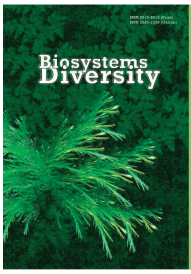

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Range of *Pterostichus oblongopunctatus* (Coleoptera, Carabidae) in conditions of global climate change

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Using geodata technology, we conducted a bioclimatic modeling of the spatial distribution of the common palearctic ground beetle – *Pterostichus oblongopunctatus* (Fabricius, 1787). The range of comfort of the territories included in this species' range was obtained. We used the data on 510 sampling points, obtained as a result of the authors' field surveys and the data base of the GBIF global fund of biodiversity and 19 climatic parameters from the WorldClim open base and MaxEnt program. The results determined the factors which have the greatest impact on the current distribution of *P. oblongopunctatus*. The main climatic factors affecting the distribution of *P. oblongopunctatus* are average annual temperature, average 24-hour amplitude of temperature over each month, average temperature over the driest quarter, average temperature over the warmest quarter of the year, total of precipitations in the driest month of the year. We performed a prediction of possible change in the range by two scenarios (RCP 2.6 and RCP 8.5) for 2050 and 2070. Using QGIS program, we estimated the areas of the species' range, and compared them. According to the scenario RCP 2.6, by 2050, the range of the species will contract due to decrease in the territories with moderately continental climate, and by 2070, a restoration of the range would take place, for according to this scenario, the average annual temperature stabilizes. According to the scenario RCP 8.5, the range will contract by 2050 and will continue to decrease by 2070, for the concentration of CO_2 continues to increase along with increase in average annual temperature. Climate changes can affect the life cycle of the beetle, its life expectancy and activity over the season. With changes in temperature, eggs and larvae of *P. oblongopunctatus* can be more vulnerable.

Keywords: global warming; climate change; range; ground beetles; modeling spatial distribution.

Introduction

The problem of changes in ranges of common species in the conditions of global climate change is one most relevant problems of current ecology (Hijmans et al., 2005; Alonso-Carné et al., 2017). Climate change over the recent decades is an undeniable fact, which is proved by monitoring the rise in annual average temperature of air and ocean, melting of snow and ice on large areas and other climatic indicators. Climate change is a complex and multi-aspect phenomenon which affects practically all bioclimatic parameters (Zamolodchikov, 2016). Distribution of species is to a large extent determined by their ecological needs and peculiarities of spatial distribution of the most important factors limiting their global distribution (Musolin, 2007). They influence the spatial-temporal structure and system of interaction of organisms and their communities with the environment.

Modeling spatial distribution of individuals demonstrates the relationship between the presence of a particular species in the studied territory and the existing combination of bioclimatic factors. Modern geodata technologies and open data bases on bioclimatic parameters allow highly accurate prediction and mapping of the territories of distribution of biological objects, based on the knowledge of the limits of species' adaptability combined with spatial distribution of ecological factors of the environment (Panagos et al., 2017; Poggio et al., 2018). The following categories of reaction of insects to environmental changes are distinguished: change in range, number, phenology, voltinism (number of generations per season), morphology, physiology and behaviour (Musolin, 2007).

The object of our study was *Pterostichus oblongopunctatus* (Fabricius, 1787), a transpalaearctic species distributed from Northern and Central Europe to the Caucasus and Siberia eastwards to Japan (Kryzhanovskij et al., 1995; Hurka, 1996; Bousquet, 2003). It is one of commonest forest species of ground beetles in the south of the forest zone, in the forest-steppe zone and in the north of the steppe zone of Earasia (Kryshtak, 1956; Putchkov, 2018). In south of its range, its abundance reliably increases in conditions of 40–100% density of tree crowns, on loamy soils, at average levels of mineralization of soil. In the steppe zone of Ukraine the species is present in 19.5% of all studied forest ecosystems in the regions (Brygadyrenko, 2016a). According to Putchkov (2018), one of the factors which sometimes increase in the number of this forest species in the steppe zone is the humidity and shade regime (Brygadyrenko, 2015b, 2016b). Its occurrence in fields is related to intense irrigation, the species is common in old gardens and city parks of the forest and forest-steppe zones of Ukraine (Putchkov, 2018).

According to Putchkov (2018), in Ukraine, females of the species with eggs have been "recorded in April–May. Larvae develop from May to June. Appearance of young beetles was observed in August–September. Imagoes overwinter. Zoophage, consumes lepidopterans related to soil (Noctuidae, Geometridae, Cydia), Staphylinidae (genus *Philonthus*), larvae and pupae of scarabs (Scarabaeidae), darkling beetles

(Tenebrionidae), click beetles (Elateridae), worms and their cocoons, small slugs. They have been observed to eat trama of mushrooms and larvae of Mycetophilidae, which live in them, and also sporadically – fruits of strawberry". This species is distinct in the high diversity of its diet in undamaged forest ecosystems both at the larva and imago stages of development (Schelvis & Siepel, 1988; Komarov & Brygadyrenko, 2011). Duration of reproductive period is affected by the latitude of the inhabited location, absolute height above sea level, anomalous weather conditions and habitats (Van Schaick Zillesen, 1985; Sharova & Filippov, 2003; Matalin, 2006). In the forest-steppe, *P. oblongopunctatus* breeds from early April to late July (Sharova & Denisova, 1997); in broad-leaved forests, the reproductive period lasts from late April to late July (Heerdt et al., 1976); in coniferous-broad leaved forests – from early May to Mid July; in the northern taiga – from early June to early July (Sharova & Filippov, 2003). In highland areas of the Chechen Republic *P. oblongopunctatus* is active from early May to late September.

