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The Study of Bioindicators Possibilities of Ants (Hymenoptera: Formicidae) Under the Conditions of Industrial Pollution

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Abstract. Ant assemblages were studied under the influence of chemical, coal and cement dust, lead-zinc and metallurgical industry wastes in Kuzbass, Russia. The distribution of nests of various ants' species, types of nests, dimensional characteristics and their share by areas were analyzed. It has been revealed that with the increase of anthropogenic impact, the size of the ground parts of the ant nests decreases, and the number of underground nests grows. The predominance of *L. niger* and *M. rubra* nests in the ant assemblages indicates a high degree of anthropogenic stress, and a decrease in their share appears to be an indicator of a decrease in anthropogenic impact. We conclude that the number of nests of the genus *Lasius*, the ratio of underground and dome (in the form of earthen mounds and mounds from plant residues) nests, and the linear dimensions of nests can be used as a bioindicator of the industrial emissions' impact on biocenosis.

1. Introduction

Currently, with the increasing degree of human impact on the environment, the search for a reliable bioindicator that fully reflects the changes occurring in the ecosystem becomes urgent. Ants serve as one of such indicators. This faunal community have high species diversity; and as one of the main components of most biocenosis, constantly inhabiting the same place, are widely advocated as good indicators of ecosystem health and disturbance. Thanks to these traits, ants have been frequently used in biodiversity and conservation studies [1-4].

Particularly, the role of ants in the turnover of radionuclides and radioactivity impact on an ant community are studied in the work of Swedish scientists who call ants "a key organism in the forest ecosystem" [5]. Also, the abilities of heavy metals accumulation in the bodies and nests of *Formica lugubris* are shown; and it can be used as novel ecotoxicological biomarkers [6].

In southeastern Brazil, on the areas impacted by gold mining activities, *Camponotus fastigatus* are considered a good indicator of rehabilitation; and *Ectatomma edentatum*, *Dorymyrmex brunneus*, *Crematogaster evallans*, and *Solenopsis invicta* prove to indicate the incompleteness of the rehabilitation process [7-8]. In Russia, under coal mining conditions of Siberia, ants of the *Formica* genus are considered to act as an indicator of the restoration of sites [9].

The relation between individual genera of ants and differences in the properties of the soil is revealed by the example of the Brazilian Atlantic Forest. For example, *Gnamptogenys*, *Crematogaster*

and *Labidus* are found only in unaltered / natural forests; in contrast to species of genus *Atta*, which are associated with degraded areas of forest, and thus can act as an indicator of its recovery [10].

The study of ants in the area of impact by the Middle Ural Copper Smelter (Russia) led to the conclusion that Stand basal area and cover of the field layer are most likely to influence ants' diversity and abundance [11].

The study of urbanized, agricultural, and natural areas in New Damietta, Egypt, revealed a change in the species composition and a number of parameters for any type of impact. The indicator species, for example, *Messor aegyptiacus*, have also been found [12].

But, aiming at developing a method for using species – level information for bioindication when species are highly diverse and patchily distributed on a chronosequence of rainforest restoration in northern Australia, the scientists could not but acknowledge that restoration of the full suite of ecosystem functions relies on more than just ants [13].

Furthermore, the studies in southwestern United States and Mexico made the researchers conclude that most desert ants cannot be used as indicators of changes in biodiversity resulting from anthropogenic changes in ecosystem structure and function and that they are remarkably resistant to disturbance and environmental stress [14].

In general, as shown in the review paper by M. N. Santos in 2016, ants in urbanization conditions have not been studied properly yet; particularly, there are not enough data for cities with a high degree of human impact on nature [15].

Therefore, the purpose of this work is to study the reaction of ant assemblages to various types of exposure and to search for possible bioindicator characteristics of ants under the conditions of industrial pollution.

2. Methods and materials

The study was conducted in the territory of Kemerovo Region (Kuzbass), Russia, located in southwestern Siberia. The region characteristically exhibits a high degree of the environment transformation because of mining and processing of minerals, for example, coal, lead-zinc rock, etc. The materials were collected in five cities with well-developed industry and in relatively clean areas, as control data (Table 1).

