Prognostication in plant protection. Review of the past, present and future of nonliner dynamics method.

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By carrying out a theoretical synthesis of the information on the regularities of population dynamics of some insect pests of agricultural plants and based on the past and present the authors have analysed the dynamics of many years in the number of the insect populations. An attempt to determine the presence of synchronism of outbreaks of the insects' mass reproduction with the years of sharp changes in the solar activity has been made; the relationship between the changes in the number of the insects and meteorological and heliographic factors has been analysed. An analysis of the dynamics of the sun pest reproduction taking into account the duration of sunshine on the materials of one of the outbreaks (local population) in the Kupiansk district of the Kharkiv region showed the unreliability of this index as a predicate of the prognosis; and the reproduction rate of the local population of the sun pest does not change depending on the duration of the solar radiance. It is determined that this principle is also unsuitable for forecasting the dynamics in the number of this pest. The linear differential equations, in which not only the meteorological factors but also the indices of the solar activity (global factor) were used as variables were unsuitable for prog nostication the dynamics in the number of the insects. The examples listed in the article confirm the fundamental regularity, namely the polycyclic dynamics of various natural systems and the synchronism in their development. The synchronization is inevitable because all objects of inanimate and living nature consist of the same chemical elements, and the conservation and conversion of energy is universal in nature. Based on the methodology of the cyclic dynamics it is possible to develop the algorithms for prognostication the regular mass reproduction of harmful insects.

Key words: population dynamics, population cycles, insect number, synergetic approach, nonlinear dynamics, prognostication, solar activity.

Introduction

At the beginning and in the middle of the twentieth century in the former USSR, including Ukraine, the mass reproductions of multi-faceted and specialised insect pests of agricultural crops, fruit and forest stands were noted. Among them the webworm beetle dominated. 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. The beginning of prognostication in plant protection in Ukraine was in 1913. 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, 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”, where 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 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 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 outbreaks 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. Chizhevskiy) 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. Krysthal 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" (Belanovsky, 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 enormous 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.

In 1957 there was a "sudden", unexpected mass reproduction of the webworm beetle: according to I. Ya. Poliakov (Poliakov, 1964) this pest was not considered a mass any more. I.Ya. Poliakov (Poliakov, 1980) made an attempt to identify the reasons of this mass reproduction, substantiate the forecast of its population dynamics and solve the immediate 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; Biletskyi, 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 after 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. 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.

We used the available data on the population dynamics of some insect pests in agricultural plants to to determine the presence of synchronism in insects mass reproduction outbreaks regards the years of sharp changes in the solar activity. The relationship between the changes in the insect numbers, meteorological and heliographic factors has been analysed.

**Discussion**

These works are still remained unknown for many ecologists who studied and are studying 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 1, Appendix).

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 prognosticat in 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 2–4.

**Table 2.** The years with increased number of some insect pests versus meteorological factors (indicated in the text) in Zaporizhzhia region

| Insects                  | Years                     | 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 borer      | 1974, 1975, 1978–1979, 1989–1994, 2000–2004 | 0.2150 | 21.56 |
| 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 |
The analysis of the linear regression data presented in Table 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 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).

### Table 3. The years with increased number of some insect pests versus meteorological factors in Cherkasy region

| insects                        | Years                        | Determination 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 corn borer            | 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 |

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### Table 4. The years with increased number of some insect pests versus meteorological factors in Volyn region

| insects                        | Years                        | 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 it was 500-600/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 |

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 sunspots on the visible disk of the Sun).

The results are given in Table 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/m² or 89 times. 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 6).

Table 5. Density of hibernating sun pests in hibernation places (Kharkiv geographic population) in 1995–2005

| Years | Wolf number W | Density of bugs in hibernation places, specimens/m² |
|-------|---------------|-----------------------------------------------------|
|       |               | 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 data from Table 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).

Table 6. Changes in reproduction rate of Kupiansk local population of sun pest depending on long-term sunshine dynamics (1966–1981)

| 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  | 326                                      | -228                                | 0,5                          |
| 1981  | 504                                      | +15                                 | 2                            |

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.

The synchronism of the mass reproduction of the most common insect pests in Ukraine is given in Table 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 8, 9).

Table 7. Beginning of harmful insect regular mass reproduction towards the years of sharp changes in solar activity in Ukraine (SA)

| №   | Name of insect | Years of mass reproduction | Beginning of regular mass reproduction (%) | 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                          |               |

Table 8. Fracture rates of long-term course of natural processes on the Earth and statistic assessments of fractures connection with sharp changes in solar activity (Druzhynin, 1969; Influence ..., 1971; Druzhynin, 1974)

| Process name                | Total number of years | Relative fracture rate in the years of solar activity | Probabilities difference of Chi-square criterion | Probability of chance differences in probability of fractures, % |
|-----------------------------|-----------------------|-------------------------------------------------------|-----------------------------------------------|-------------------------------------------------------------|
| 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%. We have obtained the analogous results as for the Kharkiv region (Table 9).

Table 9. Frequencies of long-term fractures of some heliographic factors and yield capacity of winter crops and their synchronism with the years of sharp changes in solar activity, Kharkiv region

| Process name                      | Total number of years | Relative fracture rates | Chi-square criterion | Probability level, % |
|-----------------------------------|-----------------------|-------------------------|---------------------|----------------------|
| 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                      | 100                 | 50                   | 4,90                | < 2,50               |

The data given in Table 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 10).

Table 10. Global mass reproduction of some harmful insects towards the years of sharp changes in solar activity

| Name of insects        | Years of global mass reproduction | Beginning of regular mass reproduction, % | \begin{align*} & \text{In the years of sharp changes} & \text{1 year after the benchmarks} & \text{in other years} \end{align*} |
|------------------------|-------------------------------------|------------------------------------------|--------------------------------------------|
| Turnip moth            | 1923–1925 1946–1950                 | 100,0                                    | 0,0                                        | 0,0                                     |
| European corn borer    | 1928–1929                             | 100,0                                    | 0,0                                        | 0,0                                     |
| Webworm beetle         | 1929–1930 1975 1901–1905 1909–1914 1923–1929 1931–1933 1936–1941 | 100,0                                    | 0,0                                        | 0,0                                     |
| Sun pest               | 1948–1957 1964–1970 1972–1981 1984–1991 1997–1998 | 100,0                                    | 0,0                                        | 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 1947–1948                 | 100,0                                    | 0,0                                        | 0,0                                     |
| Gypsy moth             | 1912–1913 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                                     |

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 (Table 10). 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. Vernadsky (Vernadsky, 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 ...” (Vernadsky, 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. Vernadsky, P.A. Kropotkin, K.E. Tsiiolkovsky, O.L. Chizhevsky, P.A. Sorokin, N.D. Kondratiev, A.A. Bohdanov, 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).

Conclusions

The analysis of the dynamics of the sun pest reproduction, in the Kupiansk district, Kharkiv region, showed the unreliability of this index as a forecast predicate; the reproduction rate of the sun pest local population is not changed depending on the sunshine duration. We determined that this principle is also unsuitable for prognostication of the dynamics in the number of this pest. 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 insect numbers.

The cases described in this article confirmed the fundamental regularity, namely the polycyclic dynamics of various natural systems and the synchronism in their development. The synchronization is inevitable because all objects of inanimate and living nature consist of the same chemical elements, and the conservation and conversion of energy is universal. Based on harmful pest cyclic dynamics it is possible to prognostic their regular mass reproduction.

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### Appendix

**Table 1. Dynamics and periods of solar activity, year/W (1756–2018)**

| 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 56 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                           |

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