ISSN 1067-4136, Russian Journal of Ecology, 2021, Vol. 52, No. 4, pp. 329–339. © Pleiades Publishing, Ltd., 2021.

A Reconnaissance Method for Small Mammal Abundance Assessment in Urban Environments

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Received December 26, 2020; revised February 9, 2021; accepted February 17, 2021

Abstract—We propose a new reconnaissance method for mouse-sized mammal abundance estimation that does not involve animal capture. For survey purposes, we used plastic bottles without covers, which were baited and set out with free entry and exit for animals. Two patterns of setting out were tested: 5 and 10 m intervals on transects of 120 m in length. The total abundance of small mammals was estimated by the proportion of bottles in which baits were absent or eaten. These values were compared with data obtained in the same places by means of snap-trap lines or live-trap plots. We determined empirical coefficients for the conversion of the bottle attendance index into relative numbers (individuals per 100 trap nights) or community density (individuals per ha). It was shown that the method can be used in urban environments and combines quantitative estimation with low labour expenditures and high simplicity.

Keywords: mouse-sized mammals, abundance assessment, noninvasive method, snap trap, live trap

DOI: 10.1134/S106741362104010X

Mouse-sized mammals are an important part of not only natural but also transformed ecosystems, including urban environments. In the latter case, this group of animals is considered mainly from the standpoint of pest management because they are carriers of natural focal infections and parasites and are pests of agricultural crops. Communities of mouse-sized mammals that live in urban and suburban areas can include both native and invasive species, that are extensively controlled in many parts of the world [1–4]. The effectiveness of extermination measures depends, among other things, on precise targeting, for which it is necessary to assess the abundance of animals at a large scale. Similar data are needed for studying of density-dependent dispersal [5]. At the same time some pest small mammals have reduced in distribution and abundance and now fall in the category of endangered species [6].

In studies of small mammals (mainly mouse-sized rodents and shrews), the non-triviality of the task of assessing their abundance became apparent at the dawn of population studies [7–10]. The complexity of studying animals of this group is due to their secretive lifestyle, high species diversity, and complex population dynamics. Many classical methods for assessing abundance are difficult to apply in urban environments for several reasons. Primarily, when working in urban areas, researchers often encounter theft and vandalism of scientific equipment, which leads to increased costs and can reduce the volume and quality of the data obtained [11, 12]. Another problem is the high degree of fragmentation of the urban landscape and very different properties of separate patches, which affects the range of applicable methods. For example, in a city, it is difficult to find suitable locations for placing capture-mark-recapture (CMR) plots that allow the most detailed data to be obtained in natural conditions. Radio-tracking can also be difficult in areas of the city where there are a large number of obstacles to radio waves. Some traditional accounting devices can be dangerous or inconvenient for people and pets (for example, snap traps or pitfall traps).

One of the possible solutions to these problems is the use of indirect methods for estimating abundance. Indirect methods require the least effort and time. The use of minimally invasive and non-invasive techniques in studies has become a worldwide trend [12]. For small mammals, indirect counts can be successfully applied, first of all, to species that leave visible signs of their presence – burrows, “houses”, trails, etc. [13–16]. In relation to hidden species, this approach usually turns out to be too unreliable, requiring the researcher to be highly skilled but still producing an extremely subjective result.

There is also another group of indirect accounting methods that use technical devices of varying degrees of complexity – tracking tunnels, track plates, hair tubes, camera traps, analysis of faeces or pellets of predators, etc. [17–21]. However, these methods, in addition to unquestionable advantages, also have a number of disadvantages, including relatively high cost and/or complexity. The possibility of their use in urban environments is questionable. As far as we know, only track plates have been successfully tested in cities [21]. The development of indirect methods continues to maximize the cost-effectiveness of monitoring at a large scale, which is needed in the field of applied ecology for many purposes, including pest management [3, 22, 23]. To overcome the low reliability of abundance estimates with indirect methods (abundance indices), it is recommended that at least two indirect methods be used simultaneously [17]. This recommendation is another reason for the development of new, simple methods for assessing small mammal abundance.

One of the most inexpensive and low-effort methods that can provide interesting results is the monitoring of discarded bottles in search of animals that accidentally died there [24–26]. The method can provide information on the species diversity of the community of small mammals with some reservations [27]. Unfortunately, the method cannot be employed in a controlled manner since the researcher does not choose locations for the bottles, which severely limits its application possibilities. An interesting feature of the method is that there is no need to hide equipment since discarded bottles are a frequent occurrence in cities and do not attract attention. We decided to modify this approach for large-scale reconnaissance in urban environments at the level of communities of murine rodents and shrews. It is obvious that to increase the reliability of the abundance estimate and the comparability of the results, the bottles should be placed regularly. We chose to place them on short transects which is easy to place in modern cities where there are many linear landscape elements (biotopes along parts of transport and power infrastructure, such as lawns, roadsides, right-of-way habitats, etc.). To switch from presence/absence data to quantitative assessment, we planned to determine the parameters for the conversion of abundance estimates obtained with the suggested method into more traditional ones. In addition, we do not approve of the cruel deaths of animals, as happens in discarded bottles. Therefore, the aim of our study was to test a new reconnaissance method for estimating mouse-sized mammal abundance that does not require the removal of animals and combines quantitative assessment with low labour intensity, low cost, extreme simplicity and the possibility of large-scale use in anthropogenic and seminatural conditions.