This species is quite a convenient practical object for physiological studies: there are studies of the effect of nickel on its own and in combination with chlorpyrifos and heightened temperature on larvae (Bednarska & Laskowski, 2009) and imagines of this species (Bednarska & Laskowski, 2007; Bednarska et al., 2009; Bednarska & Kaszowska, 2014). Toxicological studies on this species led to a number of important conclusions being drawn on the toxicology of the pollutants, applicable for other species of ground beetles and insects in general (Łagisz et al., 2002; Bednarska et al., 2010a, 2010b, 2012, 2016, 2017; Bednarska & Stachowicz, 2012; Simon et al., 2016). Work on different aspects of populational diversity on genetic (Siepel, 1988; Den Boer et al., 1992; Lagisz et al., 2010) and morphological (Emetz, 1986; Schwerk & Jaskuła, 2018) levels allow one to state that *P. oblongopunctatus* is one of the best studied species of ground beetles.

P. oblongopunctatus is a typical element of urban forest plantations and anthropogenically transformed territories (Grechanichenko & Guseva, 2000; Magura et al., 2008; Gardiner & Harwood, 2017). Thus, the studied species of ground beetle is a practical object for modeling changes in the range in conditions of global climate changes, one of the priority factors which affects natural populations in XXI century (Kotze et al., 2011). It was experimentally determined that temperature is an important limiting factor for this species of ground beetle (Thiele, 1975, 1977; Bednarska & Laskowski, 2007).

The objective of this study was to assess the distribution of *P. oblongopunctatus* in the context of changes in global climate conditions by using ecological-climatic modeling.

Material and methods

Material for this study was collected in the field by the authors (120 sites), and also the data obtained from the GBIF open data base (390 sites). Collecting in the field was performed in different years on the territory of Russia (Tatarstan, Chechen Republic, Sverdlov Oblast, west slope of the Urals, Perm Krai) and Ukraine (Table 1).

Table 1
Places where *P. oblongopunctatus* was collected
for the analysis of changes in the range

Country, region	Oblast, region
Ukraine	Kyiv, Cherkasy, Poltava, Kharkiv, Dnipropetrovsk. Zaporizhia, Mykolaiv, Donetsk Oblasts
Tatarstan	Kazan, Rybno-Slobodsky district, Apastovsky district, Volga-Kama National Reserve, Laishevsky district, Zelenodolsky district, Vysokogorsky district, Verhneuslonsky district, Island biotopes on the Volga
Sverdlovsk Oblast	Ekaterinburg, Pripyshminskiye Bory National Park, Zyrianovsky district, Visim National Natural Biosphere Reserve
Kemerovo Oblast	Kemerovo
Mari El Republic	Mariy Chodra National Park
Chechen Republic	Vedensky and Sharoysky districts

The beetles were sampled using pitfall traps and soil samples, and also collected manually, mostly in mesophilous habitats in flood-plain, broad-leaved and coniferous forests; more rarely – in shrub and meadow communities. This allowed broad data to be obtained which reflected different aspects of ecology and biology of this species. In total over 11 thousand imagoes of *P. oblongopunctatus* were collected.

For bioclimatic modeling (Molyneux et al., 2013), WorldClim data of global base of climatic data (www.worldclim.org) were used: 19 bioclimatic variables with spatial resolution of 30 seconds. For the analysis of changes in the range of *P. oblongopunctatus*, we used bioclimatic data for the years 1960–1990 (version 1.4 WorldClim), bioclimatic data for 1970–2000 (version 2 WorldClim), and also two scenarios of "low emissions" (RCP 2.6) and "high emissions" (RCP 8.5) out of four predicted scenarios, RCP 2.6, RCP 4.5, RCP 6.0, RCP 8.5, which became known as "representative concentrations pathways" (www.global-climate-change.ru). RCP correlate with a broad spectrum of probable changes in anthropogenic emissions of greenhouse gases and are used for demonstrating their concentration in the atmosphere. The scenario of "low emissions", RCP 2.6, includes constant and ambitious actions orientated towards reduction of anthropogenic emissions of greenhouse gases. Trajectories of RCP 2.6 have a large variation of annual changes in temperature, which leads to slowing and even stopping its growth after 2050. The reasons for such slowing are determined by the dynamic of CO_2 concentration, which in turn is related to significant absolute decrease in anthropogenic emissions of greenhouse gases, starting from 2020 in RCP 2.6.

RCP 8.5 characterizes a situation when global economic development remains associated with use of fossil fuel without any measures of climatic policy being taken. During the realization of RCP 8.5, by 2100, the concentration of CO_2 will reach 936 ppm, and the average global temperature will reach 16.8 °C. In other words, warming over 2010–2100 will equal 2.4 °C. During RCP 2.6, by 2100, concentration of CO_2 will equal 421 ppm, and growth of global temperature – only 0.1 °C. According to the prognosis of the Intergovernmental Panel on Climate Change (IPCC), on the trajectory of RCP 8.5, annual increase in temperature will vary within 0.03–0.05 °C.

The mean value of global temperature in 1850–1990 (pre-industrial level) equaled 13.6 °C (Fick & Hijmans, 2017). Therefore, after achieving the goals of the Paris Agreement, mean global temperature should not exceed 15.6 °C. According to the prognosis on the CMIP 5 ensemble of models, global temperature will reach 15.6 °C in 2042 according to RCP 8.5; in 2056 according to RCP 4.5; and in 2062 according to RCP 6.0. Only scenario RCP 2.6 appears to correspond to the goal of the Paris Agreement.

