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POLYCYCLIC CHARACTER, SYNCHRONISM AND NONLINEARITY OF INSECT POPULATION DYNAMICS AND PROGNOSTICATION PROBLEM

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ПОЛІЦИКЛІЧНІСТЬ, СИНХРОННІСТЬ І НЕЛІНІЙНІСТЬ ПОПУЛЯЦІЙНОЇ ДИНАМІКИ КОМАХ ТА ПРОБЛЕМИ ПРОГНОЗУВАННЯ

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Based on the past and present a theoretical synthesis of the regularities of population dynamics of the most common insect pests of agricultural plants, forest and fruit plantations has been done in the monograph.

The polycyclic character of their dynamics in space and time, regional and global synchronism and nonlinearity of the latter have been shown.

An analysis of the aggravated rates (mass reproduction of insects), the ranges of their prognostication and the prospects for the development of phytosanitary (ecological) forecasting as the basis for controlling the dynamics of the populations of harmful and beneficial organisms in ecosystems have been performed from the standpoint of nonlinear dynamics.

The monograph is intended for a wide range of specialists, biologists, ecologists and those people who are interested in this problem.

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CONTENT

> *Nowadays natural sciences are open for everything unexpected, which is no longer regarded as the result of the imperfect knowledge or inadequate control.*
>
> *Illia Prihozhyn, Isabella Stengers.*
> *Order out of chaos: a new dialogue between man and nature.*

INTRODUCTION

According to synergrtics, the insects' population is a complicated open biological system with a chaotic nonlinear dynamics in space and time. In this connection, the forecasting of their development in the future is not an easy task. It is enough to remember an "unexpected", "sudden", "unforeseen" mass reproduction of acridoid grasshoppers (Acrididae (Lat.), Turnip moth (*Scotia segetum* (Lat.), beet webworm (*Margarita sticticallis* (Lat.), corn ground beetle (*Zabrus tenebrioides* (Lat.), pentatomid eurygaster (*Eurygaster integriceps* (Lat.), beet root weevil (*Asproparthenis* (*=Bothynoderes) punctiventris* (Lat.) and a number of insect pests of forest and fruit and berry plantations (Stankevich, Beleckij & Zabrodina, 2019).

About three hundred years ago the French naturalist Rene Reamur (1683–1757) in 1735 for the first time described the mass reproduction of the common silvery moth (*Autographa gamma* (Lat.) in the environs of Paris, and laid the foundations for the meteorological and parasitic ideas of the insects' population dynamics, but the entomologists still ascertain and describe mass reproduction of the insects referring to their "unpredictability".

End of the XXth – the beginning of the XXIst centuries again were marked by mass reproduction of the acridoid grasshoppers (Acrididae (Lat.) in Kazakhstan, Russia, Ukraine and other regions of the world (Chajka, Baklanova & Serdyuk, 2010, Sergeev, 2010). In 2008 in the eastern regions of Russia, including Primorskii and Khabarovskii territories another outbreak of the webworm beetle (*Margarita sticticallis* (Lat.) reproduction was noted (Frolov, 2011).

In 1997–1998, after a short depression, a sunn pest (*Eurygaster integriceps* (Lat.) again declared about itself in Bulgaria, Hungry, Russia, Romania, Ukraine, Iraq, Iran, Jordan, Syria and Turkey. In 1997–1998 in the countries of the Middle East 5 million hectares of wheat were damaged by capsid grain bug from the genus of *Eurygaster*. At the same time, the annual expenditures for monitoring and protection of crops were about 40 million $ (Beletskij, 2011). In 2008–2010 the mass reproduction of the sunn pest (Eurygaster integriceps (Lat.) was reiterated again (Beleckij, 2015).

On the problem of the dynamics of insects' populations an almost limitless number of works have now been published; but nevertheless, there are still no answers to the topical questions. They are: what are the mechanisms of population dynamics; is it possible to predict future mass reproduction of insects in the future, and what are the limits of predictability? (Beleckij, Stankevich, 2018).

In the last two decades the fundamental works concerning the problems of chaos and predictability of the complicated systems' behavior in the future have been published. At the same time, it is proved that it is impossible to predict for a long time even relatively "simple" mechanical systems, not speaking about complex biological, ecological, economic, social, climatic, meteorological and other natural systems (Kravcov, 1997, Malineckij, 1997, Nikolas. & Prigozhin, 2003, Glushkov, Serga & Bunyakova, 2009, Malineckij & Potapov, 2010).

The proposed monograph is the result of theoretical synthesis of the insects' population dynamics from the positions of nonlinear dynamics methodology (synergrtics) with the substantiation of the possibility to forecast in ecology and plant protection.

The monograph is intended for a wide range of specialists, biologists, ecologists and those who are interested in this problem.

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ESSENCE OF THE PROBLEM

The problem of the population dynamics is one of the central problems of ecology. It arose with the appearance of mankind and its agricultural activities. It is determined by the time dimensions: the past, the present and the future. That is why the prognostication is a history oriented from the past to the future. Such a comparison has a certain sense because there is some symmetry between the prognostication and the past and the axis of this symmetry is the present; and prognostication of the mass reproduction of insects is a reflection of the history or chronological sequence of the dynamics of their populations over time. Moreover the chronicle of the mass reproduction of insects already contains the information on the results of the interaction of the populations with almost all environmental factors (Moiseev, 2001).

The insects, as one of the oldest and most numerous groups of animals that appeared on Earth about 400 million years ago, have the “genetic memory” in the past and, accordingly, transmit the genetic information from generation to generation using the genetic code according to the evolutionary triad: heredity, variability and natural selection (Moiseev, 2001). The latter is especially intensified during the cyclic recurrence of the mass reproductions, i.e. at different time intervals between the beginnings of the regular or so-called population cycles (Beletskij, 2011; Stankevich, Beleckij & Zabrodina, 2019). However as it is known at present the population cycles are not an exact repetition of the past in the future. They contain the information of the past, but the genetic and ecological structure (organization) of the populations is now naturally changing (Shvarc, 1969).

According to the scientific cosmological theories the possibility of producing new information in any evolutionary process is related to the cosmic principle of the hypothesis put forward by Harvard scientist David Lazer about the Universe of the thermodynamic equilibrium at zero temperature. An interesting consequence of this hypothesis is the assertion that the Universe can never contain enough information about the future development; something new can appear at any time and the system can pass to a new level of development which in the nonequilibrium and nonlinear dynamics (synergetics) is called bifurcation (Malineckij, 1997, Prigozhin & Stengers, 1986, Kurdyumov & Malineckij, 2001, Glushkov, Serga & Bunyakova, 2009). Therefore ... “we never know in advance when the next bifurcation will occur. The accident arises again and again like a phoenix from the ashes ... “ (Prigozhin & Stengers, 1986).

That is why in recent years the problem of the catastrophic events or the so-called in synergetics the appearing of the aggravated ranges in nonlinear systems has become very urgent. It is happened when one or several quantities characterizing the system grow ad infinitum in a finite time (Kurdyumov & Malineckij, 2001). In the population ecology these are the “unexpected” catastrophic mass reproduction of the insects (Beleckij, Stankevich, 2018).

The authors have hopes that based on the methodology of nonlinear dynamics (synergetics) it is possible not only to reveal the regularities of this complex ecological process, but also to learn to forecast it in the future in order to improve the prognostication.

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PART 1. THEORETICAL CONCEPTS OF THE POPULATION DYNAMICS OF INSECTS: THE PAST, THE PRESENT AND THE FUTURE. SYNERGETIC APPROACH

A theory is a generalized system of scientific knowledge. It should perform the following main functions: the descriptive, explanatory, synthesizing and prognostic ones. The latter is the main function. The prognostication theory should show how it is possible to synthesize the scenario of the future having very little knowledge of the mechanism of those processes that are caused by human interference in nature (Nalimov, 1983).

The population dynamics is the sum of the environmental and population factors that directly or indirectly influence the dynamics of its density and numbers. All the main factors of the population dynamics such as the mutation process, population cycles, isolation and natural selection, i.e. the Darwin evolutionary triad are simultaneously present and interacting at any time within the real natural populations (Moiseiev, 2001).

The theories explaining the seasonal and annual changes in the number of insects. The historical registers about the regularities of the insects' number dynamics are not numerous and they are fragmentary**.** The earliest studies of the ecology of insects were made by the French naturalist R. Reaumur (1683–1757). In his paper, published in 1735, the naturalist describes the original observations about the influence of some environmental factors on the development of the insects. In the same year for the first time Reaumur described the mass appearance of *Autographa gamma* in France, and during the next few years he performed a number of observations on the development of the insects at different temperature regimes. Reaumur is the author of the classical studies of parasitism among the insects and he is rightfully considered the founder of the parasitic and meteorological concepts of the insecsts' population dynamics.

With the invention of the thermometer the temperature has become the most obvious factor in the environment; and it is naturally that the first studies in the field of the insects' ecology primarily were devoted to this factor.

The earliest observations of the influence of the upper temperature limits on the ontogenesis and survival of insects were performed by O. Byutchli (1848–1920) in 1874 and by F. Graber (1844–1892) in 1887 (Biletskyi, 2011, Biletskyi & Stankevych, 2018).

At the beginning of the XIXth century revealing the reaction of insects to various changes in temperature, precipitation, relative humidity of air and various combinations of the latter became the basis for the formation of the climatic concept for the insects' number regulation.

In the middle of the nineteenth century two theoretical concepts of the population dynamics were formulated simultaneously. They are "the moving equilibrium" concept (Spencer, 1858) and the trophoclimatic one, formulated by K.F. Rouille (1814–1858). Their essence and conceptual foundations are described in the review of I.Ya Poliakov (1912–1992), who showed the formation of the basic theoretical ideas about the dynamics of the populations in the historical aspect.

The theory of the evolution by Charles Darwin (1809–1882) (Darwin, 1937) became the real scientific one. According to Charles Darwin the number of animal and plant organisms fluctuates in the natural environment more or less regularly, depending on the environmental and population changes; and like other biological systems, the basis of these fluctuations is the self-regulation of the populations. Despite the fact that Charles Darwin shared the views of T. Malthus (1766–1834) on the volatility of the populations' number, he emphasized the logical nature of this process and laid the foundations for the development of modern population ecology and biology in general. "Later this theory was modified and interpreted on the basis of Genetics regulations; and now it is the very core around which all modern Biology is built" (Mayr, 1982).

The main regulations of Darwin's evolutionary theory, especially which concern the populations' dynamics, have become a powerful incentive for further studies of the population ecology, the development and improvement of the theoretical ideas about the dynamics of the animals' number. The problem of the populations' dynamics soon became one of the most important in the ecological researches.

In the late 30s and in the early 40s of the twentieth century the domestic and foreign scientists simultaneously formulated the factorial dynamics of the populations, namely the parasitic, biocoenotic and the climatic ones. The main theses an the critical analysis of the above-mentioned theories are given in the monograph by Ye.M. Biletskyi (Biletskyi, 2011).

A characteristic feature of these theories was a clandestine attempt to fully explain the causes of the fluctuations in the number of any organisms by their reaction to any abiotic factors. A.M. Giliarov (1943-2013) (Giliarov, 1981) qualified such an approach to ecology as "outecological reductionism". As the author points out, the latter was a progressive methodology and prevailed in ecology until about the sixties.

In the 50s of the twentieth century at the example of the mouse-like rodents I.Ya. Poliakov formulated a theoretical conception of changing the viability of the populations in the process of their number gradation. Its essence lies in the fact that the viability of the population in the given period (its structure, physiological condition of separate age groups, the pace of development, reproduction intensity, survival, and resistance to various adverse factors) is determined by those conditions in which the age groups that constitute it, developed in the past. The author of this concept believes that the populations are differed not only in age composition, the ratio of sexes, and body proportions, but also in the nature of the reactions to the same environmental factors. This variability is formed under the direct influence of the nutritional conditions and climatic factors in which the individuals undergo the separate stages of ontogenesis or under the influence of the corresponding age fractions of the populations. Poliakov believed that the pests of the agricultural crops belonged to such groups of animals for which the physical factors and the forage reserve of the environment had a decisive importance in the dynamics of the populations. The morphophysiological properties of the populations, their reactions to the energy resources and climatic factors, the nature of the intrapopulation and intraspecies relationships and the importance of the latter for the trends in the population changes are formed under the influence of these factors. The basic and fundamentally new provision of this theory is that it allows us to judge in advance the dynamics of the number and the probable factors that can affect it, to appreciate the state of the forage reserve, the physical environment and the morphophysiological properties of the population; and this makes this theory acceptable for solving the problems of the forecasting (Poliakov, 1976).

In the last years of the twentieth century the theoretical concepts called by H.A. Viktorov (1925–1974) (Viktorov, 1983) as stohastizm and reguliacionizm were popular among the domestic and foreign ecologists; and the current stage of the researches in the populations dynamics was called by him as the search for the mechanisms for the number regulation.

The adherents of the first direction considered the effects of environmental factors on the population to be of a random nature. The combinations of different factors determine the changes in the number of the insects (ups and downs); and a favourable combination of the conditions that determine the rise in the number is observed in nature very seldom unlike the unfavourable one.

The representatives of the second direction consider the fluctuations in the number as a regulated process. They believe that the number random changes, caused by the direct or indirect effects of abiotic (mainly physical) factors, are indemnified for the activity of the regulatory mechanisms that are controled by the changes in the population density based on the principle of the negative feedback. As the adherents of the reguliacionizm think, the biotic factors of the environment, responding to the changes in the number of other organisms, can play this role.

According to the ideas of most modern ecologists, the change in the number of insects is considered as the interaction of various mechanisms. H.A. Viktorov divided them into modifying and regulating ones. He related the climatic and other geographical factors of the environment to the modifying mechanisms; the natural enemies (parasites, predators and pathogens), the intraspecies relations (competition) as well as the trophic factors (quantity, quality and availability of food) he reckoned to the regulating mechanisms.

More than seven decades ago the trophic theory of the populations' dynamics was formulated on the basis of example of the forest insects. The founder of this theory D.F. Rudniev (1902–1987) considered the number and quality of food as the main factor in the dynamics of the number of the stem- and needle-feeding insects. According to this author the weather and other environmental factors have an indirect effect on the number of populations through the condition of the forage crops. He wrote that "…they can only accelerate or slow down the growth rate of the population, which main direction is determined by the physiological condition of the plants themselves".

In the late 60s and in the early 70s of the twentieth century P. M. Rafes (1903-1991) substantiated the biogeocoenotic theory of the dynamics of the forest insects' population. Its conceptual basis is the dependence of the formation and size as well as the changes in the population on the biogeocoenosis as a supersystem, and the interdependence between the previous (a plant) and the following (a phytophagus) links in the nutrition chains. In accordance with this theory the population together with the factors regulating its number is a dependent system, namely it is a separate element in the biogeocoenoses. In this case the state of the population and the changes it undergoes are determined by the flow of the matter passing through it along the nutrition chains and carries out the circulation of matter in the given biogeocoenosis (Rafes, 1978). At the example of *Ocneria dispar* P.M. Rafes concluded that the mass reproduction of any herbivorous insects is a sign of the fact that the rate of its nutritional resource delivery has increased since the quality of the fodder became better and the possibility of its consumption also has increased (for example, due to the weather). So, the autrhor thinks that the circulation of matter and the flow of energy in the biogeocoenosis determine the productivity (number) of each population, and thus the ratio of the number of partners in relation to the trophic links.

Evaluating the biogeocoenosis theory of P.M. Rafes as an attempt to the systemic approach to the population dynamics analysis, one should admit that it was one of the variants of the trophic theory (Biletskyi, 2011, Biletskyi & Stankevych, 2018).

The dynamics of the populations number as an elementary factor of microevolution. S.S. Chetverikov (1880–1959) was the first who pointed out the general nature of the fluctuations in the number of the individuals in the natural populations and the possible evolutionary significance of this phenomenon at the example of the insects' "waves of life" (Chetverikov, 1905)**.**

Later the geneticists and evolutionists have shown that the population waves are an elementary factor in microevolution. They lead to the weakening of the natural selection with an increase in the number of the individuals in the natural populations and intensify the selection when the number of the individuals is decreasing.

In two decades S.S. Chetverikov in his work "About Some Moments of the Evolutionary Process from the Point of View of Modern Genetics" performed the theoretical synthesis of Darwinism and genetics and laid the foundations of the population genetics and the genetic theory of the species formation (Chetverikov, 1926).

Thanks to the above mentioned works, the fundamental importance of the populations which constitute the population of any species has been established in Biology. It became clear that all the evolutionary changes, called in 1938–1939 by N. V. Timofieiev-Ressovskyi (1900-1981) as microevolution, took place exactly at the population level (Timofieiev-Ressovskyi, 1958).

The detailed researches on the population genetics at the example of the insects were carried out in the 30s of the twentieth century by

N. P. Dubynin (1906–1998) and D. D. Romashova (1899–1963). They substantiated the theory of genetic and automatic processes that explain the regularities of the mass insect appearance. The analyses that were carried out by the authors showed that the genetic and automatic processes (GAP) were taking place throughout the whole life of the populations (Dubinin, 1932). They occur in the populations with a constant number, but they are especially intensive in the period of declining the numbers, when the genetic structure of the populations is restructured. With the increase in the number during the genetic and automatic processes the continuous differentiation of the genetic composition of the populations is extremely slow, but nonetheless it takes place.

The genetic and automatic processes can have a significant effect on the dynamics of the population changing the fertility and viability of the individuals in the populations, especially at that time when any mutation that has arisen, finds itself under the pressure of the natural selection. The changes in the number of the populations are the expression of various ecological dependencies between the environment and the organism. With the help of these dependencies the external environment realises a part of its influence for the genetic structure of the species and its evolutionary process. Thus, the theory of the genetic and automatic processes revealed some reasons for the fluctuations of the number of insects, which are based on the dynamics of the genetic composition of the populations.

The question of the populations's dynamics of harmful insects and rodents as limited panmixies were widely presented in the works of the famous biologist-evolutionist I.I. Shmalgauzen (1884–1963). The conclusions of I.I. Shmalgauzen (Shmalgauzen, 1946) about the four phases of changes in the number and their derivative effects are important for the theory of the populations' dynamics in the methodological aspect.

The first phase is an increase in number under the favorable conditions with the weakening of the natural selection action. It is associated with the accumulation and combination of the mutations (an increase in the individual variability).

The second phase is a relative stabilization accompanied by the increased competition, as well as a direct struggle for the existence. It is associated with the effective selection of the most favourable combinations and the reduction of the variability.

The third phase is a more or less sharp reduction in the number under the pressure of the powerful eliminating factors. It is associated with the subsequent reduction of the variability and, partially, with the occasional experiences of some more favourable combinations.

The fourth phase is a new reproduction; it is associated with the rapid proliferations of the surviving combinations and the subsequent accumulation of new mutations.

I.I. Shmalgauzen believed that the cyclic changes in the number of the populations made only a partial limitation of panmixia during the periods of depression, but their evolutionary importance is beyond doubt.

To know the laws of the insect populations' dynamics, the following conclusions are important:

– the populations are capable to maintain their number in a state of dynamic equilibrium despite the constant changes in the environmental factors; this is achieved by the adaptive homeostatic reactions of the separate individuals, the dynamics of the ecological structure of the population and the changes in its genetic composition;

– the fluctuations in the quality of the population; it is as much characteristic of its attribute as the number of the fluctuations.

As the author believed, an indispensable condition for maintaining the viability of the populations in the changing environmental conditions is the high degree of its genetic heterogeneity which is ensured by such ecological mechanisms as different way of life of various intrapopulation groups of animals, strict laws of the couples formation, different rates of sexual maturation of males and females, different ratios of sexes in different age groups and others.

According to S. S. Schwartz (1919–1976) (Schwartz, 1980) the ecological mechanisms of the evolutionary process are manifested in the three most important forms based on changing the age structure of the population (age selection), the change in the number (the non-selective elimination) and the change in the spatial structure of the population.

The sharp changes in the number are the most important factor for the transformation of the population and, contrary to the generally accepted notions, this factor (the non-selective elimination) affects the ecological structure of the populations and, as a rule, it has a strictly selective action, transforming it in certain directions which correspond to the changes in the environment. The sharp fluctuations in the number of the population, like the age selection, contribute to the rapid mobilization of the population reserves and, as a rule, they are one of the factors of its adaptive evolution (Schwartz, 1980).

At present there are many facts which show that the enrichment of the genetic fund of the populations is of the fundamental importance. Therefore it is naturally that the special mechanisms for maintaining the heterogeneity of the populations must exist. One of these mechanisms is the increased viability of heterozygotes. Heterozygosity in the populations is achieved by mixing the individuals, especially during the migration periods, when the probability of coupling the individuals from the populations of different genetic structures increases. The migrations and intermixing are one of the main mechanisms for the insects that maintain the genetic heterogeneity of the populations and prevent the depletion of the general genetic fund.

The genetic heterogeneity of the populations is one of the prerequisites for the microevolutionary transformations. However, as S.S. Schwartz rightly said "Natural selection can not work on credit. This means that the genetic heterogeneity of the populations is not only a prerequisite for their transformation, but it also increases the survival of the populations at the current moment in its history" (Schwartz, 1980).

Thanks to the researches of S.S. Schwartz (Schwartz, 1980) and other ecologists-evolutionists, there was a convergence of the evolutionary and ecological ideas. The beginning of a new stage of the ecological mechanisms of the microevolutionary process study during the development of the modern synthetic theory of evolution has been set. To know the ecological peculiarities of the populations, the relationship between the level and type of the number dynamics, the fertility, life duration, etc., the ecological and genetic structure of the populations was characteristic for that stage of the researches. The change in the ecological structure of the population, including the change in its number, leads not only to the genetic drift, that is, to the random change in the frequency of different genotypes birth, but also to the directed transformation of the genetic composition of the populations (the ecological mechanisms of the evolutionary process). The comprehensive study of these laws creates the preconditions for the development of a theory of management of the qualitative composition of the populations.

The synthesis of the evolutionary and environmental ideas, the creation of a single evolutionary and ecological approach to the study of the vital problems contributed to the exceeding of the biological knowledge the bounds of the empirical specificity and marked a new stage in the theory of Biology (Biletskyi & Stankevych, 2018).

The theories that explain the regularities of the population cycles. For many decades the problem of the insects' mass reproduction has taken one of the central places in the environmental researches all around the world**.** However, up to the present time the frequency of the mass reproductions outbreaks of certain types of harmful insects remains the subject of reflection, and the laws of the insects' reproductions are almost not studied (Biletskyi, 2011, Biletskyi et al., 2017, Biletskyi & Stankevych, 2018).

The recurrence of many years insects and other animals mass reproductions was observed long ago, but the natural character of this phenomenon was first shown by F.P. Keppen (1833-1908) (Keppen, 1870) at the example of the analysis of the massive appearance and migration of harmful locusts in Russia and the European countries in the period from 592 to 1866.

In the mid-twenties and in the early thirties of the twentieth century, based on the analysis of the historical data, the ecologists put forward the theoretical ideas about the frequency of the mass reproductions (rodents and insects), their relationship and interaction with the cycles of the solar activity, climate and natural enemies (zoophagous and entomophagous). Several different theories were proposed to explain the causes of the cyclic oscillations. They are the meteorological theory, the theory of random oscillations, the theory of the interaction between the populations (a predator – a victim and a parasite – a host) and the theory of the trophic levels (Odum, 1986).

However, all the attempts to link the cyclic fluctuations of numbers with the climatic factors are still remain unsuccessful (Odum, 1986).

The issue of the connection of the population cycles of insects and other animals with a long-term dynamics of the solar activity has long been discussed in the environmental literature.

This question, which has grown into the theoretical problem about the possibility of using the indicators of the latter as a criterion for predicting the appearance of the agricultural crops pests, has always affected the basis of the population dynamics theory (Biletskyi, 2011).

The first attempt to establish a connection between the massive reproductions of the insects belonged to F.P. Keppen (Keppen, 1870). After analyzing the mass reproductions and migrations of the harmful locusts in Russia and in the European countries for almost 1300 years historical period, he compared them with the long-term dynamics of the sun-spots and came to the conclusion that the periods with the particularly significant reproductions and subsequent migrations of the locust species in most cases had begun during the epochs of the minimum solar activity, in a year after the minimum or one year before it.

According to his data, the immense outbreaks of the locust populations took place in 1333–1339, 1689–1693, 1800–1806, 1822–1829, and in 1855–1862. These periods lasted for several years and ended on the sixth or seventh year after the minimum of the sun–spots (Keppen, 1870).

Half a century later M.M Kulagin (1860–1940) (Kulagin, 1921) turned to this problem again. Having systematized the historical materials as for the mass reproductions of the locust in Russia and some countries of Europe in the XVIIIth and XIXth centuries and compared them with the dynamics of the sun-spots, he came to the conclusion that the frequency in the dynamics of the number of the locusts is absent. This is due to the complexity of those factors that determine the dynamics of their populations. The mass breedings of the locust are more often observed in warm years and not in cold ones, although there are some exceptions (Kulagin, 1921).

In 1930, summarizing the chronicles of *Pyrausta sticticalis* mass reproductions in the central chernozem areas for the period of 1854-1929, M.M. Konakov also established the fact of their coincidence with the dynamics of the solar activity. For 61 years, from 1854 to 1915, the outbreaks in the number of this pest occurred five times (1855, 1867, 1889, 1901 and 1912), with the strict adherence to the minimum of the sun-spots or in the year preceding it. Only in 1878 (the year of the minimum), there was no *Pyrausta sticticalis*, but *Acridoidea*, *Anisoplia austriaca*, *Autographa gamma*, *Ocneria dispar* and *Dendrolimus pini* appeared in a great number. Beginning from 1916 to 1922, the outbreaks in number of *Pyrausta sticticalis* and *Locusta migratoria* were observed annually, and only in 1922 the mass reproductions of *Autographa gamma* and *Yponomenta malinellus* were noted (Konakov, 1930).

Since the middle of the fifties of the twentieth century the problem of the solar-induced outbreaks of the insect numbers concerning *Schistocerca gregaria* was especially intensively developed by M.S. Shcherbynovskyi (1891–1964). As M.S. Shcherbynovskyi pointed out, the cyclic character is one of the characteristic aspects in the life and reproduction of *Schistocerca gregaria*. According to his data, the outbreaks of this pest reproductions occurred 13 times over 150 years and repeated with the average intervals between the maximum outbreaks in 11,5 years. In addition, the synchronousness in the bases, process and extinction of the outbreaks in the number of *Schistocerca gregaria* on the vast territory of two continents, from India to Morocco was observed. These facts indicate that the proliferations of *Schistocerca gregaria* depend not only on the ecological conditions of its habitats, but also on some processes that cover the whole continents and cause more or less similar changes in the ecological environment in the permanent reservations of the pest, remoted from one another to tens of thousands of kilometres. According to M.S. Shcherbynovskyi (Shcherbynovskyi, 1952) the main reason for the cyclic nature of *Schistocerca gregaria* mass reproduction is the change in the solar activity that affects the dynamics and the circulation regime of the atmosphere and, accordingly, the weather in the zone of the primary centres of this pest reproduction. *Schistocerca gregaria* reacts upon these very changes with the cyclic recurrence of the reproductions and migrations of the flocks, flying thousands of kilometers from their primary centres. The author believed that under the conditions of savanna, desert and semi-desert, the form of *Schistocerca gregaria* existence and migration of its flock evolved during each year as well as during the cycles of its mass reproduction that could be evaluated as a reaction of the species to the geological course of the rhythms of weather conditions in the desert zones of their main natural habitat.

M.S. Shcherbynovskyi (Shcherbynovskyi, 1952) wrote that during the monsoon period in the arid districts of the tropical zone the rapid growth of the vegetation begins, which in turn leads to a sharp increase in the number of the locusts, to the formation of the last flock form that carries out the long-distant migrations. He proved that the migration has the same cycles as the solar activity. Along with it he denied emphatically all the anti-scientific explanations of the reasons for the temporary mass reproductions and extinction of the insects as the self-regulation of the species life of the organisms or the “dynamic equilibrium” between the “hosts” and their parasites. With the help of the dialectical methods Shcherbynovskyi tried to disclose the material causes of the observed natural phenomena. He proposed to lift up from the earth surface to the air where the energy that goes to us from a single energy source of our planetary system, the Sun, is transformed” (Shcherbynovskyi, 1952).

Later, in the 60's of the twentieth century M.S Shcherbynovskyi developed the idea that the outbreaks in the number of all harmful insects depend on the Sun activity, and in order to improve the methods of their mass reproductions forecasting he recommended to consider the trinominal dependence and conditionality. They are as follows:

– the rhythm of the solar activity variability;

– the regime of the atmospheric circulation, which is subordinated not only to the rotation of the Earth around the axis, but also to the pulses of wave and corpuscular radiation of the Sun;

– the ecological changes in the biocoenoses caused by the unsteady spatial and temporal seasonal changes in the weather regime under the influence of the solar and human activities.

The main works of M.S. Shcherbynovskyi made a significant contribution to the substantiation of the problem “The Sun – Biosphere”. At one time they were appreciated by O.L. Chyzhevskyi (1874–1977) (Chizhevskyi, 1995).

However, at that time these works did not obtain the recognition among the entomologists, mainly because the natural history didn’t possess the convincing evidencies of the real links between the Earth and the outer space. This problem was very complicated and not very familiar to the ecologists (Benkevych, 1948).

The detailed investigations of the changing regularities in the number of *Ocneria dispar* were made by V.I. Benkevych (Benkevych, 1984). He analysed the chronicles of this pest mass reproductions in the European part of the USSR for the period of 100 years and showed their connection with the solar activity, circulation regime of the atmosphere, weather and climate. As it was established by the author, most of the outbreaks in the number of *Ocneria dispar* took place at the stage of decline and during the minimum of the 11-year cycles of the solar activity, or in 2, 3, and 4 years after the maximum index of the reccurent processes and the maximum of the meridial processes of the atmospheric circulation development, namely in May, June or in November – March. The solar activity creates a cyclic background of *Ocneria dispar* massive reproductions, and it is not an ordinary modifying factor. The regulatory role of the Sun activity is manifested in regulating the influence power of other modifying factors and giving them a peculiar cyclic recurrence (Benkevych, 1984).