MATERIAL AND METHODS

Study Design and Fieldwork

For estimation of small mammal abundance, we used plastic (PET – polyethylene terephthalate) bottles of 0.5 litre volume with a neck diameter of 38 mm (Fig. 1a). Inside each bottle, some rye-bread (cube 1.5–2 cm^3) with unrefined sunflower oil was set out as bait. For free animal pass in and out, the bottles were laid down on their sides and checked every morning for the next four days. Nibbling and absence of bait were interpreted as evidence of mammal attendance. We did not take into account the bait, which had signs of being eaten by arthropods. If a bottle was relocated or deformed, it was not counted. We replaced the bait or bottle if necessary. In line transects 120 m in length, two patterns of bottle disposition were tested: every 5 m and every 10 m. Thus, each transect consisted of either 25 bottles at 5 m intervals or 13 bottles at 10 m intervals. For comparison of the proposed abundance estimation method with the traditional method of trap lines and between the two arrangement patterns, lines of snap traps were put out at the same transects two days after the survey with bottles (Fig. 1b). We inserted the delay between the bottle and snap trap surveys to level the prebaiting effect. The interval between each snap trap was 5 m (25 traps in the transect). Every trap was covered with a plastic cap for rainproofing and higher catch efficiency by canalisation of the approach to the snap-trap on the side with bait. A survey was taken over four days with daily checking of traps and renewal of baits, which were the same as in the bottles. Therefore, the catching effort capacity was 100 trap-nights per trap line (25 traps × 4 days). All the captured animals were identified to species. The cases when the bait was lacking or nibbled but an animal was not caught (catch failure) were registered. In the same category, we included cases in which the trap was sprung but the bait was left untouched. The work was carried out in the several forest-parks of Yekaterinburg (from 2016 to 2018) and in the natural forest area (2018) 127 km apart in the Sverdlovsk region, Russia. Between one and six transects with a distance of 200 m or more between them were set out in each habitat. Of the 41 samples, 20 surveys were taken with a pattern of 5 m intervals between the bottles, and 21 surveys were taken with a 10 m interval pattern.

To accurately estimate the proposed method adequacy, we used as a control indicator the relative density obtained on two plots of live traps that were spaced in an 8 m grid: plot 1, 10 × 10 traps (72 × 72 m) in a dark coniferous forest, and plot 2, 10 × 5 traps (72 × 32 m) in a meadow. The plots were independent (127 km from each other). The line of 25 bottles was set out diagonally through the survey area of plot 1, and in plot 2, the line contained only 16 bottles because of the heterogeneous surrounding habitats and was located parallel to the longer side and in the centre of the survey area. In both plots, the bottles were spaced at 5 m. Surveys of small mammal visitation were taken on two days in the morning (two checks). After that, a survey with live traps began and continued for four days. Wooden live traps with a treadle (weight-triggered) were used (Fig. 1c). The captured animals were

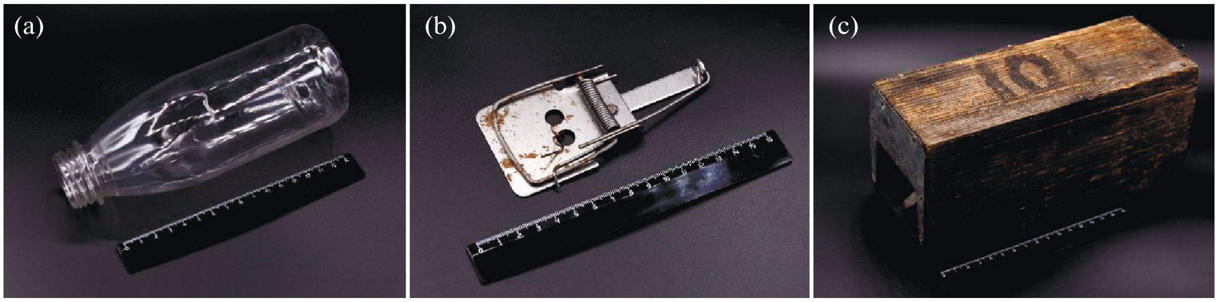

Fig. 1. Instruments used for small mammal abundance surveys: (a) PET bottle; (b) snap trap: (c) live trap.

marked and released at the same point at which they were captured. Their taxonomic locations were identified. For comparison between the bottle-line method and the live trap plot method (capture-mark-recapture, CMR), a data-obtaining cycle took 6 days. Four such cycles were implemented for each plot at least 21 days apart.

