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An Analysis of Temperate Deciduous Shrub Phenology in Downer Woods, University of Wisconsin-Milwaukee, Wisconsin, USA

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AN ANALYSIS OF TEMPERATE DECIDUOUS SHRUB PHENOLOGY IN DOWNER WOODS, UNIVERSITY OF WISCONSIN-MILWAUKEE, WISCONSIN, USA

by

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ABSTRACT

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Under the Supervision of Professor Alison Donnelly

Shrub species, both native and non-native, are an important component of temperate deciduous forest ecosystems but are an often-overlooked and under-studied functional group. Shrubs tend to leaf-out earlier than trees in spring and retain their leaves later in autumn thus extending the overall growing season and the carbon uptake period of the forest ecosystem. In this study, a range of 5- native and 3- non-native shrub species were identified in a deciduous urban woodlot, and the phenology was monitored over a 3-year period on the University of Wisconsin-Milwaukee campus. The aim of this work was to determine any variation in the timing (DOY) and duration (days) of key spring (bud-open, leaf-out, full-leaf unfolded) and autumn (leaf color, leaf fall) phenophases between native and non-native species. Preliminary results revealed interesting findings with buckthorn *Rhamnus cathartica* (an alien invasive/non-native species) consistently leafing out later than most native species and taking longer to reach full-leaf unfolded. Additionally, non-native species such as European privet *Lingustrum vulgare* have a longer growing season than native species ranging from 14 days to 35 days longer in non-native species than native species across the three-year period. This shows how non-native species can lengthen the fall season compared to native species. These results could add to the understanding of how non-native shrub species may gain a competitive advantage over native shrubs and may help inform future conservation management plans.

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1. Introduction

Temperate deciduous forest ecosystems encompass a great amount of area and biodiversity across the world today. These forests extend across roughly 304 million hectares of land which is about 1/3 of all land area in the United States (Figure 1) (McKinley et al. 2011). While forests are not only habitat to plant, animal, and insect species across the world, temperate deciduous forests also acts as a carbon sink sequestering CO_2 from the atmosphere and storing it in biomass (Yu 2013, Donnelly & Yu 2019). When looking at the way the earth and ecosystems within the earth interact, there are many important roles temperate deciduous forests play in ecosystem structure and environmental health contributing to services such as nutrient cycling and ecosystem productivity (Fridley 2012).

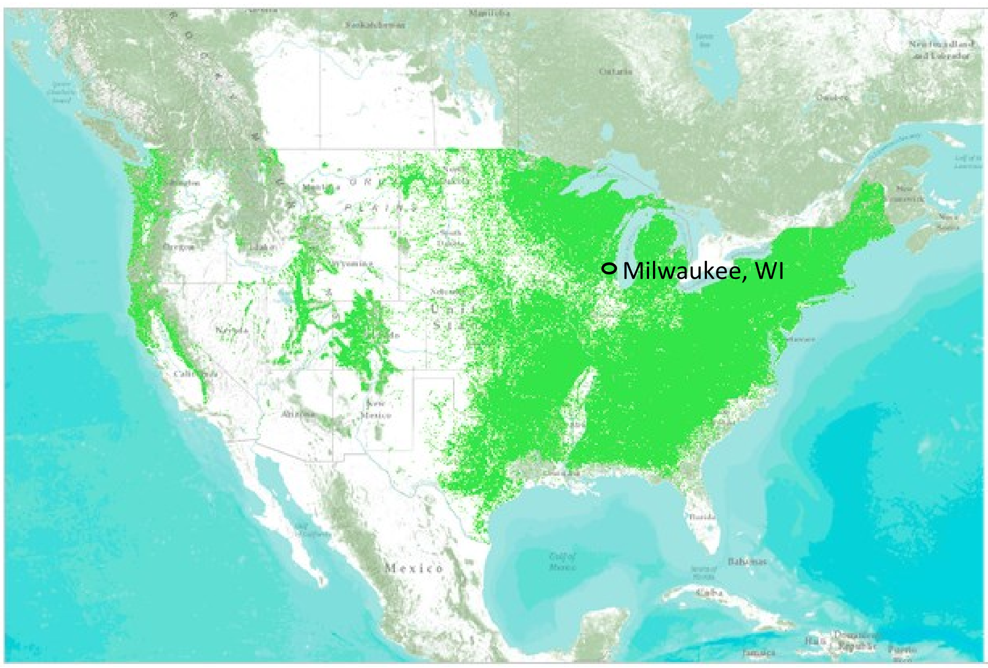


Figure 1: Deciduous forest cover within the contiguous United States. Retrieved from National Land Cover Database.

There are generally three levels to a deciduous forest: the top layer or canopy which encompasses the tall, deciduous trees, the understory, where the shrubs are located, and then the bottom layer or forest floor, including mosses, small herb and flower species. Temperate deciduous forests include different species of trees such as maple, oak, and birch trees. Trees hold the majority of biomass within forest ecosystems which is one of the reasons trees are most commonly studied than other ecosystem vegetation (Gill et al. 2015; Huff et al. 2018). While trees are at the forefront of studying ecosystems, another important group of plants is shrubs.

Shrubs also play an important role in carbon sequestration and ecosystem function (Huff et al. 2018) but are often overlooked and under-researched in temperate many forest ecosystems. Shrubs, distinguished in this research, are small/medium plants typically associated with having many woody-stems as opposed to one main trunk that a tree would have. Shrubs also play an important role in forest ecosystems by providing food and habitat for other species as well as sequestering carbon dioxide (CO_2) from the atmosphere, similarly to trees (Keenan et al. 2014). Key components to understanding shrub function within the biosphere include shrub influence on the carbon budget and shrub phenology.

Phenology refers to the study of the timing of life-cycles of living organisms in relation to temperature, day length, and other meteorological parameters (Lieth 1973). In an assessment report published by the Intergovernmental Panel on Climate Change, (IPCC) phenology is defined as "the timing of seasonal activities of animals and plants" (Parry 2007). These phases include parts of the spring phenology including bud burst, leaf out, and the point in which the entire leaf of the plant is full size. In contrast, fall phenophases include timing of leaf color and leaf fall. These will be studied thoroughly during this research project.

Recording and analyzing major phenophases of different organism's lifecycles is important in the study of phenology. Direct observations are difficult to come by due to the extensity of work ground observations require. Few studies are completed by one or a small number of researchers on a specific small area of study due to the necessity of requiring many researchers to cover an extensive study area. Although direct phenophase observations are complex, these observations are helpful in looking at relationships between the atmosphere and the biological activity at ground level (Menzel 2006).

Understanding vegetation phenology is becoming important for climate change research since phenophase modifications can indicate global climate and ecosystem disruption (Fu et al. 2018). Unlike shrubs, researchers already have a diverse knowledge of tree phenology. Trees have been studied due to their accessibility and abundance in forest ecosystems. Tree canopy covers much of a temperate deciduous forest ecosystem which makes them easy to research whether it be from ground observations or from satellite. Jolly et al. (2004) expresses how there is minimal research showing findings on both canopy and ground layer phenology. While we look at trees as contributing to the large 'carbon sink' we have on land today, shrubs are also important when looking at carbon flux measurements.

There is limited research when it comes to understanding specific aspects of phenology. Gathering a deeper knowledge of shrub phenology will help the scientific community look forwards towards understanding the implications of climate change (Polgar and Primack 2011).

The following questions will help guide this research project:

1. How do the spring and autumn phenophases of non-native shrub species differ from those of native species?
2. How does the duration of spring and fall phenology compare between native and non-native shrub species?
3. How do local temperature patterns influence phenophase timing and duration of temperate deciduous shrubs?

2. Literature Review

2.1 What is Phenology?

Phenology is an extensive geographic topic studying the way vegetation and other living organisms relate to and are seasonally affected by different aspects of earth's natural systems such as weather, climate, elevation, location, etc. Phenology studies these biological and geographic relationships (Lieth 1973) as well as looks at seasonal variation and different lifecycle patterns of living organisms. Yu (2013) expresses the different stages of phenophases of trees including six key spring phenophases listed as: buds visible, buds swollen, buds open, leaves out, leaf fully unfolded, and leaf expansion for the spring season. Additionally, Yu (2013) looks at fall phenophase categories including leaf color and leaf fall. These are the main phenophases of trees commonly assessed in literature and similar phenophases will be assessed with shrubs.

There are suggested responses to climate change such as changes in growing season timeline (Ren et al. 2018), leaf senescence occurrences (Panchen et al. 2015), and the general widespread growth of forests and other ecosystems (Kramer et al. 2000). In Ren et al., (2018) completed at a location in inner Mongolia from 2000-2016 studying grassland steppes, the growing season start (SOS) advanced more than 2 days, 7 days, and 10.6 days in different areas of study. Distinct research of vegetation shows data from the recent 4-5 decades have seen an advancement of flowering occurrences in plants ranging from 1 to almost 4 days early on average per decade (Menzel, 2002). Plants and animals of boreal and temperate climate zones have already shown trends in a shifting of phenological phases in the northern hemisphere

(Menzel 2002). Discovering changes such as the advance of flowering contributes to important findings in phenology which contributes to our baseline knowledge of this field.

In Asia, phenological 'shifts' have been assessed and concluded that climate change and human interaction with the environment have become the main contributor to phenological changes (Suepa et al. 2016). Studies in Mongolia (Ren et al., 2018) had similarities to a study carried out in Eastern China (Fu et al., 2018) based on the latitude/longitude, similar species, and methodology of research. Both studies took place in semi-arid climates and discussed changes in the growing season as well as conclusions that precipitation in the semi-arid climate is one of the main drivers of the growing season changes. This is important because understanding how different climate regions or biomes are changing over time can help make conclusions and predictions about other similar locations. Menzel (2002) reported that phenology is a 'simple' way to track, assess, and analyze behaviors of different species of plant and animals.

2.2 Climate Change & Phenology

Phenology in relation to shrubs is looking at the biological timeline of events in relation to climate change. The breadth of knowledge on the phenology of trees, general leaf phenology (Palakit et al. 2018), as well as how animals and other species will be affected by climate change is a key component in indicating climatic changes' effect on ecosystems across the world. With warmer temperatures associated with climate change, we expect to see an earlier leaf out in many deciduous shrub and tree species (Donnelly et al., 2019). Additionally, in particularly arid/semi-arid climate regions, researchers such as Fu et al. (2018) and Ren et al. (2018) were able to link precipitations influence to phenological changes in growing seasons.

The earth is experiencing climatologic variations that are affecting ecosystems including species of flowers, trees, and shrubs (Primack et al. 2015). With a fear of a changing climate due to anthropogenic influences on the earth's atmosphere, there is pertinent information currently missing from discussion that needs to be understood about the way plants and animals will react to a change in climate. It is believed that climate change has caused growing seasons to lengthen which could affect productivity of shrubs as well as CO_2 intake from shrubs and other deciduous forest species (Jolly 2004). Yu (2013) and Fabian and Menzel (1999) show lengthening of growing seasons in the spring season. Further research needs to be conducted on responses to a changing climate in order to determine logistics of the two-way relationship between shrubs and the climate.

Earth and atmospheric conditions throughout history have always had natural variation but with anthropogenic impacts affecting our environment, looking forward, we are expecting to see a general rise in temperatures and an increase in rainfall events (IPCC 2014). Understanding how climatological changes, such as rise in temperature or increased rainfall, can influence variability in vegetation contributes to the study of how climate change will drastically alter vegetation cover in certain locations (Schwartz & Marotz 1988). Climate patterns and climatic changes can lead us to think bud burst and leaf fall occurrences are changing in plant species. This is important to the study because it allows us to see how phenology is being affected by a changing climate and what the implications are of a change in phenology.

Other ways in which trees and shrubs can be affected by climate change is how the water cycle impacts the growth and health of plants within an ecosystem. Altered transpiration of water from the plant to the atmosphere could impact relative humidity in the atmosphere as well as overall dynamics of the ground layer and surrounding atmosphere of a forest (Schwartz 1993).

Additionally, plant health and soil nutrient content are also important factors for studying carbon sequestration (Kell 2012).

Important to note for the purpose of this research is that temperature recordings on a day-to-day basis are considered meteorological temperature while climate would encompass long term patterns of temperature; both items will be considered briefly in this research with the main focus on phenology of shrub species.

2.3 Field Work: *In Situ* Observations

Potential reasoning as to why shrubs are not widely studied is due to the accessibility. Shrubs are not always visible to satellite due to foliage cover from trees. Often, it would be difficult to delineate between shrubs and trees on a larger scale using satellite imagery. With downsides to satellite imagery, introducing field work and ground observations to a satellite image-based project might be the supplemental information needed to fully encompass phenology of a forest or other ecosystem. Also, shrubs are much smaller species so higher resolution imagery is required and is still not always going to encompass specific features of phenophases. Satellites could contribute to a general forest leaf color-leaf fall analysis but doing things on an individual plant level would not be possible.

Timing is a key component in field work. In a study by Menzel et al. (2006), timing of phenological seasons based on individual trees were observed in the field. Using *in situ* observations, individual shrub species can be analyzed to determine the start and end of the phenology season. Detecting phenophase changes using remote sensing would likely occur on a larger scale but for this specific urban forest, *in situ* observations will likely bring the most accuracy in observations. *In situ* observations require large amounts of field work including taking individual analysis of every shrub being identified on the timeline required. Shrubs are a perfect example of how ground observation methodology can be utilized, although it may be difficult to gather individualized information on shrubs.

Table 1 shows examples of tree and shrub phenology studied across different continents. This table, although just a short list of research conducted, represents *in-situ* observations across the world. Commonly seen, over time and with the influence of climate on these ecosystems, growing seasons and phenophases throughout spring and fall are lengthening.

Table 1: Additional *in-situ* observations in studies across the world.

