PLANT PHENOLOGICAL RESPONSES TO CLIMATE CHANGE

IN THE NORTHERN GREAT PLAINS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

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Climate change has been associated with shifts in phenological events which could be disrupting evolved species relationships. The current first flowering times of plants were compared to historical data in the Red River Valley. This gave insight as to what effects climate change is currently having on species in this area. By merging climate variable data from the same time period it was possible to correlate first flowering dates with climate variables for that specific year. Variation in plant flowering times was analyzed over the century to better understand potential ecological consequences of climate change. First flowering times were found to have shifted since previously recorded. The lengthening growing season in the Red River Valley as a result of climate change has resulted in significant shifts in the timing of plant life cycles. The second study used an experimental approach to test the effects of warming on plant species in the tallgrass prairie. Measuring phenological and species composition responses to the temperature changes showed evidence that increasing air temperatures are leading to earlier flowering. There was also a significant increase in species richness. The results of both studies conclude that climate change has the potential to impact the plant community by shifting phenological responses in the tallgrass prairie in the Northern Great Plains.

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GENERAL INTRODUCTION

The connection between abiotic factors and biological organisms is very important. The role of climate in the biology of species living on the planet is one such interaction between abiotic and biotic elements. Because there is strong evidence that the planet's climate is changing, there is a need for better understanding of the impacts of climate on many species around the world. Changes in climate could have different impacts in different environments and the various species within those environments. There could also be cascading effects on many other species due to the interconnected relationships of species within ecosystems. One way to study the effects of climate change is to look at changes in phenology of these organisms. Phenology is the study of seasonal life cycle events (e.g., plant germination and flowering, migratory bird behavior). Phenology can reflect the relationship between organisms and their abiotic environment. By looking at phenological events and their relationship to climate change, I hope to understand how the tallgrass prairie has changed and may continue to change in the future.

The first study used historical data of first flowering dates from 1910 to 1961 collected by O. A. Stevens and recent observations from 2007 to 2009 to look at changes in first flowering times. The objectives of this study was to 1) analyze O.A. Stevens' data of first flowering times with climate variables to look for trends and relationships, 2) compare the recent first flowering times of plants (2007 to 2009) and historical first flowering times (1910 to 1961), and 3) determine if first flowering times of different species have changed since last century.

The second study was a manipulative experiment to build on what was found in the first study. Passive heating chambers were used to increase the temperature in plots on tallgrass prairie in Minnesota to isolate the influence of increased temperature on plants. The objectives of this study are 1) assess phenological effects of artificially increasing temperature, 2) determine effects of warming on species composition, 3) determine if invasive species will thrive under warmer conditions, and 4) determine if warming will affect productivity.

PAPER 1. SHIFTS IN FIRST FLOWERING TIMES IN THE NORTHERN GREAT PLAINS FROM 1910 TO 2009

Abstract

Climate change is associated with phenological shifts in an increasing number of organisms worldwide. Plants growing in alpine regions and northern latitudes that traditionally have short growing seasons are shifting to earlier phenophase initiation disrupting evolved species relationships. The first flowering times of plants were compared in the Red River Valley region of North Dakota and Minnesota in spring 2007, 2008, and 2009 to first flowering times in 1910 to 1961 using historical data from O.A. Stevens. The goal was to examine what, if any, effects climate change is having on species in the areas straddling the prairie to woodland ecotone near Fargo, ND. The first objective was to determine if plant flowering times had shifted earlier over the century, to better understand potential ecological consequences of climate change. By merging climate variable data from the same time period it was also possible to correlate first flowering dates with climate variables for that specific year. Analyses of correlations among climate variables and phenological shifts yielded insight into mechanisms initiating flowering in this plant community. Also, first flowering times have shifted both earlier and later compared to previous records. The results of this study show that lengthening growing season in the Red River Valley as a result of climate change has resulted in significant shifts in the timing of plant life cycles with potentially important ecological implications.

Introduction

Phenology is the study of seasonal timing of life cycle events (Rathcke and Lacey 1985). In the past few years interest in phenology has grown due to the insight it provides on climate change and the effect climate change is having on the biosphere (Post et al. 2008, Walther et al. 2002, Cleland et al. 2007, Root et al. 2003). The aspect of phenology that is being researched in this study is the timing of first flowering of plants in the Northern Great Plains.

The timing of flowering of plants is potentially very important for the fitness of individuals. Ecological relationships between plants and pollinators or plants and herbivores are dependent on the timing of life cycle events for the interacting species. According to Waser (1979), seed set per flower in ocotillo, *Fouquieria splendens,* is greatest at the time that hummingbirds migrate implying that selection has favored those individuals that synchronize flowering so as to maximize pollinator visitation. In a study conducted by Schemske on *Impatiens pallida,* there is strong evidence that in some populations, early-summer flowering increases fitness relative to later flowering due to increasing levels of herbivory in mid- and late-summer (Schemske 1984).

There are three major physical environmental factors that have been identified as important determinants of flowering onset: photoperiod, temperature, and moisture (Rathcke and Lacey 1985). Photoperiod has been reported to be a major controller of flowering in short-lived herbs, however, most temperate woody species and some perennial herbs flower in response to temperature. Moisture is a major factor in inducing flowering in seasonal tropical forests (Rathcke and Lacey 1985).

The Earth's average temperature has warmed by about 0.6 degrees Celsius over the past hundred years (IPCC 2007). The rate of warming from 1976 onwards has been greater than at any other time in the last 1000 years (Walther et al. 2002). There is strong evidence that this is due to increasing concentrations of greenhouse gases in the atmosphere which trap reflected radiation and cause higher temperatures (IPCC 2007). If atmospheric CO_2 concentrations continue to increase, as they have over the past hundred years, global temperature increase due to the greenhouse effect is predicted to have continuing effects on precipitation patterns, soil moisture, and snow and ice cover (IPCC 2007). One of the effects of increasing air temperatures is an earlier initiation of spring and of spring phenological events.

Regional changes in climate should have a greater impact on ecology than global changes (Walther et al. 2002). Shifts in climate leading to earlier springs in the Northern Great Plains could result in significant changes in local flowering phenology. Studies researching phenological responses to climate change using historical data have shown that many plant species are now flowering earlier than they have in the past (Bradley et al. 1999, Miller-Rushing and Primack 2008). One study in southern Wisconsin has shown that over a 61-year period several phenological events, including flowering times of plant species and arrival times of migrant birds, were shifting to earlier dates in concert with increasing spring temperatures (Bradley et al. 1999). This study also suggested that since the seasonal temperature changes are magnified at higher latitudes and alpine regions, there may be more significant changes in phenological responses in those regions than would be shown in tropical regions (Bradley et al. 1999, Inouye et al. 2002, Inouye et al.

2003). However, in contrast to climate change effects on the phenology of alpine communities, we know little about how climate change is affecting native plants in northern latitudes particularly in the Northern Great Plains. In a study conducted in Concord, Massachusetts using archival data collected by Henry David Thoreau and botanist Alfred Hosmer, Miller-Rushing and Primack found that the first flowering times of local plants species were on average seven days earlier than when observed by Thoreau (Miller-Rushing and Primack 2008). The conclusion was that the timing shifts were due to rising winter and spring temperatures in the area (Miller-Rushing and Primack 2008). These phenological shifts in plant species could have significant ecological consequences. There could be a disruption of relationships between pollinators and plants, and ultimately changes in plant species' reproductive success (Saavedra et al. 2003). There could also be changes in species distribution and abundance (Walther et al. 2002). In some cases increased damage from spring frost is believed to result from earlier flowering (Inouye 2008).

