

Dependency of Outbreaks Distribution from Insects-defoliators' Seasonal Development

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Abstract

Analysis of data on the population dynamics of foliage browsing insects in time and space was conducted in the Ukraine. For each of the main species, correlation indices were calculated between outbreak characteristics (mean and specific foci area, outbreak probability), weather elements (air temperature, precipitation), indices (hydrothermal coefficient, winter severity) and the dates of air temperature transition over and below different limits (0, 5, 10, and 15°C).

The population dynamics of insects with different types of seasonal development depends on peculiarities in insect seasonal development and in particular, on weather conditions of the region. For insect species which hibernate in the egg stage (*Tortrix viridana*, *Neodiprion sertifer*, *Lymantria dispar*), the initiation of outbreaks occurs more often in years when larval feeding begins early.

Outbreaks of insect species that hibernate in the larval stage (*Dendrolimus pini*, *Euproctis chrysorrhoea*) often follow years when dry and hot weather occurs during the period when young larvae are feeding at the end of the summer.

Outbreaks of insect species that hibernate in the pupal stage begin in years following after the occurrence of an early spring (*Panolis flammea*) or a dry and hot June (*Bupalus piniarius*) and are associated with conditions that promote the rapid development of young larvae.

The occurrence of outbreaks of insect species whose feeding takes place at the end of the season are also associated with warm and dry weather during the feeding period which promotes synchrony in the completion of their seasonal development with completion of the period of vegetation by the host tree.

Introduction

Analysis of many years of data suggests that not all foliage browsing insects cause outbreaks of mass propagation (Meshkova 2002a) and that the dynamics of different geographical and ecological populations is not the same (Meshkova 1999, 2001b, 2001e).

Differences in the spread of geographical population foci indicate that it depends on certain indices which are rather stable for separate regions (Meshkova 1999). In our opinion, such indices are not only air temperature, precipitation and hydrothermal indices, but also the dates and rates of the annual course of air temperature (Meshkova 2001c; 2001d).

Our observations on the foci of different foliage browsing insects show that occurrence of an early spring is favorable for survival of the spring complex of larvae (Meshkova 2002b; 2002c).

According to phenological theory (Meshkova 2002a), the most frequent and intensive outbreaks of foliage browsing insects in the South are associated with an early production of host-tree vegetation in the Spring and acceleration of insect development due to temperature. In conditions of a more continental climate (that is evaluated as the difference in air temperature between July and January) east of the Ukraine, air temperature increases rather fast in the spring however soil temperature increases rather slowly. Hatching of larvae is dependent on air temperature but bud break begins only after the soil thaws and translocation of water in the stems begin. Therefore in the East, larval hatch

coincides with the occurrence of the youngest leaves which have a high nitrogen content and almost no protective substances (phenols, tannins). In the West, larval hatch coincides with more developed foliage that has accumulated protective substances, due in part to high availability of water in stands in these regions.

Differences in the intensity and frequency of outbreaks of different insect species were supposedly dependent on peculiarities in their seasonal development. The main foliage browsing insect species were classified into four groups (Meshkova, 2001a) that differ mainly by their overwintering stage: group 1 – egg (larvae feeding in spring), group 2 – larvae (feeding in spring and at the end of vegetation (autumn)), for example *Dendrolimus pini* L., *Euproctis chrysorrhoea* L.), group 3 – pupae (feeding in spring or in summer-autumn), and group 4 – eonymph (feeding in summer-autumn, for example, *Diprion pini* L.). Subgroups differ by the terms of diapause: subgroup 1a – development from egg to egg without diapause, summer diapause of eggs transits to winter diapause (*Tortrix viridana* L.); subgroup 1b – summer diapause of pupae or eonymph, swarming in autumn, winter diapause of eggs (*Operophtera brumata* L., *Neodiprion sertifer* Geoffr.); subgroup 3a – summer diapause of pupae transits to winter diapause (*Panolis flammea*); subgroup 3b – winter diapause of pupae transits to summer diapause (*Bupalus piniarius* L.).

