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ANALYSIS OF SPECIES DIVERSITY OF ANTS (HYMENOPTERA: FORMICIDAE) IN LVIV (UKRAINE)

O. Doroshenko , K. Nazaruk 

Ivan Franko National University of Lviv, 4 Hrushevsky St., Lviv 79005, Ukraine

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Background. The paper presents the results of original research on the diversity of ants (Hymenoptera: Formicidae) in Lviv (Ukraine). In Ukraine, 146 species of ants from 39 genera of five subfamilies are known at present. Ants play an important role in ecosystems. They build their nests in the soil, which contributes to better soil formation. Ants are important links in trophic chains. They are the most adaptable to settling new territories. The diversity of ants in Lviv is potentially very high due to a good geographical location between Polissia and the Carpathians. However, today there are almost no articles on ants' taxonomic groups in Lviv. This study aims to present new records of Lviv myrmecofauna, and to investigate ants' seasonal rhythms.

Materials and Methods. The objects of our research were ants (Formicidae), collected from three different park areas in Lviv, and the territories of the Botanical garden of Ivan Franko National University of Lviv between 2020 and 2021. Main sampling methods were hand collecting and usage of sweet baits (Romero, 1989). In addition, we investigated ants' behavioral traits related to the winter dormancy state.

Results and Discussion. We analyzed 90 samples of worker ants. In the course of identification, 20 different species belonging to seven genera (*Formica* Linnaeus, 1758, *Lasius* Fabricius, 1804, *Camponotus* Mayr, 1861, *Myrmecina* Curtis, 1829, *Myrmica* Latreille, 1804, *Temnothorax* Nylander, 1856 and *Tetramorium* Mayr, 1855) were found, which in turn belong to two subfamilies: Formicinae Lepeletier, 1836 and Myrmecinae Emery, 1877. Numerous species belong to genera *Lasius*, *Formica*, *Myrmica*, and *Tetramorium*, which are mentioned as common in Eastern Europe. Behavioral research related to hibernation shows that *Formica polyctena* Forster, 1850 begins to enter hibernation earlier than other species, namely on 30.09.21 at an average air temperature of +12 °C. They were the latest to leave this state, at the end of April 25.04.22 at the same



temperature. On the other hand, *Lasius niger* (Linnaeus, 1758) remained active the longest in autumn, namely until 21.10.21 at a temperature of +3 °C, and came to the surface one of the earliest on 24.03.22 at +9 °C.

Conclusion. We recorded 20 ant species that have not been mentioned for Lviv because of the absence of any published information. The data obtained within this study show the important role of botanical gardens in preserving the biodiversity of ants despite their small area. Therefore, the topic of the diversity of the myrmecofauna of Ukraine, and urban areas in particular, is relevant and insufficiently researched today.

Keywords: Hymenoptera, Formicidae, urban fauna, species diversity, behavior, Lviv, Ukraine

INTRODUCTION

Ants are a diverse group of social insects that are widespread in the world fauna and are an important element of ecosystems, actively modulating the environment. Their role in the control of plant pest populations is a well-known topic of numerous studies (Adlung 1966; Trigos-Peral, 2021; Way 1992). Ant fauna is an essential element of trophic chains and contributes to the spread of some plant species. Their nests are a necessary link in the life cycle of many myrmecophilous invertebrates. In addition, during their life, the ant family circulates biogenic and mineral substances, aerates the soil, and normalizes its pH (Finér, 2013). All this has a direct impact on vegetation and small animals. Thus, ants are one of the key groups of invertebrates, including those in urban areas and park zones (Radchenko, 2016).