Acridologist A.N. Dobretsov (Dobretsov, 1967) also believed that there was a close connection between the population cycles of the locust and the solar cycles. Thus, analyzing the cyclic recurrence of outbreaks in the number of the solitary locusts’ species in the Krasnoiarskyi Krai, he came to the conclusion that they had the relationship with the droughts, which in this region mainly happened in the ninth or tenth years of the eleven-year solar cycle.

Many foreign ecologists associated the outbreaks of the harmful insects' massive reproductions with the cyclic recurrence of the solar activity (Biletskyi, 2011).

However, the hypothesis of the solar-terrestrial relationship between the harmful insects' mass reproductions and the solar activity was not recognised by the well-known Japanese ecologist K. Miiashita. He denied the frequency of the harmful insects' mass reproduction and their conditionality by the Sun. He showed the demonstrative results of his researches with a detailed analysis of the long-term (over 60–70 years) changes in the number of 12 species of pests of the agricultural and forest plants in different regions of Japan (Miiashita, 1963). The main conclusion of the author is that the outbreaks of the mass reproductions for most kinds of pests are irregular, and their duration varies. The exception is only the gregarious locusts, which dynamics number coincides with the changes in the solar activity of many years. The mass proliferations of the forest pests and the dynamics of the Sun activity in different regions of Germany are asynchronous; such a conclusion is made by the German ecologist D. Klimetzek (Klimetzek, 1976).

As we think, the main reason for the scepsis lies in the outdated methodological approach to assessing the cyclic character of the population dynamics, which consists of an unambiguous explanation of this complex environmental process, an attempt to bring the changes in number to one or more environmental factors, and to distinguish the main one among them; but such factor can not exist according to the systemic approach.

The linear approach to explain the characteristics of the solar activity and its terrestrial manifestations is also an important reason of the contradictions presented in the ecological literature. One more popular reason is misunderstanding of the fact that in the self-organised systems of populations, biogeocoenoses and biosphere there are direct and indirect connections that provide the hierarchy, interaction, synchronization and homeostasis of these systems. According to modern imaginations the solar activity is a complex open system with strange attractors and chaos; it has a sensitivity to the initial conditions, and its index W (Wolf number) is measured quite roughly; so one can expect only the forecasting of several long-term vibrations of the solar activity (Malinetskyi, 1997).

That is why the opponents' indications as for the lack of analysis and the confirmation of the connection between the Sun and environment are true (Viktorov, 1983).

In this regard H.A. Viktorov (1925–1974) (Viktorov, 1983) wrote that "the establishment of a connection between the fluctuations in the number and the rhythm of the solar activity requires more substantiated evidences based on the clarification of causal relationships, but not on a simple statement of the cyclic character with a certain average period of the fluctuations".

Naturally, this circumstance caused some scepticism in a part of domestic and foreign ecologists, even in those cases where the solar-ecological synchronization was established on the basis of a qualitative model.

In one time Yu.I. Vitynskyi (1926–2003) successfully described the situation in heliobiology. He pointed out that there were more sceptics than the adherents of that theory, who thought about the reality of the solar activity influence on the biosphere; especially it concerned the biologists and physicians.

We think that to some extent this is explained by the fact that the researchers of the connections between the Sun and the Earth often identify the terms of periodicity, rhythm and cyclic character (Vozovik, 1970). In order to clearly differentiate these notions and the necessity for a theoretical substantiation of the insects' mass reproductions regularities we consider it necessary to use such terms and notions in our general conclusions and studies.

A cycle is a complete or incomplete (interrupted) process which elements (phases, stages, steps, etc.), following one after another or in their turn, form a single row or a single whole.

A cycle character is the presence or existence of a cycle or cycles in the development (or structure) of something.

A rhythm is a regular (uniform) alternation, passing (correlation) and (or) recurrence of any elements characteristic to the development and proceeding of any system in space and time.

A rhythmical pace is the presence of a rhythm in the development (or structure) of something. The rhythm and rhythmical pace are manifested not only in their combination, alternation and recurrence of the cycles, but also in the cycles themselves and within them. It is not quite correct to bring the meaning of the term "rtythm" only to the uniform recurrence and periodicity. Despite its widespreading the periodicity is only a special case of the rhythmical pace. So, the rhythm is the most common property of inanimate and living matter organization; and the manifestation of its regularities is unlimited.

A period is the interval of time (or another dimension) during which something is happening (beginnig, developing and ending). Thus, the cycle period is a period of time during which it is proceeding (from its beginning to the end).

A periodicity is a regular (including uniform) recurrence of any (completed) phenomena, processes (cycles) in time and (or) in space through certain but necessarily equal units of any measurement system. The authors briefly formulated the difference between the notions of the cycle, rhythm and period as follows: the cycle is a process and a phenomenon; the rhythm is its characteristic, internal organization, and structure; the period is the measure (in any units of measurement) of the process and the phenomenon from the beginning to the end.

In many respects such a description of the processes and phenomena, occurring in the inorganic and organic world, is in a harmony with the dialectical concept of the development, according to which the recurrence (cyclic character) is a necessary sign of any law, the presence of the internal legitimity in the processes and phenomena and it has the objective character.

According to the scientists, the biological processes and phenomena are of a cyclic character. On the one hand their cyclic nature is explained by the constant influence of the external cosmic factors, and on the other – by autofluctuations inherent in any material system (Ivanytskyi, 1997; Chizhevskyi, 1995).

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PART 2. POLICYCYLIC CHARACTER, SYNCHRONISM AND NONLINEARITY OF INSECTS MASS REPRODUCTIONS

The chronicle of massive reproductions of the insect pests. The desert locust (*Schistocerca gregaria Forskal* Lat., 1775) is widespread in the tropical and subtropical regions of Africa and Southwest Asia. As a result of the analysis, the historical data on the mass reproductions of *Schistocerca gregaria* in the natural habitat is summarized and supplemented. This natural habitat is relatively divided into four regions: the eastern, western, central, and southern ones. The eastern region includes Afghanistan, Iraq, Iran, Pakistan, India, Saudi Arabia, Yemen, Oman, Eritrea, Ethiopia, Somalia and Egypt; the west region includes Mauritania, Senegal, Mali, Niger, Guinea, Guinea-Bissau, Burkina Faso and Western Sahara; the central region includes Angola, Zambia, Zaire, Sudan and Chad; and the southern region includes Botswana, Namibia and South Africa.

In the eastern region the massive reproductions of *Schistocerca gregaria* took place in 1843–1845, 1862–1873, 1875–1881, 1889–1908, 1912–1919, 1926–1936, 1939–1946, 1950–1954, 1966–1968, 1972–1975, 1981–1983, 1986–1990, 1992– 1995, and in 2003–2004; in the western region it took place in 1863–1867, 1890–1894, 1900–1903, 1905–1911, 1913–1919, 1926–1936, 1940–1947, 1950–1952, 1966–1968, 1972–1975, 1979–1983, 1986–1989 , 1992–1995, and in 2003–2004; in the central region its massive reproductions occurred in 1863–1866, 1869–1870, 1877–1880, 1889–1896, 1903–1909, 1913–1917, 1926–1932, 1936– 1939, 1940–1952, 1965–1970, 1973–1980, 1986–1990, 1992–1995, and in 2003–2004; in the southern region it took place in 1900–1909, 1912–1917, 1926–1932, 1940–1947, 1959–1962, 1968–1970, 1978–1981, 1986–1990, 1992–1995, and in 2003–2004. In the natural habitat the reproductions of *Schistocerca gregaria* took place in 1800–1803, 1810–1813, 1821–1826, 1833–1834, 1843–1845, 1860–1866, 1878–1881, 1890–1896, 1900–1909, 1913–1917, 1926 –1932, 1939–1946, 1950–1960, 1965–1970, 1973–1980, 1986–1990, 1992–1995, and in 2003–2004.

Locusta migratoria migratorioides (Fairmaire & L.J. Reiche, 1849) is widespread in all African countries, and during the period of 1889–2003 its mass reproductions occured in 1889–1892, 1903–1907, 1913–1914, 1927– 1929, 1936–1938, 1946–1951, 1953–1956, 1961–1968 , 1977– 1978, 1986–1989, 1992–1994, and in 2003–2004. In 1889 D. Caruters observed the transmigration of this locust over the Red Sea. Its flock included about 40 billion specimens, and their mass exceeded the mass of copper, lead and zinc extracted for the entire nineteenth century. In 1954 10 billion of individuals of this type of pests turned about 500 km² of flowering land in Kenya into a languid desert. In 1998, the flocks of *Locusta migratoris capito* (Lat.) (Saussure, 1884) touched down the island of Madagascar and destroyed 2 million hectares of rice. And in 2004 the flock of *Locusta migratoris capito* of 10 km long flew from Egypt to Israel.

Nomadacris septemfascuata (Audinet–Serville, 1838). From 1847 to 2004 there were 13 mass reproductions of this type in Namibia, Botswana and Zambia in 1847–1857, 1891–1892, 1906–1907, 1913–1920, 1927–1930, 1935–1938, 1940–1944, 1956–1958, 1961–1968, 1977 –1978, 1986 1989, 1993–1994, and in 2004–2005.

Chortoicetes terminifera (Walker, 1870). In the eastern and north–western regions of Australia the massive reproductions of this species were marked in 1934, 1937–1939, 1946–1947, 1950–1951, 1953–1955, 1973–1974, 1977–1979, 1984–1987, 1990, 1999–2001, and in 2006.

Calliptamus italicus (Linnaeus, 1758). According to the chronicles the massive reproductions of this pest in Kyivska Rus took place in 1008, 1024, 1083–1086, 1092, 1094–1095, 1103, 1195–1196, 1408, 1501, 1534, 1536, 1541–1542, 1579, 1583, 1601 1603, 1615, 1646–1648, 1652, and in 1685; in Ukraine it took place in 1688–1690, 1710–1713, 1719–1720, 1743–1744, 1748– 1749, 1756–1757, 1780–1783, 1793–1794, 1796–1799, 1803–1810, 1820–1823, 1825–1829 , 1834–1839, 1841–1843, 1850–1852, 1859–1860, 1862–1864, 1866– 1869, 1884–1888, 1890–1893, 1901–1903, 1910–1913, 1923–1925, 1930–1932, 1937–1939, 1945–1947, 1951–1953, 1995–1997, and in 2003.

Dociostaurus maroccanus (Thunberg, 1815). The natural habitat of *Dociostaurus maroccanus* is the steppes of the southwestern part of Ukraine, the Southern Crimea and the foothills of Ciscaucasus, Transcaucasus, Central Asia and Kazakhstan. As a pest of sugar beets *Dociostaurus maroccanus* was noted in Hungary, Bulgaria, Greece, and Yugoslavia (Camprag, 1973). The mass proliferations of this pest were: in 1901-1902, 1905, 1909, 1929-1932, and in 1939 in Bulgaria; in 1919 - 1925, 1937-1940, and in 1948-1949 in Hungary; in 1930-1933 and in 1946-1948 in Yugoslavia; in 1949 and in 1974 in Syria; in 1953 in Somalia; in 1955 in Morocco; in 1960 in Iraq; in 1993, 2000 and in 2006-

2008 in Kazakhstan; in 2002 in Afghanistan; and in 2000-2001 in Chechnia.

Locusta migratoria (Linnaeus, 1758) in Ukraine. *Migratoria rossica* L. (Uvarov et Zolotarevskyi, 1929). In Ukraine the mass proliferations of this pest took place in 1708–1712, 1719– 1720, 1726–1732, 1745–1748, 1756–1757, 1780–1785, 1793–1794, 1797–1799, 1804–1806, 1822–1825, 1834–1836, 1844–1848, 1850–1858, 1853, 1855–1860, 1862–1864, 1866–1868, 1875–1876, 1880–1882, 1890–1894, 1896–1897, 1899, 1912, 1920–1923, 1933, 1938, 1946, and in 1995–1996.

The solitary locusts are *Podisma pedestris* (Linnaeus, 1758), *Gomphocerus sibiricus* (Linnaeus, 1767), *Pararcyptera microptera* (Fischer von Waldheim, 1833) and *Stauroderus scalaris* (Fischer von Waldheim, 1849). In Krasnoiarskyi Krai their mass proliferations were noted in 1726, 1755–1756, 1840, 1902–1903, 1911–1913, 1942–1943, 1946–1948, 1951–1955, 1962– 1967 1986–1988, and in 1999–2002.

The mass reproduction of *Melolontha sp*. (Fabricius, 1775) took place in 1856–1861, 1863–1864, 1867–1868, 1879–1880, 1892–1893, 1895–1896, 1899–1900, 1905–1906, 1929–1932, 1936–1938, 1946–1947, 1949 –1952, 1957– 1958 1962–1963, 1965–1966, 1985–1986, and in 2009–2010.

The mass reproduction of *Letrus apterus* (Laxmann, 1770) were in 1846–1847 1852, 1867, 1873, 1879–1880, 1898–1902, 1933–1935, 1972, 1975, and in 2000–2001.

The mass reproduction of Elateridae (Leach, 1815) and Tenebrionidae (Latreille, 1802) occurred in 1873, 1879, 1881 1885–1890, 1900, 1916–1920, 1931–1940, 1972–1975, and in 1989–1990.

Opatrum sabulosum (Linnaeus, 1761) and *Pedinus femoralis* (Linnaeus, 1767) (beetles) massively reproducted in 1879–1881, 1925–1926, 1930, 1936, 1938, 1945–1948, 1953–1954, and in 1983–1985.

Scotia (Agrotis) segetum (Denis & Schiffermüller, 1775). The first mass reproduction of this pest in Europe was recorded in 1572, in Ukraine it was noted in 1638, in the Volga region – in 1764. In 1790 the caterpillars of this pest destroyed the spiked cereals in Latvia, and in 1795 – in the St. Petersburg province. At the beginning of the nineteenth century *Scotia (Agrotis) segetum* caused a great damage in the nonblack-soil belt of Russia and in the countries of Baltia. During the historical period of 1813-1999 there were 22 mass reproductions of *Scotia (Agrotis) segetum* in 1813-1819, 1823-1825, 1836-1842, 1846–1852, 1855–1856, 1867–

1868, 1880–1881, 1892–1896, 1899–1900, 1907–1909, 1915–1919, 1923–1925, 1934–1941, 1946–1950, 1955–1957, 1964–1968, 1971–1973, 1981–1984, 1997–1998 and in 2007–2008.

Scotia (Agrotis) exclamationis (Linnaeus, 1758). The mass reproductions of this pest in Ukraine were in 1836–1840, 1843–1844, 1850–1852, 1855–1856, 1860, 1869–1870, 1879–1880, 1893–1895, 1907–1909, 1923–1924, 1936–1940, 1967–1968, 1972–1973, 1976, 1982–1984, 1987, and in 1999–2003.

Autographa gamma (Linnaeus, 1758). In Ukraine the mass proliferations of *Autographa gamma* were registered in 1829, 1833, 1839–1840, 1854 1859–1860, 1864–1865, 1870–1871, 1879–1880, 1888–1889, 1899–1900, 1910, 1912–1913, 1922, 1928–1930, 1946, 1953, 1960 1961 1988, and in 1995–1996.

Heliotis viriplaca (Hufnagel, 1766). In Ukraine during one century (1875–1976) the mass reproductions of this pest was noted in 1875, 1879, 1881–1882, 1886–1888, 1892–1894, 1897–1898, 1904–1905, 1928, 1934, 1945, 1948–1949, 1953, and in 1976–1977.

Mametstra brassicae (Linnaeus, 1758). In Ukraine the outbreaks of this pest mass reproduction took place in 1871, 1878–1879, 1896, 1904–1905, 1908–1909, 1912–1914, 1922–1923, 1927–1928, 1932–1933, 1937–1938, 1956–1957, 1964 –1965, 1969–1970, 1973–1975, 1985–1986, 1990–1991, 1994, 1997–1998, and in 2000–2002.

Mythimna unipuncta (Haworth, 1809). In the Far East its mass reproduction took place in 1926, 1939, 1943, 1950, 1953, 1955, 1966–1967, 1969–1970, 1972–1973, 1975, 1978, 1983, and in 1985.

Ostrinia nubilalis (Hubner, 1796). From 1852 to 2006 in Ukraine there were 11 outbreaks of mass reproduction of this pest. They took place in 1852 1869–1870, 1879–1880, 1886–1887, 1892–1901, 1911–1918, 1929–1934, 1961–1962, 1977–1978, 1986–1996, and in 2006–2008.

Margaritia sticticalis (Linnaeus, 1761). Known from the chronicles the first mass reproduction of this pest in Ukraine was dated 1686 (The Chronicle of the Eye–Witness, 1878, p. 164), the second one occured in 1769. According to the more accurate data its mass reproductions in Ukraine were in 1855, 1869, 1880, 1901, 1912–1913, 1920–1921, 1929–1932, 1935–1936, 1956, 1975 and in 2011–2013.

Eurygaster integriceps (Puton, 1881). In Europe the massive proliferations of *Eurygaster integriceps* are known from the XIXth century, in Asia – from the end of the 1st century A. D. In Iraq during the reign of Harun-ar-Rashid (766-809), a caliph from the Abbasids dynasty, the Arabs went hungry for several years because of the destruction of wheat and barley crops caused by the mites. In Iran, according to the legend information, during the massive proliferations of *Eurygaster integriceps* in 1736 Nadir Shah Afshar (1688-1747) ordered his warriors to burn out the wild growing cereals in the mountain centres of the hibernation of *Eurygaster integriceps* and thus, as the legend said, he saved Iran from the disaster of this pest. If the legend information is true, then in 200 years, namely, in 1936-1937, the massive reproductions of *Eurygaster integriceps* were recured again in the countries of the Middle and Far East, Kazakhstan, the republics of Central Asia, the Caucasus, the Volga region and in Ukraine.

The formation of *Eurygaster integriceps* as a dangerous pest of wheat and barley has been accomplished during several subsequent historical stages. The first stage is the formation of the mites' primary harmfulness centres and, accordingly, the formation of the prerequisites for a focal increase in their number. The second stage is the settling of the mites and the separation of their geographical populations as a result of the agriculture development in the Western and Middle Asia and Transcaucasus, with their subsequent settling in the Southeast Europe, steppe and forest-steppe areas of Asia and Europe.

In Stavropolskyi Krai, according to the data clarified by us, the massive reproductions of *Eurygaster integriceps* took place in 1854–1856, 1865–1867, 1880–1884, 1892–1896, 1901–1905, 1909–1912, 1926, 1937–1941, 1950–1952, 1967–1968, 1984–1986, 1992–1994, 1997, 2003, and in 2007. In 2009 the next outbreak began.

In Rostov region the massive reproductions of *Eurygaster integriceps* took place in 1892–1893, 1901–1905, 1909–1912, 1916, 1923– 1924, 1937–1941, 1948–1949, 1955–1958, 1967–1968, 1984–1986, 1992–1994, and in 1996–2000. In 2009 the next outbreak began.

In republics of Adygea, Dagestan, Ingushetia, Kabardino-Balkaria, Karachaievo-Cherkessia, North Ossetia (Alania), Kalmykia, and in Volgograd region another massive reproduction of *Eurygaster integriceps* began in 2008, in Chechnyia it began in 2007.

In the steppe zone of the Volga region the mass reproductions occurred in 1890–1892, 1900–1905, 1909–1912, 1931, 1937–1941, 1952–1956, 1967–1968, 1972–1973, 1986–1988, and in 1996–2000; in 2008 the next outbreak began.

In the Central Chernozem region of Russia the masses of *Eurygaster integriceps* were in 1890–1894, 1901–1904, 1909–1912, 1937–1941, 1954–1956, 1967–1968, 1984–1986, and in 1996–2000; in 2009 the next mass reproduction began.

The massive reproductions of nine local populations of *Eurygaster integriceps* (Dnipropetrovsk, Donetsk, Zaporozhzhia, Kirovograd, Luhansk, Mykolaiv, Odessa, Kharkiv and Kherson) in Ukraine were in 1890–1896. In 1901–1902, 1909–1912, and in 1925–1926 they took place in Luhansk, Odessa and Kharkiv; in 1937–1941, 1950–1956, 1967–1968, and in 1972–1973 the mass reproductions were noted in Kharkiv and Kherson; in 1980–1984 and in 1992–1995 – in other regions, and in 2008 the next mass reproduction began.

The mass reproductions of the Crimea population of *Eurygaster integriceps* took place in 1870–1871, 1880–1881, 1890–1892, 1916, 1931, 1938–1941, 1955–1958, and in 1997–1998. In 2010 another massive reproduction of *Eurygaster integriceps* began in all administrative districts of the Crimea Autonomous Republic.

According to the information specified by us, the mass reproductions of *Eurygaster integriceps* in the countries of the Middle and Far East were: in Iraq – in 1909–1912, 1920–1921, 1924–1928, 1937–1938, 1943–1949, 1953–1958, 1978–1981, 1986–1991, and in 1997–1998; in Iran – in 1735–1736, 1909–1911, 1920–1921, 1924–1932, 1937–1938, 1943–1949, 1953–1958, 1978–1981, 1986–1991, and in 1997–1998; in Jordan – in 1924–1928, 1935–1938, 1943–1949, 1953–1958, 1989–1992, and in 1997–1998; in Lebanon – in 1924–1928, 1935–1938, 1956–1958, 1961–1966, 1989–1992, and in 1997–1998; in Palestine – in 1920–1921, 1924–1928, 1937–1938, 1953–1958, 1989–1992, and in 1997–1998; in Syria – in 1909–1914, 1924–1928, 1937–1938, 1953–1958, 1961–1966, 1989–1992, and in 1997–1998; in Egypt – in 1931–1933, 1939–1941, 1956–1958, 1967–1972, 1979–1990, and in 1997–1998; in Turkey – in 1886–1889, 1909–1911, 1927–1930, 1932–1933, 1939–1941, 1956–1958, 1978–1981, 1986–1991, and in 1997–1998.; in Pakistan – in 1940–1946, 1956–1958, 1978–1981, 1986–1991, and in 1997–1998; in Morocco (*Eurygaster austriaca*, *Eurygaster maura* and *Eurygaster integriceps)* – in 1932–1934, 1940–1947, 1953–1955, 1967–1990, and in 1997–1998.

In Kazakhstan the massive proliferations of *Eurygaster integriceps* occured in 1901–1905, 1907, 1913, 1915, 1918, 1920–1922, 1924–1928, 1940–1943, 1961–1966 1986–1988, and in 1997–1998; in Kyrgyzstan – in 1901 –1905, 1907, 1913, 1915, 1918, 1920–1922, 1924–1928, 1939–1943, 1961–1966, 1986–1988, and in 1997–1998; in Uzbekistan – in 1901–1905, 1909–1913, 1915, 1918, 1920–1922, 1924–1928, 1939–1943, 1961–1966, 1986–1988, and in 1997–1998; in Tajikistan – in 1901–1905, 1907, 1909–1912, 1915, 1918, 1920–1922, 1924–1928, 1939–1943, 1961–1966, 1986–1988, and in 1997–1998; in Turkmenistan – in 1900–1905, 1907, 1909–1913, 1915, 1918, 1920 1921 1924–1928, 1939–1943, 1961–1966, 1986–1988, and in 1997–1998.

In the Palearctic realm the mass reproductions of this pest took place in 1854–1856, 1865–1867, 1880–1886, 1890–1896, 1900– 1905, 1909–1914, 1920–1922, 1924–1928, 1931–1933, 1937–1943, 1948–1957, 1964–1970, 1972–1981, 1984–1991, 1996–2003, and in 2008–2010.

The mass reproductions of *Eurygaster austriaca*, *Eurygaster maura* and *Eurygaster integriceps* in Bulgaria, Hungary, Germany, Italy, Poland, Portugal, Romania, Czechoslovakia and Yugoslavia were in 1929–1933, 1950–1956, 1964–1970, 1977–1981, 1984–1986, 1996–1998, and in 2008–2010.

Zabrus tenebrioides (Geoze, 1777). During the period from 1860 to 2001 in the Steppe and Forest-Steppe zone of Ukraine there were 13 mass reproductions of this pest in 1860–1864, 1880–1881, 1903–1905, 1923–1925, 1937–1941, 1947–1948, 1951–1953, 1957–1959, 1961–1963, 1966–1967, 1979–1982, 1991–1993, and in 2003–2007.

Mayetiola destructor (Say, 1817). From 1847 to 2000 the massive reproductions of *Mayetiola destructor* in Ukraine were in 1847–1848, 1852 1855–1856, 1874–1876, 1879–1881, 1896–1898, 1900–1903, 1906–1911, 1923–1925, 1930–1932, 1936–1938, 1947–1948, 1952–1955, 1961–1963, 1968–1969, 1972–1973, 1979–1980, 1986–1987, 1991–1992, and in 2000–2003.

Oscinella frit (Linnaeus, 1758). *Oscinella frit* severely damaged the grain crops in the western part of Latvia from 1825 to 1837, in Germany and Poland – from 1867 to 1870. In Ukraine its mass reproductions took place in 1880–1882, 1890–1892, 1902–1903, 1907–1909, 1911–1912, 1923–1925, 1930–1932, 1949–1953, 1961–1962, 1972–1975, 1985–1986, 1991–1992, and in 2000–2003.

Anisoplia austriaca (Herbst, 1783). In Ukraine for the period from 1841 to 1996 there were registered 17 mass reproductions in 1841–1842, 1845–1846, 1856–1857, 1860–1861, 1868–1869, 1879–1880, 1886–1887, 1896–1903, 1906 1910 1915–1917, 1924–1925 1936–1939, 1956–1957, 1962–1964, 1966–1969, 1980–1984, and in 1996–2007.

Apamea sordens (Hufnagel, 1766). In the Forest-Steppe zone of Ukraine the massive reproductions of this pest were in 1871, 1881, 1885–1887, 1896, 1911–1913, 1923–1924, 1933, 1939–1940, 1946–1947, 1950–1951, 1960, and in 1963–1965.

Apamea anceps (Denis & Schiffermüller, 1775). The mass proliferations of *Apamea anceps* were noted in Northern Kazakhstan in 1887–1888, 1901–1903, 1911–1912, 1924–1926, 1937–1939, 1949–1951, 1957–1959, 1965–1966, 1969–1970, 1974–1975, 1980–1981, 1992, and in 2003–2004.

Amphiposa fucosa (Freyer, 1830). The mass reproductions in Ukraine were in 1877–1879, 1886–1887, 1889–1892, 1913–1914, 1929–1932, 1960, and in 1986–1989; in Tatarstan – in 1877–1881, 1885, 1960, and in 1986–1987; in the south of Moscow region they took place in 1913–1914.

Oria musculosa (Hubner, 1808). In the Steppe zone of Ukraine the mass reproductions occurred in 1882, 1884, 1886–1889, 1891–1896, 1898–1902, 1910–1913, and in 1931–1933.

Cerapteryx graminis (Linnaeus, 1758). The caterpillars of this pest damage rye, oats, and barley and meadow grasses. In Ukraine (Forest-steppe and Polissia) they caused the damages in 1842, 1847–1849, 1854–1855, 1866–1867, 1878, 1880, 1882, 1886–1889, 1896, 1912, 1919, 1923, and in 1926–1928. In the northern districts of Karelia and in the Leningrad province these caterpillars caused the damages in 1924-1927; in 1907 they were noted in Finland. Earlier this pest was noted in 1866–1867, 1880–1881, 1882–1883, 1885–1886, 1891–1893, 1896–1897, 1914–1916, 1920–1921 and in 1925–1926. In 1890–1891, 1911–1916 and in 1921 it was noted in Sweden, in 1899, 1911 and in 1917 – in Norway, in 1917 and in 1919 – in England, in 1923 – in Denmark, in 1917 – in Scotland, in 1923–1924 and in 1928 – in Germany, in 1915 – in Austria-Hungary. In the Baltic State of Kurliandiia *Cerapteryx graminis* caused the damages in 1854; in the environs of Lītava it was noted in 1829. In Riga and Revel *Cerapteryx graminis* together with *Agrotis segetum* destroyed the crops of peas. The damages of flax and peas were known in 1787.

Oulema melanopus (Linnaeus, 1758). Over the past 118 years the mass reproductions of *Oulema melanopus* in Ukraine took place in 1878–1880, 1882, 1894–1895, 1907–1910, 1912–1914, 1934–1935, 1938–1939, 1952, 1955–1956, 1962–1963, 1971– 1972, 1983–1988, and in 1995–1996.

Cephus pygmaeus (Linnaeus, 1767). The mass reproductions of this pest in Ukraine took place in 1850, 1870, 1875 1878 1880–1883, 1887–1888, 1893–1895, 1902–1903, 1907–1910, and in 1912–1914. In the last century this pest was in the depression, and its number did not exceed the economic threshold of harmfulness.

Chlorops pumilionis (Bjerkander, 1778). In Ukraine (mainly in Polissia) the massive reproductions were in 1879–1881, 1887–1888, 1923–1924, 1952–1954, 1956–1957 and in 1962–1963.

Opomysa florum (Fabricius, 1794). In 1829, 1968–1969, 1980–1984, 1986–1987, and in 1990–1991 the mass proliferations of *Opomysa florum* took place in Polissia.

Acyrthosiphon pisum (Harris, 1776). The mass reproductions of this pest in Ukraine were noted in 1903–1905, 1911, 1913–1914, 1923, 1926, 1929, 1931–1932, 1937, 1963–1964, 1973 and in 1986.

Chaetocnema sp. (Stephens, 1831) The mass reproductions of this pest in Ukraine were noted in 1841–1842 1852, 1858, 1878–1880, 1922, 1933, 1946–1947, 1953–1954, 1958–1959, 1968–1969, and in 1990.