Zamolodchikov (2016) suggested a statistical model of the dynamic of average annual global temperature which combines logarithmic effect of carbon dioxide concentration growth and contribution of the climatic cycles. Parameters of the model are determined according to known data of instrumental measurements over 1850–2010. The model proves the reliable presence of two cyclic process of periodicity in the dynamics, equaling 10.5 and 68.8 years. According to the model, maxima of this cycle should be observed in the years 1944, 2012, 2081. The amount of annual change in temperature was positive and was within 0.08–0.09 °C in 1989–2000. This particular period was characteristic of the fastest factual growth of global temperature. However, subsequently, the annual change due to the 68.8-year cycle started to decrease, and in 2005, it fell to 0.05 °C, and from 2012 became negative, i.e. decreasing the tempi of global temperature growth. According to this model, exceeding the threshold of 2 °C will occur in 2061 at RCP 8.5 and in 2075 at RCP 6.0.

We used QGIS 3.4.3 (Quantum GIS, 2019) for working with layers, calculation of points number in the polygons, assessment of area of the predicted ranges. Predicting potential range was made using Maxent 3.4.1 program (Phillips, S. J., Dudík, M., & Schapire, R. E., 2017: MaxEnt software for modeling species niches and distributions (Version 3.4.1), http://biodiversityinformatics.amnh.org/open_source/maxent).

Results

Modeling in medium MaxEnt demonstrated that the greatest impact on the spatial distribution of *P. oblongopunctatus* was caused by the following bioclimatic variables of Bioclim (percentage of contribution of each variable is provided in Table 2):

– BIO 01 – average annual temperature;

– BIO 02 – average 24-hour amplitude of temperature for each month;

– BIO 09 – average temperature of the driest quarter;

– BIO 10 – average temperature of the warmest quarter of the year;

– BIO 14 – total of precipitations in the driest month of the year.

For the assessment of the obtained model, a testing selection was created, which included 25% of the species presence points. The results are presented in logistical format which provides 0 to 1 assessment of the probability of this species inhabiting a particular geographic point. The map of potential distribution of the studied species demonstrates how different territories are appropriate for it according to their climatic characteristics.

An important indicator of the model's reliability is Area Under the Curve (AUC). AUC is assessment of the ability of the model to demonstrate presence of the species in a geographic point, where it could live with a high percentage of probability. In our case, AUC equals 0.975. That means a 97.5% probability that the species will actually live where is predicted to live. The model of distribution of *P. oblongopunctatus* corresponds to the current knowledge of the places where the species lives (Fig. 1).

Table 2
Percentage of contribution and importance
with permutation of the studied bioclimatic parameters

Bioclimatic parameters	Contribution of bioclimatic parameter, %	Importance of the parameter during permutation, %
BIO 14	52.6	1.7
BIO 01	14.3	11.4
BIO 11	10.3	0.0
BIO 09	7.4	1.9
BIO 02	6.0	18.1
BIO 04	3.2	1.7
BIO 13	2.6	8.8
BIO 10	1.2	43.6
BIO 19	0.4	5.5

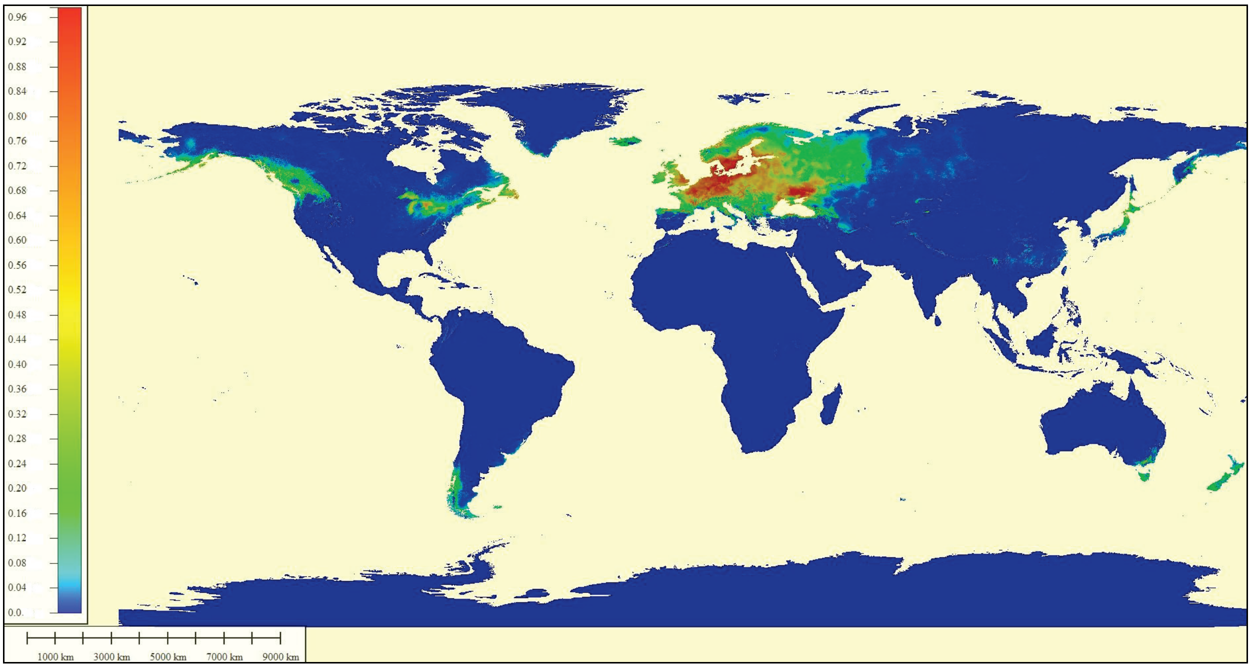

Fig. 1. Map of potential distribution of *P. oblongopunctatus*: colour scale of the comfort range: dark blue – unfavourable (0–0.03); light blue – less favourable (0.04–0.12); yellow and green – favourable territories (0.13–0.60); red and orange – most favourable territories (0.61–0.98)

Using QGIS, we performed an analysis of the number of points in the polygons for each factor. The number of points in each polygon was obtained from the table and on their basis diagrams were built. Out of 510 points, 390 are in the range of average annual temperature 4–10 ºC (Fig. 2). Perhaps, this is most favourable temperature for this species. During the analysis of average 24-hour amplitude of temperature, 384 points were obtained in range of 7–10 ºC (Fig. 3).

