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THE NORTHWARD RANGE SHIFTING OF AGAPANTHIOLA LEUCASPIS UNDER THE CLIMATE CHANGE

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Abstract. *Agapanthiola leucaspis* is a steppe transpalearctic cerambycid species, widely distributed from the Pannonian lowland in Europe to the Mongolian plateau in Asia. In Ukraine, the species was previously known from the Pontic Plains and the Crimean Peninsula. However, in the last decade, a number of new localities of *A. leucaspis* have been discovered far outside the original range. We previously hypothesized a possible link between the northward spread of *A. leucaspis* and the current climate change. In this paper, we tested this hypothesis using computer simulations with GIS technologies. Our primary objective was to determine the critical value of key climatic factors that could potentially trigger the northward and montane range expansion of *A. leucaspis.* We collected all available data, including our own materials, scientific collections, published scientific papers, and citizen science data on the distribution of *A. leucaspis* in Ukraine and neighboring countries. These data were separated by the time of records before 2000 and after 2000 according to the change of the current understanding of climatic norm of 1950-2000 due to global warming. As a result, we determined the ecological valency of *A. leucaspis* in relation to climatic factors and built a model of its original range. Further simulations were associated with a +2.0°C change in global temperature parameters in 0.5°C increments and a 30% increase and decrease in precipitation in 10% increments. Resultantly, we found that the amount of precipitation and the seasonality of temperatures, especially in winter, are crucial factors for the observed fluctuation of *A. leucaspis* range. An increase in average temperatures eliminates the winter frosts which are limiting factor for the spread of *A. leucaspis* to the north. The decrease in average annual precipitation increases the probability of the species survival in areas where this was previously impossible. We have shown that to expand the current range of *A. leucaspis*, it is enough to warm the climate in the annual average by +0.5°C and reduce the amount of precipitation by 10%. A warmer and drier climate is the main abiotic factor for the expansion of *A. leucaspis* into higher latitudes and mountains.

Keywords: Cerambycidae, biological invasions, biogeography, climate changes, modeling, GIS-technologies.

1. INTRODUCTION

Climate changes affect ecosystems, altering them via the changes in species composition. These cause biological invasions that have affected both autochthonous biota and human economic activity (Zamoroka, 2017). One of these species is *Agapanthiola leucaspis* (Steven, 1817), a steppe longhorn beetle, whose range has begun to change as global warming progresses (Zamoroka & Hleba, 2019).

Until the present, *A. leucaspis* was known only from the Pontic steppes in Bessarabia, Crimea, coastal lowlands of Black Sea and Sea of Azov (Zahajkevych, 1991; Bartenev, 2009; Zamoroka & Hleba, 2019; Zamoroka, 2022). However, in the last decade, the species was registered outside the known range in the central, northern and western parts of Ukraine (Zamoroka & Hleba, 2019). Such range expansion may have negative consequences for both natural ecosystems and economic (especially agricultural) activities in Ukraine, as *A. leucaspis* is polyphagous on herbaceous plants, including wild, agricultural and ornamental plants.

In order to establish the critical threshold value of the climatic driver that triggered the process of expansion of the range of *A. leucaspis,* as well as predicting its future changes, we conducted simulations using modern GIS technologies. As a result, we built a model of the original range of A. leucaspis, which existed before the onset of modern climate change. We also produced predictions of the distribution of *A. leucaspis* with an increase in average temperatures by 0.5–1.0–1.5–2.0°C and with a change in the amount of precipitation both in the direction of increase and in the direction of decrease by 10–20–30%.

2. THEORETICAL BACKGROUND

Climate change is a long-term and permanent process that is characterized by statistically significant changes in average weather conditions over a significant period of time. The reasons of climate change are complex and include many factors, among which the following can be distinguished: solar activity, meteor showers, cosmic gas and dust clouds, cyclical changes in the Earth's orbit (Milankovich cycles), movement of tectonic plates, oceanic conveyor, volcanic activity, biosphere and human activity (Milankovitch, 1998; Kaufman et al, 2009; Ganopolski et al., 2016).

