*Евразиатский энтомол. журнал 24(1): 53–60*
*doi 10.15298/euroasentj.24.01.13*



# 3d-modeling of nest mounds of red wood ants (Hymenoptera: Formicidae)

# 3d-моделирование куполов муравейников рыжих лесных муравьёв (Hymenoptera: Formicidae)

**Е.В. Бургов**
**E.V. Burgov**

National Research Center «Kurchatov Institute», Akademika Kurchatova Square 1, Moscow 123182 Russia; Institute of Ecology and Evolution A.N. Severtsov, the Russian Academy of Sciences, Leninsky Avenue 33, Moscow 119071 Russia. E-mail: burgov_ev@yandex.ru.

Национальный исследовательский центр «Курчатовский институт», пл. Академика Курчатова 1, Москва 123182 Россия; Институт проблем экологии и эволюции им А.Н. Северцова РАН, Ленинский проспект 33, Москва 119071 Россия.

***Key words:*** Ants, *Formica rufa* group, anthill, nest mound, photoscanning, 3d-modeling.

***Ключевые слова:*** муравьи, группа *Formica rufa*, муравейник, купол гнезда, фотосканирование, 3d-моделирование.

***Abstract.*** The ant nest is the most important element of a colony's infrastructure. Anthill construction is one of the most highly organized processes of ant activity. The nests of red wood ants (*Formica rufa* group) are still insufficiently studied in terms of the internal structure of the nest mound made of plant debris, the ratio of materials used by the ants. This is partly due to the nature of the materials — the structure is usually not preserved when the mound material is sampled — and partly to the use of outdated and inefficient methods of description. This article discusses the use of photoscanning techniques in the excavation of ant nests and the monitoring of anthill construction. It is shown that photoscanning can be used to track nest construction with assessment of changes in nest mound volume, highlighting areas of intensive construction and subsidence. It is also shown that during the excavation of an anthill, it is possible to estimate the volume of individual parts of the nest mound, including the top layer and inner cone, as well as samples taken from them. Labor costs for field work and data processing were estimated. The most labor-intensive stage of the initial methodology, namely marking reference points on the model, is revealed. Some solutions are proposed to optimize the marking.

***Резюме.*** Гнездо муравьёв — важнейший элемент инфраструктуры семьи. Строительство муравейника — один из самых высокоорганизованных процессов деятельности муравьёв. Гнёзда рыжих лесных муравьёв (группа *Formica rufa*) в вопросах внутренней структуры купола, соотношения используемых муравьями материалов и т.д. исследованы недостаточно. Это связано, с одной стороны, с особенностями материалов — при взятии пробы материала купола обычно не сохраняют структуру, а с другой стороны — с использованием устаревших и неэффективных методов описания. В статье рассматривается применение методики фотосканирования куполов муравейников при раскопке гнезда и при отслеживании процесса строительства. Показано, что с помощью фотосканирования можно отслеживать строительство гнёзд с оценкой изменения объёма купола, выделением областей интенсивного строительства и просадки. Также обсуждается, что при раскопке куполов муравейников можно оценивать объёмы частей купола (покровного слоя, внутреннего конуса) и проб, взятых из них. Проведена оценка трудозатрат при полевой работе и при обработке данных. Выявлен наиболее трудозатратный момент исходной методики — разметка реперных (опорных) точек на модели. Предложены варианты решения, позволяющие оптимизировать разметку.

## Introduction

The ant nest is the home and shelter of the ant colony. For small colonies of some species, the nest is the only place where individuals communicate and coordinate their actions. Nest building is one of the most highly organized processes in the life of an ant colony [Zakharov, 1991]. The nest parameters (e.g. number of exits, mound size, etc.) reflect the state of the ant colony [Zakharov et al., 2015]. The evolution of ant sociality is closely linked to the evolution of nest building [Sudd, 1967; Zakharov, 1991]. Thus, the study of ant nest structure and the specifics of the construction process, is important not only for revealing behavioral traits of species, but also for studying the evolution of ants.

The accurate modeling of the anthill surface is necessary for solving a number of myrmecological problems, e.g.: studying the process of nest construction, describing the restoration of anthills after damage, tasks related to geomorphology and soil science. One of the most informative ways to study nest structure is to excavate anthills. [Dlussky, 1981]. When observing ant nest construction or excavating an anthill using standard methods [Dlussky, 2009], it is useful to have an auxiliary method that allows us to quickly obtain data from which we can first build models of nest transects and then a holistic model of the underground and/or aboveground parts of the anthill.

There are methods of studying nest construction using special formicaries in which ants build nests that are then conveniently studied. [Mikheyev, Tschinkel, 2004]. Under laboratory conditions using such formicaries, dynamic

How to cite this article: Burgov E.V. 2025. 3d-modeling of nest mounds of red wood ants (Hymenoptera: Formicidae) // Euroasian Entomological Journal. Vol.24. No.1. P.53–60. https://doi.org/10.15298/euroasentj.24.01.13

modeling of small anthills is possible using tomography [Minter et al., 2012; De Macedo et al., 2021]. It is difficult to use such methods to build dynamic models of large anthills. It is possible to perform tomography of individual parts of large nests, but a different approach is required to describe the surface of the entire anthill. It is difficult to use such methods to build dynamic models of large anthills. It is possible to perform tomography of individual parts of large nests, but a different approach is required to describe the surface of the entire anthill.