The objectives of this study were to analyze the history and geography of insect outbreaks in the Ukraine and to determine what combinations of weather conditions are most favorable for different insect species.

Methods

We assumed that if weather conditions that are favorable for certain insect populations can occur in some years in one point, then there are regions where such situations occur more often.

We calculated the correlation coefficients between climatic indices including air temperature, precipitation, hydrothermal coefficients for different months, indices of winter severity, dates of late spring and early autumn frosts, dates of stable transition of air temperature over and below different limits (0, 5, 10, and 15°C) and indices that characterize foliage browsing insects outbreaks, the probability of outbreaks, mean annual foci area, and specific annual foci area (Meshkova 1999, 2002c).

Such correlation indices were calculated on the one hand for mean data for many years on weather elements and on insect outbreaks for 25 points within the Ukraine, and on the other hand for a single point, Kharkiv for the period 1894–2001.

Data on the history and geography of insect outbreaks were obtained from the literature, archives of the Ministry of Forest Management (later – State Committee of Forest Management of Ukraine), the laboratory of forest protection of Ukrainian Research Institute of Forestry & Forest Melioration, and from our own investigations. Meteorological indices were obtained from respective electronic data bases. Data for 1894–1999 were obtained from the Kharkiv regional meteorological Center.

Statistics were calculated with the help of standard computer programs (Microsoft Excel 5.0. and Statistica 4.3 for Windows). The reliability of coincidence for insect outbreak years and certain weather elements was estimated using χ^2 criteria (Rokitskij 1973).

Results

The foci area for *Tortrix viridana* L. covers more than half of the area that contains foci from all leaf-browsing insects. There is a significant correlation in the probability of its outbreaks with latitude ($r=-0.41$; $P=0.05$), longitude ($r=-0.67$; $P=0.01$), continentality ($r=-0.57$; $P=0.05$), suggesting that outbreaks occur more often in regions with higher air temperature and lower precipitation during the vegetation period. There is also a high correlation with indices that characterize the integral influence of temperature and precipitation ($r=-0.75$; $P=0.01$).

The probability of *T. viridana* outbreaks is higher in regions where the dates of the last spring frost occur earlier ($r = -0.49$; $P=0.05$) and there is a stable transition of air temperature over 10° ($r = -0.58$; $P=0.05$) with a shorter interval between the dates of stable transition of air temperature over 0° and 15° ($r = -0.51$; $P=0.05$), 5° and 10° ($r = -0.54$; $P=0.05$); This means that outbreaks are more frequent in the regions that experience more early springs and shorter periods of larval feeding.

When we take into account data over many years at one point (Kharkiv, 1894–2000), we often see the coincidence of years with earlier larval hatching and years of high larval density ($r=-0.53$; $0.01 < P < 0.05$) as well as an increase in foci area ($r=-0.42$; $P=0.05$). This means that the early hatch of larvae is favorable for *T. viridana* populations.

For *Lymantria dispar* L. there is a negative relationship between latitude and foci area ($r = -0.64$; $P=0.05$), latitude and outbreak probability ($r = -0.63$; $P=0.05$). Dependence of outbreak probability is reliable for longitude ($r=0.54$; $P=0.05$) and the continentality index ($r=0.52$; $P=0.05$). This means that the more favorable conditions for gypsy moth populations occur in the East and South of Ukraine.

There is a positive correlation between gypsy moth foci area and air temperature in January ($r=0.62$; $P=0.05$) and in Autumn – in September ($r=0.44$), October ($r=0.56$; $P=0.05$), November ($r=0.57$; $P=0.05$), December ($r=0.59$; $P=0.05$). This suggests that the most favorable conditions for gypsy moth populations occur in those regions with a warm autumn. These conditions are favorable for eggs to complete their embryonation and to enter diapause.

