Phenology of Plants at the Kleinstuck Preserve

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Phenology is the study of the timing of plant and animal life cycle events such as migration for birds or blooming for flowers (Project Budburst).It is primarily concerned with the dates of first occurrence of life cycle events. Researchers studying phenology make inferences regarding how the timing of life cycle events is influenced by seasonal climate change and affects an organism's ability to survive, reproduce, and compete. Because it is easy to track individual plants since they are sessile, the study of phenology in plants is of particular interest.

Over the past 200 years, concentrations of carbon dioxide and other greenhouse gases (water vapor, methane, and ozone) have increased in the atmosphere due to the burning of fossil fuels, like coal and oil, and deforestation (United States EPA). Increases in the concentrations of these gases is allowing less heat that enters earth's atmosphere from the sun to escape in the form of infraredrays through the earth's atmosphere causing earth's average temperature to rise.This phenomenon has been termed "global warming." According to NOAA and NASA data, the Earth's average surface temperature has increased by about 1.2 to 1.4 degrees Fahrenheit in the last 100 years (United States EPA). The greatest increases in average temperatures for each season have been observed for the spring and winter seasons (Schwartz, Ahas, &Aasa, 2006). Zhou et al. (2001) found that with global warming, the length of growing seasons (period during which temperature and other environmental factors are conducive to agricultural growth) in temperate regions (regions between the tropics and polar circle) has increased by as much as 12-18 days since the late 1970s (Nord & Lynch, 2001).

An individual plant's phenology is influenced by genetic factors as well as environmental factors including temperature, moisture, light intensity, light quality, photoperiod, carbon dioxide, and minerals (Rathcke& Lacey).Temperature is of particular interest because of global warming and because it has an influence on the other environmental factors. More specifically, temperature influences the rate of evaporation of moisture from soil and the amount of carbon dioxide that can be held by the air. Because many life cycle events are sensitive to temperature, phenological records can be a useful proxy for temperature. Increases in temperature due to global warming is causing spring life cycle events such as emerging growth, flowering and bloomingto occur earlier and fall life cycle events such as plant deathto occur later each year.Notably, researchers have found that plant leafing and blooming are occurring earlier each year especially since the mid-1950s (Walther, 2003 as cited by Schwartz, Ahas, &Aasa, 2006).

However, the effects of global warming on plant phenology are more complicated than all spring life cycle events simply occurring earlier and all fall life cycle events occurring later. Although this is the overall pattern, the effects of global warming on plant phenology differ depending on a number of factors.

First, the effects of global warming on the phenology of plants may differ depending on the latitude since the degree of global warming and effects of global warming vary according to latitude.Specifically, scientists believe that most areas in the United States will warm. However northern regions and particularly Alaska are expected to experience the most warming (United States EPA). Also, in one study, researchers studied bloom times in the northern hemisphere and found thatabove

40 degrees latitude north, spring blooms have been occurring an average of 0.32 days earlier each year whereas below 35 degrees latitude north, blooms have been occurring later every year (Zhang et al. as cited by Thompson, 2007). Between 35 and 40 degrees latitude north, the researchers observed a transition zone between the two patterns. Zhang et al. suggest that spring blooms are occurring later below 35 degrees latitude north because winter is a key time in seed development. Seeds need to chill and lie dormant for proper development and shorter winters and warming temperature are interfering with that process causing delayed sprouting. Thus, although regions further north are experiencing greater increases in temperature each year, because regions further south are already warmer than regions in the north, the increases in temperature in the southern part of the north hemisphere take away enough chilly winter days to interfere with seed development whereas the increases in temperature occurring in the northern part of the north hemisphere have not taken away enough chilly winter days to interfere with seed development and instead simply cause flowers to bloom earlier. Zhang et al. predict that as global temperatures continue to increase, the transition zone is likely to move north, with later spring bloom times moving further north as more chilly winter days disappear.It should be noted thatZhang et al. suggest that the changes in bloom time are the result of changes in time of sprouting that cause a general shift earlier or later in the timing of spring life cycle events. Thus, their findings and hypotheses are not limited to blooming times but likely apply to all spring life cycle events.

