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Impact of climate change on biodiversity loss of entomofauna in agricultural landscapes of Ukraine

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ABSTRACT

Analysis of long-term data on the state of populations of entomofauna in agricultural landscapes is of practical importance for determining the feasibility of chemical protection of agroecosystems. Through the example of species of a harmful entomological complex of winter wheat in different natural and climatic zones of Ukraine, the dynamics of the population size of insects under global warming and the indicator of the living planet index (LPI) have been studied. Indicators of long-term insect's population size were used as input data based on the results of state phytosanitary monitoring. According to the analysed data on the state of indicator populations during 2009-2017, the indicators of the population size and weighted LPI were constantly decreasing. The correlation between the size of an insect's population and the course of natural warming does not make it possible to unambiguously explain the state of populations by the effect of an increased amount of heat.

Keywords: agricultural landscapes, climate warming, insects, population size, loss, dynamics

INTRODUCTION

At present, agricultural land in Ukraine occupies almost 71% of the territory (StateGeoCadastre, 2012). Thus, biodiversity in the country is represented by inhabitants of agricultural landscapes, among which insects are predominant (about 35.000 species) (Ministry of Environmental Protection and Natural Resources of Ukraine, 2015). For many years, environmentalists have been concerned about the global biodiversity loss of many terrestrial and aquatic vertebrates (Ceballos and Ehrlich, 2002). However, similar concerns about the condition of invertebrate taxa, especially insects, have only recently been emphasized (Sanchez-Bayo and Wyckhuys, 2019). Insect's populations and their geographical distribution began to decrease, which is believed to be the first step towards their extinction (Diamond, 1989). The scientific community perceived a decrease of 75% of insect biomass in some protected areas of Germany over 27 years as a shocking fact (Hallman et al., 2017). Recent papers note that the decline of arthropod biomass in the jungles of Puerto Rico is 78–98% (Lister and Garcia, 2018).

Global biodiversity loss is inextricably linked to the ecological state of ecosystems on the planet, which provide humankind with food, freshwater, clean air, energy, raw materials for medicine, opportunities for recreation, etc. The economic assessment of global ecosystem services conducted in 2011 showed that they cost between USD 125 and 145 trillion a year. Accordingly, biodiversity loss during 1997–2011 alone caused an economic loss of USD 4.3-20.2 trillion (Constanza et al., 2014).

The total value of ecosystem services in Miyun County (PRC) ranges from CNY 2,968.34 to 3,759.77. In terms of aspects of ecosystem services for agriculture, the largest share of total services (up to 35%) is the support of the environmental stability of soils (Zhang et al., 2015).

The main factors that cause a decrease in the population of insects include: 1) loss of habitat and transition to intensive farming and urbanization; 2) pollution, mainly with synthetic pesticides and fertilizers; 3) biological factors, including pathogens; and 4) climate change (Sanchez-Bayo and Wyckhuys, 2019). Some environmentalists consider climate warming to be the main factor in the decrease in the number of butterflies and wild bees in temperate latitudes (Bartomeus et al., 2011, Breed et al., 2012).

Meteorologists found that during 1991–2016, the average annual air temperature in Ukraine exceeded the norm by 1.0 °C, in 2017 by 1.8 °C (Lisovyy et al., 2017). The impact of climate change on the entomological diversity of agricultural landscapes in Ukraine has been adequately investigated. Thus, in the Forest-steppe zone, a significant diversity loss of entomofauna has been observed due to a complex of environmental factors (Lisovyy et al., 2019). The relevance of the study is determined by the probable effect of climate indicators on the number and distribution of the main pests of agroecosystems in Ukraine, which determine the possible crop losses.

The purpose of this study was to investigate the long-term dynamics of the main phytophagous insects' population of Ukrainian agroecosystems in different agro-ecological zones under climate change.

MATERIALS AND METHODS

Considering the species richness of entomofauna in the Ukrainian agroecosystems, the state of populations was studied during 2005–2017 through the example of an indicator group of species – the entomological complex of the main phytophagous organism of winter wheat crops. The long-term database of the population size of entomological complexes in different agroecological zones was used as input data. The long-term monitoring is carried out by specialists of the Administration of Phytosanitary Safety of the State Food and Consumer Service of Ukraine.

