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Article

Impact of Climate Change on Phenology of Entomophilous Plants and Honey Bee (*Apis mellifera* L.)

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Abstract: Changes in the dates of phenological phases of plants and insects reflect changes in climate. The aim of the study was to determine the phenological patterns and interrelationships of spring-flowering entomophilous plants (*Corylus avellana* L., *Alnus incana* Moench., *Tussilago farfara* L., *Salix caprea* L., *Acer platanoides* L., *Taraxacum officinale* L., *Prunus* L., *Malus domestica* Mill.) and the honey bee (*Apis mellifera* L.) in response to climate change. The research was carried out at Vokė Branch of the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, using data from phenological observations during 1961–2020. The results of the studies showed that over a 60-year period, a trend towards earlier dates of all phenological events studied was observed. Significant and larger-scale changes occurred starting from the decade 1981–1990. Throughout the entire study period, with the exception of one decade, the dates of honeybee emergence on flowers correlated reliably with the dates of entomophilous plant phenophases. Due to the advance of plants phenophase dates the synchrony with honeybee emergence dates changes however, these changes had a positive effect on the foraging conditions of overwintering honeybees.

Keywords: entomophilous plants; phenophases; honeybee; climate change

1. Introduction

For decades, climate change and the associated changes in the natural environment have been a major focus of attention worldwide. Plants are easily visible indicators of climate change, and a trend towards earlier dates of their developmental phases has been observed. Across European countries from mid to northern latitudes, 78% of cases of plant phenophases started earlier in spring period between 1971 and 2000 [1–3]. During the last decades of the last century, earlier dates of plant phenophase occurrence in spring were observed in most northern hemisphere countries (latitudes 30°N to 80°N) [2,4–7]. Advancement rates of phenophases in Europe ranged from 3 to 8.3 days per decade [8]. Since the 1980s, due to climate warming, plant phenophase occurrences have become earlier at -0.45 days per year [9]. Warming conditions affected the onset of flowering differently in different parts of Europe for different plants, however, in almost all cases the earlier onset of plant phenophases, especially in spring, was also associated with temperature changes [10–13].

There have also been notable changes in insect phenology, particularly in the honey bee (*Apis mellifera* L.), which is important in agricultural ecosystems for pollinating plants. Around 73% of the world's crops are pollinated by bees. And while the number of apiaries has increased by 45% in the last decade, the global bee population is declining due to the spread of bee diseases and changes in biodiversity caused by anthropogenic pressures [14–17].

In southern Europe, the emergence of honeybees on flowers was later until the mid-1970s [18]. It has been suggested that the emergence of honeybees depended on the temperature in February – April and that earlier emergence coincided with warmer springs. Trends in long-term observational data showed a strong correlation between the dates of honeybee emergence and temperature, suggesting that climate change is influencing the annual spring emergence of honeybees. In Central Europe, there has recently been increasing concern about the decline of pollinator species and phenological changes caused by rising temperatures, which could disrupt phenological synchrony between plants and pollinators [19].

In temperate climates, the onset of flowering of plants, especially entomophilous ones, and the emergence of honeybees on flowers in spring usually coincide. Increasingly warm winters associated with climate change may result in a mismatch between honeybee and plant phenology [15,20,21].

Aim of research: to determine the phenological patterns and interrelationships between spring-flowering entomophilous plants and honeybees in response to climate change.

2. Results

According to average data for the period 1961–2020, the earliest flowering dates in Lithuania were at the end of March for common hazel and grey alder. For other entomophilous plants studied, flowering started in April (coltsfoot, goat willow and Norway maple) at regular intervals (early, mid and late in the month), or in May until the middle of the month (common dandelion, European plum and apple tree). The evolution of flowering start dates of the plants studied for each decade over a period of 60 years is shown in the results presented in Table 1 (Table 1).

Table 1. Variation in mean dates of flowering onset of entomophilous plants.