In order to draw conclusions about long term (100 years) shifts in biological events, long-term data sets containing records of phenological events before the changes in climate observed since the 1970s are required. Here the results of a comparative study is presented, building on the historical observations made in the Northern Great Plains by O.A. Stevens, who recorded the first flowering dates of hundreds of plant species from 1910 to 1961 (Travers and Dunnell 2009). If increasing annual temperatures and shifts in the growing season in the Northern Great Plains over the last 100 years (Badh et al. 2009) have not resulted in corresponding biological shifts then we would expect that the first flowering times of plant species in the area will not have changed. A field survey was conducted to test this null hypothesis. The objectives of this study were to 1) analyze O.A. Stevens' data of first flowering times of local plants with climate variables to look for trends and relationships 2) compare first flowering times of plants between 2007 to 2009 and 1910 to 1961 before temperatures began rising in the area.

Materials and Methods

Climate Measurements

In order to characterize two of the main components of climate in the Northern Great Plains, temperature and precipitation, over the past century, summarized daily climate data was compiled that was collected in Fargo, North Dakota as part of the National Atmospheric and Oceanic Administration (NOAA) National Weather Service (NWS) observing network. The data included daily measures of the maximum and minimum temperature and detectable precipitation from January 1, 1910 to the present. The data collection station was originally located in Moorhead, MN at 46°52'N / 96°44'W and an elevation of 281.9 meters above sea level. However, in March of 1930 the station was moved to the Fargo Hector International Airport at 46°56'N / 96°49'W and an elevation of 274.3 meters above sea level.

The daily mean temperature from these data was calculated by averaging the maximum and minimum from each day. These daily values were then used to calculate monthly and annual averages for each year from 1910 to 2009. In addition, the daily measurements of detectable precipitation were used to calculate monthly and yearly averages of precipitation over the same time period.

Flowering Phenology from 1910 to 1961

In order to estimate the first flowering dates of plants in the Northern Great Plains the hand-written notes of O.A. Stevens, an experienced botanist and author of the Handbook of North Dakota Plants (1963), were examined and digitized. O. A. Stevens observed the flowering phenology of plants in the Red River Valley area near Fargo, ND and Moorhead, MN from 1910 to 1961 (Travers and Dunnell 2009, Stevens 1961). Each year during the growing season (March to September) he recorded the first flowering date and the species name for plants throughout North Dakota and western Minnesota but concentrated within 20 miles of the Fargo/Moorhead area. Stevens' notebooks are stored in the North Dakota State University library archives (http://library.ndsu.edu/archives/collections-university-archives/records-papers).

Stevens' hand-written notes of first flowering dates were transcribed for a total of 753 plant species that were observed predominantly in Fargo, ND and in a 5,821 acre section of native tall-grass prairie fifteen miles east of Fargo, ND (Bluestem Prairie Preserve, Clay County, MN). This section of prairie has been managed by the Nature Conservancy since 1975 (prior to that it was uncultivated) and has a rich flora of native species. The scientific name of the species and the date of flowering were recorded into an Excel spreadsheet. Only observations of first flowering time were transcribed, and did not include any observation marked as "not first flowering." Because Stevens used plant names that in some cases have changed due to taxonomic revision, I identified current and past synonyms of both common and scientific names for the species listed in his notes by matching original and recent nomenclature with the USDA NRCS Plants Database (plants.usda.gov). Synonyms were included in the database (Travers and Dunnell 2009). The dates of first flowering were converted to Julian date, or day since the beginning of each year, by subtracting the numerical conversion of flowering date from the value of January 1 in the pertinent year to standardize the data for year to year comparisons. The transcribed observations began March 18, 1910 and continued through September 10, 1961. The complete dataset is archived online and available at Ecological Archives (http://esapubs.org/archive; see Travers and Dunnell 2009).

In order to examine the relationships between climate variables (i.e. temperature and precipitation) and the timing of first flowering of plant species over the 50 year period between 1911 and 1961 a separate stepwise regression analyses was conducted on the first flowering data for each species. In order to minimize disproportionate influence of outlying values, only data from 1911 to 1961 were included in this regression analysis (1910 was not included). In each analysis the Julian date of first flowering each year was the dependent variable and six climate variables plus year were the independent variables. The independent variables include: mean daily temperature averaged within February, March, April, and May; snowfall (inches during previous winter); last freeze date in spring (Julian day of last minimum temperature of 0°C); and year. All stepwise regression analyses used the forward format and were conducted using SAS (SAS Institute, Cary, NC, USA). Stepwise regressions were only conducted on those species that had been observed a minimum of 10 years for a total of 178 species. The order of predictive ability of the independent variables was determined for those variables with p-values less than 0.05 based on decreasing magnitude of their partial R^2 values.

Flowering Phenology from 2007 to 2009

In order to assess first flowering times of plants between 2007 and 2009, the species in flower were observed and recorded at two primary locations in the Red River Valley region near Fargo, ND. The first flowering dates of plants were identified from April 16, 2008 until August 21, 2008 at Bluestem Prairie Preserve and the Sheyenne National Grassland. The Sheyenne National Grassland is comprised of 70,180 acres of mixed grass prairie in Ransom County and Richland County in North Dakota. Herbaceous and woody plants in flower were recorded at Bluestem Prairie Preserve approximately twice a week and at the Sheyenne National Grassland approximately once a week during the observation period of 2008. In 2009, the same census methodology was implemented from April 17 to August 30. In addition to our own observations, data collected from another botanist, Dale Rheder, was analyzed, who recorded the first flowering dates of plants in Bluestem Prairie Preserve on a weekly basis from April 1 to August 30 in 2007. I am confident that the data from 2007 are accurate based on corroboration between my data and Dale Rheder's observations in 2008 and 2009.

The null hypothesis was tested that climate change has had no impact on the flowering phenology of plants in the Northern Great Plains by determining if the Julian dates of first flowering times for species in 2007, 2008, and 2009 are statistically indistinguishable from the mean flowering times of the same species between 1910 and 1961. The z-scores were calculated of each flowering time in 2007, 2008, and 2009 based on the mean and standard deviation of flowering times for the same species between 1910 and 1961. The quantity "z" represents the distance between the raw score and the population mean in units of the standard deviation. Here, the population mean and standard deviation were derived from the first flowering time data for 1910 to 1961. A negative value for the z-score indicates that the flowering date of a given species for 2007, 2008 or 2009 was earlier than the mean between 1910 and 1961; a positive z-score indicates the flowering time was later than the mean. A z-score above 2 or below -2 indicates a flowering time divergent from over 95% of the flowering times observed between 1910 and 1961.

Results

Climate Measurements

Daily measures of air temperature indicate that average annual temperatures in Fargo have increased over the years between 1900 and 2007 (Figure 1.1). In particular the scatter plot indicates an upswing in average temperature since the 1970s that is commensurate with global air temperature trends (IPCC 2007). The average annual temperature within the first nine years of this time period (1900 and 1909) was three degrees (Fahrenheit) lower than in the last nine years (1998 and 2007). Monthly averages of air temperature over the same time period indicate that temperature increases in February and May are statistically significant (Feb: b=0.05*, R^2=0.06; March: b=0.01ns, R^2=0.005; April: b=0.01ns, R^2=0.01; May: b=0.03*, R^2=0.04; * indicates $p<0.05$).