Over the past 30 years, the average annual and average seasonal temperature on the territory of Ukraine exceeded the climatic norm of 1961-1990. The climatic norm for Ukraine is an average annual temperature of 7.98°C and an average annual precipitation of 614 mm. During 1991-2010, an increase in the temperature of the lower layer of the troposphere was recorded in Ukraine by 0.8°C, or by 10% of the norm, and the amount of precipitation during this period increased by 19.0 mm, or by 3.1% of the norm (Osadchyi & Babichenko, 2013; Shevchenko et al., 2014; Savchuk et al., 2020). According to data from the Borys Sreznevskyi Central Geophysical Observatory (CGO, n.d.), over the 11-year period (2010-2020) in Ukraine, the average temperature of the lower layer of the troposphere increased by 1.86°C or by 23.3% to the norm, and the precipitation decreased by 37 mm or 6% from the norm. The warming has accelerated, the climate has become warmer and a little drier.

3. RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The algorithm of our study included: 1) collection of raw data from field studies, entomological collections and open sources; 2) arrangement of data and preparation of the input matrix; 3) statistical processing and GIS modeling; 4) interpretation of the obtained research results.

The input matrix was prepared using MS Office 2019 Excel spreadsheets in the following format: ID – unique identifier for each individual record; Lat. – geographic coordinate of northern latitude in decimal format; Lon. – geographic coordinate of eastern longitude in decimal format; Locality – the name of the locality where the species was found; Date – year, month and date of the record. In addition, we used open data on the distribution of *A. leucaspis* in neighboring countries: Slovakia, Hungary, Romania, Moldova and Russia.

Modeling was conducted using free software DIVA-GIS for mapping biological data based on geographic information systems (GIS) technologies. For this, climatic data Worldclim v.1.3 was downloaded from the official website (http://www.diva-gis.org) for the 1950-2000 climate norm with a resolution of 2.5 geographic minutes. A GIS map of the territory of Ukraine with administrative subdivision has also been uploaded. The materials uploaded to the program were saved as a shapefile containing a geocoded map and an input matrix. Pre-2000 and post-2000 distribution maps of *A. leucaspis* were created in two separate layers, displayed with different colors and different dot shapes.

Modeling of the original range of *A. leucaspis* was conducted using Ecological Niche Modeling (ENM) tool. The following bioclimatic indicators were used for modeling: 1 – Annular mean temperature; 2 – Mean monthly temperature range; 3 – Isothermality (2/7)(*100); 4 – Temperature seasonality (STD*100); 5 – Max temperature of warmest month; 6 – Min temperature of coldest month; 7 – Temperature annual range (5-7); 8 – Mean temperature of wettest quarter; 9 – Mean temperature of driest quarter; 10 – Mean temperature of warmest quarter; 11 – Mean temperature of coldest quarter; 12 – Annual precipitation; 13 – Precipitation of wettest month; 14 – Precipitation of driest month; 15 – Precipitation Saesonality (CV); 16 – Precipitation of wettest quarter; 17 – Precipitation of dries quarter; 18 – Precipitation of warmest quarter; 19 – Precipitation of coldest quarter. Modeling of the climatic changes affecting on *A. leucaspis* range dynamics was carried out by setting the amplitude of climatic values in increments of +0.5°C (for temperature indicators) and +10% or –10% (for precipitation indicators). The following coordinates were used to display the coverage value of the territory of Ukraine: Xmin=22.47, Xmax=40.22, Ymin=42.80, Ymax=53.21.

4. RESULTS AND DISCUSSION

As a result of the modeling of the ecological niche, it was possible to determine the ecological valence of *A. leucaspis* (Fig. 1), which is characterized by a temperature optimum within the range of 9-12°C and an optimum of average annual precipitation within 450-550 mm. Our results show that only 10% of *A. leucaspis* sites known before 2000 reached the 7°C isotherm (Fig. 1a); isotherm 9°C – 15%; isotherm 10°C – 15%. Whereas 25% of cases reached the 11°C isotherm and 35% – 12°C isotherm. From the rank analysis (Fig. 1c), it can be seen that 4 cases were recorded in the temperature range of 6.6-7.7°C, 5 – in the range of 8.8-9.9°C; 6 – within 7.7-8.8°C; 13 – in the range of 9.9-11°C and 18 cases – in the range of 11.1-12.1°C.

Regarding average annual precipitation, only 5% of all known *A. leucaspis* records occur on the 400 mm isohyet (Fig. 1b); 35% – on the isohyet of 500 mm; 30% – on the isohyet of 600 mm; 10% on the isohyet of 700 mm; the remaining 10% are cases of isohyets less than 400 mm and more than 700 mm. The rank analysis (Fig. 1d) showed that 8 cases were recorded in the range of average annual precipitation of 352-432.8 mm, 12 cases - 432.8-513.6 mm; 15 cases – 513.6-594.4 mm; 7 cases – 594.4-675.2 mm; 4 cases - 675.2-756 mm.

