Study of ants as bioindicators of industrial pollution in Kemerovo Region, Russia

S V Blinova[1] and T I Dobrydina[2]

[1] Kemerovo State University, Department of Ecology and Nature Management, 650000, 6 Krasnaya Street, Kemerovo, Russian Federation
[2] Kemerovo State University, Department of Foreign Languages in Professional Communication, 650000, 6 Krasnaya Street, Kemerovo, Russian Federation

E-mail: sv_blinova@mail.ru

Abstract. The myrmecocomplexes of five industrial cities in the territory of Kuzbass, Russia, were studied. The general trends in the reaction of ants to the pollution by gaseous (chemical industry) and solid (coal and cement dust, lead and zinc waste and metallurgical industry) emissions were revealed. It was found out that the proportion of species of subfamilies, species richness and density of the settlement can be used as bioindicators. The predominance of L. niger and M. rubra nests in myrmecocomplexes immediately indicates a high degree of man-made impact.

1. Introduction

Ants are one of the essential components of most terrestrial ecosystems. Settled in urbanized areas, they are exposed to many factors of anthropogenic and recreational nature. There is an opinion that urban conditions are more severe for the life of ants: only some species settle and survive [1]. Therefore, the myrmecocomplexes of cities differ from natural biocenoses by poor species diversity [2-3] and the presence of 1-2 mass widespread species [4]. The abundance of relatively rare species often increases at a time when the number of nests of background species decreases [5].

To adapt the urban conditions of existence, ants are noticed to go into the soil [6], where they often create multi-species communities, and even on anthropogenically disturbed sites [7].

Emissions of industrial enterprises are one of the main types of human impact on the environment. According to the observations [8-9], industrial pollution leads to limiting the number of species, reducing the density of nests and their richness. However, the reaction of ants to man-caused impacts can be different. Thus, the diversity of dominant species and their quantity increase as they approach the source of emissions of sulfur production [10]. The domination of ants among predators – geobionts is detected in the area of the sulfur basin [11]. In the immediate vicinity of the nitrogen complex, no ants are recorded [11].

In the areas of industrial pollution, the spatial structure of ants' populations changes, the proportion of larvae and pupae in families increases, the mass decreases [9], the chemical composition of the body (including the accumulation of various elements in the body of ants) changes [12-13].

Close to the Finnish metallurgical industry, a decrease in the relative abundance of two of the five identified species Formica s.str was recorded when compared with the areas not exposed to the metallurgical industry. The volume of nesting hills in the contaminated area is 34% lower than in relatively clean areas [14]. In this case, the morphological features of Formica s.str. do not change [14].

In the Czech Republic, on the dumps formed after the extraction of brown coal, the same kinds of ants as in natural cenoses were found. However, a number of species were recorded only on the dumps and not found in natural cenoses [15]. In Italy, the representation of the individual genera Formicidae and the number of forest cold-hearted species vary on the coal dumps, which were formed in different times [16].

According to Puszkar T. [17] and Majer J.D. [18], Formicidae appear to be an informative component of land ecosystems and can serve as indicators of habitat conditions thanks to their high abundance, species diversity, complex structure of communities and stability in habitat.

It is shown that the ants' communities can be used as of the environmental consequences of land use in mangrove forest systems [19] and post-fire regeneration [20] in Brazil. Yamaguchi T. [3] suggests using Messor aciculatus as bioindicators of the changes in soil in the cities of Japan.

The example of Italy shows [21] that indicators of species richness and abundance of ants can act as bioindicators of the rehabilitation / disturbance of various biotopes. The other authors suggest using a species composition to control the development of agrocenoses. At the same time, it is pointed out that for each locality there should exist its own set of indicator species [22].

Obviously, the bioindicator for each locality comes from the specific environmental conditions and available biodiversity. Therefore, the purpose of this work is to identify possible indicators in the characteristics of myrmecocomplexes of industrial cities.