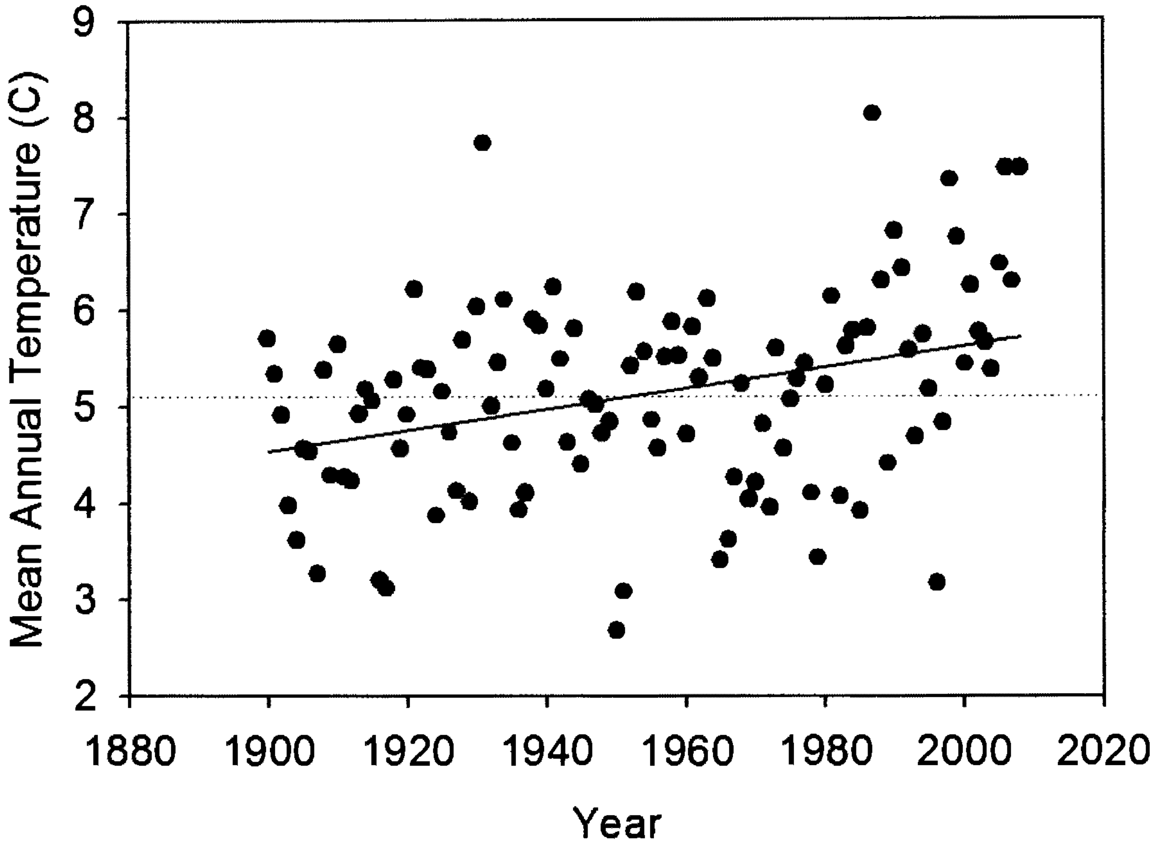

Figure 1.1. Mean annual temperature (˚C) at Fargo, ND. The dotted line represents the grand mean annual temperature from 1900 to 2008. The solid line is the linear best-fit regression line (Y=6.3+0.02X, P<0.01, D=106, R=0.09).

In concordance with the increasing annual air temperature and spring air temperatures, the growing season in Fargo has increased in length over the last 100 years (Figure 1.2). The ten year average of the number of days between the last and first frost ($\leq$ 32 ˚F) of spring increased from 132 days to 154 days over the period 1910 to 2007. In particular, the growing season increased dramatically after 1970. This pattern has been seen throughout North Dakota (Bahd et al. 2009).

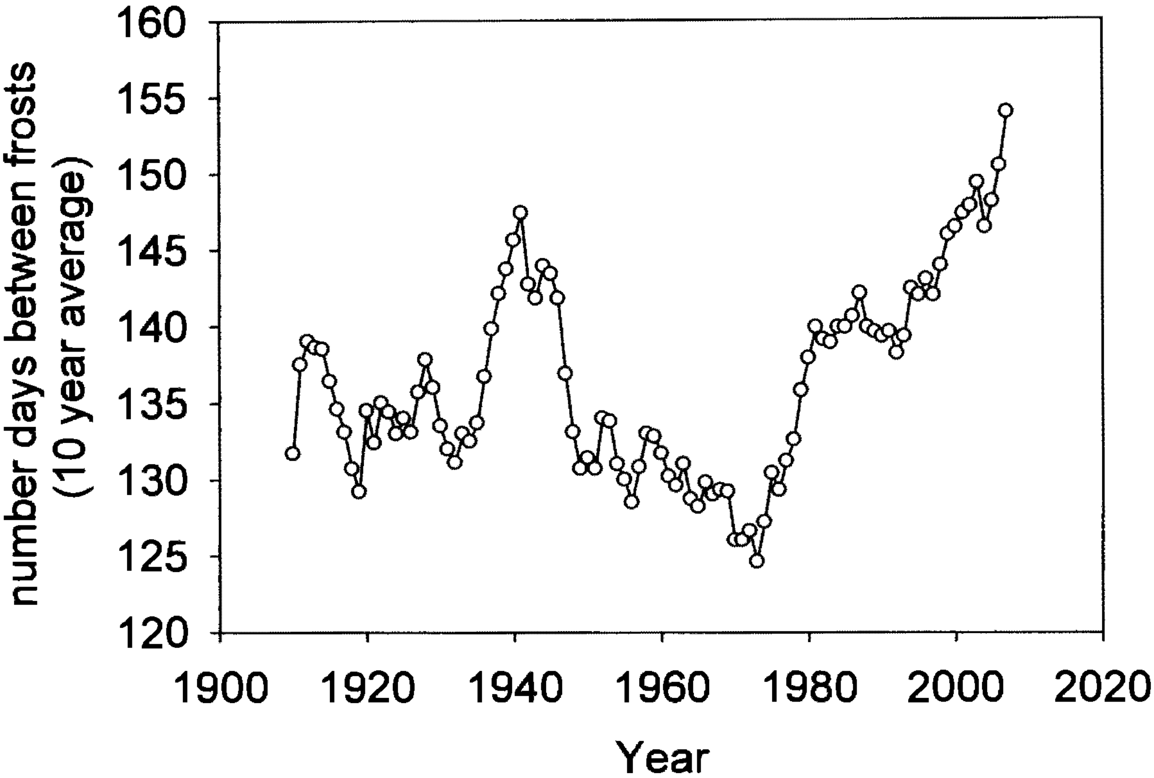

Figure 1.2. Growing season (number of days between last and first frost) by year. Values are averaged over the previous ten years starting in 1910.

Annual precipitation in the Fargo area varied considerably between 1900 and 2007 (Figure 1.3.) Quadratic regression analysis indicates that during the middle of the last century, average precipitation decreased. However, since the 1970s annual precipitation has increased back up to levels seen in the early 1900s. Seventeen percent of the variance in annual precipitation is explained by a parabolic model.