Second, the effects of global warming on the phenology of plants may differ depending on whether the particular region being studied is urban or rural. Higher temperatures have been observed in urban area than rural areas, a phenomenon termed the "urban heat island" effect (Zhang, Friedl, Schaaf, &Strahler, 2004).In North America, the average spring temperature and mean annual temperature is 1-3 degrees Celcius higher in urban areas compared to rural areas. As would be expected, the phenology of plants in urban areas has been observed to differ from the phenology of plants in rural areas. Zhang, Friedl, Schaaf, and Strahler (2004) found that the covering of land with vegetation, a phenomenon referred to as "green-up" and indicative of a life cycle event referred to in phenology as sprouting or"emerging growth," occurred 4-9 days earlier in urban areas compared to rural areas in North America.

As a result of global warming, germinating earlier offers an advantage in terms of interspecific and intraspecific competition. The seedling stage associated with sprouting is the most vulnerable time in a plant's life and how early seeds germinate influences how soon a seed will demonstrate other spring life cycle events(Rathcke& Lacey, 1985). It is important for seeds to germinate at a time that will result in spring life cycle events, particularly sprouting, occurring when environmental conditions are favorable. Generally, in temperate regions,plants from seeds that germinate unusually early in the season have lower probabilities of survival, due to the risk of frost, than plants from seeds germinating later, but plants fromearly germinating seeds that do survive have greater fitness (as measured by biomass, survival, and reproductive success) than plants from seeds that germinate later likely because they have a longer growing season (Ratchke& Lacey). Ross &Harper further demonstrated that plants from early germinating seeds grow more quickly and continually increase their ability to acquire resources at the expense of plants from later germinating seeds (as cited by Ratchke & Lacey). Thus, surviving plants from seeds that germinate early not only have a longer growing season but also grow at a faster rate than plants from seeds that germinate later. This is likely because plants from early germinating seeds get early access to resources and thus have access to more resources than plants from later germinating seeds. With global warming, there is a lower risk for frost earlier in the year and thus it is becoming less beneficial for plants to sprout later in order to protect from frost and more beneficial for plants to sprout earlier (Schwartz, 2003). Plants that germinate andsprout earlier are getting the earliest access to resources and greatest reproductive successand fitness without taking the risk of death through frost. It is worth noting that species that reproduce only one time during their lives more commonly produce seeds that will germinate at different times than plants that reproduce every year (Rathcke& Lacey, 2003). Perhaps this is because plants that only reproduce once during their lifetime risk complete reproductive failure if they produce all seeds that will germinate during a single unfavorable period.

Invasive species are species that are not native to a particular region but arrived from another region and have characteristics that allow them to outcompete native species (as defined for the present study). Invasive species often have characteristics that give them the ability to take large proportions of available resources (e.g., nutrients from the soil, sunlight, moisture, and space) from other species (USA National Phenology Network). In many cases, the presence of an invasive species leads to an overall decrease in species richness in an area because an invasive species causes other species to go extinct. It is likely that the phenology of invasive species influences their ability to outcompete other species, particularly by favoring the ability of invasive species to gain access to resources.

The purposes of the present study were 1) to observe differences in the phenology and growth of three invasive species (flower, shrub, vine) and three native species (flower, shrub, vine) at the Kleinstuck Preserve in Kalamazoo, Michigan and 2) to design a simple protocol so that neighbors of the Kleinstuck preserve can study phenology as a means by which to study and learn more about the preserve and global warming. Kalamazoo, Michigan is located approximately 42 degrees north latitude and is thus considered a temperate region. We hypothesized that spring life cycle events would occur when expected according to current phenology records but due to global warming, life cycle events would occur observably earlier across years if the study was continued by community members for greater than five years. Furthermore, we predicted that due to the risk of reproductive failure as the result of producing seeds that germinate during a single unfavorable period, there would be greater variation in the timing of life cycle events among subjects for species that only reproduced once during their lifetime than for other species.Lastly, because demonstrating life cycle events earlier gives a plant access to more resources, we predicted that invasive species would demonstrate spring life cycle events earlier than native species. We also predicted that invasive species would grow at a faster rate than native species.

Methods

Study Site

In 1922,the Kleinstuck Preserve was donated to the Michigan Board of Education by Caroline Kleinstuck in memory of her husband to be used for research and educational purposes. In 2007, the Stewards of Kleinstuck formed with the goal of involving the community in improving the preserve's health by eradicating invasive species, improving eroded sites, and promoting a more diverse and functioning ecosystem for the benefit of both the preserve and the community (The Stewards of Kleinstuck).