2. Methods and materials

The studies were conducted in the territory of Kuznetsk-Salair mountain region of Altai-Sayan mountain country in the administrative boundaries of Kemerovo Region (Kuzbass), Russia. The region is characterized by a high degree of the environment transformation as a result of mining and processing of minerals, for example, coal, lead-zinc rock, etc. The materials were collected in relatively clean areas, as control data, and in 5 cities with well-developed industry (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, there were identified model areas, located along a transect passing through opposite the wind rose along the gradient of pollution reduction. The model area (1), located in close proximity to the sources of emissions of the main pollutants, is taken for the zero mark. 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, were served as the control. At each area, 6-15 test sites 5x5 m were laid. All the selected areas are grass-cereals meadows.

All the materials were conducted in 1996–2015 by 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 data, the mean values for the study time ± standard deviation are given.

3.Results and discussion

The conducted studies made it possible to reveal the changes in the taxonomic and ecological structure

of myrmecocomplexes in industrial contaminated areas in comparison with relatively clean zones. The general tendencies on all studied areas were revealed. Thus, a decrease in species richness, which is associated with a change in the taxonomic structure of the myrmecocomplexes, was recorded: most of the myrmecocomplexes included Formicinae and Myrmicinae. In the most contaminated areas, a decrease in the richness of Myrmicinae subfamily species, compared to natural cenoses, was observed. The contribution of subfamilies to the faunistic structure dramatically changes when exposed to solid and complex pollutants. For example, in the areas, affected by complex industrial emissions, there are 16% Myrmicinae species and 84% Formicinae species in the most polluted zone; and, respectively, 31% and 69% in natural ecosystems. In the areas, affected by gaseous emissions, the contribution of subfamilies to faunal structure is less expressed, but in any case the richness of Myrmicinae in the affected area is always lower than in the control: there are 29.2% Myrmicinae subfamily species and 70.8% Formicinae; and respectively, 34.2% and 65.8% in natural ecosystems.

However, the proportion of the Formicidae subfamilies' species in myrmecocomplexes differs not only in general comparing the territory of the city and the control. The ratio of the species of the ants' subfamilies to the model areas located at different distances from the sources of industrial emissions is changing. Thus, in areas strongly effected by solid and complex industrial emissions, the minimum proportion of ants of the subfamily Myrmicinae (zero) is recorded. At a distance from the sources of pollution, the richness of Myrmicinae species increases, reaching a maximum in the relatively clean zone of the city (on average 40%). In the control, the richness of the species somewhat decreases again (an average of 31%). According to our observations, the absence of nests of representatives of the subfamily Myrmicinae in model areas of meadows in the conditions of Kuznetsk-Salair mountain region indicates a strong degree of man-made impact on them.