In-situ Observations	Studies	Details
Europe	Menzel and Fabian 1999	Average growing season is lengthening in the late 1900's around ~10.8 days
Asia	Matsumoto et al. 2013	Trends in advancement in beginning of growing season and delays in the end of growing season with Ginko biloba, longer season
United States	Yu 2013	Downer Woods, Milwaukee tree research concludes connections between satellite data and *in-situ* observations as well as climatic influences on phenology such as air temperature, wind speed/direction, soil temperature.

2.4 Spring and Fall Phenology

The timing of leaf senescence in trees between species is extremely important related to climate because if we are experiencing warmer and longer summers, we may see later leaf color and leaf fall timing in the fall season. These variables may contribute to less predictability of senescence. Understanding these commonalities is a key step in creating a set of variables scientists can use as groundwork and comparisons as well as test-runs for any potential modeling techniques. In a study by Gill et al. (2015) regarding fall leaf senescence in the Northern Hemisphere analyzing 64 publications, there was a general delay in leaf senescence of trees in autumn months of roughly 0.3 days and was more delayed at lower latitudes   This leads us into the first type of methodology in which we can begin the research of shrubs and strengthen our understanding of phenology beginning with leaf senescence. In the autumn season, temperature and precipitation are the primary forces that drive phenological changes (Fu et al. 2018).

In addition, research is being conducted on whether or not spring is starting earlier in the year than usual. Similarly, in another study by Jolly et al., (2004) in a project conducted looking at saplings and shrubs in the northeastern part of the United States, a model was created so that the researchers could intentionally extend the growing season in a simulation. This simulation would allow the researchers to understand influences a lengthening growing season will have on leaf area index and productivity (Jolly et al., 2004). In early spring, since there is minimal canopy cover from trees above, the shrubs and understory species are likely the only organisms contributing to carbon exchange (Donnelly & Yu 2019). Across the research community, shrubs are found to leaf out earlier than tree species (Jolly et al. 2004). In Minnesota, United States, over five growing seasons from 2009-2013, researchers contributed to above ground and below ground intentional warming to understand the responses of 16 different species (Rice et al. 2018). The study concluded that warming temperatures significantly contributed to a lengthening of the growing season between 11-30 days and leaf unfolding in particular (Rice et al. 2018).

Table 2 explains the different temperate deciduous forest seasons that will be discussed in this research as well as the associated phenophases. This region in the United States experiences four seasons of winter, spring, summer, and fall and for the purpose of this research, spring and fall phenology will be studied.

Table 2: The four seasons associated with temperate deciduous ecosystems such as the urban forest of Downer Woods, Milwaukee, Wisconsin. With these seasons, the key phenophases of shrub leaf phenology were studied for the spring and fall seasons.

Deciduous Phenophases	
Winter: A season which shrubs are dormant, no bud burst is occurring.	Spring: Begins the DOY budburst starts to occur in shrub species. Budburst (300-390), leaf out (400-490), and full leaf out (500-590) are measured during the spring season. Once full leaf out occurs, Summer begins.
Summer: All leaves are full leaf-out. Minimal activity occurs until leaves start to color.	Fall: The DOY leaves start to color, Fall begins. In Fall, leaf color (800-890) and leaf fall (900-990) are recorded. Once all leaves have fallen, Winter begins.

2.5 Ecology of Species

Shrubs are an extremely important part of a forest or temperate ecosystem due to factors such as carbon storage, photosynthesis, habitat, food for other organisms, and successful life needs. Since there is extensive research regarding other living organisms and their response to changing climate conditions (Skaggs 2004), shrubs are often overlooked; researchers may assume their presence in an ecosystem will be less impacted than that of larger organisms. The ecology of the species of shrubs I am researching is important to understanding how different species have variations in phenophases. Table 3 shows a breakdown of important features of the eight species of shrubs that will be studied in this research project.

Table 3: Background information on eight studied shrub species, their status as native or non-native, the number of shrubs in this research, and a description of the shrub.

Shrub	**Non-native/Native**	**# of shrubs in study**	**Notes**
***Lingustrum vulgare* (Privet)**	Non-native	3	The privet species are all located similarly in the southern part of Downer Woods.
***Viburnum acerifolium* (Mapleleaf Viburnum)**	Native	10	These shrubs are spread throughout Downer Woods. This species had indications of insect damage, some shrubs had to be discluded due to damages. This shrub has maple tree-like leaves.
***Ribes americanum* (Wild Currant)**	Native	5	Flowering, native shrub that produces berries. All 5 shrubs are located centrally in Downer Woods.
***Rhamnus cathartica* (Buckthorn)**	Non-native	5	Tall understory shrubs, found commonly throughout the entire state. Commonly leafs out earlier in spring and loses leaves late into the fall season.
***Cornus alternifolia* (Pagoda Dogwood)**	Native	3	Commonly found in the northern United States, the structure of this shrub is pagoda-esque in the layering of its branches.
***Lonicera morrowii* (Honeysuckle)**	Non-native	6	Multi-stemmed shrubs with very dense leaf pack. Honeysuckle in this research is spread throughout Downer Woods.
***Prunus virginiana* (Chokecherry)**	Native	4	Large native shrub often mistaken for trees. Chokecherry is not found in clusters in Downer Woods but more commonly spread out in the forest.
Viburnum lentago (Nannyberry)	Native	5	Nannyberry is a taller, tree-like shrub. This species had indications of mildew multiple times throughout this research.

3. Materials and Methodologies

3.1 Downer Woods

The study area is located in Downer Woods; an 11.1 acre temperate deciduous forest right on the University of Wisconsin-Milwaukee (UWM) campus (43°4'52"N, 87°52'51"W) (Yu 2013) (Figure 2). This study site was chosen due to accessibility and reliability. The forest is located directly on the UWM campus as well as managed by the UWM field station.

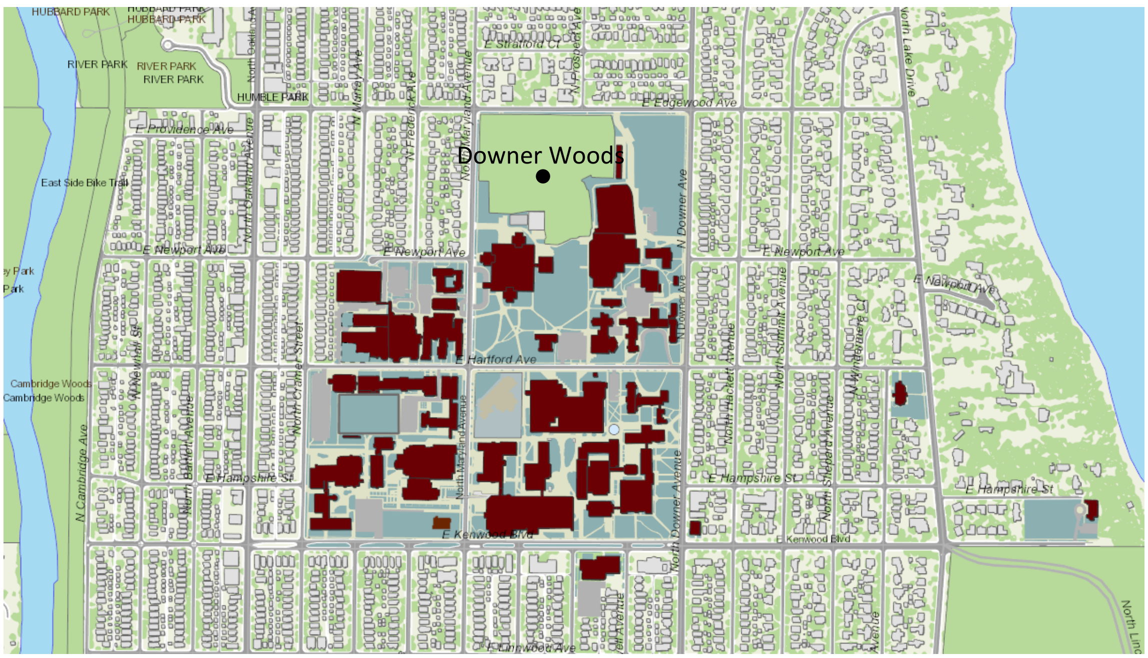


Figure 2: Downer Woods is located on the northern part of the University of Wisconsin-Milwaukee campus in Milwaukee, Wisconsin. To the south of the campus is urban, downtown Milwaukee while to the east is Lake Michigan.

Additionally, one of the key components of this study area is that it is an urban forest that has a wide variety of shrub and tree species including both native and non-native species. Yu (2013) discusses how there are few specific phenological observation research studies occurring in urban areas up to date. This shows the need for extensive phenological studies to occur in urban forests due to the large impact urban sprawl and population increase have had on our landscape.

This forest supplies research space for biological, phenological, and geographic studies in a location that is surrounded by an urban landscape. Having this resource on campus makes the woodlot accessible and fairly easy to manage from a research and data standpoint. There is a camera (PhenoCam) that oversees the forest taking imagery that contributes to a supplemental viewpoint of the canopy and foliage changes throughout the year. Images are recorded every 30 minutes during the daytime and takes images both in near-infrared and visible imagery. This PhenoCam helps monitor the forest closer to the ground level in addition to satellite imagery.

3.2 Timeline

This project is time-sensitive and required different methods of gathering observations and analyzing data. Starting in the spring of 2017, data collection began by collecting field observations of the spring phenophases of shrubs (Budburst, leaf out, full leaf out) throughout Downer Woods. Initially 36 shrubs were recorded and since that time, 6 additional shrubs have been added into the research. Ground observations were recorded by percentages of the phenophases until all leaves on each shrub were at the full leaf out stage. Spring data collection stayed consistent until spring of 2019.

In the fall of 2017, the first fall season of shrub observations was completed. Ground readings of leaf color and leaf fall timing and percentage were taken throughout the fall until 100% the leaves had fallen off the shrubs. This collection was completed on paper signifying the percentage each shrub was at during the coloration and leaf fall stage. Fall of 2018 is when the SPAD (Soil Plant Analysis Development) chlorophyll meter (Section 3.4 below) was introduced to the research project. The SPAD was then utilized for fall of 2018 and fall of 2019. This data will be published at a later date.

The three-year fall phenology was documented and recorded consistently in order to maintain accuracy. The current research findings and conclusions have been assessed through the fall of 2019 but this project will continue on with the help of faculty at UWM.

Looking closely in relation to the Day of Year (DOY), observation data will be based on this numerical timeline throughout the year. Using DOY, it can be determined at what stages throughout the year phenophases occur and relate timing to other species and other years. After visual observations and SPAD readings are recorded, all data is input into a spreadsheet to organize, analyze, and conduct statistical analysis and measurements.

At the end of the research period, temperature data was downloaded from four different HOBO temperature loggers; three located within Downer Woods, one closely to the north in Shorewood. The data used in this research will include spring 2017-Fall 2019 temperature broken down by DOY.

3.3 Direct Observations

The species studies in this research include both native and non-native species. These species include: *Viburnum lentago* (nannyberry), *Viburnum acerifolium* (Maple Leave Viburnum), *Ribes americanum* (Wild Currant), *Prunus virginiana* (Chokecherry), *Rhamnus cathartica* (Buckthorn), *Cornus alternifolia* (Pagoda Dogwood), *Lonicera morrowii* (Honeysuckle), *Lingustrum vulgare* (Privet). Further description about species is located in Study Area.

There are multiple parts to taking observations throughout this research project that are necessary to understanding the full scope of phenophases of shrubs in Downer Woods. First, the largest part of this research project was the amount of ground readings taken and field work put in. Visual observations of the shrubs were taken every-other day. These observations were recorded on charts of paper, later to be logged on an Excel sheet for analysis. Records included labeling the status of a shrub based on the criteria of bud burst, leaf out, full leaf out for spring and leaf color and leaf fall for Autumn. Numerically, records were listed on a basis of percent (%) of total shrub phenophase position and then given a value of 300-390 for spring bud burst, 400-490 for spring leaf out, then 500-590 for full leaf unfolded (Table 4, Spring Phenology) and 800-890 for fall leaf color, 900-990 for fall leaf fall (Table 5, Fall Phenology).

Table 4: This table shows the numerical indications of the status of spring phenophases of individual shrubs. In the spring, shrubs are analyzed by the total percentage of the shrub bud burst, leaf out and the final step of the full leaf being unfolded. Protocol adapted from Schwartz and Liang (2013).

Code	Deciduous Phenophase	Percentage
300	Bud burst	<10%
310	Bud burst	10-30%
330	Bud burst	30-50%
350	Bud burst	50-70%
370	Bud burst	70-90%
390	Bud burst	>90%
400	Leaf out	<10%
410	Leaf out	10-30%
430	Leaf out	30-50%
450	Leaf out	50-70%
470	Leaf out	70-90%
490	Leaf out	>90%
500	Full leaf unfolded	<10%
510	Full leaf unfolded	10-30%
530	Full leaf unfolded	30-50%
550	Full leaf unfolded	50-70%
570	Full leaf unfolded	70-90%
590	Full leaf unfolded	>90%

Table 5: This table shows the numerical indications of the status of phenophases of individual shrubs. Specifically, this chart shows fall phenophases including leaf color categorized by percent of total leaf color and number equivalent for analysis purposes. Protocol adapted from Schwartz and Liang (2013).

Code	Deciduous Phenophase	Percentage
800	Leaf color	<10%
810	Leaf color	10-30%
830	Leaf color	30-50%
850	Leaf color	50-70%
870	Leaf color	70-90%
890	Leaf color	>90%
900	Leaf fall	<10%
910	Leaf fall	10-30%
930	Leaf fall	30-50%
950	Leaf fall	50-70%
970	Leaf fall	70-90%
990	Leaf fall	>90%

3.4 Temperature

Air temperature is widely known as the greatest factor that influences spring phenology (Menzel et al., 2006, Schwartz et al., 2006). Located just 0.8 km away from Lake Michigan, wind patterns and currents off of the lake can have an influence on temperature and weather patterns that happen near Downer Woods such as rainfall, lake-effect snow, and wind speed and direction (Yang 2014). While wind patterns will not be assessed in this study directly, it is important to understand influences wind may have on temperature in Downer Woods.