Table 1. Some characteristics of the cities studied.

city	dominant industry	dominant emissions
Kemerovo	chemical	gaseous emissions
Prokopyevsk	mining coal	coal dust
Topki	cement production	lime (cement) dust
Novokuznetsk	metallurgical	integrated (solid and gaseous)
Salair	mining	solid

In each studied city, we identified model areas, located along a transect passing through opposite the wind rose along the gradient of pollution reduction. For the zero mark, the model area (1), located in close proximity to the sources of emissions of the main pollutants, was taken. As the distribution of solid and gaseous pollutants occurs at different distances, the model area (2) with medium impact is located for cities with gaseous emissions at a distance of 5.1-10 km from the emission sources, for solid ones – 1.31-6 km; the model area (3) with a weak degree of impact, respectively, 10.1 and further, 6.1 and further. Similar biotopes, located 30-45 km from the city limits opposite the wind rose, served as the control. At each area, 6-15 test sites 5x5 m were laid. All the selected areas were grass-cereals meadows. In general, we chose and considered the areas with varying degrees of recreational exposure separately. For a more objective assessment of the impact by industrial pollution and

urbanization on ant assemblages, only the areas with a low degree of recreational load are analyzed in this paper.

All the materials were collected in 1996–2017 by applying standard myrmecological methods. 10–15 working individuals were taken from the nest for faunistic studies. Quantitative counting of the nests was carried out on the routes and test sites measuring 5x5 m. The sites were inspected and, if necessary, the soil was dug out. The nest density, calculated for one test site, was used as an indicator of abundance. All received materials were processed in Microsoft Excel 2016 and Statistica v.6.0. For numerical values, the mean values for the study time \pm standard deviation are given.

In our study, we specify underground ants' nests (without any ground structures) and dome nests, which can be divided into two types – soil hills (in the form of earthen mounds) and anthills (mounds from plant residues).

3. Results and discussion

Our study in urbanized and anthropogenically degraded areas allowed us to identify species that were resistant to any kind of anthropogenic impact. Thus, in the model areas, located at different distances from sources of industrial emissions, nests of four genera of ants were recorded. Generally, in the polluted area, the genus *Lasius* reached the largest species abundance and density of settlements. A direct correlation between the degree of pollution and the occurrence of *Lasius* nests ($r = 0.78$ with $p < 0.05$) was noted. In the most polluted areas, all encountered nests belonged only to the ants of the genus *Lasius*. However, there was an exception: in the coal mining area, the nest *Tetramorium caespitum* L., located directly in the coal crumb, was found in the first year of the study.

Under the conditions of Kuzbass, the species *Lasius niger* L. appears to be the most widespread and the most abundant. The second largest and most abundant species is *Myrmica rubra* L. It is noteworthy that the results of our observations regarding to the structure of ant assemblages in the urbanized territories almost completely correspond to the results of the study in southern Finland [16]. However, it should be noted that *M. rubra* settlements tend to locate in the areas exposed only by gaseous pollutants and are not found in the areas with a high degree of exposure by solid industrial emissions.

In the area of strong impact of the industrial emissions, a mono-type settlement *L. niger* was observed in the model areas. The density of nests with a high degree of exposure can range from 0.9 ± 0.5 (coal dust) to 1.2 ± 0.2 nests / 25 m^2 (complex emissions). With increasing distance from sources of industrial pollution or industrial emissions, the other species of the *Lasius* appear: *L. flavus* Fabr., *L. alienus* Först., *L. platythorax* Seifert. The latter species is found in the areas with woody vegetation, and thus it is served as an indicator of the forest cenosis restoration.

However, in general, with a decrease of the impact, the proportion of nests of the genus *Lasius* in the biocenosis decreases. It occurs when moving along the transect in the direction of reducing the degree of pollution (Figure 1b), as well in the direction of reducing the volume of industrial emissions (Figure 1a). Thus, the analysis of the structure of ant assemblages and the proportion of nests of the genus *Lasius* can be used as a bioindicator of the impact of industrial emissions on biocenosis.