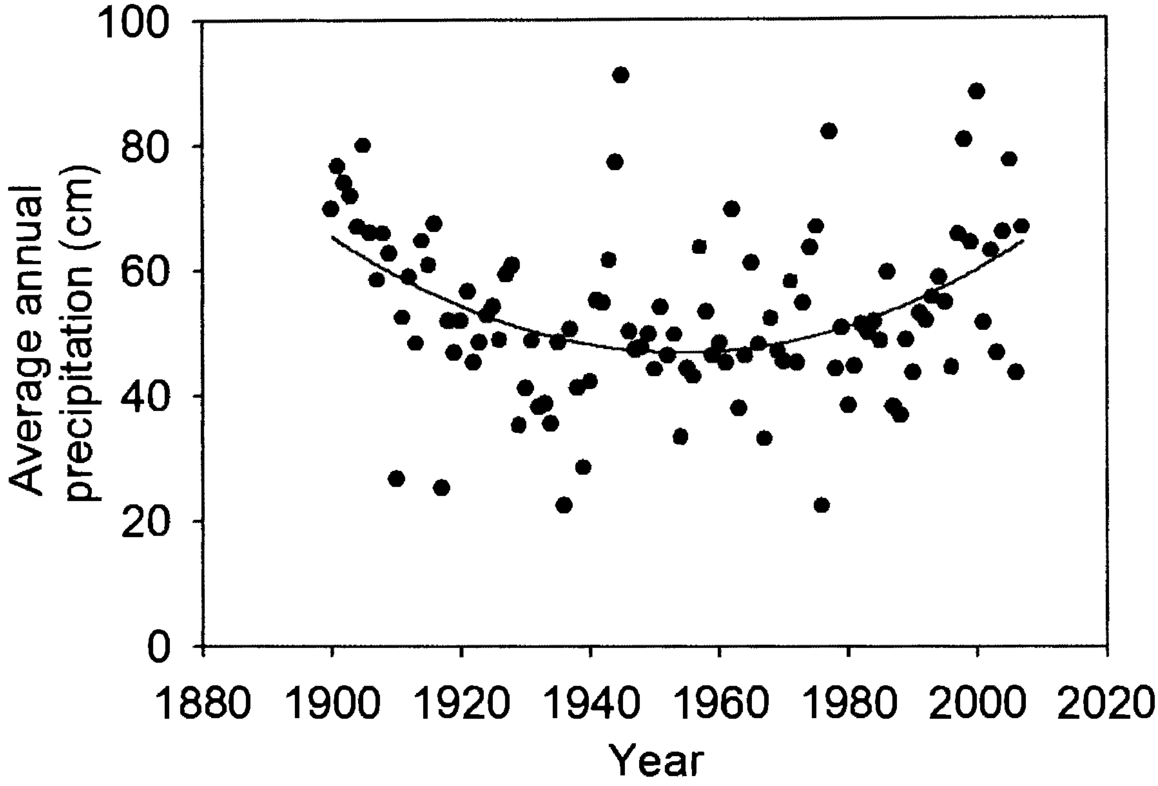

Figure 1.3. Average annual precipitation (centimeters) at Fargo, ND. The solid line is the quadratic best-fit regression line ($Y=9552-9.8X+0.002X^2$, $P<0.01$, $DF=108$, $R^2=0.17$).

The three contemporary years during which first flowering dates were observed for plants in the Red River Valley varied considerably in temperature and precipitation patterns (Table 1.1). The first year of the study, 2007, was warmer on average than the next two years. In contrast 2008 and 2009 were more typical of the period between 1910 and 1961.

Table 1.1. Climate summary during study years. Mean air temperature (°Celsius), annual precipitation (cm), and total winter snowfall (cm) for 1910-1961, 2007, 2008, and 2009.

Year(s)	Mean Air Temperature					Annual Precipitation	Winter Snowfall
	Annual	February	March	April	May		
1910-1961 (Range, Mean)	2.68 - 7.73, 5.00	-21.68 - -6.07, -14.28	-9.16 - 4.94, -3.63	0.76 - 10.84, 5.82	8.24 - 17.58, 12.87	22.54 - 91.14, 29.21	23.62 - 209.04, 90.88
2007(Mean ± SE)	6.29 + 0.74	-14.18 + 1.78	-0.23 + 1.24	6.03 + 1.62	15.76 + 0.74	66.6	129.8
2008	4.43 + 0.73	-13.65 + 1.22	-5.13 + 1.19	4.97 + 0.65	12.14 + 0.73	77.7	188.5
2009	4.62 + 0.71	-11.36 + 1.32	-4.42 + 1.41	5.52 + 0.94	12.09 + 0.74	63.2	176.5

Flowering Phenology from 1910 to 1961

There were a total of 753 plant species observed by O.A. Stevens and recorded in the database of observations from 1910 to 1961 (Travers and Dunnell 2009). Not all of these species were observed every year. O.A. Stevens observed between 17 and 309 species per year (Figure 1.4). On average 88 species were observed per year. Species included in the analysis presented here include 631 herbaceous and 122 woody species.

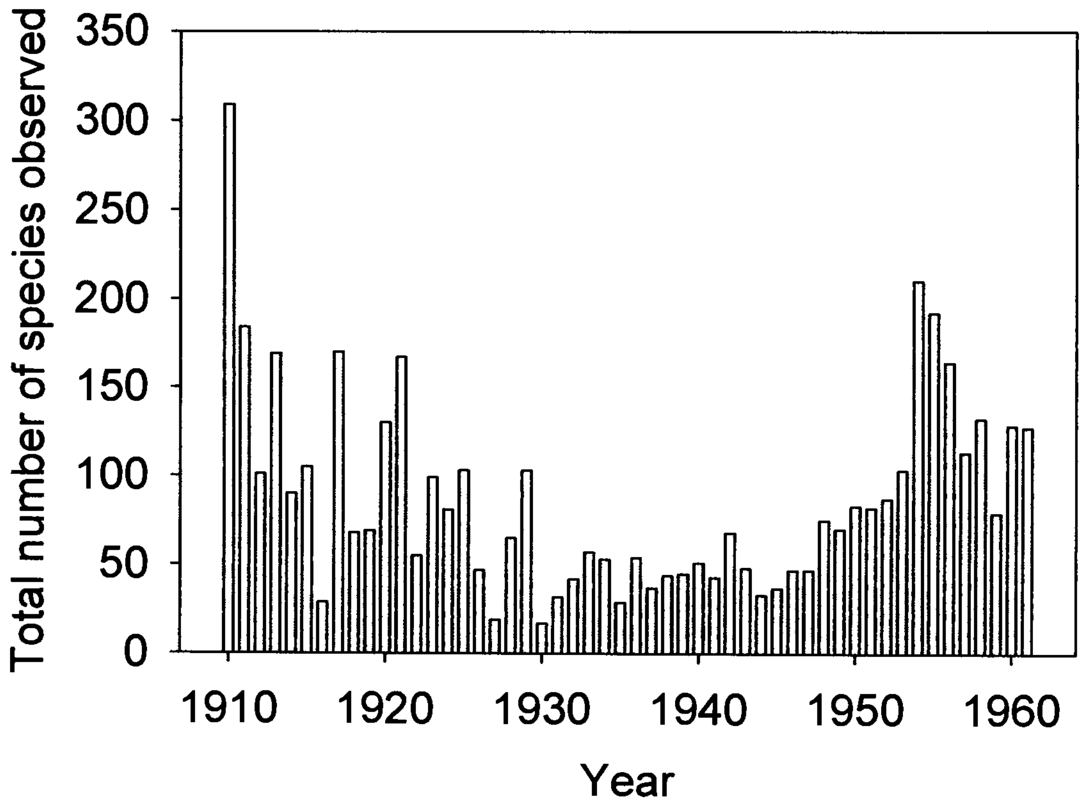

Figure 1.4. Number of woody and herbaceous species observed each year by O.A. Stevens from 1910 to 1961.

O.A. Stevens' first flowering dates range from 3/18/1910 to 9/10/1961. The earliest flowering date observed in a specific year was March 18 and the latest flowering date observed was September 23.

To explain the variation in first flowering times from 1910 to 1961, a stepwise regression was conducted. As a result of only including species with ten or more observation years in regression analysis, a total of 178 species were analyzed individually using the forward approach to stepwise model building. Different species had different numbers of significant predictors of flowering time according to an alpha level of 0.05 in the model. There were a total of 20 species that had three top predictors with a p-value of less than 0.05. A total of 55 species had two top predictors. There were 63 species that had one top predictor. 40 species had no top predictor with a p-value of less than 0.05 (Appendix 1). The overall R^2 values range from 0.0041 to 0.9943 depending on the species. The specific predictor of first flowering depends on the species, but the predictor that explained the greatest variation in first flowering time was most commonly the average temperature in April followed by May as the next most common predictor (Figure 1.5).

