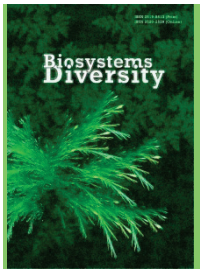

Biosystems Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers.,
2023, 31(3), 345–349
doi: 10.15421/012340

Changes in the Carpathian fauna of Malachiinae beetles (Coleoptera, Melyridae) in the context of temperature increase

V. V. Mirutenko, P. S. Lovas, V. G. Roshko, L. M. Felbaba-Klushyna

Uzhhorod National University, Uzhhorod, Ukraine

Article info

Received 29.06.2023
Received in revised form 01.08.2023
Accepted 14.08.2023

Uzhhorod National University, Voloshyna st., 32, Uzhhorod, 88000 Ukraine. Tel.: +38-050-924-91-69. E-mail: vladyslav.mirutenko@uzhnu.edu.ua

Mirutenko, V. V., Lovas, P. S., Roshko, V. G., & Felbaba-Klushyna, L. M. (2023). Changes in the Carpathian fauna of Malachiinae beetles (Coleoptera, Melyridae) in the context of temperature increase. Biosystems Diversity, 31(3), 345–349. doi:10.15421/012340

Over last century in Europe a tendency of change in species ranges has occurred for insects of different taxonomic groups. We analyzed the changes that have taken place in the distribution of some soft-winged beetles (Malachiinae, Melyridae) species in the Carpathian region. The obtained data are based on a study of museum beetles' collections and the authors' collected materials. Data comparison relating to species distribution shows that the Carpathian fauna during the second half of the 20th century increased by 12 species. Some species have significantly changed their ranges. Species of Southern European and Mediterranean (*Anthomalachius strangulatus*, *Clanoptilus spinipennis*), Central-East European (*Apalochrus femoralis*, *Clanoptilus falcifer*) origin spread to the East Carpathian region. And vice versa, some species (e.g. *Malachius scutellaris*) from Central European and the Carpathian regions have spread beyond their borders of ranges to the East and North. Malachiinae species are anthophilic insects. Their life cycles, flight period, and distribution depend on the phenology of host plants. Acceleration of phenophases of the host plants and intensification of the metamorphosis processes due to increase in air temperature has caused an earlier appearance of soft-winged beetles in recent years and contributed to expansion of the ranges of some species of them. In our opinion, expansion of the species ranges and penetration of new beetle species into the Carpathian region from surrounding areas are related to the climate changes, in particular to warming. This thesis is confirmed by multiyear air temperature data of the Transcarpathian Centre of Hydrometeorology. On a background of increase in regional air temperature by about 0.8 °C an average air temperature in foothills of Ukrainian Carpathians has increased by 1.7 °C during last 50–60 years.

Keywords: insect diversity; beetle fauna; communities; ecological characteristics; distribution.

Introduction

Climate change and global warming have a significant impact on the functioning of ecosystems. The impact of the climate change on insects and their life cycles is the subject of much research (Logana et al., 2006; Khaliq et al., 2014; Pozsgai et al., 2018; Irmler, 2022). First of all, this applies to phytophagous insects, the vital activity of which depends on the temperature regime, as well as on the composition and condition of the vegetation cover and on the phenophases of the development of specific plant taxa (Bale et al., 2002; Jaworski & Hilszczański, 2013). Climate change, mainly driven by warming, facilitates the penetration of invasive species into new territories (Tobin et al., 2014; Hulme, 2017), additionally, it contributes a gradual widening of the ranges of some native species (Couet et al., 2022; Viznovych & Zamoroka, 2022). This impact is especially noticeable in mountain regions, where it is observed through both vertical and vegetation zonation (Chen et al., 2011; Couet et al., 2022).

Among geographical areas, mountain systems differ by having greater biological diversity resulting from the variety of landscapes and microclimatic conditions. Mountain systems might therefore be described as centres of biodiversity, with increased endemism. Such diversity of environmental conditions and the impact of a biota on surrounding areas have led to the development of a rich and interesting ecological and zoogeographical environment where, in the mountainous areas of Europe, coleopterous complexes have formed.

The Carpathian region is situated in the centre of the European continent, and is mostly covered by the Carpathian Mountains. The arc of the Carpathian Mountains stretches across the Czech Republic, Slovakia, Hungary, Poland, Ukraine, Romania, and Serbia. There are three main parts to this arc: the Western, Eastern, and Southern Carpathians or the Transylvanian Alps. The relief of most Carpathian arrays is gently sloping. The climate of the Carpathians is moderately continental and major climatic differences are influenced by altitude, causing altitude climatic and landscape zoning with forest-steppe landscapes spreading across the foothills in the south-west and south-east, where most of the foothills and mountain slopes are occupied by forest landscapes. The lower forest zone contains different species of oak with overlying beech forests. The beech and pine forests contain European beech, European silver fir and spruce, with larch and pine sometimes located above. At the upper boundary of the forest spread are thickets of mountain pine. A high-altitude mountain-meadow area with meadows and a sub-alpine zone of creeping shrubs and alpine meadows is situated above the forest zone. Wildlife is preserved in the Carpathians better than in neighbouring areas of Europe with a wide network of large nature reserves and national parks contributing to this (Oszlányi et al., 2004).

