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ORIGINAL ARTICLE

Forecasting the potential area of an invasive species *Cylindrocopturus adspersus* LeConte (Coleoptera: Curculionidae) in Ukraine

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Abstract

The sunflower stem weevil, *Cylindrocopturus adspersus* LeConte is a quarantine intra-stem pest of sunflower, distributed mainly in the United States, and discovered in the Kherson region of Ukraine in 2020. The objective of this study was to establish a possible distribution zone of this species in Ukraine based on the results of bioclimatic modeling. The model was built by using programs DIVA GIS version 7.5.0 and BIOCLIM, which search for areas that are suitable for a particular organism, through geographic information systems and by comparing the world climate with the climate of areas in which it has already been identified.

Analysis of the model shows that in Ukraine the pest can acclimatize in the Kherson region only (zone with up to 2.5% probability). Geographically, the territory is limited to 46–47° of north latitude and to 33–34° of north longitude. It is located on the Black Sea Lowland and covers territory lying no higher than 50 meters above the Black Sea level, whose land--surface temperature in July averages more than 28°C. The North Crimean Canal and Krasnoznaamyansky Canal pass through the territory, which is limited in the south by Sivash, Karkinitsky Bay and Dzharilgatsky Bay of the Black Sea, in the west – by the Dnipro Delta, and in the north – by Kakhovka Reservoir and Kakhovskiy canal. The analysis of values of climatic predictors for the territories which are suitable for acclimatization of a phytophage demonstrated its high ecological plasticity and potential ability to move not only on coastal territories, but also on territories with a continental climate.

Keywords: bioclimatic model, invasion, pests, sunflower

Introduction

Today, the problem of insect invasion has become a priority for the world economy. There is literature devoted to "biotic rain" – to the global movement of invasive species between continents. Recent academic research of invasive species shows the introduction of different species to Europe – Coccoidea (Łagowska *et al.* 2015), forest insects (Eschen *et al.* 2015; Roques 2015; Brockerhoff and Liebhold 2017), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) (Haack *et al.* 2015); to Asia – insect invasions into agro-ecosystems and into forest ecosystems of China (Wan and Yang 2016; Lu and Sun 2017; Qi and Lu 2018), Taiwan and Hong Kong (Lu *et al.* 2018), Japan (Yamanaka *et al.* 2015); to South America – the integration process of adventitious phytophagous into forest ecosystems of Brazil (Schühli *et al.* 2016). The same intensity of species exchange is characteristic for North America (Yamanaka *et al.* 2015), which is a potential source of economically important pest species. The most glaring example is the global invasion of the Asian ladybird *Harmonia axyridis* Pallas, which has spread to four continents over the past 35 years (Andrianov *et al.* 2018).

The importance of invasive species for Europe and Ukraine has increased over the past 5 years, including:

western corn rootworm beetle *Diabrotica virgifera virgifera* LeConte (Skripnik and Makarus 2018; Borzich 2020), the American white moth *Hyphantria cunea* Drury (whose range in Ukraine has expanded considerably) (Nakonechna *et al*. 2019), the peach twig borer, *Anarsia lineatella* Zell (Klechkovskiy and Ydicka 2021), the frosted moth-bug *Metcalfa pruinosa* Say (Popova *et al*. 2018), and drosophila – *Drosophila suzukii* Matsumura (Skripnik 2018). There has also been the danger of the proliferation of the eastern cherry fruit fly *Rhagoletis cingulate* Loew (Titova *et al*. 2017a). An analysis of phytosanitary risks for Ukraine was carried out for certain potentially dangerous species, such as: the oriental spider mite *Eutetranychus orientalis* Klein (Titova *et al.* 2020), the lemon-tree borer *Oemona hirta* Fabricius (Titova *et al*. 2017b), *Cydia inopinata* Heinrich (Titova *et al*. 2019), and the brown marmorated bug *Halyomorpha halys* Stal – for which there is an international monitoring system (Skripnik 2019).

