proceedings

Proceedings

Pros and Cons of Climate Change for Forest Phytophagous Insects †

Valentyna Meshkova

1 Ukrainian Research Institute of Forestry & Forest Melioration, Pushkinska str. 86, 61024, Kharkiv, Ukraine; Valentynameshkova@gmail.com
* Correspondence: Valentynameshkova@gmail.com
† Presented at the 1st International Electronic Conference on Entomology (IECE 2021), 1–15 July 2021; Available online: https://iece.sciforum.net/.

Abstract: The aim of the research was to assess a possible reaction of forest phytophages with different types of seasonal development on climate change. The patterns of seasonal development for foliage browsing insects and possible changes with temperature increase were analyzed considering hibernating stage and the presence of summer diapause. Analysis shows that forest phytophagous insects can adapt to climate change by the acceleration of development, expanding the range of host plants, changing the location of individual stages, or spreading the range. Species that are monophages throughout their current range will remain monophages. The survival rate and harmfulness of phytophagous insects will depend on their synchronicity with the appearance of foliage and entomophages. The harmfulness of phytophages will increase with an increase in their voltinism and with an increase in the vulnerability of trees under conditions of aridity and anthropogenic pressure and will decrease as a result of a decrease in the size of insects and their fertility during rapid development. Hibernation of individuals at stages that are not adapted to new combinations of temperature and photoperiod can also be negative results of climate change.

Keywords: foliage browsing insect; entomophage; seasonal development; photoperiod; harmfulness

Citation: Meshkova, V. Proc and cons of Climate Change for Forest Phytophagous insects, in Proceedings of the 1st International Electronic Conference on Entomology, 1–15 July 2021, MDPI: Basel, Switzerland, doi:10.3390/IECE-10373

Published: 30 June 2021

1. Introduction

Climate change is to increase the temperature, CO2 concentration, the frequency of drought, fires, and hurricanes [1]. Of these factors, the greatest value for insects has a temperature that affects their survival and development directly and indirectly through the availability and quality of food [2–4]. Within the limits between the lower and the upper thresholds of temperature, the survival, the rate of development of insects as poikilothermic organisms depend on temperature [3]. This suggests that the acceleration of insect development will bring to increase the number of generations. This will negatively affect the health condition of trees, which will be weakened by the action of the above-mentioned and other factors [5].

At the same time, in the zone of a temperate climate with winter, spring, summer, and autumn, insects are adapted to hibernate in the most protected places and in the least vulnerable stage [6]. This is one of the reasons for the predominance of monovoltine forest phytophages. The signal to change the rate of development (acceleration, slowdown) or diapause is most often the length of the day (photoperiod), less often - temperature level and food quality. An increase in temperature without changing the photoperiod may ambiguously affect the survival and harmfulness of phytophagous species [7].

When studying the foliage browsing insects, it was found that in addition to the daily values of the temperature and their sums during the development of certain stages of insects the high importance belongs to the dates of the stable transition of temperature over 0, 5, 10, 15 ° C in spring (D0s, D5s, D10s, D15s) and below these limits in autumn (D0au, D5au, D10au, D15au), as these dates separate the phenological seasons of the year [2]. So the spring starts after D0s, summer lasts between D15s and D15au, autumn between D15au and D0au. Deadlines for the thawing of the soil, sap flow, budburst, and the development of -related insects are dedicated to these dates.

On the examples of insects with different types of seasonal development, it was shown that population dynamics (probability, severity, duration of outbreaks and intervals as well as intervals between them) are related to the features of seasonal development of foliage browsing insects at particular weather conditions of the region [8, 9]. The dates and temperature thresholds and sums were estimated also for stem pests in different regions, particularly in Ukraine [10–12]. Comparison data on seasonal development of these insects in different regions allows suggesting some consequences of climate warming.

The aim of this paper was to assess a possible reaction to climate change of forest phytophages with different types of seasonal development.

2. Materials and Methods

Partially published author's data for almost 50-year-old on phytophagous insects of oak (*Quercus robur* L.) and pine (*Pinus sylvestris* L.) were used. Here weather conditions in the Kharkiv region are presented, which is located in the northeastern part of Ukraine on the border of the forest-steppe and steppe (50º00 'N, 36º10' E).

Temperature of particular months was taken from archives and since 2005 from website https://rp5.ua. Actual dates of temperature transition over and below different limits were evaluated by our approach [2]. Predicted dates of such transition for 2021–2050 were taken from [7] (Table 1).