The beetles of the Malachiinae subfamily (soft-winged flower beetles) share similar biological and ecological characteristics and, in a temperate zone, the beetles produce one generation annually with most adults emerging in May–June and flying until July. For the majority of the Malachiinae species, emergence will depend very much on conditions of their habitats, such as altitude, temperature and humidity. They occupy a wide variety of natural and anthropogenic biocoenoses and they are common components of biological communities such as open landscapes and forest communities. In an imago stage they inhabit a mostly grassy vegetation layer, and most species are first order consumers. Larvae of soft-winged flower beetles are second order consumers. They have a predatory lifestyle, and whilst acting as facultative decomposers they can be fed the dead remains of small invertebrates. Their trophic activity impacts on the populations of a wide range of insect herbivores (aphids, thrips, springtails, larvae of bark beetles, grinder, silkworms, wasps, sawflies, fruit flies, etc.) (Kolibáč et al., 2005).

Within the superfamily Cleroidea, beetles of the Melyridae family account for about two-thirds of the total number of species. They are widespread in all zoogeographical regions of the world. Among them Malachiinae beetles comprise approximately 4,000 described species,

with more than 1440 of these being Palaearctic (Kolibáč et al., 2005; Mayor, 2007). The European fauna comprises 312 species (Mayor, 2007).

However, the composition of the fauna of European regions is not constant. It is known there is a current trend to latitudinal and elevational shifts of terrestrial species distribution (Chen et al., 2011). Have similar changes in the fauna of some groups of beetles taken place ? The aim of this work is to identify changes of ranges for some Malachiinae beetles species that have occurred during the last century.

Materials and methods

The published data regarding the modern entomological fauna of the different Carpathian regions: Western Carpathians (Holecová & Zach, 1996; Szalóki & Merkl, 2005; Szafraniec et al., 2010; Holtman et al., 2014), Eastern Carpathians (Shparyk & Sirenko, 2005; Mirutenko, 2010), Southern Carpathians (Merkl, 2008; Merkl et al., 2011; Merkl et al., 2016) was compared with data from earlier studies from the end of 19th and beginning of 20th centuries (Nowicki, 1873; Łomnicki, 1884, 1913; Fleck, 1906; Roubal, 1936) to the second part of 20th century (Horvátovich, 1969; Burakowski et al., 1986).

Our own study on the composition of the Malachiinae fauna was carried out on the south-west macro slope of the Eastern Carpathians and in the Transcarpathian Lowland during field seasons in 1996–2018 (Mirutenko, 2010; Mirutenko & Mateleshko, 2017). Material was collected monthly during regular field trips.

Collection materials of recent and current years from the State Museum of Natural History of the National Academy of Science of Ukraine (Lviv, Ukraine), the Zoological Museum of the Taras Shevchenko National University of Kyiv (Kyiv, Ukraine), the Slovak National Museum-Natural History Museum (Bratislava, Slovakia), the Matra Museum (Gyongyos, Hungary), the Department of Entomology, National Museum (Prague, Czech Republic), and the National Museum of Bosnia and Herzegovina (Sarajevo, Bosnia and Herzegovina) were also used. In total, approximately 1,900 specimens from museum collections and over 2,800 specimens of beetles from the author's own collection were processed.

Information relating to the general geographical distribution of the species from the end of 19th – middle of 20th century to the present is based on publications by Peyron (1877), Abeille de Perrin (1890), Hicker (1925), Greiner (1937), Kolibáč et al. (2005), Mayor (2007), on data of Global Biodiversity Information Facility Database (GBIF), as well as on the materials of museum collections.

Data from the Transcarpathian Regional Centre of Hydrometeorology of long-term meteorological observations, in particular data on air temperature, were used.

Analysis of fauna change

As of the first half of the 20th century, the Malachiinae fauna of the Carpathian region counted 24 species (Nowicki, 1873; Łomnicki, 1882; Hormuzaki, 1888; Fleck, 1906; Roubal, 1926; Roubal, 1936). The region cannot be considered poorly studied at that time in terms of beetle fauna, especially considering the rather thorough entomological studies of Jan Roubal (1926, 1936). As for the Malachiinae, the Carpathians are characterized by the absence of endemism, possibly due to close ties to the fauna of adjacent territories. Currently, the Carpathians hosts 36 species of the Malachiinae beetles (Mirutenko, 2010; Mirutenko, & Mateleshko, 2017) (Table 1).