Cassida nebulosa (Linnaeus, 1758). The mass reproductions of this pest in Ukraine were noted in 1834, 1841, 1859, 1871, 1878, 1897, and 1903, 1911–1912 and in 1915.

Cassida viridis (Linnaeus, 1758). Its mass reproductions in Ukraine occurred in 1840–1841, 1859–1860, 1871, 1878, 1897, 1903, and in 1911–1912.

Asproparthenis punctiventris (Germar, 1824). The mass proliferations of *Asproparthenis punctiventris* in Ukraine were in 1851–1855, 1868–1869, 1875–1877, 1880–1881, 1891–1893, 1896–1897, 1904–1906, 1911–1912, 1920–1922, 1928–1930, 1936 –1940, 1947– 1949 1952–1957, 1963–1964, 1973–1976, 1986–1988, 1998–200, and in 2010–2012.

Plutella maculipennis (Linnaeus, 1758). The mass reproductions of this pest in Ukraine were noted in 1908, 1914–1916, 1923, 1928, 1938, 1946, 1952, 1958, 1964, 1970–1972, 1976–1978, 1987–1988, and in 1995–2000

Pieris brassicae (Linnaeus, 1758). In Ukraine the mass reproductions of this widespread pest took place in 1846–1847, 1851–1852, 1854–1855, 1862, 1866, 1868, 1910, 1913, 1927, 1931–1932, 1936–1937, 1947–1948, 1981–1982, 1991–1992, and in 2001–2002.

Athalia rosae (Linnaeus, 1758). The mass reproductions of this pest in Ukraine were noted in 1756, 1760, 1782, 1806, 1818, 1833, 1835–1836, 1838, 1866, 1878–1879, 1889, 1895–1896, 1922–1924, 1925–1928, 1956, and in 1978–1979.

Rhynchites auratus (Scopoli, 1763). The mass reproductions of this pest took place in 1903, 1913–1914, 1916–1917, 1924–1925, 1937–1941, and in 1947–1949.

Aporia crataegi (Linnaeus, 1758). The mass reproductions of this pest occurred in 1838–1839, 1849–1853, 1859–1860, 1867–1869, 1896–1897, 1906–1907, 1910–1911, 1916–1917, 1923–1925, 1933–1934, 1946–1948, 1954–1956, 1966– 1967 1980–1983, 1993–1994, and in 2003–2004.

Yponomeuta malinellus (Zeller, 1838). The mass reproductions of this pest were noted in 1843–1845, 1857–1858, 1874–1875, 1884–1885, 1894–1896, 1903–1905, 1916–1919, 1924–1925, 1934–1936, 1946–1948, 1957–1959, 1965–1967, 1973– 1975, 1985–1987, and in 1994–1996.

Malacosoma neustria (Linnaeus, 1758). Its mass reproductions took place in 1826–1829, 1838–1839, 1843–1844, 1849–1850, 1856–1857, 1862–1866, 1882–1883, 1889–1890, 1903–1907, 1915–1916, 1923–1925, 1933–1936, 1947–1948 1956–1957, 1967–1968, 1977–1978, 1987–1988, and in 1998–1999.

Cydia pomonella (Linnaeus, 1758). The mass reproductions of this pest took place in 1855–1856, 1868–1869, 1879–1880, 1885, 1888–1890, 1894–1896, 1898–1899, 1936–1937, 1950–1952, 1955–1956, 1960–1961, 1986–1987, 1993–1996, and in 2007–2008.

Operophthera brumata (Linnaeus, 1758). The mass reproductions of this pest took place in 1844–1845, 1848–1850, 1856, 1868–1869, 1880–1881, 1892–1893 1903–1904, 1911–1912, 1948–1951, 1953–1954, 1960–1965, 1967, 1972–1977, 1979–1980, 1986, 1993–1994, and in 1999–2001.

Tortrix viridana (Linnaeus, 1758). The mass reproductions of this pest took place in 1853–1854, 1864, 1875, 1886, 1906–1910, 1923–1925, 1929, 1947–1949, 1952–1954, 1961–1964, 1966, 1968, 1972–1975, 1983–1984, 1986–1988, 1992, 1996–1998, and in 2000.

Euproctis chrysorrhoea (Linnaeus, 1758). The mass reproductions of this pest took place in 1841–1842, 1847–1848, 1855–1856, 1859–1860, 1862–1863, 1867–1868, 1880–1881, 1885–1888, 1896–1897, 1907–1909, 1912–1913, 1920–1921, 1924–1925, 1929–1930, 1933–1934, 1937–1941, 1948–1951, 1958–1959, 1965–1967, 1971–1973, 1983–1984, and in 1997–2000.

Ocneria dispar (Linnaeus, 1758). The mass reproductions of this pest took place in 1837–1839, 1841–1842, 1850–1852, 1859–1863, 1868–1871, 1879–1880, 1886–1887, 1895–1898, 1907–1910, 1912–1914, 1920–1923, 1931–1936, 1942– 1944, 1948–1952, 1956–1957, 1964–1968, 1972–1973, 1982–1983, and in 1995–1997.

Ocneria monacha (Linnaeus, 1758). The mass reproductions of *Ocneria monacha* took place in 1846–1849, 1851–1852, 1855–1860, 1863–1867, 1889–1892, 1905–1907, 1925–1927, 1937–1942, 1946–1950, 1952–1960, 1978–1980, 1987–1988, and in 1999–2000.

Dendrolimus pini (Linnaeus, 1758). The mass reproductions of this pest occurred in 1839–1842, 1850–1854, 1863–1870, 1875–1877, 1883–1884, 1890–1891, 1896–1899, 1902–1904, 1913–1915, 1923–1925, 1937–1941, 1947–1948, 1961–1962, 1971–1973, 1977–1978, 1983–1988, and in 1995–1998.

Dasychira pudibunda (Linnaeus, 1758). The mass reproductions of this pest occurred in 1853–1855, 1867–1868, 1883–1884, 1901–1902, 1917–1918, 1926–1928, 1932–1933, 1940–1941, 1953–1955, 1964–1965, 1968–1970, 1980–1981, 1986–1989, and in 1997–1999.

Phalera bucephala (Linnaeus, 1758). The mass reproductions of this pest occurred in 1875, 1893–1894, 1941–1942, 1945–1946, 1953–1954, 1958–1959, 1962, 1966, 1968, and in 1972.

Panolis flammea (Denis & Schiffermüller, 1775). The mass proliferations of *Panolis flammea* were noted in 1825–1827, 1888, 1892, 1912, 1922–1925, 1930–1931, 1938–1940, 1946–1947, 1957–1959, 1962–1964, 1973–1975, 1983–1985, and in 1997–2000.

Bupalus piniarius (Linnaeus, 1758). The mass proliferations of *Bupalus piniarius* were noted in 1869–1872, 1875–1880, 1890–1896, 1914–1915, 1918–1919, 1923–1925, 1937–1941, 1947–1948, 1956–1957, 1961–1966, 1971–1972, 1975–1980, 1988–1992, and in 1995–1999.

Diprion pini (Linnaeus, 1758). The mass proliferations of *Diprion pini* were noted in 1838–1839, 1842–1844, 1848–1849, 1854–1855, 1875–1876, 1883–1884, 1887–1891, 1899–1900, 1903–1904, 1910–1911, 1926–1930, 1932–1933, 1936–1938 1941–1943. 1947–1950, 1956–1957, 1966–1968, 1978–1972–1973, 1975–1976, 1978–1980, 1983–1984, 1991–1994, 1997–2000, and in 2002–2005.

Neodiprion sertifer (Geoffroy, 1785). The mass reproductions of this pest took plce in 1880–1881, 1886–1887, 1893–1894, 1907–1908, 1917–1918, 1922–1924, 1934–1937, 1945–1948, 1950–1955, 1958–1960, 1964–

1966, 1972–1973, 1975– 1976, 1978–1980, 1983–1984, 1991–1994, 1995–2000, and in 2009–2010.

As it can be seen from the above-mentioned chronology of mass reproduction of the certain types of harmful insects, the outbeaks in number are often of a random character, and their frequency is from 2-3 to 1000 years. Such data can not explain the theories based on the dependence of the number of insects on the hydrothermal coefficient or the availability of the fodder plants (Poliakov, 1964). In the twentieth century the theoretical concepts, called by H.A. Viktorov (Viktorov, 1967) as a stochasticism and regulatsionism were popular among the ecologists; and he considered the current stage of the researches in the population dynamics as a searching for the mechanisms of the number regulation. In the twenty-first century the necessity for the theoretical synthesis in the insects' ecology has arisen. This synthesis should predict the appearance of a new theory, in which the limitations of the old theories are dialectically removed (Biletskyi, 2011, Beleckij, Stankevich & Nemerickaja, 2017, Biletskyi & Stankevych, 2018). This article is one of the first steps in creating the theory that will explain the recur.

rance and cyclic character of the mass reproductions of insects. To do this task the synergistic synthesis which takes into account the systemic regularities of the insects' development and interaction with the systems of the organizations of higher level is necessary. It also should take in account the illinearity of the population dynamics and chaos, as well as the aggravated regimes and the limited prognoses (Stankevich, Beleckij, Zabrodina, 2019).

Population cycles of insects (in space and time).

The seasonal, annual and long-term dynamics of insect populations suggest constant cyclic changes in the structure (organization) of the latter in the process of interaction with the cyclically changing environmental factors (space, geophysical, biotic, etc.). The long-term changes in the number of insects which are recurred over time were called the population cycles and genetic and automatic processes. In recent years an almost unlimited number of works have been published in which the regularities of the population cycles are presented, but the problem is still relevant, debatable and needs the further research taking into account the modern methodology of nonlinear dynamics. The extensive materials have been accumulated in the literature as for the connection, interaction, and synchronization of space, climatic, trophic and population cycles that allow performing the interdisciplinary synthesis; as it is known the latter without fail assumes the emergence of a theory. In the process of the interdisciplinary synthesis of the theoretical ideas of domestic and foreign ecologists about the changes in the number of populations from the positions of a systematic approach, the analysis of modern achievements in astrophysics, biorhythmology, biophysics, space physics, heliobiology, climatology and other natural sciences, the long-term analysis and generalization of the historical information on mass reproduction of 70 species of insect pests of agriculture and forestry in Ukraine and in other regions as well as based on our own studies of the ecology of the sun pest, we have substantiated the theory of cyclic character of the insect populations dynamics.

The cycling of mass insect breeding.

De Mole noted the cyclic character of the mass reproductions of the locusts more than 150 years ago. A quarter of a century later F.P. Keppen put forward a hypothesis about the connection of the mass reproductions of the above-mentioned pests with the long-term dynamics of sun-spots. Then Swinton noted the mass appearance of the locusts in the eras of the sun-spots minima. In several regions of Africa and Asia B.P. Uvarov noted the simultaneous appearance of the desert locusts, which was connected with the changes in the sun-spots. In 1952 N.S. Shcherbinovsky (without reference to the works of F.P. Keppen) substantiated the cyclic character of the mass reproduction of schistocerca as a natural process. The data of the long-term dynamics of the geographical populations of some species of insects generalised by us also indicate their cyclic character in time (Table 2.1).

Table 2.1

Population cycles of insects (in space and time) (Beletsky, Stankevich, 2018)

№	Insect species, region, years of mass reproductions	Duration of mass reproductions	Year intervals between the next mass reproductions, years
1	**2**	**3**	**4**
1	Desert locust or schistocerca		
	Eastern region (1843–2003)	3, 5, 8	5–6, 7, 9, 11, 13–14, 19, 23, 100
	Western region (1863–2003)	4, 5, 7	5, 6–7, 8, 10, 11, 17, 20, 100
	Central region (1863-2003)	4, 5, 7	6, 8, 10, 12, 13, 15, 100

	Southern region (1900-2003) Range (1800-2003)	4, 7	6, 8, 10, 11, 14, 100 6, 10–11, 12–13, 17, 18, 100
2	African migratory locust (1889–2003)	2, 4	7, 8–9, 10, 14, 100
3	African red locust (1847–2004)	2, 4	5, 7, 8, 9, 11, 15, 44, 100
4	Australian plague locust (1934–2006)	2, 3	3–4, 5, 7, 9, 15
5	Italian locust in Ukraine (1711–2003)	1, 2, 3, 4	3, 4, 6–7, 8, 9, 11–13, 24, 44, 100, 200, 300
6	Asiatic migratory locust in Ukraine (1708–1995)	4, 5	3, 4, 6–7, 8, 9–10, 11, 50, 100, 200
7	Turnip moth (1813–2007)	2, 3, 5, 7, 8	7–8, 9–10, 11–12, 19, 100, 200
8	Heart moth (1836–1999)	1, 2, 3, 5	4, 5, 6, 7, 9, 12–13, 14
9	Gamma moth (1829–1995)	1, 2	5, 6, 9, 10–11, 18, 28
10	Marbled clover (1875–1976)	1, 2	5–6, 7, 11, 23–24
11	Mamestra cabbage moth (1871–2000)	1, 2, 3	3, 4–5, 7, 8, 10, 12, 21
12	European corn borer (1869–2006)	2	6, 7, 9, 10, 16, 18, 42, 100
13	Webworm beetle (1855–2011)	3, 4	6, 8, 9, 10, 12, 14, 16, 100
14	Sun pest:		
	Ukraine (1870–2008)	2	8, 10–11, 12, 14, 16, 17
	Stavropol territory (1854–2009)	1, 3, 5	8, 9, 12–13, 15, 17
	Krasnodar territory (1854–2009)	3, 5	8, 9, 12–13, 15, 17
	Rostov region (1892–2009)	2, 4	8, 9, 11, 12–14, 17
	Volga region (1890–2008)	3, 5	8, 10–11, 12–14, 15

	Central Chernozem Region of Russia (1850–2009)	3, 5	8, 11–12, 13–14,28
	Iraq (1909–1997)	2	4, 6, 8, 9, 10, 11,25
	Iran (1909–1997)	2	4, 6, 8, 10–11, 13,23
	Jordan (1924–1997)	2, 4	4, 7–8, 10, 36
	Lebanon (1924–1997)	3, 4	4, 5, 7, 8,21, 28
	Palestine (1920–1997)	2, 4	4, 7–8, 18,36
	Syria (1909–1997)	4, 6	4, 7–8, 15, 28
	Egypt (1931–1997)	3	8, 12, 17–18, 21
	Turkey (1886–1997)	3	5, 7, 8, 11, 22–23
	Pakistan (1940–1997)	2, 3	8, 11, 16, 22
	Kazakhstan (1901–1997)	1, 3	3, 4, 6, 11, 14, 23–25
	Kyrgyzstan (1901–1997)	1, 3	3, 4, 6, 11, 14, 23–25
	Uzbekistan (1901–1997)	1, 3	3, 4, 6, 11,23–25
	Tajikistan (1901–1997)	1, 3	3, 4, 6, 11, 23–25
	Turkmenistan (1900–1997)	1, 5, 6	3, 4, 6, 11, 14, 23–25
	Palearctic (1854–1995)	3, 7, 8	8, 11–12, 15–16
15	Ground beetle (1863–2003)	2, 3	4–5, 6, 12, 13, 14, 20, 23
16	Hessian fly (1847–2000)	2, 3, 4	5, 6–7, 8–9,11, 17, 19
17	Frit fly (1880–2000)	2, 3	4, 5, 6, 9, 10, 12–13, 19

18	Anisoplia austriaca beetle (1841–1996)	2, 3, 4	4, 6, 7, 8, 9–10, 11–12, 14, 16
19	Apamea noctuid moth in Ukraine (1871–1963)	1, 2, 3	3, 4, 6, 7, 9, 10–11, 12, 15
20	Owlet moth in Nothern Kazakhstan (1857–2003)	2, 3	5, 6, 8, 9, 10, 11, 12, 14
21	Beet root weevil (1851–2010)	2, 3	5,7–8, 9–10, 11, 17, 100
22	Diamond black moth (1908–2000)	1, 3	5,6, 8, 9, 10, 11, 100
23	Cabbage butterfly (1846–2001)	1, 2	3, 4, 5, 8, 10, 11, 14, 42
24	Turnip fly (1756–1978)	1, 2	2, 3, 4, 6, 11–12, 14–15, 22, 27, 31
25	White thorn butterfly (1838–2003)	2, 3	6, 7–8, 10, 11, 12–13, 14, 29, 100
26	Brown–tail moth (1841–1997)	2, 3	3–4, 5–6, 7–8, 10–11, 12, 14, 100
27	Apple ermine (1843–1994)	2, 3	8, 9, 10–11, 12–13, 17, 100
28	Lackey moth (1826–1998)	2, 4	5,6,7, 8, 9, 10, 11, 12, 14, 20, 100
29	Codling moth (1855–2007)	2, 3	3–4, 5–6, 7, 11, 13, 14, 33, 44
30	Winter moth (1844–1999)	1, 2	5–6, 7, 8, 9, 11, 12, 37, 100
31	Green oak roller moth (1853–2000)	1, 3	3, 4, 5, 6, 7, 9, 11, 20
32	Gypsy moth (1837–1995)	2, 3, 4, 5	5, 6, 7, 8–9, 10, 11, 13
33	Nun moth (1846–1999)	2, 3, 4, 5	4, 5, 6, 8–9, 12, 20, 26, 100
34	Piny moth (1839–1995)	2, 3, 4, 5	6, 7, 8, 10–11, 12, 14, 100
35	Pale tussock moth (1853–1997)	2, 3	8, 9, 11, 14, 16

36	Pine noctuid (1825–1997)	1, 3	5, 8, 10, 11, 14, 20
37	Pine looper moth (1869–1995)	2, 5, 6	4, 5, 6, 7, 9–10, 13, 15, 24
38	Pine sawfly (1838–2002)	2, 3, 5	4, 5, 6, 8, 9–10, 12, 16, 21
39	European pine sawfly (1880–2009)	2, 3	3, 5, 6, 7, 8, 10, 11–12, 14

Based on the data from the table it can be concluded that the mass reproductions of 39 species of insects are of cyclic and polycyclic characters, but they are not periodic!

In the scientific literature the problem of the possibility to use the solar activity indices (Wolf numbers) as one of the criteria for forecasting the mass reproduction of insects has long being discussed. In particular some acridologists and other scientists propose using the erads of minima or maxima numbers of the solar activity as the criteria for forecasting the beginning of the regular population cycles. If it were so, then it would not be difficult to forecast the beginning of the regular mass reproductions of insects. In fact the mass reproductions of the locusts and other harmful insects do not occur periodically, but they have the cyclic character, i.e. they took place at different intervals. Moreover the outbreaks of their numbers occur both in the eras of minima and in the eras of maxima of the solar activity and on different branches of its dynamics (the growth branches and the branches of decline). This is evidenced by the historical and statistical analysis performed by us at the example of different species of insects and their mass reproduction in time in different regions of the world.

According to the data given in Table 2.2 we can make the following important methodological conclusion: the mass reproductions of insects took place in different eras of 11-year cycles of the solar activity, therefore the above-mentioned criteria are unsuitable for forecasting their beginning.

Earlier the German entomologist Klimetzek came to a similar conclusion having performed an analogous analysis of the relationship between the mass reproductions of the pine looper moth, pine noctuid, nun moth, piny moth and pine sawflies in Germany for the period of 1810-1970. The findings of the latter were confirmed by V.L. Meshkova (2002).

Table 2.2

Probability of beginning of regular mass reproductions of some species of insects in the Palearctic in different eras of solar activity dynamics (SA) (Beletsky, 2011)

Species of insect	**Years of mass reproductions**	**Probability (%) of beginning of regular mass reproductions in different eras of SA**			
		minimum of SA	**branch of SA growth**	**maximum of SA**	**branch of SA decline**
1	**2**	**3**	**4**	**5**	**6**
Desert locust or schistocerca:					
eastern region	1843–2003	14,0	14,0	0,0	72,0
western region	1863–2003	22,0	14,0	14,0	50,0
central region	1863–2003	28,0	28,0	0,0	44,0
southern region	1900–2003	10,0	20,0	10,0	60,0
range	1800–2003	44,0	11,0	6,0	39,0
African migratory locust (in the range)	1889–2003	42,0	25,0	0,0	33,0
African red locust (in the range)	1847–2004	24,0	38,0	0,0	38,0
Australian plague locust (in the range)	1936–2006	20,0	20,0	10,0	50,0
Marrocan locust (in the range)	1901–1974	14,0	14,0	14,0	58,0
Asiatic migratory locust (in Ukraine)	1708–1995	18,0	10,0	4,0	68,0
Solitary locusts (in the range)	1726–1999	14,0	14,0	14,0	58,0
Italian locust (in Ukraine)	1711–2003	20,0	16,0	4,0	60,0
Turnip moth	1813–1999	28,0	38,0	10,0	24,0
Heart moth	1836–1999	29,0	29,0	18,0	24,0
Gamma moth	1829–1995	29,0	29,0	18,0	24,0

Mamestra cabbage moth	1871–2000	17,0	56,0	11,0	16,0
European corn borer	1869–2006	30,0	20,0	0,0	50,0
Webworm beetle	1855–2011	17,0	42,0	8,0	33,0
Sun pest:					
Stavropol territory	1854–2009	19,0	31,0	6,0	44,0
Krasnodar territory	1854–2009	16,0	38,0	8,0	38,0
Rostov region	1892–2009	31,0	31,0	15,0	23,0
Volga region	1890–2009	27,0	18,0	0,0	55,0
Central Chernozem Region of Russia	1890–2009	44,0	22,0	12,0	22,0
Iraq	1909–1907	30,0	10,0	20,0	40,0
Iran	1909–1997	33,0	11,0	11,0	45,0
Jordan	1924–1997	28,0	14,0	29,0	29,0
Lebanon	1924–1997	29,0	29,0	28,0	14,0
Palestine	1920–1997	29,0	14,0	28,0	29,0
Syria	1909–1997	25,0	12,0	25,0	38,0
Egypt	1931–1997	16,0	50,0	17,0	17,0
Turkey	1886–1997	22,0	33,0	0,0	45,0
Pakistan	1940–1997	40,0	40,0	0,0	20,0
Palearctic	1854–1995	27,0	13,0	0,0	60,0
Ukraine	1870–2008	21,0	36,0	14,0	29,0
Cereal bug, eurygaster bug and sun pest in Bulgaria, Hungry, German, Italy, Poland, Portugal, Romania, Czechoslovakia and Yugoslavia	1928–2008	57,0	0,0	14,0	29,0
Ground beetle	1860–2003	8,0	26,0	40,0	26,0
Hessian fly	1847–2000	16,0	11,0	26,0	47,0
Oat frit fly	1880–2000	15,0	16,0	0,0	54,0
Anisoplia austriaca beetle	1841–1996	29,0	29,0	12,0	30,0
Apamea noctuid beetle	1871–1963	16,0	16,0	20,0	67,0
Owlet moth (Northen Kazakhstan)	1887–2003	0,0	0,0	11,0	50,0

Brighton wainscot	1882–1931	43,0	43,0	29,0	57,0
Cereal leaf beetle	1878–1995	8,0	8,0	28,0	46,0
Beet root weevil	1851–2010	12,0	12,0	23,0	53,0
Diamond black moth	1908–2010	10,0	10,0	17,0	18,0
Cabbage butterfly	1846–2001	29,0	29,0	0,0	43,0
White thorn butterfly	1838–2003	19,0	19,0	0,0	37,0
Brown-tail moth	1841–1997	14,0	14,0	0,0	50,0
Apple ermine	1843–1994	20,0	20,0	14,0	27,0
Lackey moth	1826–1998	39,0	39,0	6,0	16,0
Codling moth	1855–2007	7,0	7,0	14,0	57,0
Winter moth	1844–1999	35,0	35,0	40,0	30,0
Gypsy moth	1837–1993	5,0	5,0	26,0	58,0
Pine noctuid	1825–1997	17,0	17,0	15,0	54,0
Pine looper moth	1869–1995	22,0	22,0	12,0	43,0
Pine sawfly	1838–2002	26,0	26,0	25,0	57,0
European pine sawfly	1880–2009	22,0	22,0	0,0	39,0

N.Ye. Beletskaya in 2003 having analysed the dynamics of the population rates of nine geographic populations of the sun pest in Ukraine for the period of 1947–2002 came to the conclusion that Wolf numbers are unsuitable for forecasting the population dynamics of this pest (2003).

Based on the prognostic Wolf numbers (W) S.A. Triebel (1989) forecasted the beginning of the regular mass reproductions of the webworm beetle on the 22nd solar cycle in 1993 and he forecasted that the peak of the outbreak would happen in 1996–1997. The forecast did not come true!

V.P. Kravchenko and V.N. Chaika (2002) having analysed the average density of the hibernating stock of the webworm beetle caterpillars for the period of 1972–2001 and the dynamics of Wolf numbers over the indicated period found out that the correlation between these indices was very low (r = -0.2). Nevertheless a logical analysis of many years' materials on the density dynamics of this pest and on the dynamics of Wolf numbers indicates that a connection between them is still taking place. In 1974-1976 the maximum spreading of this pest was under the minimum solar activity; in 1986-1988 the SA minimum coincided with the beginning of the population growth; in 1999–2001 there was a synchronous increase in the numbers and in the solar activity. As a result the authors came to the conclusion that the population cycles of the webworm beetle are connected with the extremum of SA, and they believe that this phenomenon is coordinated with the theory of the cyclic character. The incompatibility of the mathematical analysis with logical modeling is explained by the concept of metapopulation dynamics. At the same time the influence of the solar activity is global, and the outbreaks of mass reproduction of insects have the local character. The authors' explanation is logical. Indeed, the metapopulations consist of semi-isolated local populations that differ in genetic and ecological structures. The general dynamics of the geographical populations is determined by the total state of the local populations. Moreover the range of the webworm beetle includes 14 countries of the Old and New Worlds or 11 million 552 thousand km^2, and the area of Ukraine does not exceed 5,2 % of this index. In this regard the average data on the dynamics of the population number only in Ukraine, not taking into account the state of the populations in the range, eliminates the mathematical relationship of the influence of solar activity on this pest population dynamics.

Therefore to forecast the mass reproductions of insects a different criterion which is in interaction with the weather and climatic and trophic cycles is necessary. The overwhelming majority of geophysicists, heliophysicists, climatologists, hydrologists and ecologists consider this criterion to be the sharp changes in the solar activity which influence the biosphere, biogeocenoses and their constituent populations. For the first time we have used the years of sharp changes in SA or the so-called years of solar benchmarks to analyse the mass reproduction of harmful insects and substantiate the long-term forecast of the outbreaks in their numbers in different regions and we also have carried out a historical and statistical analysis of the mass reproduction of 70 species of insects in connection with the sharp changes in solar activity in Ukraine for the period of 1854–1985 (Table 2.3).

Table 2.3

Frequency of mass reproductions of 70 species of insects in Ukraine depending on sharp changes in solar activity (1854–1985) (Beletsky, Stankevich, 2018)

Relative frequency of mass reproductions, %			Chi-square criterion of probability difference significance	Probability of random differences in probabilities of mass reproductions, %
during the years of solar benchmarks	a year after bebchmark	other years		
90,0	76,6	29,0	11,11	<0,5

From the data given in Table 2.3 it follows that the frequencies of the mass reproductions of insects for the researched period (1854–1985) during the years of benchmarks were 2,5–3,0 times higher than the frequencies in the other years. At the same time the chi-square criterion was high enough (11.11) and the probability level was relatively small (less than 0,5). This fact makes it possible to assert that the synchronism of the mass reproductions of 70 species of insects over the specified historical period with the years of sharp changes in the solar activity takes place in Ukraine.

This conclusion is also true for the mass reproduction of the separate species of insects in various regions of the world with different soil and climatic conditions (Table 2.4).