Temperature data was recovered from HOBO temperature data loggers located at three stations (Site 11, Site 23, and Site 56) throughout Downer Woods. In addition to this data, a nearby HOBO temperature logger located in Shorewood, WI, just north of the UW-Milwaukee campus, was also used in order to complete the dataset. The Shorewood data was recorded in a standard National Weather Service shelter, located approximately 2 km northwest of Downer Woods (M.D. Schwartz, personal correspondence). Temperature was downloaded including Air Maximum, Air Minimum, Air Mean, and Soil Temperatures (25 cm below the surface) in the form of Fahrenheit. Temperature data was converted to Celsius (°C) and will be used in the form of °C for the purpose of this project. All sites except the Shorewood site included soil temperature at 25cm depth as well. With this dataset, Site 11 and the Shorewood data were used due to having the most complete set of temperature data needed for analysis.

Utilizing temperature data collected for Downer Woods, temperature and in-situ observations were compared in order to see correlations in temperature data and phenophase timing and duration. As stated by Yu 2013, "The relationship between spring phenology and lower atmospheric parameters is an important issue in phenological research" (p. 10).

Additionally, with the study area being held in Milwaukee, Wisconsin, temperatures can vary to extremes day to day.

In addition to Downer Woods temperature logs, temperature data was downloaded from the United States National Climate Data Center (Climate Data Online) and the National Oceanic and Atmospheric Administration (NOAA) Climate temperature records in order to retrieve average daily temperatures for the state of Wisconsin as a whole and Milwaukee, Wisconsin which was recorded at Milwaukee General Mitchell Airport.

3.5 Statistical Analysis

For the analysis component to this research, data was collected on paper copies and transferred to the Microsoft Excel in order to combine all research components and organize by each phenological season and year. Before analysis could begin, a linear interpolation had to be completed in order to fill missing values of DOY data. Linear interpolation was completed using R programming software. For example, a shrub may have been recorded as 850 for leaf color, then the next sampling date, it may have reached 890 for leaf color. We then would have had a missing data point for 870. After linear interpolation was complete, those missing values were filled in.

3.5.1 Temperature

Temperature data was statistically analyzed using IBM Statistical Package for Social Sciences (SPSS). Temperature data was first broken down into year, season, month, and day (DOY) in order to be analyzed on different levels. Each scale of measurement had different analysis completed. Descriptive statistics were calculated for each scale including mean, maximum, minimum, standard deviation, and standard error. From here, tables were made showing mean numbers between months, seasons, and years for comparison. This was completed for both air temperature and soil temperatures.

In addition, a One-way ANOVA was completed to show significance in differences between the years for annual air temperature as well as seasonal differences for spring and fall. A Tukey HSD (Honest Significance Difference) Post-hoc was completed, which is based on a standardized range distribution, to then determine details on specific variations in the data. Further analysis will be completed with correlations between air temperature and phenology.

3.5.2 Phenology

The timing (DOY) and duration (number of days) of each phenophase category for each species, species group (ie. native and non-native) and for the community as a whole is presented. Correlation was used to determine the relationship between temperature variables and phenology timing and duration. Additionally, with DOY, a mean was calculated signifying when each species hits a certain threshold (ex. 100% budburst, 50% leaf fall, etc.) to get a general understanding of differences in means among species as well as between the native species and non-native species. These averages can then be used for further statistical analysis including looking at trends in the means over the 3-year period. Trends were broken up between species and then as a native community and non-native community to be able to compare and contrast native and non-native species as well as conduct analysis on a species level.

Along with analysis between species and between natives v. non-native species, the entire study community was assessed and compared between years to determine annually if there are major changes in phenological phases of the entire shrub population. These averages and trends were then compared to temperature data to determine how temperature may have influenced the whole population of shrubs.

Since temperature and phenology data have been analyzed separately, understanding the relationship was the next goal in statistical analysis. A Pearson's R correlation was completed between mean daily air temperature and phenophase day of year (DOY) for both spring and fall to assess how much of an influence temperature may have played on changing of phenophase DOY's.

4. Results

4.1 Wisconsin and Milwaukee Climate Parameters

In order to put Downer Woods in context, mean monthly temperatures for Downer Woods were compared with averages of Milwaukee General Mitchell Airport and the state of Wisconsin in order to understand how an urban Milwaukee setting may differ from the overall state average temperature (Figure 3). The green and orange boxes show the phenological seasons of spring and fall for each year.

Overall, the state of Wisconsin tends to be colder in the fall and winter months most likely because Milwaukee/Downer Woods is located in a fairly southern part of the state where temperatures are typically warmer than further to the north. Additionally, Downer Woods seemed to stay slightly cooler than Milwaukee General Mitchell Airport especially seen in the late spring and summer months (Figure 3).

Temperature patterns over the three years are fairly consistent with cold winters with an average range between -9°C and 0°C and moderately warm summers ranging between an average of 15°C to 25°C. A common trend between all three data sets seems to be an abrupt rise in temperatures mid-spring season while fall temperatures taper off at a faster rate.

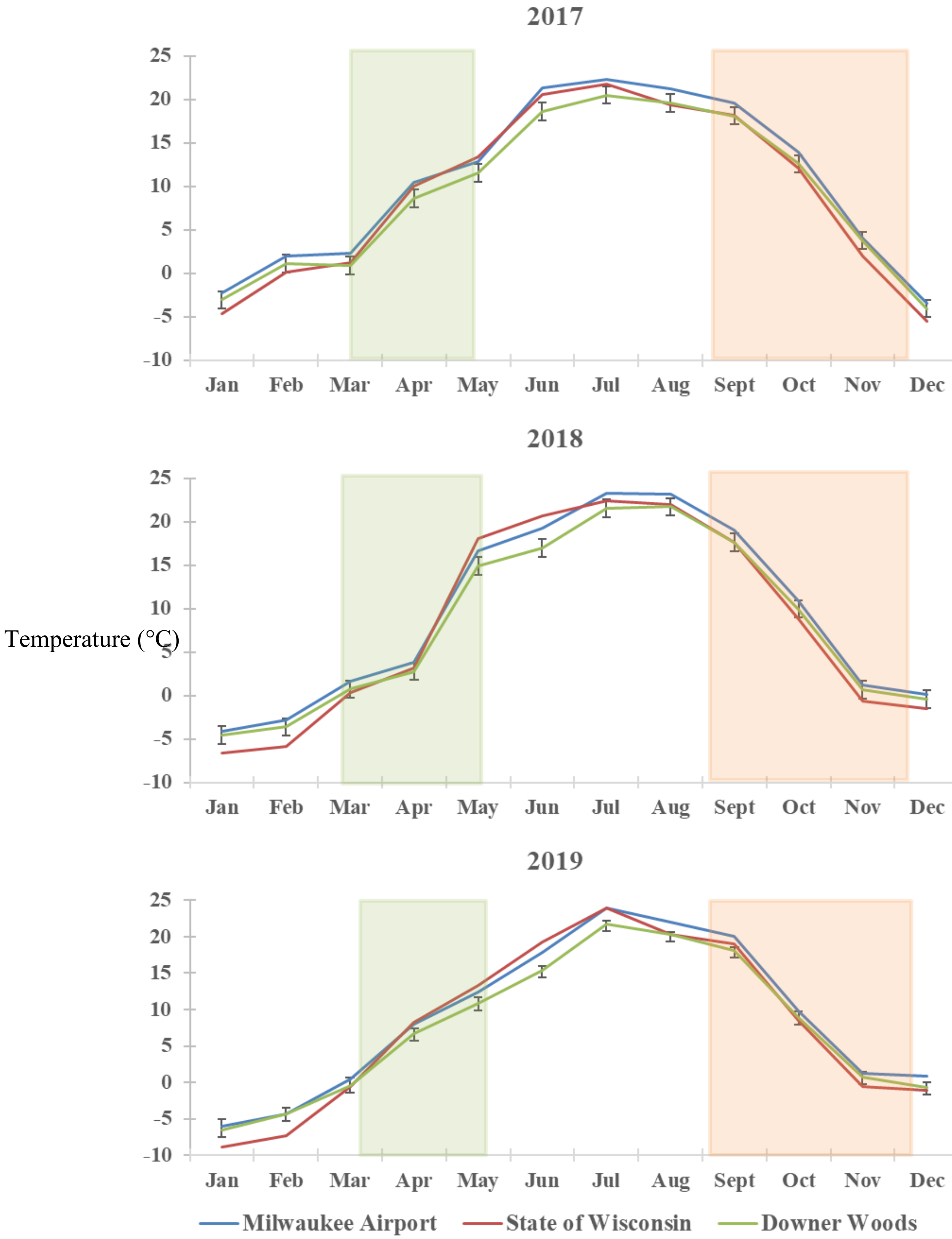


Figure 3: Mean monthly air temperature (°C) for Milwaukee General Mitchell Airport, State of Wisconsin, and Downer Woods over 2017-2019. Shaded boxes represent the spring and fall season for which *in situ* phenology data were collected (green=spring, orange=fall).
*SE only available for Downer Woods

4.2 Climate Parameters of Downer Woods, Study Site

4.2.1 Air Temperature

Figure 4 illustrates average daily temperatures (°C) at Downer Woods from 2017-2019 of all four HOBO sites (Sites 11, 23, 56, and Shorewood) for visual comparison.

There were no significant differences found between the four sites. Due to missing data for 2019 for sites 23 and 56, data for Site 11 and Shorewood were combined and used for analysis for both soil and air temperature.

Overall patterns for the study period show similar trends with a number of outstanding temperatures recorded. In early 2019 (about DOY 30) extreme cold temperatures (e.g., below -25°C) struck Downer Woods (Figure 4). Also shown is a greater variation of temperatures in winter with more moderate temperature variation throughout summer and early fall.

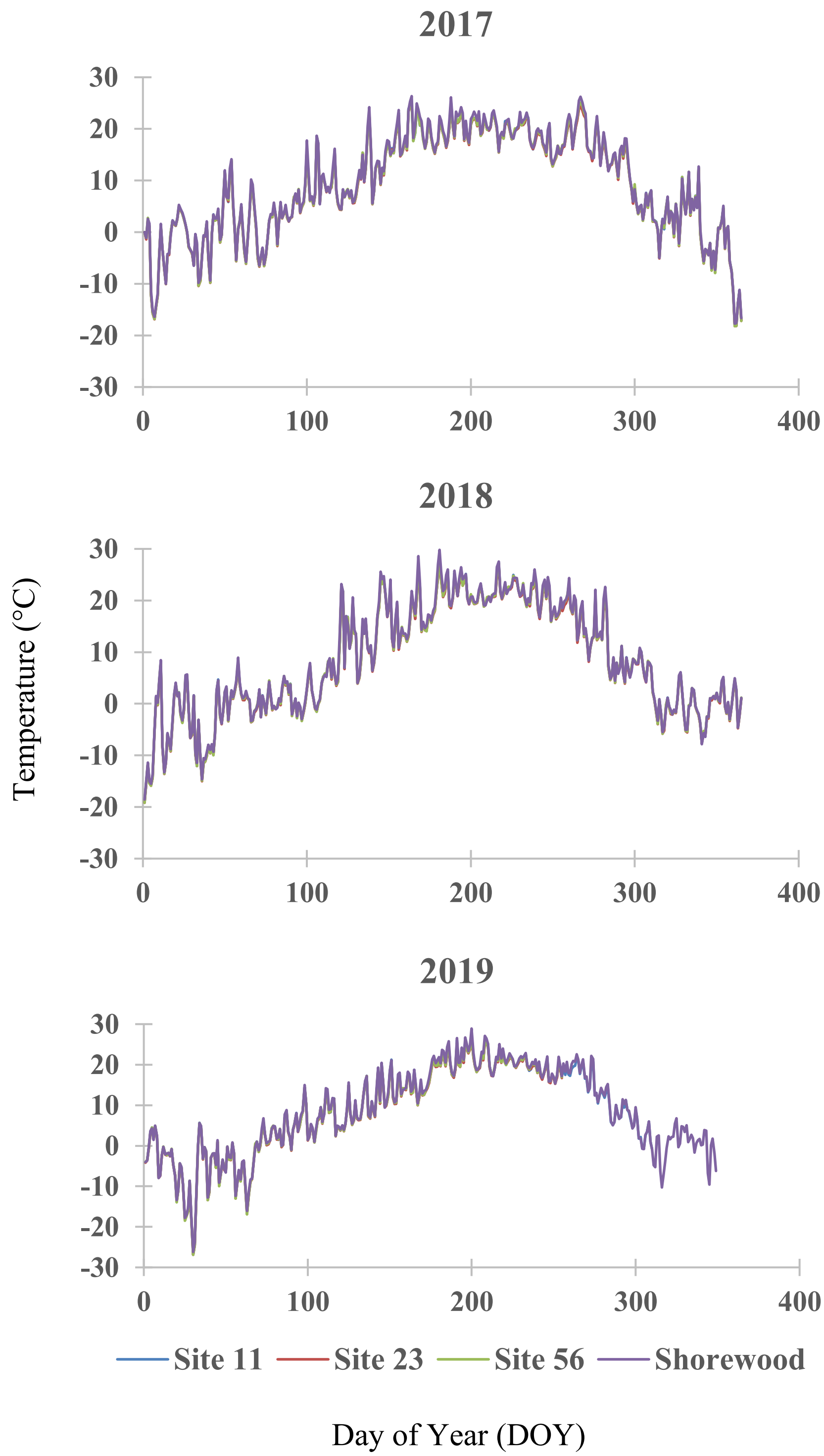


Figure 4: Mean daily air temperature (°C) for all 4 sites (11, 23, 56, Shorewood) over three-year (2017-2019) period at Downer Woods on the UW-Milwaukee campus. Note: trend line for Shorewood masks the other sites. For 2019, data was collected through DOY 350 at the time of analysis.