The following species were added to the fauna list: *Apalochrus femoralis* Erichson, 1840, *Troglops cephalotes* (Olivier, 1790), *Hypebaeus flavicollis* (Erichson, 1840), *Charopus thoracicus* Morawitz, 1861, *Charopus philoctetes* Abeille de Perrin, 1885, *Ceratistes cervulus* (Reitter, 1894), *Clanoptilus spinipennis* (Germar, 1824), *C. falcifer* (Abeille de Perrin, 1882), *C. affinis* (Ménétries, 1832), *Anthomalachius strangulatus* (Abeille de Perrin, 1885), *Ebaeus coerulescens* Erichson, 1840, *Sphinginus coarctatus* (Erichson, 1840).

We analyzed the changes in the distribution of some species that occurred during the second half of the 20th and the beginning of the 21st centuries. It should be noted that over past decades some species of Southern European and Mediterranean distribution have expanded the boundaries of their ranges and spread into other regions, including the Carpathians.

Table 1
Faunistic list of Malachiinae beetles of the Carpathian region

Species	As of the first half of the 20th century	As of the beginning of the 21st century
Apalochrus femoralis Erichson, 1840	–	+
Troglops albicans (Linnaeus, 1767)	+	+
T. cephalotes (Olivier, 1790)	–	+
Hypebaeus flavipes (Fabricius, 1787)	+	+
H. flavicollis (Erichson, 1840)	–	+
Charopus concolor (Fabricius, 1801)	+	+
Ch. flavipes (Paykull, 1798)	+	+
Ch. philoctetes Abeille de Perrin, 1885	–	+
Ch. thoracicus Morawitz, 1861	–	+
Cordylepherus viridis (Fabricius, 1787)	+	+
Malachius aeneus (Linnaeus, 1758)	+	+
M. bipustulatus (Linnaeus, 1758)	+	+
M. rubidus Erichson, 1840	+*	+
M. scutellaris Erichson, 1840	+	+
Anthomalachius strangulatus (Abeille de Perrin, 1885)	–	+
Ceratistes cervulus (Reitter, 1894)	–	+
Clanoptilus affinis (Ménétries, 1832)	–	+
C. ambiguus (Peyron, 1877)	+	+
C. elegans (Olivier, 1790)	+	+
C. falcifer (Abeille de Perrin, 1882)	–	+
C. geniculatus (Germar, 1824)	+	+
C. marginellus (Olivier, 1790)	+	+
C. spinipennis (Germar, 1824)	–	+
Anthocomus bipunctatus (Harrer, 1784)	+	+
A. coccineus (Schaller, 1783)	+	+
A. fasciatus (Linnaeus, 1758)	+*	+
Attalus analis (Panzer, 1796)	+	+
Ebaeus appendiculatus Erichson, 1840	+	+
E. ater Kiesenwetter, 1863	+**	?
E. coerulescens Erichson, 1840	–	+
E. flavicornis Erichson, 1840	+	+
E. pedicularis (Fabricius, 1777)	+	?
Axinotarsus marginalis (Castelnau, 1840)	+	+
A. pulicarius (Fabricius, 1775)	+	+
A. ruficollis (Olivier, 1790)	+	+
Sphinginus coarctatus (Erichson, 1840)	–	+***
Total	24	36

Note: * – collection of the State Natural History Museum, Lviv, Ukraine, ** – collection of the Zoological Museum of the Taras Shevchenko National University of Kyiv, Ukraine, *** – collection of the Matra Museum, Gyongyos, Hungary.

Apalochrus femoralis Erichson, 1840 is a species with disjunctive range: western and southern parts of Central Europe, the Volga region, and Eastern Europe as for the first half of 20th century (Jakobson, 1905; Hicker, 1925; Greiner, 1937; Constantin, 2014). It extended its range gradually to all Central Europe and has already entered the lower foothills of the Carpathians (Mirutenko & Mateleshko, 2017), where it was not previously recorded (Fig. 1). Nowadays, the range of the species is most probably already continuous, and not disjunctive.

There is a gradual spread of the species in the foothills of the Ukrainian Carpathians along channel beds and in wetlands. This is because the typical habitats for these species are areas with grass and shrub vegetation in and around wetlands (Mirutenko & Mateleshko, 2017).