Plants	Periods						
	1961–1970	1971–1980	1981–1990	1991–2000	2001–2010	2011–2020	1961–2020
Common hazel	04.05±4* 14.3**	03.28±3 10.9	03.24±7 27.5	03.16±5 21.9	03.22±5 20.8	03.17±7 27.5	03.24±2 21.5
Grey alder	04.05±4 13.7	03.29±3 11.5	03.26±7 26.6	03.18±5 18.7	03.23±5 19.1	03.18±6 25.0	03.25±2 20.1
Coltsfoot	04.11±3 8.3	04.05±3 9.4	04.01±4 13.7	04.04±2 7.3	04.03±2 7.5	03.30±3 11.8	04.04±1 10.2
Goat willow	04.20±3 8.1	04.16±3 8.1	04.14±4 11.7	04.12±1 4.4	04.08±2 7.8	04.05±4 11.9	04.12±1 9.9
Norway maple	05.04±2 4.4	05.05±1 3.2	04.29±3 9.0	04.28±2 4.6	04.25±2 5.3	04.24±2 4.5	04.29±1 6.2
Common dandelion	05.05±2 4.3	05.06±2 4.5	05.03±3 7.4	05.02±2 5.6	04.30±1 3.7	04.27±2 4.9	05.02±1 5.6
European plum	05.11±2 4.4	05.13±2 4.3	05.07±3 7.1	05.05±2 5.1	05.03±2 4.6	04.29±2 5.5	05.06±1 6.2
Apple tree	05.18±2 4.7	05.19±2 3.9	05.14±2 5.5	05.12±2 4.9	05.10±2 3.9	05.07±2 4.2	05.13±1 5.5

Note: * – standard error in the numerator ± SE, ** – in the denominator the coefficient of variation CV, %.

The results show that during the first decade of the study, the earliest plant phenophases occurred at the beginning of the first ten-day period of April and the latest – at the end of the second ten-day period of May. During the following ten-day period, there was advancement in the dates of phenophases of the plants that flowered in April (4 – 9 days). In contrast, the phenophase onset dates of May-flowering plants became later by 1 to 2 days. For these plants, increased earliness of the phenophase onset dates (5 to 7 days) was observed in the period from 1981 to 1990. Moreover, as shown by the values of coefficients of variation, the variation in phenophase onset dates for all plant species in that decade was greater than that of other decades. It was found that until 2000, irrespective of the variation in the mean dates of phenophase occurrence (early or late), there was advancement in the dates of phenophase occurrence during the four decades, with the following increases in earliness of the dates of phenophase occurrence: for common hazel -20 days, and for grey alder -18 days. The dates for early flowering of coltsfoot, goat willow, Norway maple and European plum were advanced by almost a week (6 – 8 days) during that period. There was a smaller change (-3 days) in the phenophases dates for common dandelion. In the last two decades, the dates of

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occurrence of plant phenophases have been both later and earlier compared to the average dates of 1991–2000. The average data for the last decade shows that flowering started in March for even three plant species (common hazel, grey alder and coltsfoot). For most of other plant species, flowering started in April, however, the intervals between phenophase dates of the plants that flowered in the same month changed. Particularly large changes in phenophase dates were observed when comparing the average data for the first and last decades of the survey. It can be observed that between 1961 and 1970, 4 plant species flowered in May, while between 2011 and 2020, only one plant species flowered.

The rapid advance in the dates of occurrence of entomophilous plant phenophases from the decade 1981–1990 was confirmed by statistical evaluation of the data. It is from that decade onwards that the most negative values of change were found (Table 2). It should be noted that during the following two decades the magnitude of advancement of the phenophase dates decreased and even for some plant species (common hazel, European plum, apple tree) shifted to a delayed pattern. However, a similar degree of advancement of phenophase dates reappeared in the last decade.

Table 2. Variation in mean dates of flowering onset of entomophilous plants.