In addition, an inverse correlation between the gross industrial emissions and the number of species of the Myrmicinae subfamily ($r = -0.82$ at $p < 0.05$) was detected. In years with a relatively high level of environmental pollution, the nests of this subfamily ants were not recorded near the sources of industrial emissions (Figure. 1). With a decrease in industrial emissions due to a fall in the production capacity of enterprises, in 2–5 years, individual nests of Myrmicinae were found in the model areas in the zone of strong impact. With prevailing solid emissions, Tetramorium caespitum L. is first recorded, with gaseous – Myrmica rubra L. With relatively low stable volumes of industrial emissions, during seven years, one to three Myrmicinae species appear in the model areas.
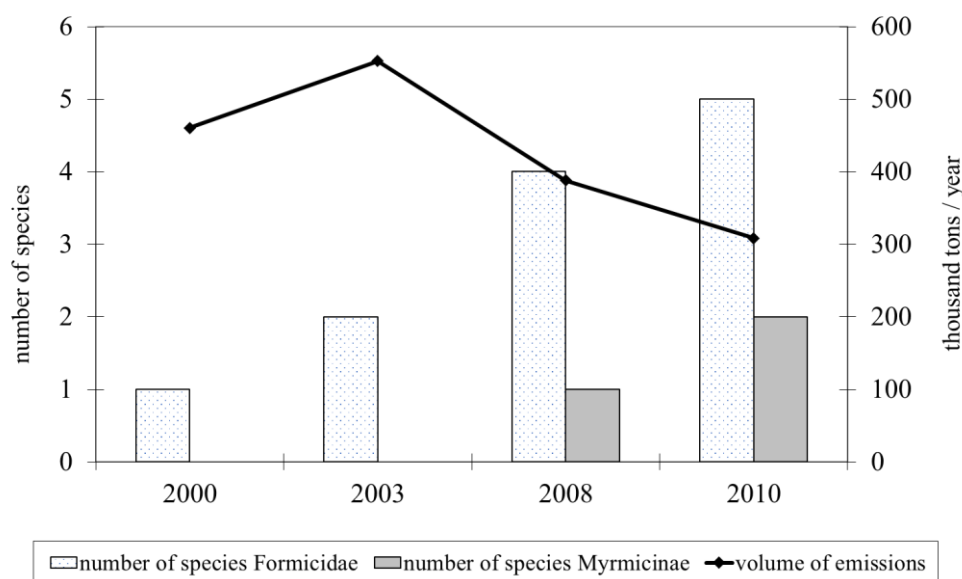

Figure 1. The number of the Formicidae near the source of emissions and the volume of complex industrial emissions in different years; designation of areas is in the text.

The species richness of the myrmecocomplexes of the studied areas can also act as an indicator of pollution of meadows. So, a decrease in the species richness of ants is observed at any type and level of pollution of model areas. Near the emission sources, 1–3 species of Formicidae were recorded. With a decrease in the degree of impact, the species richness of the myrmecocomplexes increases: in the zone of weak impact, there are on average 5.3 ± 2.1 species; in the control their number reaches 8.1 ± 1.2. Significant differences (at $p < 0.01$) of the species richness of Formicidae in the zone of strong man-caused impact and the control zone were revealed.

The change in the density of ants' settlements on grass-cereals meadows located along the gradient of pollution reduction can be used as another indicator. Two main trends in the density of species were identified. The first is quasi-adaptive: the species reach a maximum density at some distance from the emission sources; the density again decreases somewhat to the control (Figure 2). Such a change in density is characteristic of areas exposed to gaseous emissions and coal dust emissions. In the second case (cement dust, lead-zinc production waste, and complex emissions), the density changes according to the non-adaptive type: the minimum is recorded near the emission sources, the maximum is recorded in the control (Figure 3). However, in any case, the density of the nests in the zone of strong impact of industrial emissions is always significantly lower (at $p < 0.01$) than in the zone of weak impact.
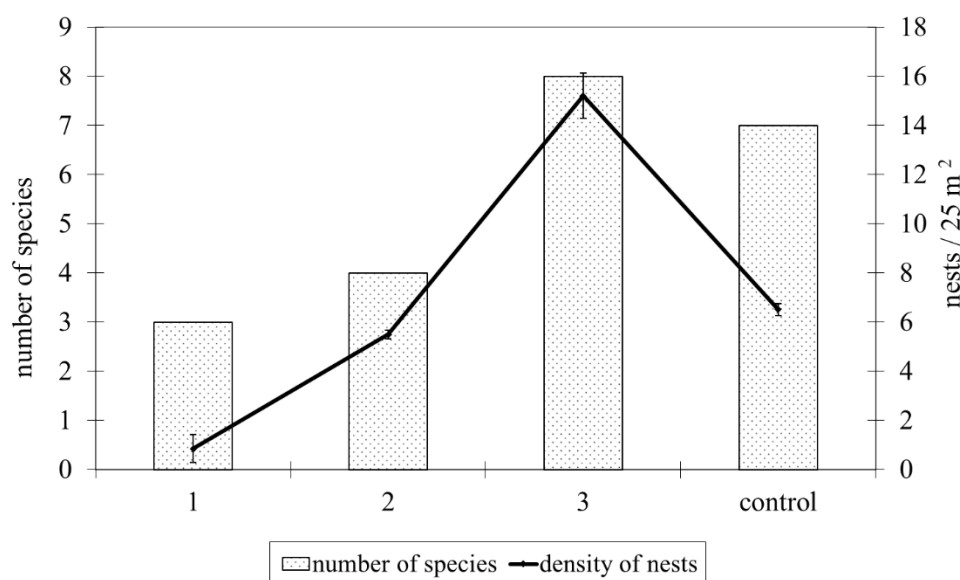