Anthomalachius strangulatus (Abeille de Perrin, 1885) is distributed across the territory of Central-South Europe and also Iran (Jakobson, 1905; Greiner, 1937; *Clanoptilus strangulatus* (Abeille, 1885) in GBIF Secretariat (2022), GBIF Backbone Taxonomy, Checklist. doi: 10.15468/39omei) to North. Now the species is distributed in Europe except the Iberian Peninsula, Scandinavia, Baltic regions (Mayor, 2007), and in Central Asia (Tshernyshev, 2009) (Fig. 2). And, if the data on the distribution in south-west of Russia, east and south of Ukraine can be explained by a lack of data for the beginning of the 20th century, then it is evident that there is an expansion of the species to the northern parts of the Central and Western Europe region (Northern Germany, Czech Republic, Slovakia, Poland, west of Ukraine).

Clanoptilus spinipennis (Germar, 1824) had a North- and East Mediterranean range in the early twentieth century (Jakobson, 1905; Hicker, 1925; Greiner, 1937). But, by the end of the century, it had extended to

Central and Eastern Europe (North Macedonia, Poland, Romania, Ukraine, south-western part of Russia) (Mayor, 2007) including the Carpathian region (Southern and Eastern Carpathians) (Mirutenko, 2002) (Fig. 3).

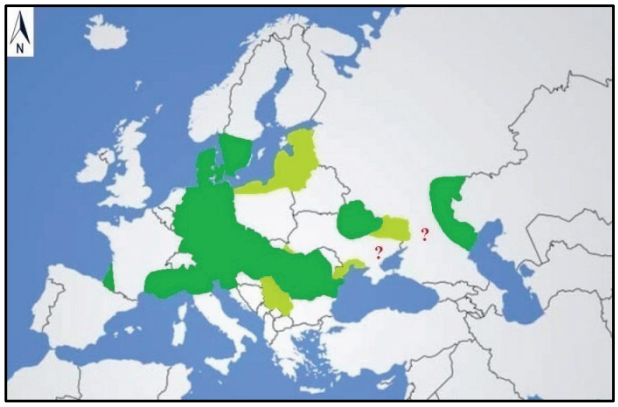

Fig. 1. Range expansion of *Apalochrus femoralis* (here and after: dark green colour is well-known regions (countries) of the species distribution as of the first half of 20th century, light green colour is an extension of the range to the current time; question mark indicates regions of probable species distribution for which there are no published data)

Fig. 2. Range expansion of *Anthomalachius strangulatus*: * – territory of Iran is marked on the map completely, since there is no reliable information about the detailed species occurrence in this region (Mirutenko & Ghahari, 2016), and distribution cited as "Persia" (Jakobson, 1905)

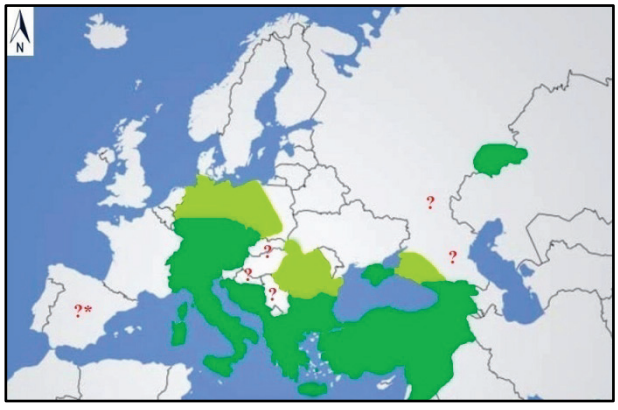

Fig. 3. Range expansion of *Clanoptilus spinipennis*: * – the distribution in Spain was mentioned by E. Abeille de Perrin (Abeille de Perrin, 1890), however, it was not confirmed in the subsequent years

Clanoptilus falcifer (Abeille de Perrin, 1882) expanded its range from Central and South-Eastern Europe, the Caucasus and Asia Minor (Abeille de Perrin, 1890; Jakobson, 1905; Hicker, 1925; Greiner, 1937) to Greece, Eastern Turkey (Yildirim & Bulak, 2012), and into the Eastern Carpathians in Ukraine also (Mirutenko, 2002) (Fig. 4).

Fig. 4. Range expansion of *Clanoptilus falcifer*

From the late 19th century to the middle of 20th century *Malachius scutellaris* Erichson, 1840 was distributed in Central Europe (Peyron, 1877; Abeille de Perrin, 1890; Jakobson, 1905; Hicker, 1925; Greiner, 1937). However, by the end of the 20th century the species had expanded to the East, and for nowadays it is known in Latvia, Lithuania, Turkey, Syria (Mayor, 2007), in the south and east of Ukraine, as well as in the south-western part of Russia (Mirutenko & Kravchenko, 2011) (Fig. 5).