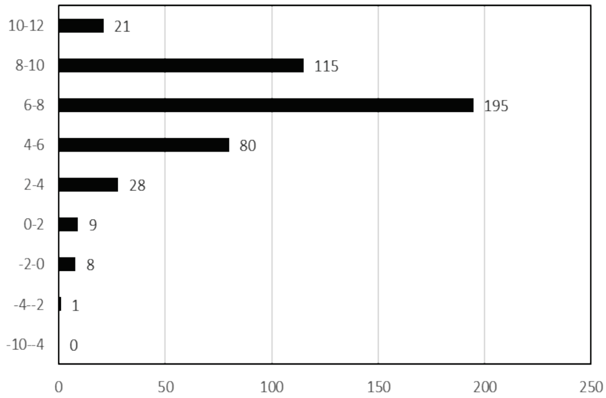

Fig. 2. Distribution of records points in *P. oblongopunctatus* (abscissa axis) depending on average annual air temperature (ordinate axis, ºC)

Analysis of average temperature of the warmest quarter demonstrates that 437 points are in the range of 9.0–10.5 (Fig. 4). At the analysis of total of precipitations of the driest month of the year, 347 points are in the range of 25–50 mm (Fig. 5).

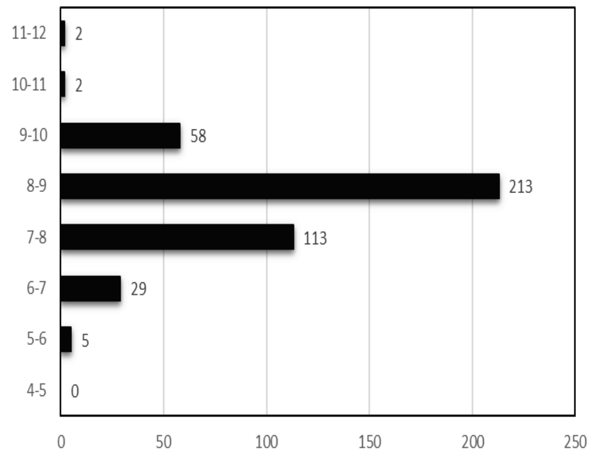

Fig. 3. Distribution of record points in of *P. oblongopunctatus* (abscissa axis) depending on the average 24-hour amplitude of temperature (ordinate axis, ºC) for each month

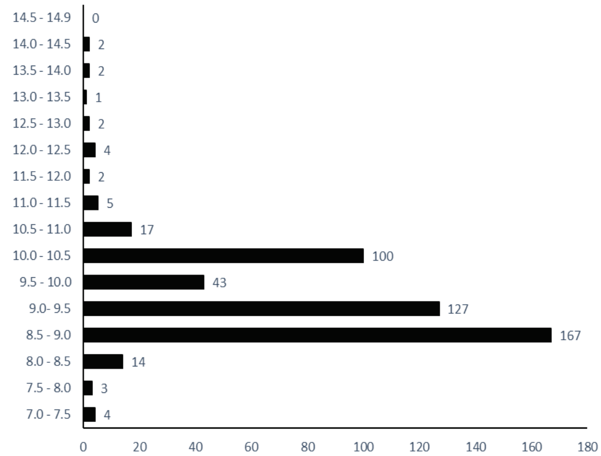

Fig. 4. Distribution of records points in *P. oblongopunctatus* (abscissa axis) depending on the average temperature of the warmest quarter of the year (ordinate axis, ºC)

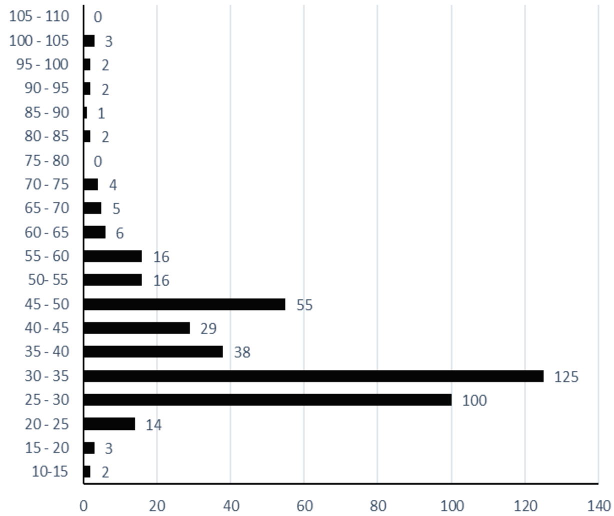

Fig. 5. Distribution of record points in *P. oblongopunctatus* (abscissa axis) depending on the total amount of precipitations (mm) over the driest month of the year

In QGIS program, using a calculator of fields, we estimated the area of current range, area of ranges predicted for 2050 and 2070 according to the scenarios RCP 2.6. and RCP 8.5 (Fig. 6).