For method appropriateness estimation under high density residential area conditions, we undertook probe surveys on ten lines of different lengths on the lawns and waste grounds of Yekaterinburg, Russia. We recorded animal visits and cases of bottle loss or deformation.

Data Analysis

As an abundance indicator in the proposed method, we calculated the index of bottle attendance (BA)—the portion of bottles with eaten bait of the total number of bottles. Analysis of index daily dynamics was performed by means of Freedman's criterion on the basis of total data. The abundance indicator at snap trap surveys was defined as the ratio of the sum of captured animals and trap failures to the number of trap-nights (trap attendance index, TA). We always took into account trap failures since the lightest animals (*Sorex* spp. especially) can be registered by bottles but are very seldom captured in the snap traps we used because of specifity in their construction (Fig. 1b).

Since the method is positioned as reconnaissance, the survey duration should be minimal. We used the data obtained by the bottles for 1st, 2nd, 3rd, and 4th day separately versus the data obtained by the snap traps for 4 days totally to determine the optimal duration of counting necessary for an adequate assessment of small mammal abundance. We did not use day by day comparison because an estimate after several days of trapping by snap traps is considered more accurate than after one day and is the traditional approach.

The small mammal community density on CMR plots was determined by the count of captured and marked animals for four days (the probability of a new unmarked individual appearing by the end of the term was negligibly small) divided by survey area (8 × 8 m per trap × number of traps). There are more accurate methods for estimating animal density based on CMR data, but they are usually designed to account for a single species. The use of bottles did not allow us to distinguish species, so the use of more complex statistical techniques would have been redundant.

For determination of the optimal duration of bottle surveys and comparison of abundance estimation accuracy between two disposition patterns (in 5 and in 10 m), we used regression analysis. We transformed indices to a logit-function with the formula logit(y) = ln[(p + 0.01)/(1 – p + 0.01)], where p is an index (TA or BA). A constant of 0.01 was added to solve the problem of 0s and 1s in the data according to a previously described procedure [28]. Logit transformation is considered the most appropriate for proportion data processing [29]. Pearson's correlation coefficients (R) were calculated between the BA from each of four survey days and the TA obtained by snap traps for four days total. The trap data were considered more accurate than bottle data a priori. We used analogic procedures to compare abundance indicators obtained by bottle lines and CMR plots. The calculations were implemented in the program package STATISTICA version 6.0, StatSoft Inc.

RESULTS

Dynamics of Bottle Attendance

When testing the methodology, it was found that the bait pieces were almost always eaten whole. In bait-free bottles, rodent faeces were often noted (81%, $N = 125$). When analysing the attendance in bottles during the counting cycle, it was found that the indicator grew from the first to the fourth day (Fig. 2). The trend was statistically significant for both schemes of bottle placement (10 m interval: $\chi^2 = 26.46$, $N = 21$, $p < 0.0001$; 5 m interval: $\chi^2 = 30.69$, $N = 20$, $p < 0.0001$).

Comparison of Abundance Estimates Obtained from Bottles and Snap Traps

Among the animals caught by snap traps were individuals of the following species: *Myodes glareolus* (Schreber, 1780), *M. rutilus* (Pallas, 1779), *Apodemus*

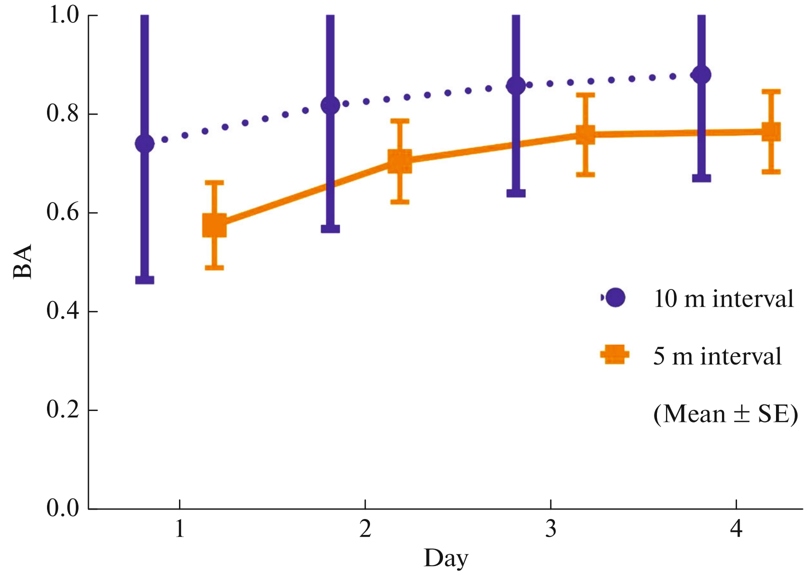

Fig. 2. Bottle attendance index (BA) at different intervals between bottles (5 or 10 m) on each of the four consecutive days of counting.

agrarius (Pallas, 1771), *Sylvaemus uralensis* (Pallas, 1811), *Sorex araneus* (Linnaeus, 1758), *Microtus agrestis* (Linnaeus, 1761), *M. arvalis* (Pallas, 1778), and *M. oeconomus* (Pallas, 1776).