Subjects

A native and invasive, flower, shrub, and vine were selected from a list of plants present in Kleinstuck Preserve provided by the Stewards of Kleinstuck (The Stewards of Kleinstuck). We selected *Arisaema triphyllum*(Jack-in-the-pulpit) as our native flower and *Alliaria petiolata* (Garlic Mustard) as our invasive flower, *Salix caprea* (Pussy Willow) as our native shrub and *Euonymus alatus (*Winged Wahoo) as our invasive shrub, and *Vitis riparia* (Riverbank Grape) as our native vine and *Celastrus orbiculatus* (Asian Bittersweet) as our invasive vine.

We identified, marked (using flagging tape), photographed, and mapped three subjects of each species except Pussy Willow, which was not identified within the preserve (Figure 1). Each species was assigned a symbol and each subject was assigned a number 1-3 based on the subject's location in preserve. All selected subjects were along the trail or easily visible and accessible from the trail so that community members could easily observe the phenology of selected subjects after our completion of the study. Subjects were distributed so that all subjects and particularly subjects of the same species were not concentrated in a single region.

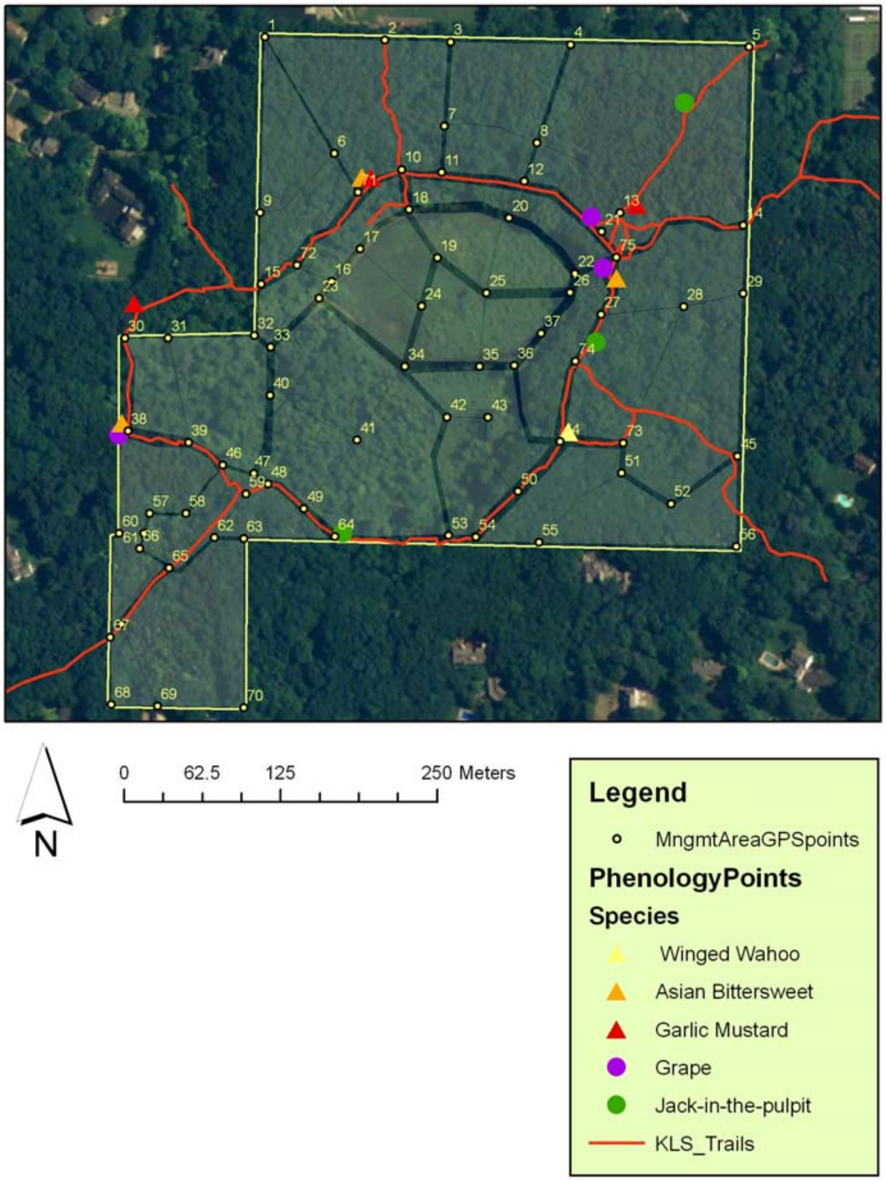

Figure 1. Map showing location of each subject.