Figure 2. The density of nests and the number of ants' species on the areas located at different distances from coal dust sources, on average, without taking into account Formica s.str nests; designation of areas is in the text.

Representatives of different genera react differently to man-caused impacts. The Lasius genus is the most responsive: a direct correlation was found between the degree of pollution and the quantity of Lasius nests in the myrmecocomplex ($r = 0.78$ at $p < 0.05$). Lasius niger L. is urbophilic and the most flexible species, which is noted by the russian researchers [5-7]. So, in a zone of strong impact on the model areas, a mono-species settlement of L. niger was recorded. With increasing distance from the pollution sources or industrial emissions, the other species of the genus Lasius (L. flavus Fabr., L. alienus Först., L. platythorax Seifert) appear. However, in general, with a decrease in the degree of influence, the proportion of Lasius genus nests decreases from 100% in the area of strong pollution to 25% in the control.
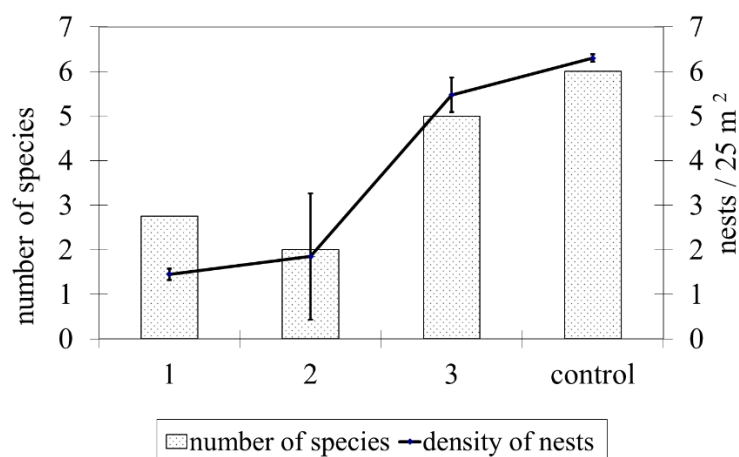
Figure 3. The density of nests and the number of ants' species on areas located at different distances from the sources of complex emissions, on average; designation of areas is in the text.

The genus Myrmica ants exhibit a non-adaptive response to solid emissions and quasi-adaptive – to gaseous. In the most polluted areas, the total density of the settlement of this genus does not exceed 0.27 nests / 25 m^2. With a reduction in industrial emissions, the density of the Myrmica nests increases. For example, in the period from 2004 to 2010, in the areas exposed to complex industrial emissions, the reduction of emissions from 457 to 308.3 thousand tons was noted; the density of Myrmica settlements increased from 0 to 0.1 nests / 25 m^2.

According to our observations, the ants of M. rubra tend to the areas exposed to anthropogenic influence. In the most polluted area (near the sources of man-made pollution), the other species of this genus were not found. In natural cenoses, the density of M. rubra nests is minimal. It is interesting, that on the dumps formed as a result of the extraction of brown coal in the Czech Republic, the nests of Myrmica rubra were detected only in natural cenoses [16]. Probably, such differences are due to the difference in climatic conditions and competition between species.