Considering the aforementioned, it is obvious that the data of the ant species is an important part of the integral faunal characteristics of the region. In addition, the presence or absence of certain species in the territories can characterize the ecological condition of these territories. The prevalence of certain species and the overall diversity of ants can act as a bioindicator that responds to external stress at a finer level than vertebrates (Bharti, 2016). This phenomenon is explained by the sensitivity of ants towards the microclimate of the soil, the impact of territory fragmentation by anthropogenic factors, and the disruption of complex species groups. In this case, the ant complex is usually greatly degraded with the total predominance of a few opportunistic species, which makes it less stable (Andersen, 2004).

The diversity of biotopes and climatic zones of Ukraine allows the existence of an incredible diversity of ants, one of the largest among European countries. A total of 39 genera are found in Ukraine, containing 146 extant species, including several invasive ones (Radchenko, 2016). This figure is the largest among neighboring countries: Poland (108), Belarus (62), and Romania (130) (Michlewicz, 2022). Even though myrmecofauna research was conducted on the territory of Ukraine, at the moment there is no information about the species composition of ants in the park zones of Lviv. In Kyiv, a comprehensive study of myrmecofauna was conducted, which proved the diversity of ants even in densely populated cities and the area around them (Radchenko, 2019).

Lviv region lies within the forest-steppe zone and the Ukrainian Carpathian zone, and Lviv itself is relatively close to the Ukrainian part of Roztochia, which makes it a potentially interesting research region. Park areas and botanical gardens are partly isolated islands with potentially unique fauna. Thus, the study of the myrmecofauna of

the park areas of Lviv is relevant and allows expanding knowledge about the impact of urbanization on entomocomplexes and the role of such areas in preserving the biotic diversity.

In addition to assessing species composition and diversity, our goal was to determine the timing and describe patterns of ant family behavior during key periods of the year such as autumn entry and spring exit from winter dormancy. It is a necessary part of ants' annual cycle in a temperate continental climate, including in the territory of Lviv region. Such information would help to better understand when ants stop actively performing the above-mentioned activities and go to the deeper layers of the soil (Lopatina, 2018).

MATERIALS AND METHODS

The study of ant species composition was conducted on the territory of park zones and the botanical garden in Lviv during the field seasons of 2021 and 2022. When choosing the sites, it was considered that the greatest diversity of ants is usually observed in open forest-steppe areas. The sites were selected so that their climate and geological conditions differ along with the level of anthropogenic impact (**Fig. 1**).