In analysis, classification of foliage browsing insects by the types of seasonal development considering voltinism, hibernating stage and summer diapause [2] were used. The deadlines for the development of individual stages of insects were analyzed taking into account the type of seasonal development, the deadlines of the appearance after hibernation, and termination of active development in autumn.

When calculating the deadlines for the development of stages, which appeared after the end of hibernation, the evaluated dependences of their duration from temperature and the sum of temperature were used [2].

An example: larvae hatch at D10s. It is known that they develop 31 days at 13 ºC and 18 days at 18 ºC. Considering the actual and predicted value of temperature (Table

1), at Д10=109 and 13 ºC the pupae will appear on the 140th day from the 1st January, that is on the 19th of May, and at D10s=105 and 18 ºC – on the 123rd day, that is on the 2nd of May.

3. Results

The analysis of meteorological data indicates a tendency towards an increase in temperature in all months, an earlier beginning of the growing season, a later completion, and a longer duration (Table 1). At the same time, even several decades ago, in some years, the timing of these events was beyond the predicted limits. This indicates the ability of phytophagous insects to adapt to predicted climate changes.

Table 1. Dates (top) and days from the 1st January (bottom)* for a stable transition of daily air temperature up and down through 0ºC, 5ºC, 10ºC and 15ºC for different periods and predicted by modified A1B climate change scenario for Kharkiv

Limits of transition	**1892–2000**			**1981–2010**			**2021–2050 [7]**		
	start	**end**	**length**	**start**	**end**	**length**	**start**	**end**	**length**
0ºC	17.03 76 (15–99)	27.11 326 (296–348)	251	15.03 75	20.11 325	251	9.03 69	4.12 339	271
5ºC	1.04 95 (74–113)	26.10 300 (280–332)	206	1.04 92	27.10 301	210	25.03 85	29.10 303	219
10ºC	23.04 113 (97–129)	30.09 277 (261–295	165	24.04 115	10.10 284	170	18.04 109	17.10 291	183
15ºC	8.05 136 (114–158)	10.09 253 (239–274)	118	11.05 132	11.09 255	124	10.05 131	17.09 261	131

Note: * – mean and limits

In accordance with our classification [2], foliage browsing insects were divided into groups by hibernating stage: group 1 – egg hibernates (larvae feeding in spring); group 2 – larva hibernates, feeding in spring and at the end of vegetation, for example, *Dendrolimus pini* (Linnaeus, 1758), *Euproctis chrysorrhoea* (Linnaeus, 1758); group 3 – pupa hibernates (larvae feeding in spring or in summer-autumn); group 4 – eonymph hibernates (larvae feeding in summer-autumn, for example, *Diprion pini* (Linnaeus, 1758). Subgroups differ by the presence of summer diapause: subgroup 1a – summer diapause of eggs transits to winter diapause (*Tortrix viridana* Linnaeus, 1758)); subgroup 1b – summer diapause of pupae or eonymph, swarming in autumn, winter diapause of eggs – *Operophthera brumata* (Linnaeus, 1758), *Neodiprion sertifer* (Geoffroy, 1785); subgroup 3a – summer diapause of pupae transits to winter diapause – *Panolis flammea* (Denis & Schiff., 1775); subgroup 3b – winter diapause of pupae transits to summer diapause – *Bupalus piniarius* (Linnaeus, 1758).

Members of groups 1–3 are monovoltine throughout the entire range, and representatives of group 4 are known to have different variants of cycles [13].

The date of hatching the species of group 1 and the renewal of active feeding of the larvae of group 2 approximately corresponds to D10s and will correspond to it with a change in climate since only in this case the maximum coincidence of the time of appearance of the larvae and the required food will be ensured.

The development of group 1 larvae from hatching to pupation depends on temperature. With the expected earlier transition D0s and higher may temperature, pupation and swarming of group 1a will occur earlier. The feeding period will become shorter. Pupation of larvae of group 1b will also occur earlier. The consequence of this for the species of groups 1a and 1b may be a decrease in the size of pupae and the fecundity of adults.

At the same time, regardless of the timing of the completion of larvae feeding of group 1a, the adults will not become earlier, since its timing is determined by the photoperiodic response which depends on the geographical coordinates of the point.