Table 2.4

Mass reproductions of different species of insects in various regions of the world and sharp changes in solar activity (SA) (Beletsky, Stankevich, 2018)

Species of insect, region	Years of mass reproductions	Relative frequencies of mass reproductions, %		
		during the years of solar benchmarks	next year after benchmark	other years
1	2	3	4	5
Desert locust:				
eastern region	1843–2003	84,0	8,0	8,0
western region	1863–2003	78,0	22,0	0,0
central region	1863–2003	57,0	36,0	7,0
southern region	1900–2003	80,0	20,0	0,0
range	1800–2003	82,0	18,0	0,0
African migratory locust in the range	1889–2003	75,0	0,0	25,0
African red locust in the range	1847–2004	85,0	15,0	0,0
Australian plague locust in the range	1934–2006	89,0	11,0	0,0
Asiatic locust in Ukraine	1708–1995	64,0	25,0	11,0
Italian locust in Ukraine	1711–2003	81,0	15,0	4,0
Turnip moth in Ukraine	1813–2007	90,0	10,0	0,0
Heart moth in Ukraine	1836–1999	82,0	18,0	0,0
Gamma moth in Ukraine	1829–1995	74,0	16,0	10,0

Alfalfa worm in Ukraine	1875–1976	54,0	46,0	0,0
Mamestra cabbage moth in Ukraine	1871–2000	79,0	16,0	5,0
European corn borer in Ukraine	1869–2006	80,0	20,0	0,0
Webworm beetle in Ukraine	1835–2011	79,0	7,0	14,0
Sun pest: in Ukraine	1870–2008	69,0	31,0	0,0
in Stavropol territory	1854–2009	73,0	27,0	0,0
in Krasnodar territory	1854–2009	92,0	8,0	0,0
in Rostov region	1892–2009	67,0	33,0	0,0
in Iraq	1909–1997	78,0	22,0	0,0
in Iran	1909–1997	78,0	22,0	0,0
in Jordan	1920–1997	83,0	17,0	0,0
in Lebanon	1924–1997	83,0	17,0	0,0
in Palestine	1920–1997	83,0	17,0	0,0
in Syria	1909–1997	71,0	29,0	0,0
in Egypt	1931–1997	67,0	33,0	0,0
in Turkey	1886–1997	82,0	18,0	0,0
in Pakistan	1940–1997	80,0	20,0	0,0
in Kazakhstan	1901–1997	82,0	18,0	0,0
in Kyrgyzstan	1901–1997	82,0	18,0	0,0
in Uzbekistan	1901–1997	70,0	30,0	0,0
in Tajikistan	1901–1997	73,0	27,0	0,0
in Turkmenistan	1900–1997	73,0	27,0	0,0
in Palearctic	1854–1995	86,0	7,0	7,0
Ground beetle in Ukraine	1860–2003	85,0	15,0	0,0
Hessian fly in Ukraine	1847–2000	95,0	5,0	0,0
Frit fly	1880–2000	69,0	31,0	0,0
Anisoplia austriaca beetle in Ukraine	1841–1996	82,0	18,0	0,0
Apamea noctuid beetle in Ukraine	1871–1963	75,0	17,0	8,0
Owlet moth in Northen Kazakhstan	1887–2003	54,0	46,0	0,0
Cereal leaf beetle in Ukraine	1878–1995	77,0	15,0	8,0

Beet root weevil	1841–2010	82,0	18,0	0,0
Diamond black moth	1908–2000	61,0	31,0	8,0
Cabbage butterfly	1846–2001	72,0	21,0	7,0
Turnip fly	1756–1978	56,0	31,0	13,0
White thorn butterfly	1838–2003	88,0	12,0	0,0
Brown-tail moth	1841–1997	86,0	9,0	5,0
Apple ermine	1843–1994	67,0	33,0	0,0
Lackey moth	1826–1998	94,0	6,0	0,0
Codling moth	1855–2007	64,0	21,0	15,0
Winter moth	1844–1999	88,0	6,0	6,0
Green oak roller moth	1853–2000	83,0	6,0	11,0
Gypsy moth	1837–1995	84,0	10,0	6,0
Nun moth	1846–1999	69,0	23,0	8,0
Piny moth	1839–1995	82,0	18,0	0,0
Pale tussock moth	1853–1997	71,0	22,0	7,0
Pine noctuid	1825–1997	39,0	53,0	8,0
Pine looper moth	1869–1995	86,0	14,0	0,0
Pine sawfly	1838–2002	88,0	12,0	0,0
European pine sawfly	1880–2009	88,0	6,0	6,0

Spatial and temporal synchronization of insects mass reproductions

Over the past three decades the problem of spatial and temporal synchronization of biological processes has become a priority in many branches of modern science and first of all in ecology which is the systems science founded about 150 years ago. In the light of modern ideas the phenomena in Space and on the Earth are characterised by orientation, cyclic character and synchronism; as it is known the latter is one of the fundamental laws of development of any material system (biological, ecological, economic, social, etc.) (Beletsky, Stankevich, 2018).

Long ago the ecologists noticed the coincidence of the population cycles among many animal species including the insects which simultaneously breed in a vast territory.

Synchronism of mass reproduction of some insects (Beletsky, Stankevich, 2018)

Desert locust or schistocerca In 1929 B.P. Uvarov noted its simultaneous mass reproduction in the states of the desert-steppe zone of Africa and West Asia. In 1986-1990 and 2003-2004 it simultaneously bred on a mass scale in the eastern, western, central and southern regions of Africa and Western Asia.

In 1986–1990 and in 2003 the African migratory locust and the African red locust bred simultaneously with the desert locust. The Australian plague locust bred in Australia and on the island of Tasmania; the Italian locust bred in Ukraine and the solitaty locusts bred in Siberia and Yakutia.

Asiatic migratory locust: 1875–1876 – in Russia, Ukraine, Portugal and Ukraine; 1912–1914 – in Russia, China and Ukraine; 1944–1946 – in Kazakhstan and Ukraine; 1995–1996 – in Kazakhstan and Ukraine.

Italian locust: the synchronous mass reproductions took place: 1823–1824 – in the south of France and in Ukraine; 1844–1847 – in Algeria, Transcaucasia, Moldova and Ukraine; 1863–1868 – in Spain, Kazakhstan, the island of Sardinia, Hungary and Ukraine; 1888–1889 – in Hungary, Georgia, Russia and Ukraine; 1892–1897 – in Hungary, the Rostov region and Ukraine; 1919–1923 – in Bulgaria, Ciscaucasus, the Lower Volga region, Kazakhstan, Kulunda, China and the steppe regions of Canada; 1936–1939 – in Ciscaucasus, the Lower Volga region, Western Siberia, Northern China, Ukraine and Yugoslavia; 1945–1947 – in Moldova and Ukraine; 1951–1955 – in Kazakhstan, the Volga region, North. China and Southern Ukraine; 1983–1986 – in the south of Russia, the Volga region and India; 1992–1999 – in the Lower Volga region, Kazakhstan, Western Siberia and Ukraine; 2003-2008 – in Western Siberia and Ukraine.

Turnip moth: 1813–1819 – in the Baltic States, St. Petersburg Province and Ukraine; 1823–1825 – in the south of France, Russia and Ukraine; 1836–1842 – in Western and Eastern Europe, Russia and Ukraine; 1846–1852 – in Russia (18 provinces) and Ukraine; 1855–1856 – in Russia and Ukraine; 1861–1868 – in Russia and Ukraine; 1880–1881 – in Russia and Ukraine; 1892–1896 – in Germany, Russia and Ukraine; 1899–1900 – in Russia and Ukraine; 1907–1909 – in Hungary, Russia, Ukraine, Czechoslovakia, Finland and Yugoslavia; 1915–1919 – in England, Africa, Hungary, Bulgaria, Germany, Russia, Egypt, Ukraine and Czechoslovakia; 1923–1925 – in Austria, America, Brazil, Denmark, Transcaucasus, Spain, Italy, Korea, Morocco, Russia, Ukraine, Czechoslovakia and Japan; 1936–1941 – in Kazakhstan, Kyrgyzstan, Russia and Ukraine; 1946– 1950 – in Hungary, Kazakhstan, Kyrgyzstan, Russia, Serbia, Romania, Ukraine, Czechoslovakia and Yugoslavia; 1955–1956 – in Hungary, Bulgaria, Russia, Serbia, Czech Republic and Croatia;

1971– 1975 – in Germany, Russia and Ukraine; 1982– 1987 – in Germany, Poland, Russia and Ukraine; 1995– 2003 – in Russia, Greece, Slovakia and Ukraine.

Gamma moth: 1826–1829 – in Holland, East Prussia, Russia and Ukraine; 1833 – in Russia and Ukraine; 1839 – in Russia and, Ukraine; 1854 – in Russia and Ukraine; 1860 – in Russia and Ukraine; 1871 – in Austria, Russia and Ukraine; 1878–1879 – in Russia and Ukraine; 1899–1900 – in England, Russia and Ukraine; 1912-1913 – in Russia and Ukraine; 1922 – in Russia and Ukraine; 1928–1930 – in Germany, Holland, Poland, Ukraine and Czechoslovakia; 1946 – in Germany, Denmark, Russia, Ukraine, southern Sweden and southern Finland; 1953–1954 – in Russia and Ukraine; 1962–1963 – in Hungary and Ukraine.

Mamestra cabbage moth: 1871 – in Belarus and Ukraine; 1878–1879 – in Belarus and Ukraine; 1964–1965 – in Hungary, Russia, Serbia and Ukraine; 1969–1970 – in Hungary, Serbia and Ukraine; 1985–1986 – in Serbia and Ukraine.

European corn borer: 1886–1887 – in England, Moldova, East India and Ukraine; 1892–1895 – in England, Hungary and Ukraine; 1896–1899 – in Hungary, India, Ukraine and Yugoslavia; 1900–1905 – in Bulgaria, Hungary, Germany and Ukraine; 1908–1909 – in Georgia, Egypt, Italy, the North Caucasus, Ukraine, Philippines and France; 1928–1939 – in the Amur Region, North Africa, the USA and Ukraine; 1949–1950 – in the USA; 1986–1996 –in Ukraine and France; 2006–2007 – in Russia and Ukraine.

Webworm beetle: 1680–1686 – in Kiev Rus; 1769–1770 – in the Astrakhan region; 1901 – in Bulgaria, Hungary, Russia and Ukraine; 1909–1910 – in North America, Russia and Ukraine; 1914–1915 – in Bulgaria, Hungary, Romania, Ukraine and Yugoslavia; 1921–1922 – in Bulgaria, Hungary, Russia, Ukraine and Czechoslovakia; 1929–1930 – in Bulgaria, Hungary, Germany, Poland, Northern Manchuria, Russia, Ukraine and Yugoslavia; 1935 – in Russia, Romania and Ukraine; 1975 – in Bulgaria, Germany, Poland, Russia, Northern Kazakhstan, Ukraine, Czechoslovakia and Yugoslavia; 1984–1989 – in Kalmykia, Eastern Siberia and the Far East; 1986–1988 – in Russia, Ukraine and China; 2000–2002 – in Russia and Ukraine.

Sun pest: Over the past 146 years (1854–2009) 15 mass reproductions of the sun pest and other capsid grain bugs were recorded in the Palaearctic. 11 (73%) of them had a global scale: in 1901–1905, 1909–1914, 1923–1929, 1931–1933, 1936–1943, 1948–1957, 1964–1970, 1972–

1981, 1984–1991, 1996–2003, and 2009–2010. During these years the capsid grain bugs simultaneously bread in 6–22 regions of the world.

Ground beetle: 1863–1865 – in Bulgaria and Ukraine; 1946–1947 – in Syria and Ukraine; 1957–1959 – in the North Caucasus and Ukraine.

Hessian fly: 1879–1880 – in Russia and Ukraine; 1900 – in Canada, USA and Ukraine; 1923–1925 – in Poland and Ukraine; 1978–1981 – in Kokchetav and the Kustanai regions; 1986–1987 – in Ukraine and South Carolina (the USA).

Frit fly: 1880 – in Russia and Ukraine; 1923–1925 – in Russia and Ukraine; 1972–1975 – in Russia and Ukraine; 1991–1992 – in Russia and Ukraine.

Beet root weevil: 1880–1881 – in Russia and Ukraine; 1905 – in Hungary and Ukraine; 1922–1923 – in Bulgaria and Ukraine; 1937–1938 – in Hungary and Ukraine; 1947-1948 – in Germany and Ukraine; 1962–1964 – in Bulgaria and Ukraine.

Diamond black moth: 1946 – in Lithuania and Ukraine; 1964 – in Lithuania and Ukraine.

Cabbage butterfly: 1927 – in Germany and Ukraine.

Codling moth: 1855–1856 – in South Australia, South America, South Africa, the island of Tasmania, the USA and Ukraine; 1885–1886 – in South Australia, South Africa, the USA and Ukraine; 1933–1937 – in Armenia, Bashkiria, Belarus, Central Asia, Kazakhstan, Tatarstan, the Central Chernozem Region of Russia and Ukraine; 1955–1958 – in Austria, Australia, Bulgaria, Germany, Canada, Romania, Ukraine and France; 1993–1996 – in Russia and Ukraine; 2007–2008 – in Russia and Ukraine.

Winter moth: 1852–1893 – in Denmark and Ukraine; 1903–1904 – in Denmark and Ukraine; 1948–1951 – in Lithuania and Ukraine; 1953–1954 – in England, Denmark, Slovakia and Ukraine; 1960 – in England, Denmark, Lithuania, Slovakia and Ukraine; 1972–1977 – in Germany, Slovakia and Ukraine; 1979–1980 – in Denmark, Germany, Slovakia, Ukraine and Croatia; 1993–1994– in Belarus, Germany, Poland, Slovakia, Ukraine and Croatia; 1999-2001 – in Austria, Romania and Ukraine.

Lackey moth: 1882–1883, 1947–1948, and 1997–1998 – in Russia, Massachusetts (the USA) and Ukraine; 1955–1956 – in Bashkiria, Bulgaria, Hungary, Netherlands, Romania and Ukraine.

White thorn butterfly: 1849, 1852, and 1859 – in Moldova and Ukraine; 1867–1869 – in Russia and Ukraine. *ia*

Gypsy moth: 1861–1863 – in Russia and Ukraine; 1869–1871 – in Bashkiria, Russia and Ukraine; 1877–1880 – in Bashkiria and Ukraine; 1884–1886 – in Germany, Russia and Ukraine; 1898–1899 – in Russia and Ukraine; 1907–1910 – in Bashkiria, Russia and Ukraine; 1912–1913 – in Bashkiria, Italy, Canada, Germany, Romania, the USA, Ural and Ukraine; 1920–1922 – in Bashkiria, Russia and Ukraine; 1929–1934 – in Germany, Russia and Ukraine; 1953–1955 – in Bashkiria, Bulgaria, Russia, Slovakia and Ukraine; 1964–1968 – in Bulgaria, Poland, Russia, Slovakia and Ukraine; 1982–1988 – in Italy, the North Caucasus, Germany, Canada, Poland, Russia, Romania, Slovakia, the USA, Ural, Ukraine and Croatia; 1995 – in the Crimea and China.

Brown-tail moth: 1867, 1912, 1920-1921, 1924-1925, 1929 and 1937–1941 – in England, Russia, Ukraine and Czechoslovakia; 1948–1951 – in Poland, Romania and Ukraine; 2000 – in Poland, Romania and Ukraine.

Green roller oak moth: 1875, 1886, 1910, and 1920 – in Canada and Ukraine; 1947-1949 – in Denmark, Russia and Ukraine; 1929 – in Germany, Russia and Ukraine; 1960-1963, and 1966 – in Germany, Russia, Slovakia and Ukraine; 1983-1984 – in Poland, Ukraine and Croatia; 1988 – in Poland and Ukraine; 1996 – in Austria, Belarus, Germany, Poland, Romania and Ukraine.

Piny moth: 1839–1842, 1863–1870, and 1875–1877 – in Germany, Poland, Russia and Ukraine; 1890–1891, 1897–1900, and 1927–1928 – in Germany, Russia and Ukraine; 1902–1904, 1913–1915, and 1923–1925 – in Russia and Ukraine; 1937–1941, and 1995–1998 – in Belarus, Germany, Russia and Ukraine; 1953–1955, and 1958–1959 – in Belarus, Germany, Poland, Russia and Ukraine; 1966, 1982–1985 – in Poland and Ukraine (Meshkova, 2002).

Nun moth: 1846–1849 – in Bashkiria, Germany, Denmark, Ukraine and Czech Republic; 1857 – in Russia and the Kingdom of Poland; 1863–1867 – in Germany and Ukraine; 1889–1892 – in Belgium, Poland, Russia, Romania, Ukraine and Czech Republic; 1905 – in Austria, Belgium, Germany, Poland and Ukraine; 1925 – in Austria, Belgium, Spain, Poland, Russia, Romania and Ukraine; 1946–1950 – in Austria, Bashkiria, Germany, Poland, Spain, Russia, Ukraine, Switzerland, Sweden and Czech Republic; 1952–1960 – Austria, Bashkiria, Germany, Poland, Spain, Russia, Romania, Ukraine and Yugoslavia; 1978-1980 – in Belarus, Germany, Denmark, Poland and Ukraine; 1999 – in Austria, Poland and Ukraine. "In 1845–1867 the mass invasion by the nun moth which spread from Orenburg to the East Prussia was the greatest disaster; in 1888–1891 the tremendous areas from Silesia to Hungary were invated by the nun moth" (Fredericks, 1932, p. 672).

Pine looper moth: 1869–1872, and 1876 – in Germany, Russia and Ukraine; 1880, and 1891–1897 – in Germany and Ukraine; 1927–1930 – in Germany, Russia and Ukraine; 1937–1941 – in the Voronezh Region, Germany, Denmark, Krasnoyarsk Territory, Netherlands, Ukraine and Scotland; 1961-1966 – in the Kurgan region and Ukraine; 1971 – in Belarus, Germany, Russia and Ukraine; 1983–1984 – in England, Russia, Ukraine and Scotland; 1999–2000– in Austria, Poland and Ukraine.

Pine noctuid: 1925– in Germany and Ukraine. "The forest disaster observed in the Northern Germany dates back to 1925 and was caused by the mass reproduction of the pine noctuid. The invasion spread over 500 thousand hectares, and 170 thousand hectares were eaten away and left naked" (Fredericks, 1932, p. 431).

Pine sawfly: In 1935–1936, 1941–1943, 1953–1954, 1957–1958, and in 1966–1968 the mass reproductions of the piny sawfly simultaneously took place in Belarus, Russia and Ukraine; in 1976 they took place in Poland, the Rostov Region and Ukraine; in 1983 the pine sawfly bred in Russia and Ukraine; in 1991–1992 –in Belarus, Poland, Russia and Ukraine; in 1997–2000 – in Austria, Poland and Ukraine.

European pine sawfly: 1866 –in Ukraine and Finland; 1880 – in Germany, Ukraine, Finland, Czech Republic and Estonia; 1907 – in Russia and Ukraine; 1934–1937 – in Austria, Hungary, Karelia, Russia, Ukraine and Czech Republic; 1945–1948 – in Austria, Belarus, Georgia, the Netherlands, Germany, Norway, Poland, Ukraine and Scotland; 1958–1960 – in Austria, Belarus, Germany, Russia, Ukraine, Finland, Czech Republic, Sweden and Scotland; 1963–1966 – in Denmark, Russia and Ukraine; 1972–1974 – in Germany, Poland and Ukraine (Meshkova, 2002).

Note: the years of global mass reproductions are underlined.

The mass reproductions were especially significant in Ukraine in 1868–2009 when from 20 to 41 species of insects damaging the agricultural plants and forest plantations simultaneously appeared on a mass scale. During this historical period the synchronism of the mass reproductions was observed:

in 1868–1870 among 28 species of insects: the Italian locust, Asiatic locusts, May beetles, scarab beetle, turnip moth, heart moth, gamma moth, Europen corn borer, webworm beetle, sun pest, anisoplia austriaca beetle, apamea noctuid moth, wheat sawfly borer, beet root weevil, beet leaf beetle, green tortoise beetle, cabbage butterfly, mamestra cabbage moth, white thorn butterfly, lackey moth, codling moth, brown-tail moth, gypsy moth, nun moth, piny moth, pale tussock moth, winter moth and pine looper moth;

in 1878–1880 among 34 species of insects: the Italian locust, Asiatic locust, May beetles, scarab beetle, the larvae of click beetles and darkling beetles, the tenebrionid beetle, turnip moth, heart moth, alfalfa worm, gamma moth, Europen corn borer, webworm beetle, ground beetle, anisoplia austriaca beetle, cereal leaf beetle, euxora noctuid moth, wheat sawfly borer, Hessian fly, oat frit fly, green-eyed fly, pea weevil, beet root weevil, beet flea beetles, beet leaf beetle, green tortoise beetle, mamestra cabbage moth, turnip fly, codling moth, brown-tail moth, gypsy moth, piny moth, satin moth, blossom feeder, and pine looper moth;

in 1890–1896 among 40 species of insects: the Italian locust, Asiatic locust, May beetles, scarab beetle, the larvae of click beetles and darkling beetles, turnip moth, heart moth, alfalfa worm, gamma moth, webworm beetle, sun pest, anisoplia austriaca beetle, cereal leaf beetle, apamea noctuid moth, euxora noctuid moth, brighton wainscot, wheat sawfly borer, Hessian fly, oat frit fly, clover seed weevils, beet root weevil, beet leaf beetle, green tortoise beetle, mamestra cabbage moth, turnip fly, white thorn butterfly, apple ermine, lackey moth, codling moth, apple sawfly, brown-tail moth, gypsy moth, nun moth, piny moth, buff-tip moth, blossom feeder, pine noctuid, pine looper moth, and pine sawfly;

in 1910–1914 among 32 species: the Italian locust, Asiatic locust, turnip moth, alfalfa worm, gamma moth, Europen corn borer, webworm beetle, sun pest, anisoplia austriaca beetle, cereal leaf beetle, apamea noctuid moth, euxora noctuid moth, brighton wainscot, wheat sawfly borer, Hessian fly, oat frit fly, pea aphid, clover seed weevils, beet root weevil, beet fly, beet leaf beetle, green tortoise beetle, diamond black moth, cabbage butterfly, mamestra cabbage moth, cherry weevil, lackey moth, brown-tail moth, gypsy moth, piny moth, painted lady and pine looper moth;

in 1923–1926 among 35 species: the Italian locust, Asiatic locust, the larvae of click beetles and darkling beetles, the tenebrionid beetle, turnip moth, heart moth, clover cutworm, gamma moth, Europen corn borer, webworm beetle, sun pest, ground beetle, anisoplia austriaca beetle, apamea noctuid moth, Hessian fly, oat frit fly, green-eyed fly, pea aphid, clover seed weevils, beet root weevil, beet fly, cabbage aphid, diamond black moth, cabbage butterfly, mamestra cabbage moth, turnip fly, cherry weevil, white thorn butterfly, apple ermine, lackey moth, green oak roller moth, pine noctuid, pine looper moth, pine sawfly and European pine sawfly;

in 1934–1942 among 32 species: the Italian locust, Asiatic locust, May beetles, the larvae of click beetles and darkling beetles, the tenebrionid beetle, turnip moth, alfalfa moth, clover cutworm, gamma moth, European corn borer, webworm beetle, ground beetle, apamea noctuid moth, euxora noctuid moth, brighton wainscot, oat frit fly, wheat opomyza, pea aphid, clover seed weevils, beet fly, diamond black moth, cabbage butterfly, mamestra cabbage moth, lackey moth, green oak roller moth, brown-tail moth, gypsy moth, piny moth, pine noctuid, pine looper moth, and pine sawfly;

1946-1950 among 30 species: the Italian locust, Asiatic locust, May beetles, the larvae of click beetles and darkling beetles, the tenebrionid beetle, turnip moth, heart moth, webworm beetle, sun pest, ground beetle, anisoplia austriaca beetle, cereal leaf beetle, apamea noctuid moth, Hessian fly, pea aphid, pea weevil, beet root weevil, diamond black moth, cabbage butterfly, cherry weevil, lackey moth, codling moth, brown-tail moth, gypsy moth, nun moth, buff-tip moth, pine noctuid, pine looper moth, pine sawfly and European pine sawfly;

in 1956–1960 among 34 species: the Italian locust, Asiatic locust, May beetles, turnip moth, alfalfa moth, gamma moth, webworm beetle, sun pest, apamea noctuid moth, Hessian fly, oat frit fly, beet root weevil, beet flea beetles, mamestra cabbage moth, cabbage butterfly, cherry weevil, white thorn butterfly, lackey moth, codling moth, green oak roller moth, brown-tail moth, gypsy moth, nun moth, small eggar, satin moth, buff-tip moth, fox moth, poplar kitten, oak puss moth, painted lady, poplar trip moth, pine noctuid, pine looper moth, and European pine sawfly;

in 1964–1968 among 41 species: the Italian locust, May beetles, the tenebrionid beetle, turnip moth, alfalfa worm, gamma moth, webworm beetle, sun pest, ground beetle, anisoplia austriaca beetle, cereal leaf beetle, apamea noctuid moth, euxora noctuid moth, Hessian fly, oat frit fly, green-eyed fly, beet root weevil, beet flea beetles, diamond black moth, turnip fly, Colorado potato beetle, white thorn butterfly, apple ermine, lackey moth, codling moth, green oak roller moth, brown-tail moth, gypsy moth, nun moth, piny moth, small eggar, buff-tip moth, fox moth, oak puss moth, green budworm moths, winter moth, poplar trip moth, pine noctuid, pine looper moth, pine sawfly and European pine sawfly;

in 1972–1977 among 33 species: May beetles, the larvae of click beetles and darkling beetles, the tenebrionid beetle, turnip moth, heart moth, gamma moth, Europen corn borer, webworm beetle, alfalfa moth, sun pest, wheat aphid, ground beetle, anisoplia austriaca beetle, cereal leaf beetle, Hessian fly, oat frit fly, wheat opomyza, pea aphid, pea weevil, beet roor weevil, beet leaf beetle, cabbage aphid, diamond black moth, cabbage butterfly, white thorn butterfly, lackey moth, codling moth, green oak roller moth, brown-tail moth, gypsy moth, green budworm moths, painted lady and pine sawfly;

in 1986–1988 among 22 species: the Europen corn borer, webworm beetle, gamma moth, cereal flea beetle, cereal leaf beetle, pea aphid, pea weevil, Hessian fly, wheat opomyza, wheat aphid, beet root weevil, grey beet weevil, black beetroot weevil, mamestra cabbage moth, sun pest, green budworm moths, gypsy moth, piny moth, green oak roller moth, lackey moth, codling moth and pine looper moth;

in 1990–1995 among 22 species: the larvae of click beetles and darkling beetles, European corn borer, sun pest, wheat opomyza, ground beetle, Hessian fly, oat frit fly, beet leaf beetle, beet root weevil, cruciferous fleas, diamond black moth, rose chafer, codling moth, winter moth, gamma moth, apple ermine, sloe bug, Bishop’s Mitre, cabbage butterfly, pine sawfly and European pine sawfly;

in 2000–2010 among 20 species: the Italian locust, Asiatic locust, winter moth, mamestra cabbage moth, European corn borer, webworm beetle, gamma moth, sun pest, ground beetle, scarab beetles, Hessian fly, oat frit fly,white thorn butterfly, brown-tail moth, green oak roller moth, piny moth, nun moth, pine sawfly and European pine sawfly.

Spatial and temporal synchronization of the mass insect reproductions (regional and global) is explained by the fact that the biological systems are formed and developed in the external environment and under the influence of the latter, so the synchronization of the population cycles is inevitable. The synchronization processes ensure the coordination of various processes and phenomena and their reinforcement and interaction, and create the preconditions for the formation of an organization (structure) based on relationships of a resonant type. Such an organization may have the increased stability in the structural plan and at the same time the increased sensitivity to informationally significant external influences, in particular, to the corresponding geophysical and space factors (Prigozhin & Stengers, 1986; Shurgin & Obut, 1986).

The global synchronization of the mass reproductions of insect cannot be explained by the interaction of their populations with weather factors since the coincidence of the latter is unlikely even within the same region.

The vast majority of the researchers believe that the population cycles are self-oscillations of the biological systems synchronised by the solar activity (Vladimirskij, 1982; Benkevich, 1984; Chizhevskij, 1995; Ivanickij, 1997).

At least the solar activity can create the double effects: the “cyclic background” of changes in the Earth’s processes and a part of the fractures of the long-term course distorting this “cyclic background” (Benkevich, 1984).

The generalised data of the mass reproduction of insects, sharp changes in the solar activity and atmospheric circulation are presented in Table 2.5.

Table 2.5

Synchronism of insect population cycles in Ukraine (1868-2010) with sharp changes in solar activity and forms of atmospheric circulation (Beletsky, Stankevich, 2018)

Years		**Dominating forms of atmospheric circulation**		
simultaneous mass reproductions of several species of insects	**sharp changes in solar activity (SA)**	**W – western**	**E – eastern**	**C – meridional**
1868–1870	1868, 1870	–	–	+
1878–1880	1878, 1880	–	–	+
1890–1896	1890, 1892–1896	–	–	+
1910–1914	1910–1913	–	–	+
1923–1926	1923–1925	–	–	+
1934–1942	1934–1937, 1930–1940	–	–	+
1946–1950	1946–1948, 1950	–	+	–

1956–1960	1956	+	–	–
1964–1968	1964–1968	–	–	+
1972–1977	1972–1973, 1977	–	–	+
1986–1988	1986–1988	–	–	+
1990–1995	1990–1991, 1993	+	–	–
2000–2010	2000, 2003, 2006	–	–	+

As it is seen from the data given in Table 2.5 all 13 mass reproduction of insects began exactly (100 %) in the years of sharp changes in the solar activity. Of 13 population cycles 11 ones or 84,6% began during the years of the domination of the eastern and meridian forms of atmospheric circulation and only two of them (in 1956–1960 and in 1990–1995) or 1,6% began during the years of the domination of the western atmospheric circulation form. Warm and dry weather prevails on the Earth under the eastern and meridional forms of atmospheric circulation, and cold and humid weather prevails and under the west form (Druzhinin, Sazonov & Yagodinskij, 1974). That means that the vast majority of the mass reproductions of insects began in the years of dry weather, and the droughts are synchronous with the dynamics of the solar activity (Table 2.6).

Table 2.6

History of droughts in Ukraine and sharp changes in solar activity (SA) (Beletsky, Stankevich, 2018)

Years	
droughts	**Sharp changes in SA**
1	**2**
1821–1824	1821, 1823
1826	1826
1833–1834	1833
1845	1845
1847–1848	1847–1848
1854	1854
1856–1857	1856
1859–1866	1859–1862, 1865

1873	1873
1875	1875
1880	1880
1882–1888	1882–1887
1891–1892	1890
1894–1896	1894, 1896
1901	1901
1911	1911
1914–1915	1913,1915
1917–1918	1917–1918
1920–1921	1920, 1922
1924	1924
1928	1991
1930	1929
1933	1933
1942–1944	1942–1944
1946–1949	1946–1948
1951–1954	1950, 1952–1953
1956–1957	1956
1961–1962	1961
1966–1968	1966–1968
1971–1972	1971–1972
1979	1979
1981	1981
1983–1984	1983–1984
1986	1986
1991	1991
1994–1996	1994–1996
1998–2000	1998–2000
2003	2003
2007	2007
2009	2009
2010	2010
2012	2012

“Chi-square” – 13,6 $P < 0{,}05$

Cyclic character as a universal property of development and functioning of natural systems (Beletsky, Stankevich, 2018)

Cyclic character is inherent in a wide range of processes and phenomena of a space, geophysical and biological nature. It is known in the state of sidereal and solar activity, comet and meteor flows, in the activation of the planets of the solar system, in fluctuations of the magnetic and electromagnetic fields, in the tectonic, seismic and volcanic activities of the lithosphere, in atmospheric changes (pressure, precipitation, temperature and circulation mode) and in the biosphere (biological rhythms).