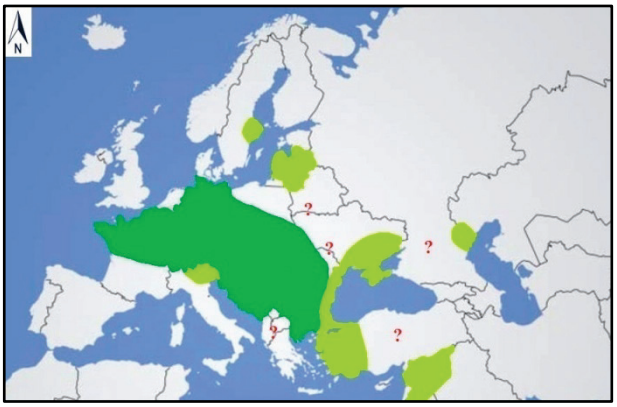

Fig. 5. *Range expansion of Malachius scutellaris*

Discussion

Changes in the composition of the fauna of different territories occur against the background of a gradual increase in average annual air temperatures. Over the last century, the average global temperature on the planet has increased by about 0.8 ºC (IPCC, 2007). The Carpathian region is no exception (Micu et al., 2021). The data of multi years' climate observation carried out by the Transcarpathian Regional Centre of Hydrometeorology indicate the increase of average air temperature in the foothills of the Transcarpathian region, also (Fig. 6).

Long-term data indicate the increase of the average annual air temperature in the foothills of the Ukrainian Carpathians by 1.7 °C from the late 1950s (1955–1959) to the present (2013–2017) (see trend line). Also, it should be noted that during the last 12 years the average annual temperature has not been below 10 °C. While there were only two similar years in the 1950s.

Speed of metabolism, biological activity, and phenology of insects, and in particular beetles, as poikilothermic animals depend on environment temperature (Logan et al., 2006; Régnière et al., 2012). The effect of global temperature increase on expansion of species ranges was demonstrated by Chen et al. (2011). Species react to climate changes by shifts of their latitudinal and elevational spreading. The average speed of species elevational shift is 11.0 m per decade, and the northward latitudinal shift is 16.9 km per decade (Chen et al., 2011). However, the rate of spread of a species depends on the ecological characteristics of the species, the availability of suitable habitats in new territories, the availability of a trophic base, and other ecosystem factors.

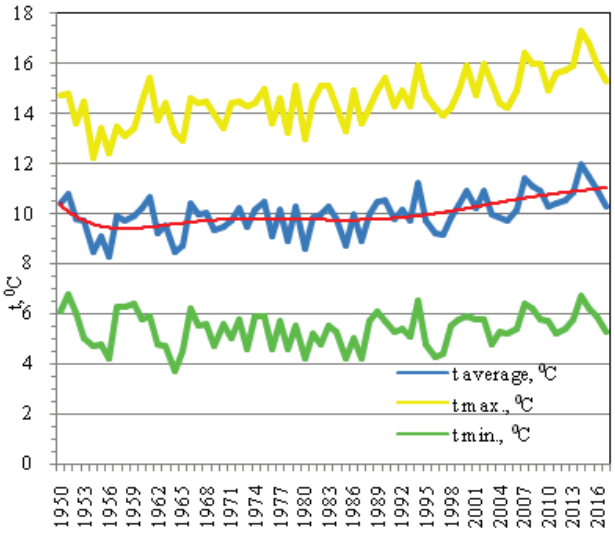

Fig. 6. Fluctuations of annual air temperatures in Uzhhorod town (foothills) from 1950 to 2017 (red line is a trend line)

Most of the soft-winged beetles are anthophilic insects. Their life cycles, flight periods, and distribution are closely tied to a periods of host plant phenology. In recent years, the acceleration of plant phenophases is attributed to increasing air temperatures. In turn, the earliest appearance of beetle imagoes is evidently attributed to a combination of shifts in plant phenophases and an acceleration of the metamorphosis processes during individual life stages. The speed of these processes directly depends on the sum of effective temperatures.

In our opinion, the expansion of the species ranges and penetration of new species into the Carpathian region from surrounding areas can be attributed to climate change, particularly warming. This hypothesis confirmed by the multi year air temperature data provided by the Transcarpathian Centre of Hydrometeorology (Fig. 6). In mountainous ecosystems, the increase in average annual temperatures results in upward movement of ranges of species' elevational gradients.

For Malachiinae beetles the possibility of expansion into new territories by transport or with agricultural products can be excluded, since these species are neither synanthropic nor pests of cultivated plants.

Conclusions

Data comparison relating to species distribution shows that the Carpathian fauna during the second half of the 20th century was enriched by the species of Mediterranean, South European, Central-East European origin. At the same time, some species from the Central European and Carpathian regions have spread beyond their borders.