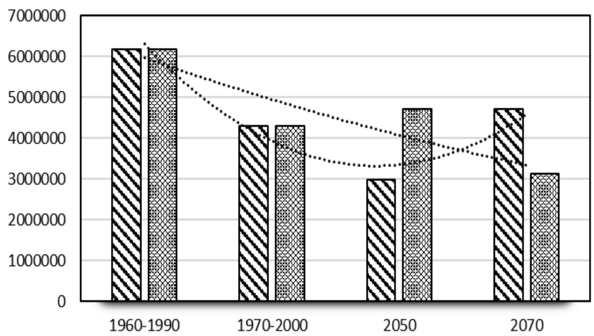

Fig. 6. Change in the area of range (km^2) of *P. oblongopunctatus*: striped column – scenario RCP 2.6, grey column – scenario RCP 8.5

According to the first scenario, beginning with the second half of the XX century to 2020, the content of CO_2 will increase, as well as the global average annual temperature. After 2020, anthropogenic emissions will decrease, and the average annual temperature will stabilize. According to the model we obtained, the area of range of *P. oblongopunctatus* will decrease until 2050 (Fig. 7), and by 2070, due to decrease in CO_2 concentration and reduction of average annual increase in temperature, the range will begin to recover (Fig. 8).

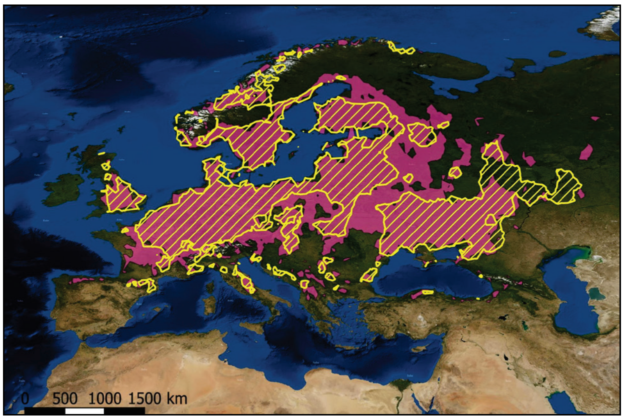

Fig. 7. Change in the area of range by 2050 according to the scenario RCP 2.6: lilac tint – current range, diagonally hatched (yellow) areas – range in year 2050

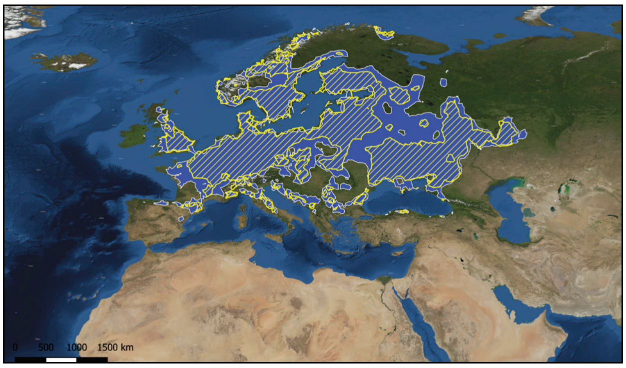

Fig. 8. Change in the range by 2070 according to scenario RCP 2.6: plain tint – range as at 2070, hatched areas – range in 2050

According to scenario RCP 8.5 (Fig. 9), the range of the species looks different – the concentration of CO_2 and mean annual temperature will continue to increase, which will lead to reduction of the range and shift of the borders of the comfort zone to areas with a mild maritime climate. Areas with continental climate become unfavourable for survival of *P. oblongopunctatus*, which is perhaps related to the sharpening of temperature differences and reduction of the amount of precipitations.

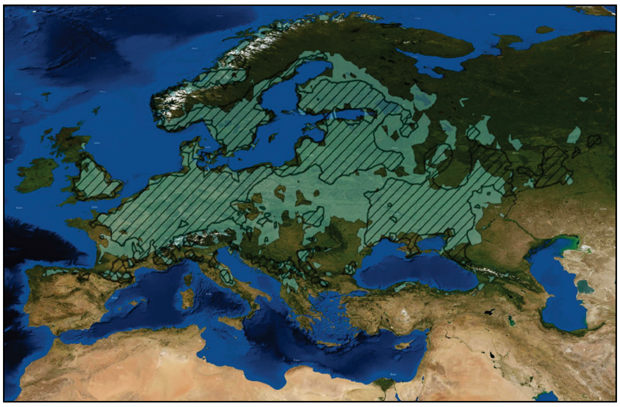

Fig. 9. Change in area of range by 2070 according to RCP 8.5: Plain tint – range as at 2050, hatched areas – range as at 2070

According to scenario RCP 2.6, by 2050 in North America, the range will significantly contract inside the continent, but increase in the islands (Fig. 10). The same picture can be seen in the islands of the coast of the Pacific Ocean in Asia (Fig. 11). According to scenario RCP 8.5, *P. oblongopunctatus* will not live in these islands.

We used the MaxEnt program for assessment of the contribution of mean monthly maximum and minimum temperatures to the realization of life cycle of *P. oblongopunctatus*, particularly jackknife function. The result of the analysis is demonstrated in bar charts (Fig. 12, 13).