On average, annual average air temperature ranged between 7.56±2.73°C and 9.02±2.51°C at the study site (Table 6) but no statistically significant differences were recorded between the years (Table 7). However, seasonal statistical differences ($p<0.05$) were recorded for spring.

Average spring (March-May) temperature varied across the years (Table 8). Since Spring months (March-May) were statistically significant between the three-year period, a Tukey HSD test was carried out in order to determine between which years there were significant differences. Table 9 shows this output expressing how every month was different between the years except the months of March and May between 2017 and 2018 and May between 2017 and 2019.

March of 2017 was significantly ($p=0.006$) warmer by 6.4°C than March of 2019. April 2017 was significantly warmer ($p<0.000$) by 11.24°C than April 2018 (Table 9). May of 2018 was also significantly warmer ($p=0.003$) than May of 2019 by 7.89°C but the greatest difference between months was April of 2017 and 2018 with a mean difference of 11.24°C (Table 9).

Table 6: Mean seasonal (spring and fall) and annual temperature (°C) for Site 11 and Shorewood temperature data in Downer Woods over three-year period (2017-2019). There is no statistical significance between the years except Spring season (Tables 8-9).

	ANNUAL	SPRING (MARCH-MAY)	FALL (SEPT-NOV)
2017	9.02±2.51	7.02±2.60	11.48±3.41
2018	8.19±2.75	6.13±3.61	9.41±4.0
2019	7.56±2.73	5.7±2.69	9.27±7.11

Table 7: One-way ANOVA showing variance between average daily temperatures for the three-year (2017-2019) period, both annual air and annual soil variance.

	MEAN SQUARE	F	P VALUE
Average Daily Air Temperature	242.22	0.70	0.49
Average Daily Soil Temperature	495.97	2.40	0.08

Table 8: One-way ANOVA showing variance of seasons broken down by month between the three-year (2017-2019) period.

AIR MEAN	MONTH	SUM OF SQUARES	MEAN SQUARE	F	P VALUE
SPRING	MARCH	844.74	422.37	6.62	**0.002***
	APRIL	1898.56	949.28	21.10	**0.000***
	MAY	987.25	493.63	5.95	**0.004***
FALL	SEPTEMBER	16.71	8.36	0.34	0.71
	OCTOBER	332.87	166.43	2.32	0.10
	NOVEMBER	112.53	56.27	1.08	0.34

Table 9: Tukey HSD output of monthly differences between the years 2017-2019 with P-value showing significance. Since the spring months show statistical significance from one another, the table describes differences between each month based on the year.

Month	Year		Mean Difference	Std. Error	Sig. (P-value)
MARCH	2017	2018	0.01524	2.02938	0.972
		2019	6.40094*	2.02938	**0.006***
	2018	2017	-0.01524	2.02938	0.972
		2019	6.38570*	2.02938	**0.006***
	2019	2017	-6.40094*	2.02938	**0.006***
		2018	-6.38570*	2.02938	**0.006***
APRIL	2017	2018	11.24439*	1.73196	**0.000***
		2019	5.30476*	1.73196	**0.008***
	2018	2017	-11.24439*	1.73196	**0.000***
		2019	-5.93963*	1.73196	**0.003***
	2019	2017	-5.30476*	1.73196	**0.008***
		2018	5.93963*	1.73196	**0.003***
MAY	2017	2018	-2.89128	2.31358	0.427
		2019	4.99645	2.31358	0.084
	2018	2017	2.89128	2.31358	0.427
		2019	7.88773*	2.31358	**0.003***
	2019	2017	-4.99645	2.31358	0.084
		2018	-7.88773*	2.31358	**0.003***

4.2.2 Soil Temperature

In order to visually compare soil and air temperature for Downer Woods across the three-years of the study period, both were plotted on the same graph (Figure 5). As expected, soil temperature varied less than air temperature but followed a similar annual trend.

Table 9 presents the average (±SE) spring, fall, and annual soil temperatures °C for all three years of the study for Site 11/Shorewood temperature data. Overall, the soil temperatures were consistent across the study period and coincided with general temperature patterns as expected. On average, annual soil temperature ranged between 8.74±0.42 and 10.03±0.38°C with average spring soil temperature (5.86°C) being colder than average fall soil temperature (12.07°C). There was no statistically significant difference in average daily soil temperatures between the three-year period (Table 7,10).

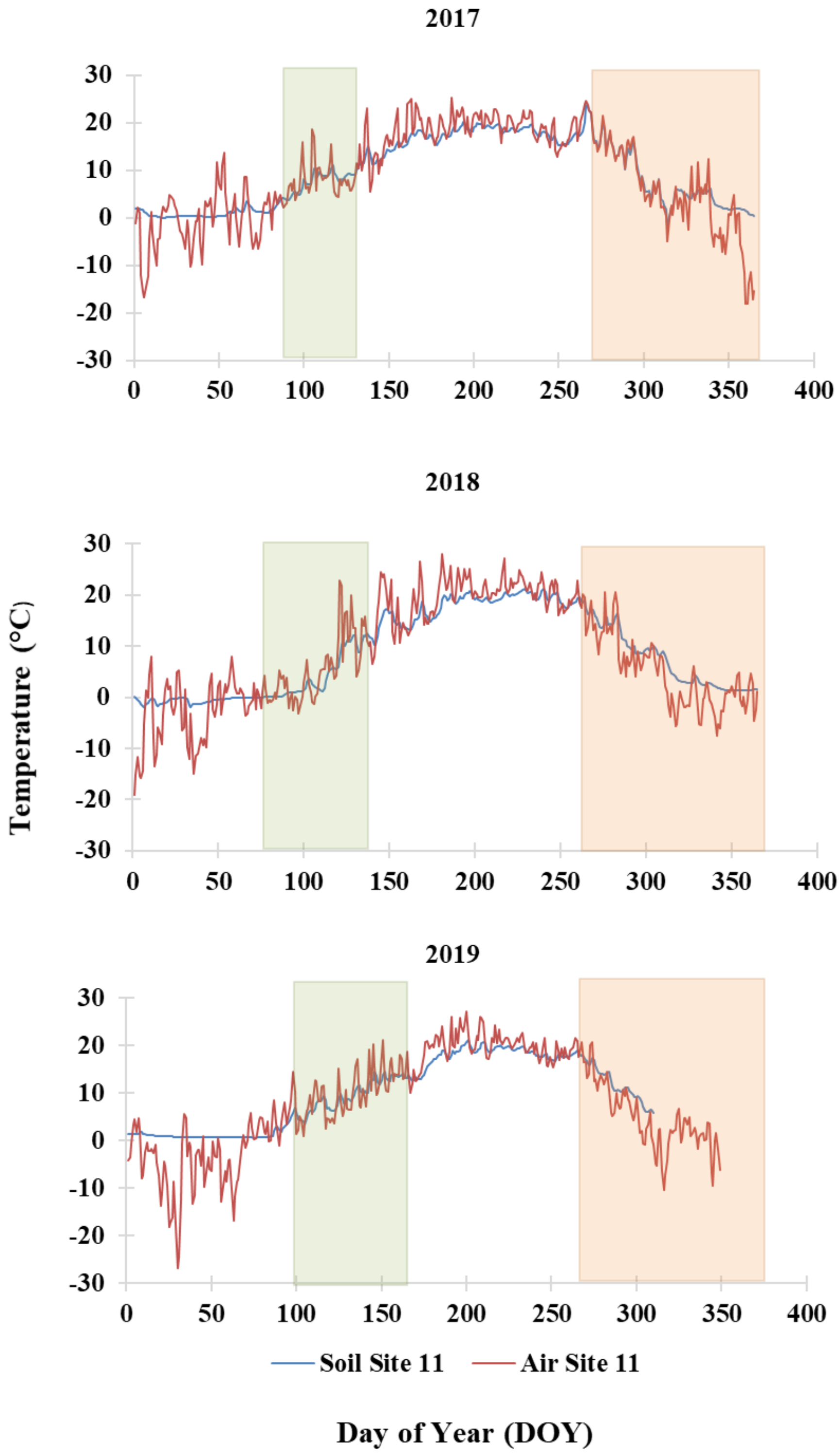


Figure 5: Mean daily soil temperature (°C) and air temperature (°C) overlying growing seasons of spring (green) and fall (orange) for the three-year study period (2017-2019) in Downer Woods for HOBO site 11/Shorewood. Note: Temperature data for 2019 is through DOY 350 based on the time period in which data was analyzed.

Table 10: Mean seasonal and annual soil temperatures (°C) (25cm below surface) and air temperature with standard error. There was no statistical significance for soil temperature across the years (p=0.082, Table 7).

	Annual		**Spring (March-May)**		**Fall (Sept-Nov)**	
	Soil	Air	Soil	Air	Soil	Air
2017	9.45±0.38	9.02±2.51	7.01±0.40	7.02±2.60	10.82±0.66	11.48±3.41
2018	8.74±0.42	8.19±2.75	4.98±0.53	6.13±3.61	11.46±0.61	9.41±4.0
2019	10.03±0.38	7.56±2.73	5.59±0.40	5.7±2.69	13.93±0.43	9.27±4.11

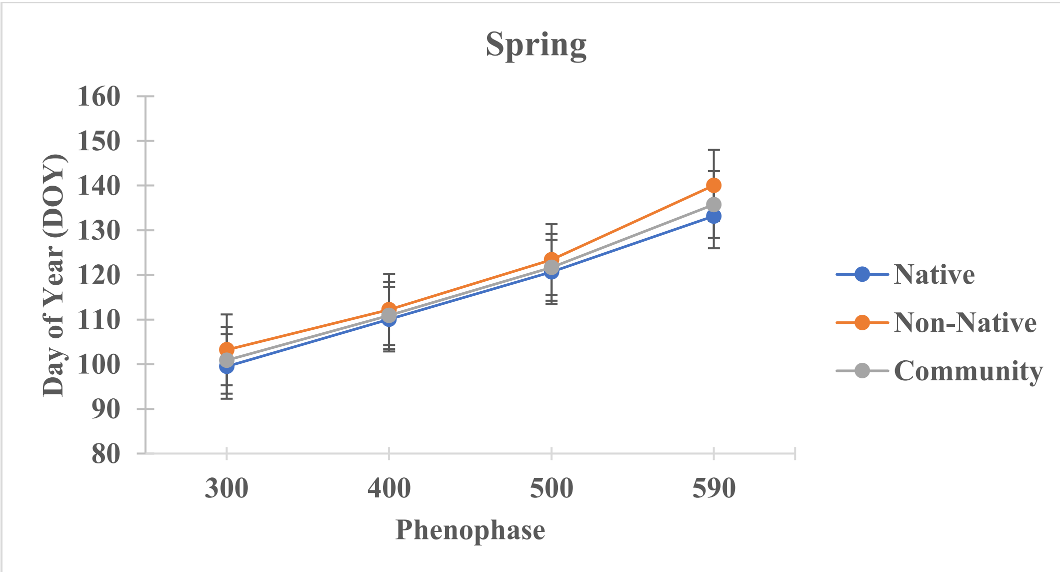
4.3 Descriptive Summary of Shrub Phenological Data

4.3.1 Community level start, end, and duration of Spring and Fall phenology

Overall, the spring season lasted nearly five weeks with budburst starting on approximately Day of Year (DOY) 101 (April 9) and full leaf out ending on DOY 135 (May 14) whereas the fall phenology season lasted eight weeks with leaf coloration beginning on DOY 252 (September 8) and leaf fall ending on DOY 308 (November 3) for the shrub community (Figure 6, Table 11).

On average, non-native species had a later start to the listed phenophases for both spring and fall phenology seasons (Figure 6, Table 11). For native species, spring season (Pheno-category 300) began on average DOY 99 and ended (Pheno-category 590) DOY 133 while non-native species began spring on average of DOY 103 and spring concluded around DOY 140. Therefore, spring began and ended later in non-native species than in native species. Additionally, fall began on DOY 248 (Pheno-category 800) on average and ended on DOY 291 (990) for native species while for non-natives, fall began on DOY 259 and ended on DOY 336 across the study period.

Table 12 shows statistical significance of the start DOY of each major phenophase across the study period (2017-2019) for native and non-native species. Both the native and non-native species showed a statistically significant different starting DOY ($p<0.05$) for all spring phenophases (300-590). Additionally, native species showed statistically significant start DOY for fall phenophases of 800 and 900 ($p=0.041$, 0.012 respectively) but not for the end of the fall season, 990. For non-native species there was no significant difference in start DOY of leaf color but there was for leaf fall, 900-990 ($p=0.00$, 0.002 respectively).