The linear regression of logit-transformed indices revealed a positive relationship between values in all cases (Fig. 3). For pairwise comparisons of indices by day, the correlation was more pronounced for the 10 m scheme than for the 5 m scheme (Table 1).

The maximum value of r fell on the second day of counting for 10 m intervals between the bottles and on the third day of counting for 5 m intervals. The abundance estimates obtained from the bottles in the 10 m scheme were more suitable for recalculation into TA, since the angle of the regression line is closer to 45°. The equations for recalculating the BA into the TA using the linear regression equation of logit-transformed values of both indices are as follows for day 1 (1) and day 2 (2) of counting by bottles:

$$\mathrm{TA} = \left[1 + \left(\mathrm{BA}^{-1} - 1\right)^{0.814} / e^{1.035}\right]^{-1}; \quad (1)$$

$$\mathrm{TA} = \left[1 + \left(\mathrm{BA}^{-1} - 1\right)^{0.897} / e^{0.178}\right]^{-1}. \quad (2)$$

Table 1. Correlation coefficients and their significance, reflecting the relationship between the BA (on separate days and at an interval of 5 or 10 m) and TA (a total of 4 days at an interval of 5 m)

Interval, day	r	p
10 m; day 1	0.76	0.00007
10 m; day 2	0.85	0.00000
10 m; day 3	0.83	0.00000
10 m; day 4	0.83	0.00000
5 m; day 1	0.65	0.00202
5 m; day 2	0.77	0.00008
5 m; day 3	0.82	0.00001
5 m; day 4	0.80	0.00002

Comparison of Abundance Estimates Obtained from Bottles and Live Traps

The relative density of the community of small mammals determined by a direct method varied from 1.6 to 214 individuals per hectare (Table 2). Among the captured animals were samples of the following species: *M. glareolus*, *A. agrarius*, *S. uralensis*, *Sorex* spp., *Microtus* spp.

The results obtained using bottles and live traps demonstrate a significant degree of change consistency (the Pearson correlation coefficient on the first day of counting by bottles: $r = 0.83$, $p = 0.01$; on the second day: $r = 0.88$, $p = 0.004$). High and reliable correlations make it possible to recalculate the values of the relative numbers obtained by the indirect method (bottle lines) into relative density of individuals per hectare (Fig. 4).

The equation to convert the BA into the relative density on day 1 (3) and on day 2 (4):