Multidimensional converting (Fig. 1e) shows the distribution of occurrences of *A. leucaspis* in the space of ecological dimensions of average annual precipitation and average annual temperatures. The centroid indicates the cases that are within the ecological optimum of the species, grouping the points colored in green. Other points colored red show cases that are outside the optimum, in the pessimum. Bioclimatic analysis (Fig. 1f) of the ecological niche of *A. leucaspis* showed that the most limiting factors (numbers on the graph in Fig. 1f explained in the methods) for it are: Temperature seasonality (4); Annual precipitation (12); Precipitation of wettest quarter (16); Precipitation of dries quarter (17); Precipitation of warmest quarter (18); Precipitation of coldest quarter (19).

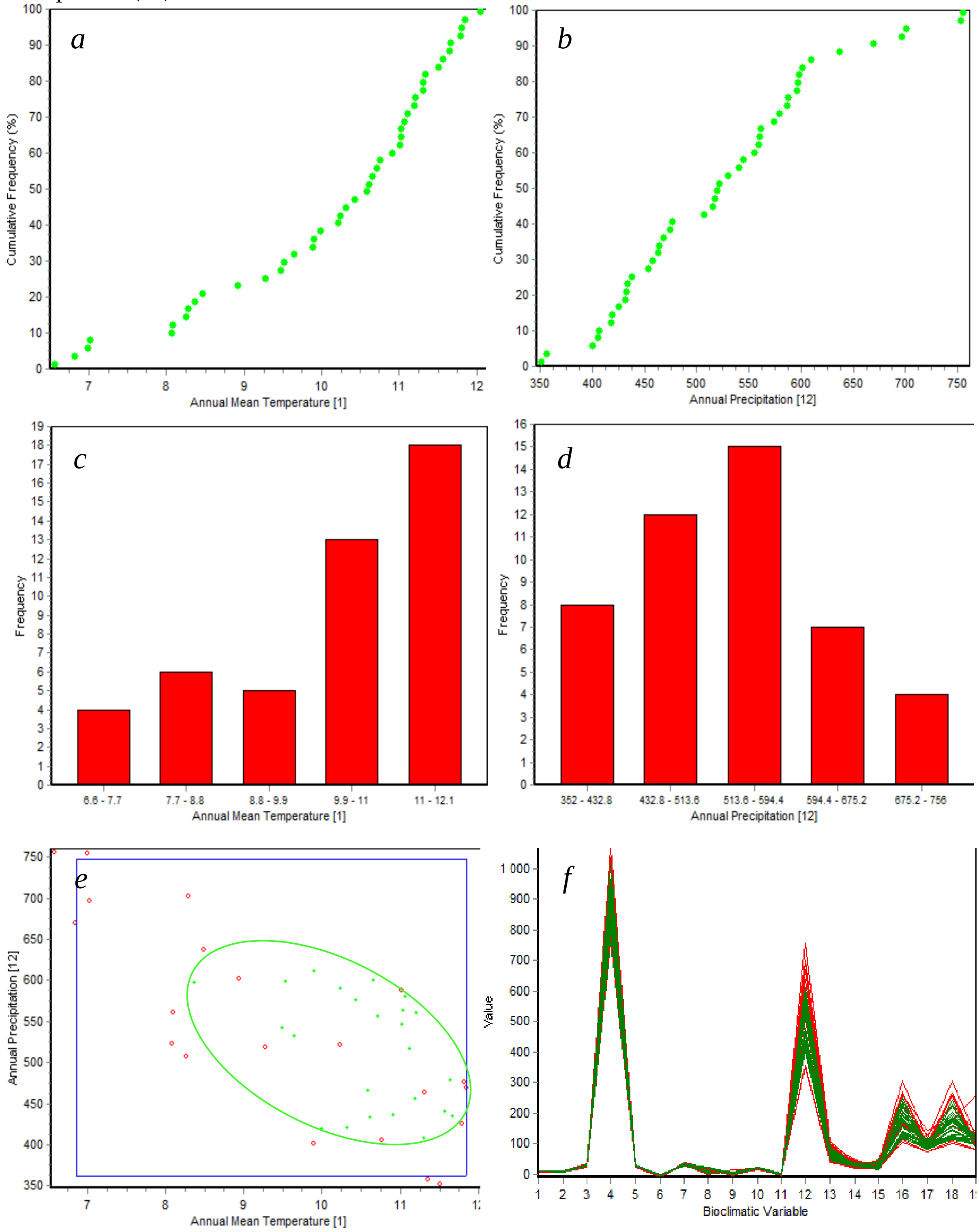

Fig. 1. Characteristics of the ecological niche of A. leucaspis: cumulative frequency of occurrence of the species according to the average annual temperature (a) and amount of precipitation (b); ranked frequency of occurrence of the species by average