Our previous studies have shown that ratios of the relative number of species (portion) of the subfamilies Myrmicinae and Formicinae, the species richness of the ant assemblages on the studied areas and changes in the density of settlements on them can act as the indicators of the state of the environment [17]. However, it is known that due to the processes of modification of its internal environment occurring in an anthill, many species of ants are able to adapt to a certain extent to changes in the habitat and survive under conditions that are detrimental to many other animal species [18]. One of the adaptations to the urban conditions of existence is the ants going into the soil [19]. Therefore, the most informative indicator, which, in our opinion, can be used as a bioindicator, is the proportion of underground nests without external structures in the model area. This applies primarily to those species of ants, which are able, depending on environmental conditions, to change the type of the nest.

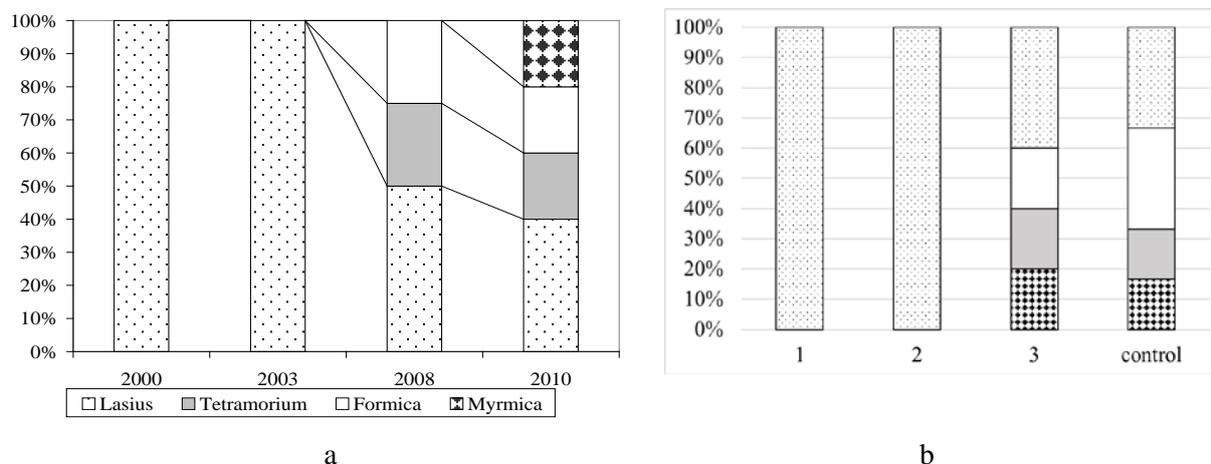


Figure 1. Changes in the structure of ant assemblages in the area of impact of complex emissions: a - a model area in the zone of strong impact with a decrease in gross emissions; b - at different distances from emission sources, on an average over the years of the study. The designation of the areas is in the text above.

It has been revealed that the ratio of underground and dome (in the form of earthen mounds and mounds from plant residues) nests varies depending on the distance to the emission sources (Figure 2). A positive correlation was noted between the level of pollution and the proportion of underground nests ($r = 0.98$ at $p < 0.05$) and a negative correlation with the portion of dome nests ($r = -0.98$ at $p < 0.05$). At the same time, the nests in the form of earthen mounds were registered in all the studied areas; nests with plant mounds were found only in the area of weak influence of industrial enterprises and control. This fact can be explained by the fact that nests in the form of mounds from plant residues are characteristic of representatives of the genus *Formica*, who are not settled in the area of strong anthropogenic impact.