Particularly, adults of *Neodiprion sertifer* appear after D15au, and of *Operophtera brumata* after D10au. That is, the swarming of these species in the east occurs earlier than in the west, and earlier in the north than in the south. Since these species hibernate at the egg stage, the adults appear late enough so that the laid eggs do not hatch in the absence of food. Since the autumn transition of temperature will be shifted to later dates, individuals with the latest swarming will gain advantages.

The viability of species with 1a and 1b type of seasonal development is most dependent on the timing of the appearance of available food and parasitoids. The development of buds of deciduous trees begins after thawing of the soil, that is, after about D5s, and parasitoids emerge later since they must undergo maturation feeding on flowering plants. The shifts of D5s and D10s will determine the degree of synchronicity in the development of larvae and foliage of the host plant.

Species of group 2 hibernate as larvae of different ages with 2 feeding periods. The beginning of the first and the end of the second period depend on the availability of available food - the budburst for deciduous trees and the beginning of the active vegetation of conifers. The spring period begins at D10s, and the autumn period ends at D10au.

Pupae, adults, and eggs of group 2 species develop in summer on close dates in different regions, because these dates are closed to the summer solstice. Some part of larvae which late in development stop this process and resumes it simultaneously with the appearance of larvae a new generation in August. The age composition of hibernating *Dendrolimus pini* is very diverse (from 2nd to 6th instars). One part of the population completes its development for one year and another for two years.

Therefore, it can be expected that with an increase in the period between D10s – D10au, the species of this group will develop within one year. The dependence of its survival on synchronicity with parasitoids is less pronounced than that of other groups, since in summer they are infested by polygamous or non-specialized species.

Swarming for insects of 3a group, hibernating at the pupal stage, occurs at D5s, and hatching at D10s (for *Panolis flammea*, it coincides with the appearance of young pine needles). Pupation occurs at about the same time as for representatives of group 1a, but the pupa stops developing until the next spring. The signal for the beginning of their development is soil thawing and D5s, which is predicted to occur earlier. As in the species of group 1a and 1b, the development time of larvae of group 3a will be reduced, which can negatively affect the size of pupae and the fertility of adults [14], and, in addition, their survival during a long stay in the forest litter.

As for species of groups 1a and 1b, the viability of individuals of group 3a depends on synchronization with the spring development of parasitoids hibernating in the forest litter. Since pupae of these species spend 9–10 months in the litter, their drying may increase with increasing temperature.

The dates of swarming for *Bupalus piniarius* are close to the dates of the summer solstice, and after D15au the larvae gradually descend into the forest litter. There, caterpillars of the last instar pupate, and younger ones often die. With an increase in the duration of the D15s – D15au period, the proportion of caterpillars with successful completion of development will increase.

The representative of group 4 is the only common foliage browsing species capable of having 2 generations a year (spring and autumn), and sometimes an additional intermediate generation (summer generation) initiated by individuals emerging from diapausing cocoons. The emergence of adults from overwintered cocoons occurs at about D10s. The larvae of the spring generation feed in June, and those of the autumn generation feed in August, until about D15au.

In northern regions and in cold years, depending on the combination of photoperiod and temperature by the time of cocooning, the specimens of *Diprion pini* develop according to one of the following options: cocoons enter diapause for several years, until next spring, into summer diapause (leaving it simultaneously with the appearance of the autumn generation), and sometimes only the autumn generation develops without the spring one [2, 13].

With an increase in the duration of the growing season (D10s – D10au) and an increase in temperature, the bivoltine development of *Diprion pini* will dominate. A further increase in the number of generations of this species is impossible due to its photoperiodic reaction.

4. Discussion

The common foliage browsing and xylophagous insects, living in the forests of Ukraine, are monovoltine throughout their range [5, 10–12]. After warming, they will not change the development cycle, but they can change the timing and duration of its individual parts. As the analysis of long-term data shows, in some years phenological phenomena occurred not only in the predicted dates but also in earlier periods (Table 1). At the same time, the average air temperature in May (when the leaves and larvae of spring phytophages develop), for 1892–2000, was 15.4±0.19 °C and ranged from 11.2 to 20.1 ° C [2].

The only widespread bivoltine foliage browsing species, *Diprion pini*, can develop, depending on the combination of temperature and photoperiod, as monovoltine with the presence of either spring or autumn generations. With an increase in temperature, bivoltine development is expected.