annual temperature (c) and amount of precipitation (g); multidimensional converting of environmental variables (d); bioclimatic characteristics of the habitat (f)

From the analysis of the ecological niche of *A. leucaspis*, it follows that the northern limit of the original range of the species in Ukraine coincided with the +8°C isotherm and the 550 mm isohyet. These indicators are the approximate boundary between forest-steppe subbiome and steppe biome. A very few known records of *A. leucaspis* outside of this limit indicate local microclimatic conditions rather than a general trend. Based on the obtained results, we modeled the original range of *A. leucaspis* under the climatic norm of 1950-2000 (Fig. 2).

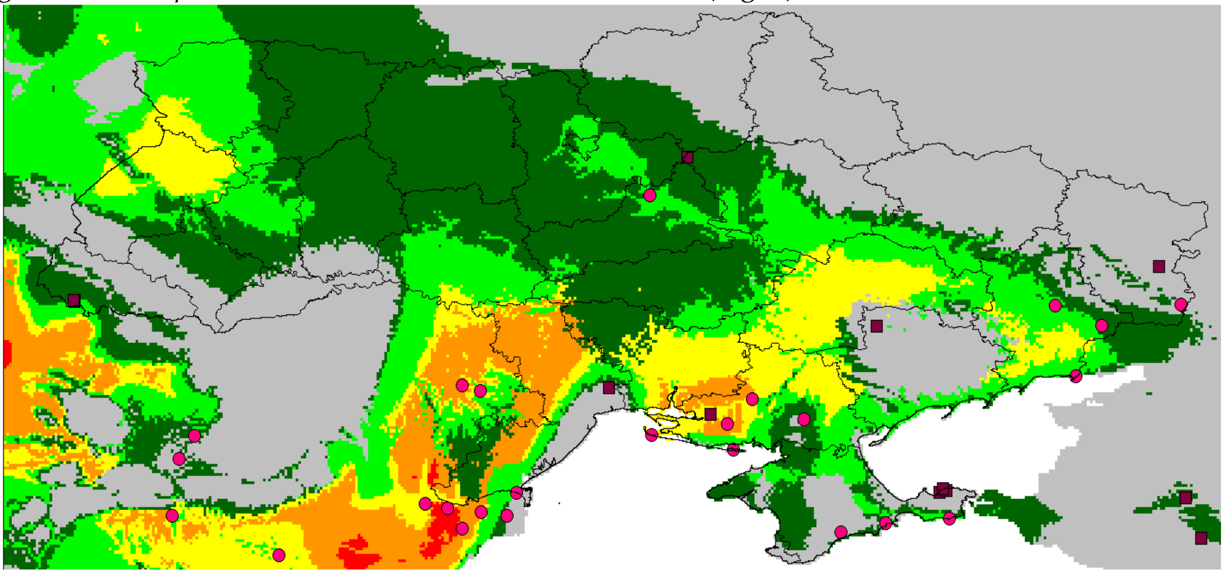

Fig. 2. Model of the suitability of environmental conditions for the original range of A. leucaspis according to the climatic norm of 1950-2000: gradient from dark green (low, 0-2.5 percentiles) to red (excellent 20-50 percentiles); circles – records of the species before 2000; squares – records of the species after 2000