Until 2005, the following species were included in this complex: corn flies – Oscinella (*Oscinosoma frit* L. and *Oscinella pusilla* Mg.), Hessian fly (*Mayetiola destructor* Say.), wheat bulb fly (*Hylemyia coarctata* Flln.), Phorbia (*Phorbia securis* Tiensum), and Opomyza (*Opomyza florum* F.); cereal aphids – corn aphid (*Schizaphis graminum* Rond.) and English Grain Aphid (*Sitobion avenae* F.); bugs – corn bug (*Eurygaster integriceps* Put.), tortoise bug (*E. maura* L.), Eurygaster austriacus (*E. austriaca* Schr.), and Bishop's Mitre shield bug (*Aelia acuminata* L.); cereal beetles – grain beetle (*Anisoplia austriaca* Hrbst.) and Anisoplia chafers (*A. segetum* Hrbst., *A. agricola* Poda.); wheat thrips (*Haplothrips tritici* Kurd.); turnip moth (*Agrotis segetum* Schiff.), corn ground beetle (*Zabrus tenebrioides* Geoze.); and click beetles (*Elateridae*) (Kozak, 2007).

A long-term database of the Ukrainian Hydrometeorological Centre was used to analyse the occurrence of natural warming. The sum of effective temperatures (SET) above 10 °C was calculated for the growing season for each climatic zone.

The natural and climatic zones of Ukraine are characterized by specific indicators of the SET norm. In the period 1986–2005, the temperature norms were as follows: for Polissia 969 °C, for the Forest-steppe 1124 °C, and for the Steppe 1400 °C.

Indicators of the population size of insects and SET were averaged by zone for each year of analysis. The Pearson correlation coefficient between the long-term dynamics of SET and the population size of insects was calculated to determine the effect of global warming on the state of populations. The following notes are used in the text: * – significant correlation at 0.1; ** – significant correlation at 0.05; *** – significant correlation at 0.01.

According to the LPI method (WWF, 2014), everything was calculated as a percentage (share) of the estimated population size at the time when monitoring was started. In fact, for each population the indicator was normalized to the "starting population size"; the value of the index was determined as the average of the indices of all species included in the calculation for each time interval (WWF, 2014). The trend of LPI dynamics was also calculated.

RESULTS AND DISCUSSION

Climate warming according to the SET indicator in different climatic zones of Ukraine during 2005–2017 is shown in Figure 1.

The analysis of climate data showed that in 2005–2017 in Ukraine the sum of effective temperatures exceeded the climatic norms of the regions almost all the time, but the warming rates were different. For example, in Polissia the excess relative to the norm was minimum +1 °C in 2005 and 2008, maximum + 331 °C in 2012. On average, over the years under analysis, the sum of temperatures increased by 207 °C.

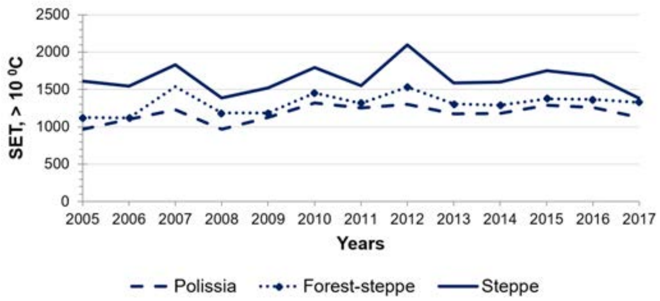

Figure 1. Dynamics of changes in SET (>10 °C) in different climatic zones of Ukraine over the years

In the Forest-steppe, the minimum excess of the sum of effective temperatures was registered in 2009 and it was 16 °C, the maximum in 2012 (+726 °C). On average, the sum of temperatures in the zone increased by 230 °C about the climatic norm.

In the Steppe zone in 2008 and 2017 a slight decrease in SET concerning the climatic norm, 15 °C and 20 °C respectively, was detected. The maximum increase of heat (+700 °C) was registered in 2012, which was recognized as the warmest year in all areas during the period under investigation. On average in the Steppe zone, the sum of temperatures increased by 368 °C.

In terms of the reaction of populations, the harmful entomological complex of wheat, which had been formed on crops by the middle of the 20th century, can be divided into three groups of species.

The first group (cereal fly, wheat bulb fly, cereal aphids, wheat thrips and corn sawfly) appeared to be most sensitive. These species lost their ecological constancy and significantly reduced their population size, which led to their exclusion from the list of phytophagous insects that must be monitored. The second group included species that are sensitive to climate change (Oscinella, Phorbia, Hessian fly) (Figures 2, 3).