The study of mound nests of red wood ants (*Formica rufa* group; hereafter RWA) is particularly difficult. In these ant species, under normal moisture conditions, nest usually consists of an aboveground part, including a dome-shaped nest mound of pant residues and a «soil base» — embankment usually built of soil (Fig. 1), and an underground part [Dlussky, 1967; Zakharov et al., 2013]. A nest mound consists of an inner cone and a cover layer (Fig. 1). Figure 1 shows the structure of the aboveground part of an anthill, which is characteristic of RWA nests under mesophytic conditions. In dry conditions, the inner cone may be below ground level.

RWA nest mounds are usually constructed from a variety of plant materials (needles, small twigs, large pieces of dry grass, etc.). When sampling the nest mound material or simply cutting to examine the internal structures, some of the material will usually crumble away, disrupting the structure. In particular, because of these characteristics, the internal structure of the RWA nest mound is still insufficiently studied: the main components are known, but there is very little data on the use of different materials, on the quantitative ratios of these materials, on the volume of passages and chambers.

Photoscanning is proposed as a universal method for 3d-modeling of large ant nests. This method is widely used in geodesy and geomorphology (e.g. aerial photography) to build models of architectural complexes and landscapes. Using photoscanning in these areas significantly reduces labor costs (both in the field and in the lab). Photoscanning is a method of building three-dimensional models by taking photos of an object from different angles. To build models correctly, the photos must reflect the entire surface to be modeled and overlap.

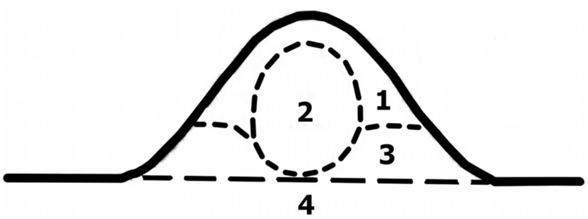



Fig. 1. Arrangement of the aboveground part of the nest of red wood ants under mesophytic conditions according to Zakharov et al. [2013], some modifications. Designations: 1 — cover (top) layer, 2 — inner cone (built of relatively large twigs), 3 — soil base (embankment usually built of soil).

Рис. 1. Устройство наземной части гнезда рыжих лесных муравьёв в мезофитных условиях по Захарову с соавт. [Zakharov et al., 2013], с изменениями. Обозначения: 1 — покровный слой, 2 — внутренний конус (собран из относительно крупных веточек), 3 — вал (обычно построен из почвы).

The use of this method for photoscanning of anthills was presented and discussed for the first time at the XVI All-Russian myrmecological symposium in memory of A.A. Zakharov [Burgov, Lokteev, 2022]. The present paper discusses the results of testing this method in monitoring anthill construction and nest excavation of red wood ants, and also suggests some adjustments to the first version of the method to reduce labor costs.

# Material and methods

## Photoscanning

Photoscanning is a collection of photographic material (photo array) and its subsequent processing with the help of special software, for example, Agisoft Metashape, which was used in this work. This and similar programs are widely used to build models of landscapes, interiors, contrasting objects on a homogeneous background, etc. The program compares photos from the array, calculates the camera position when taking the photo, the mutual location of points (pixels), and generates point clouds and three-dimensional models. In the case of anthill scanning there are a number of peculiarities that are reflected in the photoscanning methodology.

***Photo equipment requirements.*** Since this software is quite tolerant of photo quality (at least as far as scanning anthills is concerned), most modern camera phones can be used. Digital cameras can also be used. It is desirable that the focal length ("zoom") of the lens does not change while scanning an anthill. If you are using a camera or phone that allows you to change the focal length («zoom in» or «zoom out») — you cannot do this during a scanning. You start shooting at one focal length (e.g. 35 mm) and you should continue and finish shooting at the same focal length.

***Markers.*** An anthill and its surroundings usually contain many identical objects (needles, plants on and around the ant nest, fallen leaves, etc.). Unless additional tricks are used, there will be many false matches when trying to match photos of an anthill from different angles. Errors may occur that do not allow you to build a surface model.

Therefore, markers — special marks on images recognized by the Agisoft Metashape program — are used to scan the anthills to ensure correct construction of the 3D model. Markers can be generated by the program itself, but to simplify the preparation they are available at the link: https://disk.yandex.ru/i/Ynv3oAtzwFiFQQ. They were printed on heavy paper; the bottom part (without the image) was covered with tape for waterproofing. Each marker is individually recognized by the program and has its own number. Markers with the same number cannot be used in the same photoscanning (for example, by printing them twice). To scan an anthill 0.5–1.5 m in diameter, it is sufficient to prepare 30 markers. A larger number of markers may be required to scan nest aggregation (e.g. *Formica cinerea* Mayr 1853).

Within a single scanning, the position of markers should not change: they should not be blown away by wind; they should not fall, turned over, etc. However, in a series of scannings of the same anthill, the position of the markers may change.

***Photoscanning.*** Before starting shooting, the surface of the anthill and up to 1 meter of ground around it should be cleared of wind-blown objects — grass, thin branches, etc. Next, the markers should be placed on the surface of the anthill. They should be evenly distributed over the entire scanned surface. The recommended distance between the markers is 15–20 cm for nests about 0.5 m in diameter and 30–40 cm for nests over 1 m in diameter. The markers should not cover objects of interest on the anthill surface (e.g., bird damage or sampling areas).