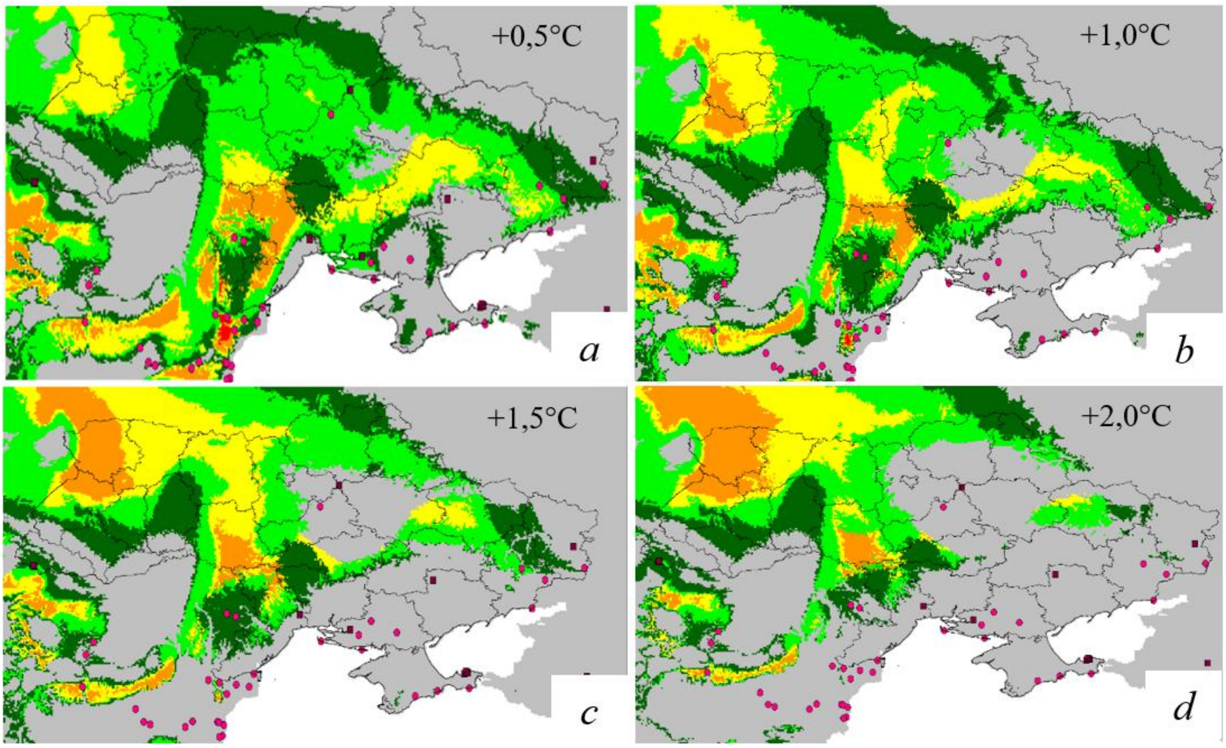

Fig. 3. The models of the range shifting of A. leucaspis under the conditions of temperature change of +2°C with a step of +0.5°C

As a result of modeling, it was possible to establish that the most favorable conditions for the existence of *A. leucaspis* in Ukraine were: Odesa Region, part of Mykolaiv and Kherson Regions

(Fig. 2). This range coincided with the steppe biome. Yellow and orange colors on the map indicate a high and very high probability of the existence of *A. leucaspis* populations in these areas.

Since over the last two decades *A. leucaspis* was found far beyond its original range: in the Chernihiv and Transcarpathian Regions, we tested the hypothesis about the influence of global climate changes on the expansion of the species in Polissya and the foothills of Carpathians. For this purpose, two models were created: the first predicted a climate change in average annual temperatures up to +2°C with a step of +0.5°C (Fig. 3); the second – also a change in the amount of precipitation, both in the direction of increasing and decreasing of the rainfalls (Fig. 4.).