Some species of soft-winged beetles have expanded their ranges. Southern European and Mediterranean (e.g. *A. strangulatus*, *C. spinipennis*), Central-East European (e.g. *C. falcifer*, *A. femoralis*) Malachiinae species were added to a list of the Carpathian fauna. Conversely, some species (e.g. *M. scutellaris*) have spread beyond the Central European and the Carpathian regions to the East and North. Obviously, expansion of species ranges and penetration of new beetle species into the Carpathian region from surrounding areas are related to the climate changes, in particular to warming. Climate changes have caused changes in insect communities. Through the study of entomological museum collections, we can observe a certain evolution of beetle communities in the composition of the fauna of the Carpathian region.

A part of the studies in the Slovak National Museum-Natural History Museum, Bratislava (March–May, 2017) has been conducted under the financial support of the Slovak Academic Information Agency in the framework of the National Scholarship Programme of the Slovak Republic for the Support of Mobility of Students, PhD Students, University Teachers, Researches and Artists. Work with the beetles' collection of the Department of Entomology, National Museum, Prague, Czech Republic was carried out by Vladyslav Mirutenko in a framework of the Visegrad Scholarship Program for Post-Master's scholarship. The processing of the collection of the National Museum of Bosnia and Herzegovina was carried out by Vladyslav Mirutenko with the assistance of the British Entomological and Natural History Society under financial support of the Professor Hering Memorial Research Fund.

The authors are grateful to Volodymyr Rizun (the State Museum of Natural History, L'viv, Ukraine), Mykola Biliashivskyi (the Zoological Museum of the Taras Shevchenko National University of Kyiv, Ukraine), Vladimir Jansky (the Slovak National Museum-Natural History Museum, Bratislava, Slovakia), Jiří Hájek (Department of Entomology, National Museum, Prague, Czech Republic), Dejan Kulijer (the National Museum of Bosnia and Herzegovina, Sarajevo, Bosnia and Herzegovina) for the possibility to work on entomological collections, and to staffs of the Transcarpathian Regional Centre of Hydrometeorology (Uzhhorod, Ukraine) for the provided long-term air temperature data.

We also thank Dr. Lizzie Abderrahim (Department of English and German Studies, the Universitat Rovira i Virgili, Tarragona, Spain) for linguistic revision of the text.

References

Abeille de Perrin, E. (1890). Malachides d'Europe et pays voisins [Malachids of Europe and neighboring countries]. Annales de la Societe entomologique de France, Série 6(10), 181–680 (in French).

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J. C., Farrar, J., Good, J. E. G., Harrington, R., Hartley, S., Jones, T. H., Lindroth, R. L., Press, M. C., Symnioudis, I., & Watt, A. D. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. Global Change Biology, 8, 1–16.

Burakowski, B., Mroszkowski, M., & Stefańska, J. (1986). Chrząszcze (Coleoptera) Dermestoidea, Bostrichoidea, Cleroidea i Lymexyloidea [Beetles (Coleoptera) of Dermestoidea, Bostrichoidea, Cleroidea and Lymexyloidea]. In: Burakowski, B. (Ed.). Katalog fauny Polski [Catalogue of Polish fauna]. Panstwowe Wydawnictwo Naukowe, Warszawa. Vol. 23(11). Pp. 143–187 (in Polish).

Chen, I.-C., Hill, J., Ohlemüller, R., Roy, D., & Thomas, C. (2011). Rapid range shifts of species associated with high levels of climate warming. Science, 333(6045), 1024–1026.

Constantin, R., (2014). Malachiidae: In: Tronquet, M. et al. (Eds.). Catalogue des Coléoptères de France. Association Roussillonnaise d'Entomologie edition, Perpignan. Pp. 472–477 (in French).

Couet, J., Marjakangas, E. L., Santangeli, A., Kålås, J. A., Lindström, Å., & Lehikoinen, A. (2022). Short-lived species move uphill faster under climate change. Oecologia, 198, 877–888.

Fleck, E. (1906). Die Coleopteren Rumaniens [Coleoptera of Romania]. Buletinul Societătei de Sciinte, 13–15(3–4), 176–179 (in German).

Greiner, J. (1937). Fam. Malachiidae. Pars 159. In: Junk, W., & Schenkling, S. (Eds.). Coleopterorum Catalogus. s'-Gravenhage, Junk, Berlin. Pp. 3–169.

Hicker, R. (1925). Malacodermata. In: Winkler, A. (Ed.). Catalogus Coleopterorum Regionis Palaearcticae. Winkler & Wagner, Wien. Pp. 524–562.

Holecová, M., & Zach, P. (1996). Prehľad fauny chrobákov (Coleoptera) žijúcich na duboch na území Slovenska [Overview of the beetle fauna (Coleoptera) living on oaks in Slovakia]. Folia Faunistica Slovaca, 1, 39–52.