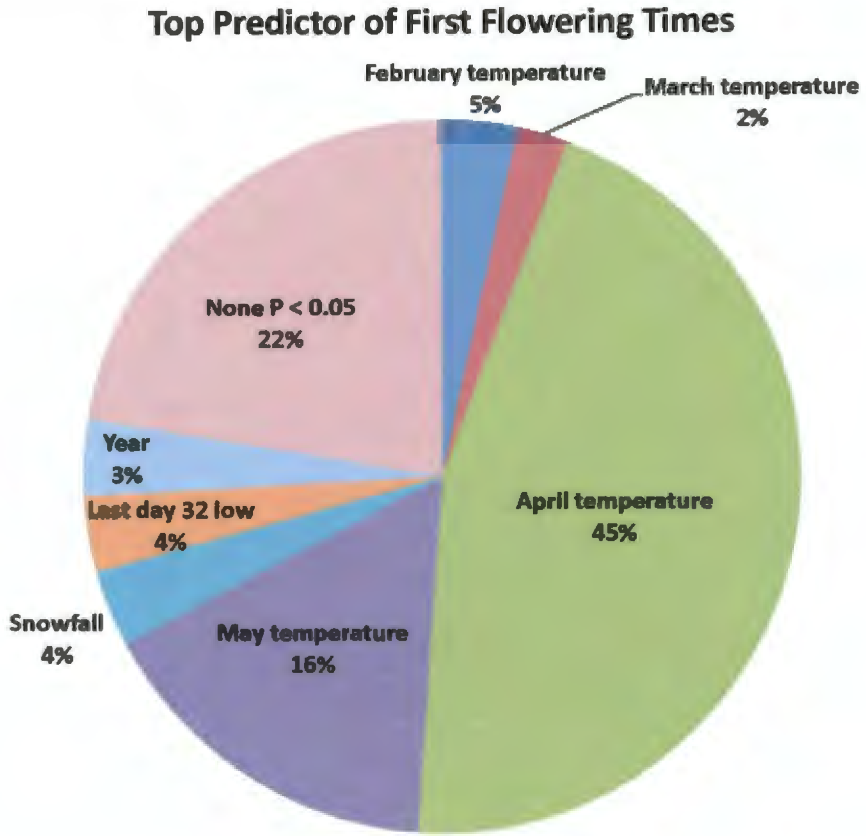

Figure 1.5. Percentage of species out of 178 analyzed by stepwise regression. Each of the possible independent variables as the leading predictor. The slope of the relationship between the predictor and first flowering date could be either positive or negative.

Flowering Phenology from 2007 to 2009

In 2007, 2008, and 2009, a total of 60, 170, and 166 species, respectively, were observed in the Red River Valley region of Minnesota and North Dakota. However, not all species observed in these three years were previously observed by O.A. Stevens. In 2007, six species out of the 41 total (15%) also observed previously by O.A. Stevens had a z-score of less than -2.0 (Figure 1.6). These species included *Rosa arkansana, Pedicularis canadensis, Pediomelum esculentum, Echinacea purpurea, Liatris aspera*, and *Penstemon gracilis*. Most of the species with low z-scores are plants that flower relatively early in the growing season. The one species, *Parnassia palustris*, out of 41 (2%) with a z-score more than 2.0, which flowered later than in O.A. Stevens' data, is one that flowers in the second half of the growing season. The mean z-score in 2007 was -0.98.

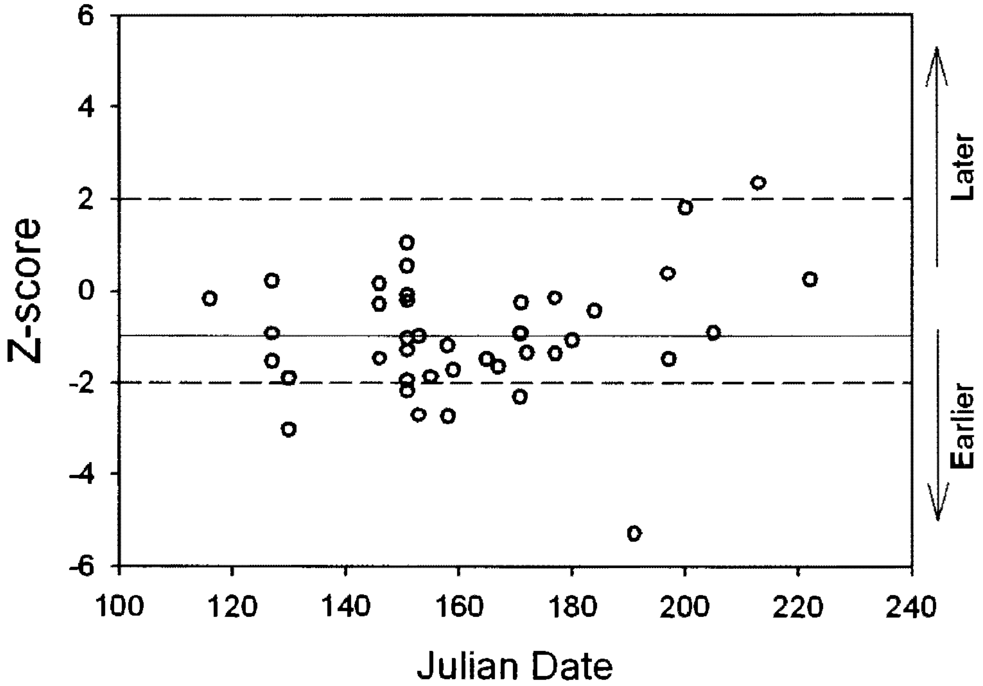

Figure 1.6. The z-scores for first flowering dates of species observed in 2007 compared to when they flowered between 1910 and 1961. The dotted lines indicate standard deviation limits of 2 or -2. The solid line indicates the average z-score for 2007.

In 2008 one species (*Panicum virgatum*) out of 100 flowered early enough to have a z-score of less than -2.0 (Figure 1.7). However, seven species (7%) flowered later than observed by Stevens, with a z-score of more than 2.0. These species were *Shepherdia argentea, Rudbeckia hirta, Asclepias ovalifolia, Echinacea angustifolia, Catalpa speciosa, Psoralea argophylla*, and *Calylophus serrulatus*. The mean z-score in 2008 was 0.69.