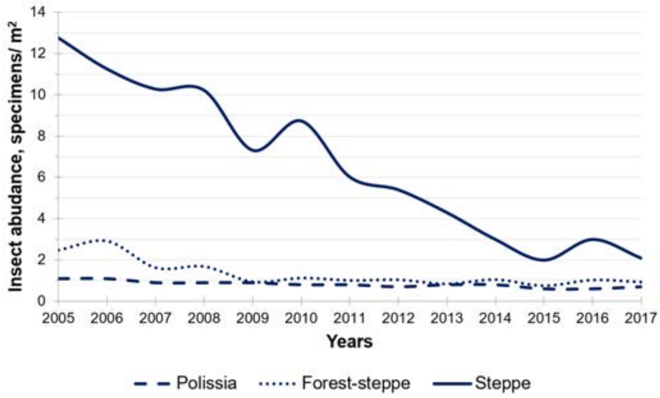

Figure 2. Long-term dynamics of the population size of Phorbia on winter wheat crops

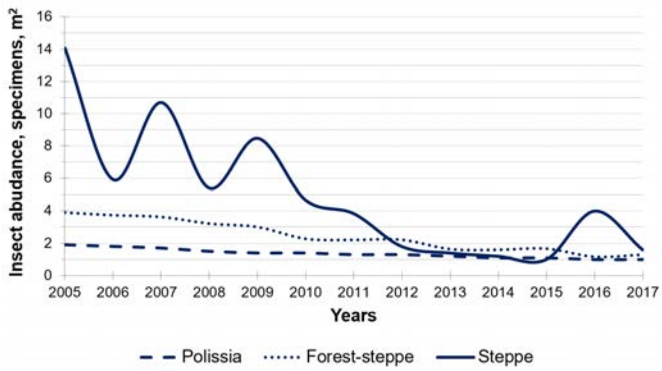

Figure 3. Long-term dynamics of the population size of Oscinella on winter wheat crops

This is confirmed by dynamics in the state of populations and the presence of an inverse correlation between population size and SET indicators. According to Chaddock scale, the strength of the relationship (r) for corn flies is defined as noticeable and moderate and is -0.69***, -0.50*, -0.49* (Polissia) and -0.53*, -0.38, -0.43 (Forest-steppe) for Phorbia, Oscinella and Hessian fly, respectively. There are no such correlations in the Steppe zone. The strength of the relationship is defined as weak and are -0.04, -0.05 and -0.03 for Phorbia, Oscinella and Hessian fly, respectively.

The nature of the response of populations of corn flies to heat increase in the Steppe may be determined by the pressure of the environmental factor that can reach the limit of insect tolerance to temperature.

The third group included species that do not actively respond to climate change due to environmental flexibility (capsid grain bugs, *Zabrus tenebrioides*, cereal beetles, turnip moth and click beetles) (Figures 4–6).

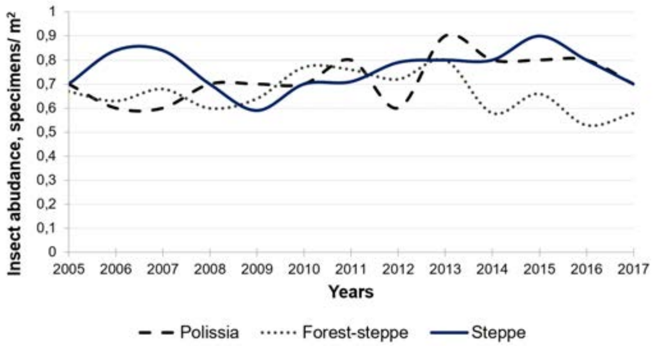

Figure 4. Long-term dynamics of the population size of cereal beetles on winter wheat crops

This is confirmed by the weak and moderate correlation between long-term population size and climate change indicators. Thus, the correlations between the population size of cereal beetles and the natural course of warming in different zones are 0.13 (Polissia), 0.30 (Forest-steppe) and 0.43 (Steppe).

The correlation is direct, which can be explained by the features of the biology of beetles: the long period of development of larvae in the soil should eliminate the correlation relationship. For *Zabrus tenebrioides*, the correlations are -0.20, -0.02, -0.32, respectively; for click beetles -0.31, -0.01, -0.06. For the turnip moth, the correlations are -0.69***, -0.159 and -0.080, respectively.

A corn bug is the main phytophagous insect of winter wheat in the Steppe zone. Since the end of the 20th century, in the context of global warming, the bugs have increased the population size and distribution in the Forest-steppe of Ukraine; they began to significantly damage wheat, which is not typical for these phytophagous insects.

As can be seen from Figure 5, the population size of the bugs began to decrease in the Forest-steppe zone from 1.6 specimens/m^2 in 2005 to 5 specimens/m^2 in 2008, in the Steppe zone it decreased significantly since 2009 – 3 specimens/m^2. In 2012, it did not reach the level of the harmfulness threshold (less than 1 specimen/m^2) and subsequently slightly changed (Figure 5). Correlation analysis did not reveal a relationship between the population size of the bugs and SET: r is -0.10 for the Forest-steppe and -0.28 for the Steppe zone.