The anthill should be photographed from different angles, going around in a circle. Photos should cover the entire surface to be scanned (e.g., the nest mound). It is also necessary to cover a small area around the scanned object in order to provide a «data reserve». For the purposes of this work, this «reserve» over the scan area corresponded to the diameter of the mound of the scanned ant nest, i.e., a number of photos reflected the nest mound and the area around it corresponding to its diameter. Such a large «reserve» is not necessary, but it is impossible to cover only the area of interest with photos. Adjacent photos should overlap. A desirable overlap value is 70 %. An image «torn off» from the rest is unlikely to be used in modeling.

The following is the procedure for scanning an anthill with a nest mound of 0.5–1.5 m in diameter.

1. Selection of the first angle (avoid taking pictures of the same area twice).

2. A series of photos from this angle: general plan (with «reserve» on the sides), closer photos (usually — the center, right and left sides). In total — 4 photos from the same angle.

3. Step to the side. The next series of similar photos from a new angle. And so on — several times, consistently walking in a circle around the anthill to return to the area from which the first angle was taken.

4. It is useful to take additional photos from above, it helps to align the photos. But it is not necessary to take them at every point along the route around the anthill.

An example of a photo sequence (Anthill Gel-2, 24.VII.2022) can be viewed at the link: https://disk.yandex.ru/d/56nGzxpuS_Popw.

***Reference objects and coordinate system.*** For quick collection of illustrative material (as an alternative to simple photography or sketching; e.g., of anthill damage) it is sufficient to use the present method without laying reference objects. In this case it will be possible to build a model of the anthill surface and even to estimate some dimensions (relying on marker sizes). However, if it is necessary to build and compare models of an anthill in dynamics (for example, to follow the process of building or nest excavation), it is necessary to lay reference objects.

A reference point is a point with known and unchanging coordinates. In the present work, a reference object is an object in the survey area and/or specially brought there. On such objects there are points, the coordinates of which are fixed and do not change over a series of scannings. Reference objects can be trees (on which points can be made with a knife or marker), sections of rebar hammered into the ground, with marks on them, etc. The main requirement for the object itself is that it should not move during the series of scannings (from one to another).

It is desirable to place the reference points approximately at the level of the surface to be scanned, so that they fall on the photos more often during scanning (in case of good preparation the reference points should fall on at least 30 % of the photos, better — on all of them, and sometimes — in pairs). It should be possible to measure and check (re-measure) the distances between the reference points. Repeated measurements are necessary to ensure that the reference objects have not moved. If they are placed in such a way that during the construction of the anthill, part of the nest mound is between the reference points, preventing you from measuring the distance between them, important data may not be obtained. In other words, the reference points should be close enough to the object being scanned to get enough photos, but far enough away from it to be able to measure the distances between them.

In principle, real geographic coordinates can be used if the coordinates of the reference points are obtained with accurate geodetic equipment. However, this is not very convenient and is only really necessary if t the model of the anthill needs to be accurately oriented to the sides of the world. If this is not necessary, a local coordinate system can be used (one of the reference objects arbitrarily assigned the coordinates 0, 0, 0 on the X, Y and Z axes). To scan the nest mound, three reference points are sufficient, because, three points always lie in the same plane. It is sufficient to measure (and, check if necessary) the distances between them (in meters) and to calculate their local coordinates (coordinates in the local coordinate system) by the law of cosines, placing all three points on the X-Y plane.

You can use a level (laser or bubble level) when laying reference points on the reference objects. Sometimes it may be necessary, mainly for the convenience of model perception and visualization. For example, when taking soil samples from an anthill and estimating their volume using photoscanning, there is no such need. And, on the contrary, when estimating the intensity of anthill construction, it is necessary to use a level and set the horizontal plane of model building.

***Method Testing.*** The study was carried out in 2021–2022 in Ryazan Region in Ryazansky and Klepikovsky districts.

Digital cameras and other devices (Canon 7d with 35 mm lens, Samsung A52, Xiaomi Redmi Note 8) were used to take photos. The device, lens focal length and photo resolution were not changed during a single scanning of the anthill. The photo resolution values used are as follows: Canon 7d — 5184x3456, Samsung A52 — 4624 x 3468, Xiaomi Redmi Note 8 — 4000x3000 pixels.

***Excavating an anthill.*** A nest of red wood ants I-18, in Klepikovsky district of Ryazan Region in a pine and spruce forest, was chosen as a model. Part of the anthill

Table 1. Tested anthills
Таблица 1. Модельные муравейники

| Tested anthills | Ant species | Dates of material collection | Task | Features of the nest structure | Reference objects |
|---|---|---|---|---|---|
| I-18 | *Formica aquilonia* Yarrow, 1955 | 1.X.2021 | Modeling of the nest during excavation | Mound diameter more than 1 m, embankment | Marks on trees |
| Gel-1 | *F. rufa* Linnaeus, 1761 | June – November 2022 | Construction tracking | Pine root fragment dry and damaged by wood pests at the base of the mound | Marks on rebar driven into the ground |
| Gel-2 | *F. rufa* Linnaeus, 1761 | June – November 2022 | Construction tracking | Stump at the base of the nest mound | Marks on the stump |

complex, including nest I-18, was inventoried in 2012. The anthills were measured, photographed, and workers were sampled. At that time, ants *Formica aquilonia* Yarrow, 1955 were living in nest I-18. In 2021, many nests in this complex were abandoned, including I-18. It was decided to dismantle the nest mound, take samples of nesting material from different layers, and conduct a step-by-step photoscanning. Three reference points were placed on the trees around the tested nest. The nest I-18 was excavated (1.X.2021). The coordinates of the reference points on the trees were later obtained using a total station.