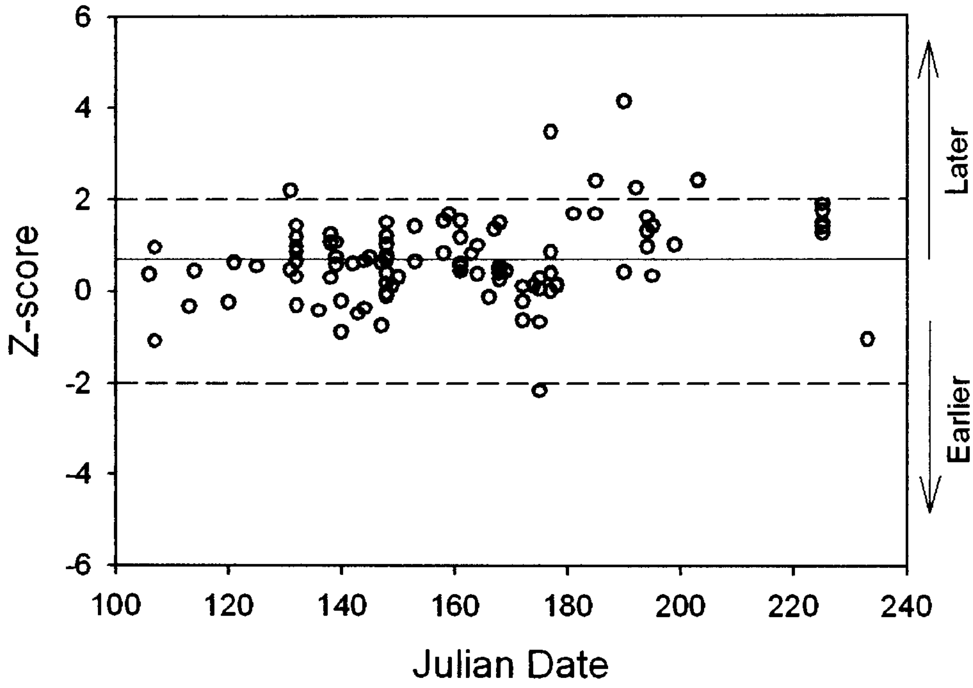

Figure 1.7. The z-scores for first flowering dates of species observed in 2008 compared to when they flowered between 1910 and 1961. The dotted lines indicate standard deviation limits of 2 or -2. The solid line indicates the average z-score for 2008.

The 2009 observations show that five out of 96 species (5.2%) flowered relatively late, with a z-score of more than 2.0 (Figure 1.8). These species were *Lactuca pulchella, Viola pubescens var. pubescens, Rudbeckia hirta, Echinacea angustifolia,* and *Lobelia spicata*. The average z-score in 2009 was 0.46.

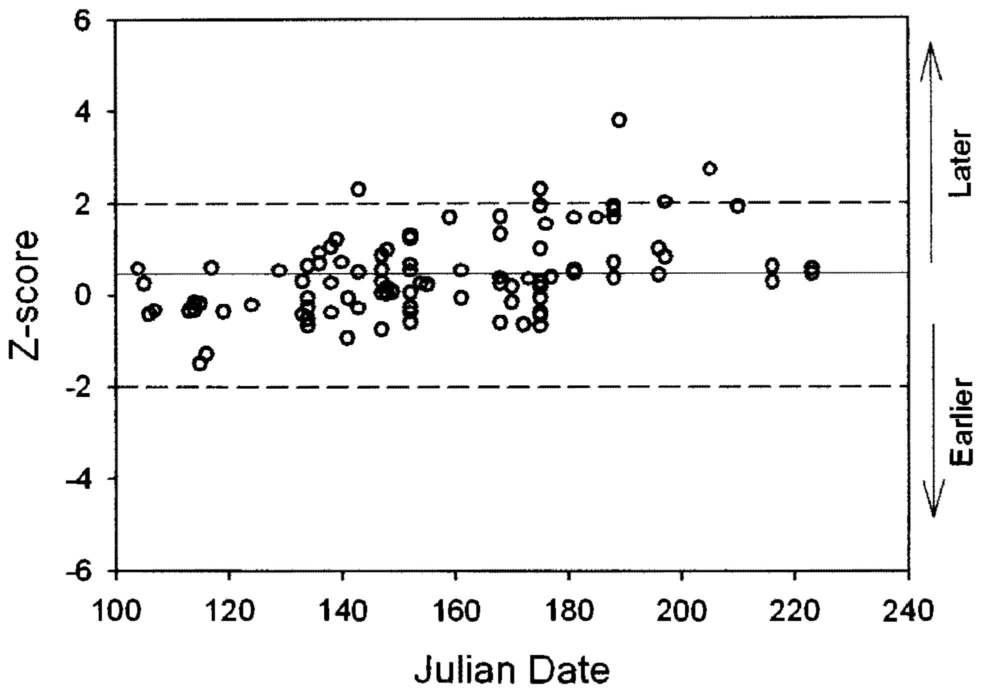

Figure 1.8. The z-scores for first flowering dates of species observed in 2009 compared to when they flowered between 1910 and 1961. The dotted lines indicate standard deviation limits of 2 or -2. The solid line indicates the average z-score for 2009.

Discussion

The results showed evidence for disrupted phenological patterns for flowering plants in 2007 to 2009 relative to the patterns in the same species in the same location prior to climate change. Seventeen, eight, and five percent of the species observed in 2007, 2008, and 2009 respectively flowered either earlier or later than from 1910 to 1961. Correspondingly the average annual temperature was warmest in 2007. The temperature in 2008 and 2009 were more typical of the first half of the last century. Earlier flowering and spring green-up has been found to occur for some plant species in other studies (Miller-Rushing and Primack 2008, Bradley et al. 1999, Menzel et al. 2006, Root et al.

2003). In the three years analyzed here flowering time was earlier than expected in only one of them. Later flowering by species relative to the previous century is unreported to our knowledge.

The data from this study do not support the null hypothesis that flowering times of plant species have not changed, rather they are consistent with the hypothesis that phenological shifts in flowering are due to changes in air temperature and growing season length in the Northern Great Plains. Climate data indicate that regional air temperatures have increased since the middle of the 1970s resulting in earlier springs, later falls, and increased growing season. Because regression analysis indicates that spring temperatures, particularly April and May temperatures, are important in determining first flowering times we would expect flowering times to be earlier in warmer years since the 1970s. It is unknown when these plant species flowered in the intervening years during the recent climate warming but our data indicate that in one relatively warm spring, 2007, there were species that flowered earlier than during Stevens' observations (Figure 1.6). Warmer spring temperatures could explain the earlier first flowering times in 2007, which had a very warm spring. In that year 15% of the species flowered early relative to the last century. There is no first flowering data from 1990 to 2006 during which there was an upswing in temperatures, but it is possible that plants flowered early at that time as well.

In all three years, but particularly 2008 and 2009, there were plant species that flowered later than expected based on Stevens' data (with a z-score of more than 2.0). The average annual temperatures in the later two years were not significantly colder than during Stevens' time. A possible explanation is that in the presence of longer growing seasons, including a delayed killing frost in the fall, selection against late flowering has been relaxed. In the early part of the last century those individuals that would have been killed before seeds were fully matured would survive today. Moreover, by flowering and fruiting later, the late flowering plant species may avoid competition for pollinators and resources with earlier flowering species.

There are many implications of shifting phenology. Schemske (1977) found there are reproductive benefits, such as high seed set, for flowering at the right time presumably because synchronizing flowering to match pollinator abundances or avoid herbivores can increase fitness. Shifts in first flowering time have led to more frost damage due to earlier initiation of flowering (Inouye 2008). Willis et al. (2008) found evidence for differences among plant families in their tendency to track changes in climate over time and corresponding differences among families in extinction rates. In our study there was little evidence of some families of plants tracking climate change better than others, however, additional years of observation will be informative.

Regardless of whether flowering times have shifted earlier or later with the changing climate there is the potential for pollination or other ecological relationships (e.g., herbivory, disease) to be disrupted from an optimal synchronization. Longer growing seasons may also have allowed competitor plant species (e.g., invasive species) and disease agents with previously southern distributions to shift their ranges north (Walther et al. 2002) so that they now interact with plants in the Red River Valley. Flowering and fruiting earlier or later could impact these types of ecological relationships as well. This study does not have data regarding these ecological relationships. However, it does provide the first step in indicating which species may be more at risk of cascading ecological effects of climate change.

