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ORIGINAL ARTICLE

Cycle populations dynamics of harmful insects

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We studied the reproduction cycles of 39 pest insect species and revealed that they, being cyclical and polycyclic in nature, are not strictly periodic and occur at different intervals. Moreover, we registered the outbreaks in their numbers in the periods with minimum and maximum of solar activity. The frequencies of the mass reproductions during the years of benchmarks were 2.5–3.0 times higher than the frequencies during the other years for the period of 1854–1985. We asserted that the synchronism of 70 species mass reproductions took place in Ukraine during some period with the years of sharp changes in the solar activity. The global synchronization of insect mass reproductions cannot be only explained by the weather factors since they are unlikely even within the same region. We suggested that the population cycles are self-oscillations of the biological systems synchronised by the solar activity, which can create the double effect: the "cyclic background" in the Earth changes and a part of the fractures of the long-term course distorting this "cyclic background". The over helming majority of insect mass reproductions began in dry periods, and the droughts are synchronous with the dynamics of the solar activity. We believed that the cyclic character and recurrence are the universal properties of the development and functioning of any natural systems in space and time. This conclusion could be the conceptual basis for regularities in long-term recurrence of mass insect reproduction. Our idea of cyclic population dynamics reflects its descriptive, explanatory, prognostic and synthesizing functions and combines the previously proposed climatic and trophic theories. We developed the method and algorithms for a long-term forecast of insect mass reproductions on cyclic character of the population dynamics. According to the modern concepts of nonlinear dynamics (synergetics), the mass reproductions of insects are definitely programmed in present and future.

Keywords: Insects; Pests; Population dynamics; Cyclic character of mass reproductions; Synchronism; Nonlinearity; Aggravated rates

Introduction

The seasonal, annual and long-term dynamics of insect populations suggest the 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 that are recurred over time were called the population cycles. 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. We performed the long-term retrospective analysis of 70 insect pest species in Ukraine and other countries regions and substantiated the theory of cyclic insect population dynamics and gradation.

Materials and Methods

We conducted a theoretical synthesis of population dynamics regularities of the most common insect pests, damaged the agriculture fields, forest and fruit plantations and analyzed the seasonal and annual changes in insect numbers. We also checked the possibilities of using the solar activity indices (Wolf numbers) for the forecasting the population booms and their spatial and temporal synchronization.

Results and Discussion

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 sunspots 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 sunspots. N.S. Shcherbinovsky (1952) substantiated the cyclic character of the mass reproduction of schistocerca as a natural process without reference to F.P. Keppen (1870). We generalize the of the long-term dynamics os some insect species and indicated their cyclic temporal character (Table 1).

Table 1. Spatial and temporal insect population cycles (from Beletsky, Stankevich, 2018).

№	species, region and mass reproduction period	Duration of mass reproduction, uears	intervals between the next population boom, years
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)	4, 7	6, 8, 10, 11, 14, 100
	Range (1800-2003)		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 recent scientific literature, the usage of solar activity indices (Wolf numbers) for the forecasting of insect mass reproduction has being discussed. In particular, some acridologists proposed the periods with minima or maxima numbers of solar activity as the beginning of the regular population cycles. In fact, the pest mass reproductions do not occur periodically, but they have the cyclic character and have different intervals. Moreover, the outbreaks of their numbers occur in periods with minima and maxima of the solar activity and should be graphically placed on the growth curve branches and decliane branches. 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.

Table 2. Probability of pest regular mass reproductions in Palearctic in different periods solar activity (SA) (Beletsky, 2011).

Species of insect	Years of mass reproductions	Probability (%) of regular mass reproductions in SA period			
		minimum SA	SA growth	maximum SA	SA decline
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

According to the data given in Table 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, pine moth and pine sawflies in Germany for the period of 1810-1970. V.L. Meshkova (2002) confirmed these ideas.

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 concluded 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 11,552,000 km², while the area of Ukraine does not exceed 5.2% from this. 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 used the years of sharp changes in SA or the so-called years of solar benchmarks to analyse the pest mass reproduction. We also substantiated the long-term forecast of the outbreaks in their numbers in different regions and carried out a historical and statistical analysis for 70 pest species regards the sharp changes in solar activity in Ukraine for 1854-1985 (Table 3).

Table 3. Frequency of pest mass reproductions vs. sharp changes in solar activity (70 species, Ukraine, 1854–1985) (Beletsky, Stankevich, 2018).

Relative frequency of mass reproductions, %			**Chi-square value**	**Probability of random differences in mass reproductions, %**
during the years of solar benchmarks	a year after bebchmark	in other years		
90.0	76.6	29.0	11.11	<0.5

From the data given in Table 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 in various regions with different soil and climatic conditions (Table 4).

Table 4. Mass reproductions of different species in various regions vs. sharp changes in solar activity (SA) (Beletsky, Stankevich, 2018).

Species and 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 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, and 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 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***.***
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).
<u>Note: the years of global mass reproductions are underlined.</u>

The mass reproductions were especially significant in Ukraine in 1868–2009 when 20-41 species damaged the agriculture fields and forest plantations. During this historical period the synchronism of the mass reproductions was observed:
in <u>1868–1870</u>: 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 <u>1878–1880</u>: 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: 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: 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: 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: 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;

in 1946-1950: 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: 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: 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: 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: 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: 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: 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 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 5.

All 13 mass reproduction of insects began exactly in the years with sharp changes in the solar activity (Table 5). From 13 population cycles, 11 or 84.6% started during the years of the domination of the eastern and meridian forms of atmospheric circulation and only two of them or 1.6% began during the years of the domination of the western atmospheric circulation form (in 1956–1960 and in 1990–1995). 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 et al., 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 6).

Table 5. Synchronism in insect population cycles vs. sharp changes in solar activity and forms of atmospheric circulation (Ukraine, 1868-2010, Beletsky, Stankevich, 2018).

Years		Dominating forms of atmospheric circulation		
period of mass reproductions	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	–	–	+

Table 6. Droughts in Ukraine and sharp changes in solar activity (SA) (Beletsky, Stankevich, 2018).

Years	
droughts	Sharp changes in SA
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, and V.N. Yagodinsky). However, nowadays the number of publications on this problem is drastically decreased. More than two thousand articles dedicated just to the relationship of the animal population dynamics with the cyclic changes in the solar activity have been published by the middle of the 50s (Cole, 1956). 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. Many scientists in their works developed a similar point of view. 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.

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). Whereas 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. He also underlined the important role of the geomagnetic field for the genetic processes of the gene, chromosome and population level. In particular, this geophysical factor affects the genetic code and genetic homeostasis, and the genetic and ecological structures of the populations.

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 Poliakov 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 such relationships are 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).

E.N. Beletsky (2011) did 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 other regions, and he 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 humankind faced the problem of the mass reproduction of insects since ancient times 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 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 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, some 336 thousand hectares or by 11 times higher 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).

Conclusion

We 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). 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.
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". 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. 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. 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 long-term forecast of the mass reproductions of insects as well as the algorithms for their forecasting was developed on the theory of the cyclic character of the population dynamics.

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