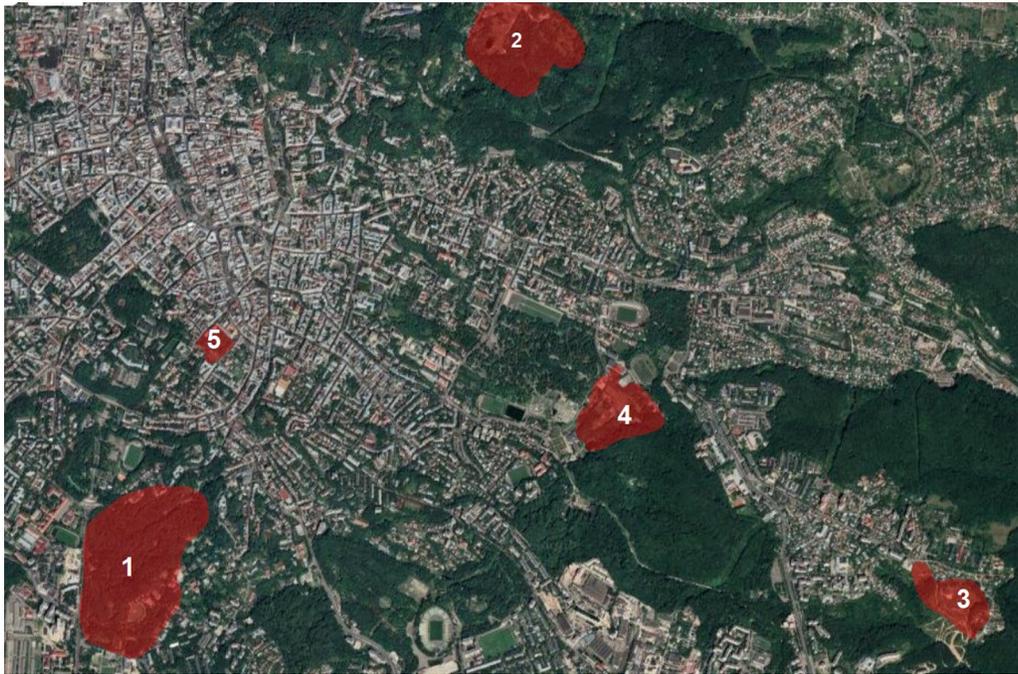


Fig. 1. Schematic map of collection areas. 1 – Stryiskyi Park; 2 – Znesinnia Park; 3 – Vynnykivskiyi Park; 4 – Botanical garden at 4 Kyrlyo and Methodiy St.; 5 – Botanical garden at 44 Cheremshyna St.

1. Stryiskyi Park is the most urbanized area among those under study. The main feature of this park is the high level of fragmentation of green areas by paths. On the territory of the park, high humidity and lower temperature were observed due to artificial water bodies and a dense canopy.
2. The area of Znesinnia Regional Landscape Park has the greatest variety of landscapes and the least anthropogenic load, due to the large area of the park itself. The studied area partially included forest and meadow areas around the lake.

3. Part of Vynnykivskiy Park was selected as the third research area. The recreational load is moderate and not constant, sandy soils prevail, which ensures the representation of forest-steppe species of ants.
4. The Botanical garden of Ivan Franko National University of Lviv located at 4 Kyrylo and Methodiy St. covers a total area of two hectares and generally represents a forest-steppe zone.
5. The Botanical garden of Ivan Franko National University of Lviv located at 44 Cheremshyna St. occupies 16.5 hectares and has various types of landscapes with a small artificial lake and greenhouses.

The Sørensen index was used for statistical analysis of the results, which depicted the similarity of the territories in terms of species composition (Magurran, 1988):

$$CS = \frac{2 \cdot C}{A + B}.$$

In the formula, *A* and *B* are the numbers of species in samples. *C* is the number of species that are common for both samples.

The main methods of sampling ants were the classic route method and direct manual collection of workers. Sampling was carried out from the nest, or, in case of problematic detection of it, directly from the substrate. Edible baits were also used to locate species that spend most of their time under the surface of the substrate and to identify foraging paths (Romero, 1989).

RESULTS AND DISCUSSION

A total of 90 ant samples were collected at 5 research sites in Lviv (see **Table**). Thus, we identified 20 species belonging to seven genera (*Formica*, *Lasius*, *Camponotus*, *Myrmecina*, *Myrmica*, *Temnothorax* and *Tetramorium*), which in turn belong to two subfamilies: Formicinae and Myrmicinae.

In addition to the presence of certain species in the selected territory, we studied their distribution. Both the number of finds of a species on the territory and the density of the same anthills located in the immediate vicinity influenced the determination of prevalence.

The obtained data confirm the general trend towards greater biodiversity in the territories with lower anthropogenic load, namely the vast majority of the identified species occur in the territory of Znesinnia Park (14 species). In addition, it is clearly visible that not only the number of species but also the distribution is the smallest in Stryiskiy Park. Thus, none of the species actually occurs very often in this territory. Also, this table partially confirms the report of O. G. Radchenko, about the eurybiontity of such species as *Myrmica rubra* (L., 1758) and *Lasius flavus* (Fabricius, 1782). The species were observed in territories with different anthropogenic load and with different abiotic conditions of the environment. In addition, the most common species found in all 5 sites was *Lasius niger*, which is an opportunistic species that often inhabits degraded sites.

