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Research Article

The phenological stages of forestry species under the impact of climate change• Early data

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Abstract

Urban areas have a dual role in climate change· they are major contributors to climate change as they produce more than 70 percent of greenhouse gas emissions and they also accept the impact of it. Urban trees have great value in urban ecosystems because of their role as carbon sinks, so they contribute to climate change mitigation. The aim of this paper is to collect data about the impact of climate change on forestry species in urban areas via the science of phenology. In recent years, via phenology, the observation and study of the effects of climate change are possible, as there appears to be a shift in the start of biological events, and also a change in their duration. These changes in the seasonal activity of plants, from time to time, are a sensitive but perfectly visible indicator of changes in the functioning of ecosystems. Phenology refers to the recording of dates in which different phases of the plant's life cycle such as budburst, flowering, dormancy, and hibernation have been observed both in species and in plant communities. Temperature, solar radiation, and water availability are the three factors that affect plant phenology. To appreciate the impact of climate change on the phenological stages of forestry species, three Phenological Monitoring Areas (PMA) were created in three urban spaces in Thessaloniki, in December 2020, within the framework of the project LIFE CliVut (Climate Value of Urban Trees) LIFE18 GIC/IT/001217. Each PMA contains 20 species (10 species of trees and 10 species of shrubs), and 100 individuals (5 individuals per species). The monitoring of the phenological stages of the forestry species was carried out throughout a year on a weekly basis according to the protocol that was created in the frame of the project taking into consideration the BBCH scale.

Introduction

Phenology is the study of the temporal occurrence of biological events that repeat each year, the occurrence of which depends on biotic and abiotic factors [1,2]. Plant phenology refers to the recording of dates when different phases of the plant life cycle are observed both in specific species and in plant communities. Phenological stages depend on genetic factors but environmental factors such as temperature and humidity affect the beginning and the end of each phase [3,4]. Extensive urbanization affects the temperature of urban areas and consequently, phenology. As for urbanization, has been estimated that above half of the world's population who live in urban regions will be twice as large by 2030 as the corresponding rural [5-7]. Also, one of the biggest problems that humanity has to face is climate change. Climate change affects bioclimatic conditions during the growing period of trees. Also, it affects the phenological stages such as the beginning and the end of flowering [8,9]. Temperature is the major abiotic factor that affects phenology [10]. So, global warming is increasingly disrupting the phenological phases [11,10]. The time of leaf development, the time of the beginning of flowering, the time of development of fruit, and the time of leaf fall consist of the main observations of the plant in the frame of phenology [12]. These changes can be easily observed [13]. The recording of the start date of phenological stages and relating them to temperature play an important role in plant phenology study. The early start of leaf development and the

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early start of flowering in areas of medium and high latitudes can be characterized as a result of anthropogenic intervention in the climate and the high temperatures. Results of these phenological phases arise mainly from observations and also from satellite images [14]. The changes in phenological phases of the forest species are the most characteristic indicators of the response of organisms to climate change [15]. Various studies highlight the important role of forest phenology as one of the most important biomarkers to study the direct impact of global warming on different species at a temporal and spatial scale [16]. Temperature regulates the phenological phases. For example, the emergence of new leaves and the end of the leafing season are affected by environmental temperature [13]. The sensitivity of phenology to temperature changes makes it an indicator of vegetation response to environmental changes and can be used to monitor the effects of climate change globally [17,18]. Higher temperatures in late winter and early spring promote the early leaf development and flowering of plants. Many observations and investigations prove the shifting of phenological events in response to climate change in different regions. Menzel and Fabian in 1999, described the lengthening of the growing season in Europe. The leaf development is particularly sensitive to temperature [19]. It has been scientifically documented that the phenological phases, such as flowering or leafing, are closely related to air temperature [20]. As warmer temperatures affect the phenological events, the phenological data reflect the biological response to this feature of climate change [21].

The monitoring of the phenological stages of species offers many benefits. Firstly, phenology is an indicator to detect climate variability and climate change. As for urban areas, they host a rich and varied flora and can offer suitable habitats for many animal species, contributing to biodiversity conservation. Phenology contributes to the correct choice of species, to the control of diseases of species, to predict when to plant the best plants for bees and other pollinators, to manage insect pests, and to designing shelters for beneficial insects in an urban green area. So, the main aim of this study is to collect data about the impact of climate change on forestry species in urban areas via the science of phenology as there is no data for all forest species till now. Also, the study contributes to the understanding of the response to high temperatures of species in Mediterranean ecosystems.