One of the most important invasive species is the sunflower stem weevil, *Cylindrocopturus adspersus* LeConte – an intra-stem phytophage of sunflower, that is mainly distributed in the United States (USA). In the USA, the acclimatization zones of *C. adspersus* are represented by five gradations: low (to 2.5%), medium (2.5–5%), high (5–10%), very high (10–20%) and exceptional (20–37%) probability (Fig. 1). They are located in a compact conglomeration in the territories of the Great Plains and in the western part of the Mississippi basin, bounded by the Rocky Mountains in the west, and by the Ozark Plateau and the Mississippi River system in the east, between 90 and 110° north longitude and 30 and 50° north latitude. Analysis of climatic indicators demonstrates the existence of the weevil even in areas characterized by very low winter temperatures of −17°C with an average winter temperature of –9°C. This demonstrates a high ecological

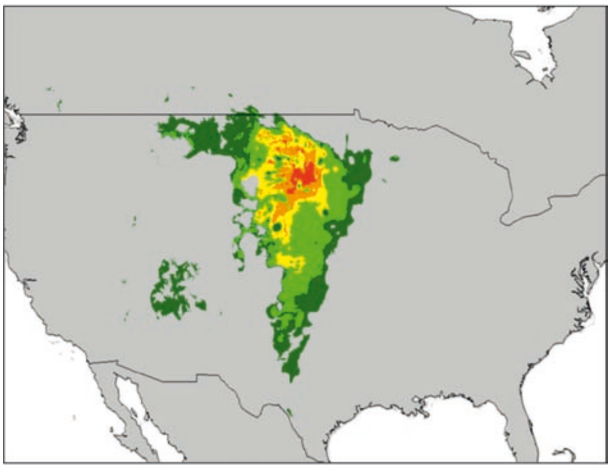

Fig. 1. Predicted range of the sunflower stem weevil, *Cylindrocopturus adspersus* LeConte in North America (the USA)

plasticity of the species, which under a combination of certain conditions could be a phytosanitary problem similar to that caused by the Colorado potato beetle *Leptinotarsa decemlineata* Say.

In 2020 the larvae of the sunflower stem weevil was found in Ukraine, in the Novotroitsk district of the Kherson region. Currently, it is not possible to determine if it is actually the development in the so-called "phantom area" (Fokin 2015, 2016; Fokin *et al.* 2017) (the period, within a short time frame, of the reproduction of an invasive species in new territories provided by a successful coincidence of weather conditions, particularly in relation to global climate change), or the species is in the first phase of the invasive process. Nevertheless, the fact of phytophage detection and its potentially high harmfulness (the sunflower damage is identical to that of the tumbling flower beetle and the sunflower stem borer) create the need for phytosanitary risks analysis (PRA) and analysis of the predictive area *C. adspersus* based on bioclimatic modeling (according to the principles of GIS-technologies) as well as the complex of climatic predictors (19 parameters) for Ukraine. The basis for the development of a bioclimatic model of the sunflower stem weevil spreading is one of the successful attempts to build such models for Ukraine in relation to the western corn rootworm, *D. virgifera virgifera* and white fringed, *Naupactus leucoloma* Boh. beetles, fall armyworm, *Spodoptera frugiperda* (J.E. Smith), southern armyworm, *S. eridania* Cramer and Egyptian cotton leafworm, *S. littoralis* Boisd, mulberg moth, *H. cunea* Drury, harlequin ladybird, *Harmonia axyridis* Pallas (Fokin *et al*. 2017).

Materials and Methods

The data base of the spreading of sunflower stem weevil contains 67 geographical points from Canada, United States and Asia. Reconstruction of possible ways *C. adspersus* could penetrate into the territory of Ukraine was based on data about import and transportation of the seed material via roads throughout the territory of the Kherson region in 2018–2019 (Fokin *et al.* 2017).