Holtman, J., Jászay, T., & Mirutenko, V. (2014). Malachiidae a Dasytidae (Coleoptera) na Slovensku [Malachiidae and Dasytidae (Coleoptera) in Slovakia]. Folia Faunistica Slovaca, 19(3), 299–311 (in Slovak).

Hormuzaki, C. (1888). Beiträge zur Käferfauna der Bucovina und Nordrumänîens [Contributions to the beetle fauna of Bucovina and northern Romania]. Entomoligische Nachrichten, 7, 108 (in German).

Horvátovich, S. (1969). A kárpátmedencei lágytestű bogarak (Col., Malacodermata) faunisztikai és fenológiai adatai [Faunal and phenological data of soft-winged beetles (Col., Malacodermata) of the Carpathian Basin]. Rovartani Közlemények, 22(8), 131–249 (in Hungarian).

Hulme, P. E. (2017). Climate change and biological invasions: Evidence, expectations, and response options. Biological Reviews, 92(3), 1297–1313.

IPCC (2007). Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the Fourth assessment report of the intergovernmental panel on climate change. IPCC, Geneva.

Irmler, U. (2022). Seasonal shift in carabid phenology over a period of 18 years. European Journal of Entomology, 119, 183–190.

Jakobson, G. (1905). Zygiidae (Melyridae, Malachiidae). In: Jakobson, G. Zhuki Rossii i Zapadnoj Evropy. Izdatelstvo A. F. Devriena, Saint Petersburg. Pp. 687–712 (in Russian).

Jaworski, T., & Hilszczański, J. (2013). The effect of temperature and humidity changes on insects development their impact on forest ecosystems in the context of expected climate change. Leśne Prace Badawcze, 74(4), 345–355.

Khaliq, A., Javed, M., Sohail, M., & Sagheer, M. (2014). Environmental effects on insects and their population dynamics. Journal of Entomology and Zoology Studies, 2(2), 1–7.