The universal character of the spatial and temporal organization of the material world and the unity of cyclic changes in inorganic and organic nature are indicated in the works of many naturalists (N.A. Agajanian, B.S. Aliakrinsky, P.K. Anokhin, E.S. Bauer, L.S. Berg, E.P. Borisenkov, V.I. Vernadsky, B.V. Vladimirsky, Yu.I. Vitinsky, I.P. Druzhinin, A.P. Dubrov, V.A. Zubakov, S.V. Kalesnik, G.I. Komin, V I. Krut, B.L. Lichkov, A.A. Maximov, A.V. Maximov, E. V. Maximov, K.K. Markov, N.N. Moiseev, A.I. Ol, A.S. Presman, A.P. Reznikov, B.M. Rubashev, B.I. Sazonov, G.I. Tamrazian, A.A. Trofimuk, Yu.A. Kholodov, V.V. Chernyshev, A.L. Chizhevsky, A.V. Shnitnikov, N.S. Shcherbinovsky, M.S. Eigenson, V.N. Yagodinsky, and many others). The number of publications on this problem is hardly visible at present. Suffice it to say that more than two thousand works only on the relationship of the animal population dynamics with the cyclic changes in the solar activity have been published by the middle of the 50s in the twentieth century (Cole, 1956) not mentioning the other issues of this complex and versatile natural and scientific problem.

We restrict ourselves to indicating only some of the fundamental works having the important methodological significance for understanding the universe character of the cyclic nature of processes and phenomena.

B.L. Lichkov (1965) in his monograph “On the Foundations of the Modern Theory of the Earth” identifies the geological periods of 500 million years long, and inside them there are geological, climatic and biospheric cycles interconnected with each other and with the rhythms of the universe. According to the author they constitute a multiple of the cosmic years, i.e., the period of the revolution of the Solar system round the center of the Galaxy. In the process of a detailed analysis B.L. Lichkov (1965) came to the conclusion that the “waves of life” are in interaction with the cosmic and geophysical environmental factors. A similar point of view was developed by many scientists in their works. They believed that the cyclic character coverd a very diverse oscillatory processes ranging from the elementary physical processes to the complex heliogeophysical and ecological and biological ones.

The cyclic processes and phenomena are characterised by spasmodic or explosive nature disrupting the course of the natural environment. In this connection the cyclic character as a form of manifestation of dialectical contradictions in its dynamics is directly related to the general laws of the nature development: the law of the negation of negation and the transition of the quantitative changes to qualitative ones. The last law is characterised by the qualitative leaps, explosive processes, phase transitions, sudden gene mutations, and the outbreaks of mass reproduction of the populations of animals and microorganisms, etc.

The cyclic process is a progressive and evolutionary one. The cycle should be considered as a volution development along the spiral, and since each development is carried out in a contradictory way, then its progression is in the unity with the elements of the cyclic character. In the light of modern concepts of the natural sciences the sign of the recurrence and cyclic character of phenomena is taken as an objective criterion for the presence of an internal regulation.

P.K. Anokhin (1978) believed that the basis for the development of life and its relationship to the external inorganic world was the recurred effects of this external world on the organism. The consistency and recurrence are the main temporal parameters which represent a universal form of communication of already existing living beings with the environment, that is, the “inscription” of “living matter” into the already prepared spatial and temporal system of the world.

Thus the population dynamics is a cyclic process of the recurrence of mass reproduction of animals including the insects. These cycles are carried out against the background of changes in the external environment and make certain adjustments to this process accelerating or slowing down the realization of the internal trends.

In the process of the heliobiological researches A.P. Dubrov (1974) revealed the cyclic changes in such fundamental processes as genetic, physiological, and biochemical ones and showed their connection with the variations in the geomagnetic field during its calm and disturbed periods. He discovered a coordinated course of the curves reflecting the changes in the geomagnetic field and in the most important genetic index, namely the mitotic activity (cell division ability), while the "seasonal" dynamics of changes in the concentration of ST and TZ genes in the third Drosophila chromosome completely coincides with the changes in the geomagnetic field for a specific period in the place of the experiments. The important role of the geomagnetic field for the genetic processes of the gene, chromosome and population levels is shown by A.P. Dubrov (1974). In particular this geophysical factor affects the genetic code and genetic homeostasis, and the genetic and ecological structures of the populations.

Summarizing the above-mentioned facts an important methodological conclusion can be drawn: the cyclic character and recurrence are a universal property of the development and functioning of any natural systems in space and time. This conclusion serves as a conceptual basis for the theoretical synthesis of the regularities of long-term recurrence of the mass insect appearance through the law of cyclic character, and the latter, as it was shown in the generalization process, is a universal property of the development, functioning and transformation of any system organization.

Theory of cyclic character of population dynamics (Beletsky, Stankevich, 2018)

The main regulations of the modern theory of the population dynamics and its practical application in forecasting are described in the works of I.Ya. Poliakov (1968, 1976). According to this theory the dynamics of harmful organisms is connected with the changes in their vital activity under the influence of nutritional conditions, heat and water exchange in which the development of the separate generations or age groups took place. The variability of these conditions causes a qualitative morphophysiological rearrangement of the state of populations which is manifested in the changes in their static spreading, reproduction intensity, and development and survival rates. He called this theory the "modern unified theory". According to his ideas the energy resources and physical environmental factors form all the properties of the population including its reaction to the same factors in the future as well as the nature and regulating importance of intra-and interspecies relationships. The feedback principle is characteristic of the entire set of relationships between the populations and the environment. At the same time the interaction between the food reserve and the population with the simultaneous dependence of both components on the climatic factors becomes decisive.

I.Ya. Poliakov considered that the climatic conditions and energy resources were the main factors guiding the evolution of species on the Earth and they are still remainrd the same. Only those forms that could ensure a positive energy balance have survived, i.e. the amount of energy received from the fodder or synthesised by the plants should exceed all life-support needs including the expenditure of energy and the accumulated reserves for the reproduction.

The biotic factors (parasites, predators, pathogens and intraspecies relationships) are manifested themselves depending on the degree of favourable conditions for the pest reproductions. The predators, parasites, and pathogens do not determine the pest dynamics under the optimal conditions for the mass reproduction of the harmful species populations. The phytophages serve as the energy supply sources for the predators and parasites and their phenology leads to cutting off the least viable part of the phytophage population that is late or begins the development and activity too early, and this fact does not correspond to the optimal standards. As a result in the ecosystem there are such relationships between the components which are based on the energy and its balancing and ensure the stability of the ecosystem as a whole; this is called homeostasis. According to I.Ya. Poliakov the mechanisms that ensure the balance of relationships in the triad of plant-phytophage-entomophages components in agrocenoses are destroyed under the influence of anthropogenic activity (tillage, sowing dates, fertilizers and other agricultural techniques). Therefore under the conditions of the anthropogenic landscape the dependence of the population dynamics of harmful species on the state of the energy resources (food) and climatic factors is increasing. This theory underlies the compiling of the annual forecasts. Later I.Ya. Poliakov suggested that when developing the long-term forecasts for some objects it is necessary to take into consideration the long-term variability of solar radiation activity since it significantly affects the state of the climatic factors. “However the impact on the results nature of human production activity is more powerful. Therefore it is impossible to use the cyclic changes in the activity of solar radiation as predictors (indices) of long-term forecasts of the harmful species spreading. The comparison of the long-term data on observations of the population dynamics of certain harmful species and their complexes with the cycles of the Sun activity shows that now there is no such a degree of correlation where it was in the past”. Here the author emphasises the possibility of using the 100-year and 50-year periodicity of changes in the solar activity as a criterion for the background long-term forecast for some species. He believed that the changes in radiation activity affect the rate of the species response and the factors that determine the dynamics of its development and spreading.

One can agree with these contradictory statements if to have in mind the long-term (one-year) forecasts; the cyclic character is the fundamental and universal property of the long-term forecasts for the development and functioning of the populations in the case of the long-term forecasts of the mass reproduction of pests.

Thus the extensive materials on the connection, interaction and synchronization of space, climatic, trophic and population cycles have been accumulated in the literature; they give the opportunity to perform the interdisciplinary synthesis, and the latter, as it is known, necessarily assumes the emergence of a theory.

Really “... The creation of any theory, like the discovery of any natural law, often leads not only to the intradisciplinary synthesis but also to interdisciplinary one, and moreover the wider the scope of phenomena covered by this theory or this law is, the greater the degree is” (Kedrov, 1961).

In the process of the interdisciplinary synthesis of theoretical ideas of domestic and foreign ecologists about the changes in the number of the populations from the positions of a systematic approach, the analysis of modern achievements of astrophysics, biorhythmology, biophysics, space physics, heliobiology, climatology and other natural sciences, the long-term analysis and generalization of the historical information on the mass reproduction of 70 species of insect pests of agriculture and forestry in Ukraine and in other regions as well as based on his own studies of the ecology of the sun pest E.N. Beletsky (2011) substantiated the theory of cyclic character of the insect population dynamics.

The conceptual basis of this theory is the connection, interaction and synchronization in the development of the biosphere, biogeocenoses and populations with the space and climatic cycles; the cyclic character as a universal property of the development and functioning of any material system explains the regularities of the mass reproduction of harmful insects in space and time and serves as an objective criterion (predictor) for forecasting the population cycles.

The main consequences arising from this theory are given below:

1. The long-term recurrence of the insects’ mass reproduction is a

regular process of development and functioning of the populations synchronised with the cycles of the solar activity, weather and climate and determining the energy resources, namely the trophic base and spatial and temporal organization as well as the genetic and ecological structures of the populations.

2. The cyclic character as a universal regularity of the development process explains the recurrence of the mass reproduction of harmful insects and serves as a criterion for their forecasting.
3. The theory of the population dynamics cyclic character performs the descriptive, explanatory, prognostic and synthesizing functions. Through the law of cyclic character it combines the previously proposed theories, i.e. the climatic and trophic ones.
4. An intersystem method for a lon-term forecast of the mass reproductions of insects as well as the algorithms for their forecasting have been developed on the basis of the theory of the population dynamics cyclic character.

In the last decade an ecological and genetic theory explaining the mechanism of the dynamics in the number of the phytophagous insects (Chaika, 2000) and a phenological theory explaining the difference in the dynamics of populations of the individual species of pine and leaf-gnawing insects and their synchronism with the fodder plants and entomophages (Meshkova, 2009) have been substantiated in Ukraine. The above-mentioned theories are widely discussed in the entomological literature.

Nonlinearity of mass reproduction of insects as analogues of aggravated rates. A possible mechanism of their catastrophic number from the position of synergetics (Beletsky, Stankevich, 2018)

The twentieth century was characterised by a colossal intellectual breakthrough prepared by the development of science and technology in the previous centuries. Science is still a fundamental factor of progress. Nevertheless the scientific progress has obviously slowed down as for one issue and we can hardly demonstrate our former power. Such an issue is the problem of forecasting (Kravtsov, 1997). This issue is especially relevant in the ecology of the populations and plant protection where the problem of the mass reproduction of insects has been known to mankind since time immemorial and it is remained insufficiently studied and debated today. First of all it is the knowledge of the fundamental laws and mechanisms of this complex ecological process, and no less important is the possibility of its forecasting as well as the limiting time of forecasting, i.e. the horizon of forecasting (prognosis).

To imagine the psychological shock of the mass reproduction of harmful insects that took place at the beginning of the last century we cite the "unexpected" mass reproduction of the webworm beetle described by K.N. Rossikov (Rossikov, 1903): "The year of 1901 will remain in the memory of the agricultural population of most parts of our country for a long time. Throughout the summer a "worm" in the elemental ammounts appeared in a vast area from Tomsk to Kamenetz-Podolsk; a "worm" was the name used everywhere for the caterpillar of the famous butterfly – the webworm beetle or snowstorm. The "worm" was appearing during the whole summer in different parts of our country at the same time. It has been observed since May and throughout the whole June, July, August and September. All this time the "worm" was cuasing the devastations which reached the enormous sizes in the areas of beet and hemp cultivation. The worm entirely devoured the crops of plantations and fields turning the latter into monotonous bare, black and dusty spaces. The colossal devastations made by the "worm", its movement in hordes along the areas of several tens of square miles and the flight of the innumerable mass of the butterflies during the whole summer terrified and feared the entire agricultural population of the entire Central Chernozem Region of Russia" (Rossikov, 1903).

The catastrophic mass reproduction of the webworm beetle in 1929 was approximately within the same boundaries as in 1901. In 1929 the number of the caterpillars was so high that when they moved (migrated) through the railway, the trains had to stop. Especially great number of the caterpillars was in the south of the beet-growing area (from 250 to 800 specimens per 1 plant). "On the railroad near the Dolinskaya station the fire-screens smoked along the whole front of the Borisovka and Pelagievka plantations adjacent to the railroad-bed; that was the protection from the caterpillars coming from the estranged strip; in addition hundreds of workers with the brooms in their hands stood along the ditch throughout the front and swept away the caterpillars breaking through the fire. Usually two attacks were observed daily: the first attack was at 7–11 a.m. and the second one was at 15 p.m. On the railroad tracks a special train crew in a steam locomotive led by the head of the station doused the caterpillar crawling across the track with the steam. The dead caterpillars, shot down by the steam, laid along the rails. The black walls of the peasant houses facing the railroad track attracted the attention: they were completely covered with the caterpillars and every morning the mistresses swept them off the walls with the brooms. The farmsteads of the Pelagievka state farm were filled with the crawling caterpillars. The porch of the office and its walls were half-covered with the treacle in order to block the access of the caterpillars to the premises; however they made the way inside the room over the stuck corpses and crawled along the tables and walls, crawled into the office books, and crawled onto people; even the house flowers were completely eaten by the caterpillars (Yanovskaya, 1932, p. 139).

In 1975 a global (unpredictable) outbreak of the mass reproduction of the webworm beetle again took place over the vast territory of the former USSR as well as in some regions of Bulgaria, Hungary, Romania, Czechoslovakia, Yugoslavia, Mongolia, and the Chinese People’s Republic. This mass reproduction was not forecasted and was qualified as “unexpected” although already in 1969 a mass flight of this pest butterflies was noted in the North Caucasus, then it was noted in the southeastern regions of Ukraine and in the Central Chernozem Region; in 1970 the destructive measures were carried out in those regions and their scope was increasing from year to year (in 1974 it amounted to 1,5 million hectares). A similar situation recurred in 1988. In the “Forecast .... for 1988 ”it was indicated that the breeding grounds of the webworm beetle would be spread in those places where the previous year (1987) there was an increase in the number of the third generation of its caterpillars. In the whole in the USSR it was planned to treat against the webworm beetle various agricultural crops on the area of 1,5 million hectares, but in fact 13,1 million hectares were treated, and about 6 million hectares were treated in Ukraine.

The workers of the Omsk plant protection station were convinced that it was almost impossible to plan the scope of protection against the beetle based on the developing phytosanitary (ecological) forecasts. Thus “According to the forecast for 1986 it was planned to control the webworm beetle on an area of 30 thousand hectares (alfalfa, sweet clover, rapeseed and row crops), but in 1986 336 thousand hectares or 11 times more were treated in one track!” (Kalinina, 1988, p. 13).

In 1957 the unpredictable and “unexpected” mass reproductions included the outbreaks in the number of the owlet moth in the virgin areas of the Trans-Urals, Western Siberia and Northern Kazakhstan; in 1995–1996 there were the mass reproductions of the locusts in Kazakhstan and Ukraine; in 1992-1999 the situation recurred in the Lower Volga Region, Western Siberia and Kazakhstan; in 2003-2008 – in Western Siberia and Ukraine. In 2003 the mass reproduction of the Italian locust in the Crimea reached an unusual scale (for the first time the movement of swarms with a density of larvae of 5000 specimens/m² was recorded (Chaika et al., 2009).

The following question arises: why the phytosanitary forecasts are not justified themselves? According to the authors' opinion in a general way it happens because all types of forecasts for plant protection are developed on the basis of the outdated linear methodology which assumes having one cause and effect and unlimited possibilities of forecasting in which the future should always be derived from the past (the so-called Laplace determinism). The future scenario is built with the undoubted confidence in its implementation (Nalimov, 1983). However the nonlinearity of the overwhelming majority of complex open natural systems, including the insect populations, makes fundamentally unreliable and insufficient the forecasts-extrapolations that are still very common, because the development is carried out through the contingency in choosing a path at the moment of bifurcation (a sharp change in the nature of movement), and the contingency itself is not usually recurred again (Prigogine, 1986; Kravtsov, 1997; Malinetsky, 1997; Kurdiumov, 2001; Malinetsky, Potapov, 2002). In addition it is very important that at certain stages the possibility of super-fast development (aggravated rates) lies behind the non-linearity; in the ecology of insect populations it is the mass reproduction. The basis of the super-fast (catastrophic) development is a nonlinear positive feedback systemic connection (Malinetsky, Potapov, 2002). The latter facilitates the departure of the system from the equilibrium to instability; at the same time the nonlinear positive feedback is present at every point of the environment or the production of substance is present in each local region of the environment (for example a local population in ecology), which is proportional to the concentration of the substance in this region; it increases in a nonlinear manner and accelerates the production of a substance (density, number, biomass, etc.) (Malinetsky, Potapov, 2002).

This synergetic regulation is not coordinated with the dominant classical concepts of ecology about the linearity of the cause and effect relationships of the insect population dynamics with the environmental factors as well as their ability to forecast in the future (Kniazeva and Kurdiumov, 2002), i.e. Laplace determinism prevails in the modern ecology of populations. Perhaps that is why the "unexpected" and unpredictable mass reproductions of harmful insects arise. However the results of the researches carried out in the 20th and at the beginning of the 21st centuries showed that the dynamics of the nonlinear systems (media) is a possibility of unexpected catastrophic processes that are characteristic of almost all nonlinear natural systems including the insect populations. On the one hand their long-term dynamics is limited to the forecasting and on the other hand their mass reproductions have already taken place in various regions in the past. For example in 1008 the mass reproductions of the locusts took place in the Principality of Kiev; in 1708 – in Italy, Romania, and Ukraine; in 1583 – in the Wild Field (Zaporizhian Sich); in 1783 – in Ukraine, Russia and Italy. The mass reproduction of the turnip moth was in Ukraine in 1823 and in 1923. In 1086 the webworm beetle bred on a mas scale in Kiev Rus, in 1986 – in the Omsk region, Western Siberia, Altai Territory and Melitopol district of Zaporozhzhya region. In 1086 the mass reproductions of the sun pest were noted in Iraq, 1100 years later, in 1909 they took place in Russia, Ukraine, Turkey and Jordan; in 1736 – in Iran; in 1936 – in Ukraine, Russia, and in the countries of the Near and Middle East (Beletsky, 2011). Paradoxically enough, but according to the modern concepts of nonlinear dynamics (synergetics) they are programmed in the present and in the future (Kniazeva, Kurdiumov, 2002).

Conclusions

1. It has been established that the mass reproductions of 39 species of insects are cyclical and polycyclic in nature, but they are not periodic, that is they occur at different intervals. Moreover the outbreaks in their numbers take place both in the eras of the solar activity minima and in the eras of its maxima and on different branches of the solar activity dynamics (the growth branches and the branches of decline).

2. The frequencies of the mass reproductions of insects for the period of 1854–1985 during the years of benchmarks were 2,5–3,0 times higher than the frequencies during the other years. At the same time the chi-square criterion was high enough (11,11) and the probability level was relatively small (less than 0,5). This fact makes it possible to assert that the synchronism of the mass reproductions of 70 species of insects over the specified historical period with the years of sharp changes in the solar activity takes place in Ukraine.

3. The global synchronization of the mass reproductions of insect cannot be explained by the interaction of their populations with weather factors since the coincidence of the latter is unlikely even within the same

region. The population cycles are self-oscillations of the biological systems synchronised by the solar activity. At least the solar activity can create the double effects: the “cyclic background” of changes in the Earth’s processes and a part of the fractures of the long-term course distorting this “cyclic background”.

4. The overhelming majority of the mass reproductions of insects began in the years of dry weather, and the droughts are synchronous with the dynamics of the solar activity.

5. The cyclic character and recurrence are the universal properties of the development and functioning of any natural systems in space and time. This conclusion serves as a conceptual basis for the theoretical synthesis of the regularities of long-term recurrence of the mass insect appearance through the law of cyclic character, and the latter, as it was shown in the generalization process, is a universal property of the development, functioning and transformation of any system organization.

6. The theory of cyclic character of the population dynamics performs the descriptive, explanatory, prognostic and synthesizing functions. Through the law of cyclic character it combines the previously proposed theories, i.e. the climatic and trophic ones. The intersystem methods for a lon-term forecast of the mass reproductions of insects as well as the algorithms for their forecasting have been developed on the basis of the theory of the cyclic character of the population dynamics.

7. According to modern concepts of nonlinear dynamics (synergetics) the mass reproductions of insects are programmed in the present and in the future.

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PART 3. WANDERING OF MASS REPRODUCTION OF HARMFUL INSECTS WITHIN THE NATURAL HABITAT

The wandering of nonlinear systems along the field of the possible development paths is one of the important characteristics of dynamic nonlinear systems in synergetics. At the same time the nonlinear system "non-rigidly" follows the "prescription" and makes a sort of wandering along the field of the possible development paths in accordance with the nonlinear dynamics in the real nature of our random being (stochastism and determinism (Kniazeva, Kurdiumov, 2002).

This theoretical position of nonlinear dynamics is important for the theory and practice of harmful insect population ecology, in the first turn it is necessary for establishing the migration of their mass reproduction primary breeding grounds as the prognostication of the aggravated regimes (the beginning of mass reproduction in space), predicting and making decisions (management) in plant protection. It must be assumed that ignorance of these regularities of the nonlinear systems dynamics was the cause of the repeated errors in predicting and "sudden" appearance of "unexpected" and unpredictable mass reproductions of short-horned grasshoppers and locusts, winter moth, webworm beetle, sun pest and some other insect pests.

Predicting the future from the standpoint of synergetics proved to be more difficult task than it was previously thought by the representatives of classical science. It turned out that in principle it is impossible to give a long-term prognosis of the meteorological, chemical and ecological systems behavior (Malinetskii, 1997; Moiseiev, 2001; Nicholas, Prigozhin, 2003).

Over the past 30 years it has been shown that there is another important class of objects. Formally they are deterministic, and knowing exactly their current state it is possible to establish what will happen to the system in any distant future. But at the same time it is possible to predict its behavior only for a limited period of time. Even small inaccuracy in the value of the initial state of the system grows in due course, and from some time we lose the ability to predict anything. During this period the system has the chaotic state (Malinetskii, 1997). It is obviously that such a pattern is also characteristic for the vast majority of the insect pests, which mass reproduction is still impossible to predict for a long period of time due to the inaccuracy of the primary quantitative and qualitative data and their chaotic dynamics of numbers and nonlinearity. Very little is known about the properties of the nonlinear world. One of the greatest ideas of the nonlinear world is that of the solutions ramification or bifurcations. Bifurcation is a change in the number or stability of a certain type of solutions (Malinetskii, 1997), and it is the ramification point of the possible evolutionary paths. Therefore taking into account the complexity of the nonlinear systems dynamics (in our case the insect populations) perhaps we should rely on the qualitative prognoses like: ... when we should expect the regular mass reproduction of one or another insect in the scope of this or that year.

Short-horned grasshoppers and locusts (mass reproduction in space and time)

The mass reproduction of short-horned grasshoppers and locusts has been known to mankind since the onset of agriculture and plant growing. We have done a retrospective analysis of their mass reproduction based on the information presented in the scientific literature (Figuier, 1869; Keppen, 1870; Kulagin, 1921; Kripiakevich, 1927; Borisenkov. 1988; Barash, 1989; Yavornytskyi, 1990; Sergeiev, 2007; Sergeiev, 2010; Biletskyi, 2011).

The first mass reproduction of the short-horned grasshoppers and locusts in the history was noted in 1490 BC. In 1104 BC the short-horned grasshoppers and locusts flew upon Libya. In 904 BC they devastated Palestine; in 104 BC these pests devastated some regions of the Chinese Empire, when due to the crop failure and famine caused by the locust invasion the campaign of the Emperor Wang Ti against the Tavans did not take place.

In 203 and 172 BC the Italian locust completely destroyed all the crops in the southern Italy.

In 63 AD the Parthian king Vologezez was forced to raise the siege of the Armenian fortress Tigranocerta because the locust completely destroyed all the grasses, leaving his cavalry without forage.

In the 4th century AD Saint Jerome mentioned the catastrophic mass reproduction of the locusts in Palestine.

In 456 in Phrygia (an ancient country in the northwestern part of Asia Minor) the catastrophic reproduction of the desert locusts took place; in 576 it was in Syria and Mesopotamia (one of the oldest centres of civilization); in 580 the mass reproduction of the locusts took place in the same area again; in 592-593 the locusts appeared in Germany on a mass scale; in 677 they were in Syria. In 678-679 the mass reproduction took place in the Chinese empire; in 722 – again in Syria; in 784 in Syria the locusts destroyed all the vegetation and packed all the houses (Keppen, 1870).

In 872–874 the mass reproduction of the locusts took place in Germany and France; in 929 – in Egypt; in 957 – in Syria and Mesopotamia; in 960, 969 and 1002 – in Syria; in 1010 – again in Syria; in 1084 – in Germany, England, France, Poland and Russia; in 1092 the mass reproduction of the locusts took place near Constantinople.

The first mass reproduction of the locusts (“prusi” – Old-Slavonic) was dated in 1008; then in 1094-1095 it was noted in Kiev’s Russ; then the mass reproduction of the locusts was noted in the Grand Princedom of Kyiv in 1103, 1195-1196, 1237, 1338-1339, 1401, 1408, 1472-1475, 1501, 1527, 1534, 1541-1542, 1546-1549, 1583, and in 1601-1603; then it was noted in Ukraine in 1645-1646, 1648-1649, 1652, 1681, 1689-1691, 1700-1709, 1713, 1719-1720, 1726, 1743, 1747-1749, 1756-1758, 1783, 1793, 1799-1802, 1804-1806, 1811-1818, 1820-1829, 1839-1840, 1846-1849, 1851-1852, 1859-1860, 1862-1864, 1866-1869, 1884-1888, 1890-1893, 1901-1903, 1910-1913, 1923-1925, 1930-1932, 1937-1939, 1945-1947, 1951-1953, and in 1995-1997 it was noted in the South of Ukraine, in 2003 the mass reproduction of the locusts was noted in the Autonomous Republic of the Crimea; the density of the larvae was up to 5000 specimens/m^2). The mass reproduction of the Italian locusts in the Lower Volga region was noted in 1968–1969, 1972, 1978–1983 (Sergeiev, 2010).

Over the period of 63–2003 the reoccurrence of the mass locust reproduction that occurred in the past amounted to 800 years (1195–1995), 700 years (1237–1937), 500 years (1401–1901), 400 years (1008–1408), 300 years (1389–1689), 200 years (1401–1601), 100 years (1401–1501), 100 years (1713–1813) and 100 years (1811–1911).

During the given period the catastrophic mass reproduction of the locusts was described in the works of the historians, ecologists, writers and even travelers. In 1649 there was a great crop failure; only the seeds fall of rye gave the yield in the places there the Cossacks were encamped; the spring rye was harvested by hand. The same year there was a terrible amount of the locusts that ate the cereals; and there was also a great number of mice; no one could remember that there had been so many mice earlier; so there was a high cost of bread, salt and hay ”(Yavornytskyi, 1990).

“In the year of 1583 the locusts rampaged in the Zaporozhian steppes; Samiilo Zborovskyi, the owner of the Zolochev town of Lviv District, who at this time was sailing with a detachment of the Polish gentry along the Dnipro to connect with the Zaporozhian Cossacks for a joint campaign against the Tsar Ivan the Terrible of Moscow, met a cloud of the locusts below the Khortytsia Island on the Dnipro that caused the death of 300 horses and a lot of horses became swollen" (Yavornytskyi, 1990).

"The year 1647 was unusual as numerous signs in the heaven and on the earth threatened with the unknown disasters and unprecedented events. The chronicles of that time informed that in the spring, having hatched in an unprecedented great number from the Wild Field, the locusts had eaten the crops and grasses, and this fact betokened the Tatar raids ... "(Senkevich, 1983).

"In 1709 the locusts stopped the army of Charles XII, the King of Sweden, retreating to Bessarabia after the Poltava defeat. The king thought it was the hail as the locust hit his army very heavily. The men and horses were blinded by this living hail falling from the cloud that darkened the sunlight. All the villages laying on its way were ruined. The same year a significant part of Europe was devastated by it" (Figuier, 1869).

"In 1735 the clouds of the locusts darkened the sunlight and moonlight for the Chinese. Not only the standing crops but even the grain stored in the shops, even the clothes in the houses were devoured by these insects "(Figuier, 1869).

"In 1739 the locusts covered the entire surface of the soil from Tangor to Mogador (Moroccan Empire). The entire area adjacent to the Sahara was devastated while on the other side of the El-Kos River not a single insect was seen" (Figuier, 1869). According to the chronicles the mass reproduction of the locusts also took place in the Middle Ages; later the literary sources recorded the numerous outbreaks of their numbers during the 19th and 20th centuries when there were more than 84 outbreaks of these insects. Judging by the information (Sergeiev, 2007) the mass reproductions in the territory of the former USSR not only reduced but, on the contrary, sharply reinforced with a significant increase in the treated areas. Thus in 2000 10 million hectares including 8 million hectares in Kazakhstan and 2 million hectares in Russia were treated to control the locusts. In 1989 and 1996, that is only two times, the treated areas were a little more than 4 million hectares.

In 1999 during the catastrophic mass reproduction of the locusts in Kazakhstan they destroyed 220 thousand hectares of cereals, and the losses amounted to 15 million US dollars; at the same time the costs for the locust control amounted to $ 4,8 million in 1999, and in 2000 the costs were $ 23 million. Further examples are given according to M.G. Sergeiev and A.V. Lachinskii (Sergeiev, 2007).