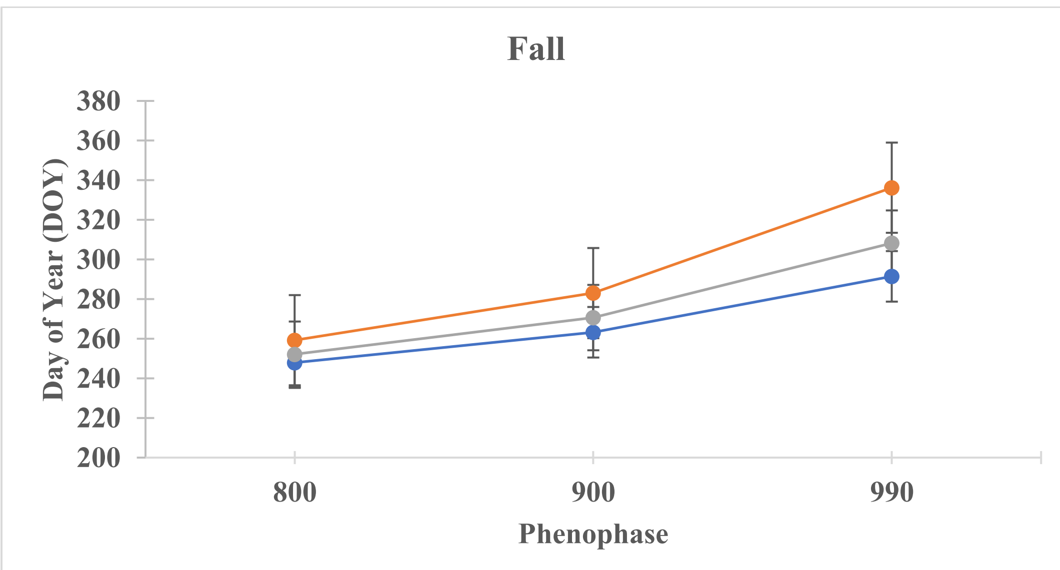


Figure 6: Average starting DOY of the study period for each major phenophase in Spring and Fall. The figure also creates a visual for the duration of each phenophase. Corresponding statistical analysis in Tables 11-12. (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season).

Table 11: Average start Day of Year (DOY) (±SE) of each major phenophase among the three-year (2017-2019) period. (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season). *Phenophase 990 for native and non-native groups shows statistically significant difference ($p<0.05$) in timing (DOY) between the groups of shrubs.

	SPRING			
	300	**400**	**500**	**590**
COMMUNITY	100.89±3.17	110.89±2.69	121.70±2.90	135.76±2.22
NATIVE	99.49±4.37	110.08±3.50	120.67±3.30	133.18±2.63
NON-NATIVE	103.21±4.54	112.24±4.32	123.42±4.90	140.06±4.10

	FALL		
	800	**900**	**990**
COMMUNITY	252.17 ±2.63	270.66±3.98	308.25±5.32
NATIVE	247. 92±2.24	263.26±2.61	**291.46±2.97***
NON-NATIVE	259.25±5.27	283.01±6.59	**336.21±9.98***

Table 12: One-way ANOVA showing statistical significance of average start DOY for each major phenophase between the three-year study period (2017-2019). (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season).

	PHENO-CATEGORY	SUM OF SQUARES	MEAN SQUARE	F	SIG.
NATIVE	300	10620.481	5310.241	173.772	**0.000***
	400	4637.173	2318.586	238.903	**0.000***
	500	3737.751	1868.875	42.243	**0.000***
	590	4930.104	2465.052	191.367	**0.000***
	800	359.443	179.721	3.531	**0.041***
	900	1437.654	718.827	4.879	**0.012***
	990	855.934	427.967	1.851	0.166
NON-NATIVE	300	1581.505	790.752	17.378	**0.000***
	400	1403.739	701.870	20.173	**0.000***
	500	1959.730	979.865	18.361	**0.000***
	590	2540.173	1270.087	82.824	**0.000***
	800	386.689	193.345	0.687	0.511
	900	13105.130	6552.565	168.113	**0.000***
	990	1165.469	582.735	7.355	**0.002***

Table 13 shows the average duration of the spring and fall phenological season for the three-year (2017-2019) study period (±SE). Table 13 also expresses the difference between native and non-native species for both spring and fall seasons for the study period (2017-2019). There is no statistically significant differences between the two groups of shrubs except for the fall of 2019 ($p=0.02$). In this instance, the duration of the fall 2019 was significantly different between the native group and non-native group as a whole with the non-native species having a significantly longer season than the native species of about 45 days longer.

A one-way ANOVA shows statistically significant ($p<0.05$) differences between the duration of the spring season for the three-year period (Table 14). Native species ($p=0.028$) and non-native species ($p=0.027$) are then broken-down using Tukey HSD analysis (Table 15) to show differences in the duration for the spring season by year.

In 2018, the duration of the spring season was shorter than spring of 2017 and significantly shorter ($p=0.023$) than spring of 2019 by 23.5 days for the native species. For non-native species, spring of 2019 was significantly longer by 17 days than spring of 2017 ($p=0.039$) and 2018 ($p=0.043$) (Table 13).

Table 13: Average duration for Community, Native, and Non-Native species with ±SE as well as statistical significance of Spring and Fall season between the Native and Non-Native groups.

	2017		2018		2019	
COMMUNITY						
SPRING (300-590)	28.94±	4.79	23.96±	2.68	44.32±	3.05
FALL (800-990)	55.83±	10.55	57.63±	4.22	**62.58±**	**8.61***
NATIVE						
SPRING (300-590)	31.49±	8.75	21.15±	2.97	44.65±	4.63
FALL (800-990)	32.25±	6.28	50.94±	4.82	**45.07±**	**1.34***
NON-NATIVE						
SPRING (300-590)	26.39±	0.20	26.78±	5.29	44.00±	3.93
FALL (800-990)	79.42±	8.04	64.31±	5.76	**80.10±**	**12.82***

YEAR		**Mean Square**	**F**	**Sig.**
2017	Spring	56.679	0.311	0.601
	Fall	1125.670	1.965	0.220
2018	Spring	59.361	1.034	0.349
	Fall	334.668	3.031	0.132
2019	Spring	0.768	0.009	0.928
	Fall	2413.930	11.290	**0.020***

Table 14: One-way ANOVA showing variance of duration of spring and fall season between the native and non-native species among the three-year study period.

		SUM OF SQUARES	MEAN SQUARE	F	SIG.
NATIVE	Spring **(300-590)**	1386.145	693.073	5.009	**0.028***
	Fall **(800-990)**	776.267	388.134	3.800	0.059
NON-NATIVE	Spring **(300-590)**	606.882	303.441	6.973	**0.027***
	Fall **(800-990)**	606.302	303.151	0.496	0.632

Table 15: Tukey HSD test presenting statistically significant differences in duration of spring for the 2017, 2018, and 2019 seasons.

			MEAN DIFFERENCE	STD. ERROR	SIG.
NATIVE	2017	2018	10.3600	7.8908	0.417
		2019	-13.1400	7.8908	0.261
	2018	2017	-10.3600	7.8908	0.417
		2019	-23.5000*	7.4396	**0.023***
	2019	2017	13.1400	7.8908	0.261
		2018	23.5000*	7.4396	**0.023***
NON-NATIVE	2017	2018	-0.3667	5.3863	0.997
		2019	-17.6000*	5.3863	**0.039***
	2018	2017	0.3667	5.3863	0.997
		2019	-17.2333*	5.3863	**0.043***
	2019	2017	17.6000*	5.3863	**0.039***
		2018	17.2333*	5.3863	**0.043***

4.3.2 Species level phenology start, end, and duration of Spring and Fall phenology

Table 16 represents the descriptive statistics for native shrub species across the three-year study period. This table shows mean starting DOY for each major phenophase, ±SE, maximum and minimum values recorded for each species as a whole. Similarly, Table 16 shows case summaries for non-native species as averages across the study period.

In general, for native species, wild currant tended to leaf out earlier in spring than other species (Table 16, Figure 7). For non-native species, buckthorn tended to leaf out later in spring than other species (Table 17, Figure 7). The starting leaf color (pheno-category 800) was significantly ($p<0.05$) later for buckthorn (non-native) at DOY 273 than the other species (Table 17).

Figure 7 shows how the starting DOY can compare between the species for each major phenophase. The start of leaf fall (pheno-category 900) is when the non-native group tends to group together and begin later than the native group for the fall phenology (Figure 7). The steeper trend between phenophases 900 and 990 (start to end of leaf fall) indicate a longer fall for buckthorn, privet, and honeysuckle, the non-native species. This makes the difference between the native and non-native species clear specifically for the fall season.

Table 16: A three-year average of species summaries for pheno-category starting DOY for each native species broken up into season. (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season).

Species	Season	Pheno-Category	Mean	Std. Error	Minimum	Maximum
Chokecherry	Spring	300	102.29	4.31	91.00	118.00
		400	109.87	2.92	101.00	121.13
		500	119.25	2.18	108.00	128.00
		590	132.30	2.66	116.00	143.00
	Fall	800	245.67	2.61	233.00	257.00
		900	268.78	4.58	250.00	284.00
		990	287.80	2.97	268.00	300.00
Dogwood	Spring	300	103.40	6.04	91.00	118.00
		400	113.20	3.87	103.00	122.50
		500	131.40	1.36	127.00	135.00
		590	144.20	1.83	140.00	149.00
	Fall	800	254.60	4.23	242.00	267.00
		900	273.80	4.75	266.00	291.00
		990	299.50	2.01	290.00	303.00
Maple Leaf Viburnum	Spring	300	104.33	2.97	89.00	118.00
		400	113.30	1.59	102.00	123.00
		500	128.36	1.55	113.00	137.00
		590	138.05	1.74	123.00	149.00
	Fall	800	242.00	0.00	242.00	242.00
		900	259.21	0.77	256.00	264.00
		990	294.56	4.24	268.00	340.00
Nannyberry	Spring	300	91.75	5.88	68.00	120.00
		400	107.87	2.51	98.90	121.33
		500	115.47	2.16	104.00	126.50
		590	134.80	2.33	123.00	145.00
	Fall	800	237.80	0.80	237.00	241.00
		900	251.82	1.77	245.00	257.00
		990	287.93	3.42	273.00	317.00
Wild Currant	Spring	300	96.69	3.64	83.00	118.00
		400	106.72	2.51	97.00	121.17
		500	113.22	2.05	104.50	123.67
		590	128.80	2.42	117.00	139.00
	Fall	800	241.60	1.86	236.00	257.00
		900	266.79	4.53	253.00	300.00
		990	289.33	4.95	267.00	324.00

Table 17: A three-year average of species summaries for pheno-category starting DOY for each non-native species broken up into season(300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season).

Species	Season	Pheno Category	Mean	Std. Error	Minimum	Maximum
Buckthorn	Spring	300	103.56	3.34	89.00	124.00
		400	115.41	2.75	102.00	129.67
		500	130.36	2.50	111.00	138.00
		590	150.00	0.89	148.00	153.00
	Fall	800	273.20	3.80	257.00	294.00
		900	284.86	5.81	257.00	304.00
		990	336.00	2.49	320.00	349.00
Privet	Spring	300	105.00	5.70	83.00	120.00
		400	111.45	2.63	101.17	121.82
		500	124.89	3.40	109.00	132.00
		590	136.67	4.17	117.00	149.00
	Fall	800	256.86	4.26	245.00	274.00
		900	283.78	8.27	257.00	314.00
		990	343.89	3.14	324.00	354.00
Honeysuckle	Spring	300	93.67	2.20	87.00	100.00
		400	106.31	2.63	97.00	118.40
		500	114.78	1.69	111.00	123.50
		590	131.89	2.66	123.00	139.00
	Fall	800	247.50	2.43	236.00	261.00
		900	276.17	4.56	257.00	304.00
		990	331.08	2.64	319.00	341.00

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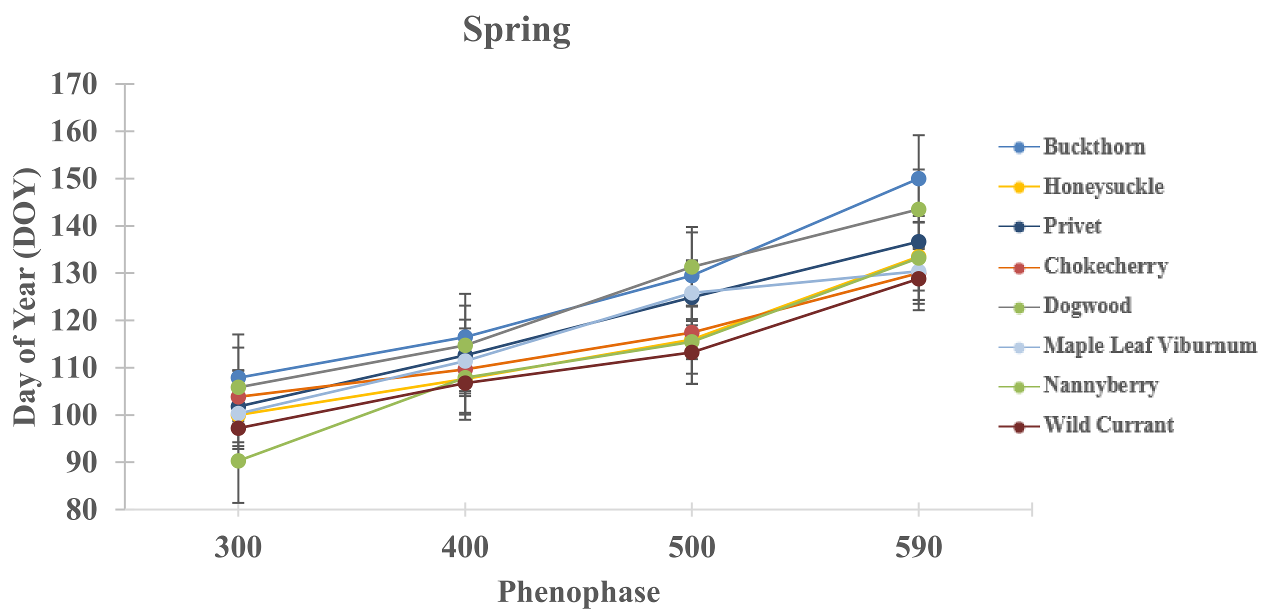

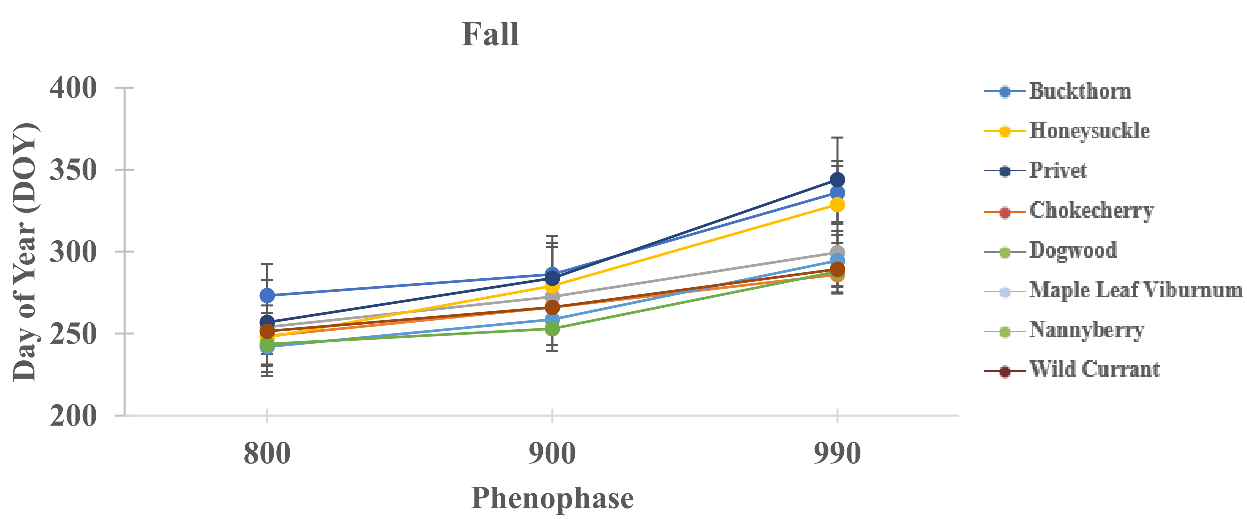

Figure 7: Average starting DOY (Day of Year) of the study period (2017-2019) for each major phenophase in Spring and Fall broken down by species. The figure also shows the length of each phenophase. (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season). Statistical analysis presented in Tables 18 and 19.