Data Collection

During the study period (April 21st, 2009 - May 27th, 2009), we made six visits to the preserve (April 21st, May 5th,May 7th, May 10th, May 14th, and May 27th). During each visit, we recorded observable physical changes, including the occurrence of life cycle events,and photographed each subject. During our fourth and fifth visits(May 10th and May 14th), we recorded the height of allshrubs and flowers, and girth of all vines.

Data Compilation and Future Protocol

The life cycle eventsdemonstrated throughout each year by each of our selected species and the range of dates of first occurrence within which each life cycle event is expected to occur was identified using the USA National Phenology Networkand Project Budburst. In order to display the phenology data we were able to collect during the study period clearly as well as develop a way for community members to record their phenological observations in an organized and scientific way, phenology tables were created. A table for each specieswas created showing each life cycle event that took place in that particular species, each life cycle event's expected occurrence, and for life cycle events we were able to observe during the study period, the observed date of first occurrence. Blank spaces for data of observed first occurrence wereleft for community members to fill in for life cycle events that did not take place during our study period. Furthermore, photographs of each life cycle event are shown in Appendix A so that community members can easily identify life cycle events. Growth for all subjects and species was compiled into a single table. It is not anticipated that community members continue to record growth data.

Results

We found no differences between the expected dates of first occurrence and the observed dates of first occurrence in any species with the exception ofearlier than expected dates of first occurrence for unfolded leafs in all Jack-in-the-pulpit subjects, 2nd year flower inGarlic Mustard2, and first ripe fruit in all Garlic Mustard subjects(Tables I-IV). No differences in phenology wereobservedamongJack-in-the-pulpit subjects or Asian Bittersweet subjects(Tables I and V). Among Garlic Mustard subjects, Garlic Mustard 2 exhibited 2nd year flower two weeks before Garlic Mustards 1 and 3 (April 21st versus May 5th) and Garlic Mustards 1 and 2exhibited fruit two weeksbefore Garlic Mustard 3 (May 14th versus May 27th; Table II). All three Winged Wahoo subjects already had leaves by our first visit (April 21st). Only Winged Wahoo 1 showed a first flower on May 7th whereas Winged Wahoos 1 and 2 did not exhibit a first flower before our last visit on May 27th (Table III).Riverbank Grape 1 and 3demonstrated a first leaf (May 5th) butRiverbank Grape 2 did not demonstrate first leaf before May 27th (Table IV).

We found that height (flowers, shrubs) or girth(vines) was greater in all invasive species than native species as of our last visit on May 27th. We also found that invasive species displayed higher growth rates than native species. Average height or girth increased more in one week (May 7th - May 14th) in invasive species than native species (Table VI).

Table I. Expected and observed first dates of occurrence for life cycle events in Jack-in-the-pulpit (JP) subjects. Flowering was not observed due to risk of damaging plant when checking for flowering.

Life cycle event	Expected date	Observed date JP1	Observed date JP2	Observed date JP3
Emerging growth	April to June	May 5	May 5	May 5
Unfolded leaves	June to July	May 14	May 14	May 14
Leaves withered	July to August			
First ripe fruit	August to September			

Table II. Expected and observed first dates of occurrence for life cycle events in Garlic Mustard(GM) subjects. All selected Garlic Mustard subjects were in their 2nd year.

Life cycle event	Expected date	Observed date GM1	Observed date GM2	Observed date GM3
1st Year basal rosette	April to June	N/A	N/A	N/A
2nd Year first flower	Late April to June	May 5	April 21	May 5
1st Ripe fruit	Mid-June to Early August	May 14	May 14	May 27th
2nd Year plant death	Post Seed Dispersal			

Table III. Expected and observed first dates of occurrence for life cycle events in Winged Wahoo (WW) subjects.

Life cycle event	Expected date	Observed date WW1	Observed date WW2	Observed date WW3
First leaf	March to April	Leaves all present April 21	Leaves all present April 21	Leaves all present April 21
First flower	April to July	May 7		
First ripe fruit	July to September			
50% Color	September to November			
50% Leaf fall	November to December			

Table IV. Expected and observed dates of first occurrence for life cycle events in Riverbank Grape (RBG) subjects.