Materials and methods

Three Phenological Monitoring Areas (PMAs) were created in three urban spaces in Thessaloniki, on December 2020, within the framework of the project LIFE CliVut (Climate Value of Urban Trees) LIFE18 GIC/IT/001217. One in the industrial area TITAN, one in the School of Forestry, and the last one in the American Farm School. Each PMA contains 20 species (10 species of trees and 10 species of shrubs), and 100 individuals (5 individuals per species). The forest species are presented below Table 1.

The planting arrangement of individuals depended on the shape and size of the area facilities. Trees were planted at a distance of 5m from each other while shrubs were planted at a distance of 4m. The phenological stages of the plants were studied from March to December 2021 and continue to be studied till now.

For each individual, observations on the date of sample collection, leaf development, flower development, development of fruit, and leaf fall were recorded.

The monitoring of the phenological stages of the forestry species was carried out throughout a year on a weekly basis according to the protocol that was created in the frame of the project taking into consideration the BBCH scale. The BBCH scale was used to present the phenological stages [22,23].

The Global Phenological Monitoring Network has introduced the BBCH scale as a standard system for describing the phenological stages of plant development [24]. The decimal code, which is divided into principal and secondary growth stages, is based on the well-known cereal code developed by Zadoks, et al. [25] Table 2.

Especially, the phenophases according to the BBCH scale are described below.

Principal growth stage 1: Leaf development

BBCH11: Leaf unfolding (First leaves visible and unfolded): Looking at a singular plant we would notice at least 10% of the leaves as unfolded.

BBCH19: First adult leaf: Looking at a singular plant we would notice that 90% of the leaves have reached complete morphological development (adult leaf).

Table 1: Trees and Shrubs species in the three PMAs areas.

Species			
Trees		Shrubs	
Acer campestre	*Carpinus betulus*	*Spartium junceum*	*Phillyrea latifolia*
Tilia cordata	*Sorbus domestica*	*Euonymus europaeus*	*Salix caprea*
Quercus pubescnens	*Alnus glutinosa*	*Berberis vulgaris*	*Cornus sanguinea*
Quercus ilex	*Fraxinus angustifolia*	*Corylus avellana*	*Ligustrum vulgare*
Prunus avium	*Populus canescens*	*Sambucus nigra*	*Punica granatum*

Table 2: Stage Description-Code.

Stage Description	Code
Germination/sprouting/bud development	0
Leaf development	1
Formation of side shoots	2
Stem elongation or rosette growth	3
Development of harvestable vegetative plant parts	4
Inflorescence emergence	5
Flowering	6
Development of fruit	7
Ripening or maturity of fruit and seed	8
Senescence, beginning of dormancy	9

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Principal growth stage 9: Senescence

BBCH93: Leaf senescence: Looking at a singular plant we would notice the first fallen leaves (senescence).

Reproductive pheno-phases

Principal growth stage 6: Flowering

BBCH61: Flowering beginning: Looking at a singular plant we would notice at least 10% of the flowers as open with evidence of anthers releasing pollen.

BBCH65: Full Flowering: Looking at a singular plant we would notice at least 50% of the flowers as open with evidence of anthers releasing pollen.

BBCH85: Advanced ripening: increase in the intensity of cultivar-specific color: Looking at a singular plant we would notice the majority (>50%) of the fruits increasing their specific fruit color.

Results

Table 3.

Discussion-Conclusion

In this research, the contribution of phenology to the investigation of the effects of climate change was investigated via the weekly observations carried out in the 3 PMAs that were created in Greece and specifically in Thessaloniki through the LIFE CLIVUT program.

Leaf development, senescence, flowering, and ripening fruit of the ten (10) tree species and the ten (10) shrub species were observed. In each PMA, if at least 3 plants show the same specific phenological phase, that phase will be attributed to the species. The measurements started in the spring of 2021 and it is still too early to extract general conclusions. So, the first observations are presented and they will be continued to understand the effects of climate change on species and general ecosystems.

In general, as for the stage of leaf development, *Acer campestre*, *Alnus glutinosa*, and *Quercus ilex* developed their leaves about a month earlier. *Prunus avium* developed its leaves earlier about two months. The species *Fraxinus angustifolia* and *Populus canescens* developed their leaves later than usual.

Table 3: First data of trees in the three PMAs.