The maximum similarity of ant fauna, according to the Sørensen index, was noted for Znesinnia Park and the territories of the Botanical garden on Cheremshyna St. and Kyrylo and Methodiy St. (similarity index 77 % and 64 % respectively). The similarities between faunas fluctuated from 30 % to 55 % between the three parks. Sørensen index equals 60 % for the two Botanical garden areas based on our data. Such results prove the thesis about the complexity and diversity of the ant fauna on the relatively small territory of the Botanical gardens. Its similarity with Znesinnia Park is quite high according to the results of the Sørensen index.

List of ant species in Lviv

Species	Investigated area					Hygropreferendum	Thermopreferendum
	Znesinnia	Vynnykivskiy Park	Stryiskiy Park	Botanical garden on 44 Chermshiny St.	Botanical garden on 4 Kyryla and Methodia St.		
<i>Formica cinerea</i> Mayr, 1853	-	+	-	-	-	mes-xer	mes-mac
<i>Formica cunicularia</i> Latreille, 1798	-	+	-	+++	+++	mes-xer	mes-mac
<i>Formica fusca</i> Linnaeus, 1758	+	-	+	++	-	mes	mic-mes
<i>Formica polyctena</i> Forster, 1850	++	+++	-	-	++	mes	mes
<i>Formica rufa</i> Linnaeus, 1761	+	-	-	++	-	mes	mes
<i>Formica rufibarbis</i> Fabricius, 1793	++	++	-	+	-	mes-xer	mes-mac
<i>Lasius brunneus</i> (Latreille, 1798)	+	-	-	+	++	hyg-mes	mic-mes
<i>Lasius emarginatus</i> (Olivier, 1792)	-	-	+	-	-	mes-xer	mes-mac
<i>Lasius flavus</i> Fabricius, 1782	+	++	++	++	+	hyg-mes	mic-mes
<i>Lasius fuliginosus</i> (Latreille, 1798)	+	-	-	++	-	mes	mes
<i>Lasius niger</i> (Linnaeus, 1758)	+++	+++	+	++	+++	mes	mes
<i>Lasius paralienus</i> Seifert, 1992	+	-	-	-	-	mes	mes-mac
<i>Lasius umbratus</i> (Nylander, 1846)	+	-	-	-	-	mes	mes
<i>Camponotus fallax</i> (Nylander, 1856)	-	-	-	+	-	mes-xer	mes-mac
<i>Myrmecina graminicola</i> (Latreille, 1802)	-	-	+	-	-	mes	mes-mac
<i>Myrmica rubra</i> Linnaeus, 1758	+	+	+++	+++	+++	hyg-mes	mic-mes
<i>Myrmica rugulosa</i> Nylander, 1849	+	-	-	+	-	mes-xer	mes-mac
<i>Myrmica schencki</i> Viereck, 1903	-	-	+	-	-	mes-xer	mes-mac
<i>Temnothorax crassispinus</i> (Karavaiev, 1926)	++	-	-	-	++	mes	mes
<i>Tetramorium caespitum</i> (Linnaeus, 1758)	++	+	-	++	++	mes-xer	mes-mac
Total	14	8	6	12	8	-	-

Comments: – the species was not found in this area; + individual nests of a certain species were observed; ++ the species is common for this area; +++ more than five nests of the species were observed or the number of samples constitutes more than a quarter of all samples of the area. Hygropreferenda: hyg-mes – hygromesophile; mes – mesophile; mes-xer – mesoxerophile. Thermopreferenda: mic-mes – micromesothermic; mes – mesothermic; mes-mac – mesomacothermic (Radchenko, 2019)

The most common genera with the largest number of species are typical European ant genera, namely *Formica*, *Lasius* and *Myrmica*. *L. fuliginosus* differs well from other members of the genus due to the specific shape of the head (Fig. 2). On the contrary, members of the subgenus *Formica* have a similar appearance. *F. polyctena*'s light pubescence of the mesosoma is the main species trait (Fig. 3).