The possible spread of the sunflower stem weevil, *C. adspersus* was modelled by using programs DIVA-GIS version 7.5.0 and BIOCLIM. These programs use geographic information systems to search for habitable areas of a particular organism by comparing the world climate base with the climate of areas in which it has already been found (Berest and Titar 2007). With these programs a cartographic model indicating the six-stage conditions suitability can be built. Modelling was performed according to the following climatic predictors: the average temperature and rainfall during the dry, wet, warm and cold periods, the average annual, maximum and minimum temperatures, their annual and average monthly variations, the sum of effective temperatures, precipitation throughout the year and the seasons, as well as rainy and dry months. Algorithm for the model construction: a data base is created in the DBF file with the geographical coordinates of the species registration, DIVA-GIS is launched, the tools window is opened and there is a transfer to options, then to the climate tab. The last cells should be filled as follows: Folder h:/bioclim/clim-2_5/diva_clim/, where "h" is the disk on which the program is installed. Below there is a cell worldclim_2-5m; Columns 8640; rows 3600. When entering data for processing, it is necessary to specify the geographic boundaries for the model construction – for the globe: X min –180; max 180; Y min – 60; max 90. Then, the parameters are set: Index – index_2-5m; Altitude – alt_2-5m; Min temperature – tmin_2-5m; Max temperature – tmax_2-5m; Precipitation – prec_2-5m; Projection – GEOGRAPHIC; Map units – DEGREES; Datum – WGS84 and the program remembers the way to climate indicators. To build the potential areas, we consistently insert files with geographic maps, with spreading points (file DBF), open the window modeling, go to bioclim/domain and set the parameters. In the output we specify the name of the derived file and build a predictive model in the form of a map. Zones are built depending on the suitability for pest acclimatization: exceptional – with acclimatization probability 20–33% (red zones on the map), with a very high – 10–20% (orange), high – 5–10% (yellow), medium – 2.5–5% (light green), low suitability – probability up to 2.5% (dark green) and unsuitable for the species – with zero acclimatization probability (gray zones) (Fokin *et al.* 2017).

Statistical analysis of bioclimetic models was provided by software products DIVA-GIS version 7.5.0 and BIOCLIM.

Results and Discussion

On the territory of Ukraine (located between 52°22'46" and 44°23'11" north latitude parallels and 22°08'13" and 40°13'40" east longitude meridians) single specimens of *C. adspersus* were first detected in November 2020 in the field LLC "Ailand" in the Novotroitsk district of Kherson region. Two larvae were found in the sample from five plants (geographic coordinates of the phytophage detection point were 46°16'04" and 34°25'24"). The sample was taken from the edge of a field. The field area was 30.5 ha and was located 5 km from the R-47 Kherson – Genichesk highway. Import probably took place with plant residues during transportation of the sunflower seeds (Fig. 2).

Fig. 2. Reconstruction of possible spreading of sunflower stem weevil in southern Ukraine (2020 – the year of the phytophage identification)

A bioclimatic model was built in order to establish the possible distribution zone of the species in Ukraine, according to which *C. adspersus* is able to acclimatize only in the Kherson region (zone with a probability up to 2.5%). Geographically, the area is limited by 46–47° of northern latitude and 33–34° of northern longitude. It is located on the Black Sea lowland and covers an area which lies not higher than 50 meters above the Black Sea level. In July the land surface temperature exceeds 28°C. The Pivnichno-Kryms'kyi and Krasnoznayamyansky Channels pass through the area. In the south it is limited by Sivash, by Karkinitsky and Dzharilgatsky Bays of the Black Sea, in the west – the Dnipro delta, and in the north – the Kakhovka Reservoir and Kakhovskiy canal (Fig. 3). Analysis of zone climatic conditions of possible acclimatization (Table 1) shows that the general indicators of climatic predictors determined on the periphery (clockwise, starting from

Fig. 3. Projected zone (dark green) of the sunflower stem weevil *Cylindrocopturus adspersus* LeConte in Ukraine (Kherson region)

Table 1. Climatic conditions of the possible acclimatization zone *Cylindrocopturus adspersus* LeConte in Ukraine (Kherson region)

Climatic predictors	Part of the cell	
	central	peripheral
The global mean temperature [°C]	10.07	9.67
The maximum temperature during the warm period [°C]	28.74	28.7
The minimum temperature during the cold period [°C]	–5.7	–5.48
The average temperature during the cold period [°C]	–1.07	–0.915
Total amount of precipitation [mm]	407.3	408.5
The amount of precipitation during the warm period [mm]	128.9	128.8

the south) and in its center are nearly the same: the average temperature is 10°C, maximum summer temperature is 28.7°C, average winter temperature within is –1°C, and minimal – 5.7 (in some locations –6.3 and –6.4°C). The amount of precipitation is also the same – up to 408 mm, including the summer period – up to 129 mm.

There were two possible ways of phytophage invasion and both of them were associated with seed transportation by truck (the years of seed procurement and transportation are shown under arrows in Fig. 2). The most probable was the import from the Crimean Peninsula on the Dzhankoy – Novotroitske route (the closest to the point of pest detection – the port of Henichesk is currently closed) (Fig. 2). This scenario is similar to how the American tomato moth came to Ukraine – it was detected in 2010 in the Crimea (Saksky district, Orekhovo settlement, the village Chervone, greenhouses of LLC "Persha Krymska Ahrarna Kompania") in the Odesa region near Illichivsk. In 2012, the species had spread to the Kherson region (Kherson), and in 2013 to the Mykolaiv region (Fokin *et al*. 2017).