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PAPER 2. EFFECTS OF EXPERIMENTAL WARMING ON PLANT SPECIES AT BLUESTEM PRAIRIE PRESERVE, MN

Abstract

Studies of biological responses to increased air temperatures associated with climate change have found earlier initiation of phenological events, but most of these studies have been correlative. There is a need for manipulative studies to isolate and test the effects of a single variable on phenological patterns. To manipulate air temperature in a pattern consistent with climate change a heating experiment using passive heating chambers was conducted in Bluestem Prairie Preserve in Minnesota. The phenological and species composition responses to the temperature changes of tallgrass prairie plant species were measured. Increased temperatures showed increases in first flowering and maximum flowering and significantly increased species richness. Climate change has the potential to impact the plant community by shifting the flowering phenology of plants and by changing the species composition of the prairie.

Introduction

The Earth's average temperature has warmed by about 0.6 degrees Celsius over the past hundred years. The rate of warming from 1976 onwards has been greater than at any other time in the last 1000 years (Walther et al. 2002). Increases in temperature have the potential to have significant effects on the biosphere. Shifts in temperature could have significant local effects as well. Shifts leading to earlier springs in the Northern Great Plains could result in significant changes in local flowering phenology. In Fargo, increases in temperature since 1976 have led to longer growing seasons (Badh et al. 2009) (Figure 1.2).

Studies looking at phenological responses to current climate change have shown that many plant species are now flowering earlier than they have in the past (Bradley et al. 1999, Miller-Rushing and Primack 2008). One study in southern Wisconsin found that over a 61-year period several phenological events, including flowering times of plant species and arrival times of migrant birds, were shifting to earlier dates along with increasing spring temperatures (Bradley et al 1999). In Concord, Massachusetts a study using archival data collected by Henry David Thoreau and botanist Alfred Hosmer, found that the first flowering times of local plants species were on average seven days earlier than when observed by Thoreau. The conclusion was that the timing shifts were due to rising winter and spring temperatures in the area (Miller-Rushing and Primack 2008). In the first study the results showed significant shifts in flowering times in some plant species, with some flowering times shifting earlier and some later in the Northern Great Plains. These shifts in phenological events are based on correlative studies where biological shifts are compared with changes in temperatures. A correlative approach cannot distinguish between the effects of increased temperature due to climate change and corresponding changes in other environmental characteristics (e.g., precipitation, humidity, land use). There is a need for experimental studies that can demonstrate what happens when only one variable, temperature, is increased.

Only a few other manipulative experiments have been conducted to study effects of increasing temperature using passive heating chambers on plant species in the

Northern Great Plains. There have been studies using open top chambers to study the effects of increases of CO_2 on plant species (Rogers 1983, Leadley and Drake 1993). In one study in a subalpine meadow in the Colorado Rocky Mountains they found that warming, using electrical heaters suspended 2 meters aboveground, had negative effects on flower production in certain plants, which may have cascading effects on the fitness of their pollinators (Saavedra et al. 2003). In a study using passive heating chambers, warming had also shown to cause an overall decline in biodiversity in the tundra (Walker et al. 2006). Another manipulative study assessed sensitivity of *Andropogon gerardii* and *Sorghastrum nutans* to variation in temperature and precipitation that was altered in a manner consistent with predictions of future climate for the study region. They found that *S. nutans* was more responsive than *A. gerardii* to the stress caused by alterations in water and temperature (Nippert et al. 2009.) These studies show effects that may occur in the future due to climate change. It is important to see what effects will occur on the tallgrass prairie. I was interested in experimentally manipulating temperature in order to isolate the effect of shifts in temperature on plant biotic responses

The four questions of this experiment that will be important to answer are 1) Is phenology affected by warming?, 2) Will warming affect species composition?, 3) Will invasive species thrive under warmer conditions?, and 4) Will warmer temperatures affect productivity? This experiment was conducted in the Northern Great Plains on tallgrass prairie which has a short growing season. This habitat has not been studied in great detail and may show unique changes when warmed.

Materials and Methods

To manipulate air temperature in a pattern consistent with climate change a heating experiment in Bluestem Prairie Preserve (15 miles east of Fargo, ND, Clay County, MN) was conducted through the use of a passive heating chamber. I was interested in the phenological and ecological responses to those temperature changes of tallgrass prairie plants. The experiment was conducted on seven 25x25 meter plots. Starting on April 15, 2009, a single heating chamber (cone) was placed on each plot. A heating chamber (cone) is an open-top enclosure made of Sun-Lite HP (0.040 inch thick), a fiberglass material specially designed for solar applications. The cone has a basal diameter of 1.48 meters and a height of 40 centimeters. The design from "Temperature Enhancement Experiments" by Giles M. Marion was followed for this experiment (Marion 1996). The cone acts as both a solar trap and as a windshield to effectively raise temperatures inside the cone without interfering with precipitation reaching the ground. In addition, a control circle of the same basal diameter in each plot was established. A control is a circle of string of the same diameter as the cone that was placed approximately 6 meters to the direct east or west of the cone. A coin toss was used to determine which treatment was on the east or west position. On April 20, 2009 a HOBO thermometer was placed above ground in the center of each circle (cone and control) in each plot to measure hourly temperature. Leaf litter was placed over the thermometers to negate the effects of the sun shining directly on the thermometers. There were a total of seven plots with one cone and one control in each. The plots were arranged on Bluestem Prairie Preserve to include a variety of different plant communities (Figure 2.1).