The most high and reliable ($P=0.01$) correlation of gypsy moth outbreaks probability is related to the months from May to September ($r=0.7$; $r=0.8$; $r=0.82$; $r=0.8$; $r=0.72$), and then becomes lower for October ($r=0.54$; $P=0.05$). Negative dependence of outbreak probability with latitude agrees with its positive dependence on temperature. This means that warm conditions in the south are favorable for gypsy moth populations.

There is an explanation for the positive correlation of specific foci area with the sum of negative temperatures for the period with negative air temperature ($r=0.52$; $P=0.05$). The natural selection of a specimen, that enters a deep diapause earlier is more intensive in regions with colder winters.

The negative correlation of mean ($r = -0.49$; $P=0.05$) and specific ($r = -0.62$; $P=0.05$) foci areas with precipitation for periods with negative air temperature and a positive correlation with index of winter severity ($r=0.46$ and $r=0.4$ respectively) can be associated with a weakening of host plants that occurs in frosty dry winters.

There are negative correlations between annual precipitation, for periods with positive temperature and monthly temperature over 10°C and gypsy moth specific foci area ($r=-0.62$; $r=-0.50$ and $r=-0.55$ respectively) and with probability of outbreaks ($r=-0.68$; $r=-0.67$ and $r=-0.7$ respectively). This suggests that conditions are more favorable for gypsy moth outbreaks in regions with less precipitation.

There is a negative correlation between gypsy moth foci area and precipitation in almost all months except December and January, but the correlation is highest in August ($r = -0.53$). The correlation coefficient between specific areas and monthly precipitation are highest for July ($r = -0.7$) and August ($r = -0.67$) but they are also reliable at $P=0.05$ for April ($r = -0.64$), May ($r = -0.6$), June ($r = -0.6$), and September ($r = -0.53$). The most significant ($P=0.01$) correlation coefficients between precipitation and probability of gypsy moth outbreaks occur for the months of July ($r = -0.8$), August ($r = -0.8$) and September ($r = -0.78$), but they are rather high also for April ($r = -0.63$), May ($r = -0.6$), June and October ($r = -0.56$). The high correlation between air temperature and precipitation in July–August and indices characterizing gypsy moth foci is probably related to the influence of weather conditions during the period of oviposition and embryonation.

It is clear that integral indices which characterize periods of drought are also correlated negatively with the spread of gypsy moth foci (correlation indices for mean, specific foci area and outbreak probability with hydrothermal coefficient of vegetation period are $r = -0.4$; $r = -0.62$ and $r = -0.79$ respectively).

A negative correlation was found between the probability of gypsy moth outbreaks and the date air temperature over 10° stabilizes in the spring ($r=-0.62$; $P=0.05$). This means that occurrence of an early spring is favorable for development of gypsy moth outbreaks.

For *Neodiprion sertifer* Geoffr., a reliable but moderate positive correlation was found between specific area and air temperature during the vegetation period ($r=0.55-0.58$; $P=0.01$). The correlation of mean, specific foci area and outbreak probability with precipitation is negative. The correlations are negative between mean area and April precipitation ($P=0.05$; $r = -0.47$), and highly significant ($P=0.01$) between specific area with precipitation in April ($r = -0.64$) and July ($r = -0.59$). The correlation between mean area and precipitation in other months is reliable at $P=0.05$. Negative correlation coefficients were calculated between *Neodiprion sertifer* mean and specific foci area and precipitation for the year and vegetative season, and for the hydrothermal coefficient.

The negative correlation calculated between specific foci area and outbreak probability with the dates when stable air temperatures over 5° occurs in spring ($r=-0.61$ and $r=-0.47$) and 10° ($r = -0.56$ and $r = -0.58$) suggests, conditions are favorable for *N. sertifer* survival in regions where spring begins earlier.