Plants	Slope of different periods						
	1961–1970	1971–1980	1981–1990	1991–2000	2001–2010	2011–2020	1961–2020
Common hazel	1.15	1.87	-4.63	-1.32	0.42	-4.56	-0.36
Grey alder	1.35	1.24	-4.55	-1.12	-0.02	-3.74	-0.35
Coltsfoot	1.02	1.47	-1.45	0.48	-0.10	-1.84	-0.17
Goat willow	1.98	1.58	-1.70	-0.33	-0.21	-2.21	-0.29
Norway maple	0.81	0.87	-2.16	-0.64	-0.27	-1.02	-0.22
Common dandelion	0.51	1.42	-1.64	-1.15	-0.17	-0.78	-0.17
European plum	0.24	1.39	-1.80	-1.14	0.01	-1.26	-0.26
Apple tree	0.0	1.05	-1.33	-1.14	0.28	-0.41	-0.25

The onset of entomophilous plant flowering is of great ecological importance as a food source for insects, especially honeybees, which start to fly and feed after winter. Based on average data over a 60-year period, honeybees emerged on flowers in Lithuania on 4 April (Table 3). During the first research decade, the latest honeybee emergence was at the end of the first ten-day period. In the following decades, the dates of honeybee emergence became earlier and close to the long-term average. It should be noted that from 1981 to 1990 the variation in the dates of honeybee emergence on flowers, and the direction and magnitude of their variation increased. It is from that decade onwards that the trend towards earlier dates of honeybee emergence on flowers was established. More significant changes occurred between 1981 and 1990 and between 2011 and 2020 (Table 3).

Table 3. Variation in average dates of honeybee emergence on flowers over a 60-year period.

Periods	Average date	±SE	CV, %	Slope
1961 – 1970	04.10	2.8	8.9	1.23
1971 – 1980	04.04	2.6	8.6	1.52
1981 – 1990	04.03	3.6	12.3	-1.86
1991 – 2000	04.04	3.2	10.8	-0.06
2001 – 2010	04.01	2.7	9.5	-0.22
2011 – 2020	04.04	3.3	11.2	-1.96
1961 – 2020	04.04	1.2	10.2	-0.10

The honeybee emergence was influenced by changes in ambient temperature. In the 1961–2020 study period, the dates of honeybee emergence were most strongly influenced by the average temperature in March, although weak and moderate correlations were also found with earlier months (Table 4). However, the average temperatures in February and March determined the timing of honeybee emergence by 53–86% in the three previous decades, from 1961 to 1990. The correlation coefficients obtained confirmed strong correlations. Strong correlations with the average temperature in April were found only in the decade 1961 to 1970. It should be noted that during the last two decades (2001–2020) the average temperatures in March had the greatest influence on the of honeybee emergence.

Table 4. Correlation coefficients between monthly mean temperature and dates of honeybee emergence on flowers.

Periods	Coefficient of correlation r of different periods and months			
	January	February	March	April
1961–1970	-0.36	-0.93**	-0.73*	-0.70*
1971–1980	-0.60	-0.76**	-0.79**	-0.45
1981–1990	-0.51	-0.77**	-0.77**	-0.57
1991–2000	0.03	-0.13	-0.41	0.51
2001–2010	-0.37	-0.41	-0.89**	-0.23
2011–2020	-0.40	-0.52	-0.73*	-0.33
1961–2020	-0.41**	-0.59**	-0.71**	-0.22

Note: significant values with – *p < 0.05 and **p < 0.01.

The dates of the honeybee emergence were correlated with the dates of the phenophase onset of entomophilous plants flowering in spring, and correlations between those phenological phenomena were established. The results showed that, for the period 1961–2020, the dates of the honeybee emergence were strongly correlated with the dates of the flowering start of common hazel, grey alder, coltsfoot and goat willow. The correlation coefficients between the dates of honeybee appearance on flowers and the dates of the phenophase start of those 4 plant species were r = 0.74**–0.81** (Table 5). In addition, the dates of the onset of honeybee emergence were also correlated with the phenophase dates of entomophilous plants that subsequently bloomed, however, the correlation coefficients showed moderate correlation relationships.