***Tracking nest building.*** Two anthills of *Formica rufa* Linnaeus, 1761 in the Ryazansky district of Ryazan Region were selected to follow the process of nest building in 2022. Both nests were located in a pine forest and had nest mounds less than 50 cm in diameter. The first anthill (Gel-1) was built on the basis of a fragment of a pine root that was dry and partially damaged by wood pests, while the second (Gel-2) was built on the basis of a tree stump that already had ant passages inside at the time of the beginning of observations. Both colonies showed significant building activity at the beginning of the observations, which was the reason for their selection as model objects.

To ensure the construction of correct models of the nest mound surfaces, 3 pieces of rebar were hammered around the anthill Gel-1. At the level of the anthill under construction, three colored marks were placed on the rebar using a laser level. The distances between the marks were measured with a tape measure and monitored throughout the observation period. The coordinates of the reference points around the Gel-1 ant hill were calculated using the law of cosines. On the stump where the Gel-2 anthill was built was layed 3 reference points were marked with a permanent marker. The coordinates of the reference points were then determined using a total station. Scanning was carried out in 2022 from June to September with a control in November.

Students of schools of the Ryazan Region took part in the collection of material. In June 2022, they were engaged in photoscanning of the anthill Gel-1. Within the framework of schoolchildren's activities, the possibility of applying the methodology to the students' research work was considered; the compatibility of models collected by different people using different photographic equipment was verified.

Table 2. Volume of material collected
Таблица 2. Объём собранного материала

| Tested anthills | Number of built models of ant mound surface | Average number of photos per model |
|---|---|---|
| I-18 | 10 | 66 |
| Gel-1 | 20 | 48 |
| Gel-2 | 13 | 53 |

A local coordinate system was used for data collection and modeling of anthills. During the process of photoscanning, control measurements were made to compare the actual sizes of the objects with their sizes on the resulting models.

The volume of material collected, including the number of photos per model, is shown in Table 2.

***Building and comparing models.*** The model was built using the Agisoft Metashape program. After importing the photos into the project, we started the automatic recognition of markers on the photos and began the procedure of aligning the photos. Then we manually marked reference points on all photos and entered their local coordinates. After entering the coordinates of the reference points, we re-aligned the photos and created a dense point cloud.

The accuracy of the method and the estimation of the nest mound volumes were evaluated using dense point clouds constructed in the local coordinate system. The point clouds were processed by a specially developed set of procedures in Python using the Matplotlib library. To obtain a height map, the anthill area was uniformly divided into small cells (1x1 mm or 2x2 mm), and the height in each cell was taken to be equal to the average value of the vertical coordinates of the cloud points falling within the cell. If there were no points in a cell, the missing information was filled in by linear interpolation of the values of the surrounding cells. The change in the volume of the nest mound was calculated as the difference between the sums of the heights of all its cells multiplied by the area of a cell. The areas of the height map included in the anthill were defined by a manually generated bitmask.

Nomenclatural acts introduced in the present work are registered in ZooBank (www.zoobank.org) under urn:lsid:zoobank.org:pub:08E7B1EE-0474-4F53-B55E-A3D9A4A4D129.

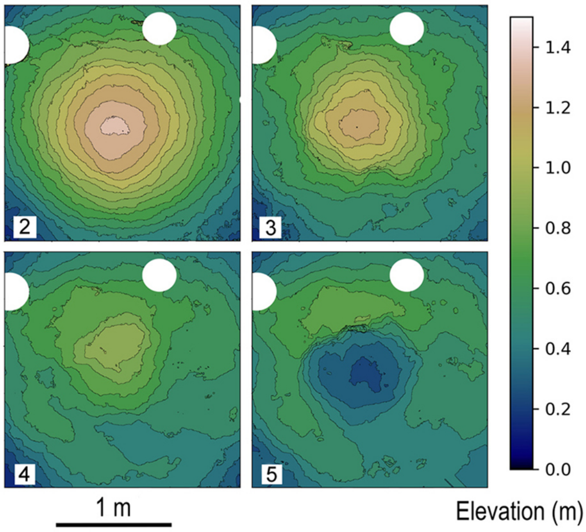
## Results and Discussion

***Efficiency of model building.*** Of the 43 photo sequences collected, 42 models were built. 40 models were built without errors. Reasons for errors in model building: an insufficient number of photos, change of marker positions during shooting, change of lighting during photoscanning (Table 3). Insufficient number of photos proved to be critical in the current sample. It was not possible to build a single model from such data. The errors caused by the other two reasons could be compensated by processing the material, but it increased the time of working with the model by about 0.5 hours.

The time required to scan an anthill in the field (including preparing of the surface for scanning and placing markers on the anthill) was no more than 10–15 minutes for each model. The time required for the operator to work on the computer to build each model was about 1–2 hours. The time required for a computer to perform all the necessary calculations on a model — from 1 hour to 2 days, depending on the capacity of the machine.