The correlation is positive between the date when the transition of air temperature below 15° in autumn is stable with both specific area ($r=0.58$; $P=0.05$) and outbreak probability ($r=0.58$; $P=0.05$). This means that conditions are more favorable for outbreaks of *N. sertifer* in areas where the transition of air temperature below 15° occurs late in the autumn. The correlation between outbreak probability and intervals between the transition of stable air temperature in autumn below 15° and 10° ($r = -0.64$; $P=0.05$), 15° and 5°C ($r = -0.66$; $P=0.05$) is higher. This suggests that shorter intervals are better for *Neodiprion sertifer* populations. It is during this time that the pronymphs change into pupae, and when adults swarm and lays eggs.

Outbreaks of *N. sertifer* in the Kharkiv region coincide with those years when the date of stable transition of air temperature over 10°C is earlier than 23.IV ($\chi^2=10.6$; $P<0.01$). The reliability is even higher when this occurs earlier than 16 April ($\chi^2=11.3$; $P<0.01$).

The probability of *Euproctis chrysorrhoea* L. outbreaks is higher in the south ($r=-0.53$ with latitude). A positive dependence with longitude is calculated for specific foci area ($r=0.64$) and outbreak probability ($r=0.67$; $P=0.05$); this means that outbreaks of this pest occur more often and with greater intensity in the East of Ukraine. The same dependence is determined for continentality index which increases from the West to East ($r=0.74$ and $r=0.58$ for specific foci area and outbreak probability respectively).

The probability of *E. chrysorrhoea* outbreaks correlates reliably with air temperature in May ($r=0.67$; $P=0.05$), June ($r=0.76$; $P=0.01$), July ($r=0.80$; $P=0.01$), August ($r=0.77$; $P=0.01$) and September ($r=0.6$; $P=0.05$). Influence of air temperature on *E. chrysorrhoea* outbreak probability increases from spring to summer, and is maximal during the period of moth flight and when neonate larvae appear. This can be explained by the fact that survival of neonate larvae is essential in the life cycle of this species, which appear almost simultaneously in different points of area (Meshkova 2001). Rapid development of eggs within a short time period promotes species survival. At locations with higher July temperatures, insect development accelerates and therefore from a geographical perspective, we see such changes of correlation coefficients by months. The beginning of larval feeding (that coincides with initiation of spring) and completion of larval feeding (that coincides with completion of the vegetation period) varies strongly in different regions. Therefore the correlation of air temperature with *E. chrysorrhoea* outbreak probability is less for the early spring or autumn months.

A negative essential correlation is determined between *E. chrysorrhoea* outbreak probability and precipitation for the vegetation period ($P=0.01$). Correlation indices for July, August and September ($r = -0.71$; $r = -0.8$; $r = -0.8$) indicate that conditions are more favorable for the development of young larvae in locations where there is less precipitation during this period.

The correlation index for *E. chrysorrhoea* outbreak probability and hydrothermal coefficient for vegetation season is -0.79 ($P=0.01$). This supports the notion that the growth of outbreak probability occurs under dry conditions. The negative influence of winter severity coefficient on outbreak area ($r=-0.51$) suggests that *E. chrysorrhoea* foci spread more in regions with low winter precipitation and low temperature, that is in the regions characterized with low host plant resistance.

The probability of *E. chrysorrhoea* outbreaks is higher in the regions where the date of air temperature transition below 15° ($r=0.64$) occurs later.

Analysis of many years of data for Kharkiv (1894–2000) shows that the mean hydrothermal index for July is equal to 0.1 ± 0.006 . It is equal to 0.09 ± 0.01 in the years of outbreaks and to 0.07 ± 0.01 in previous years. Coincidence of *E. chrysorrhoea* outbreaks with the years following after years when the hydrothermal index for July is less than 0.09 is significant with a probability of 99.9% ($\chi^2=10.3$).

For *Dendrolimus pini* L, there is a positive correlation with foci area and April air temperature ($r=0.71$; $P=0.05$) (this is the period when larvae begin feeding after hibernation) as well as with air temperature during August–October ($r = 0.65$ – 0.68), which is the period of young larval feeding. We found a high correlation of specific foci area with annual year temperature ($r=0.69$).