In 1992 in the Lower Volga Region and Western Kazakhstan the areas of the Italian locust population gradually expanded to the east, in Kyrgyzstan only from 1997 to 2000 their number increased by 7 times. In the south of Western Siberia a sharp increase in the number of these pests began in 1999, and the outbreak reached its maximum in 2000. The above-mentioned authors believe that this fact was facilitated by weather conditions.

A great number of the Italian locust was not only in the Western Kazakhstan, the Lower Volga Region and Ciscaucasus, but also in Ukraine (the southern steppe regions and the Autonomous Republic of Crimea). The mass reproduction of the Italian locust was noted in 2005–2006 in France.

At the end of the XX and the beginning of the XXI centuries the large flocks of the migratory locusts (*Locusta migratoria* L.) were recorded in some regions of the European part of Russia, in the south of Siberia, in Central Asia and in the East Kazakhstan. After a long depression (since 1992) another mass reproduction of the desert locust (*Schistocerca gregaria* Forsk) began in West Africa in October. In September 2000 the locusts spread over 15 countries of West and North Africa and populated the huge territories. We predicted the beginning of this mass reproduction of the desert locusts back in 1996 (Zachary, 1996). This outbreak occurred in 2003-2005 and caused the monetary damage of $ 1 billion; only in 2003–2005 13 million hectares were treated to control the desert locusts in 22 countries on three continents (Lachinskii, 2001).

In the south of Africa in 1995–1996 the local species of brown locust *Locusta pardalina* Walk (kindred to the migratory locusts) propagated on a mass scale. At that time the costs for its controlling amounted to about $ 3,5 million.

In 2004 another outbreak in the number of the migratory locusts was recorded in China on the border with Kazakhstan, Russia and Mongolia.

In 2004-2005 in Australia there was one of the greatest mass reproductions of the Australian gregarious locust (*Chorthoicetes terminifera* Walk) over the last decades. At the same time about 450 thousand hectares were treated.

In 1999-2001, 2004 and 2006 the powerful outbreaks in the number of this pest were recorded in the southwestern Australia, where the mass locust reproduction occurs not often (Sergeiev, 2007).

Mass reproduction of webworm beetle

A webworm beetle is one of the most common pests of many agricultural and wild growing plants. It is known that its natural habitat includes 14 countries of the Old and New Worlds and, according to the calculations, the area of this territory is about 11,552 million km² while the area of Ukraine does not exceed 5,2% of this territory (Kravchenko, 2002). This fact is a real limitation for the regional forecasting of the locusts mass reproduction, especially when using the solar activity as a predictor expressed in terms of the relative Wolf's numbers (W).

The first known mass reproduction of the webworm beetle in the Principality of Kyiv was in 1680. "In 1680 in Ukraine there was a torrid sun heat and aridity; all the water and grasses dried out; the worms propagated and ate the beans, cabbage, peas, hemp and buckwheat and passed from one field to another" (Yavornytskyi, 1990). The second mass reproduction took place in 1686. "The same year everything was black with the worms which were the caterpillars' height; they caused a great damage to the hemps and to other potion, but intentionally did no harm. The flocks of them went along the road to the town and through the gateway; from the town the flocks went to the gardens without fear of the rains, though the summer was wet" (the Chronicle of Eye-Witness, 1878).

The mass reproduction of the webworm beetle in our country was first noted by the famous academician and traveler Peter Simon Pallas (1743–1811) on May 12, 1763 when he saw the flying butterflies in huge numbers near Saratov; there were so many of them that they looked like "the gnats in a young oak grove" (Rossikov, 1903).

Eversmann classified the webworm beetle as a harmful insect in the broad sense of the word, indicating that the latter appeared annually in the southwestern foothills of the Urals and the adjacent steppes, and its caterpillars caused the great damage to the vegetation there (Rossikov, 1903).

According to S.M. Mokrzhetskii (Mokrzhetskii, 1902) the webworm beetle caused the great damage in the United States of North America at one time. F.B. Paddock in his article "The sugar-beet web worm" published in the journal "Economic Entomology" in December 1912 reported that in 1909–1910 the beet plantations in America suffered heavily from the webworm beetle; from 35 to 55% of all the cultivated beets were lost and the losses amounted to 2–5 percent of the sugar content. Paddock believed that the webworm beetle had appeared on the Pacific coast and then spread to the states of Colorado and Nebraska in

1869, and the harm from it became apparent after many years of its first appearance in America.

The wandering of the mass reproduction breeding grounds within the natural habitat is most clearly manifested in the case of the webworm beetle. Thus in 1769 such breeding grounds were near Syzran (The Volga region); 100 years later in 1869 they were noted in the Kyiv and Podolsk provinces; in another 100 years, in 1969, the mass reproduction breeding grounds were noted in the North Caucasus and in 1869 – in the USA.

In 1853 the initial breeding ground appeared in the Veliko-Anadolsk Forestry (the southeastern part of the Yekaterinoslav province and in the Krasnoyarsk District (Dobretsov, 1980). In 1854 it moved to the Sarepta (the Volga Region) where its caterpillars completely destroyed all the plants except the cereals across the territory of 200 versts. In 1854–1855 the caterpillars damaged the vegetable crops in some regions of the Kharkiv province (Keppen, 1870), and already in 1855 the webworm beetle propagated on a mass scale in all regions of the southern Russia, in the Volga Region, in Siberia and Ukraine. The separate breeding grounds with a high density of caterpillars of the webworm beetle cyclically arose in 1864 in the Tauride province; in 1847 they were noted in the Tula region, in 1868–1869 they were in the Kyiv and Poltava provinces, in 1870 there was a great number of them in the vicinity of Astrakhan; in 1873 the breeding grounds occurred in the Don region; in 1880 they were noted in the Kyiv, Yekaterinoslav, Poltava and Kharkiv provinces as well as everywhere in the area of beet-growing; in 1892 they appeared in the Don region (Keppen, 1870).

In 1900 the breeding grounds of the webworm beetle occurred in the Kharkiv, Kyiv, Yekaterinoslav, Don, Poltava and Nizhnii Novgorod provinces; in 1901 they occurred over a vast territory from the countries of the Baltic Sea to Kazakhstan and Siberia (Konakov, 1930).

In 1902 the separate breeding grounds with a high density of the webworm beetle's caterpillars were recorded in the Kyiv, Voronezh and Kherson provinces and in the Don region; in 1903 they were noted in the Kiev and Kherson provinces, in 1909 they again occurred in the Kyiv and Kherson provinces and in the USA.

In 1912 a catastrophic mass reproduction of the webworm beetle was noted in the territory of several districts of the Astrakhan province; then the beetles destroyed all the vegetation (except the cereals) both wild growing and cultivated one, many garden crops and thus, caused a national disaster (Sakharov, 1923). According to V.G. Averin (Averin, 1913) in

1912 great numbers of the webworm beetles were found on beets, potatoes, clover and beans in Kharkiv, Sumy and Kupiansk districts; and already in 1913 they propagated in the Kharkiv province in an enormous number and caused not less than a million rubles of monetary damage. I.A. Porchinskii (Belskii, 1932) indicated that in 1912 the webworm beetles propagated heavily over a vast area from Central and Western Siberia to the provinces of the South-West Russia. They caused damage to water-melon, melon and gourd plantations, sunflowers, beets and many other crops. In 1915 the beetles propagated in the Astrakhan and Kyiv provinces; in 1915 the webworm beetle propagated in the Voronezh, Don and Orel provinces.

In 1921 the mass reproduction of the webworm beetle was recorded throughout the beet-growing areas, and its appearance was like a national disaster (Lindeman, 1923). In 1922 on the Right Bank of Ukraine, in the region of Smila and even in more southern districts "… it was difficult to find some specimens of butterflies" (Zverozomb-Zubovskyi, 1924), while hundreds of acres of beet crops were again damaged in the Central Chernozem Republic (Konakov, 1930). In addition to the Central Chernozem Region the webworm beetle on a mass scale propagated in the southeastern Poland, throughout the territory of Ukraine; in some regions of the Kyiv, Poltava and Chernihiv regions its caterpillars destroyed from 60 to 100% of the sugar beet crops (Konakov, 1930). In the Don region the vegetable gardens were completely destroyed in some places; the crops of corn and fodder grasses were also severely damaged at the experimental station (Averin, 1913). In 1929 a catastrophic mass reproduction of the webworm beetle was noted over a vast territory, the northern border of which passed through Tver, Kostroma, Perm, Sverdlovsk, Tara, Tomsk, Krasnoyarsk, Irkutsk and Verkhnedvinsk in the east, in the southeast the border passed through Minusinsk, Semipalatinsk, Akmolinsk, Astrakhan, Kislovodsk, Novorossiisk and the southern coast of the Provish river, in the west it passed through Poland. A great number of the webworm beetle also appeared in Bulgaria, Hungary, Germany, Poland, Romania and Yugoslavia. Was it possible to predict the sudden reproduction of the beetle in 1929? At one time many entomologists and ecologists gave a negative answer to this question. After this huge mass reproduction of the webworm beetle a theoretical concept was developed which explained the conditions for the occurrence of this pest mass reproduction and determined the ways to prevent its harmfulness. I.Ya. Poliakov (Poliakov,

1964) wrote at one time: “If to take into consideration this concept then at present there are no favourable conditions for the mass appearance of the webworm beetle. The increasing intensity of soil cultivation in the agricultural areas and the development of large areas in Kazakhstan, where the reservation and accumulation of the webworm beetle with its subsequent flight to other districts could be possible, prevent from its appearance”.

“Probably there is enough reason to consider the webworm beetle a former mass pest despite the fact that not a great number of this species is annually observed in almost all agricultural areas” (Poliakov, 1964). Unfortunately the prognosis of the leading forecaster of the former USSR did not come true! The analysis of the regular mass reproduction, especially global (in 1975 and 1988), indicates that the primary breeding grounds with a high number of this pest made a regular wandering within its natural habitat.

According to the data of A.N. Frolov (Frolov, 2011) in 2008 another outbreak of the webworm beetle reproduction first began in the Trans-Baikal Region of the Russian Federation. In 2009 the area infested by the pest continued to grow in the Amur Region. The number of the pest that exceeded the threshold was noted in Buriatiia, Altai and Krasnoyarsk Districts, Irkutsk, Novosibirsk, Kemerovo and Tomsk Regions and in Khakasiia; its appearance was also noted on the Sakhalin Island. In Ukraine the last mass reproduction of the webworm beetle was recorded in 2011–2013. In 2011 the webworm beetle was spread almost everywhere in the southern and eastern regions but in the central regions of Ukraine it was spread locally; the outbreaks of its numbers were also noted here although in 2008–2010 they were not of an economic importance here.

In the “Forecast ... of the Russian Federation for 2010” the information indicates that in 2010 there was the mass of the beetles in the Voronezh Region despite the high temperature and low humidity of the air; the females had a well-developed fat body and the forming, maturing and mature egg production. This statement contradicts both the past and modern ideas of the researchers studying the biology and ecology of the webworm beetle in the zone of its spreading during the mass reproduction and depression! All the researches were unanimous in the fact that high temperatures and droughts were the causes of the pests’ infertility.

Triebel S.A., assessing the phytosanitary situation in Ukraine in 2014, clearly indicated that in 2014 the acreage treated with the products controlling the webworm beetle could amount to two and even more million hectares. However the webworm beetle again played the forecasters a trick. Its mass reproduction, which began in Ukraine in 2011, ended in 2013 when 1 million 209 thousand ha were treated against the beetle in the steppe and forest-steppe zones of the republic, i.e. in 2013 there was the peak of this pest number, although this fact was predicted yet in 2014–2015 (Belaiev, 2003).

Wandering of mass reproduction of a sun pest in the natural habitat

In the European habitat the mass reproduction of the sun pest has been known since the 19th century, in the Asian habitat it has been known since 809. It is known that 1100 years later in 1909 the mass reproduction of the sun pest was recurred in the Krasnodar and Stavropol Districts, in Rostov Region, Iraq, Iran, Syria, Turkey, Tajikistan, Uzbekistan, Ukraine, the Volga Region and in the Central Chernozem Region.

As the old residents witnessed in 1909 there was a huge number of the sun pest in the Rostov Region; the local residents plowed the soil in order to destroy the bug’s larvae (Peredelskii, 1947).

According to V.G. Averin in 1909 the bugs of the sun pest completely destroyed the wheat crops in the Zmiivskyi district of the Kharkiv province (Averin, 1913). In 1925–1927 the mass reproduction of the sun pest took place in the Luhansk, Odessa and Kharkiv regions. In 1927 the primary breeding grounds of this pest were found in two bordering districts of Turkey; and already in 1928–1929 the bugs populated the greater part of the Kiliiska valley, the granary of Turkey. In 1929 the destruction of wheat and barley due to the damage caused by the sun pest reached the losses estimated at one million German marks (Peredelskii, 1947). According to the legendary data of Nadir Shah Arshar the similar situation was in Iran in 1736-1737 (Peredelskii, 1947). 200 years later beginning from 1937 the regular mass reproduction of this pest began in Iraq, Iran, Jordan, Lebanon, Syria, Palestine, in the Stavropol and Krasnodar Districts, in the Rostov Region, in the Volga steppe zone, in the Central Chernozem Region and in Ukraine. In 1972-1973 the regular mass reproduction of the sun pest took place in the Kharkiv and Kherson regions. It is significant that in 1972 the primary breeding ground with a high density of up to 50 specimens/m^2 first appeared in Velykoburlukskyi district (the ravine forest, Prykolotne village) and then it appeared in the Kharkiv region (in the outlying districts of the habitat) in the village of Communist, the educational and experimental farm of the Kharkiv

Agricultural Institute (now the Kharkiv National Agrarian University named after V.V. Dokuchaiev).

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PART 4. PROBLEM OF PROGNOSTICATION IN PLANT PROTECTION. THE PAST, THE PRESENT AND THE FUTURE THE METHOD OF NONLINER DYNAMICS

At the beginning and in the middle of the twentieth century in the former USSR, including Ukraine, the mass reproductions of multi-facated and specialised insect pests of agricultural crops, fruit and forest stands were noted. Among them the webworm beetle dominanted. In 1912 and 1920 the mass reproduction of this pest over a vast territory was one of the prerequisites for organizing the prognostication in plant protection.

It was the year of 1913 that should be considered the beginning of prognostication in plant protection in Ukraine. Since this year the entomological bureau of the Kharkiv provincial zemstvo headed by V. Averin has begun to publish the “Newsletter on agricultural pests and measures to control them” with a separate section “On the expected appearance of pests” (Averin, 1913).

In 1925 under the People’s Land Commissariat in Ukraine (Kharkiv) the plant protection departments under the guidance of V.H. Averin and the Central Plant Protection Station were organised. In 1925–1929 the station was headed by A.A. Mihulin; under his guidance the “All-Ukrainian network of observation points” (OP) was created in 1925 and its information and methodical support was developed.

Ukrainian ecologists took an active part in organizing and establishing the prognostication in plant protection. In 1925 V.H. Averin published the article “The Periodic Appearance of the Most Important Pests of Agriculture in Ukraine” and the article “The Waves of Life of the Most Important Pests in Ukraine” in which he showed the wave (cyclic) nature of the harmful insect mass reproduction. In 1930 N.A. Grossheim described the history of the mass reproduction of multi-faceted and specialised pests, emphasizing their unexpected appearance and sharply criticizing the climatic, parasitic and trophic theories of the insect populations’ dynamics. He recommended using the periodicity as a criterion for the forecasting (Grossheim, 1930).

In the 30s the fundamental studies of the population ecology under the guidance of Professor A.H. Lebediev began at the Department of Ecology of the Terrestrial Animals of the Institute of Zoology of the Academy of Sciences of Ukraine. In the article “On the Importance of Forecast as for Harmful Insects” he also noted the periodicity of the harmful insects’ mass reproductions and their probable association with the space and meteorological factors (Lebediev, 1930). The theoretical foundations and prognostication methods in plant protection were first substantiated by S.P. Ivanov in 1936 in his work “The Mass Reproductions of Pests and Methods of Their Forecast” (Ivanov, 1936).

The criteria proposed in his work are still being used by the experts of the phytosanitary monitoring and prognostication service of Ukraine, although they are outdated and do not meet the methodology of modern studies of the population ecology of the insects. In addition S.P. Ivanov was the the first who called the one-year forecast the “long-term” one as it was accepted in meteorology; and even now it is being widely used in the plant protection forecast without any specification, although the work “Prognostication. Terminology” (Lisichkin, 1990) was published about 30 years ago.

In 1938 a collective monograph by S.P. Ivanov, M.M. Levitt and Ye.M. Yemchuk “Mass Reproductions of Animals and Gradation Theories” was published. This is the first work containing a critical analysis of the theoretical concepts of domestic and foreign ecologists on the population dynamics at the example of the harmful insects’ mass reproduction with an analysis of 325 domestic and 686 foreign literature sources. One of the chapters of this monograph is devoted to an acute debatable problem, namely to the periodicity of the insects mass reproduction and to a critical analysis of the existing in the 1930s theoretical ideas about the connection of the mass reproductions outbreakes with the climate dynamics and the appearance of the sun-spots (Ivanov, 1938). The authors of this monograph did not deny the possible connection of “Sunny weather” (the definition of the solar activity by O. L. Chizhevskyi) with the dynamics of the insect populations, but they indicated that it has not yet been determined (late 30s of the last century). By the way till now the question as for the connection of the solar activity with the processes and phenomena occurring in the biosphere, biogeocenoses and populations remains acute debatable despite the fact that most researchers of the solar-terrestrial relations continued and are still continuing to indicate its presence.

In 1940 and 1950 on the initiative of the Ukrainian ecologists (A.F. Kryshtal and others) and taking into account the urgency of the mass reproduction problem the All-Union Ecological Conferences on the problem of “Mass Reproduction of Animals and Their Forecast” were held in Kyiv on the basis of the T.H. Shevchenko State University. At the same time the works

"On the Mass Reproduction of Insects" (Belanovskyi, 1940) and "Features of the Mass Reproduction of Insects and the Principles of Their Prognostication" (Ivanov, 1936) were published. The authors critically summarised the earlier works of the Ukrainian ecologists and made the important conclusions for prognostication in plant protection; they are as follows:

– if the forecast is developed on the basis of the quantitative data obtained from the autumn surveys, then one should not take into account the weather conditions forecasted for the next year because weather forecast for such a long period can only be probabilistic, and therefore it has no prospects to compare the meteorologic factors of this winter, next spring and insect phenology;

– the results of the autumn surveys must be compared with the dynamics of the previous years;

– a qualitative assessment of the population variation of the insects (average weight and sex ratio) should be made;

– it is necessary to determine the infection of the hibernating stage of the insects with the parasites and the affection caused by the pathogens.

These criteria are still taken into account by the specialists of the monitoring and forecasting services.

Afterwards the ecologists tried to explain the reasons of the mass reproduction of the insects by their reaction to the environmental factors, mainly air temperature and humidity in the laboratory, transferring the results of the laboratory studies to the natural conditions, and it was a gross methodological error.

Air temperature and humidity really create a natural background against which the development of the biological systems, including the insects, takes place. However this does not mean that these factors play a leading role in the dynamics of the populations. The famous American ecologist Kenneth Watt wrote: "In thousands of scientific articles the temperature and humidity have been assigned a leading role as the main factors affecting the development of various organisms. However this enourmous work has not yet led to the fact that their influence could be used in the population models" (Watt, 1971).

In 1954 "The theory of changing the vital activity of the populations at the example of mouse-like rodents" was substantiated by the famous Russian ecologist I.Ya. Poliakov. Its essence, the vital activity of the populations (their ecological and morphophysiological structure) in a given period, is determined by the conditions under which the age groups it consists of developed in the past. In his opinion the main and fundamentally new thesis of this theory is that the latter allows one to judge the dynamics of the population and the probable factors that can affect it according to the state of the forage reserve, physical environment, and morphophysiological structure of the populations (Poliakov, 1954). Based on this theory the annual forecasts in plant protection (regarding harmful rodents and insects) were developed and are still being developed. In relation to the mass reproductions of the insects, namely the pests of the agricultural crops, fruit and forest stands, he replaced the prognostication of the mass reproduction with the economic resource prognostication, and more often with a prospective assessment of the phytosanitary condition of a given territory for the purpose of planning and organizing plant protection (Maksimov, 1984).

The failure of these forecasts was confirmed 3 years later. In 1957 an unprecedented in the history of domestic entomology the outbreak of the mass reproduction of the owlet moth (*Hadena sordida* Bkh) was noted. It covered all the regions of Northern Kazakhstan, some regions of Western Siberia, Altai Territory, Trans-Urals and Bashkiria. Only during 1957 the caterpillars of the owlet moth destroyed 150 million poods of grain in the virgin regions of Kazakhstan and Siberia; and the territory populated by this pest exceeded 10 million hectares (Grigorieva, 1965; Shek, 1965). In Northern Kazakhstan the main breeding ground was concentrated in the eastern part of the Kustanai and southeastern part of the Kokchetav regions with the caterpillars’ density of 300 and more specimens per square meter.

It was the year of 1957 that convincingly showed not only the lack of the methods for prognostication of the mass reproduction, but also the theory on which they should be based.

In 1975 there was a “sudden”, unexpected mass reproduction of the webworm beetle, and, according to I. Ya. Poliakov (Poliakov, 1964) this pest was not considered a mass one any more.

I.Ya. Poliakov (Poliakov, 1980) in 1980 made an attempt to identify the reasons of this mass reproduction, substantiate the forecast of its population dynamics and solve the immidiate tasks to improve the prognostication.

At the same time he noted that until 1929 this pest had appeared on a mass scale with an interval of 5-10 years. From 1853 to 1935 (for 82 years) nine great increases in its number were noted in the European part of the USSR; each of them lasted from one to five years. The last outbreak occurred after a 35-year interval. There were no such long depressions before. However this is not true. In the literary sources the local mass reproductions of this pest were recorded in Ukraine and Russia in 1947–1950 and in 1956–1957 (Shvareva, 1963; Dobretsov, 1980; Knor, 1981; Triebel, 1989; Kravchenko, 2002; Biletskyi, 2006; Frolov, 2010; Biletskiy, 2015). I.Ya. Poliakov made the following assumptions.

The mass reproduction of the webworm beetle in the former USSR was due not only to the condition of climatic factors (these factors are not indicated). According to the fundamental studies of the climatologists the climatic factors include solar radiation (SR), atmospheric circulation (AC) and the underlying surface (US) (Shvareva, 1963; Borisenkov, 1982).

One of the main reasons was the radical transformations of the landscape in the thirties which were taking place under the influence of the socialist reconstruction of the agricultural production and its further intensification. The stations for the development of the webworm beetle were significantly reduced aafter the organization of collective and state farms. The wave of the regular mass reproduction of this pest was presumably associated with the creation of the shelterbelt forest on the area of more than 2 million hectares, large areas of irrigated and watering land, and the expansion of crops of perennial legume grasses and row crops. In addition there were no methods for long-term forecasts of the webworm beetle spreading, phenology and harmfulness as the bases for the decision-making; and also the methods to protect the agricultural crops from this pest have not been developed (Poliakov, 1980).

At the same time I.Ya. Poliakov defined the tasks of further improving the forecasts regarding the appearance and spreading of the webworm beetle; they are the followings:

– a complete transition to the mathematical modeling of the population dynamics of the webworm beetle;

– planning the protective treatments and determining the time and place of their conducting using a computer;

– organization of automated collection and processing of the information concerning the status of this pest (number and phenology);

– improving the methods for calculating the butterflies and caterpillars in order to ensure the accuracy of up to ± 40% at the lowest labour costs.

The first task is too optimistic! In his time the famous French mathematician Jacques Hadamard (Hadamard, 1970) wrote in this connection: “the construction of the prognostication models in ecology using the differential equations looks like a parody of Physics”; and G. G. Winberg (Winberg, 1981) noted the difficulties in formalising the biological systems (at the example of the populations) using the mathematical methods.

These works are still remained unknown for many ecologists who studied and are studing the regularities of the population dynamics of the harmful insects. Moreover the year of 1975 served as a powerful stimulus for the intensification of the researches in the field of solar and biospheric relations taking into account the results of studies carried out before 1975.

To develop the forecasts the ecologists used the indices of long-term dynamics of the solar activity expressed in the relative Wolf system numbers (W) (Table 4.1).

Table 4.1

Dynamics of solar activity (1756–2018) $\frac{\text{year}}{\text{W}}$)
(Beleckij, Stankevich, 2018)

I	1756	1757	1758	1759	1760	1761	1762	1763	1764	1765	1766			
	10	32	48	54	63	86	61	45	36	21	11			
II	1767	1768	1769	1770	1771	1772	1773	1774	1775					
	38	70	106	100	82	66	35	31	7					
III	1776	1777	1778	1779	1780	1781	1782	1783	1784					
	20	92	154	126	85	68	38	23	10					
IV	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794	1795	1796	1797	1798
	24	83	132	131	118	90	67	60	47	41	21	16	6	4
V	1799	1800	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810		
	7	14	34	45	43	47	42	28	10	8	2	0		
VI	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	
	1	5	12	14	35	46	41	30	24	16	7	4	2	
VII	1824	1825	1826	1827	1828	1829	1830	1831	1832	1833				
	8	7	36	50	62	67	71	48	27	8				
VIII	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843				
	13	57	121	138	103	86	63	37	24	11				
IX	1844	1845	1846	1847	1848	1849	1850	1851	1852	1853	1854	1855	1856	
	15	40	61	98	125	96	66	64	54	39	21	7	4	
X	1857	1858	1859	1860	1861	1862	1863	1864	1865	1866	1867			
	23	55	94	96	77	59	44	47	30	16	7			
XI	1868	1869	1870	1871	1872	1873	1874	1875	1876	1877	1878			
	37	74	138	111	102	66	45	77	11	12	3			
XII	1879	1880	1881	1882	1883	1884	1885	1886	1887	1888	1889			
	6	32	54	60	64	63	52	25	13	7	6			
XIII	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901		
	7	36	73	85	78	64	42	26	27	12	9	3		
XIV	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913		
	5	24	42	63	54	62	48	44	19	6	4	1		
XV	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923				
	10	47	57	104	81	64	38	26	14	6				
XVI	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933				

	17 44 64 69 78 65 36 21 11 6
XVII	1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944
	9 36 80 114 110 88 68 47 31 16 10
XVIII	1945 1946 1947 1948 1949 1950 1951 1952 1953 1954
	33 92 151 136 135 84 69 31 14 4
XIX	1955 1956 1957 1958 1959 1960 1961 1962 1963 1964
	38 142 190 185 159 122 54 38 28 10
XX	1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976
	15 47 94 106 105 104 67 69 38 34 15 13
XXI	1977 1978 1979 1980 1981 1982 1983 1984 1985 1986
	27 92 155 155 140 156 88 57 21 14
XXII	1987 1988 1989 1990 1991 1992 1993 1994 1995 1996
	33 112 191 182 191 129 72 43 27 13
XXIII	1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
	27 83 125 160 159 163 103 61 43 24 13
XXIV	2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
	5 6 24 75 75 129 119 75 15 14 4

In 2009 S.V. Dovhan (Dovhan, 2009) performed a statistical generalization of the long-term quantitative data presented by the Republican Phytosanitary Monitoring Service and the forecast of the dynamics of the average density of some widespread harmful insects in Ukraine in order to develop the quantitative models for their prognosticatin for the next year (season). The indices of temperature, precipitation, relative humidity and duration of sunshine were used as the predicates (factors). The linear regression equations served as the prognostic models. To analyse the authenticity of the number dynamics correlation of some insect pests we partially used the information presented in the monograph (Dovhan, 2008) without giving the prognostic equations of the linear regression; some data are presented in Tables 4.2, 4.3 and 4.4.