In all three sequences (I-18, Gel-1, Gel-2), the models are similarly positioned and compare well. Control measurements of the anthills taken during the excavation and during construction monitoring coincide with similar measurements on the models. There was a difficulty in matching the Gel-2 anthill models that was more related to the choice of model anthill than to the methodology. This is described in more detail below.

***Application of the method to document red wood ant nest excavation.*** The anthill of I-18 (*F. aquilonia*) had a «classic» appearance for a nest of red wood ants built in a mature spruce forest, and some construction features. The border between nest mound built of plant residues and the soil base (embankment) was quite well distinguished. The nest mound was built of dry needles and small twigs with admixtures of soil and tree resin, and the soil nest base consisted mainly of compacted decomposed plant material. The soil base material resembled peat. The nest mound could be divided into three parts based on the mechanical properties of the material: a cover layer, a cortical layer and an inner cone. The cover layer consisted mainly of spruce needles, was loose and easily separated from the cortex layer. The cortical layer was similar to the cover layer in terms of plant material composition, but it contained a significant amount of resin in addition to needles. When removed, the cortical layer partially retained its structure, and




Figs 2–5. Elevation maps of different parts of the anthill I-18 (*F. aquilonia*). 2 — cover (top) layer of the nest mound; 3 — cortical layer of the nest mound; 4 — inner cone; 5 — soil nest base (embankment). White circles indicate trees.

Рис. 2–5. Карты высот различных частей муравейника И-18 (*F. aquilonia*). 2 — купол (покровный слой); 3 — корковый слой купола; 4 — внутренний конус; 5 — вал. Белыми кругами обозначены деревья.

several monoliths were taken from it. The inner cone consisted mainly of relatively large twigs.

Based on the results of photoscanning, elevation maps were made (Figs 2–5). During the excavation, the anthill I-18 was scanned 10 times: 1 — initial surface scanning (Fig. 2); 2 — samples of cover (top) layer were taken; 3 — half of the cover (top) layer was removed; 4 — the entire cover layer was removed — the cortical layer was fully exposed (Fig. 3); 5 — samples of the cortical layer were taken; 6 — the cortical layer was removed — the inner cone was opened (Fig. 4); 7 — the inner cone was cut; 8 — the entire inner cone was removed — the embankment was completely opened (Fig. 5); 9 and 10 — the embankment was cut.

The synchronized surface models compare well. The undisturbed parts of the surface before and after sampling are almost completely consistent. This allows us to estimate the volumes of both the samples taken and the functional parts of the anthill as a whole.

Table 3. Errors in the building nest mound models
Таблица 3. Ошибки построения моделей куполов муравейников

| Tested anthills | Number of built models of ant mound surface | Number of the models with errors | Causes of the errors | Final number of models |
|---|---|---|---|---|
| I-18 | 10 | 0 | 0 | 10 |
| Gel-1 | 12 | 0 | 0 | 12 |
| Gel-1* | 8 | 2 | A — 1; B — 1. | 7** |
| Gel-2 | 13 | 1 | C | 13 |

Note. Reasons for the errors: A — not enough photos to build a model; B — one of the markers changed position during taking pictures (e.g., blown away by wind); C — changing the lighting during shooting; * — models based on the material collected by schoolchildren; ** — the insufficient number of proved to be critical in building models.

Примечание. Причины ошибок: A — недостаточно фотографий для построения модели; B — один из маркеров изменил положение (сдуло ветром) во время съёмки; C — изменение освещения во время съёмки; * — модели, построенные на основании материала, собранного школьниками; ** — недостаток фотографий оказался критичным для построения моделей.

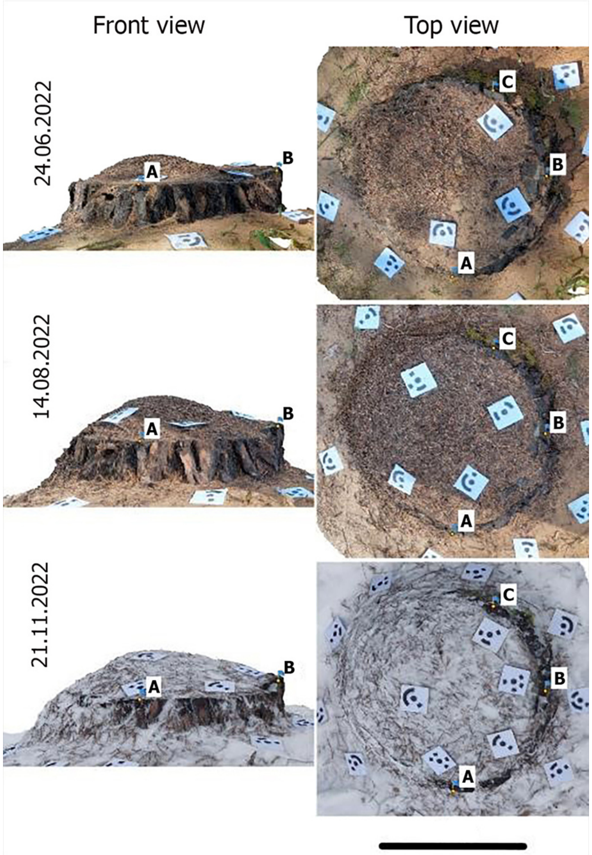



Fig. 6. Models of the anthill of red wood ants Gel-2 (*Formica rufa*) at the beginning, middle and end of the season 2022. Designations: A, B, C — reference points. Scale bar 50 cm.