$$D = 134.6 + 21.6\ln\left[\mathrm{BA}/(1 - \mathrm{BA})\right]; \quad (3)$$

$$D = 114.0 + 21.3\ln\left[\mathrm{BA}/(1 - \mathrm{BA})\right]. \quad (4)$$

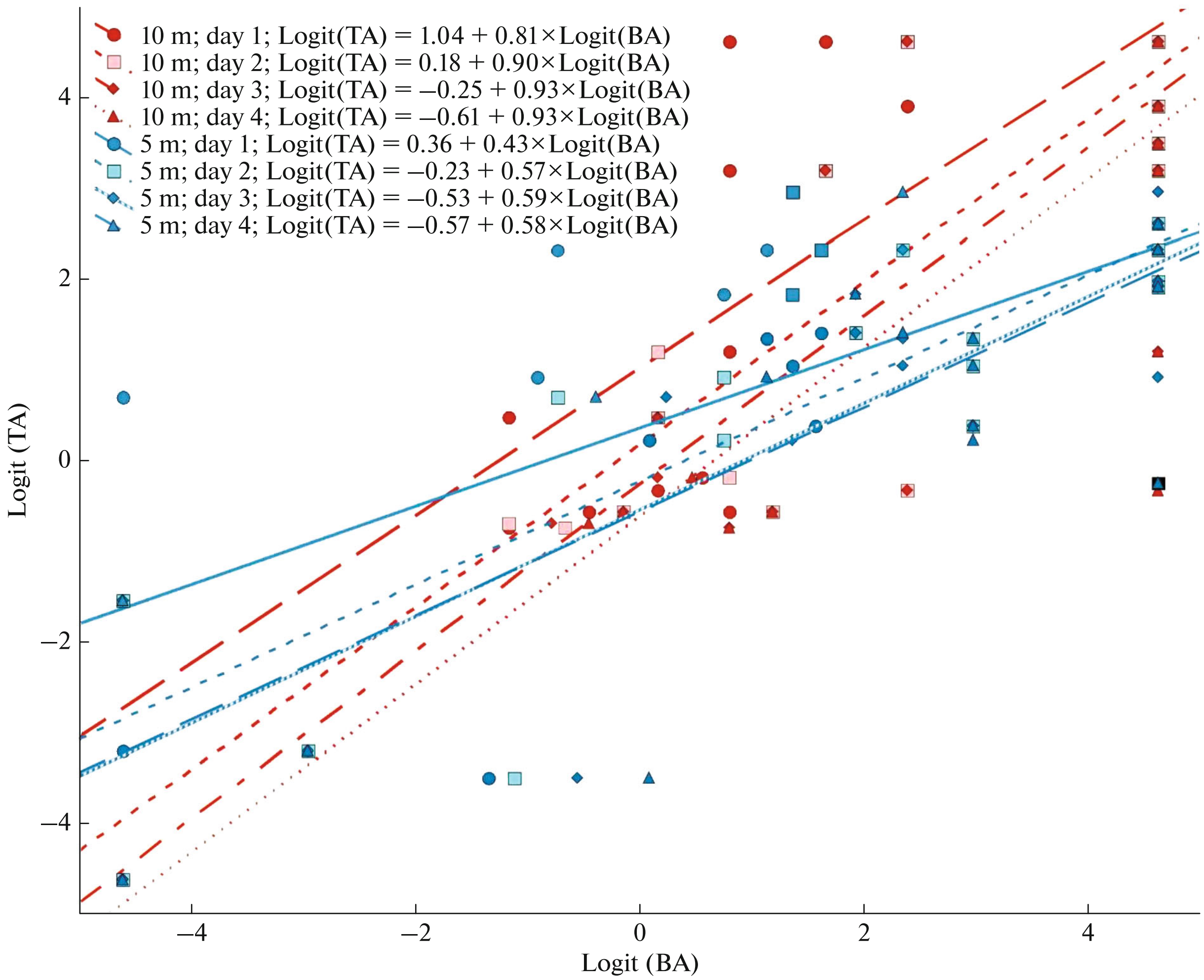

Fig. 3. Equations and graphs of linear regression between logit-converted values of TA (total over 4 days at an interval of 5 m) and BA (1-4 days at 5 and 10 m intervals).

Evaluation of the Laboriousness of the used Methods for Assessing the Abundance and the Possibility of ~~using~~ Bottles in High Density Residential Area

In the course of the study, we compared three methods by their laboriousness. Checking the line of bottles with a length of 120 m in a team of two people took approximately 5 minutes in the scheme with 10 m intervals and up to 10 minutes with intervals of 5 m. Checking the trap lines of the same length required 25–30 minutes. The most time-consuming was the

Table 2. The abundance of small mammals according to the counting by bottles (BA) at the 5 m interval (separately on the first and second day) and the live traps (for whole sampling session). Estimates for plot 1 (southern taiga) and plot 2 (artificial meadow) with different seasonal abundance of small mammals

Plot	Number of captured, ind.	Relative density, ind./ha^{-1}	BA at day 1	BA at day 2
1	1	1.6	0.00	0.00
1	39	60.9	0.08	0.20
2	26	81.3	0.13	0.31
2	45	140.6	0.25	0.79
1	104	162.5	1.00	1.00
2	60	187.5	0.63	0.69
2	61	190.6	0.81	0.81
1	137	214.1	0.84	1.00