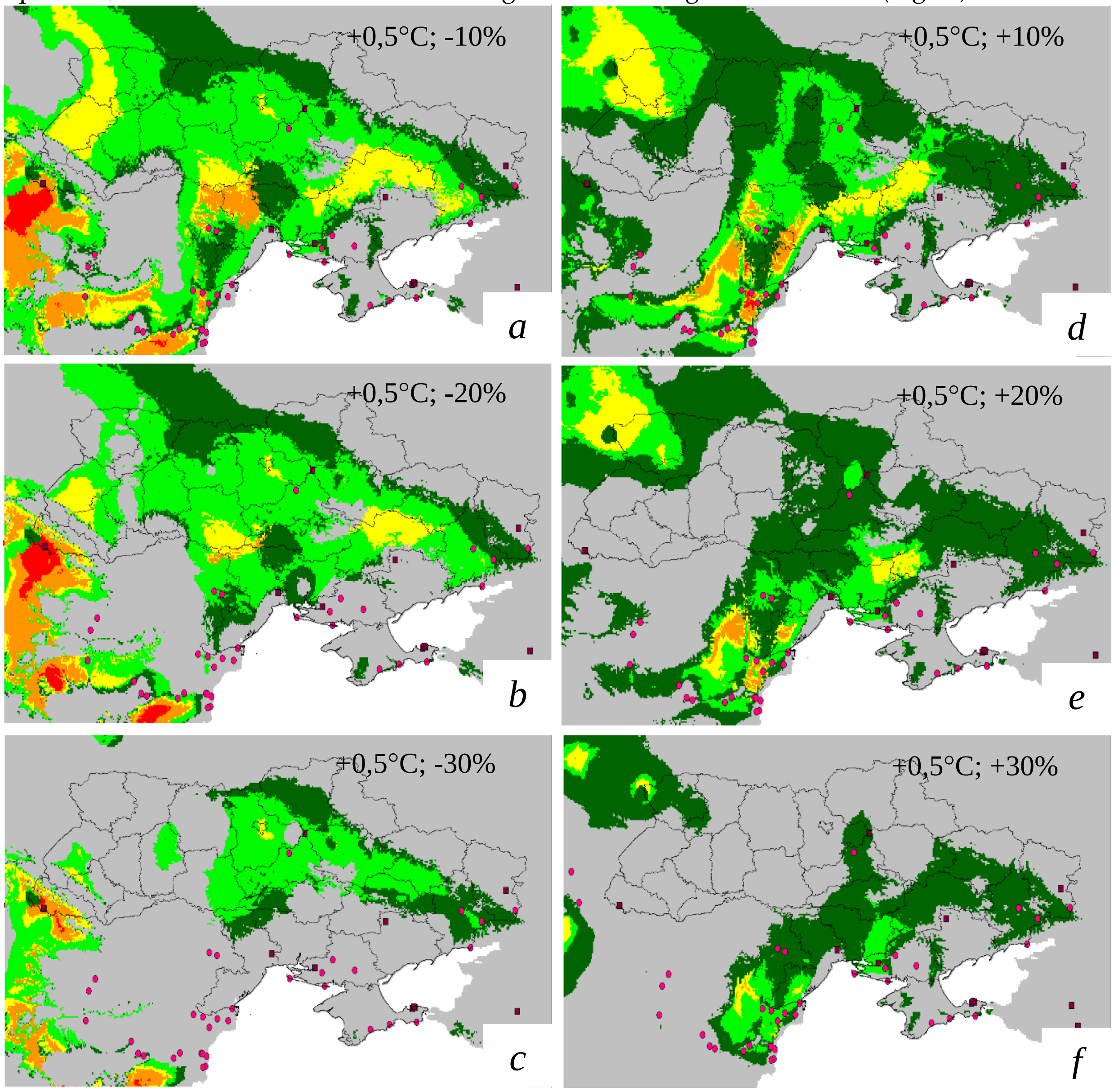

Fig. 4. The models of the range shifting of A. leucaspis under the conditions of temperature change of +0.5°C with decreasing (a-c) and increasing (d-f) of annual precipitation on 10%–20%–30%

The model demonstrates that the optimal environmental conditions for the existence of stable populations of *A. leucaspis* will change only slightly with a warming of +0.5°C (Fig. 3a), remaining close to the initial range. However, the climate warming of +1°C, favorable conditions for the existence of *A. leucaspis* shift much further north, reaching the south of Polissya (Fig. 3b). This scenario describes the already existing range change relatively well. Further climate warming may lead to unsuitable living conditions for *A. leucaspis* in southern Ukraine. Although, we assume that the preservation of the species in the south is quite possible in separate microsites with a suitable microclimate.

To fully understand the shift of the range of *A. leucaspis* under the climate changes, we conducted further modeling taking into account the possible redistribution of precipitation (Fig. 4). Here, we have given only the results for a temperature change of +0.5°C, since when the climate warms to +1.0-2.0°C with a simultaneous change in the amount of precipitation by 10-30%, the conditions become unsuitable for the existence of *A. leucaspis* on territory of Ukraine. Our models demonstrate that the consequences of changing precipitation are critical for the survival of *A. leucaspis.*

In the case (Fig 4a) of climate warming with a simultaneous decrease in precipitation by 10%, the ecological conditions for the spread of *A. leucaspis* in Ukraine become the most suitable. In all other cases (Fig 4b-f), the range should be drastically reduced to the separate refugia. The greatest impact on the range reduction is the increase in the amount of precipitation (Fig 4d-f).