Рис. 6. Модели муравейника рыжих лесных муравьёв Гел-2 (*Formica rufa*) в начале, середине и конце сезона 2022 г. Обозначения: A, B, C — реперные точки. Масштаб: 50 см.

***Tracking nest building.*** As a result of following the construction of the anthills, 32 models were made. Both anthills, Gel-1 and Gel-2 (*F. rufa*) had enlarged domes (visually) during June–August. The Gel-1 nest was built in a fire trench that was renovated in the spring of 2022.

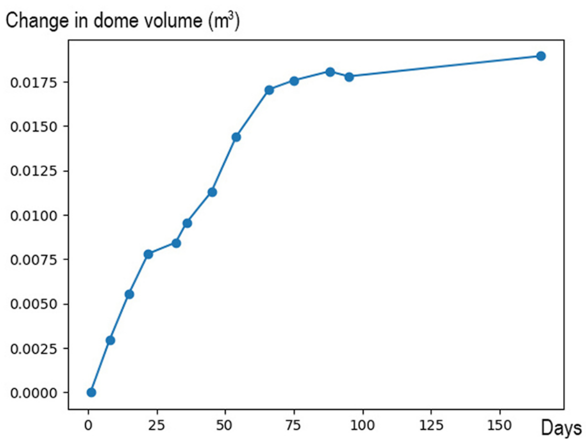



Fig. 7. Changes in the nest mound volume during construction of the Gel-2 (*Formica rufa*) nest.

Рис. 7. Изменение объёма купола при строительстве гнезда Гел-2 (*Formica rufa*).

By comparing the Gel-1 ant nest models, constructing a time series, and evaluating the change in dome volume, it was found that the nest mound was slowly sliding downwards. This could be explained by the settlement of the soil beneath it. The rebar, on which the reference points were plotted, was driven quite deeply into the dense layer of soil. The Gel-1 anthill itself was on loose soil that had apparently compacted over time. Further manipulations with models will be needed to track changes in the volume of its dome.

The Gel-2 anthill was more successful. It was possible to synchronize the constructed models without shifts (Fig. 6) and to quantify the dynamics of the nest mound construction (Fig. 7).

The application of the method to describe the construction of nest mounds of red wood ants shows its efficiency. It is possible not only to build models of the nest surface in dynamics, but also to monitor changes in volume, including marking areas of intensive construction and areas of subsidence.

## Adjustment of the method

The most labor-intensive part of applying the methodology to the described dataset is the marking of reference points. In almost every photo from the set it was necessary to manually mark points on trees or rebar. This took up to 75 % of the total modelling time. To reduce labor costs, it is necessary to use markers to mark reference points in the set. In other words, the reference object should also be recognized automatically. There are several ways to use markers. On wooden objects it is possible to place either markers, or their attachment points. To do this, the markers can be pierced in the center, and their attachment points can be marked on the wood with pins. A thin pin not interferes with the recognition of the markers. Important (!): do not use big drawing-pins for this purpose, as they may overlap part of the marker and prevent it from being recognized by the program.

***Photoscanning template.*** It is also possible to use a special template on which markers are placed (Figs 8–11). The current version is designed for sampling of nest mound and excavation of anthills (usually — abandoned).