Another, less probable way of invasion was via the Mykolaiv region – Kakhovka – Novotroitske with plant residues during transportation of the seeds. Such a route presupposes the intervening years: 2018 – the year of the importation from Mykolayiv to Kakhovka (hybrid F1 "Sunny Mood", originating from the Ukrainian Scientific Institute of Plant Breeding (VNIS) and in 2019 the seeds were imported from Kakhovka to Novotroitske in 2020. Nevertheless, for the period 2018–2019 the weevil was not found either in Mykolayiv region or in Kakhovka, although the possibility of its development in these years cannot be totally excluded. Synoptic conditions of 2020 in the area of phytophage detection may have contributed to its successful development – the average temperature for January – from November 10 to 20 was 13.48°C, SET was 3717°C, the total annual precipitation was 341.4 mm, the average value of Selyaninov Hydrothermal Coefficient (HTC) was 0.57.

Based on the precipitation data, a comparison of temperature and precipitation during the year in different parts of the area (Figs. 4–5) showed a normal distribution for both warm and cold periods, for the central points of the area as well as for the eastern, southern and western areas. The temperature was also distributed almost equally: maximum in the summer and short-term lowering in the spring and autumn (compared to the winter "plateau". Moreover, the December temperatures were higher than in January and February) (Fig. 4). In the southernmost and westernmost points the temperature was lower in August, with further increases in September (Figs. 4B, C).

The distribution of temperature and precipitation in a separate location in the east (Fig. 5B) was more similar to the distribution of climatic indicators in the northernmost point of the area (Fig. 5A): the temperatures were lower in March and October (although for the first spring cooling it was not so different, but lasted almost 2 months – until May).

Detection of *C. adspersus* LeConte in Ukraine could be the first step to phytophage expansion in Western Europe, where it could spread across eastern Spain between 37° and 42° north latitude and between the Prime Meridian (0° longitude) and 2° north longitude (a probability of up to 2.5%). The southern part of this lane was represented by sporadic localities between the Mediterranean coast (in the east), the Sierra Nevada (in the south) and Sierra de Segura Mountain ranges (in the west). The acclimatization zone of the weevil in the north was represented by the epicenter at the latitude of Barcelona, located between the Iberian Mountains and the Ebro River Valley. The main climatic indicators of these cells are given in Table 2. In the future, as a result of climatic changes, they could transform and significantly expand to the north. Distinct localities in the south-east were dominated by all indicators over the north-east, and most importantly, were characterized by a higher average temperature (14.75°C) and by a large amount of precipitation (418.7 mm) compared to the north-east – 13.84°C and 403.16 mm, respectively.

Of particular note was the climate of the north-eastern cell which changed somewhat in a west-east direction, from the mountain areas of the Iberian Mountains to the Mediterranean coast: the annual

Table 2. Climatic conditions of the area of possible acclimatization of *Cylindrocopturus adspersus* LeConte in Spain

Climatic predictors	Concentration places	
	the south-east	the north-east
The global mean temperature [°C]	14.76	13.84
The maximum temperature during the warm period [°C]	29.94	30.11
The minimum temperature during the cold period [°C]	3.85	1.62
The average temperature during the cold period [°C]	9.05	6.67
Total amount of precipitation [mm]	418.7	403.16
The amount of precipitation during the warm period [mm]	155.1	130.72