Our results clearly show that the expansion of the range of *A. leucaspis* to the west and north is closely connected with the climatic changes. Our model demonstrates that the optimal environmental conditions for the existence of stable populations of *A. leucaspis* will change only slightly with a warming of +0.5°C (Fig. 3a), remaining close to the original range (Fig. 2). However, with a warming of +1°C (Fig. 3b), favorable conditions for the existence of *A. leucaspis* arise much further north, reaching the south of Polissya. This scenario describes well the current range shift. With simultaneous changes in temperature and precipitation (Fig. 4), the environmental conditions for *A. leucaspis* undergo significant fluctuations. When the climate warms up to +1.0°C and more with a simultaneous change in the amount of precipitation by 10% or more, the conditions for the existence of *A. leucaspis* on the territory of Ukraine become mostly unsuitable. Its range should be sharply reduced to the amount of small isolated refugia. The greatest impact on the range reduction is the increase in the amount of precipitation.

Based on our results and the data from CGO, it can be stated that the main factor in the expansion of the range of *A. leucaspis* to the north and west of Ukraine was the decrease in the amount of precipitation for 2010-2020 by 6%. At the same time, a noticeable expansion of the range was not observed in the previous decade (1999-2010), which can be explained by an increase in the amount of precipitation by 3.1% (Osadchyi & Babichenko, 2013; Shevchenko et al., 2014; Savchuk et al., 2020). There is no doubt that the increase in average annual temperatures is an important factor in the advance of *A. leucaspis* to higher latitudes. However, we believe that seasonal temperatures, especially average winter temperatures, are the most critical for species survival. This is well illustrated by our models, in particular the bioclimatic characteristics of the niche of *A. leucaspis* (Fig. 1f).

5. CONCLUSIONS

In summary, we determined the critical threshold value of the climatic driver that triggered the process of range expansion of *A. leucaspis*. These include, the average annual rainfall and seasonal temperature changes. Warmer winters and drier climates are responsible for the northward spread not only of *A. leucaspis*, which we studied, but also of other southern species, and responsible for natural biological invasions in general.

REFERENCES

[1] Bartenev, O. F. (2009). The longhorn beetles of Eastern Ukraine and Crimea. Karazin KNU Press. CGO (n.d.) Borys Sreznevskyi Central Geophysical Observatory. http://cgo-sreznevskyi.kyiv.ua (in Ukr.)

[2] Ganopolski, A., Winkelmann, R. & Schellnhuber, H. J. (2016). Critical insolation–CO2 relation for diagnosing past and future glacial inception. *Nature, 529*, 200–203. https://doi.org/10.1038/nature16494

[3] Kaufman, D. S., Schneider, D. P., McKay, N. P., Ammann, C. M., Bradley, R. S., Briffa, K. R., Miller, G. H., Otto-bliesner, B. L., Overpeck, J. T., Vinther, B. M., Abbott, M., Axford, Y., Bird, B., Birks, H. J. B., Bjune, A. E., Briner, J., Cook, T., Chipman, M., Francus, P., ... Thomas, E. (2009). Recent Warming Reverses Long-Term Arctic Cooling. *Science, 325(5945),* 1236–239. https://doi.org/10.1126/science.1173983

[4] Milankovitch, M. (1998). *Canon of Insolation and the Ice Age Problem* (orig. publ. 1941). Hardbound. Alven Global.

[5] Osadchyi, V. I. & Babichenko, V. M (2013). The air temperature on the territory of Ukraine in today's climate conditions. *Ukrainian Geographic Journal, 4,* 32–39.

[6] Savchuk, S. V., Tymofeiev, V. Ye., Schehlov, O.A., Artemenko, V. A. & Kozlenko, I. L. (2020). Correlation communication between meteorological parameters at extreme values of maximum air temperatures. *Hydrology, Hydrochemistry and Hydroecology, 1,* 101–112.

[7] Shevchenko, O., Vlasiuk, O., Stavchuk, I., Vakoliuk, M., Illiash, O. & Rozhkova, A. (2014). *Climate change vulnerability assessment: Ukraine.* Myflaer.