Life cycle event	Expected date	Observed date RBG 1	Observed date RBG 2	Observed date RBG 3
First Leaf	April to May	May 5		May 5
First Flower	April to June			
First Ripe Fruit	July to September			
50% Leaf Fall	November to December			

Table V. Expected and observed dates of first occurrence for life cycle events in Asian Bittersweet (AB) subjects.

Life cycle event	Expected date	Observed date AB 1	Observed date AB 2	Observed date AB 3
First leaf	April to May	May 5	May 5	May 5
First flower	May to June			
First ripe fruit	July to October			
50% Leaf color	November to December			
50% Leaf fall	November to December			

Table VI. Height (in; flowers and shrubs) or girth (in; vines) for each subject on May 7th and May 14th.

Subject	Date	Height/ girth (in)	Mean	Date	Height/ girth (in)	Mean
Jack in the Pulpit 1	May 7	8.86		May 14	10	
Jack in the Pulpit 2	May 7	6.3	8	May 14	7.5	8.9
Jack in the Pulpit 3	May 7	8.86		May 14	9.4	
Garlic Mustard 1	May 7	15.96		May 14	21.5	
Garlic Mustard 2	May 7	22.8	19.7	May 14	30	27
Garlic Mustard 3	May 7	20.9		May 14	29.5	
Winged Wahoo 1	May 7	41.8		May 14	51	
Winged Wahoo 2	May 7	79.8	60.5	May 14	80	65.66
Winged Wahoo 3	May 7	60		May 14	66	
Riverbank Grape 1	May 7	4.8		May 14	5.1	
Riverbank Grape 2	May 7	3	3.4	May 14	3.2	3.6
Riverbank Grape 3	May 7	2.5		May 14	2.5	
Asian Bittersweet 1	May 7	4.2		May 14	5	
Asian Bittersweet 2	May 7	1.5	7.1	May 14	1.5	7.5
Asian Bittersweet 3	May 7	15.7		May 14	16	

Discussion

As hypothesized, we found no differences between the expected dates of first occurrence and the observed dates of first occurrence in any species with the exception of earlier than expected dates of first occurrence for unfolded leafs in all Jack-in-the-pulpit subjects, 2nd year flower in Garlic Mustard 2, and first ripe fruit for all Garlic Mustard subjects. The early unfolding of leaves in Jack-in-the-pulpit subjects in Kleinstuck preserve may be because natural selection has favored Jack-in-the-pulpit plants that exhibit life cycle events such as the unfolding of leaves early more so in Kleinstuck preserve than in the environments where the expected dates of first occurrence for the unfolding of leaves for Jack-in-the-pulpit were established. In the Kleinstuck preserve there is such an abundance of invasive species, such as Garlic Mustard, that will take resources and grow faster blocking sunlight, that the Jack-in-the-pulpit plants that manage to survive and reproduce are likely the ones who can successfully compete with these invasive species. A way they can successfully compete with these invasive species is by exhibiting life cycle events, such as the unfolding of leaves, earlier than would be expected based on observations of Jack-in-the-pulpitin other environments, which likely have less of an abundance of invasive species. Another possible explanation may be that the information available for expected dates of first occurrence for the unfolding of leaves in Jack-in-the-pulpit plants may be outdated and due to global warming, Jack-in-the-pulpit plants throughout environments where they are present or at least environments where they are present at similar latitudes to Kleinstuck preserve, are demonstrating an earlier unfolding of leaves than was recorded when information for expected date of first occurrence for unfolding of leaves in Jack-in-the-pulpit was established.The earlier than expectedobserved dates of first occurrence for 2nd year flower inGarlic Mustard 2, and first ripe fruit for all Garlic Mustard subjectsmay have been for the same reasons as this latter explanation provided to explain the early unfolding of leaves in Jack-in-the-pulpit subjects.