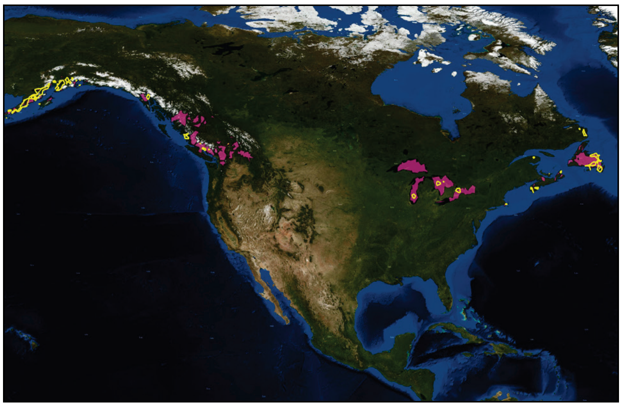

Fig. 10. Range in North America at present and in 2050 according to scenario RCP 2.6

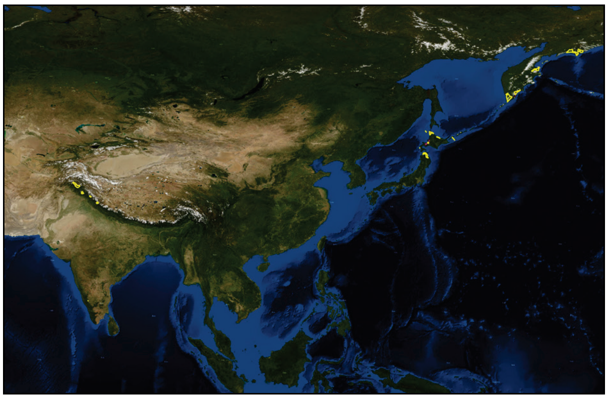

Fig. 11. Range on islands of Pacific Ocean coast: prediction for 2050 according to scenario RCP 2.6

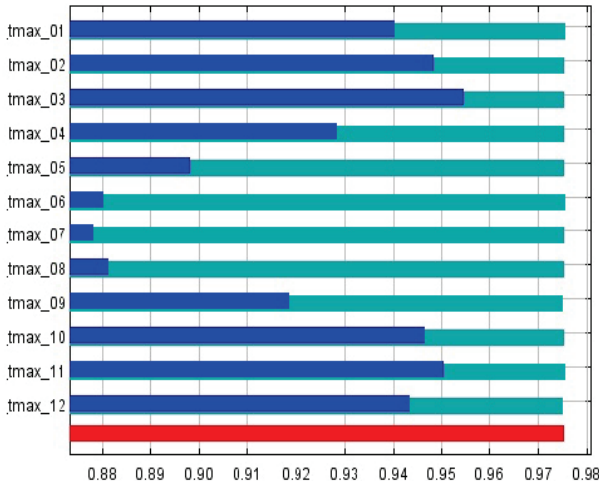

Fig. 12. Bar chart of contribution of mean monthly maximum temperature on life cycle of *P. oblongopunctatus*, parameter of factor significance (abscissa axis); mean maximum temperature from January to December (ordinate axis)

Blue bars indicate the role of the variable in development of model. The shorter is the blue bar, the larger amount of unique information a variable contains. In this case, the most significant are maximum temperatures of the cold period: January–March, September–December. A similar picture is observed for minimum temperatures.

This is supported by the fact that the development of the gonads is significantly affected by daylight hours and temperature, due to which a strong correspondence to particular seasonal periods is observed. The gonads of male *P. oblongopunctatus* become mature in the conditions of short days, i.e. in autumn before wintering and during wintering, and gonads of females – after short days become long, i.e. in spring right after wintering (Thiele, 1966; Thiele & Konen, 1975; Kreckwitz, 1980).

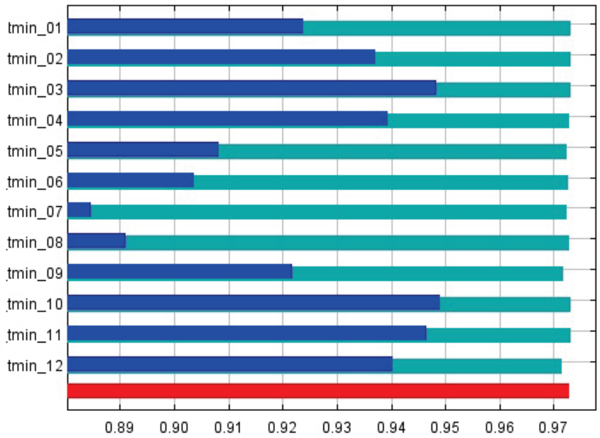

Fig. 13. Bar chart of contribution of every month's mean minimum temperature to life cycle of *P. oblongopunctatus*, parameter of factor significance (abscissa axis); mean maximum temperature from January to December (ordinate axis)

We described the seasonal dynamic and life cycle of *P. oblongopunctatus* which lives in the conditions of mountains of Chechnia. Seasonal activity was observed from early May. Females with unlayed eggs and generative males can be found from the first decade of May to late July, becoming most numerous in the second decade of June. In the third decade of May, postgenerative individuals were found in the selections in small numbers. The first juvenile specimens began to sampled in the traps in the third decade of June. The peak of juvenile individuals occurred in the second decade of July. Along with generative, postgenerative and juvenile individuals, in late July, the traps sampled immature individuals, the number of which remains stable until late September. In the autumn selections, juvenile and postgenerative individuals there were also observed. Thus, the life cycle of *P. oblongopunctatus* in the conditions of mountains of Chechnia is realized as a one-year cycle with spring-summer breeding.

Discussion

Current distribution. Mapping the ranges of this ground beetles was performed only for certain countries: the Netherlands and Great Britain (Turin et al., 1977; Luff et al., 1989). The ecology of *P. oblongopunctatus* in Fennoscandia and Denmark, according to Lindroth (1986), corresponds to its ecology in Central Europe. This famous author emphasizes the eurotopicity of *P. oblongopunctatus*, as a forest species: "eurytopic woodland species, occurring in both deciduous and coniferous forests, usually in light stands on moderately dry, mainly sour humus soil". Lindroth (1986) also accents that in the conditions of sufficiently humid and cool climate, the species comes out of the forest canopy to open territories: "In the Atlantic climate of West Norway also in open habitat". According to Koivula et al. (1999), the species statistically reliably reduces its abundance in response to decrease in the layer of forest litter in Central Finland. *P. oblongopunctatus* was found to be a common species in natural spring deposits in Late Holocene in South-Central Sweden (Hellqvist, 2014).