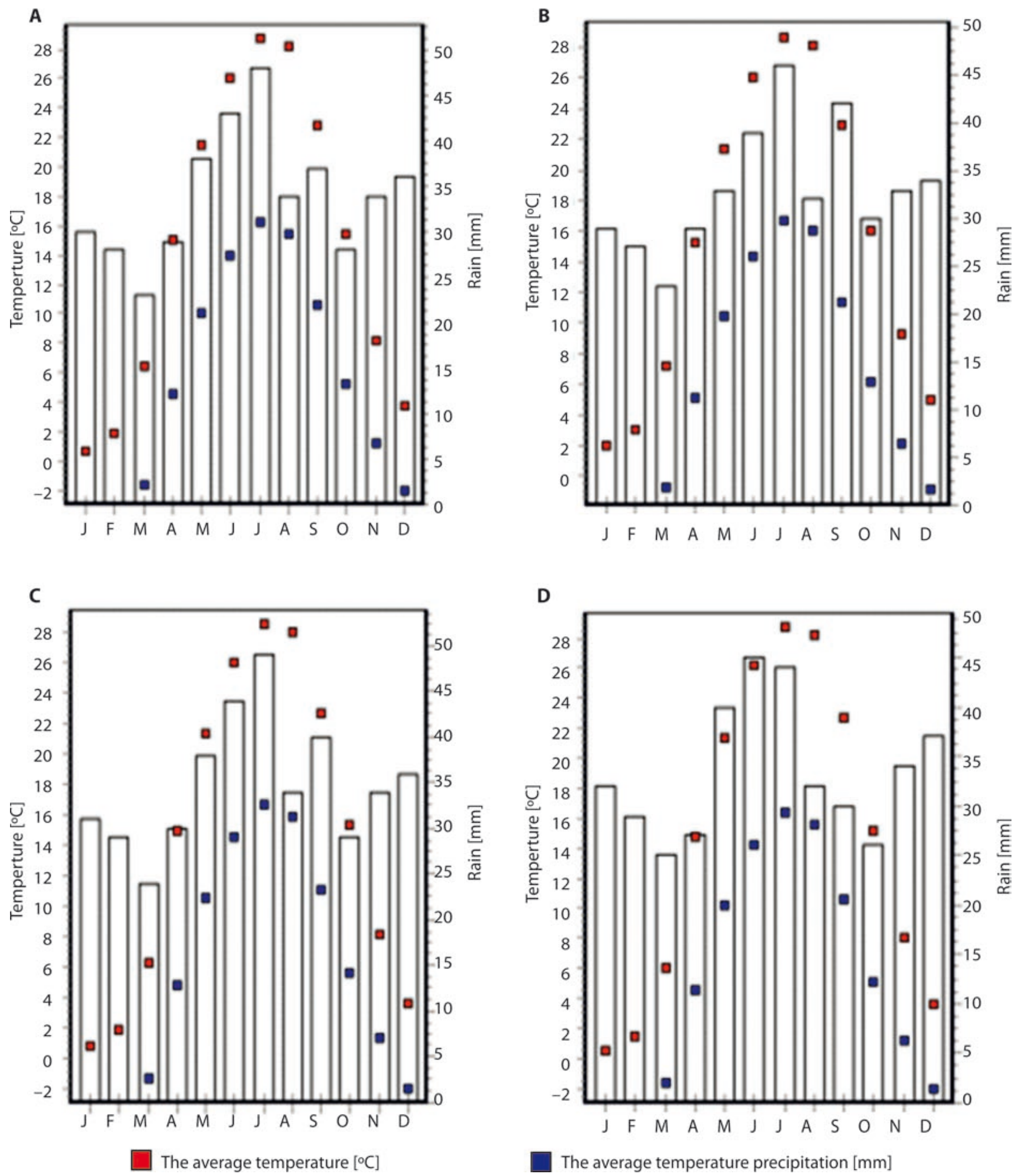

Fig. 4. The comparison of temperature conditions and precipitation throughout the year in the zone of possible acclimatization of *Cylindrocopturus adspersus* LeConte in the Kherson region: A – cell center, B – the southernmost, C – the western points, D – the eastern points