Table 5. Correlation coefficients between dates of honeybee emergence and onset of plant flowering.

Plants	Coefficient of correlation r of different periods						
	1961–1970	1971–1980	1981–1990	1991–2000	2001–2010	2011–2020	1961–2020
Common hazel	0.96**	0.91**	0.90**	0.33	0.69*	0.85**	0.75**
Grey alder	0.95**	0.75*	0.89**	0.37	0.72*	0.83**	0.74**
Coltsfoot	0.93**	0.87**	0.94**	0.51	0.77**	0.86**	0.81**
Goat willow	0.94**	0.87**	0.92**	0.16	0.91**	0.92**	0.78**
Norway maple	0.84**	0.83**	0.81**	-0.50	0.81**	0.94**	0.58**
Common dandelion	0.79**	0.67*	0.86**	0.31	0.81**	0.86**	0.56**
European plum	0.82**	0.78**	0.80**	-0.53	0.55	0.85**	0.50**
Apple tree	0.72*	0.60	0.73*	-0.46	0.40	0.63*	0.41**

Note: significant values with – *p < 0.05 and **p < 0.01.

3. Discussion

The life of honeybees is closely linked to their environment. The colony activity, anatomy and physiological functions of individual bees depend on environmental conditions. The annual life cycle of honeybee colonies is divided into two periods: an active period (from swarming to forming winter clusters) and a passive period during winter [22]. The first emergence of honeybees on flowers in spring marks the beginning of their active period. During the active period, a honeybee colony consists of three types of individuals: drones, worker bees, the queen and brood in different stages of

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development [22,23]. Each of the three individuals has its own specialisation and place in the community. Worker bees have a short summer life span of about a month. However, overwintering worker bees live until spring. In spring, worker bees produce a new generation of bees within a month, age physiologically and die. It is important for overwintering worker bees that their period of activity, which lasts for about a month until a new generation of bees develops, coincides with the flowering of entomophilous plants, as this ensures a source of food.

The importance of plant communities for bee nutrition varies due to differences in floristic composition and flowering phenology [24]. The most important are plant communities ensuring that bees forage throughout the season [25].

In the territory of Lithuania, honeybees emerge on flowers from 1 to 10 April (average 4 April). The average data for the years 1961–2020 show that honeybees emerged on flowers in spring at the same time as several plant species were flowering: the pollen-bearing common hazel and grey alder, and the nectar-bearing coltsfoot. When the flowering periods of different plants overlap honeybees are more likely to visit nectar-bearing plants than pollen-bearing ones [26]. Therefore, coltsfoot has complemented honeybee ability to feed on nectar. However, this herbaceous plant grows in small groups and is less important as a food source compared to other nectar-bearing plant species. The second and third weeks of honeybee active life coincided with goat willow flowering. Goat willow produces a very large number of flowers, which are concentrated in one place, and the flowering period lasts about two to three weeks. Although there are no massive stands of goat willow in Lithuania, it is a common plant near farmsteads, in woodlands and parks. Goat willow belongs to the *Salicaceae* family, which consists of a very large number of plant species that are widespread in Lithuania and bloom at similar times and intervals, which is why the flowering period of all willow family trees lasts more than a month. We believe that this flowering sequence was sufficient for honeybees to strengthen and successfully raise brood. Plant species belonging to the willow family are also highly productive in other regions of Europe at the beginning of the spring season [24]. In Lithuania, Norway maple and common dandelion started flowering in the fourth week of honeybee flight. According to long-term averages, the life cycle of honeybees, which were active for four weeks in spring providing pollen and nectar to the colony, ended before the flowering of orchards (apple orchards are common in Lithuania).