Starting DOY for all major phenophases showed statistical significance ($p<0.05$) in almost every species across the study period (Tables 18-19) for both spring and fall seasons. Table 18 shows statistical significance ($p<0.05$) for all native species for the spring season phenophases.

Every species showed significant differences between the three-year period for every phenophase except Dogwood for pheno-category 500. Table 19 shows similar results that every single species shows significant differences in starting DOY of major phenophases for every pheno-category for non-native species.

Table 18: One-way ANOVA showing statistical significance (p<0.05) of starting DOY for major phenophases of spring for native species across three-year study period. (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season).

PHENO-CATEGORY	SPECIES	MEAN SQUARE	SIG.
300	Chokecherry	348.21	**0.01***
	Dogwood	710.53	**0.00***
	Maple Leaf Viburnum	1307.81	**0.00***
	Nannyberry	2273.03	**0.00***
	Wild Currant	991.78	**0.00***
400	Chokecherry	278.66	**0.00***
	Dogwood	273.01	**0.01***
	Maple Leaf Viburnum	560.02	**0.00***
	Nannyberry	645.06	**0.00***
	Wild Currant	638.89	**0.00***
500	Chokecherry	206.47	**0.00***
	Dogwood	0.53	0.85
	Maple Leaf Viburnum	454.39	**0.00***
	Nannyberry	470.87	**0.00***
	Wild Currant	423.26	**0.00***
590	Chokecherry	294.30	**0.00***
	Dogwood	58.80	**0.02***
	Maple Leaf Viburnum	670.70	**0.00***
	Nannyberry	538.40	**0.00***
	Wild Currant	614.60	**0.00***

Table 19: One-way ANOVA showing statistical significance (p<0.01) of starting DOY for major phenophases of spring for non-native species across three-year study period. (300 Budburst, 400 Leaf out, 500 Full leaf out, 590 full leaf out >90%- end of Spring season. 800 Leaf color, 900 Leaf fall, 990 leaf fall >90%- end of Fall season).

PHENOCATEGORY	SPECIES	MEAN SQUARE	SIG.
300	Buckthorn	321.51	**0.01***
	Privet	477.67	**0.00***
	Honeysuckle	133.33	**0.00***
400	Buckthorn	407.87	**0.00***
	Privet	183.54	**0.00***
	Honeysuckle	245.65	**0.00***
500	Buckthorn	525.63	**0.00***
	Privet	394.11	**0.00***
	Honeysuckle	102.15	**0.00***
590	Buckthorn	1250.60	**0.00***
	Privet	613.00	**0.00***
	Honeysuckle	253.94	**0.00***

While average start DOY varied across the three-year study period for the community, groups, and species, duration results also showed interesting findings. Table 20 shows average duration for each species for the spring and fall seasons as a whole. Table 21 shows statistically significant differences (p<0.01) in the duration of each season by species.

Every native species showed significant differences (p<0.01) in the duration of the spring season across the three-year period. In addition, Chokecherry and Wild Currant also showed statistically significant differences in the fall season between the three-year period. Non-native species showed much more variation in the duration of the seasons. Both spring and fall seasons were statistically significant between all three non-native species across the study period. Buckthorn, Privet, and Honeysuckle all had p-values < 0.05 for both spring and fall in regards to the duration of the season compared between the years (Refer to Appendix for Tukey HSD breakdown*).

Table 20: A breakdown of duration of each season (Spring 300-590, Fall 800-990) by species. No data due to no Dogwood observations taken in 2017 and unhealthy Maple Leaf Viburnum fall 2019.

	SEASON	2017	2018	2019
CHOKECHERRY	Spring	13.0±3.09	13.3±5.99	34.0±5.81
	Fall	20.0±7.70	46.5±5.91	36.0±6.1
DOGWOOD	Spring	No data	22.0±9.31	53.3±11.99
	Fall	No data	50.0±3.98	44.7±1.87
MAPLE LEAF VIBURNUM	Spring	28.8±6.92	23.6±3.81	40.5±4.07
	Fall	38.8±3.44	46.2±4.74	No data
NANNYBERRY	Spring	55.2±6.31	30.4±7.13	57.8±7.65
	Fall	46.6±1.66	42.4±4.12	41.2±3.01
WILD CURRANT	Spring	29.0±5.67	16.4±6.90	37.6±4.75
	Fall	23.6±6.88	69.6±7.12	48.4±5.63
BUCKTHORN	Spring	26.0±5.53	24.0±7.62	45.4±4.52
	Fall	24.0±8.61	53.6±8.52	56.8±9.10
PRIVET	Spring	40.5±4.09	19.3±3.89	36.6±4.78
	Fall	94.0±3.10	66.0±5.44	101.0±3.26
HONEYSUCKLE	Spring	26.5±3.83	37.0±7.36	50.0±6.66
	Fall	66.3±5.53	73.3±6.23	82.5±7.30

Table 21: One-way ANOVA showing significant differences (p<0.05) between the duration (length) of the spring season (300-590) and fall season (800-990) in all species across the three-year study period.

SPECIES		SUM OF SQUARES	MEAN SQUARE	SIG.
CHOKECHERRY	Spring	1812.833	906.417	**0.000***
	Fall	1103.000	551.500	**0.020***
DOGWOOD	Spring	1178.133	1178.133	**0.001***
	Fall	0.667	0.667	0.943
MAPLE LEAF VIBURNUM	Spring	4115.396	2057.698	**0.000***
	Fall	219.700	219.700	0.325
NANNYBERRY	Spring	4360.933	2180.467	**0.000***
	Fall	80.400	40.200	0.502
WILD CURRANT	Spring	2598.533	1299.267	**0.000***
	Fall	5560.000	2780.000	**0.000***
BUCKTHORN	Spring	1630.717	815.358	**0.000***
	Fall	1758.400	879.200	**0.007***
PRIVET	Spring	1200.889	600.444	**0.008***
	Fall	2058.000	1029.000	**0.000***
HONEYSUCKLE	Spring	3224.400	1612.200	**0.021***
	Fall	1971.977	985.989	**0.002***

Starting with the native species, Dogwood was not analyzed using ANOVA and Tukey HSD due to only two years' worth of data (Appendix B). Chokecherry, Maple Leaf Viburnum, Nannyberry, and Wild Currant all showed significantly longer spring seasons in 2019 than in the other two years with a range of the mean difference being anywhere from 3-37 days longer in 2019 than the other two years. Between 2017 and 2018, Wild Currant had the greatest difference in length with a duration change of 46 days with 2018 being the shortest spring season compared to 2017 and 2019 (Figure 8).

For non-native species (Appendix C), spring was significantly longer in 2019 than in 2017 by 19.4 days and 2018 by 25.9 days for Buckthorn. Additionally, for Buckthorn fall of 2017 was significantly longer than 2018 by 24.4 days and 2019 by 21.2 days. Privet showed a significantly shorter fall season in 2017 by 28 days and 2019 by 35 days than the fall of 2018. Honeysuckle shows a significantly longer spring in 2019 than 2017 (35 days shorter) and 2018 (39 days shorter) (Figure 8).

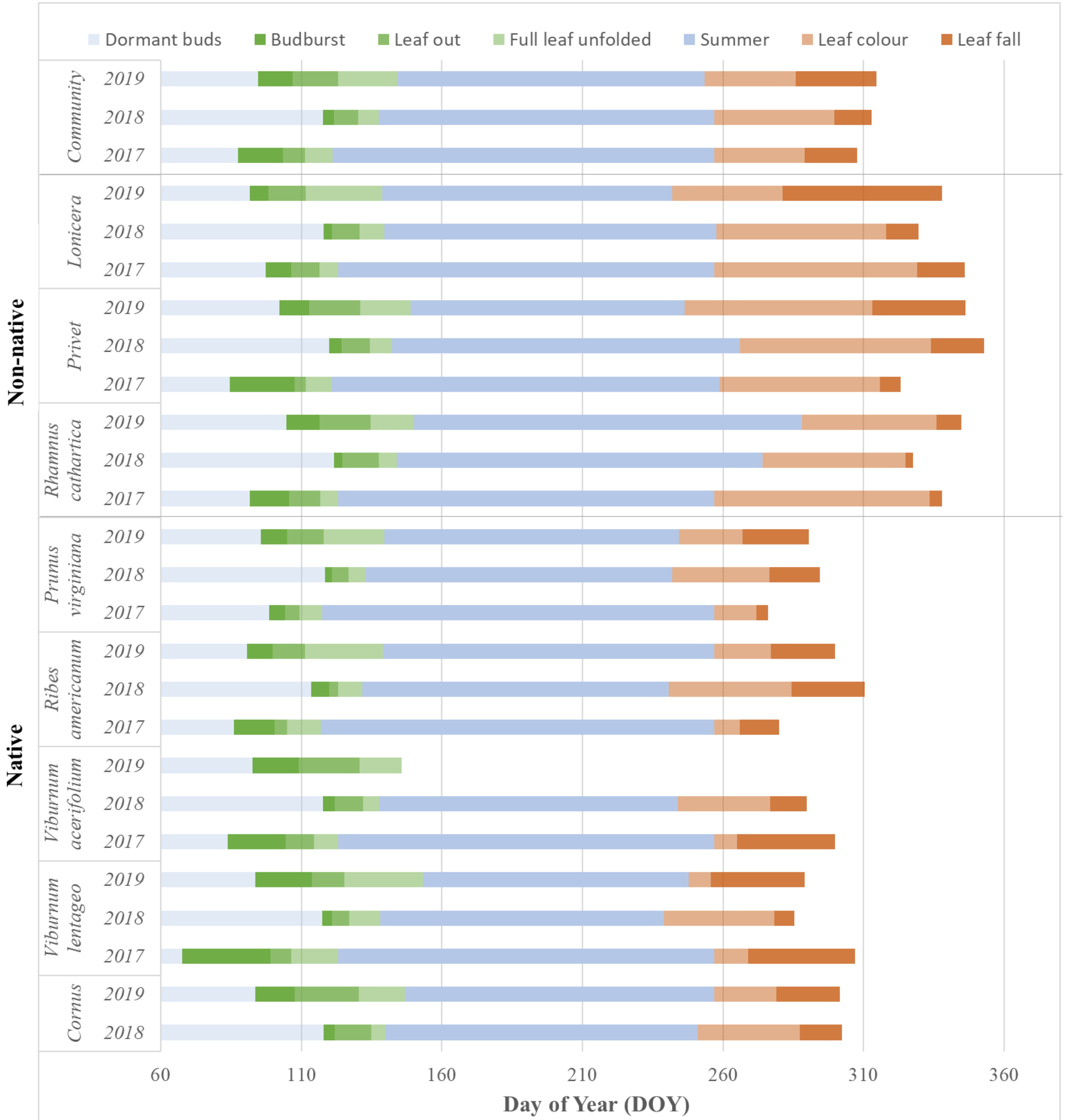

Figure 8: Timing and duration of phenophases of temperate deciduous shrubs throughout the 3-year (2017-2019) study period for Community, Native/Non-native, and species level phenology.

Figure 8 shows the timing of the phenophases for spring (300-590) and fall (800-990) as well as visually representing the duration of the spring and fall seasons for the Community level, Native/Non-Native groups, and species as well. In summary, the spring phenology season for shrubs began earlier in 2017 over the years for most species. Spring season also typically lasts between 5 to 7 weeks where native species tend to bud bust and leaf out earlier and non-native species later. The duration of spring tends to be slightly shorter in non-native species than in native species, but no statistical significance with this duration.

As for fall, the fall seasons are consistently longer than the spring season with fall typically lasting 8-10 weeks (Figure 8). Fall is significantly longer ($p=0.003$) in duration for non-native species than in native species lasting towards DOY 350 for some of the non-native shrubs while native species tend to end the fall season before DOY 310.

4.4 Correlation between phenology and temperature

Tables 22 and 23 show Pearson's r showing correlation between phenology and temperature for spring and fall seasons. The temperature parameter used is average daily spring (March-May) and fall (September-November) temperatures (°C). For phenology, spring start day of year (DOY) of bud burst (300) and end of spring DOY for >90% leaf out (590) were used as well as the duration of the spring season. For fall, beginning of fall leaf color (800), end of fall season (>90% leaf fall- 990), and duration of fall season were used for correlation.