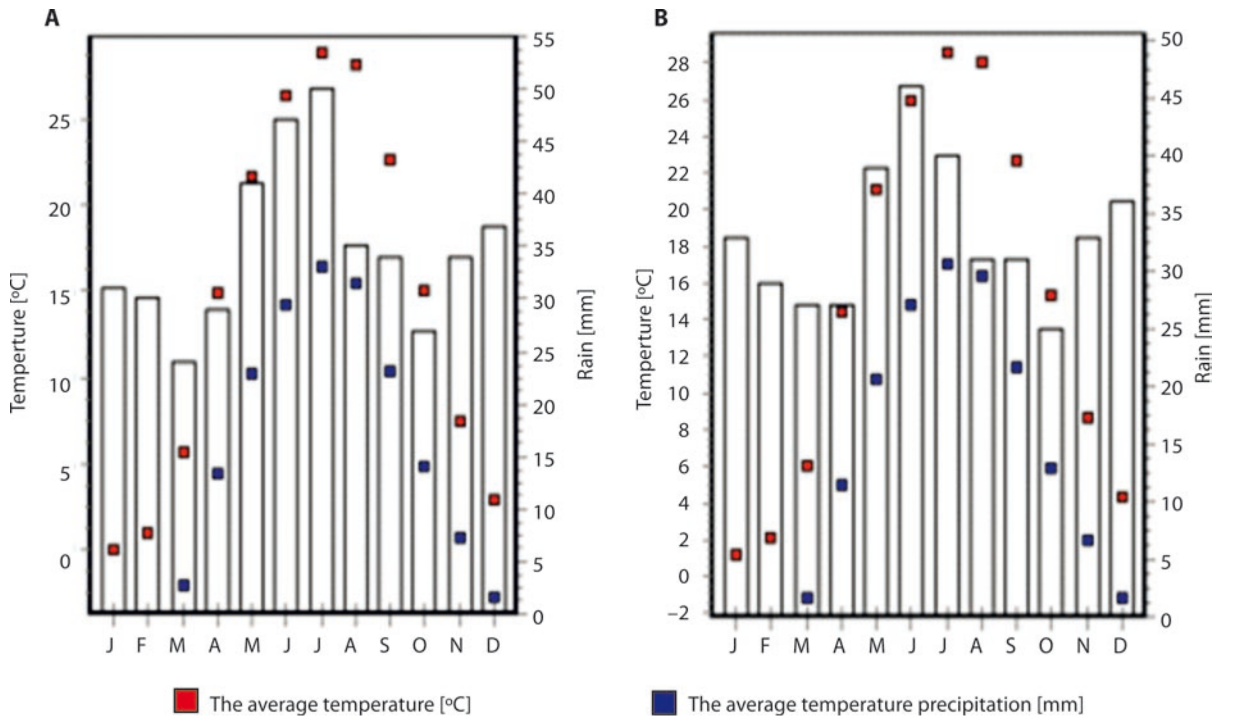

Fig. 5. A comparison of temperature conditions and precipitation throughout the year in the zone of possible acclimatization of *Cylindrocopturus adspersus* LeConte in the Kherson region: A – the northernmost point, B – separate cell in the east

average temperature increased from 13.8°C to 15.1°C, the maximum temperature in summer increased by over 2°C – from 29.4°C to 31.6°C, while the minimum winter temperature did not vary much: from 1 to 2.4°C, and the average values of this indicator changed from 6°C in the west of the cell to 6.5°C in the east, with higher temperatures of 6.8–7.4°C in its center. The total amount of precipitation significantly increased towards the sea from 363 to 472 mm, as well as the summer precipitation from 125 to 153 mm. In addition, minor pockets of the acclimatization zone up to 2.5% for the sunflower weevil were found in the eastern part of Tunisia, and in the northern part of Algeria and Morocco.

Conclusions

In Ukraine *C. adspersus* was first detected in November 2020 in the Kherson region (Novotroitsk district); analysis of climatic predictor values for the territories that are suitable for acclimatization of a phytophage demonstrated its high ecological plasticity and potential ability to move not only to coastal regions, but also to territories with a continental climate; only one territory of possible phytophage acclimatization is forecasted in Ukraine (probability of up to 2.5%) in the southern part of Kherson region between 46–47° degrees of northern latitude and 33–34° degrees of northern longitude; the Pivnichno-Kryms'kyi and Krasnoznayamyansky Channels pass through this area. In the south it is limited by Sivash, by Karkinitsky and Dzharilgatsky Bays of the Black Sea, in the west – the Dnipro delta, and in the north – the Kakhovka Reservoir and Kakhovskiy canal. The temperature regime of the potential territory is characterized by an average temperature of 10°C, the maximum summer temperature – 28.7°C, the average winter temperature –1°C, and the minimum temperature – down to –6.4°C. Detection of the phytophage in Ukraine could be the first step towards its expansion into Western Europe, where it could already acclimatize in Spain between 37 and 42° north latitude, between the Prime Meridian (0° longitude) and 2° north longitude (between the Mediterranean coast, the Sierra Nevada and Sierra de Segura mountain ranges; between the Iberian Mountains and the Ebro river valley).

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