There is a negative correlation of specific foci area with precipitation for most months (March – -0.72 ; April – -0.68 ; June – -0.65 ; July – -0.67 ; August – -0.68 ; October – -0.71 ; November – -0.7 ; December – -0.69). There is also a negative correlation of specific foci area with the hydrothermal coefficient ($r=-0.69$). This suggests that localities with low precipitation are more favorable for *D. pini*.

The reliable correlation of winter precipitation with *D. pini* foci specific area ($r=0.67$) can be explained by the fact that high water content in the litter during thaws causes the spread of infection by fungi among larvae. On the other hand, when the snow layer is dense, thaws occur slowly and larvae begin feeding later.

We determined that there is a negative correlation of indices that characterize *D. pini* outbreaks with the date of the last spring frost ($r = -0.63$; $P=0.05$) and a positive correlation ($r=0.64$) with the date of the first autumn frost. There is also a positive correlation ($r=0.69$) between mean and specific foci area with the number of days with air temperature over 5°C . This suggests that weather conditions are more favorable to *D. pini* survival in those regions that are characterized by an early beginning and late completion of warm weather. These conditions promote the rapid development of older larvae after winter and neonates at the end of the season.

A high correlation index was estimated for the interval between dates of air temperature transition over 5° and 10°C with *D. pini* mean ($r=0.63$; $P=0.05$) and specific ($r=0.71$; $P=0.05$) foci area. It is during this period that larvae initiate feeding after hibernation. The correlation between specific foci area and the interval between the dates of air temperature stable transition below 5° and 0°C in autumn is also reliable ($r=0.68$; $P=0.05$). This is during the period when winter diapause of *D. pini* caterpillars begins.

The correlation of indices that characterize dates and rates of spring development in the Kharkiv region (1894–1999) with the dynamics of *D. pini* populations in the Kharkiv region indicates that 85.7% of outbreaks begin in the years when the stable transition of air temperature over 0°C occurs before 21. ($\chi^2=4.0$; $P>0.1$), and 92.9% of outbreaks occur in the years when stable transition of air

temperature over 5°C occurs before 10.IV ($\chi^2=3.7$; $P>0.1$). This means that 78.6% of outbreaks occur in the years when the interval between stable air temperature transition over 0 and 5°C is not less than 16 days ($\chi^2=3.7$; $P>0.1$); 71.4% of outbreaks occur in the years when the interval between stable air temperature transition over 5 and 10°C is not less than 18 days ($\chi^2=6.5$; $P=0.04$). This means that an early spring with slow development and uniform soil thawing and initiation of pine vegetation in the stand promotes high quality forage for caterpillars and is favorable for survival of *D. pini* populations.

Years with higher air temperature are favorable for *D. pini* populations because a greater portion of larvae will begin hibernation in later instars. During 1894–2001 in the Kharkiv region, 92.9% of *D. pini* outbreaks began in years when the sum of positive air temperatures during July–September was over 1664°C ($\chi^2=11.9$; $P<0.01$), and 71.4% outbreaks began in years when the July temperature was over 20.7°C ($\chi^2=4.2$; $P>0.1$).

For *Panolis flammea* L., there is a positive correlation of mean foci area with the date of stable air temperature transition over 0°C ($r=0.58$) and a negative correlation with the date of such transition in autumn. The correlation is higher for mean foci area and when the interval between dates of air temperature stable transition is over 0° and 5°C ($r=-0.81$), and between dates of air temperature stable transition over 0° and 10°C ($r=-0.77$). This suggests that a rapid increase of air temperature in the spring is favorable for swarming, mating, egg laying and their development.

It was stated that 77.8% of *P. flammea* outbreaks in the Kharkiv region between 1894–2001 occur in cases when air temperature transition over 0°C in the previous year occurred not later than 17. ($\chi^2=5.5$; $P>0.05$). Thus 88.9% of outbreaks begin when stable air temperature transition over 5°C in the previous year occurs before 5.IV ($\chi^2=6.9$; $P=0.03$), and transition over 10°C occurs before 23.IV ($\chi^2=8$; $P>0.02$).