In conditions of sufficient moisture in Great Britain, *P. oblongopunctatus* lives in all kinds of soil, often under bark. According to Lindroth (1974): it is found in England, in the north up to Yorkshire (lacking in the S.E.), Wales, Scotland, Ireland. "Inhabits woodland and forests, occurring over much of Britain. It has also been recorded from Ireland. Its distribution is rather patchy, with four or five apparent centres of distribution, and it is very local in Ireland. It generally shows a preference for rather open woods on dry soils", according to Luff (1992).

According to Freude et al. (2004), in the forests of Central Europe, the species is frequently found. *P. oblongopunctatus* is mentioned for the entire territory of Ukraine (Putchkov, 2011, 2012). In Southern Europe, the range of species is studied quite well (Arndt et al., 2011; Brigic et al., 2014). Guéorguiev (2007) provided mention for only 3 places in Albania, Hieke & Wrase (1988) – for 25 in Bulgaria. Later, Guéorguiev & Guéorguiev (1995) indicate records of this species in 13 of 22 regions. Further to south, this species occurs sporadically: Hristovski & Guéorguiev (2015) for the first time recorded this species in 3 from 93 geographical regions of Macedonia, Serrano (2013) recorded *P. oblongopunctatus* only in 1 (Pyrenees) out of 23 geographical regions of Spain.

In the central part of its range, in the Czech and Slovak Republics, *P. oblongopunctatus* is "very common in all types of forests; lowlands to mountains, frequent in hills" (Hurka, 1996). This species is abundant in the forests of South Moravia (Šejnohová, 2006). The species dominates in the forests of Poland (Sklodowski, 2006, 2014; Ulrich & Zalewski, 2006; Zalewski & Ulrich, 2006; Kwiatkowski, 2011; Sklodowski & Garbalinska, 2011; Zalewski et al., 2012). There numerous reports of finding this species in Lithuania (Tamutis et al., 2011). According to contemporary data (Putchkov, 2018), the species in the Ukrainian part of the range is common "in Polesie and Forest-Steppe, more often is found in forests of different types, near water bodies, in humid areas, in woodland belts, oak forests, groves, sometimes in meadows near the woodlands. In mountains, it reaches the subalpine zone. In the Steppe, it lives only in bairak forests and floodplain tree-shrub biotopes". In the Steppe zone of Ukraine, this is one of the commonest species in different types of forests, and beyond the borders of forest communities, *P. oblongopunctatus* is recorded rarely along river banks, meadows near woodland edges, in thinned out city parks, though it prefers parts of forests with typical mesophilous microclimatic conditions and developed forest litter (Brygadyrenko, 2016). The species is common in forest ecosystems of Moldova (Nekuliseanu & Matalin, 2000).

Kryzhanovskij (1983) indicates this species as being commonest in both the taiga and mixed forest zones. Kryzhanovskij et al. (1995) indicate the following distribution for this species in Russia: the northern Russian plain, the central part of the Russian plain, the southern Russian plain, the Caucasus Major, the Urals, northern West Siberia, the middle stretch of West Siberia, southern West Sibera, The Altais-Sayan Mt. Land, Middle Siberia, and Transbaikalia. In the zone of broad-leaved forests it is one of the most numerous species of ground beetles (Sharova, 1981; Sergeeva & Grunthal, 1988; Soboleva-Dokuchaeva, 1995; Sharova & Denisova, 1997; Zherebcov, 2000; Belskaya & Zolotarev, 2017). In the Volga region, it is found quite often, but is rare in the south (Kaljuzhnaja et al., 2000). In Ciscaucasia, it lives in forests of mesophilous type (Kryzhanovskij, 1983; Sigida, 1993); in Republic of Adygheya it is common in forests, and found more frequently in humid places (Zamotajlov & Nikitsky, 2010). Babenko & Eremeyeva (2007) report that this species as dominant in upland meadows outcide the city of Kemerovo. In the Far East, a whole group of closely related species of groundbeetles is distributed (Kryzhanovskij et al., 1995).

Probable change in the range. *P. oblongopunctatus* is a polyzonal species (Putchkov, 2018), therefore the shift of its range towards the north in the XXI century is perhaps related to the change in density of distribution of forest ecosystems. In QGIS program, we obtained maps which depict the range of comfort for *P. oblongopunctatus* at the current moment (Fig. 14), prognosis according to the scenario RCP 2.6 for year 2050 (Fig. 15) and prognosis for 2070 (Fig. 16). At the same time, using GIS-technologies allows recording absence or shifting of the range.

If one analyzes which of the stages of the seasonal dynamics (stages of ontogenesis of *P. oblongopunctatus*) can become the most vulnerable, in the south the most probable will be death of eggs and larvae during spring or summer droughts. In the territory of Ukraine, the species was reported throughout the vegetative season: from early spring to late autumn (Putchkov, 2018). Spring breeding and summer development of larvae which have thinner coats and which are less able to move quickly, increases the probability that this species will suffer a negative effect from the perspective of probable summer droughts in the south part of its range. Perhaps, death of larvae in the litter can be caused by forest fires.

In the north part of the range, probably the border of distribution range of *P. oblongopunctatus* will be the northernmost parts of forest ecosystems discovered to act as biological communities. One can presume that changes in mean annual temperature in the north part of the range can have an effect on the period of activity of the studied species. Late spring and summer breeding can be replaced by spring and even early spring breeding, and the beetle's activity period can be prolonged. The duration of the development of each stage of ontogenesis in Carabidae is influenced by a number of factors: temperature regime of soil and terrestrial layer of air, moisture, daylight hours, amount and quality of food, its accessibility, etc. (Thiele, 1975, 1977; Korolev & Brygadyrenko, 2014; Brygadyrenko, 2015a; Brygadyrenko & Korolev 2015).