Fig. 2. Differences between *L. fuliginosus* and *L. niger* workers

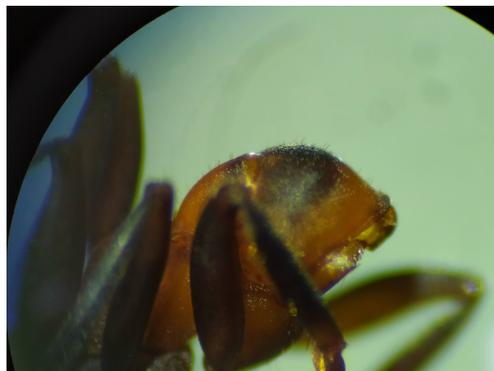


Fig. 3. Light pubescence of the *F. rufa* worker's mesosoma



Fig. 4. Prepared mesosoma with hind legs of *L. emarginatus* worker

Representatives of the genus *Lasius* are a case of high species similarity. For the most part, individuals of this genus are single-colored, but two species in the fauna of Ukraine have a clear separation into two colors. These species are very similar, and their ranges overlap. Both species are mesophylls, often found in mixed forests. Actually, *Lasius brunneus* (Latreille, 1798) does not have a dense pubescence of standing hairs all over the body, in contrast to the species *Lasius emarginatus* (Olivier, 1792) (Fig. 4).

In addition to common species, rare taxa were reported. One of these finds is *Myrmecina graminicola* (Latreille, 1802), which is the only representative of the genus in the fauna of Ukraine. The specimens of this species were collected in Stryiskyi Park. The peculiarity of this cryptobiont species and the whole genus is the small size and a scant number of workers in the ant family. Almost all of their life is spent in the upper layer of the soil and

partly in the litter, which greatly complicates the assessment of their distribution. *Camponotus fallax* (Nylander, 1856) shares a similar lifestyle, thus the species is quite rare due to its treetop lifestyle and the small number of workers in a family. For example, this

species was recorded only in two specimens on the territory of the Botanical garden. Also, we allocated species of the group of redwood ants, namely *F. polyctena* Forster, 1850 and *F. rufa* Linnaeus, 1761. The former species is one of the most common representatives of the genus in the plots under study. Both species are active entomophages, which play a major role in protecting vegetation from pests.

We investigated the hygropreferendum and thermopreferendum of the myrmecofauna of Lviv according to the corresponding species characteristics as mentioned in Radchenko 2019 (Fig. 5).

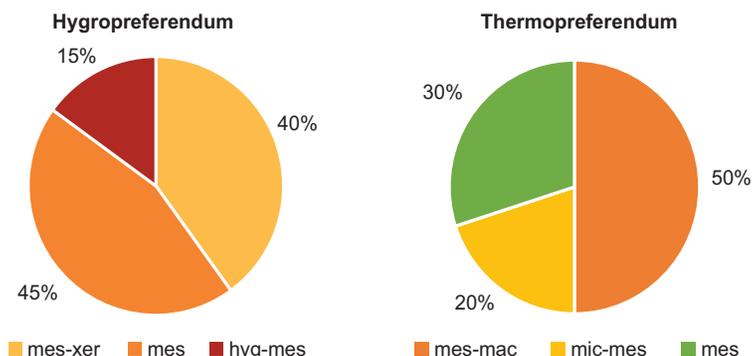


Fig. 5. Relative diversity of ants with different hygropreferendum and thermopreferendum types in the fauna of Lviv

As can be seen from the graphs, the representation of mesophiles in the myrmecofauna of parks and gardens of Lviv is the largest according to hygropreferendum, namely 45 %. Despite the fact that almost half of the discovered species belong to this group, it is not the most common. This group includes a wide range of species, both rarely recorded and common ones. Similar results are obtained for mesoxerophiles, which include slightly fewer species, namely 40 %. On the other hand, the smallest group of hygromesophiles, which includes only 15 % of the species, includes two species with a very high prevalence, which were found in all sites, namely: *Lasius flavus* and *Myrmica rubra*. As for thermopreferendum, 50 % of the detected species belong to mesomacrothermic group and are represented by various genera. Almost all species of *Myrmica* belong here. Mesothermic group also includes various species, but it is worth noting that almost all of them belong to Formicinae. Microthermic group includes a small number of species and constitutes only 30 % of their number, but it includes very common species, namely *Lasius flavus* and *Myrmica rubra*.