[8] Zahajkevych, I. K. (1991). *Ecology and taxonomy of Cerambycidae.* Naukova Dumka.

[9] Zamoroka, A. M. & Hleba, V. M. (2019). The first interception of Agapanthiola leucaspis (Coleoptera: Cerambycidae) in Western Ukraine and remarks on its biogeography and bionomy. *Proceedings of the State Natural History Museum, 35*, 111–118.

[10] Zamoroka, A. M. & Kapelyukh, Ya. I. (2016). Notes on the longhorn beetles (Coleoptera: Cerambycidae) of Nature Reserve "Medobory" (Ukraine). *Ukrainska entomofaunistyka, 8(4),* 50–76.

[11] Zamoroka, A. M. & Korytnianska, V. H. (2018). A new data on distribution of Trichoferus campestris in Ukraine. Materials of IX Congress of Ukrainian Entomological Society. Kharkiv, 162–163.

[12] Zamoroka, A. M. & Mateleshko, O. Yu. (2016). The first record of Calamobius filum (Coleoptera: Cerambycidae) in Western Ukraine with notes on its biology, ecology and distribution in Europe. *Proceedings of the State Natural History Museum, 37,* 113–120.

[13] Zamoroka, A. M. (2017). *The effect of global climatic changes on invasion of new animal species in Carpathian-Podillya region of Ukraine – the estimation of the possible ecological and economic consequences.* Conference materials "New prospective of scientific studies due to reestablishing of observatory on Mt. Pip Ivan", Ivano-Frakivsk – Verkhovyna, 7–8.

[14] Zamoroka, A.M. (2022). The longhorn beetles (Coleoptera, Cerambycidae) of Ukraine: Results of two centuries of research. *Biosystem diversity, 30 (1),* 46–74. https://doi.org/10.15421/012206

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Візнович Віолетта, Заморока Андрій. Зміщення ареалу Agapanthiola leucaspis на північ в умовах кліматичних змін. *Журнал Прикарпатського університету імені Василя Стефаника*, **9** (4) (2022), 33–41.

Agapanthiola leucaspis – степовий транспалеарктичний вид скрипунових, який широко розповсюджений від Паннонської низовини до Монгольського плато. В Україні вид раніше був відомим з Причорноморських рівнин та Кримського півострову. Однак в останнє десятиліття виявлено низку нових локалітетів *A. leucaspis* далеко за межами первинного ареалу. Раніше нами було запропоновано гіпотезу про можливий зв'язок між експансією *A. leucaspis* на північ та кліматичними змінами сучасності. У чинному дослідженні ми здійснили тестування даної гіпотези за допомогою комп'ютерного моделювання з використанням ГІС-технологій. Нашою основною метою було виявити критичне значення ключових кліматичних чинників, які потенційно могли стати причиною для розширення ареалу *A. leucaspis* на північ та у гори. Для цього ми зібрали усі доступні дані, включаючи наші власні дослідження, наукові колекції, опубліковані матеріали та відомості громадянської науки про розповсюдження *A. leucaspis* в межах України та сусідніх країн. Ці дані були розділені за часом знахідок до 2000-го та після 2000-го року, відповідно до теперішніх уявлень про зміну кліматичної норми внаслідок глобального потепління. В результаті досліджень ми визначили екологічну валентність *A. leucaspis* щодо кліматичних чинників і побудували модель її вихідного ареалу. Подальше моделювання було спряжене зі зміною параметрів глобальних температур на +2.0°C з кроком 0,5°C та збільшенням і зменшенням кількості опадів на 30% з кроком 10%. Таким чином, нам вдалось встановити, що найбільш критичними для флуктуації ареалу *A. leucaspis* є кількість опадів та сезонність температур, особливо зимових. Підвищення середньозимових температур елімінує лімітуючий фактор, яким є морози, для поширення *A. leucaspis* на північ. А зниження кількості опадів у середньорічному вимірі підвищує виживання виду на територіях, де це раніше було неможливим. Ми продемонстрували, що для наявного на сьогодні розширення ареалу *A. leucaspis* достатнім є потепління клімату у середньорічному вимірі на +0.5°C та зменшення кількості опадів на 10%. Тепліший і сухіший клімат є основним абіотичним драйвером експансії *A. leucaspis* у вищі широти та гірські пояси.

Ключові слова: скрипунові, біологічні інвазії, біогеографія, зміни клімату, моделювання, ГІС-технології.