As consistent with our hypothesis regarding variability among subjects within a species, there was greater variation in the timing of life cycle events that occurred among individuals in species we observed that reproduce only once during its lifetime compared to the other species. Garlic Mustard plants were our only selected species that reproduce only once during their lifetime and showed the most variability in the timing of their life cycle events among subjects. Among Garlic Mustard subjects, not only did Garlic Mustard 2 exhibit 2nd year flower two weeks before Garlic Mustards 1 and 3 but also Garlic Mustards 1 and 2exhibited fruit two weeksbefore Garlic Mustard 3. Although Riverbank Grape and Winged Wahoo subjects also demonstrated some variation in the timing of life cycle events among subjects, they varied on no more than one life event. However, we may have observed more variation among Garlic Mustard subjects than the other species because we observed the most life cycle events in Garlic Mustard plants of any of the species during the study period. It is possible that if the study were continued, we would find that Garlic Mustard plants did not exhibit any more variation among subjects than other species. Interestingly, all of our selected Garlic Mustard plants ended up being in their 2nd year (and thus final year of life). Given that upon selecting subjects, there was no way to distinguish between 1st and 2nd Garlic

Mustard plants, the fact that all selected Garlic Mustard plants turned out to be in their 2nd year suggests that there are more2nd year Garlic Mustard plants in the preserve than 1st year Garlic Mustard plants. Thus, we can predict that nextyear, there will be more 1st year Garlic Mustard plants than 2nd year Garlic Mustard plants.

Evidence was provided that our selected invasive species were indeed invasive at the Kleinstuck preserve. First, invasive species were much more abundant (based on non-quantitative observations) than the native species. It was far more difficult to locate three subjects of our selected native species than our selected invasive species because of this. In fact, we were never able to locate our selected native shrub, Pussy Willow. Second, for invasive and native species that demonstrated the same life cycle events, life cycle events took place earlier in invasive species. By May 5th, all Asian Bittersweet (invasive vine) subjects had leaves present whereas only two Riverbank Grape (native vine) subjects had leaves present. We were not able to observe flowering in Jack-in-the-pulpit because of the risk of damaging the plant so we do not know if flowering occurred by the end of our study period but we do know that first ripe fruit did not occur during the study period and is not expected to occur until August or September. However, flowering as well as first ripe fruit occurred in Garlic Mustard before the end of the study period. These data suggestthat getting an early start on life cycle events is a characteristic that allows invasive species to outcompete native species because of early access to resources and thus access to more resources than other species. Third, by the end of the study period, all invasive species were taller or wider than their invasive counterparts. This is likely for several reasons. First, invasive species had more time to grow before the end of the study period since theyexhibited life cycle events earlier than native species. Second, as expected, a faster growth rate was observed in invasive species than native species. This was likely because invasive species demonstrated life cycle events earlier and thus had access to more resources.Third, because invasive species are able to attain large amounts of resources, they have evolved to be larger than native species. By being larger than other species, invasive species take more resources.Overall, it appears that the phenology of invasive species helps invasive species outcompete native species.

. In conclusion, studying phenology can elucidate a great deal of information about the species in Kleinstuck preserve and if studied over the longer term, climate change. Furthermore, tracking phenology is a simple way for community members to gather scientific data that can help them learn more about the preserve as well as understand the effects of global warming.

Future Directions

It is our hope that the present study will be continued by community members. Community members may choose to track different species than the particular species observed in the present study. If community members continue to study Garlic Mustard, they will need to identify new Garlic Mustard subjects to track next year because Garlic Mustard is a biannual plant and all of our Garlic Mustard subjects were in their 2nd year. Jack-in-the-pulpit is a perennial plant that will re-emerge each year. However, it may be difficult to identify the same Jack-in-the-pulpit subjects for each year and thus it may be necessary to track different Jack-in-the-pulpit subjects each year.

It should be re-emphasized that observable changes in the phenology of species cannot be expected to occur across a period of less than five years. It is also expected that eventually, spring life cycle events would start to occur later instead of earlier than expected as predicted by Zhang et al. (as cited by Thompson, 2007). However, this would take on the shortest possible time scale decades and thus, it is very unlikely that this study would be continued long enough for this change to be observed.

Phenology is a simply way to gather scientific data. However, it is most useful if studied across the long-term. Phenology data collected across the long-term is rare to find and very valuable for scientists trying to understand the effects of global climate change. The accessibility of Kleinstuck preserve to community members and the ease of recording phenological data makes Kleinstuck preserve an ideal location in which to conduct a long-term phenology study that could provide valuable data on the preserve for the community and for scientists outside of the community.

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Appendix A (sorry, not available)

Figure 1. Jack-in-the-pulpit life cycle events with pictures.

Figure 2. Garlic Mustard life cycle events with pictures.

Figure 3. Winged Wahoo life cycle events with pictures.

Figure 4. Riverbank Grape life cycle events with pictures.

Figure 5. Asian Bittersweet life cycle events with pictures.