Spring phenology (Table 22) shows no significant correlation between temperature and the beginning spring (300), end of spring (590), nor the duration of the spring season. While non-native species phenophase DOY showed a slightly stronger correlation (r=0.56 to r=0.74) than native species (r=0.24 to r=0.31), neither relationship showed significant correlation.

As for fall correlation (Table 23), there is a strong negative relationship with fall phenology and mean air temperature for both native and non-native species. The negative correlation means that when temperature is going down, starting DOY is becoming later in the year.

Phenophase 800 (leaf color) showed strong negative correlation ($p<0.01$) for non-native species but no significant correlation for native species. As for phenophase 990 (>90% leaf fall- end of spring) and the duration of spring (800-990) there were strong negative correlations for both native and non-native species ($p<0.05$). Non-native species for 800, 990, and duration of fall show a stronger correlation with temperature than the native species.

Table 22: Correlation between spring phenology and average spring (March-May) air temperature (°C) for bud burst (300- Beginning of Spring), >90% full leaf out (590- End of Spring), and Duration of Spring.

		300 Beginning Spring	**590 End Spring**	**Duration Spring**
Native	Pearson Correlation	0.310	0.276	0.243
	Significance	0.281	0.361	0.403
Non-Native	Pearson Correlation	0.565	0.745	0.728
	Significance	0.113	0.055	0.064

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 23: Correlation between fall phenology and average fall (September-November) air temperature (°C) for leaf color (800- Beginning of Fall), >90% leaf fall (990- End of Fall), and Duration of Fall.

		800 Beginning Fall	**990 End Fall**	**Duration Fall**
Native	Pearson Correlation	-0.293	**-0.787****	**-0.660***
	Significance	0.330	**0.001****	**0.01***
Non-Native	Pearson Correlation	**-9.53****	**-0.817***	**-0.792***
	Significance	**0.000****	**0.025***	**0.034***

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

5. Discussion

5.1 Climate Conditions of Downer Woods

This study, while primarily focusing on phenology, did take into consideration climate parameters such as air temperature (°C) and soil temperature (°C) in the urban woodlot of Downer Woods, Milwaukee, in order to provide general environmental conditions to relate to the temperate deciduous forest ecosystem make up. While this study has not been conducted over a long enough period of time to draw a climatology of Downer Woods, the temperature data will be used as supplemental information to the main research topic of phenology.

It is known that timing of spring phenology can be sensitive to spring temperatures (Yu 2013), so temperature was a key component of climate conditions that was measured. For the shrubs in Downer Woods, there were no significant differences of average daily air temperature (°C) between the three-year study period (2017-2019). When broken down by season, there was statistically more variation ($p<0.05$) in spring temperatures for both the current study (2017-2019) and Yu's study in Downer Woods between 2007-2012 (Yu 2013). Fall temperatures did not vary as much showing no significant differences.

For the current shrub research, soil conditions in Downer Woods showed no statistical differences ($p<0.05$) in average daily soil temperature between the three-year (2017-2019). Since Yu did not find significant correlation between a range of climatic parameters including water balance, accumulated precipitation, wind speed and direction, and light intensity, primarily in the fall season, these parameters were not retested in this study.

5.2 *In situ* Observations of Temperate Deciduous Shrubs in Downer Woods

The research conducted relied heavily on direct observations of the phenology of eight different shrub species in Downer Woods located in Milwaukee, Wisconsin over the three-year study period of 2017-2019. Intense spring and fall *in situ* observations were recorded in order to get accurate recordings of shrub phenology for spring and fall seasons for both native (Chokecherry, Currant, Dogwood, Maple Leaf Viburnum, Nannyberry) and non-native species (Buckthorn, Honeysuckle, Privet).

Direct observations have been used widely in phenology studies in order to provide detailed phenological development of individual shrubs over time which cannot often be seen from satellite imagery (Liang & Schwartz 2009, Yu 2013, Donnelly & Yu 2019). Many studies are conducted using locations such as arboretums, botanical gardens, or common gardens while the current research in Downer Woods is located in an actual urban woodlot.

5.3 Interannual Variability of Spring Phenology

5.3.a. Timing

A study carried out by Yu (2013) focused on tree species (Boxelder, Hawthorn, White Ash, American Hophornbeam, White Oak, Red Oak, American Basswood) in the same woodlot of Downer Woods. The spring season for trees in Downer Woods had much variation in timing of phenophases for the different tree species within the five-year (2007-2012) study period with a range of starting DOY for Budburst beginning between DOY 100 (April 10) and DOY 127 (May 7) and ending full leaf out between DOY 105 (April 15) and 138 (May 18) (Yu 2013). A similar study completed in a northern Wisconsin mixed forest between the spring seasons of 2006 and

2010 also showed much variation in starting DOY for spring phenophases of 10 different tree species (8 broad leaf, 2 conifer)(Donnelly et al. 2017).

In relation to the current shrub study, both native and non-native species showed significant differences ($p<0.05$) in starting DOY of major spring phenophases such as the start of budburst which ranged from DOY 91 (Native) to 105 (Non-native) and full leaf unfolded ending between DOY 128 (Native) to 150 (Non-native). Donnelly et al. (2017) reported the DOY of budburst for northern Wisconsin tree species beginning as early as DOY 121 and full leaf out ending as late as 140 across the 10 species studied. While budburst began later in the year in trees than in shrubs, this shows how shrubs tend to have a longer spring season than trees by beginning spring/budburst earlier and ending spring/full leaf out later.

In an additional study by Fridley (2012), there were also no significant differences from starting DOY for the spring phenophases between the native and non-native groups of shrubs. Fridley's 3-year monitoring study in the northeastern United States included 43 native and 30 non-native shrubs in a common garden that represent deciduous forests similar to those of the eastern United States. While this does not align with the current shrub findings, this is most likely due to the fact that this research was completed with *in situ* observations while Fridley (2012) was completed in a common garden (Common garden observations include taking plants from different ecosystems and transferring them to one common ecosystem) with a larger number of species of shrubs in a uniform environment (Donnelly & Yu 2019).

5.3.b Duration

For spring, Yu (2013) reported the duration of the spring season to be around 18 days long for the seven tree species observed while for shrubs in Downer Woods, spring lasts around

32 days long. For this research, the spring season begins on beginning of budburst (300) and ends once leaves of the shrub are >90% full leaf out (590). Furthermore, in Donnelly et al. (2017), with a study site located in northern Wisconsin, the entire spring season lasted anywhere from 11 to 18 days with the average of all species being 13 days between the five-year period for trees from 2006-2010. While both the Yu (2013) and Donnelly et al. (2017) studies were completed on tree species, this indicates that tree species both at Downer Woods and in northern Wisconsin have a shorter spring season by 14 days for Yu (2013) and 19 days for Donnelly et al. (2017). This suggests that shrubs significantly increase the growing season in temperate deciduous forests in the state of Wisconsin.

5.4 Interannual Variability of Fall Phenology

5.4.a Timing

For this research, native species showed significantly different starting DOY for fall phenophases of 800 and 900 ($p=0.041$, $p=0.012$ respectively) where native species began leaf color and leaf fall earlier than non-native species between the three-years (2017-2019) of this study. In Downer Woods, leaf color began on average DOY 259 for non-native species and DOY 247 for native species showing non-native species begin leaf color later. Fridley had similar results to the current study when it came to fall phenology; fall phenophase timing was significantly later in the year for non-native species than native species. In Fridley (2012) non-native species began leaf fall around 28 days later. Similarly, in the current study, non-native species began leaf fall about 20 days later than native species. Together, these studies suggest that temperate deciduous forests with non-native species in the shrub layer can significantly extend the timing of the autumn growing season.

In relation to Yu (2013), the major fall phenophases of leaf color, leaf fall, and >90% leaf fall have interesting comparison to the shrub timing. For Downer Woods trees in Yu (2013), leaf color began on average on DOY 263, leaf fall begins on DOY 269, and >90% leaf fall ends on average DOY 291. In comparison to shrubs, as a community for 2017-2019 leaf color begins on DOY 252, leaf fall begins on average DOY 270, and >90% leaf fall ends on average DOY 308. While leaf fall beginning (phenophase 900) begins almost on the exact same day, leaf color begins on average 11 days earlier in shrubs and leaf fall ends 17 days later in shrubs than trees.

5.4.b Duration

Duration of fall seasons for the shrubs in Downer Woods did not quite align with Yu's findings for tree species in the same woodlot. In Yu's tree research in Downer Woods, the average duration of fall for the study period of 2007-2012 was around one-month long for an average for all species beginning around mid-September, DOY 263 and ending around mid-October DOY 291 (Yu 2013). As for the current research, fall duration lasted as short as 20 days for some native species like Chokecherry in 2017 to as long as 101 days for non-native species such as Privet in 2019. Non-native species continued to extend the fall duration with non-native fall duration ranging from 24 days (Buckthorn 2017) long to 101 days (Privet 2019) long.

With a fall season (beginning of leaf color to >90% leaf fall) total average length of 28 days for trees in Downer Woods during the years 2007-2012 and the average duration of fall for the shrubs in this research of about 58 days this shows that shrubs, on average have a fall season about 30 days longer than the trees in Downer Woods (Yu 2013). This connection shows that shrub duration is much longer than tree duration for seasonal phenology in Downer Woods, Milwaukee, Wisconsin.

In Fridley (2012), there was a large difference in fall phenology such that non-native shrub species had a growing season that was on average nearly one month longer than native species. In this research, non-native shrubs duration was significantly different than native species duration. In Downer Woods, non-native shrub species fall season was significantly longer than native species by on average 35 days, over one whole month. This is an interesting connection to Fridley whereas non-native species have a significantly longer duration of the fall season than native species duration of fall (2012). These results show that temperate deciduous forests with non-native species may increase the carbon uptake period for these ecosystems due to the influence non-native species have on the lengthening of the spring and fall seasons.

5.5 Influence of Temperature on Phenology of Shrubs

In studies completed by Yu (2013) and Donnelly et al. (2017), it was determined that Accumulated Growing Degree Days (AGDD)/Hours (GHD) did not effectively predict phenophase timing of spring, occurrence (Donnelly 2017).

While GHD/AGGD was not used in the current research, a correlation analysis was conducted to determine the role average spring temperature may play in spring and autumn shrub phenology. There was no significant correlation between mean daily air temperature and spring phenology but there was correlation showing mean daily air temperatures influence on fall phenology. This shows that with a decrease in mean daily air temperature in the fall, there is a strong negative correlation that starting day of year (DOY) of fall phenophases will begin sooner.

In Fridley (2012), leaf emergence timing was sensitive to variations in spring temperature. A specific year of 2010 showed that warmer spring was correlated with earlier bud development for shrubs. The current research shows there was no strong correlation between temperature and starting DOY for spring phenophases potentially due to direct *in situ* observations of shrubs growing in the wild in an urban forest versus Fridley's common garden observations which includes a large number of different species undergoing similar environmental and climatic conditions (Donnelly & Yu 2019).

Yu (2013) analyzed maximum, minimum, and mean daily air temperatures for the study of trees in Downer Woods. While Yu did have a strong positive correlation between spring temperature and phenophases showing that as temperatures warm, phenophases will begin earlier, the current shrub study did not see strong correlation. In relation to Yu (2013), the correlation between fall temperature and phenology of trees showed a strong negative correlation which is in agreeance with the current findings that fall temperatures have a strong negative correlation with shrub phenology. This means with a decrease in average daily fall temperature, leaf color (800) and leaf fall (900) will begin earlier.

One of the possible reasons there was no significant correlation between temperature and spring phenology could very well be due to the short study period of three-years (2017-2019). In addition, more temperature variables for both soil and air temperatures such as maximum, minimum, and other parameters could be used in analysis to see if one parameter plays more of a stronger role in phenophase development than others. Further temperature analysis could include monthly temperature analysis as well as Accumulated Degree Growing Days as used in both Yu (2013) and Donnelly et al. (2017).

5.6 Implications of Changing Phenology

Changes in average phenology timing and duration of both native and non-native shrub species have long-term implications for aspects of our environment such as ecosystem interactions and climate. It is suggested in Fridley (2012) that non-native species are driving components of forest productivity and this can have both short- and long-term effects on forest processes. The study concluded that even minor changes in the duration of seasons of specifically non-native shrub species can have effects on forest productivity, carbon sequestration, and nutrient cycling within the forest ecosystem (Fridley 2012).

In a review of shrub phenology, (Donnelly & Yu 2019) climate change will also influence shrub phenology on a species-specific level resulting in extensions of growing seasons for both native and non-native shrubs. With further research and more *in situ* observations, we can understand further how phenology will continue to change in respect to climate change and non-native ecosystem invaders (Donnelly & Yu 2019).

6. Conclusion

The goals of this study were to discover distinct characteristics about spring and fall phenology for 5 native and 3 non-native shrub species in Downer Woods. With shrubs being an under-researched component of phenology, they play a great role in ecosystem function. This study exemplifies the point that shrub growing seasons can be significantly longer than canopy-layer organisms such as trees, in a temperate deciduous forest.

Additionally, since fall phenology is not as often recognized and observed in many ecosystems, this study discovers how 5 native and 3 non-native species in an urban woodlot vary in timing and duration of both spring and fall phenophases using direct observations. Both spring and fall seasons are equally important in understanding timing, duration, and relationships of phenophases to other environmental and/or climate parameters.

Surprisingly, the timing and duration of native and non-native species did not differ as much as expected in the spring season. However, in the fall, non-native shrubs showed a significantly longer fall phenology season than the native species.