The influence of high temperatures on caterpillar development and their survival is confirmed by the fact that 88.9% of *P. flammea* outbreaks in the Kharkiv region occur after years when the mean air temperature in May is over 15°C ($\chi^2=4.5$; $P>0.1$) and 55.6% of outbreaks began in the years following those years when the hydrothermal coefficient for June was less than 0.05 ($\chi^2=6.3$; $P<0.05$).

The length of *P. flammea* larval development varied from 26 to 44 days in different years. In 1998 (before the last outbreak), it was 30 days, while in 1999 it was 32 days. In 2000, development required 36 days because of relatively cold temperatures in May; the mean air temperature was approximately 13°C. The larval feeding period did not exceed 34 days in years when outbreaks were initiated ($\chi^2=4.6$; $P=0.01$).

For *Bupalus piniarius* L., there is a reliable correlation ($P=0.01$) of specific foci area with precipitation in the winter months of December, January and February ($r=0.89$; $r=0.98$; $r=0.76$). This can be explained by the beneficial effect of additional snow cover on the survival of pupae. There is a moderate correlation ($P=0.05$) between the probability of *B. piniarius* outbreaks and precipitation of other months ($r=-0.51$ – $r=-0.74$). This is indicative of the preference by this species for mesophytic conditions. *B. piniarius* outbreaks occur more often in areas with more humid conditions unlike most other foliage browsing insects; in the Ukraine, outbreaks occur in the background of other species i.e. pine sawflies and are of short duration.

The correlation between *B. piniarius* specific foci area with the date of air temperature transition over 0° is positive ($r=0.73$; $P<0.05$). This suggests that conditions are more favorable for *B. piniarius* outbreaks in regions where spring begins later. This may be related to the requirement by larvae for a certain soil humidity that is optimal for their survival.

An analysis of the change in autumn temperatures in different regions indicates that a later decline in temperature is favorable for *B. piniarius* populations ($r=-0.82$).

The absence of a significant correlation between *B. piniarius* outbreaks and the change in spring temperature for many years observations in the Kharkiv region ($\chi^2 < 1$) can be explained. Larvae of *B. piniarius* browse the previous year's foliage which is suitable for feeding long before the swarming of moths occurs. Therefore a shift in the date of swarming does not have an effect on the conditions required for larval feeding.

A positive correlation ($P=0.05$) of *Diprion pini* L. was found between specific foci area and air temperature in March and April ($r=0.51$ and $r=0.53$ respectively); this may be related to the influence of spring conditions affecting the termination of diapause and on the emergence of imagos.

There is good correlation ($r=0.59$; $P=0.05$) between specific foci area with air temperature during the vegetation season (period with air temperature over 10°C); this is explained by the occurrence of two *D. pini* generations per year in the south, while there is only one generation in the north. A negative correlation was found between specific foci area with the date of air temperature stable transition over 5° ($r=-0.63$) reflecting the beneficial effect of an early spring for *D. pini*.

There was a significant positive correlation between the probability of *D. pini* outbreaks with precipitation in January ($r=0.6$; $P<0.01$); this may be related to the fact, that snow cover is favorable to the survival of cocoons the litter. There is a negative correlation between specified foci area with the hydrothermal coefficient for the vegetation period ($r = -0.48$) suggesting that there is an increase in *D. pini* populations in regions with less humidity.

In the Kharkiv region, 76.5% of *D. pini* outbreaks occur in those years when the transition of stable air temperatures over 10°C occurs before 23.IV ($\chi^2=8.2$; $P=0.015$); 100% of outbreaks occur in those years when the transition occurs before 30.IV ($\chi^2=5.1$; $P>0.05$), and 88.2% of *D. pini* outbreaks occur in the years when the transition is before 20.V ($\chi^2=12.8$; $P<0.01$).