Climate change over a 60-year period has altered the patterns of phenophase occurrence in many plant species. In our climate zone, common hazel and grey alder are the earliest to flower, but due to an unstable thermal regime during the winter period, the year-to-year variation in their phenophase dates was very high (CV>20 %). Our previous studies showed that the thermal regime of February ($r = -0.76$–(-0.84)) and March ($r = -0.63$–(-0.79)) had greater influence on the annual variation of flowering onset dates in common hazel [27].

Studies in various European countries have shown that the onset of flowering in spring was up to 70% dependent on changes in air temperature for most plant species [6,28,29]. For the Baltic States, the dates of early spring flowering phenophases were strongly correlated with the mean air temperatures of the preceding months: the dates of phenophases of plants occurring in March were strongly correlated with the mean temperature of February, and those of plants flowering in May were strongly correlated with the mean temperature of April [6]. In Lithuania, it was found that the onset of deciduous tree vegetation was mainly influenced by late winter and early spring (February – April) temperatures [11,13].

Warmer winter seasons led to changes in the rate of resumption of perennial plant growth (trees and shrubs). According to Jochner et al. (2016), the response of plant phenophases to mean temperature ranged from -7.7 to -2.7 days $^{\circ}C^{-1}$ in spring in 22 European countries between 1951 and 2012 [30]. Climate change is increasingly considered as an additional threat to bees by many scientists [15,17]. Environmental temperature determines bee activity, therefore, climate change characterised by increased temperatures can significantly affect bee biology, behaviour and distribution. A study in Poznan, Poland, found that the first emergence of bees was not only due to higher winter/spring temperatures, but also to higher temperatures in the previous summer and autumn [15]. Langowska found that the spring phenology of bees showed a strong negative relationship with temperature, but generally did not change over time [19]. The results of our study showed that in the last decade, the extent of the advancement of honeybee emergence on flowers was high (-1.96 days per year) and almost analogous to the results for the period 1981–1990. It should be noted that until the 1980s, there were trends in the delayed emergence of honeybees on flowers. During the same research period, temperatures in February and March accounted for 53 to 86% of honeybee emergence on flowers. However, for the last two decades, the emergence of honeybees on flowers were only statistically significantly influenced by the thermal regime of March. Indirectly, climate change affects bees through food resources. The differential response of these insects and plants to changes in temperature is thought to cause discrepancies with serious consequences. Asynchrony can negatively affect plants through reduced bee visitation and food shortages for bees [17].

In Central Europe, 31 plant species showed earlier phenophases of -0.45 days per year between 1982 and 2011 [9]. Other studies have shown that the maximum advancement occurred between 1978 and 2007, with stronger negative trends for plant species flowering in early spring, however, weaker trends for non-woody insect-pollinated species. Those trends were associated with winter and spring warming [3].

In Lithuania, the advancement of plant phenophases has been observed since 1981–1990. The magnitude of annual changes in plant phenophases changed significantly during the last decade. Notably, the annual changes in phenophase dates of the plants that start flowering in March (common hazel and grey alder) were the largest. Phenophase dates of the plants that started flowering before mid-April (coltsfoot and goat willow) were becoming earlier to a lesser extent, however, also significantly. The magnitude of the year-to-year changes in the phenophase dates of plants flowering in late April or May shows lower rates of advancement (Norway maple and European plum) and a tendency towards delay (common dandelion and apple tree).

Correlations between the dates of honeybee and plant phenophases showed that the synchrony between them was disrupted in the following decade, 1991–2000, due to the changes that occurred between 1981 and 1990. The results showed weakening of the correlations. However, in the following decades, the correlations between plant flowering and the start of honeybee flight were again strong and statistically significant. This suggests that honeybees have adapted to the changed conditions.