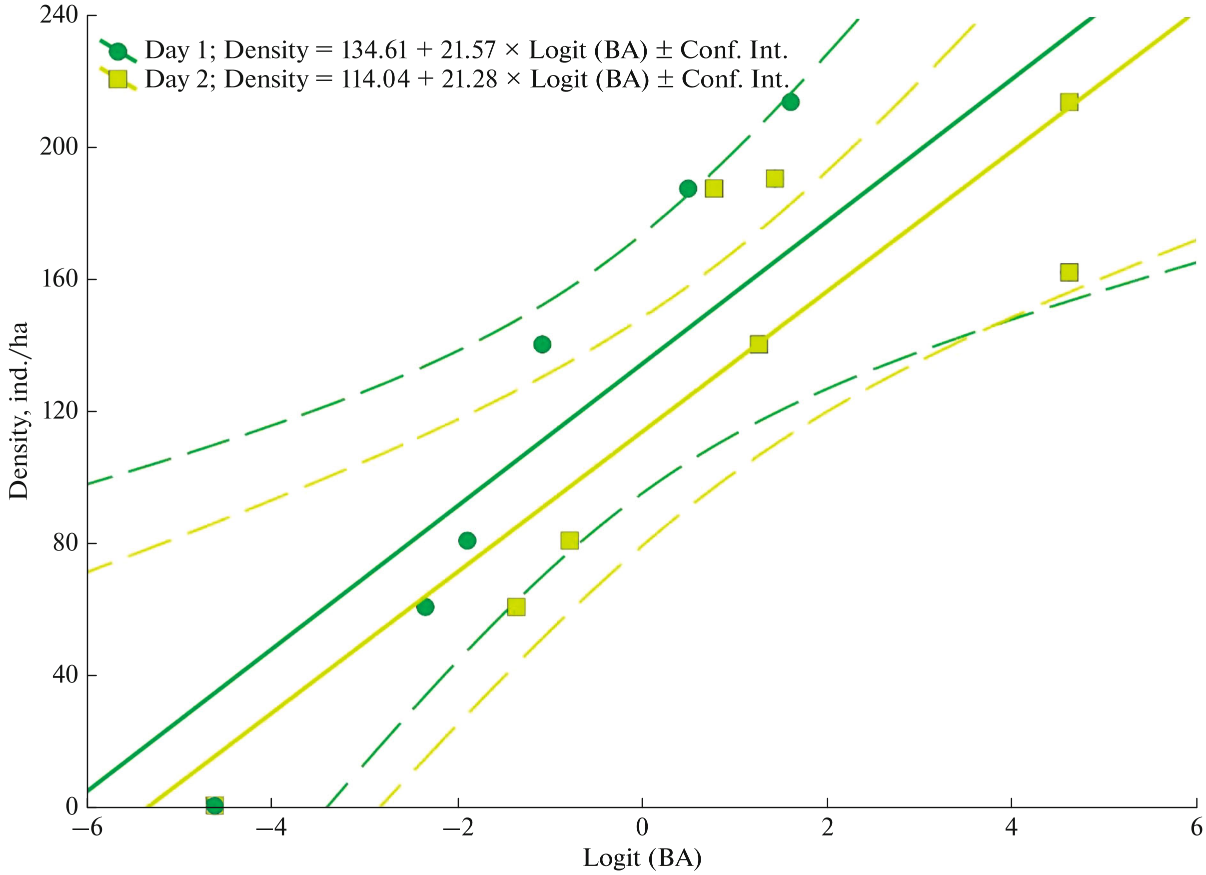

Fig. 4. Equations and graphs of linear regression according to population density (total for 4 days) and BA (on the 1st and 2nd day of counting).

work on the live trap plots – checking 50 traps took 30–60 minutes. Working with live traps, unlike bottles and snap traps, requires 2–3 of these checks per day.

The method turned out to be workable in high density residential area. Using bottles, we obtained estimates of the abundance of small mammals on 10 city lawns and wastelands. The attendance index ranged from 0 to 0.97. With a volume of trapping effort of 413 bottle-days, the loss of counting tools was recorded in 6 cases (1.4%). In the course of other stages of the study, several cases of bottle damage by dogs in urban forests were noted.

DISCUSSION

Researchers have access to many methods for assessing the abundance of mouse-like small mammals. The choice of a particular method is determined, first of all, by the scientific goals, which can be very diverse since small mammals are a popular model object in ecological research. It is impossible to cover the whole range of existing approaches in one work. Therefore, when testing the bottle line method, we set ourselves the task of calibrating it with respect to only two of the most widely used methods: trap lines (with snap traps) and CMR (with live traps in plots). Attempts to use bottles for estimating populations of small mammals have been conducted before, but they have involved cases where animals accidentally died in the discarded bottles and have not proposed formalised assessments of animal abundance [24–26]. As a result of the study, we found that the proposed method was fundamentally suitable for obtaining estimates of the abundance of small mammals. The bottles functioned as single-action bait stations. They did not contain more food than one individual could use per approach, so partially eaten baits in separate bottles were rare. These cases were not associated with the abundance of animals. The attendance index at the bottles grew from the first to the fourth day of counting at both interval distances between the bottles (Fig. 2). This could be due to two reasons: the gradual arrival of new animals at the bottle line or an increase in the proportion of animals visiting more than one bottle per day. However, in any case, the growth of BA was explained only by the training of animals by bait stations, which is a well-known phenomenon [30, 31].

In comparing the results obtained by the bottle lines and trap lines, we were convinced that the new method was close in accuracy to the traditional one; the correlation coefficient reached 0.9. When comparing the two bottle layout schemes, we should state that more accurate estimates of abundance were obtained at ten-metre intervals (Fig. 3). Most likely, with a denser location of stations, the proportion of animals visiting more than one bottle per day increased (the ratio of abundance and activity in the assessment shifts in favour of the latter). However, this assumption requires specific verification. The greatest correspondence between the estimates of abundance by bottles and snap traps resulted in the option of ten-metre intervals for the second check. However, because we are positioning the proposed method primarily as a reconnaissance method, we can recommend using a more short-term version with low labour costs but with a slight decrease in accuracy: sampling for one night. If it is necessary to compare BA with the traditional trap-line method, it is possible to calculate the number of animals per 100 trap nights. To do this, one can use the corresponding equations (1 and 2). It seems that bottle lines can replace the trap-line method only in special situations where the researcher does not need to catch animals and is interested only in the general abundance of small mammals without identifying the species composition.