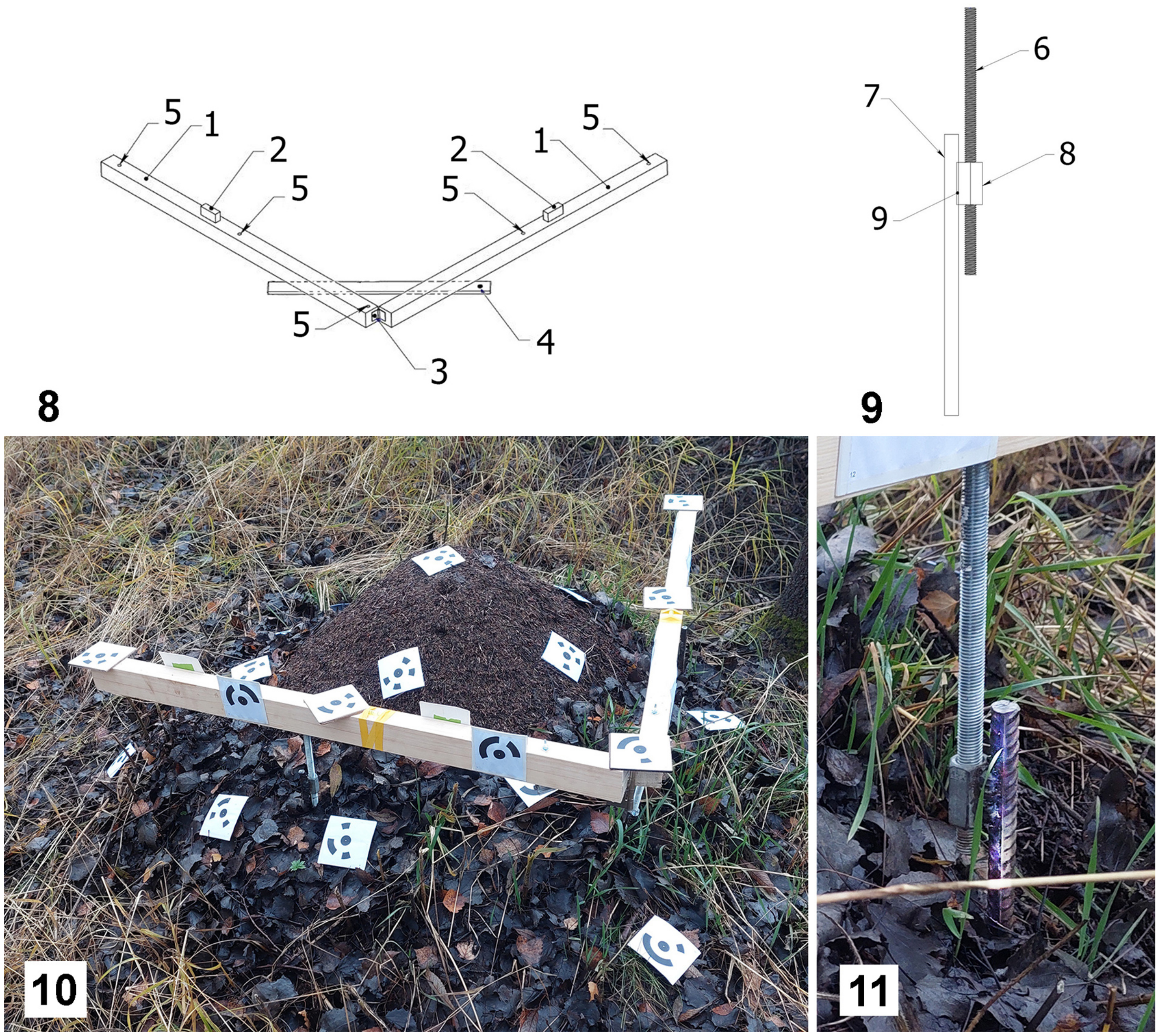
In the current design, the template is an angle assembled from two support bars, a hinge and a stiffening rail (Figs 8, 10). Bubble levels and markers are attached to the support bars. The levels allow the sides of the corner to be placed horizontally. The markers are divided into main markers, which act as reference points (Fig. 8: number 5), and auxiliary markers. There are five main markers, located on the corner of the template (the marker that sets the beginning of the local coordinate system) and two on its sides with a spacing of 0.5 m. The distance between the outermost markers varies and should be measured when the corner is turned. Auxiliary markers (located on the sides, vertically, see Fig. 10) are necessary to optimize the comparison of photos, they are placed arbitrarily.

Only three main markers are used in a scanning. When scanning an anthill about 0.5 m in diameter, the corner marker and the two closest to it. When scanning larger anthills — the corner marker and the two furthest away.

The template is mounted on the posts assembled from reinforcement pieces, nuts and studs (Figs 9, 11). By means of these posts the bars are set horizontally. As a result, the template sets the horizontal plane and the dimensions of the model. Working with the template adds a bit of time in the field, but drastically reduces it takes to complete the models. This design is not obligatory; it is only a convenient variant for solving our tasks. The design, size, and position of markers can and should be changed when solving specific problems, based on the peculiarities of nest building of model species of ants.

## Conclusion

The previously proposed methodology for photo-scanning anthills is applicable to both tracking nest construction and documenting nest excavation. The resulting models for tracking anthill construction allow us to assess changes in nest volume, highlight areas of intensive construction and nest subsidence. The use of the methodology in nest excavation allows estimation of the volume of samples taken and parts of the anthill excavated. The time of work in the field when describing an anthill is considerably reduced, the labor costs for building models in laboratory conditions are acceptable. The availability of a computer capable of processing is crucial. The experience of using the method suggests the possibility of its ap-




Figs 8–11. Template for photoscanning of nest mounds. 8, 10 — angle for forming the horizontal scanning plane and setting the model dimensions; 9, 11 — stand (3 pcs.). Designations: 1 — a bar about 1.1 m long; 2 — a bubble level; 3 — a hinge, 4 — a lath that sets the rigidity of the angle, 5 — points of fixing the main markers that serve as reference points, 6 — a piece of stud, 7 — a piece of rebar, 8 — a nut, 9 — a place of welding.

Рис. 8–11. Шаблон для фотосканирования куполов муравейников. 8, 10 — угол для формирования горизонтальной плоскости сканирования и задания размеров модели; 9, 11 — стойка (3 шт.). Обозначения: 1 — брусок длиной около 1,1 м; 2 — пузырьковый уровень; 3 — петля, 4 — рейка, задающая жёсткость угла, 5 — точки крепления маркеров, выполняющих функцию реперных точек, 6 — отрезок шпильки, 7 — отрезок арматуры, 8 — гайка, 9 — место сварки.

plication in the preparation of school and student scientific studies.

In the course of testing the method, the main point that increases the labor cost of processing was revealed. It is necessary to recognize reference points automatically. For this purpose it is suggested to use markers of the program Agisoft Metashape for marking reference points. It is also suggested to use a special template that defines horizontals and dimensions of the model, which can be made from available materials.

This method has wide illustrative possibilities. In the classic scheme of describing a red wood ant nest, there is a sketch (e.g., if the nest is damaged). To describe damage to an anthill, a myrmecologist must sketch the anthill in the field, measure the damaged areas, and estimate the percentage of damage. Photoscanning of anthills without the use of reference objects and subsequent construction of 3D models requires much less effort, and more information about the anthill can be collected.