During the last decade (2011–2020), honeybees emerged on flowers when four entomophilous plants were flowering. This indicates that there was sufficient food for honeybees to fly and forage after winter. Under such conditions, honeybees expended less energy searching for nectar and pollen and more time was left for collecting it. The most important early spring plants for early spring honey collecting are various woody plants that bloom early. Our research has shown that during the last decade in Lithuania, the emergence of honeybees on flowers is associated with the flowering of common hazel, grey alder, coltsfoot and goat willow. In addition, this decade has seen the flowering of Norway maple during the third week of honeybees' active life, which, judging from multi-year dates, previously flowered only in the fourth week of honeybees' active life. Similarly, during the last decade, plum trees have started to flower in the fourth week of honeybees' active life, i.e. with the beginning of orchard blossom. The results of our study suggest that the changes in climate have favoured overwintering honeybees, which are producing a new generation of bees. These changes, due to the earlier start of spring honey collecting, resulted in a timely food supply and have had a positive impact on the strengthening of colonies. The trends found have shown that the new generation of spring worker bees has a better chance of collecting nectar from a larger number of flowering entomophilous plants.

4. Materials and Methods

The research was carried out at Vokė Branch of the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, using archival data from phenological observations carried out in Lithuania in the period 1961–2020. The flowering onset dates (BBCH61) of the following phenological events: common hazel (*Corylus avellana* L.), grey alder (*Alnus incana* Moench), coltsfoot (*Tussilago farfara* L.), goat willow (*Salix caprea* L.), Norway maple (*Acer platanoides* L.), common dandelion (*Taraxacum officinale* L.), European plum (*Prunus* L.), apple tree (*Malus* Mill.) and the emergence of honey bees (*Apis mellifera* L.) on flowers were recorded at 5 sites: Trakų Vokė (54º63'N, 25º10'E), Akademija (55º40'N, 23º87'E), Šilutė (55º35'N, 21º48'E), Joniškėlis (56º03'N, 24º17'E), and Keturvalakiai (54º55'N, 23º15'E).

Phenological observations in each locality were carried out on the area 3–4 km in diameter (in parks, woods or near homesteads where plants grow under natural conditions), typical of the relief, soil and vegetation of that area. Observations were carried out daily in early spring and every other day thereafter. The onset of phenophase was recorded when 10% of plant flowers had reached the described developmental stage.

The study used 2700 dates of phenological events, which were transformed into the number of days since the beginning of the year. A qualitative assessment of the phenophase dates was carried out by comparing the synchrony of the data for each year of observations. In this way, phenological data differing from those of the nearest stations by more than 1 month were excluded from the calculations.

The data and its reliability were assessed using the methods recommended for phenological studies [6,7]. The phenological data was statistically evaluated by calculating the mean standard error (±SE), coefficient of variation (CV, %), and the year-to-year changes in the dates of occurrence of phenophases (SLOPE, d y^{-1}) were determined applying the regression method using the Excel software package.

5. Conclusions

Climate change in the period 1961–2020 brought the occurrence dates of phenophases of all plants studied earlier by 3 to 12 days, and the date of emergence of honeybees by 6 days. The trend in advancement has been witnessed since the 1980s.

Major changes in phenophase dates (8–20 days) with more variation and high levels of advancement occurred between 2011 and 2020. The dates of the spring season onset events were found to have the highest levels of advancement.

The variation in the dates of honeybee emergence on flowers was lower than that for plant phenophases, however, the periods of significant changes overlapped.

The dates of honeybee emergence on flowers were found to correlate strongly and significantly with the dates of plant phenophases in all periods except 1991–2000. Due to the changes brought about by climate change, the synchrony between plant phenophases and the dates of honeybee emergence on flowers was lost for a temporary period of time (one decade).

The correlation between the phenological events studied showed that in the period 2011–2020 the appearance of honeybees on flowers coincided with the flowering of 4 entomophilous plants. However, for all entomophilous plants, earlier flowering was also favourable for overwintering honeybees due to the abundance of food for a month.

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