The initiation of outbreaks occurs when air temperature in May and June (16.3°C and 20°C respectively) exceeds the mean data for many years (15.4°C and 19°C respectively). For the period of 1984–2001 in Kharkiv, 94.1% of *D. pini* outbreaks began in years when the air temperature in May exceeded 14°C ($\chi^2=3.7$; $P>0.1$), and 82.4% of outbreaks began in years when the air temperature in May exceeded 18°C ($\chi^2=2.3$; $P>0.1$).

In the years when outbreaks began, first generation of cocoons of *D. pini* were formed before 17.VI in 88.2% cases ($\chi^2=12.2$; $P<0.01$). The majority of first generation larvae complete feeding before the solstice (when photoperiodic reaction begins to have a dominant influence on developmental temps). The larvae that do not complete their development before this date often continue development after the monovoltine type. The occurrence of a larval diapause in summer allows larvae to complete their development in September simultaneously with larvae from the summer generation.

We did not find a reliable correlation between outbreaks and hydrothermal indices for the summer generation feeding period. However in 70.6% of the years when *D. pini* outbreaks occurred, the hydrothermal index in August did not exceed 0.08 ($\chi^2=2.0$; $P>0.1$).

All *D. pini* outbreaks in the Kharkiv region occurred in years when the stable transition of air temperature below 5°C occurred after 20 October ($\chi^2=5.9$; $P=0.05$).

Discussion

A reliable correlation was found between the beginning of outbreaks caused by foliage browsing insects and terms and temperature during the seasonal development of these species.

For species that hibernate in the egg stage (1st group – *Tortrix viridana*, *Lymantria dispar*, *Neodiprion sertifer*), the beginning of outbreaks coincide with the time when larval feeding begins.

For the 2nd group (hibernate as larvae), the initiation of *Dendrolimus pini* outbreaks coincides with high air temperature in June-September of the current year, while for *Euproctis chrysorrhoea*, it coincides with low hydrothermal coefficient in July of the previous and current years.

Panolis flammea outbreaks (the 3rd group, which hibernate as pupae) occur in years following after those years with an early transition of air temperature over 0, 5 and 10°C. High air temperature in May (over 15°C) of the current year and low hydrothermal coefficient in June (below 0.1) of the previous year are less coincident with outbreaks of *Panolis flammea*. Outbreak of *Bupalus piniarius* coincide with high air temperature in July of the previous year and to a lesser degree with high air temperature in September of the current year.

The beginning of *Diprion pini* outbreaks (the 4th group, hibernate as enonymphs) reliably coincide well with years when an early transition of air temperature over 10°C occurs.

Estimated correlation of dates and rates of the course of annual temperature with the dissemination of foliage browsing insects in different regions of the Ukraine allows us to obtain data to support a suggested phenological theory of population dynamics (Meshkova 2002a). The dates and rates of the development of all foliage browsing species that feed during first part of the vegetation period (before the solstice) depend on the course of temperatures. Dates and rates of the development of those foliage browsing insects that feed during the last part of the vegetation depend on the photoperiodic reaction of organisms which complete their seasonal development coincident with completion of the vegetation period of their host.

Foliage browsing insect outbreaks occur more often and are intensive in the South because:

- insects develop more rapidly at higher temperature
- tree resistance (general, and to insects) declines at low humidity
- at the absence or insignificant soil chilling to the date when larval feeding begins, the sap of host plants begins to move earlier in spring; therefore the needles of the previous year become more suitable for larvae of *Neodiprion sertifer* and *Dendrolimus pini*, while the development of current needles (for *Panolis flammea*) and budbreak of deciduous trees (for leaf-feeding larvae of the spring complex) is accelerated.

Outbreaks of foliage browsing insects occur more often and are more intensive in the East because:

- stands are more resistant in the East regions that have high precipitation, which causes slowing of larval development and a decline in their survival
- in the East regions with high continentality index, the occurrence of colder winters and hotter summers (as compared to West regions) cause a rapid increase in air temperature in the spring which results in acceleration of larval development. This is favorable for insect populations
- in the East regions there is optimal difference in the rates of air and soil heating, which allows larvae to consume the most suitable foliage immediately after hatching.

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