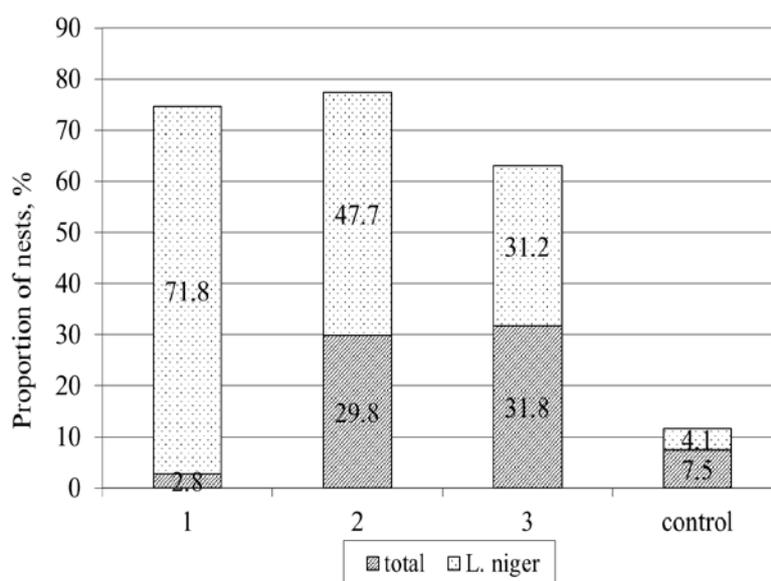


Figure 2. The ratio of different types of ant nests in the areas with varying degrees of impact of gaseous emissions; on an average over the years of the study. The designation of the areas is in the text above.

According to the analysis of the results obtained, a linear size of the nest is a good physiognomic bioindicator. We identified a direct correlation ($r \geq 0.8$ at $p < 0.05$) between the linear dimensions of the aerial part of the nests and the distance from industrial emission sources (Figure 3).

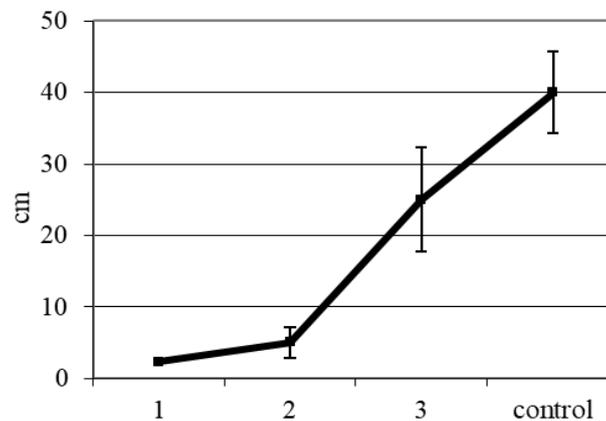


Figure 3. The height of the earthen mound of ants in areas located at different distances from the sources of complex emissions, on average over the years of the study. The designation of the areas is in the text above.

Thus, in the area of high impact, the height of earthen mounds does not exceed 5 cm with a diameter of 10 cm. With increasing distance from enterprises, their height increases and reaches maximum sizes (on average 40 cm with a diameter of about 50 cm) in the control area. The exceptions are the nests in the area of the cement plant impact: they are actually cemented and opened in layers. Their height in the most polluted areas reaches an average of 46.3 ± 10.3 cm with a diameter not exceeding 25 cm. With a decrease of contamination with cement dust, the proportion of underground nests increases ($r = 0.90$ with $p < 0.05$); the proportion of nests with a ground dome ($r = -0.94$ at $p < 0.05$) and their sizes decreases to the control up to 25.0 ± 5.0 cm in height and 30.0 ± 2.3 cm in diameter. This can probably be considered as an adaptation to the constant cement dusting. For the other types of pollution studied, the responses of the ants in relation to the size of the dome nests are similar.

In addition, when studying the ecological characteristics of the ant settlement in model areas, a direct correlation ($r = 0.89$ with $p < 0.05$) was noted between the level of pollution and the proportion of underground nests belonging to *L. niger* ants. For example, in ecosystems exposed by gaseous emissions, it has been revealed that 71.7% of all registered Formicidae nests are located underground, while in the control only 11.6%. In particular, the portion of *L. niger* amounts, respectively, 69.1% and 35.4% in the total number of discovered underground nests in the city and in the control (Figure 4).

At the same time, the following pattern was registered in various areas: the largest number of underground nests were noted in the area with a high level of pollution (97%). In the other studied areas of the city, the portion of underground nests of *L. niger* is about 88%.

