where
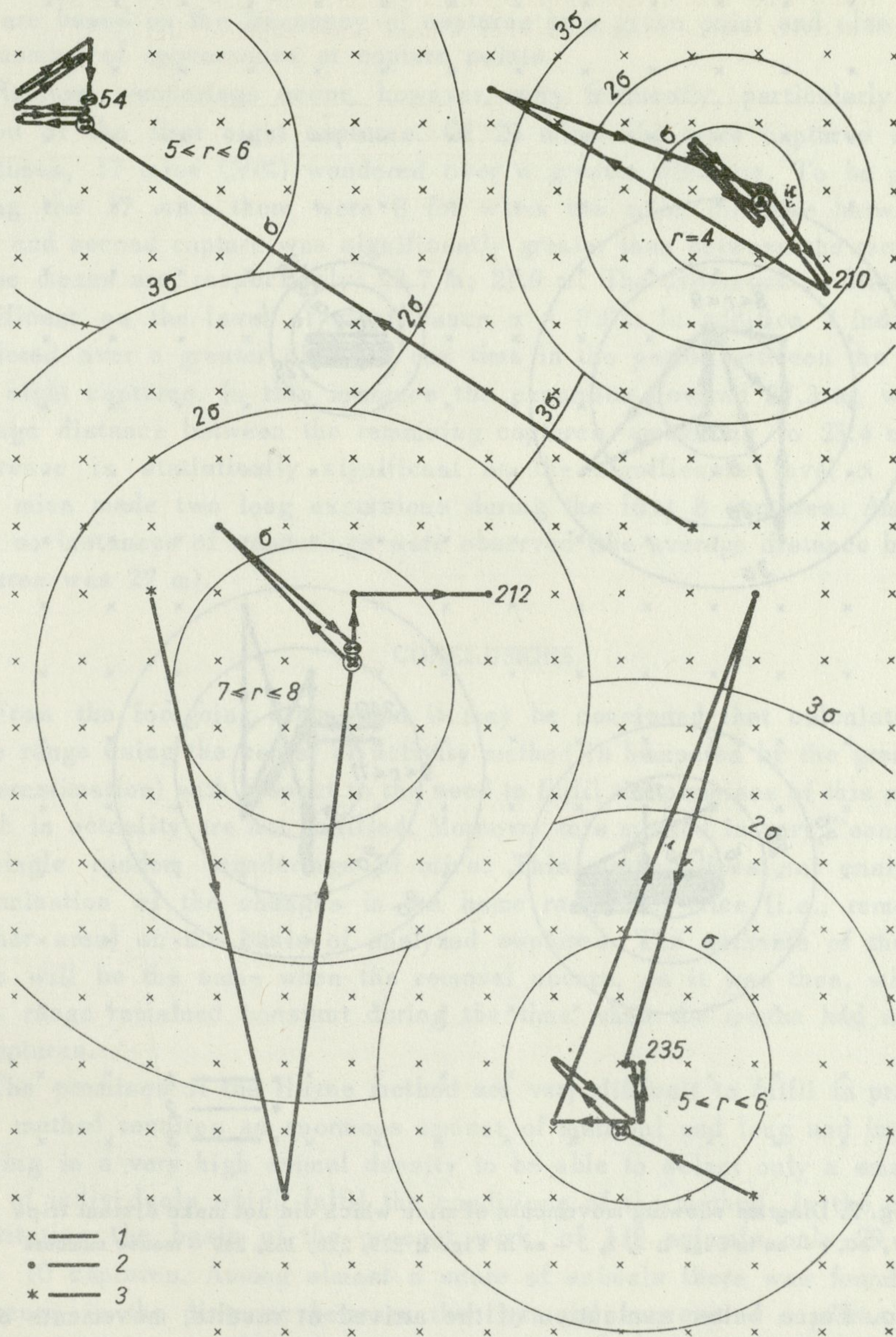
Fig. 1. Diagram showing movements of mice making distant trips

σ — standard deviation of recapture radius, 3σ — size of home range radius according to Calhoun and Casby (1958), *r* — home range size (no. of capture points)