The calculation of the correlation coefficients showed that the statistical relationship between SET indicators and the number of different species is reliable only for corn flies in Polissia and Forest-steppe, and turnip moth in Polissia.

Analysis of long-term data on the state of populations of a harmful entomological complex of winter wheat as an indicator group of species indicates a gradual decrease in the population size of insects against the backdrop of global warming in Ukraine. This conclusion is in line with the literature data on the global decline of invertebrates (Hallmann et al., 2017; Sanchez-Bayo and Wyckhuys, 2019). Correlation analysis does not make it possible to reliably link the process of loss of most populations with the increase of heat supply of the territory during the growing season.

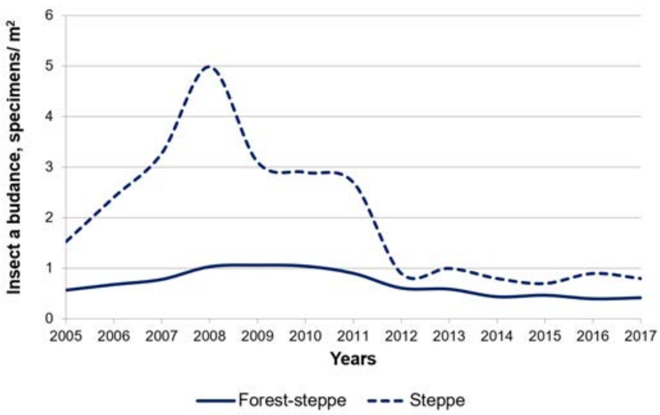

Figure 5. Long-term dynamics of the population size of corn bugs on winter wheat crops

During vegetation of cultivated plants, the complex of insects is affected by different environmental factors. It is known, for example, that climatic and weather changes determine the population size of phytophagous insects, their biotope distribution, feeding intensity (Ayres and Schneider, 2009), change the immune responses of insects, fertility, and the rate of development (Yumamura et al., 2006). The thermal effect can lead to a change in the status of a pest by suppressing or stimulating the genetic potential, as well as the relationship with the host plant (Finlay–Doney and Walter, 2012; Regniere et al., 2012). According to the law of aggregate action (Mitscherlich–Thienemann–Baule law), environmental factors will affect populations of insects collectively. The result of the complex action of factors can be manifested in the depression of the population size of insects.

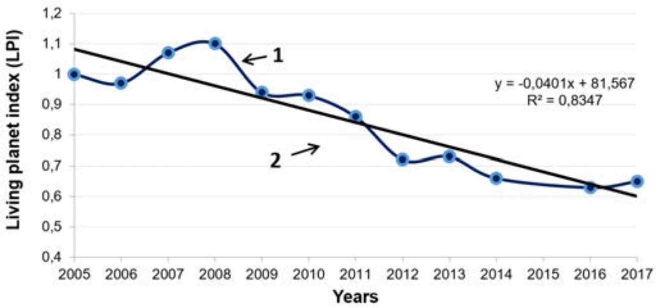

Figure 6. Long-term dynamics of weighted living planet index (LPI) in Ukraine: 1– value LPI; 2 – trend

According to the results of years of phytosanitary monitoring over the past 10 years in Ukraine, there has been a gradual decrease in the population size of insects in agricultural landscapes. Indicators of their population size reach the level of harmfulness thresholds only in some cases when the use of insecticides pays off with the preserved harvest. This conclusion is also confirmed by the calculation of the long-term dynamics of the weighted LPI index (Figure 6). The analysis shows that since 2009 there has been a stable depression in the population size of insects in Ukraine. In the context of the environmental crisis which Ukraine is experiencing, it is extremely relevant to determine the feasibility of chemical treatments of crops.

CONCLUSIONS

The analysis of the long-term state of populations of a harmful entomological complex of winter wheat as an indicator group of species makes it possible to conclude that there is a gradual decrease in the population size of insects in agricultural landscapes against the backdrop of global warming in Ukraine. This conclusion fits well with the data on the global decrease in the population size of invertebrates.

Calculation of the correlation coefficients indicates that a statistical relationship between SET indicators and the number of different species is reliable only for corn flies in Polissia and Forest-steppe, and turnip moth in Polissia of Ukraine.

Over the past 10 years in Ukraine, indicators of the population size of phytophagous insects of winter wheat have reached the level of harmfulness thresholds only in some cases, while the use of insecticides has paid off with the preserved harvest. In the context of the environmental crisis, which Ukraine is experiencing in the whole territory, it is extremely relevant to determine the feasibility of chemical treatments of crops.

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