Species hibernating at the egg stage (1a and 1b) will hatch when preferred food is available. Since the timing of the beginning of the growing season of trees depends on the timing of soil thawing, the synchronicity in the appearance of phytophagous larvae and leaves may be disrupted [15]. If the leaves begin to develop before the larvae appear, they will contain less nitrogen and more protective substances. Acceleration of larval development at elevated temperatures will lead to a decrease in the size of pupae and the fertility of adults [14]. Also, the development of these species is affected by synchronicity with entomophages hibernating in the litter, which need to undergo maturation feeding and be ready to infect the vulnerable stage of the phytophage [16, 17].

For species hibernating at the larvae stage, synchronicity with food and entomophages is less important; however, at high temperatures, the semivoltine species (*Dendrolimus pini*) will become monovoltine [18].

For the survival of species that hibernate at the pupal stage and begin feeding on young foliage (*Panolis flammea*), their synchronization with food and entomophages is important, as well as the possibility of pupae drying out during their stay in the litter in the summer months [3].

Species of groups 1a and 3a complete development before the hibernating stage (egg and pupa, respectively) at a time depending on the beginning of spring development and the sum of temperatures.

In accordance with the photoperiodic reactions, the timing of the end of the feeding of the larvae of group 2, 3a and the autumn generation of the larvae of group 4 correspond to the date of the stable transition of air temperature through 15 ° C (D15au). The swarming of adults of the species of group 1a, hibernating at the egg stage, occurs approximately at D15au for *Neodiprion sertifer* and D5au for the *Operophtera brumata*. Since the dates of these phenomena are due to the photoperiodic reaction and depend on the latitude and longitude of the area, in the case of an increase in temperature, the success of phytophagous insect depends on the time of their adaptation. So, if the adult of *Neodiprion sertifer* lays eggs in the foliage with still active vegetating, the eggs can be flooded with resin. There is also a risk of larvae appear in autumn, which will not be able to survive.

It may be suggested, that the species that can increase the number of generations will increase them. Taking into account the possible indirect negative impact of high temperature on phytophagous insects, the proportion of species with semi-hidden and hidden lifestyles will increase.

These changes will affect the harmfulness of forest phytophages, which will increase with an increase in their voltinism, decrease with a decrease in the size and fertility of insects, and will also depend on the vulnerability of trees in arid conditions and anthropogenic load.

5. Conclusions

The adaptation of forest phytophagous insects to climate change can occur by

– accelerated development (development of additional generations);

– expanding the range of host plants;

– changing location of individual stages;

– spread to new territory.

Species that are monophages throughout their current range will remain monophages.

Species that now have more than one generation in the south of the range will be able to increase their number in other parts of it as it warms.

Changes in the timing and rate of development of phytophages will depend on the type of seasonal development, and the survival rate and harmfulness will depend on the synchronicity with the appearance of foliage and entomophages.

The harmfulness of phytophages will increase with an increase in their voltinism and with an increase in the vulnerability of trees under conditions of aridity and anthropogenic pressure and will decrease as a result of a decrease in the size of insects and their fertility during rapid development.

Wintering of individuals at stages that are not adapted to new combinations of temperature and photoperiod can also be negative results of climate change.

Acknowledgments: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Jactel, H., Koricheva, J., & Castagneyrol, B. (2019). Responses of forest insect pests to climate change: not so simple. *Current opinion in insect science* 2019, *35*, 103-108. https://doi.org/10.1016/j.cois.2019.07.010

2. Meshkova, V.L. *Seasonal development of foliage browsing insects*. Novoe slovo: Kharkov, Ukraine, 2009; pp. 1–396.

3. Mech, A.M, Tobin, P.C, Teskey, R.O, Rhea, J.R, Gandhi, K.J.K. Increases in summer temperatures decrease the survival of an invasive forest insect. *Biological Invasions* 2018, *20*, 365–374. https://doi.org/10.1007/s10530-017-1537-7

4. Rosenblatt, A.E. Shifts in plant nutrient content in combined warming and drought scenarios may alter reproductive fitness across trophic levels. *Oikos* 2018, *127*, 1853–1862. https://doi.org/10.1111/oik.05272

5. Lieutier, F., & Battisti, A. (Eds.). *Bark and wood boring insects in living trees in Europe: a synthesis.*. Kluwer Academic Publishers: Dordrecht, The Netherlands, 2004; pp. 1–569.