It must be emphasized that, on average, 89.1% of all *L. niger* nests found in the city were located underground, and there were only 20% in control. The percentage of different types of *L. niger* nests can serve as one more indicator.

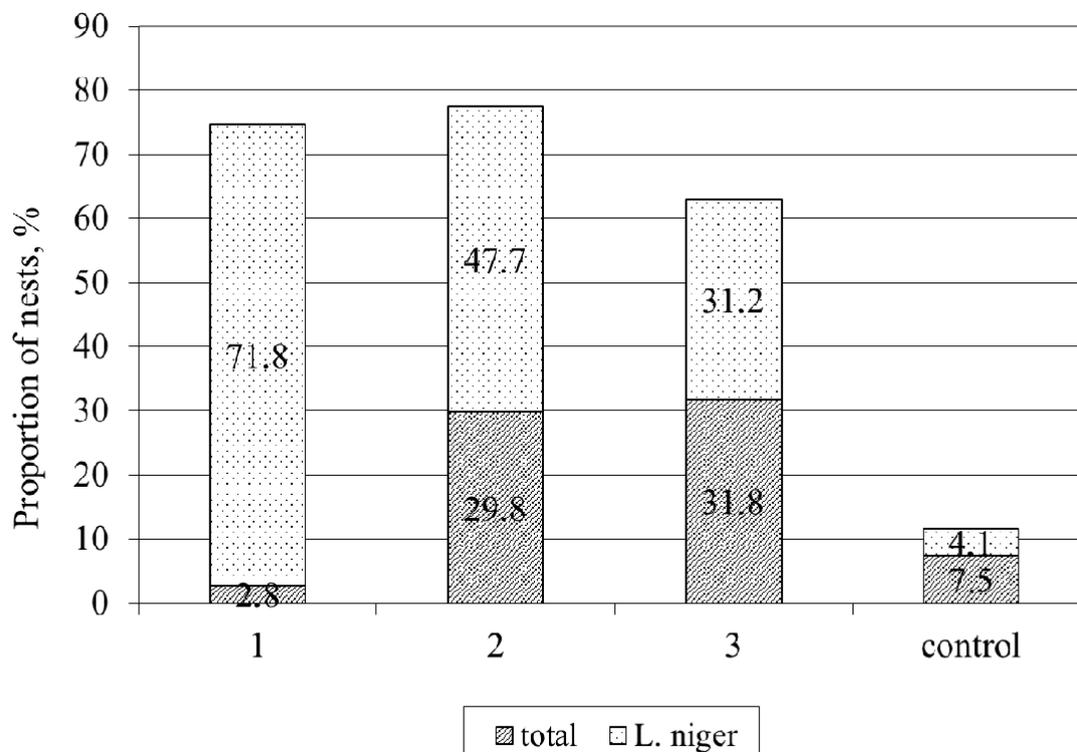


Figure 4. The percentage of underground nests of *Lasius niger* in the total number of underground nests of ants in the areas located at different distances from sources of gaseous emissions, on average over the years of research. Designation of the areas is in the text above

4. Conclusion

Thus, the results of the above study make it possible to give recommendations on the use of a number of characteristics of ant assemblages for bioindication, in particular: species richness, taxonomic structure, linear dimensions and the ratio of nests types.

Based on our previous studies and on long-term studies of Kuzbass ant assemblages in the areas affected by industrial pollution and natural conditions, we propose a scheme for the rapid assessment of the pollution level of the biogeocenosis for the temperate Palearctic:

The studied area should be attributed to the area of strong anthropogenic impact when only 1-2 species of ants are located in it, and the total number of underground nests is more than 90%. At the same time, the portion of *L. niger* in all the nests is more than 95%.

The area is considered to be of moderate anthropogenic impact when 3-4 species of ants are found on the study site, while the total number of underground nests is 50-90%, and the portion of *L. niger* nests is about 50% of all the nests.

The area is considered to be of weak anthropogenic impact, if five or more species of ants are found on the investigated site, while the total number of underground nests is less than 30%, and the portion of *L. niger* nests is less than 50% of all the nests.

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