We also investigated the seasonal changes in ants' behavior, which is related to winter dormancy. We considered the four most widespread species, which were encountered quite often and are of interest for further research.

Based on the results of the observation, it can be stated that among the ant species studied, the activity of *Formica polyctena* decreased the fastest, which may indicate that this ant enters winter diapause earlier than the other selected species. In contrast, garden ants *Lasius niger* showed some frost resistance, as individual workers were observed outside the anthill until mid-October when the average daily temperature was +4 °C. An intermediate position is occupied by *Formica cunicularia* Latreille, 1798, and *Myrmica rubra* (Linnaeus, 1758), which ceased to be visible at the same period, namely on October 7.

During the spring period of observation, it was found that among the selected ants, *Lasius niger* was the first to appear on the surface. Their activity has been noticeable since March 24 at an average daily temperature of +9 °C. At the time when *Formica polyctena* is just beginning its activity, the anthill of black garden ants is close to the level of activity before winter dormancy. It can be assumed that this early activity compensates for the small size of this species and partially gives it an advantage in the first months of spring for raising a big number of workers and alates. Thus, in that case, *L. niger* is the smallest of the species presented, and *F. polyctena*, on the contrary, is the largest. *F. cunicularia* and *M. rubra* occupy the middle position both in terms of the average size of the workers and in terms of the time of exit from diapause. This assumption about the correlation between size and seasonal activity needs further research and verification.

CONCLUSION

Firstly, the study of the myrmecofauna of the city of Lviv revealed that even in the urbanized territories of such a large city, a sufficiently large variety of ants thrive. We found 20 species and suppose that the list is not complete. Thus, this topic needs further research. The specified number of species only partly represents the diversity of Formicidae in Lviv. It may be linked to the difficulty of recording certain species, and the incomplete coverage of territories where unrecorded species may potentially be found.

Secondly, it was found that biotope segmentation and an increase in anthropogenic pressure lead to the impoverishment of the myrmecofauna. This is illustrated by the example of Stryiskyi Park. It had both lower diversity and prevalence of ants, compared to less urbanized park areas like Znesinnia Park.

The obtained results also indicate the important role of botanical gardens as elements of biodiversity conservation. The species composition of the myrmecofauna of the botanical garden is very rich and almost identical to the park zones of Lviv, despite the small area relative to them. The bulk of the collected samples mostly falls into the same species.

The most common genera with the largest number of species are typical European ants, namely *Formica*, *Lasius* and *Myrmica*, which together account for more than 80 % of all detected species. The most common species are *Myrmica rubra*, *Lasius niger*, *Lasius flavus*, *Formica polyctena*, *Formica cunicularia*, *Tetramorium ceaspitum*. Among the identified species of the tertiary relict fauna is the cryptobiont *Myrmecina graminicola*. In addition, several large perennial anthills of entomophagous species from the genus *Formica* and *Lasius fuliginosus* species were found on the territory of the botanical gardens and park areas, which have a significant impact on the number of pests.