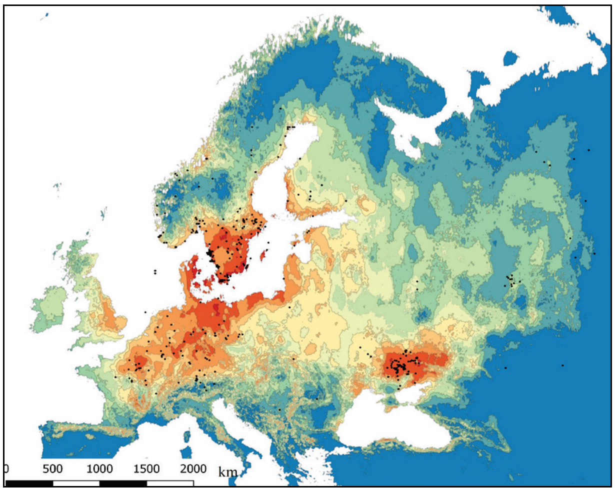

Fig. 14. Current range of comfort for *P. oblongopunctatus*: red and orange – most favourable territories, yellow and green – favourable territories, light blue – less favourable, dark blue – unfavourable territories

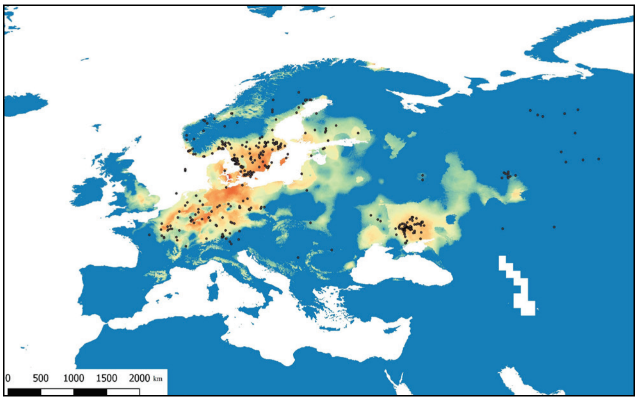

Fig. 15. Range of comfort for *P. oblongopunctatus* in 2050 according to scenario RCP 2.6: for notes see Fig. 12

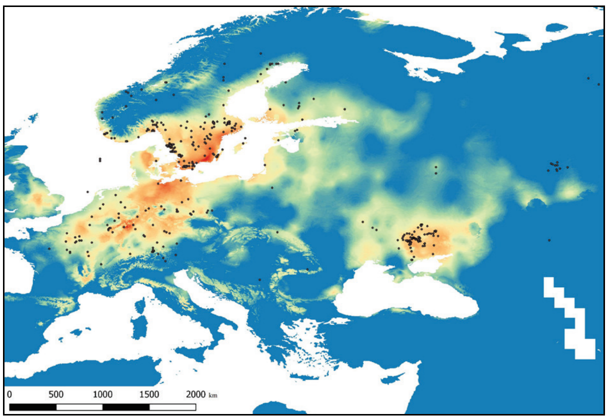

Fig. 16. Range of comfort for *P. oblongopunctatus* in 2070 according to scenario RCP 2.6: for notes see Fig. 12

Usually, the fastest development occurs among eggs, larvae of first age and pupae, whereas the development of larvae of older ages requires much more time. Even in the most unfavourable conditions, a minimum temporal threshold of pre-imago development exists, which among the majority of ground beetles of the temperate zone equals 1.0–1.5 months. One should also take into account the fact that the development of gonads of many species is controlled by photoperiod and therefore is closely associated with certain seasonal periods. Shift in range can lead to disorders of trophic relations, decrease in accessibility of the food base.

Analysis of models in range of *P. oblongopunctatus* revealed that the largest area of the range corresponds to the period 1960–1990. The zone of highest comfort is in the range of 0.85–0.92 with a maximum of 1 in the south-east coast of the central and southern part of Sweden, in south-west central and south part of Finland, in north-west countries of the Baltic, in the north of Poland and Germany, in the territory of Denmark, north-west coast of the Black Sea, eastern coasts of England and south of Kamchatka. The zone of heightened comfort for *P. oblongopunctatus* is mainly in the territory with mild maritime climate.

The model developed using contemporary bioclimatic data differs in the smaller area of the range, maximum values of the range of comfort at the territory of occurrence shift by 0.77–0.69. According to obtained contours, the predicted ranges in 2050 and 2070 according to scenario RCP 8.5 are significantly different from the predicted ranges according to scenario RCP 2.6. Large territories of Poland, Hungary, Romania, Ukraine become excluded from the zone of comfort of *P. oblongopunctatus*. According to scenario RCP 8.5, area of zone of comfort decreases on islands, whereas according to scenario RCP 2.6, an opposite effect is observed. According to scenario CRP 2.6, by 2050, a shift of the range will be observed towards the west, and also the area will decrease by 2070, when CO_2 emissions will practically stop, mean annual temperatures will have increased by 0.1 ºC, and the range of the studied species will begin to recover (Fig. 14).

Conclusions

Because the scenarios do not take into account biotic factors, food base and anthropogenic effect, the confident prognosis of change in the range is impossible. Also, it is impossible to consider all populations at the current stage of existence of the species and predict under which of the climate change scenarios they will develop in the future. However, the data we received indicate that the temperature regime is the main factor which directly or indirectly affects the distribution of this ground beetle. We hope that similar, though far from numerous, studies on the impact of global climatic changes on the distribution of certain species of ground beetles will help to conserve these zoophages which are important for natural ecosystems.

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