Species	School of Forestry			American Farm School			TITAN		
Trees	Leaf development (BBCH11)	Flowering (BBCH61)	Dormancy (BBCH93)	Leaf development (BBCH11)	Flowering (BBCH61)	Dormancy (BBCH93)	Leaf development (BBCH11)	Flowering (BBCH61)	Dormancy (BBCH93)
Prunus avium	29/03/21		13/10/21	20/05/21		09/08/21	30/03/21		12/05/21
Populus canescens	17/05/21		01/11/2021	06/04/21		09/11/2021	12/04/21		27/10/2021
Fraxinus Angustifolia	28/06/21		09/11/21	26/04/21		01/09/21	31/05/2021		21/06/21
Acer campestre	29/03/2021		09/11/2021	30/03/2021		24/08/2021	12/04/2021		24/05/2021
Carpinus betulus	17/05/2021		01/11/2021	24/05/2021		19/10/2021	24/05/2021		01/09/2021
Quercus ilex	29/03/2021			30/03/2021			30/03/2021		07/10/2021
Tilia cordata	06/05/2021		21/10/21	12/05/2021		17/08/21	20/04/2021		31/05/2021
Quercus pubescens	12/04/2021		06/12/2021	20/04/2021			12/04/2021		24/05/2021
Alnus glutinosa	29/03/2021		09/11/2021	30/03/2021		01/09/2021	30/03/2021		21/06/2021
Sorbus domestica	17/05/2021		21/11/2021	30/03/2021		22/09/2021	20/04/2021		24/08/2021
Punica granatum	28/07/21	28/07/21	09/11/2021	24/05/21		21/06/21	01/09/21		23/11/2021
Spartium junceum	28/06/21	28/06/21	21/11/2021	31/05/21		31/05/21	31/05/21	31/05/21	13/10/2021
Cornus sanuinea	29/03/2021	06/05/2021	27/10/2021	30/03/2021	12/05/2021	29/11/2021	30/03/2021		31/05/2021
Salix caprea	12/04/2021		09/11/2021	12/05/2021		09/11/2021	30/03/2021		12/04/2021
Berberis vulgaris	06/05/2021		09/11/2021	20/04/2021	20/04/2021	22/09/2021	20/04/2021	26/04/2021	08/09/2021
Ligustrum vulgare	28/06/2021		06/12/2021	14/06/2021		28/12/2021	24/05/2021		
Phyllirea latifolia	29/03/2021	06/05/2021			30/03/2021		30/03/2021		
Coryllus avellana	05/04/201		21/11/2021	20/04/2021		23/11/2021	30/03/2021		31/05/2021
Sambucus nigra	29/03/2021	12/04/2021	01/11/2021	30/03/2021	20/04/2021	09/11/2021	30/03/2021	06/04/2021	24/05/2021
Euonymus europaeus	06/05/2021	06/05/2021	21/11/2021	12/05/2021		22/09/2021	20/04/2021	26/04/2021	21/10/2021

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The other species of trees developed their leaves according to the data up to now. *Salix caprea*, *Spartium junceum*, and *Punica granatum* developed their leaves earlier. The other species of shrubs developed their leaves according to the already existing bibliography.

Changes were observed among the same species in the three regions due to the high temperatures in combination with the prevailing conditions. *Prunus avium*, *Fraxinus angustifolia*, and *Sorbus domestica* developed their leaves at different times in the three PMAs. Also, *Punica granatum Spartium junceum*, *Salix caprea, and Ligustrum vulgare* developed their leaves at different times. Most species did not develop flowers or fruits due to their young age.

Schieber, et al. [26] studied the phenology of four deciduous forest tree species (*Carpinus betulus L.*, *Fagus sylvatica L.*, *Quercus dalechampii Ten.*, *Tilia cordata Mill.*) in a beech forest stand in central Slovakia over a period of 13 years. They observed a significant correlation between the timing of leaf unfolding and air temperature. Also, Bauer, et al. 2014 [27] observed an early onset (about 6-8 days) of both phenophases in *Carpinus betulus*, *Acer campestre*, *Fraxinus angustifolia*, *Quercus robur*, *Ulmus laevis*.

Climate change is creating phenological mismatches between consumers and their resources [28]. Insects, such as caterpillars move faster than insectivorous birds breeding. In consequence, food requirements are out of sync with insect availability. Migratory species are particularly likely to experience phenological mismatches because they rely on indirect information from migration sites and waypoints [29].

The monitoring of the phenological phases by year, the creation of time series of data, and the correlation of these with various abiotic factors, as well as their use in forecasting models of phenological phases will contribute to the understanding of the effects of climate change on species and generally to the ecosystem.

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