The abundance estimates obtained by the bottles strongly correlated with the live-trapping data (up to $r = 0.88$, $p = 0.004$). Therefore, the attendance index of the bottles can be converted to relative density (equations 3 and 4). To obtain the most accurate value, it was necessary to arrange the bottles at five-metre intervals and sample for two days. We consider that for recalculation of the above equations, it is also admissible to use the results from lines with ten-metre intervals. This conclusion is based on a comparison of the accuracy of the abundance estimates obtained from the two bottle arrangement schemes with relative abundance (TA). The differences between the schemes with five- and ten-metre intervals were slight (Fig. 3); therefore, it can be assumed that the similarity will be high in the case of live traps, although empirical data were obtained only for five-metre intervals. A high degree of consistency in relative density (by CMR) and relative abundance, which was assessed by direct or indirect methods, was also noted by other researchers [32]. In this way, it is possible to obtain an approximate but formalised estimate of the community density of small mammals without using labour-intensive catching with live traps.

The proposed method of bottle lines, like any other method, has a number of limitations and disadvantages. The most obvious of them is the inability to assess the abundance of ~~individual~~ species in multi-species communities. The accuracy of abundance assessment with the bottles, of course, is lower than that of traditional methods. Specifically, this is due to a shorter accounting period (1–2 days for bottles versus 4 for traps of the two types). Although we considered one day to be a sufficient period for obtaining relevant data using bottles, it should be noted that unusual weather conditions can greatly affect the accuracy of estimates. We tested the bottle method only in forest and urban conditions. The use of bottles in other landscapes may be limited. For example, in open windy areas with poor vegetation, additional efforts and/or materials may be required to prevent bottles from blowing away. The possibility of using the bottle method in frequently flooded areas is also questionable.

Nevertheless, the proposed method has several undeniable advantages. In particular, due to the extremely low labour intensity and cost, it provides the ability to gather data simultaneously at multiple points (or from a large area) and can be used both independently and as an accessory method. It is obviously the easiest method to use and does not require the surveyor to have any special skills. This potentially provides the opportunity to use the help of unqualified volunteers to increase the scale of the study. This option is very useful for large-scale monitoring programmes [33]. At the same time, the procedure is reliably regulated, and the evaluation is formalised, which ensures comparability of the results. In addition, PET bottles with 38 mm necks are part of a generally accepted industrial standard and are widely distributed, which contributes to the comparability of results obtained by different researchers. The ability to use wasted bottles will not only reduce the cost of research but will also be useful for environmental education (recycling of PET bottles for scientific purposes). The bottle line method, unlike trapping, does not limit the mobility of animals, allowing an assessment of the abundance of small mammals without disrupting the course of natural processes. Bottles pose no danger to threatened small mammal species, while even in live traps, animals regularly die [34]. At the same time, compared to simply putting the bait on the ground, the bottles offer several advantages: simplifying the search for the location of bait stations during inspections, protection from rain and non-target species, and the ability to make labels. Bottles can be used in places actively visited by people, where the use of traditional means can be unfeasible due to theft and vandalism. The resistance of equipment to these factors can be enhanced with special written messaging, as shown earlier [11]. In addition, the bottles do not pose any danger to people or pets, unlike some traps (for example, snap traps and pitfall traps). Considering all of the above, we additionally compared the key parameters of the three methods we used to assess the total abundance of small mammals (Table 3).

A bottle-like device is used in the "bait-tube" method, which was developed specifically for surveying water shrew populations (*Neomys* spp.) [35]. The bait tubes are exposed for two weeks to collect faeces

Table 3. Comparison of the most important parameters of the methods used to assess the total abundance of small mammals

Method parameters	Bottles	Snap traps	Live traps
Accuracy	Minimal	Average	Maximal
Laboriousness	Minimal	Average	Maximal
Financial cost	Minimal	Average	Maximal
Requirements for the qualification of performer	Minimal	Average	Maximal
Duration of counting	Minimal	Average	Average
The degree of suitability conducting large-scale studies	Maximal	Average	Minimal
Exposure to vandalism and theft	Minimal	Average	Maximal
Suitability for endangered species	Maximal	Minimal	Average

left by small mammals. The presence of a water shrew is determined by the presence of residues of aquatic invertebrates in the faeces. The method gives only presence/absence data. It should be noted that the bottles also allow the collection of animal faeces.