The results of the study of seasonal changes in behavior indicate that species have different adaptations to the winter state of rest. It was determined that *Formica polyctena* enters the winter diapause earlier than the other three species, and exits this state later, unlike *Lasius niger*, which, on the contrary, enters the diapause state later and exits it earlier. The species *Formica cunicularia* and *Myrmica rubra* mostly occupy the middle position according to the time indicator. It suggests that such an adaptation may have an evolutionary advantage due to the correlation between average worker sizes and the seasonal activity of the species. Namely, the smallest size of *Lasius niger* and the largest size and high aggressiveness of *Formica polyctena* among the studied species. The data presented in the work depict the potential for a more detailed study of the species composition of ants. Therefore, the topic of the diversity of the myrmecofauna of Ukraine, and urban areas in particular, is relevant and requires further research.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: We, as the authors of this article, declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Animal Rights: All institutional, national, and institutional guidelines for the care and use of laboratory animals were followed.

Human Rights: This article does not contain any studies with human subjects performed by either of the authors.

AUTHOR CONTRIBUTIONS

Conceptualization, [O.D.; K.N.]; methodology, [O.D.; K.N.]; validation, [-]; formal analysis, [O.D.]; investigation, [O.D.]; resources, [O.D.; K.N.]; data curation, [-]; writing – original draft preparation, [O.D.]; writing – review and editing, [O.D.; K.N.]; visualization, [O.D.] supervision, [K.N.]; project administration, [K.N.]; funding acquisition, [-].

Both authors have read and agreed to the published version of the manuscript.

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АНАЛІЗ ВИДОВОГО РІЗНОМАНІТТЯ МУРАХ (HYMENOPTERA: FORMICIDAE) У м. ЛЬВОВІ (УКРАЇНА)

О. Дорошенко, К. Назарук

Львівський національний університет імені Івана Франка
вул. Грушевського, 4, Львів 79005, Україна

Вступ. У статті наведено результати дослідження різноманітності мурах (Hymenoptera: Formicidae) у Львові. Загалом в Україні відомо 146 видів мурах, які належать до 39 родів і 5 надродів. Мурахи відіграють важливу роль в екосистемах. Вони будують свої гнізда у ґрунті, що сприяє кращому ґрунтоутворенню. Мурахи є важливою ланкою у трофічних ланцюгах. Вони є найприспособанішими до заселення нових територій. Різноманітність мурах у Львові потенційно дуже висока через вдале географічне положення, однак на сьогодні статей на цю тему майже немає. Метою дослідження є представлення нових знахідок мірмекофауни м. Львова та дослідження сезонних ритмів мурах.

Матеріали та методи. Об'єктами нашого дослідження були мурахи, зібрані протягом 2020–2021 років з 3 різних паркових зон Львова і території Ботанічного саду Львівського національного університету імені Івана Франка. Також ми досліджували особливості поведінки мурах, пов'язані зі станом зимового спокою.

Результати. Проаналізовано 90 зразків робочих мурах. Після ідентифікації було виявлено 20 різних видів мурах, що належать до 7 родів, які, у свою чергу, належать до двох підродин: Formicinae і Myrmecinae. Найпоширеніші види належать до родів *Lasius*, *Formica*, *Myrmica* і *Tetramorium*, які згадуються як звичні для Східної Європи. Під час дослідження поведінки, пов'язаної зі станом зимового спокою, з'ясовано, що особини *Formica polyctena* перестають бути активними на поверхні раніше за особин інших видів (30.09.21 за середньої температури повітря +12 °C), а розпочинають активність – найпізніше (наприкінці квітня 25.04.22 за тієї ж температури). Натомість *Lasius niger* найдовше залишався активним восени, а саме до 21.10.21 за температури +3 °C, і вийшов на поверхню одним із перших 24.03.22 за +9 °C.

Висновки. На досліджуваних територіях у м. Львові зафіксовано 20 видів мурах. Зібрана інформація також показує важливу роль територій, таких як ботанічні сади, у збереженні біорізноманіття мурах, незважаючи на їхню невелику площу. Тож тема різноманітності мірмекофауни України й урбанізованих територій зокрема, на сьогодні є актуальною та недостатньо дослідженою.

Ключові слова: Hymenoptera, Formicidae, міська фауна, видове різноманіття, поведінка, Львів, Україна

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