Creating reference objects, obtaining their local coordinates and building a real model is a much more labor- and resource-intensive task. If it is solved, there is a possibility of accurate calculation of volumes of nests and their parts. The methodological analogy of such work is a small-scale topographic survey. Traditionally, such a survey is made with the help of a grid stretched horizontally over the described object and a measuring tape. Such a topographic survey of an anthill is a much more labor-intensive method in comparison with photoscanning and the creation of reference objects. In addition, with the help of photoscanning with the placement of reference objects, it is possible to track the process of anthill construction with minimal labor input, but the collection of indicative and extensive material. As a result of such work, photo series are obtained, which show the materials used in the construction of anthills, and on their basis, accurate models of the surface of anthills are built and it is possible to estimate the change in the volume of the dome.

The approach to investigating red wood ant nests using photoscanning methodology includes a number of important points. 1. Photoscanning itself is used to generate models of nest surfaces or parts of nests (and thus to estimate volumes). 2. Samples (monoliths if possible) should be taken during the excavation of anthills in order to describe the characteristics of the chamber arrangement, the use of different materials by the ants, etc. 3. The structure of the collected monoliths should be modeled on an even smaller scale to determine the number of chambers per unit volume of the nest mound. Tomography can be used for this purpose. 4. It is necessary to describe the construction of nests of different sizes and damage repair on a large sample. Such a data set will allow describing the nests of red wood ants, as well as other species that build similar anthills, at a qualitatively new level.

In general, the development of multimedia technologies will simplify the construction of models of anthills. The use of actual technical solutions will further optimize the task of accurate description (illustration, measurement) of anthills in nature.

# Acknowledgements

The author sincerely thanks Petr Sergeevich Sorokoumov, NRC «Kurchatov Institute», for program processing and comparison of the obtained anthill models; Dmitry Sergeevich Lokteev, Moscow State University of Geodesy and Cartography, for obtaining coordinates of reference points around nests Gel-2 and I-18 using a total station; Natalia Andreevna Grevtsova, NRC «Kurchatov Institute»; Alexey Yurievich Vorobyov and Alexander Sergeevich Kadyrov, Russian State University, for help in excavation of the anthill I-18; Kosyakova Alina Yurievna, FGBU National Park «Meshchera», for organization of work on the territory of the protected area; Teterevyatnikov Andrei Sergeevich and Pavlov Daniil Maximovich, NRC «Kurchatov Institute», for their help in assembling the template for photoscanning of nest mounds; students of schools of the Ryazan Region: Tenyaeva Anastasia, Serditova Sofia, Sviridova Maria, Morozova Alena, Chernaya Evangelina, Krotov Ivan, Alyoshina Amelia for collecting photographic material on the anthill Gel-1; Lamzov Denis Sergeyevich and Kalyakina Alexandra Olegovna, Gifted children's center «Helios», for organizing the work of schoolchildren. The author also thanks Geoscan Group for providing a fully functional temporary version of the Agisoft Metashape program.

The work was carried out within the state assignment of NRC «Kurchatov institute».

# References

Burgov E.V., Lokteev D.S. 2022. [3D-modeling of anthills] // [Proceedings of the XVI All-Russian Myrmecological Symposium «Ants and forest protection»]. Moscow 27–31 August 2022. P.76–81. [In Russian].

De Macedo R.B., Andò E., Joy S., Viggiani G., Pal R.K., Parker J., Andrade J.E. 2021. Unearthing real-time 3D ant tunneling mechanics // Proceedings of the National Academy of Sciences of the United States of America. Vol.118. No.36. Art. e2102267118. http://dx.doi.org/10.1073/pnas.2102267118

Dlussky G.M., 1967. [Ants of the genus *Formica*]. Moscow: Nauka. 214 p. [In Russian].

Dlussky G.M. 1981. [Ants of deserts]. Moscow: Nauka. 230 p. [In Russian].

Dlussky G.M., 2009. [Excavation of a nest and complete sampling of its population] // [Proceedings of the XIII All-Russian Myrmecological Symposium «Ants and forest protection»]. Nizhny Novgorod 26–30 August 2009. P.257–259. [In Russian].

Mikheyev A.S., Tschinkel W.R. 2004. Nest architecture of the ant *Formica pallidefulva*: Structure, costs and rules of excavation // Insectes Sociaux. Vol.51. No.1. P.30–36. https://doi.org/10.1007/s00040-003-0703-3

Minter N.J., Franks N.R., Robson Brown K.A. 2012. Morphogenesis of an extended phenotype: Four-dimensional ant nest architecture // Journal of the Royal Society Interface. Vol.9. No.68. P.586–595. http://dx.doi.org/10.1098/rsif.2011.0377

Sudd J.H. 1967. Introduction to the Behaviour of Ants. London: Arnold. 200 p.

Zakharov A.A. 1991. [Organization of communities in ants]. Moscow: Nauka. 277 p. [In Russian].

Zakharov A.A., Dlussky G.M., Goryunov D.N., Gilev A.V., Zryanin V.A., Fedoseeva E.B., Gorokhovskaya E.A., Radchenko A.G. 2013. [Monitoring of the *Formica* ants]. Moscow: KMK. 99 p. [In Russian].

Zakharov A.A., Zakharov R.A., Fedoseeva E.B. 2015. [Use of red wood ants nest parameters in anthill monitoring] // [Problems of Ecological Monitoring and Modeling of Ecosystems]. Vol.26. No.1. P.68–90. [In Russian].

*Поступила в редакцию 19.10.2024*