1 — point with trap for live captures, *2* — trapping place, *3* — first capture; 54, 210, 212, 235 — mouse numbers
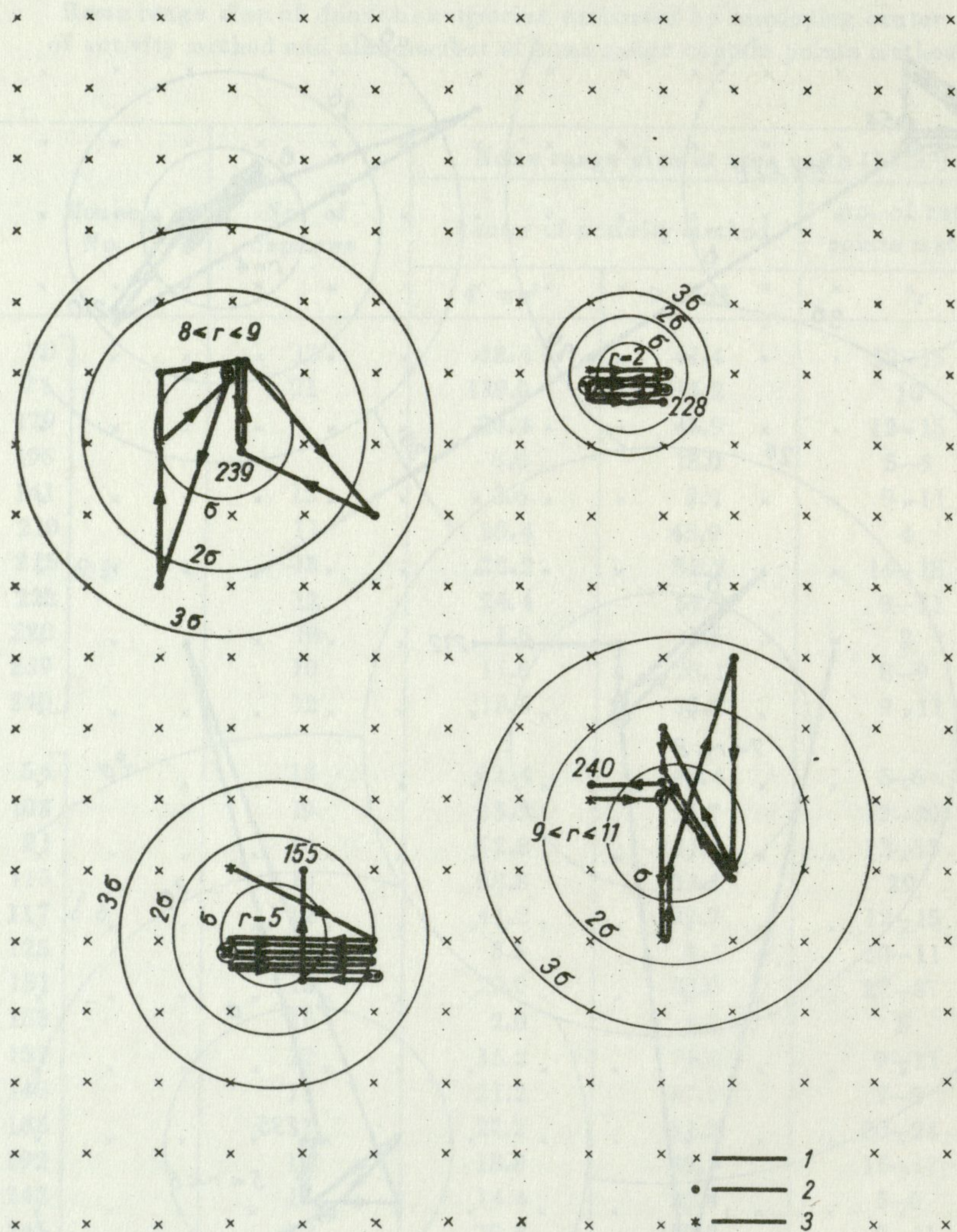
Fig. 2. Diagram showing movements of mice which did not make distant trips
σ, 3σ, r — as in Fig. 1; *1, 2, 3* — as in Fig. 1; 239, 228, 155, 240 — mouse numbers