One of the most similar indirect methods of relative abundance estimation with the bait-in-a-bottle method is the application of the chew-track card (CTC) method, which has the principal benefit of differentiating surveyed species in some cases [36]. This method is convenient for obtaining presence/absence data but is less suitable for quantitative estimation of abundance. First, the CTC method materials are not protected from gnawing by non-target species, which can lower survey efficacy. The baits in the bottles are partly protected from consumption by non-target species (arthropods, dogs, and squirrels) whose interference has always been evident and has therefore been excluded from our analyses. Second, one CTC can be used by several individuals of the same species, making the results difficult to verify. Obviously, this factor strongly affects the accuracy of the abundance estimation. In contrast to CTC, the unfixed bait in a bottle is eaten or carried away by just one animal, as previously noted. Third, valid application of the CTC with differentiation of the species by their bites and tracks cannot be implemented by volunteers without special skills. The principal advantage of both methods is the potential for large-scale application; thus, cost efficiency is an important characteristic of both methods [22, 36]. Fourth, the cost of the CTC method includes fixed expenses for bait, ink and cards, which are consumable and increase plastic waste products. The proposed method of bottle lines involves systematic expenses only for the baits since bottles can be used many times. Fifth, in contrast to CTCs mounted on trees, bottles can be regularly arranged in a manner that standardizes the procedure. Sixth, in comparison to other device types, bottles appear as ordinary waste and thus are less affected by theft or vandalism in places actively occupied by humans.

There is an approach that is fundamentally similar to the method proposed by us, but technically and procedurally different [37]. In that case the bait was pinned to pegs arranged in a line of arbitrary length. The bait had no protection against being eaten by non-target species. The accounting was carried out for 30 or more days. Calibration relative to traditional methods of abundance estimating was not carried out, as the main goal was to identify spatial heterogeneity in the distribution of small mammals.

Of the indices of small mammal abundance, excluding the capture of animals, only the track plate method has been successfully tested in urban conditions and allowed quantification of the abundance and activity of Norway rats in the slums of Salvador, Brazil [21]. The main advantage of this method is the ability to distinguish rat tracks from those of other species. However, this method does not work for mouse-sized rodents, as their tracks are very similar in structure and belong to the same size class. To date, there is no reliable and simple way to distinguish between species of mouse-sized rodents with their tracks. Nevertheless, track plates can potentially be used to estimate the abundance of small mammals at the community level, similar to our proposed method. With this goal, the bottle method has advantages. First, the use of bait reduces the time of abundance estimation to 3 days. At the same time, due to the lack of bait, the plates do not have problems with insects, which can interfere with the bottle method. Second, track plates are larger than bottles in size and require careful handling during transportation to avoid damaging the lampblack layer. Finally, the analysis of the tracks on the plates requires two people with specific experience, while the bottle method can be used by one person without experience.

In the future, the proposed method can be further developed. For example, bottles can be arranged not in a line but in a grid, obtaining density estimates without recalculation. Due to the extremely low labour intensity, the scale of such studies can be very large by the standards of other methods. We used a linear rather than a grid layout of bottles since the linear layout provides more information about the population of small mammals with the same sampling effort and, accordingly, was suitable for the reconnaissance aim [38]. In addition, transects are easier to set up in urban environments than grids. The range of species taken into account can be adjusted by changing the diameter of the inlet and/or the composition of the bait.

The possible applications of the proposed method in theoretical and applied research can be divided into the three following types:

1. Application as an auxiliary method of abundance estimation, such as:

—searching for small mammal aggregations for further study or extermination (for example, when targeting extermination operations against invasive rodent species or searching for wintering habitats in natural or semi-natural conditions);

—searching for locations with the required ratio based on levels of small mammal abundance for study by other methods (determining the research location); and

—monitoring near the site of a primary experiment (for example, around the CMR plot).

2. Application as the main method of abundance estimation, such as:

—use in cases when the application of other methods is complicated or impossible (for example, in urban areas);

—assessment of the completeness of controlling populations carried out for scientific or practical purposes (manipulative field experiments, invasive species control in wildlife, and pest control in human settlements);

—use in cases when small mammals are not the focus of a research project (for example, when studying birds of prey);

—use in tasks where large scales are more important than detailed data (for example, in the detection of "travelling waves" [39]);

—use with tasks in which the speed of data acquisition is most important factor (for example, in assessing the consequences of catastrophic events).

3. Application as one of a pair of indices used for a more reliable estimation of abundance according to the existing recommendation [17].

ACKNOWLEDGMENTS

The authors are grateful to the administration of the Botanical Garden of the Ural Branch of the Russian Academy of Sciences for permission to work in the arboretum. The authors are grateful to PhD Ivan Kshnyasev for useful advice on the statistical processing of the material and to Irina Tolkacheva for photo of traps.

FUNDING

This study was performed within the frameworks of state contract with the Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences and partly supported by the Russian Foundation for Fundamental Investigations, grant no. 20-04-00164a.

COMPLIANCE WITH ETHICAL STANDARDS

All sampling methods used in this study are in accordance with current ethical standards [40]. All field methods were approved by the Bioethics commission of the Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences (protocol #001/2020). It is important to note that snap trapping is not an essential part of the bottle-line method. In this study, such an approach was needed only to test and calibrate the methodology.

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