6. Tougeron, K. Diapause research in insects: historical review and recent work perspectives. *Entomologia Experimentalis et Applicata* 2019, *167*, 27–36. DOI: 10.1111/eea.12753

7. Shvidenko, A., Buksha, I., Krakovska, S. *Vulnerability of Ukrainian forests to climate change*. Nika-Centr, Kyiv, Ukraine, 2018; pp. 1–184 pp.

8. Meshkova, V. Dependency of outbreaks distribution from insects-defoliators' seasonal development. In *Proceedings--ecology, Survey, and Management of Forest Insects: Kraków, Poland, September 1-5, 2002* (No. 311). USDA Forest Service, Northeastern Research Station. McManus, M. L., & Liebhold, A. M. (Eds.), pp. 52–60.

9. Meshkova V. Phenological prediction of forest pest defoliators // Ecology, Survey and Management of Forest Insects. In *Proceedings--ecology, Survey, and Management of Forest Insects: Kraków, Poland, September 1-5, 2002* (No. 311). USDA Forest Service, Northeastern Research Station. McManus, M. L., & Liebhold, A. M. (Eds.), pp. 160–161.

10. Meshkova, V. L., Kochetova, A. I., Skrylnik, Yu. Ye., Zinchenko, O. V. Seasonal development of the timberman beetle *Acanthocinus aedilis* (Linnaeus, 1758) (Coleoptera: Cerambycidae) in the North-Eastern Steppe of Ukraine. *The Kharkov Entomol. Soc. Gaz*. 2017, *25 (2)*, 40–44. http://entomology.kharkiv.ua/index.php/KhESG/article/view/26

11. Meshkova, V. L., Kochetova, A. I., Zinchenko, O. V., Skrylnik, Yu. Ye. Biology of multivoltine bark beetles species (Coleoptera: Scolytinae) in the North-Eastern Steppe of the Ukraine. *The Bull. of kharkiv National Agrarian University. Ser. Phytopatology and Entomology* 2017, *1–2*, 117–124.
http://nbuv.gov.ua/UJRN/Vkhnau_ento_2017_1-2_20

12. Meshkova, V. L., Skrylnik, Yu. Ye., Zinchenko, O. V., Kochetova, A. I. Seasonal development of the pine sawyer beetle (*Monochamus galloprovincialis*) in the north-eastern steppe of Ukraine. *Forestry & Forest Melioration* 2017, *130*, 223–230. http://forestry-forestmelioration.org.ua/index.php/journal/article/view/102/90

13. Geri, C., Goussard, F. Incidence de la photophase et de la temperature sur la diapause de *Diprion pini* L. (Hym. Diprionidae). *J. Appl.Ent*. 1988, *106*, 150 – 172.

14. Gardner, J. L., Peters, A., Kearney, M. R., Joseph, L., & Heinsohn, R. Declining body size: a third universal response to warming? *Trends in ecology & evolution* 2011, *26*(6), 285-291. DOI: 10.1016/j.tree.2011.03.005

15. Lindén, A. Adaptive and nonadaptive changes in phenological synchrony. *Proceedings of the National Academy of Sciences* 2018, *115*, 5057–5059. https://doi.org/10.1073/pnas.1805698115

16. Damien, M., & Tougeron, K. Prey–predator phenological mismatch under climate change. *Current opinion in insect science* 2019, *35*, 60-68. https://doi.org/10.1016/j.cois.2019.07.002

17. Van Nouhuys, S, Lei, G Parasitoid-host metapopulation dynamics: the causes and consequences of phenological asynchrony. *Journal of Animal Ecology* 2004, *73*, 526–535. https://doi.org/10.1111/j.0021-8790.2004.00827.x

18. Geispits K.F. Photoperiodic and temperature reactions determining the seasonal development of *Dendrolimus pini* L. and *D. sibiricus* Tschetw. (Lepidoptera, Lasiocampidae). *Entomol. review.* 1965, *44 (3)*, 538–553.

19. Bakke, A. Ecological studies on bark beetles (Coleoptera: Scolytidae) associated with Scots pine (*Pinus sylvestris* L.) in Norway with particular reference to the influence of temperature. *Medd Nor Skogforsk*. 1968, *21*, 443–602.

20. Colombari, F., Battisti, A., Schroeder, L.M., Faccoli, M. Life-history traits promoting outbreaks of the pine bark beetle *Ips acuminatus* (Coleoptera: Curculionidae, Scolytinae) in the south-eastern Alps. *Eur J Forest Res*. 2012, *131*, 553–561. DOI: https://doi.org/10.1007/s10342-011-0528-y