$R = 2\sigma$. For a better evaluation of the arrived at results, movements of the individual during successive n capture are shown on the diagrams (Fig. 1, 2). Examples are cited where the differences in results of both methods were big (Fig. 1) and where the results were similar (Fig. 2). The diagrams in Figure 1 serve as illustrations of the effectiveness of the capture points method rather than of the impossibility of using the center of activity method. The latter method fails utterly in this case. The results obtained with the

capture points method are not affected by random wanderings of the animals but are based on the frequency of captures in a given point and also reflect the number of appearances at capture points.

Random wanderings occur, however, very frequently, particularly in the period of the first eight captures. Of 29 mice who were captured at least 10 times, 17 mice (59%) wandered over a greater distance. To be precise, among the 17 mice there were 8 for whom the mean distance between the first and second capture was significantly greater than between the remainder. These means are, respectively: 93.7 m; 21.9 m. The difference is statistically significant on the level of significance $\alpha = 0.01$. In addition 7 individuals wandered over a greater distance one time in the period between the second and eight captures. In this instance the excursion covered 87.3 m, with the average distance between the remaining captures amounting to 23.4 m. This difference is statistically significant on the significance level $\alpha = 0.01$. Two mice made two long excursions during the first 8 captures. Among 11 mice no instances of wanderings were observed (the average distance between captures was 27 m).

CONCLUSIONS

From the foregoing discussion it may be concluded that calculating the home range using the center of activity method is hampered by the great error (underestimation) with respect to the need to fulfil the premises of this method, which in actuality are not fulfilled. Moreover this method is very "sensitive" to single random wanderings of mice. This method does not enable any determination of the changes in the home ranges of mice (i.e., removal to another area) on the basis of analyzed captures. The estimate of the home range will be the same when the removal occurs, as it was then, when the home range remained constant during the time when the mouse had at least 10 captures.

The premises of the Hayne method are very difficult to fulfil in practice. That method requires an enormous amount of material and long and intensive trapping in a very high animal density to be able to select only a small percent of individuals which fulfil the conditions of the method. In the material constituting the basis of the present work, of 110 animals only 29 had at least 10 captures. Among almost a score of animals there was found a big difference in the distance between the first and successive captures or the existance of single distant captures outside the home range. They could be young animals with still undefined home ranges or immigrating animals seeking places for themselves in the system of the existing home ranges of settled individuals.

The less intensive the trappings, the greater is the probability of changes in the home range of the individual during the period of the ten captures.

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OCENA WIELKOŚCI AREAŁU *APODEMUS AGRARIUS* (PALL.)

Streszczenie

Oceniono wielkość areałów zajmowanych przez osobniki *Apodemus agrarius* (Pall.) metodą punktów łownych oraz metodą analizy rozkładu promienia odłowu dla obliczonego środka aktywności (Hayne 1949, Dice i Clark 1953, Calhoun i Casby 1958).

Materiał zbierano w lasach przy Stacji Terenowej Zakładu Ekologii PAN w Dziekanowie Leśnym. Na powierzchni 4,7 hektara rozstawiono 210 pułapek żywołownych sprawdzanych raz dziennie przez 43 dni. Oznakowano 192 osobniki *A. agrarius*. Dla 110 osobników łowiących się wewnątrz wyznaczonej powierzchni oceniono wielkość areału na podstawie ich trzech, czterech, pięciu i dziesięciu złowień metodą punktów łownych oraz dla 29 osobników łowiących się co najmniej 10 razy metodą obliczania środka aktywności.

Stwierdzono, że określenie wielkości areału metodą obliczania środka aktywności jest obarczone błędem (przeceną) ze względu na konieczność spełnienia założeń tej metody, które na ogół nie są spełnione (np. niezmienność areału osobniczego). Przecena miary areału może być także wynikiem włączenia do obliczeń danych dotyczących gryzoni wędrujących na znaczne odległości. Metoda punktów łownych, opierając się na częstości złowień w określonych punktach i uwzględniając kolejność ich odwiedzania, uniezależnia się od tego typu danych.

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