Table 4.2

The years of increase in the number of some insect pests depending on meteorological factors (indicated in the text) in the Zaporizhzhia region (Beleckij, Stankevich, 2018)

Name of harmful insects	The years of increase in the number of harmful insects	Determination rate R2	Percentage of changes of meteorological factors %
Turnip moth and other gnawing moths	1980, 1983, 1985, 1996–2000, 2004	0,086	0,86
European corn	1974, 1975, 1978–1979,	0,2150	21,56

borer	1989–1994, 2000–2004		
Webworm beetle	1975–1976, 1981–1982, 1988–1990, 2003–2004, 2004	0,3730	37,30
Mamestra cabbage moth	1973–1975, 1978–1979, 1985, 1990–1991,1998–2007	0,1605	16,05
Sun pest	1969, 1981, 1984, 1987, 1993–1996, 2001, 2002, 2007–2009	0,3772	37,72
Scarab beetles	1980–1981, 1985, 1987–1988, 2000, 2004	0,3268	32,68
Corn ground beetle	1976–1977, 1981–1982, 1989–1990, 1996–1997, 2000, 2002–2004	0,1382	13,82
Apple moth	1968, 1977, 1981–1983, 1989, 1997–1998, 2005–2006	0,0983	0,983

Table 4.3

The years of increase in the number of some insect pests depending on meteorological factors in the Cherkasy region (Beleckij, Stankevich, 2018)

Name of harmful insects	The years of increase in the number of harmful insects	Determina-tion rate R2	Percentage of changes of meteorological factors %
Turnip moth and other gnawing moths	1976, 1981, 1984, 1987, 1999–2001, 2003	0,2707	27,0
European corn borer	1971, 1980, 1984, 1991, 1994, 2006	0,2707	27,0
Webworm beetle	1973–1974, 1977, 1989–1990, 2008–2009	0,2079	20,7
Mamestra cabbage moth	1970, 1994, 1997–1998, 2002	0,18485	18,5
Sun pest	1969, 1981, 1986–1988, 1998, 2003–2007	0,2302	23,0
Scarab beetles	1983–1986, 1988–1994, 1999–2000	0,1294	12,9
Corn ground beetle	1973–1974, 1983–1984, 1991–1993, 2001–2003	0,4935	49,3
Beet root weevil	1973, 1978, 1980, 1987, 2005	0,0673	6,73

Grey beet weevil	1984–1990, 1994–1996, 2000–2002	0,3495	34,9
Apple moth	1970, 1972, 1976–1977, 1980–1988, 1994–1996, 2001–2008	0,2994	29,9

Table 4.4

The years of increase in the number of some insect pests depending on meteorological factors in the Volyn region (Beleckij, Stankevich, 2018)

Name of harmful insects	The years of increase in the number of harmful insects	Determination rate R2	Percentage of changes of meteorological factors %
Turnip moth and other gnawing moths	1998–2008 annual stable increase in number	0,4377	43,7
Mamestra cabbage moth	1976–1978, 1991, 2001–2003	0,582	58,2
Scarab beetles	1972–1979, 1996–1997, 1999–2009	0,5499	54,9
Corn ground beetle	1974–1975, 1987, 1992, 1996–2009	0,5354	53,5
Beet root weevil	from 1992 to 2003 was not detected in 2004–2009 0,5–0,6 ths/m²	0,4349	43,4
Grey beet weevil	1973, 1980, 1986, 1991–1994, 1997–2009	0,797	17,9
Apple moth	1973, 1976, 2004–2008	0,7611	76,1

The analysis of the linear regression data presented in Table 4.2 indicates the absence of dependence of the regular increase in the number of harmful insects on the meteorological factors (duration of sunshine, temperature and humidity) in the Zaporizhzhia region. In the Cherkasy region (Table 4.3) some dependence was noted regarding the corn ground beetle (49,3%); in the Volyn region this dependence can be noted in the cases of the gnawing moths, mamestra cabbage moth, scarab beetles, corn ground beetle, beetroot weevil and apple moth. The unauthenticity of the obtained results when conducting the traditional linear modeling of the dynamics in the number of some harmful insects testifies to the fact that the insect populations are complex and nonlinear systems and the linear method is not suitable for the mathematical modeling of the dynamics. Moreover the methodology of availability forecasting is outdated. The population dynamics is closely related to the cyclic recurrence and aggravated rates (mass reproduction) which must be detected in proper time using the phytosanitary monitoring (Kniazeva, 2002; Chaika, 2012).

At one time at the example of modeling the dynamics in the number of the sun pest in the Kharkiv region it was shown that the linear modeling is also not suitable for the prognostic purposes (Biletskyi, 2006). Based on the quantitative data on the average density of the sun pests in the hibernating places a quantitative model which is an equation of a multiple regression equation was proposed:

$$y = 3{,}0126 - 0{,}0141252 \times W + 0{,}00014457 \times W^2,$$

where “y” is an average density of the bugs in the hibernating places;

“W” is a Wolf number (an index of the number of sun-spots on the visible disk of the Sun).

Table 4.5

Density of hibernating sun pests in hibernation places (Kharkiv geographic population) in 1995–2005 (Beleckij, Stankevich, 2018)

Years	Wolf number W	Density of bugs in hibernation places, specimens/m^2		
		prognostic	actual	deviations
1995	15	2,8	1,9	0,9
1996	10	2,9	3,4	0,5
1997	21	2,7	2,9	0,2
1998	64	2,7	2,3	0,4
1999	93	3,7	1,6	2,1
2000	120	4,1	13,0	8,9
2001	111	3,7	4,2	0,5
2002	106	3,1	2,9	0,2
2003	74	2,7	3,3	0,6
2004	42	2,6	2,5	0,1
2005	20	2,7	0,6	2,1

The results are given in Table 4.5. From the data presented in the table it is seen that the quantitative model in which the indices of the solar activity of the Wolf number (w) were used as a predicate in order to forecast the density of the bugs in the hibernating places was unreliable; the error, that is the deviation of the prognostic density from the actual one was from 0,1 to 8,9 specimens/m^2 or 89 times.

Table 4.6

Changes in reproduction rate of Kupiansk local population of sun pest depending on sunshine dynamics of many years (1966–1981) (Beleckij, Stankevich, 2018)

Years	Duration of sunshine in May and June, hours	Deviation from average of many years	Reproduction rate of sun pest
1966	587	+98	3
1967	523	+34	10
1968	618	+129	19
1969	473	-16	2
1970	507	+18	6
1971	574	+85	3
1972	539	+50	6
1973	462	-27	2
1974	444	-45	1
1975	654	+165	2
1976	350	-139	1
1977	456	-33	1
1978	422	-67	1
1979	636	+147	2
1980	261	-228	0,5
1981	504	+15	2

The analysis of the dynamics of the sun pest reproduction, carried out taking into account the indices of the sunshine duration on the materials of one of the breeding grounds (local population) in the Kupiansk district of the Kharkiv region, also showed the unreliability of this index as a forecast predicate (Table 4.6).

The data from Table 4.5 indicate that the reproduction rate of the sun pest local population is not changed depending on the sunshine duration.

Therefore this principle is also unsuitable for prognostication of the dynamics in the number of this pest.

Thus the linear differential equations in which not only the meteorological factors but also the indices of the solar activity (a global factor) were used as variables, were unsuitable for forecasting the dynamics in the number of the insects.

At the end of the last century the foresight theories developed by N.D. Kondratiev and O.L. Chizhevskyi (Chizhevskyi, 1995), Yu.V. Yakovets (Yakovets, 1999; Yakovets, 2002), V.I. Vernadskyi and N.N. Moiseiev turned to be in demand and actual.

In connection with the regular mass reproduction of the webworm beetle in Ukraine and Russia the Ukrainian ecologists again turned to the solar-terrestrial concept of O.L. Chizhevskyi: “Unfortunately the forecasters did not pay attention to the brilliant works of the father of domestic heliobiology O.L. Chizhevskyi, who had substantiated the idea that the environment that affects the animate nature should be extended beyond the Earth. For the first time Chizhevskyi convincingly proved that life on our planet responds to the excitation in the Sun with an 11-year cycle”. It should be noted that the solar-terrestrial relations have been known since time immemorial! On the basis of historical and statistical analysis Chizhevskyi O.L. and his followers proved the synchronism of numerous biological, climatic, meteorological, economic, historical and social processes. However the synchronization mechanism is still not identified. As O.L. Chizhevskyi (Chizhevskyi, 1995) once wrote it was a question of the future. He took into consideration the close connection of the spatial and temporal relations and he was the first who substantiated the intersystem forecasting method (Maurin, 1982).

We have adapted this method in order to forecast the beginning of the regular mass reproduction of some species of insect pests of the agricultural crops and forest plantations; we proposed to use as the predicates the years of sharp changes in the solar activity (its growth or decrease in the adjacent years) instead of the predicates that had not suited for the forecasting purposes (relative Wolf numbers). Below the indices of the latter for the period of 1755–2018 are given.

The years of sharp changes in the solar activity for the period of 1755–2018 are as follows: 1755,1757,1761–1762, 1765–1766, 1769, 1771–1772, 1773–1774, 1775–1766, 1777–1778, 1780, 1782, 1784, 1786, 1788, 1790, 1793, 1795–1796, 1798–1799, 1801, 1805, 1807, 1810, 1813, 1815–1816, 1818, 1821, 1823, 1826, 1829, 1831, 1833, 1836–1838, 1841, 1843,1845, 1848–1850, 1854–1856, 1859–1860, 1861–1862, 1865, (1868), 1870–1871, 1872–1873, 1874–1875, 1877–1878, 1880, 1882–1883, 1884–1885, 1886–1887, 1890, 1892–1894, 1896, 1899, 1900–1901, 1903, 1905–1906, 1907–1908, 1910–1911, 1912–1913, 1915, 1917–1918, 1920, 1922–1923, 1924–1925, 1927–1928, 1929–1931, 1933–1934, 1935–1936, 1937, 1939–1940, 1941–1942, 1943–1944, 1946–1948, 1950, 1952, 1953-1954, 1955–1957, 1959, 1961, 1963–1964, 1966–1967, 1968–1969, 1971–1973, 1975–1976, 1977–1979, 1981, 1983–1984, 1986–1987, 1988–1989, 1991, 1993, 1995, 1997–1998, 2000, 2003–2004, 2006–2007, 2010–2011, 2012–2013, 2015, 2016 and 2018.

Table 4.7

Synchronism of beginning of some harmful insects’ regular mass reproduction with the years of sharp changes in solar activity in Ukraine (SA) (Beleckij, Stankevich, 2018)

№	Name of insect	Years of mass reproduction	Beginning of regular mass reproduction (%), years	
			Sharp changes in solar activity	In other years
1	Turnip moth	1923–2007	55,0	5,0
2	Gamma moth	1829–2007	70,0	30,0
3	European corn borer	1899–2006	80,0	20,0
4	Webworm beetle	1855–2011	52,0	8,0
5	Corn ground beetle	1843–2003	92,0	8,0
6	Scarab beetles	1841–1996	74,0	26,0
7	Hessian fly	1847–2000	90,0	10,0
8	Barley frit fly	1880–2000	77,0	23,0
9	Sun pest	1890–2009	73,0	27,0
10	Beet root weevil	1851–2010	90,0	10,0
11	Hedge butterfly	1838–2003	87,0	13,0
12	Green lacewings	1841–1997	86	14,0
13	Apple moth	1855–2007	71	19,0
14	Gypsy moth	1837–1995	84	16,0
15	Pine sawfly	1838–2002	95,0	5,0
16	European pine sawfly	1880–2009	88,0	12,0

The synchronism of the mass reproduction of the most common insect pests in Ukraine is given in Table 4.7.

To prove the synchronism of the vast majority of insects there is no need to use the Chi-square criterion. Both the regional and global synchronizations with the years of sharp changes in the solar activity were noted in the case of the above-mentioned insects.

With the years of sharp changes in the solar activity the climate-forming factors (solar reaction and atmospheric circulation), meteorological elements (weather factors such as temperature, precipitation, atmospheric pressure, duration of sunshine), annual growth of trees and yield capacity of the agricultural crops have been synchronised (Tables 4.8, 4.9).

Table 4.8

Fracture rates of long-term course of natural processes on the Earth and statistic assesments of fractures connection with sharp changes in solar activity (Druzhynin, 1969; Influence ..., 1971; Druzhynin, 1974)

Process name	Total number of years	Relative fracture rate		Probabilities difference of Chi-square criterion	Probability of chance differences in probability of fractures, %
		in the years of solar activity	in other years		
Planetary	736	78	58	28,8	< 0,01
Solar radiation, direct and diffused	284	86	63	15,8	< 0,05
Atmospheric circulation	3448	86	95	154,0	<0,01
Atmospheric pressure	2135	80	70	24,0	<0,01
Air temperature	5207	81	68	101,0	<0,01
Atmospheric precipitation	5670	81	67	112,0	<0,01
Annual growth of trees	1049	74	66	7,5	<1,00
Yield capacity of agricultural crops	438	83	62	21,4	<0,01

The data presented in the table indicate that the fracture rates during the years of solar benchmarks (during the years of sharp changes in the solar activity) are 8–23% higher than the frequencies in other years with high chi-square criteria (from 7,5 to 154) and, accordingly the probabilities of chance differences in the fractures in the years with sharp changes in the solar activity and in other years are low (from 1 to 0,01) which allows us to assert the non-randomness and synchronization of the long-term course of natural processes in the years of solar benchmarks with the probability from 99 to 99,9% (Biletskyi Ye.N, Stankevych S.V.). We have obtained the analogous results as for the Kharkiv region (Table 4.9).

Table 4.9

Frequencies of long-term fractures of some heliographic factors and yield capacity of winter crops in Kharkiv region and their synchronism with the years of sharp changes in solar activity (Beleckij, Stankevich, 2018)

Process name	Total number of years	Relative fracture rates			Chi-square criterion	Probability level, %
		in the years of solar benchmarks	one year after the benchmarks	in other years		
Drought	115	73	67	41	9,32	< 1,00
Air temperature	47	76	100	19	6,00	5,00
Atmospheric precipitation	81	100	82	29	7,30	< 2,50
Sunshine duration	18	100	100	50	7,90	< 2,50
Yield capacity of winter crops: wheat and rye	70 82	82 100	100 76	50 23	4,90 15,10	< 2,50

The data given in Table 4.9 also allow asserting the synchronization of the atmospheric processes and the yield capacity of winter crops (wheat and rye) with the years of sharp changes in the solar activity. The global mass reproductions of some insect pests are synchronous with the sharp changes in the solar activity or solar benchmarks (Table 4.10).

Table 4.10

Synchronism of global mass reproduction of some harmful insects with the years of sharp changes in solar activity (Beleckij, Stankevich, 2018)

Name of insects	Years of global mass reproduction	Beginning of regular mass reproduction, %		
		In the years of sharp changes	1 year after the benchmarks	in other years
Turnip moth	1923–1925	100,0	0,0	0,0
	1946–1950	100,0		
European corn borer	1928–1929	100,0	0,0	0,0
Webworm beetle	1929–1930	100,0	0,0	0,0
	1975	100,0	0,0	0,0
Sun pest	1901–1905	100,0	0,0	0,0
	1909–1914	0,0	100,0	0,0
	1923–1929	100,0	0,0	0,0
	1931–1933	100,0	0,0	0,0
	1936–1941	100,0	0,0	0,0
	1948–1957	100,0	0,0	0,0
	1964–1970	100,0	0,0	0,0
	1972–1981	100,0	0,0	0,0
	1984–1991	100,0	0,0	0,0
	1997–1998	0,0	100,0	0,0
Hessian fly	1984–1978	100,0	0.0	0.0
Apple moth	1955–1958	100,0	0.0	0,0
Hunter's moth	1993–1994	100,0	0,0	0,0
Tent caterpillar moth	1882–1883	100,0	0,0	0,0
	1947–1948	100,0	0,0	0,0
Gypsy moth	1912–1913	100,0	0,0	0,0
	1982–1988	100,0	0,0	0,0
Nun moth	1946–1950	100,0	0,0	0,0
Pine looper moth	1937–1941	100,0	0,0	0,0
Pine sawfly	1934–1937	100,0	0,0	0,0

From Table 4.10 it is seen that the beginning of the regular (global) mass reproduction of all 12 species of the widespread pests was synchronous with the years of sharp changes in the solar activity. In addition they are polycyclic. The cyclic character has been currently determined in the development of many natural systems (biological, environmental, economic and social) and even in the scientific work (Yahodynskyi, 1981; Aliakrynskyi, 1985; Vernadskyi, 1988). Analysing the results of the scientific work of the world-famous scientists V.I. Vernadskyi (Vernadskyi, 1988) noted the following: "The explosions of scientific work are recurred over the centuries, they are accumulated in one of the few generations in one or in many countries when the gifted individuals create a force changing the biosphere ..." (Vernadskyi, 1988).

This fact was confirmed by Yu.V. Yakovets (Yakovets, 2002): "If we look at Russia in the first quarter of the 20th century through the prism of the past decades then the cluster of great figures of the world science, a generation of talents will be striking. They are I.P. Pavlov, N.I. Vavilov, V.I. Vernadskyi and P.A. Kropotkin, K.E. Tsiolkovskyi and O.L. Chizhevskyi, P.A. Sorokin and N.D. Kondratiev, A.A. Bohdanov and N.A. Berdaiev and many others. They made a breakthrough in many branches of knowledge, founded the immense knowledge of a new scientific paradigm which would be completed in the new century" (Yakovets, 2002).

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PART 5. PROGNOSTICATION ALGORITHMS AND PREDICTABILITY RANGES OF MASS REPRODUCTION OF HARMFUL INSECTS ACCORDING TO THE METHOD OF NONLINER DYNAMICS

According to the classical (linear) methodology the dynamics of the populations is the changes in the number and population structure (organization) of the insects in space and time depending on abiotic and biotic factors. Moreover the changes can be predicted both in the perspective and in retrospective. In such a way the prognostication in plant protection is oriented when developing the annual and of many years prognoses in Ukraine. And if the prognoses are not justified or the outbreaks of the mass reproduction of some widespread species of harmful insects occur “unexpectedly” then the search for the possible causes will begin. The methodology to solve the “aggravated problems” from the non-traditional point of view considers a number of classical problems not only in meteorology (the catastrophic phenomena in the Earth’s atmosphere, namely the severe droughts), but also in ecology. Moreover the influence of small disturbances varies depending not only on a number of factors but also on the stage of the process development (mass reproduction) and on the location whether it falls into the centre of the population localization or on its periphery. The mass disturbance may not play any role in general and is completely “forgotten” if at the quasistationary stage it falls on the periphery of the structure (the periphery of the geographic or local range of population).

Algorithmus for prognostication the beginning of the regular mass reproduction of some insect pests in Ukraine

<u>Winter moth.</u> The mass reproduction of thi pest took place in 1823–1825, 1836–1840, 1846–1850, 1861–1863, 1871–1873, 1880–1881, 1893–1836, 1899–1900, 1907–1908, 1918, 1923–1925, 1935–1937, 1946–1950, 1956–1957, 1964–1968, 1971–1973, 1981–1984, 1997–1998 and in 2007–2008. The average period between the beginnings of the regular mass reproduction was 9 years. Of the 20 mass reproductions of the winter moth 19 occurences that constitute 95 % took place during the years of the sharp changes in the solar activity, and one occurrence (5%) took place a year later in 1846–1850. The last mass reproduction of this pest was in 2007–2008. The maximum abundance of this pest was in 2007 (the year of the severe drought); if to add 9 years (the average studies) then it will turn out

that the regular mass reproduction should be expected in 2016–2017 (that is 2016 + 1 year), and most likely it will happen in 2018 (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

The most severe drought was in Europe in July and August in 2017. According to the fundamental laws of nonequilibrium thermodynamics and synergetics the aggravated rate may occur after the drought; moreover such occurrences, namely the mass reproductions of the winter moth, were in 1918. The wandering of the mass reproductions within the range of population was observed not only in Ukraine, but also in England, Africa, Bulgaria, Hungary, Germany, Egypt, Russia and Czechoslovakia (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

Webworm beetle. The mass reproduction of thi pest took place in 1855, 1869, 1880, 1901, 1912–1913, 1920–1921, 1929–1932, 1935–1936, 1956, 1975, 1986–1988 and in 2011-2013. The average period between the beginnings of the regular mass reproduction was 13 years. Of 12 occurences of the mass reproduction 11 ones (92%) began exactly during the years of the sharp changes in the solar activity, and only one was a year later in 8169. The last mass reproduction of the webworm beetle in Ukraine took place in 2011–2013. The maximum abundance of this pest was in 2013 which means that the regular mass reproduction should be expected in 13 years, i.e. starting with 2026.

It is possible that the most severe drought of 2017 can cause the resonant disturbance of non-linear dynamics of the webworm beetle and its mass reproduction will begin approximately in 2018 (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

Corn ground beetle. The mass reproduction of this pest took place in 1863–1864, 1880–1881, 1903–1905, 1923–1925, 1931–1932, 1946–1947, 1952–1953, 1957–1959, 1963–1964, 1966–1967, 1979–1984, 1991–1992 and in 2003–2007. The average period between the beginnings of the regular mass reproduction was 11 years. Of 13 occurences of the mass reproduction 12 ones (92%) began exactly during the years of the sharp changes in the solar activity, and only one was a year later in 1863. The last mass reproduction of the corn ground beetle in Ukraine took place in 2003–2007. The maximum abundance of this pest was in 2007 which means that the regular mass reproduction should be expected in 11 years, i.e. starting with 2018 (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

Scarab beetles. Their mass reproductions took place in the Forest and Forest-Steppe region of Ukraine in 1840–1842, 1845–1846, 1856–1857, 1860–1861, 1868–1869, 1879–1880, 1886–1887, 1962–1964, 1966–1969, 1980–1984 and in 2003–2007. The average period is 10 years. 82% of the mass reproductions began exactly during the years of the sharp changes in the solar activity and 18% began a year later. Their number reached its maximum in 2007; if to add 10 years ahd then 1 year more then their regular mass reproduction should be expedcted starting with 2018 (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

Sun pest. During 118 years (1890-2008) in Ukraine there were 11 mass reproductions of this pest with an average period of 11 years between them. 8 (73%) of them took place during the years of the sharp changes in the solar activity and 3 occurences (27%) took place a year later. The last mass reproduction of the sun pests was in 2008–2009. Their number reached its maximum in 2009. In 11–12 years (in 2020–2021) we should expect the beginning of the regular mass reproduction of the scarab beetles (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

Beet root weevil. Its mass reproduction in the beet-growing zone of Ukraine took place in 1851–1855, 1868–1869, 1875–1877, 1880–1881, 1892–1893, 1896–1897, 1904–1906, 1911–1912, 1920–1922, 1928–1930, 1936–1940, 1947–1949, 1952–1957, 1963–1964, 1973–1976, 1986–1988, 1998–2000 and in 2010–2012. The average period is 9 years. Of 18 occurences of the mass reproduction 16 ones (90%) began exactly during the years of the sharp changes in the solar activity, and only two (10%) took place a year later. The last mass reproduction of this pest was noted in 2010–2012 with its maximum number in 2010. It means that the beginning of the regular mass reproduction should be expected in 2019 (Biletskyi, 2011; Biletskyi, Stankevych, 2018).

We have developed this prognosis for the Ukrainian geographic populations in general. However the geneticists and ecologists (Dubinin, 1932; Schmalhausen, 1946) have determined that the geographical populations consist of the local ones and the prognosis at the geographical level is often not confirmed. Considering this fact we have made an analysis of the long-term dynamics of the sun pest geographic populations' number in the southern, eastern, and central regions of Ukraine and identified the local populations of this pest. According to our researches the geographic populations of the sun pests are concentrated in the Barvenkovsk, Kupiansk, Lozova and Kharkiv districts of the Kharkiv region; in the Bilovodsk, Bilokurakinsk, Svatovo and Starobielsk districts of the Luhansk region; in the Artemivsk, Volodarsk and Volnovakha districts of the Donetsk region; in the Domensk, Znamenka and Maloviskovsk districts of the Kirovograd region; in the Domashevsk, Ovidiopolsk, Reneisk and Tatarburnarsk districts of the Odessa region; in the Vasylkivsk, Kryvorizhsk, Piatykhatsk, Sofievka and Soloviansk districts of the Dnipropetrovsk region; in the Bashtansk, Bratsk, Voznesensk and Vladymyr districts of the Kherson region; in the Akimovsk, Melitopol, Mykhailivsk and Prymorsk districts of the Zaporizhzhia region; in the Vysokopolsk and Chaplynsk districts of the Kherson region; and in the Krasnohvardeisk, Starokrymsk and Feodosiia districts of the Autonomous Republic of Crimea.

To analyse the sun pest local populations' dynamics of many years we have used the reproduction rates, the weight of males and females, the sex ratio, the gender index and the percentage of the black individuals within the population as the indices (Table 5.1).

As it can be seen from Table 1 the reproduction rate of the sun pest population in Kupiansk varied significantly and has been increasing from 0,3 to 34 or increasing and decreasing 113 times respectively. The weight of the males varied from 94 to 128 mg. or 1,4 times; the weight of the females varied from 101 to 160 mg. or 1,6 times. The changes in the gender index were also demonstrative.

During some years the number of the males in comparison with the number of the females increased 1,3–3,5 times, especially it occurred during the years of the mass reproductions of the Kupiansk local population of the sun pest, that is in 1970, 1984–1985, 1987–1988, 1990–1993, and in 1996 their number increased 3,6 times. The increase in the number of the males in the local population can be explained by that fact that in 1993–1995 there was a depression in the reproduction of this local population, and during these years the reproduction rate decreased from 4 (in 1993) to 0,3 (in 1995). The ratio of the males in the population sharply increased in response to the reproduction in number in 1996 (78%).

This fact confirms the theory of G.A. Viktorov (Viktorov, 1967) according to which the regulation in the number of the insects is an automatic and cybernetic process with the presence of the negative feedback as a mechanism.

At present the relationship between the sexual composition of the population and its number has been determined. At the same time the ecologists consider the dynamics of the sexual composition of the population as one of the adaptive mechanisms of the number regulation (Schwartz, 1980). In addition there is the evidence that shows that during the population cycle of the animals not only the number but also the age and genetic structure, physiological properties of the individuals and other population indices also are changing (Schwartz, 1980; Bolshakov, 1983).

Table 5.1

Changes in the structure and number of the sun pest local population (1969–2001) (Beleckij, Stankevich, 2018)

Years	Reproduction rate	Weight, mg.		Ratio, %		Gender index	% of melanists
		males	females	males	females		
1969	8	107	115	55	45	1,2	4,0
1970	12	116	122	60	40	1,5	5,0
1971	7	124	130	51	49	1,0	3,0
1972	6	123	126	47	53	0,9	4,0
1973	7	110	119	37	63	0,6	6,0
1974	2	119	124	52	47	1,1	1,0
1975	2	119	124	53	47	1,1	0,8
1976	2	118	123	52	48	1,1	0,5
1977	1	no data		50	50	1,0	-
1978	1	no data		50	50	1,0	-
1979	2	no data		50	50	1,0	-
1980	2	121	126	50	50	1,0	-
1981	3	124	129	52	48	1,1	1,0
1982	12	128	160	53	47	1,0	3,0
1983	10	117	121	43	57	0,7	3,0
1984	25	120	132	57	43	1,3	12,0
1985	34	101	123	61	39	1,5	10,0
1986	4	120	126	50	50	1,0	5,0
1987	20	125	135	64	36	1,8	2,0
1988	5	127	136	61	39	1,6	105
1989	10	116	127	50	50	1,0	1,4
1990	10	120	122	67	33	2,0	2,2
1991	5	128	134	69	31	2,2	3,0
1992	10	108	122	72	28	2,6	10,0
1993	4	125	134	70	30	2,3	4,0
1994	1,0	97	123	60	40	1,5	1,0
1995	0,3	122	129	50	50	1,0	0,3
1996	4,0	98	136	78	22	3,5	4,0
1997	0,8	94	101	61	39	1,5	0,8
1998	5,0	101	112	60	40	1,5	1,0
1999	0,7	97	105	44	56	0,8	0,5
2000	13,0	105	115	70	30	2,3	3,0
2001	2,0	133	138	50	50	1,0	0,8

Note: the gender index more than 1 means that the males dominate in the population; the gender index less than 1 means that the females dominate in the population.

The change in the ecological structure of the Izium sun pest local population is given in Table 5.2.

The cyclical changes in the ecological structure (organization) are also characteristic of the Izium local population of the sun pest. Its sudden mass reproduction was noted by N.N. Sokolov, one of the founders of the doctrine of the sun pest. In 1901 he wrote: “In the Middle Russia the sun pest first appeared in the Kharkiv province along the middle stream of the Donets, namely in the Izium district. Then it moved to the Kupiansk and Starobielsk districts of the same province as well as to the Bakhmut district of the Yekaterinoslav province” (Sokolov, 1901).

Table 5.2

Changes in the ecological structure of the Izium local population of sun pest (Beleckij, Stankevich, 2018)

Years	Density per 1 m^2		Reproduction rate	Weight, mg.		Ratio, %		Gender index
	hibernated bugs	new generation larvae		males	females	males	females	
1987	1,0	2,7	2,7	123	130	42	58	0,7
1988	0,5	3,9	7,8	117	120	56	44	1,3
1989	0,5	2,5	5,0	116	123	48	52	0,9
1990	0,2	0,5	2,5	114	126	48	52	0,9
1991	0,2	0,5	2,5	119	132	45	55	0,8
1992	0,3	1,8	6,0	122	135	45	50	1,0
1993	0,2	2,0	10,0	119	130	50	50	1,0
1994	0,2	1,8	9,0	120	125	50	50	1,0
1995	0,3	1,7	6,0	135	140	50	50	1,0
1996	0,2	2,0	10,0	128	131	40	60	0,7
1997	0,3	6,0	20,0	110	120	50	50	1,0
1998	0,8	1,0	1,0	121	139	39	61	0,6
1999	4,0	5,0	1,0	105	109	45	55	0,9
2000	0,8	1,0	1,0	105	112	48	52	0,9
2001	2,1	5,2	2,5	111	118	45	55	0,9

The analyses of the dynamics of the Izium and Kupiansk local populations of the sun pest made it possible to note the time convergences of the mass reproductions as well as the wandering of the breeding grounds in the Izium local population as one of the properties of the nonlinear dynamic systems.

For example from late May to mid July of 1993 the cloudy weather with high air humidity and the absence of sunshine was observed. Despite the unfavourable weather conditions the beginning of the regular increase in the number of the sun pest was noted in all districts of the Kharkiv region.

The beginning of the regular mass reproduction of the sun pest in the Kharkiv region took place in 1997, when the reproduction rate of this pest amounted to 17 in the Lozova Steppe region and 16 in the Kharkiv Forest-Steppe region (Table 5.3).

At the same time in 1997 the mass reproduction of the sun pest began in the North Caucasus. There the hibernated bugs with a density exceeding the threshold were found in an area of 1 million ha, and in some districts of the Rostov Region the density of the winged bugs of a new generation reached 60–90 specimens/m^2. In 1997 the vast areas were populated by the sun pest in the Krasnodar and Stavropol Territories, in the Lower and Middle Volga Regions. For example in 1997 in the Volgograd region the density of the new generation larvae ranged from 150 to 800 specimens/m^2 and the losses of grain caused by this pest in Russia were estimated at more than 3 million rubles. Moreover the mass reproductions of this pest were recorded in Bulgaria, Hungary, Romania, Yugoslavia, in the countries of the Middle and Far East (the wandering of the mass reproduction within the population range as one of the fundamental regulations on the aggravated rates).