Kolibáč, J., Majer, K., & Švihla, V. (2005). Beetles of the superfamily Cleroidea in the Czech and Slovak Republics and neighbouring areas. Clarion Production, Prague.
Logan, D., Wolesensky, W., & Joern, A. (2006). Temperature-dependent phenology and predation in arthropod systems. Ecological Modelling, 196(3–4), 471–482.
Łomnicki, A. M. (1882). Sprawozdanie z wicieczki entomologiczkej w gory Stryiskie, w r. 1880 [Report from the entomological survey in Mount Striskie, in 1880]. Krakow (in Polish).
Łomnicki, M. A. (1884). Catalogus Coleopterorum Haliciae. Custodis Musaei Dzieduszyckiani, Leopoli.
Łomnicki, M. A. (1913). Wykaz chrząszczów czyli Tęgopokrywych (Coleoptera) ziem polskich [List of beetles, i.e. Coleoptera, of Polish lands]. Catalogus Coleopterorum Poloniae, Kosmos, Seria A – Biologia, 38, 90–91 (in Polish).
Mayor, A. (2007). Family Dasytidae, Malachiidae. In: Löbl, I., & Smetana, A. (Eds.). Catalogue of Palaearctic Coleoptera. Apollo Books, Stenstrup. Vol. 4. Pp. 388–455.
Merkl, O. (2008). Data to the knowledge on the beetle fauna of Maramures, Romania (Coleoptera). Studia Universitatis "Vasile Goldis", Seria Stiintele Vietii, 18(suppl.), 243–311.
Merkl, O., Makranczy, G., Németh, T., Podlussány, A., & Szél, G. (2011). Further data to the beetle fauna of Maramureş, Romania (Coleoptera). Studia Universitatis "Vasile Goldiş", Seria Ştiinţele Vieţii, 21(4), 861–876.
Merkl, O., Németh, T., & Podlussány, A. (2016). Beetles from Sălaj county, Romania (Coleoptera, excluding Carabidae). Studia Universitatis "Vasile Goldiş", Seria Ştiinţele Vieţii, 26(suppl. 1), 5–58.
Micu, D. M., Dumitrescu, A., Cheval, S., Nita, I.-A., Birsan, M.-V. (2021). Temperature changes and elevation-warming relationships in the Carpathian Mountains. International Journal of Climatology, 41, 2154–2172.
Mirutenko, V. (2002). Novi dlia fauny Ukraiins'kyh Karpat vydy malashok (Coleoptera, Malachiidae) [New malachiid-beetle species (Coleoptera, Malachiidae) for fauna of the Ukrainian Carpathians]. Proceedings of the International Conference "Hory i liudy (u konteksti staloho rozvytku)" ["Mountains and People (in the context of sustainable development)"]. Rakhiv. Vol. 2. Pp. 408–411 (in Ukrainian).
Mirutenko, V. (2010). Ohliad zhukiv rodyn Malachiidae i Dasytidae (Insecta: Coleoptera) Ukraiins'kyh Karpat i Zakarpats'koi nyzovyny [A review of beetles of families Malachiidae and Dasytidae (Insecta: Coleoptera) of the Ukrainian Carpathians and Transcarpathian Lowland]. Ukrainska Entomofaunistyka, 1(1), 1–21 (in Ukrainian).
Mirutenko, V., & Kravchenko, O. (2011). Faunisticheskij obzor zhukov semejstva Malachiidae (Insecta: Coleoptera) Levoberezhnoji Ukrajiny [Faunistic review of the malachiid beetles (Insecta: Coleoptera) of Left-Bank Ukraine]. The Kharkov Entomological Society Gazette, 19(2), 31–37 (in Russian).
Mirutenko, V., & Ghahari, H. (2016). An annotated checklist of Malachiidae (Coleoptera: Cleroidea) from Iran. Zootaxa, 4162(2), 331–346.
Mirutenko, V., & Mateleshko, O. (2017). The first records of *Apalochrus femoralis* (Coleoptera, Malachiidae) from the Western Ukraine. Ukrainska Entomofaunistyka, 8(2), 9–10.
Nowicki, M. (1873). Beiträge zur Insektenfauna Galiziens [Contributions to the insect fauna of Galicia]. Jagellonische Univesitäts-Buchdruckerei, Krakau, 7–9, 29–30 (in German).
Oszlányi, J., Grodzińska, K., Badea, O., & Shparyk, Y. (2004). Nature conservation in Central and Eastern Europe with a special emphasis on the Carpathian Mountains. Environmental Pollution, 130(1), 127–134.
Peyron, M. (1877). Etude sur les Malachiides d'Europe et du Bassin de la Méditerranée [Study on the Malachiids of Europe and the Mediterranean Basin]. L'Abeille, Journal d'Entomologie, 15, 25–312 (in French).
Pozsgai, G., Baird, J., Littlewood, N. A., Pakeman, R. J., & Young, M. R. (2018). Phenological changes of the most commonly sampled ground beetle (Coleoptera: Carabidae) species in the UK environmental change network. International Journal of Biometeorology, 62, 1063–1074.
Régnière, J., Powell, J., Bentz, B., & Nealis, V. (2012). Effects of temperature on development, survival and reproduction of insects: Experimental design, data analysis and modeling. Journal of Insect Physiology, 58, 634–647.
Roubal, J. (1926). Zur Käferfauna von Ost-Karpaten (Černá Hora) [On the beetle fauna of the Eastern Carpathians (Chorna Hora)]. Entomologische Blätter, 22(1), 10–13 (in German).
Roubal, J. (1936). Katalog Coleopter (brouků) Slovenska a Podkarpatska [Catalogue of Coleoptera (beetles) of Slovakia and Subcarpathia]. Praha. Vol. 2. Pp. 17–28 (in Czech).
Shparyk, V., & Sirenko, A. (2005). Dopovnennia do fauny Malachiidae (Coleoptera, Insecta) Karpat i Prykarpattia [Additions to the fauna of Malachiidae (Coleoptera, Insecta) of the Carpathians and Ciscarpathian]. Bulletin of the Precarpathian National University, Biology, 5, 14–15 (in Ukrainian).
Szafraniec, S., Szafraniec, P., & Mazur, M. (2010). *Malachius scutellaris* Erichson, 1840 and some other interesting species of Melyridae (Coleoptera: Cleroidea) from the Western Beskidy Mts. Opole Scientific Society Nature Journal, 43, 95–100.
Szalóki, D., & Merkl, O. (2005). A new soft-winged flower beetle in the Hungarian fauna, with a national checklist of Malachiidae (Coleoptera). Folia Entomologica Hungarica, 66, 95–100.
Tobin, P. C., Parry, D., & Aukema, B. H. (2014). The influence of climate change on insect invasions in temperate forest ecosystems. In: Fenning, T. (Eds.). Challenges and opportunities for the world's forests in the 21st century. Forestry Sciences. Vol. 81. Springer, Dordrecht.
Tshernyshev, S. E. (2009). Anthomalachius, a new genus of soft-winged flower beetles (Coleoptera, Malachiidae: Malachiinae). Zootaxa, 2094, 23–35.
Viznovych, V., & Zamoroka, A. (2022). The northward range shifting of *Agapanthiola leucaspis* under the climate change. Journal of Vasyl Stefanyk Precarpathian National University, 9(4), 33–41.
Yildirim, E., & Bulak, Y. (2012). A contribution to the knowledge of the Malachiidae (Coleoptera: Cleroidea) fauna of Turkey. Turkish Journal of Entomology, 36(2), 231–238.