With shrubs being an under-studied component to forest ecosystems, this research helps contribute to the general knowledge of shrub phenology within a temperate deciduous forest. With trees being the main study target of research regarding carbon sequestration and other ecosystem function, shrubs seemingly have a uniquely large role in carbon sequestration as well especially confirming with this research that shrubs have a significantly longer growing season than many tree species.

7. Future Research

1. Understanding the relationship between tree and shrub phenology

2. Expansion of relationship between other climate parameters and shrub phenology

3. Longer study period will provide more in-depth analysis

4. This research will be contributed to the VEnμS satellite project in hopes to contribute in-situ shrub phenology to remote sensing data

8. Scientific Contributions

1. Rehberg, C., Donnelly, A., & Yu, R. (2019). Variation in Shrub Phenology Between Native and Invasive Species in an Urban Woodlot. *AGUFM*, *2019*, B13M-2656.

2. Donnelly, A., Yu, R., **Rehberg, C**., Meyer, G., & Young, E. B. (2020). Leaf chlorophyll estimates of temperate deciduous shrubs during autumn senescence using a SPAD-502 meter and calibration with extracted chlorophyll. *Annals of Forest Science*, *77*(2), 1-12.

3.Yu, R., Donnelly, A., & **Rehberg, C**. (2019). Monitoring Phenology in a Deciduous Urban Woodlot 2018-2019 Using the Recently Launched VENμS Micro-satellite Data. *AGUFM*, *2019*, B11N-2354.

4.Donnelly, A., Yu, R., Rehberg, C., Meyer, G., Young, E.B., (2019): Extracted leaf chlorophyll content with corresponding SPAD values of temperate deciduous native and non-native shrubs, autumn 2018, southern Wisconsin, USA. PANGAEA,

5. Radio Interview https://www.wuwm.com/post/uwm-partners-international-space-agencies-study-shrubs#stream/0

6. UW-Milwaukee Colloquium Presentation April 3rd (cancelled due to pandemic)

7. Guest Lecture in Geography 247 (Hyejin Yoon)

References

Donnelly, A., Yu, R., Caffarra, A., Hanes, J., Liang, L., Desai, A.R., Liu, L. and Schwartz, M.D., (2017). Interspecific and interannual variation in the duration of spring phenophases in a northern mixed forest. *Agricultural and Forest Meteorology*, 243, 55-67.

Donnelly, A., Yu, R. (2019). Temperate deciduous shrub phenology: the overlooked forest layer. *International Journal of Biometeorology*.

Fridley, J. (2012). Extended leaf phenology and the autumn niche in deciduous forest invasions. *Nature* 485**,** 359–362.

Fu, Y., He, H. S., Zhao, J., Larsen, D. R., Zhang, H., Sunde, M. G., & Duan, S. (2018). Climate and Spring Phenology Effects on Autumn Phenology in the Greater Khingan Mountains, Northeastern China. *Remote Sensing*, *10*(3), 1–N.PAG.

Gill, A. L., Gallinat, A. S., Sanders-DeMott, R., Rigden, A. J., Gianotti, D. J. S., Mantooth, J. A., & Templer, P. H. (2015). Changes in autumn senescence in northern hemisphere deciduous trees: a meta-analysis of autumn phenology studies. Annals of Botany, 116(6), 875–888.

Huff, S., Poudel, K., Ritchie, M., Temesgen, H. (2018). Quantifying aboveground biomass for common shrubs in northeastern California using nonlinear mixed effect models. *Forest Ecology and Management*. 424. 154-163.

Jolly, W. M., Nemani, R., Running, S. W. (2004) Enhancement of understory productivity by asynchronous phenology with overstory competitors in a temperate deciduous forest. *Tree Physiology*. 24(9):1069-1071.

Kell, D. B. (2012). Large-scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: why and how. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 367(1595), 1589–1597.

Kramer, K., Leinonen, I. & Loustau, D. (2000) The importance of phenology for the evaluation of impact of climate change on growth of boreal, temperate and Mediterranean forests ecosystems: an overview. *International Journal of Biometeorology,* 44 (67).

Lieth, H. (1973) Phenology in Productivity Studies. In: nalysis of Temperate Forest Ecosystems. 29-30 Ecoogical Studies (Analysis and Synthesis), Reichle D.E. (ed.), vol 1, Springer, Berlin, Heidelberg 29-46.

Menzel, A. (2002). Phenology: Its Importance to the Global Change Community. *Climatic Change*, *54*(4), 379.

Menzel, A., Jakobi, G., Ahas, R., Scheifinger, H., and Estrella, N. (2003). Variations of The Climatological Growing Season (1951-2000) in Germany Compared with Other Countries. *International Journal of Climatology* 23 (7): 793-812.

Menzel A, Sparks TH, Estrella N, Koch E, Aasa A, Ahas R, Alm-KüblerK, Bissolli P, Braslavská O, Briede A, Chmielewski FM, Crepinsek Z, Curnel Y, Dahl Å, Defila C, Donnelly A, Filella Y, Jatczak K, Måge F, Mestre A, Nordli Ø, Peñuelas J, Pirinen P, Remisová V, Scheifinger H Striz M, Susnik A, Wielgolaski F-E, van Vliet A, Zach S, Zust A (2006) European phenological response to climate change matches the warming pattern. *Global Change Biol* 12:1-8.

Parry, M.L.I.P.o.C.C.W.G., II (2007) Climate Change 2007: Impacts adaptation, and vulnerability: contribution of Working Group 2 to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.; New York.

Palakit, K., Siripatanadilok, S., Lumyai, P., & Duangsathaporn, K. (2018). Leaf phenology and wood formation of white cedar trees Melia azedarach L.) and their responses to climate variability. *Songklanakarin Journal of Science & Technology,* 40(1), 61–68.

Panchen, Z. A., Primack, R. B., Gallinat, A. S., Nordt, B., Stevens, A.-D., Yanjun Du, & Fahey, R. (2015). Substantial variation in leaf senescence times among 1360 temperate woody plant species: implications for phenology and ecosystem processes. *Annals of Botany,* 116(6), 865–873.

Polgar, C. A., & Primack, R. B. (2011). Leaf-out phenology of temperate woody plants: From trees to ecosystems. *New Phytologist, 191*(4), 926-941.

Primack, R. B., Laube, J., Gallinat, A. S., & Menzel, A. (2015). From observations to experiments in phenology research: investigating climate change impacts on trees and shrubs using dormant twigs. *Annals of Botany,* 116(6), 889–897.

Ren, S., Yi, S., Peichl, M., & Wang, X. (2018). Diverse Responses of Vegetation Phenology to Climate Change in Different Grasslands in Inner Mongolia during 2000-2016. *Remote Sensing,* 10(1), 1–N.PAG.

Rice, K. E., Montgomery, R. A., Stefanski, A., Rich, R. L., & Reich, P. B. (2018). Experimental warming advances phenology of groundlayer plants at the boreal-temperate forest ecotone. *American Journal of Botany, 105*(5), 851-861.

Schwartz, M. D. (1993). Assessing the onset of spring: a climatological perspective. *Physical Geography*, *14*(6), 536-550.

Schwartz, M. D., Ahas, R., & Aasa, A. (2006). Onset of spring starting earlier across the Northern Hemisphere. *Global change biology*, *12*(2), 343-351.

Schwartz, M. D., Liang, L. (2013) High-Resolution Phenological Data. *Phenology: An Integrative Environmental Science,* 19, 351-365.

Schwartz, M. D. & Marotz, G. A. (1988) Synoptic Events and Spring Phenology. *Physical Geography*, 9(2), 151-161.

Schwartz, M.D. Personal correspondence, December 12, 2019.

Suepa, T., Qi, J., Lawawirojwong, S., & Messina, J. P. (2016). Understanding spatio-temporal variation of vegetation phenology and rainfall seasonality in the monsoon Southeast Asia. *Environmental research*, *147*, 621-629.

Yang, L., J.A. Smith, M.L. Baeck, E. Bou-Zeid, S.M. Jessup, F. Tian, and H. Hu, 2014: Impact of Urbanization on Heavy Convective Precipitation under Strong Large-Scale Forcing: A Case Study over the Milwaukee–Lake Michigan Region. *J. Hydrometeor.,* **15**, 261–278

Yu, Rong, "Examining Spring and Autumn Phenology in a Temperate Deciduous Urban Woodlot" (2013). *Theses and Dissertations*. 445.

APPENDIX FOR SUPPLEMENTAL TABLES

A. Temperature

Table 14: Mean monthly temperature (°C) with standard error for Site 11 in Downer Woods over three-year period (2017-2019).

	2017	***2018***	***2019***
January	-3.07±1.10	-4.54±1.31	-6.56±1.47
February	1.13±1.09	-3.61±1.14	-4.33±0.89
March	0.89±0.77	0.73±0.40	-0.44±1.03
April	8.63±0.69	2.77±0.69	6.72±0.64
May	11.54±0.80	14.90±1.07	10.81±0.88
June	18.62±0.56	16.97±0.80	15.37±0.59
July	20.50±0.37	21.53±0.38	21.74±0.52
August	19.59±0.35	21.70±0.39	20.35±0.31
September	18.09±0.62	17.61±0.67	18.15±0.39
October	12.60±0.89	9.94±0.82	8.96±0.78
November	3.75±0.65	0.67±0.74	0.71±0.75
December	-4.08±1.36	-0.41±0.56	-0.72±0.69

B. TUKEY HSD for Native Duration between years

SPECIES				**MEAN DIFFERENCE**	**STD. ERROR**	**SIG.**
CHOKECHERRY	Spring Length	2017	2018	6.167	4.459	0.406
			2019	-24.500*	4.230	**0.003**
		2018	2017	-6.167	4.459	0.406
			2019	-30.667*	3.731	**0.000**
		2019	2017	24.500*	4.230	**0.003**
			2018	30.667*	3.731	**0.000**
	Fall Length	2017	2018	-26.50000*	7.61343	**0.024**
			2019	-26.00000*	7.61343	**0.027**
		2018	2017	26.50000*	7.61343	**0.024**
			2019	0.50000	6.21634	0.996
		2019	2017	26.00000*	7.61343	**0.027**
			2018	-0.50000	6.21634	0.996
MAPLE LEAF VIBURNUM	Spring Length	2017	2018	9.200	3.697	0.052
			2019	-19.889*	3.781	**0.000**
		2018	2017	-9.200	3.697	0.052
			2019	-29.089*	3.447	**0.000**
		2019	2017	19.889*	3.781	**0.000**
			2018	29.089*	3.447	**0.000**
NANNYBERRY	Spring Length	2017	2018	34.800*	1.904	**0.000**

			2019	-2.600	1.904	0.389
		2018	2017	-34.800*	1.904	**0.000**
			2019	-37.400*	1.904	**0.000**
		2019	2017	2.600	1.904	0.389
			2018	37.400*	1.904	**0.000**
	Fall Length	2017	2018	4.20000	4.69468	0.654
			2019	5.40000	4.69468	0.503
		2018	2017	-4.20000	4.69468	0.654
			2019	1.20000	4.69468	0.965
		2019	2017	-5.40000	4.69468	0.503
			2018	-1.20000	4.69468	0.965
WILD CURRANT	Spring Length	2017	2018	12.600*	2.597	**0.001**
			2019	-19.400*	2.597	**0.000**
		2018	2017	-12.600*	2.597	**0.001**
			2019	-32.000*	2.597	**0.000**
		2019	2017	19.400*	2.597	**0.000**
			2018	32.000*	2.597	**0.000**
	Fall Length	2017	2018	-46.00000*	7.82645	**0.000**
			2019	-14.00000	7.82645	0.215
		2018	2017	46.00000*	7.82645	**0.000**
			2019	32.00000*	7.82645	**0.004**
		2019	2017	14.00000	7.82645	0.215
			2018	-32.00000*	7.82645	**0.004**

C. TUKEY HSD for Non-Native Duration between years

SPECIES				**MEAN DIFFERENCE**	**STD. ERROR**	**SIG.**
BUCKTHORN	Spring Length	2017	2018	6.500	3.099	0.145
			2019	-19.400*	2.963	**0.000**
		2018	2017	-6.500	3.099	0.145
			2019	-25.900*	2.722	**0.000**
		2019	2017	19.400*	2.963	**0.000**
			2018	25.900*	2.722	**0.000**
	Fall Length	2017	2018	24.40000*	6.73795	**0.009**
			2019	21.20000*	6.73795	**0.021**
		2018	2017	-24.40000*	6.73795	**0.009**
			2019	-3.20000	6.73795	0.884

		2019	2017	-21.20000*	6.73795	**0.021**
			2018	3.20000	6.73795	0.884
PRIVET	Spring Length	2017	2018	7.333	5.831	0.466
			2019	-20.000*	5.831	**0.032**
		2018	2017	-7.333	5.831	0.466
			2019	-27.333*	5.831	**0.008**
		2019	2017	20.000*	5.831	0.032
			2018	27.333*	5.831	**0.008**
	Fall Length	2017	2018	28.00000*	3.05505	**0.000**
			2019	-7.00000	3.05505	0.133
		2018	2017	-28.00000*	3.05505	**0.000**
			2019	-35.00000*	3.05505	**0.000**
		2019	2017	7.00000	3.05505	0.133
			2018	35.00000*	3.05505	**0.000**
HONEYSUCKLE	Spring Length	2017	2018	4.500	13.150	0.938
			2019	-35.000*	10.737	**0.033**
		2018	2017	-4.500	13.150	0.938
			2019	-39.500*	13.150	**0.046**
		2019	2017	35.000*	10.737	**0.033**
			2018	39.500*	13.150	**0.046**
	Fall Length	2017	2018	-14.75000	6.89259	0.143
			2019	-29.75000*	5.33898	**0.001**
		2018	2017	14.75000	6.89259	0.143
			2019	-15.00000	6.65888	0.121
		2019	2017	29.75000*	5.33898	**0.001**
			2018	15.00000	6.65888	0.121