Table 5.3

Dynamics in the number of sun pest in some districts of the Kharkiv region in 1997 (Beleckij, Stankevich, 2018)

District	Reproduction rate	Ratio, %		Gender index
		males	females	
Barvenkovo	1,3	70	30	2,3
Bohodukhov	2,2	44	56	0,8
Volchansk	4,0	52	48	1,08
Zmiiv	2,0	45	55	0,8
Izium	20,0	42	58	0,8
Krasnohrad	2,0	50	50	1,0
Kupiansk	0,8	61	39	1,6
Lozova	17,0	65	35	1,8
Pervomaisk	3,8	33	67	0,5
Kharkiv	16,0	74	26	2,8

The methodology for solving the “aggravated problems” from the nontraditional point of view considers a number of classical problems not only in meteorology (the catastrophic phenomena in the Earth’s atmosphere like the severe droughts) but also in ecology. At the same time the influence of small disturbances varies depending not only on a number of factors, but also on the stage of the process development (mass reproduction) and on the location whether it falls in the center of the population localization or on its periphery. The mass disturbance may not play any role at all and is completely “forgotten” if at the quasistationary stage it falls on the periphery of the structure (the periphery of the geographic or local population range). Such situation arose at the beginning of the regular mass reproduction of the sun pest in 1997 (on the periphery range of the Kharkiv geographical population in Kharkiv district). Within the regional range this mass reproduction ended in 1999. But if the population number had grown so much that it exceeded the threshold of slow growth (during the period of the depression) then its growth would begin very rapidly in the aggravated rate. In this case it is practically impossible to predict the the beginning of the regular mass reproduction. This is explained by the fact that the nonlinearity of the population dynamics is the possibility of the unexpected changes in the direction of such processes; and their nonlinearity makes the common widespread prognoses and extrapolations fundamentally unreliable and insufficient.

Predictability ranges of mass reproduction of harmful insects according to the methodology of nonlinear dynamics

According to the classical (linear) methodology the dynamics of the populations is the changes in their number and population structure (organization) in space and time depending on abiotic and biotic factors. At the same time the changes can be predicted both in the perspective and retrospective. At least the prognostication in plant protection is oriented in that way when developing the annual and long-term prognoses in Ukraine. If the prognoses are not justified or the outbreaks of the mass reproductions of some widespread species of harmful insects occur “unexpectedly”, then the search for the possible causes will begin.

Such a situation was in Russia after the global mass reproduction of the webworm beetle in 1975 and in 1986-1988 and after the last mass reproduction of this pest in 2008–2010, the similar situation was in Ukraine in 2011–2013. Analysing this fact the Ukrainian ecologists affirmed that despite the successes achieved in studying the dynamics of the populations and despite the substantiations of the webworm beetle's periodic reproduction regularities and their synchronization with the cycles of the solar activity, this pest always appeared "unexpectedly" and "suddenly", "it keeps in fear the plant protection service and also suddenly disappears in order to reappear at a time when it is not expected (Fedorenko, 2011).

As a result of the systemic synthesis of the existing conceptual ideas about the regularities of the insects population dynamics and prognostication methods in plant protection the authors came to the following methodological conclusions:

– the existing concepts about the regularities of the insect populations dynamics and the prognostication methods in plant protection have become old-fashioned and do not meet the ideas of the modern representatives of nonequilibrium thermodynamics and synergetics (nonlinear dynamics);

– the modern ideas of the latter are presented in the fundamental publications we have considered above;

– due to these publications the dynamics of the insect populations is nonlinear and chaotic, while the positive nonlinear feedback should be considered its leading mechanism;

– temperature and precipitation, the "main" factors of linear dynamics, due to the presence of the strange attractors are not predicted reliably for a period of two weeks and especially for the next year (a season);

– the aggravated rates that arise spontaneously in any part of the insect species range and "wander" within the latter are characteristic for the insect population dynamics;

– the prognostication by the extrapolation methods taking into account the available phytosanitary situation does not give the desired results (such predictions are practically not justified);

– new sudden, unforseen and unpredictable phenomena appear in nonlinear systems as a result of bifurcations;

– the external environment under which the processes of the population variation are taking place contains the discrete (breaking) structures, called the attractors; even slight fluctuations (temperature, precipitation, drought, sudden changes in the solar radiation, the duration of sunshine, solar activity, the introduction of new agricultural techniques, the applying of pesticides, etc.) as a result of the resonant interactions can cause an excessively rapid nonlinear increase in the number of the insects;

– the qualitative information should be used when developing the algorithms for the prognostication of the beginning of the regular mass reproduction of harmful insects. The chronicle of the mass reproduction over a long historical period meets this requirement and the years of sharp changes in the solar activity serve as a predicator (criterion);

– it is practically impossible to describe (formalise) the population dynamics at the linear level when it reaches a bifurcation point in the process of evolution. The system is found itself in a state of the deterministic chaos from which a new structure is formed in the process of self-organization. In this state the system becomes very sensitive to the stress factors, so its future trajectory becomes stochastic and almost unpredictable;

– the rebuilding of the structure (organization) covers the entire population in the localization zone. The mass reproduction may cease or spread to the entire system depending on the state of the initial localization zone which is above or below the threshold level;

– this regulation illustrates well the main problems of prognostication of the harmful insects' mass reproduction. A reliable prediction of time and place is practically impossible when the population approaches a bifurcation point (an outbreak of the mass reproduction). In this case an outbreak of the mass reproduction can take place not in Ukraine, but in other regions that are a part of the species range of a particular species of the harmful insect;

– a theoretically reliable prognosis is possible when the pest populations are in a relatively stable state or depression;

– taking this regulation into account the regular mass reproductions of the webworm beetle were reliably predicted in Ukraine in 1986–1988 and in 2011–2013 with the forestalling over 4–7 years (Biletskyi, 2004; Biletskyi, 2005; Biletskyi, 2006; Biletskyi, 2011; Biletskyi, 2015).

In 2011 the aggravated rates or the appearance of the local breeding grounds with a high density of the webworm beetle's caterpillars arose in the southern, eastern and in some central regions of Ukraine. In 2012 the number of this pest continued to increase in the above-mentioned and northern regions of the republic. The extermination measures controlling the caterpillars were carried out in the area of 460 thousand hectares. In 2013 the area populated by this pest was 2,7 times more than the aera in 2012; and the extermination measures were carried out in the area of 1 million 222 thousand hectares. In 2014 it was planned to treat about 3 million hectares, but only 93 thousand hectares were treated and it was 3,5 times less than it had been planed. Thus the year of 2013 was actually the last year of the regular mass reproduction of the webworm beetle in Ukraine.

In the Russian Federation the last outbreak of the mass reproduction also lasted three years. It began in 2008 in the Trans-Baikal Territory and then in the Siberian Federal Region where for the first time the average density of the hibernating caterpillars amounted to 8 specimens per m^2. In the first half of 2010 the mass reproduction of the webworm beetle was recorded in the Altai Territory, Novosibirsk and Cheliabinsk Regions, in the republics of Khakassia and Tatarstan. In the first half of 2010 the mass reproduction of the webworm beetle was especially demonstrative in the Voronezh region.

Despite the most severe drought during the mass summer and the oviposition by the females the latters had well-developed fat bodies and mature egg production (Review ..., 2011). This fact contradicts the prevailing literature opinion of the overwhelming majority of the ecologists that the lack of precipitation and low relative humidity are the main reasons of the infertility of the webworm beetle butterflies during the mass summer and their oviposition (Piatnitskii, 1936; Poliakov, 1964; Druzheliubova, 1972; Recommendations, 1983; Triebel, 1989; Dovgan, 2008).

In spite of the opinion of most studies air temperature and precipitation are not the “main factors” in the dynamics of the insect populations (Chronicle, 1878; Mokrzhetskii, 1902; Belanovskii, 1936; Belanovskii, 1940; Belanovskii, 1950; Watt, 1971; Odum, 1986; Stryhun, 2002; Review ..., 2011).

In this regard the original researches at the example of a common beet root weevil were carried out by A.A. Stryhun in the central Forest-Steppe of Ukraine (Stryhun, 2002). For the period of 1970-2001 the number of the common beet root weevil varied from 1 to 11 specimens/m^2 in the spring and from 1,4 to 16,3 specimens/m^2 in the autumn. The author singled out the years of significant outbreaks of this pest for this period. They took place in 1974–1977, 1985–1987, 1994–1995 and in 2001. Having analysed the indices (the sums of the effective temperatures and the hydrothermal coefficients) for the given period he came to the conclusion that the meteorological conditions during the growing season and hibernation period do not explain the long-term changes in the population of the common beet root weevil.

Thus it is not recommended to use air temperature and precipitation indices for the growing period as the predicates of the development of many years and annual phytosanitary prognoses. At the same time many researchers have shown that while prognostication (prediction) it is necessary to use the methods of statistics of the non-numerical nature objects, which has been intensively developing recently. In our case it is a chronicle of the mass reproduction of harmful insects. Herman Haken was the first one who substantiated the above-mentioned idea as the principle of the cyclic causality to the method of the order and chaos parameters.

In phytosanitary prognostication such an approach, taking into account the localization of the aggravated rates in space and time, allows developing the long-term qualitative prognoses of the beginning of the regular mass reproduction of harmful insects with the forestalling of up to 5 years. The years of sharp changes in the solar activity are used as a predicate. According to the synergetic ideas the solar activity is not a completely random process. This process is modulated by a 22-year cyclic character of magnetic field and 11-year recurrence of the Wolf numbers (W). Moreover the dynamic system that determines the solar activity ("sunny weather" according to A. Chizhevskii) contains a strange attractor, and, therefore, is sensitive to the initial conditions. Considering that the Wolf numbers are determined quite roughly, therefore no more than one cycle can be calculated (Malinetskii, 1997). It is quite enough for a qualitative prognosis answering the urgent question of when and where one should expect the beginning of the regular mass reproduction of one or another species of harmful insect.

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CONCLUSION

For more than three centuries (starting with I. Newton) the ideas about the linear dynamics of the processes and events in nature and society have been dominating. In each case their cause and effect are considered to be unambiguous, which are determined by the initial conditions that are specified absolutely precisely.

One of the representatives of classical science is the famous physicist Pierre Simon Laplace (1749-1827) who affirmed that it was possible to accurately forecast the future and completely restore the past. His famous dictum that a creature capable of capturing the whole data on the state of the Universe at any given time could not only accurately forecast the future, but also restore the past to the smallest details was called “Laplace’s Demon” or “Laplace’s determinism”.

An analytical synthesis of modern theoretical concepts in the population ecology of insects and prognostic in plant protection showed that the Laplace determinism is still dominating in these spheres of knowledge. The factorial hypotheses and theories based on the assessment of several environmental factors are still dominating in the ecology of populations; and the theory according to which it is possible to judge in advance about the population dynamics and probable factors that can influence it by the state of the forage reserve and physical environment still remains the main one in the prognostic. This fact makes this theory the basis for solving the problems of forecasting the number of the pests. Such an approach to managing the population dynamics is based on the classical linear methodology. The forecasts of the appearance of rodents and insects for the next year (season) were developed on the basis of this theory. In relation to the mass reproductions of the insect pests of agricultural crops the ecological (phytosanitary) forecast was often replaced by a resource economic forecast or a prospective assessment of the phytosanitary situation in a given territory for the purpose of planning and organizing plant protection. The groundlessness of such forecasting was shown by the global outbreaks of the mass reproduction of the webworm beetle and the sun pest and by the regional mass reproductions of the locusts, turnip moth, owlet moth, and some insect pests of forest and fruit plantations.

In the last three decades a new direction called synergetics, which is interdisciplinary in nature, has been substantiated as a result of the basic research at the junction of a number of natural sciences. Synergetics made it possible to substantiate some fundamental statements. Moreover according to these ideas the natural environment and its biosphere, biogeocenoses and the constituent populations of plant and animal organisms are complex, open and unstable systems. They are characterised by self-organization, dissipation (energy dispersion), a constant exchange of the energy, matter and information with each other and with their environment. In the light of the synergetic ideas the insects and their populations are also considered to be such systems. It is very important that the latter are characterised by the self-organization, deterministic and chaotic population dynamics, the presence of localization (local populations) and the aggravated rates, the presence of strange attractors which are one of the reasons and the range of forecasting the future development.

In the process of the systemic synthesis the authors substantiated the presence of an overwhelming number of the insects with the polycyclic character of the mass reproductions and the synchronism of the latter in space and time. The so-called wandering aggravated rates within the species ranges of harmful insects and their chronicle are of a particular interest.

Taking into account the latest ideas of synergetics the authors substantiate the systemic theory of polycyclic character and nonlinear population dynamics of the insects. The theory performs all four functions of a really scientific theory: descriptive, explanatory, synthesizing and prognostic ones. The latter function is the main one.

Based on the modern concepts of synergetics the authors substantiate the hypothesis that the insect populations have their own long-term, annual and seasonal dynamics as one of the mechanisms of positive nonlinear feedback which is constantly present both in the environment and in the population dynamics.

To make the decisions in plant protection the authors recommend the scenario forecasting method as the basis. The latter is based on the determination of the state sequences of a prognostication object under various background forecasts.

GLOSSARY (Kniazeva, 2002)

Aggravation:

– aggravation time is a finite (limited) period of time during which the process is developing superfast and asymptotically;

– the aggravation problem is a certain class of model problems for the analysis of open nonlinear systems (media) in which it is assumed that the processes develop superfast, i.e. the characteristic values (for example, temperature, energy, concentration and monetary capital) increase unlimitedly over a finite time;

– aggravated rate is a rate having a long quasi-stationary stage and a stage of superfast growth of processes in the open nonlinear media.

Attractor is the stable state (structure) of the system, which as if “attracts” (from Latin *attrahere* “attract”) to itself the whole set of “trajectories” of the system determined by various starting conditions (if the system falls into a cone or sphere of an attractor then it inevitably evolves to this stable state (structure)). Whereas in most works on the problems of self-organization an attractor is understood as an image of this relatively stable state in a phase space, in this work the attractors are real structures in open nonlinear medium that are exposed to evolutionary processes in these media as a result of attenuation of the intermediate transient processes. Emphasizing this we often use a holistic new formation of the “attractors structure”.

Bifurcation point is the ramification point of the possible paths of the evolution of the system which at the level of mathematical description corresponds to the ramification of solutions of nonlinear differential equations.

Complex structure is a structure built of several simple structures (the structures with one maximum) of “different ages”.

Determined chaos is one of the areas of synergetic research which explores the types of chaos and various scenarios of transition to the chaos of the deterministic (dynamic) systems.

Dissipation is the processes of energy dissipation, its transformation into less organized forms (heat) as a result of diffusion, viscidity, friction, heat conduction, etc.

Dissipative structure is a structure resulting from the process of self-organization, the implementation of which requires the opposite (disorganizing) scattering (dissipative) factor. This concept is widely developed in the works of I. Prigogine.

Fluctuations are random deviations of the instantaneous values of quantities from their average values, an indicator of the chaotic state of the processes at the micro level of the system.

Fractal dimension is a fractional dimension (from Latin frango, fregi, fractum, ere "break", "crush") which is a characteristic of unstable, chaotic behaviuor of the systems (media), in particular described by the strange attractors.

Fractal objects (fractals) are the objects that have the properties of self-similarity or scale invariance that is they are such fragments which structures are strictly repeated through certain spatial intervals.

HS-rate is one of the types of process development in an open nonlinear medium; the erosion of structures takes place in the absence of localization. This is the rate which is unlimitedly scattering from the center of the wave (Figure 1). This rate takes place if the dissipative, erosive factor is more intense than the localization factor, namely the work of a nonlinear energy source. "H" in the appellation of this rate means "higher", higher than the S-rate that is, the processes in it develop faster than in the S-rate.

Instability near the moment of aggravation is the sensitivity of non-stationary (evolving) structures to small perturbations (fluctuations) at the asymptotic stage near the "final" state that leads to the probabilistic chaotic decay of these structures.

Liapunov instability is one of the types of instability, the instability with respect to the initial data and to the initial perturbations (deviations) which in the course of the process development lead to the arbitrarily large differences and to the exponential "scattering" of the adjacent trajectories.

LS-rate is a certain type of process development in an open nonlinear medium under an aggravated rate when there is an increasingly intensive development of the process in an increasingly narrow area near the maximum (Figure 1). These are the "converging combustion waves" when the effective localization area is decreasing. This rate takes place when the factor creating the heterogeneity in the medium (the action of non-linear volumetric sources) works much stronger than the scattering erosive factor. The main characteristic of the LS- rate is that it is developed more slowly than the S-rate. This is reflected in the appellation. "L" means "lower", lower than S-rate. "Thermal energy" is less weakly "spread" in space than in the case of the S-rate. The LS-rate in an open nonlinear medium has a number of qualitatively different solutions; their great number determines a spectrum of structures of different complexity.

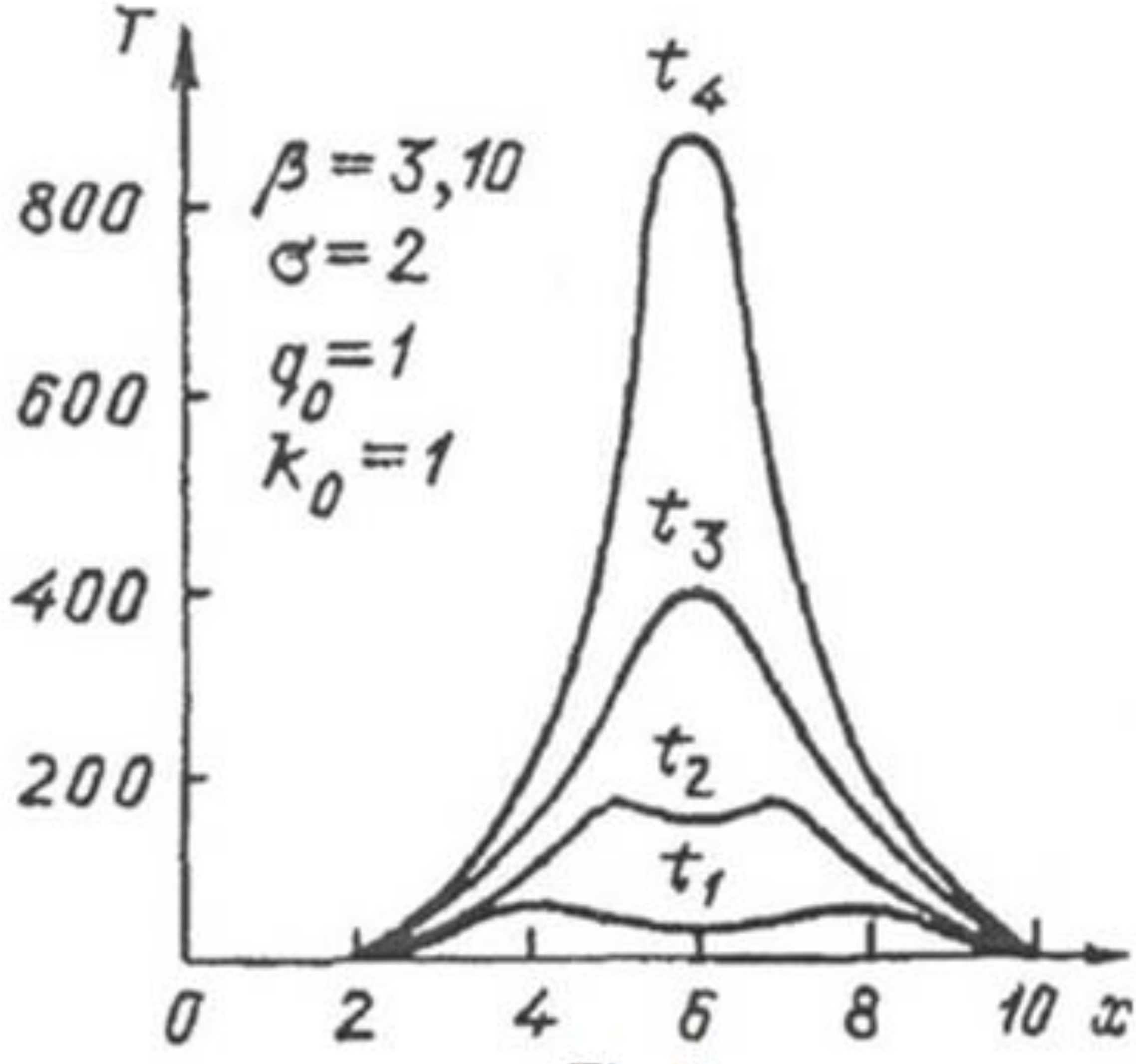

Fig. 1

Non-linear medium (system) is a medium (a system) in which the processes are described by the non-linear equations. This is a medium that can evolve in various ways and is fraught with the bifurcations.

Nonlinearity in the ideological sense is the multiform of the evolutionary paths, the possibility to choose a certain pace of the evolution among the alternative paths as well as the irreversibility of the evolutionary processes.

Nonlinearity in the mathematical sense is a certain type of mathematical equations containing the unknown quantities in the power more than 1 or the coefficients that depend on the properties of the medium. As a rule the nonlinear mathematical equations have several (more than one) qualitatively different solutions.

Non-stationary structure is an evolving structure, a structure capable of growth, complication and is subjected to decay.

Open system (medium) is certain types of systems (media) that exchange the matter, the energy and/or the information with the environment, i.e. have the sources and drains. As a rule the self-organizing open systems have the volumetric sources and drains that is they have the sources and drains at each point of the system.

Phase portrait is a sequence of possible states of the system in a phase space forming a more or less complex "trajectory" of the system evolution.

Phase space is an abstract mathematical multidimensional space which coordinates are the independent parameters of the system's motion.

Resonant excitation is the correspondence of the spatial configuration of the external action to the intrinsic (internal) structures of an open nonlinear medium (system).

Self-organization is the processes of spontaneous regulating (transition from chaos to order), formation and evolution of the structures in the open nonlinear media.

Spectrum of structures of an open nonlinear medium is a great number (set) of relatively stable states of its organization to which the processes in a given medium rush as if to the attractors. In the mathematical terms the spectrum of structures is determined by the spectrum of their own functions, i.e. the solutions of the corresponding nonlinear differential equation.

S-rate is the rate of "combustion", the rate of the development of the aggravated process when at the asymptotic stage the process is localized and develops within a certain fundamental length L (Figure 2). The appellation S-rate was introduced based on the first letters of the names of the authors of the work in which the stability of a stopped thermal wave in the basic problem for the nonlinear heat equation was first studied. The English "s" in the appellation successfully coordinates with the term "standing wave".

Stationary structure is a stable, non-developing structure, i.e. a structure that is one of the attractors of the evolution of an open nonlinear medium and is fixed on it.

Strange attractor is one of the types of attractors which phase portrait is a certain limited area through which the random wanderings occur. According to I. Prigogine a strange attractor can be called the "attracting chaos".

Structure (in an open nonlinear medium) is a process localized in certain parts of the medium, in other words it is a process that has a certain geometric shape and is able to develop and transform in the medium or be transported through the medium with the preservation of its shape.

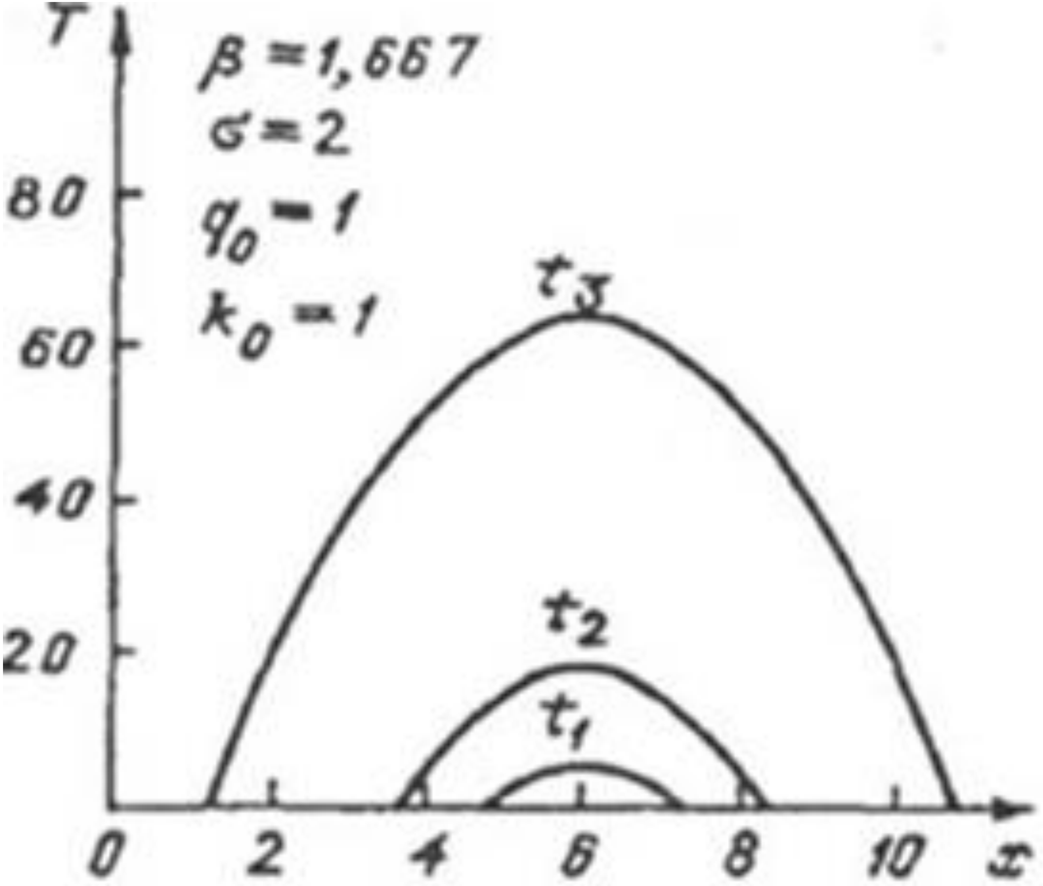
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Fig. 2

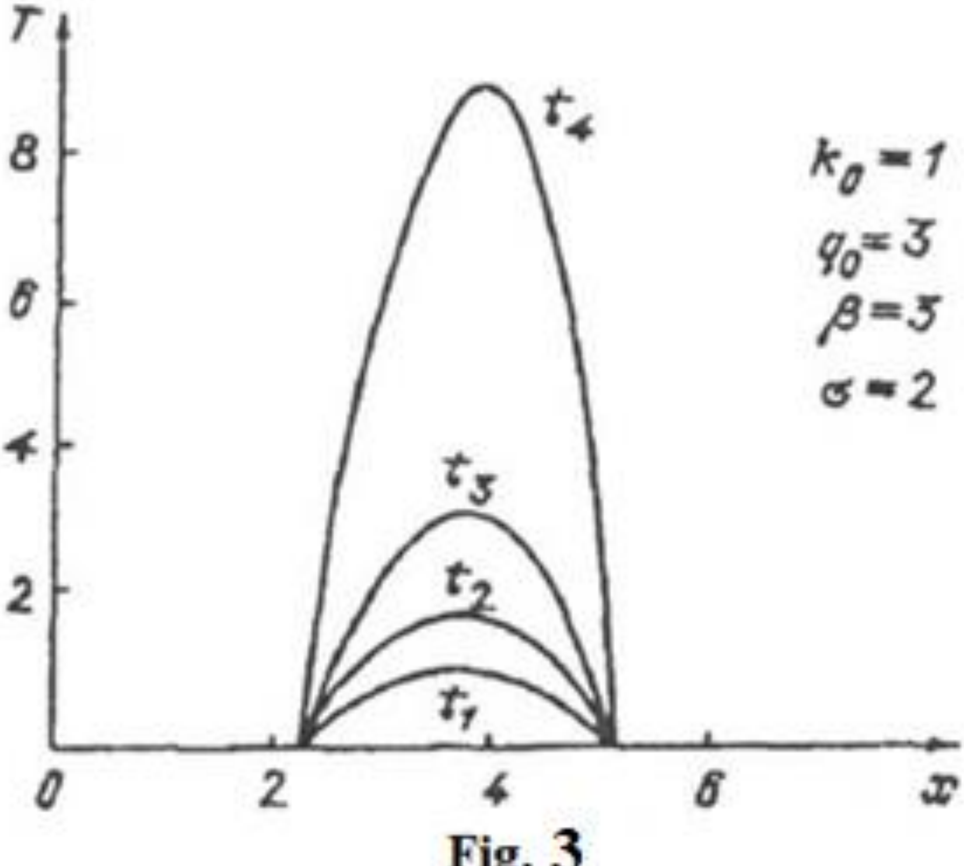
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Fig. 3

Structures of different ages are the structures that are at different stages of evolution and at different stages of approaching the moment of aggravation.

Synergetics is a new interdisciplinary direction of scientific research within the framework of which the processes of transition from chaos to order and vice versa (the processes of self-organization and self-disorganization) in the open nonlinear media of a very different nature are studied.

Thermodynamic branch is a state of thermal chaos to which, according to the second law of thermodynamics, the processes in closed systems rush. In the open systems it is one of the possible paths of evolution; generally speaking it is the most primitive path.

Unstable systems (media) are a certain class of systems (media) which behaviuor is sensitive to small perturbations and to chaotic fluctuations at the micro level; their state can change dramatically under the influence of the latter.

Volumetric nonlinear positive feedback is a mechanism of self-influencing and self-sustaining the development of processes that acts at each point of an open nonlinear medium; in other words it is the mechanism of accelerated self-development and increase of the processes throughout the environmental space. This kind of mechanism underlies the aggravated rates.

На основі минулого та сучасності в монографії виконано теоретичний синтез закономірностей популяційної динаміки найпоширеніших видів шкідливих комах сільськогосподарських рослин, лісових та плодових насаджень. Показано поліциклічний характер їх динаміки у просторі та часі, регіональний та глобальний синхронізм і нелінійність останніх. Проведено аналіз режимів із загостенням (масових розмножень комах), діапазонів їх прогнозування та перспектив розвитку фітосанітарного (екологічного) прогнозування як основи для контролю динаміки популяцій шкідливих та корисних організмів у екосистемах з погляду нелінійної динаміки.

Монографія розрахована на широке коло фахівців, біологів, екологів та всіх тих, хто цікавиться досліджуваною проблемою.

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