For the Formica genus, an inverse correlation (r = -0.68 at p <0.05) was found between the degree of pollution and species richness. However, from the genus Formica, the species of the subgenus Serviformica are adapted to live in the meadows in the area of industrial emissions impact (F. fusca L. and F. cunicularia Latr. settle in the zone of medium influence). Formica ants. str. (F. rufa L., F.pratensis Retz., F. aquilonia Yarr., F. polyctena Först.) were recorded only in the area of weak impact and in the control.

4. Conclusion

Thus, the conducted studies of myrmecocomplexes under the impact of solid (coal and cement dust, lead and zinc waste and metallurgical industry) and gaseous (chemical industry) emissions have revealed indicators that can be used for bioindicative evaluation of the degree of anthropogenic pollution. Such parameters are:

1) The ratio of the number of species (proportion) of the Myrmicinae and Formicinae subfamilies: an increase in the proportion of the former indicates a decrease in the degree of impact.

2) Species richness and density of settlement: with an increase in the degree of pollution, a decrease in these parameters is observed until complete absence. At the same time, a quasi-adaptive reaction is observed for gaseous emissions, while for solid emissions it is not adaptive.

3) Reactions of individual genera: with increasing distance from the sources of man-made pollution, species of the genus Lasius appear first, and then – the representatives of the genera Myrmica, Formica (subgenus Serviformica) and Tetramorium.

4) Ants' nests of L. niger and M. rubra: a decrease in the proportion of these species in the myrmecocomplex indicates a decrease in the degree of man-made impact.

References

[1] Vepsalainen K and Wourenrinne H 1978 *Mem. zool*. **29** 191–202
[2] Majer J D and Brown K R 1987 *J. R. Soc. West. Aust*. **69** 13–17
[3] Yamaguchi T 2005 *Entomological Science* **8** 1 17–25
[4] Pisarski B, Czechowski W 1978 *Mem. zool*. **29** 109–128
[5] Antonov I A 2013 *Russian Journal of Ecology* **44** 6 523–526
 [6] Malozemova L A and Malozemov Y A 1999 *Russian Journal of Ecolog*y **30** 4 283–286
[7] Blinova S V 2008 *Russian Journal of Ecology*. **39** 2 148–150
[8] Petal J M 1978 *Mem. zool*. **29** 99–108
[9] Petal J M 1980 *Pol. Ecol. Stud. (PRL)* **6** 4 665–672
[10] Puszkar T 1979 *Bull. Acad. Pol. Sci. Ser. sci. biol*. **27** 6 481–485
[11] Puszkar T 1982 *Ann. UM*CS. 1982 **37** 9 105–116
[12] MacKay W P, Mena R, Gardea J and Pingatore N 1997 *J. Kansas Entomol. Soc*. **70** (4) 329–334
[13] Belskaya E, Gilev A and Belskii E 2017 *Environmental Science and Pollution Research* **24** 11 10768–10777
[14] Eeva T, Sorvari J and Koivunen V 2004 *Environmental Pollution* **132** 3 533–539
[15] Holec M and Frouz J 2005 *Pedobiologia* **49** 4 345–357
[16] Ottonetti L, Tucci L and Santini G 2006 *Restoration Ecology* **14** 1 60–66
[17] Puszkar T 1978 *Mem. Zool*. **29** 129–142
[18] Majer J D 1983 *Env. Man*. **7** 4 375–383
[19] Delabie J H, Paim V R, Do Nascimento I C, Campiolo S and Mariano C S 2006 *Neotrop. Entomol*. **35** 5 602–615
[20] Teixeira M C, Schcimento J H, Nascimento J T, Louzada J N C 2005 *Sociobiology*. **45** 3 631–641
[21] Ottonetti L, Tucci L and Santini G 2004 *Redia* **87** 199–202
[22] Castracani C, Piotti A and Grasso D A 2007 *Redia* **90** 67–70