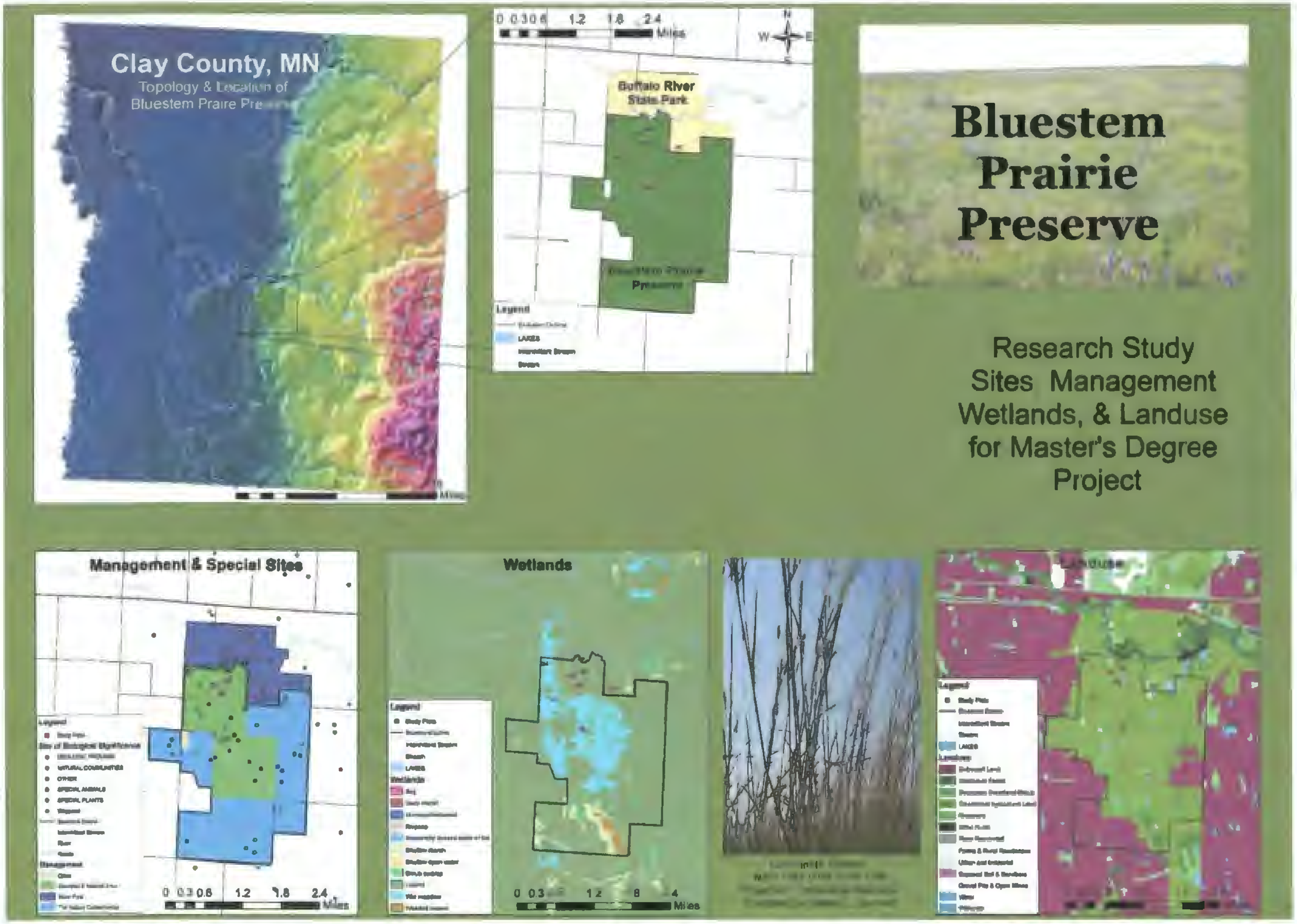


Figure 2.1. Map of plots on Bluestem Prairie Preserve. Map created using ArcGIS. Map data from MN DNR.

Each plot was visited at least once a week and the number of stems in bud, the number of stems in flower, and the number of stems with fruits were recorded for each species in both circles (Table 2.1). The weekly visits were repeated from May 1, 2009 to August 24, 2009 for a total of 19 weeks of censusing stem and species numbers. At the end of the growing season, the percent cover by individual plant species was also determined in each of the two circles per plot. The percent cover of plot 1 was measured 9/30/2009, plot 2 on 9/23/2009, plot 3 on 8/29/2009, plot 4 on 9/16/2009, plot 5 on 8/18/2009, plot 6 on 8/24/2009, and plot 7 on 8/25/2009. In order to estimate the per species percent cover, a 1.5 square meter frame of PVC pipe was used with an internal grid made of fishing line rows and columns spaced 10 cm apart. As a result of this configuration there were 225 total intercepts where the fishing lines crossed in the grid. The species of plant present was recorded at each intercept point by suspending the grid above the experimental circles, lowering a metal stake from each intercept point and recording the species of plant the stake touches. Data were only taken from each intercept that fell within the circle. The total proportion of vegetation per circle was calculated by dividing the number of intercepts that touched a live plant versus bare ground by the number of total intercepts sampled. The percent cover of each species per plot and treatment was calculated by dividing the number of intercepts of that species by the total number of vegetative intercepts. These data were used to estimate Simpson's Diversity Index according to the following formula:

$$D = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

where p = the proportion of each plant species cover and s = the number of species discovered per circle. I also calculated species richness per circle (i.e. the number of species), the percent shared species between the two circles per plot, and an estimate of species evenness according to the following equation:

$$E_D = \frac{D}{D_{max}} = \frac{1}{\sum_{i=1}^{s} p_i^2} \times \frac{1}{S}$$

The standing biomass was measured by cutting all vegetation in each circle at ground level at the end of the summer and air drying it in paper bags. Above ground vegetation was collected from plot 1, 2, 5, 6, and 7 on 10/12/2009, and from plot 3 and 4 on 10/15/2009. The paper bags full of vegetation were stored in a walk-in forced air drying oven for approximately a week. They were then weighed with and without the vegetation to calculate the standing biomass of each circle.

Table 2.1. Timeline for experiment

	2009																													
Month	APRIL				MAY				JUNE					JULY				AUGUST					SEPTEMBER				OCTOBER			
Week	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4
Setup cones		■																												
Installed HOBOs			■																											
Census plants in treatments					○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
Species ID per plot					○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○							
Estimate percent cover																						■	■	■	■	■				
Estimate standing biomass																												■		
Breakdown cones																													■	■

Results

The temperature difference between the treatments showed that on average the cones were warmer than the controls, especially in the spring (Figure 2.2). In the first month of the experiment the air temperature in the cones was an average of 3 degrees warmer than in the controls. The decrease in temperature in later months may be due to the increase in plant cover in the treatments. The variation between plots is most likely due to the variation in plant communities and habitat. Plot 3 and 4 were the wettest sites with standing water for much of the experiment and showed the lowest dip in temperature. The control treatment in plot 1 was mowed in August, so the temperature data could not be collected and was lost after May.

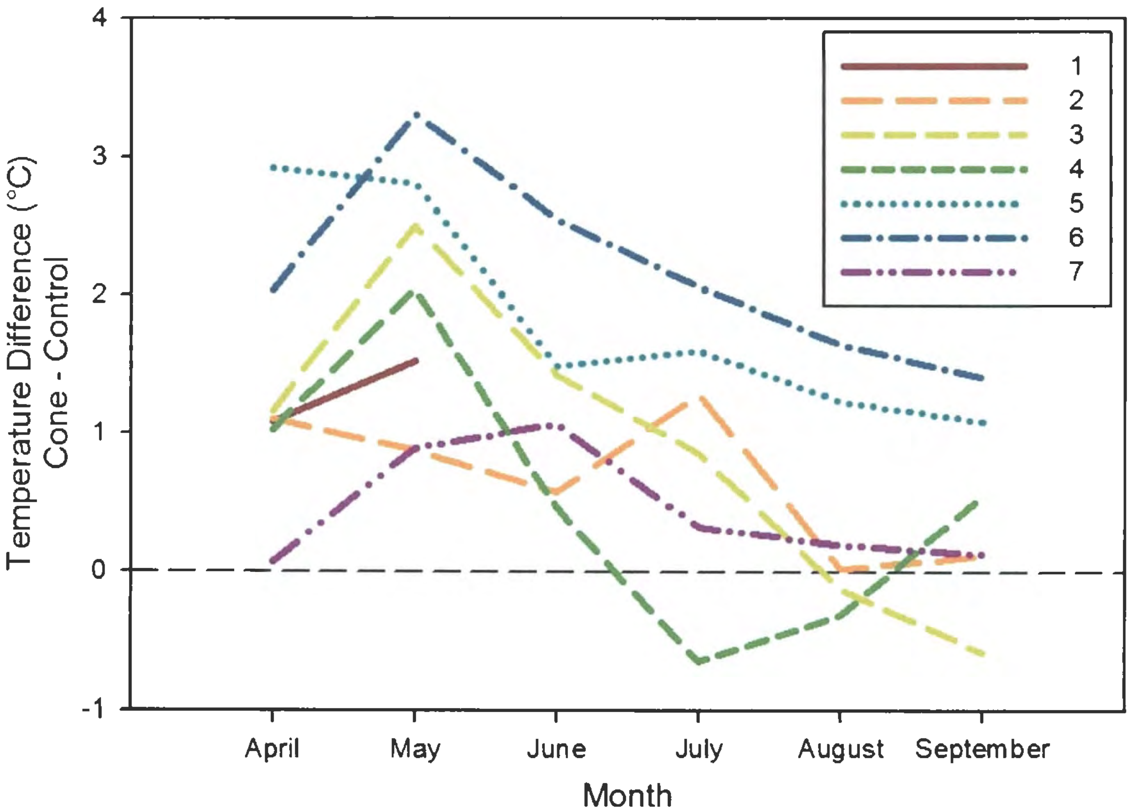


Figure 2.2. Temperature difference (cone minus control) in degrees Celsius by month. Each line represents a separate plot containing cone and control treatments.

The weekly census data indicate that there were differences between cone and control treatments over the course of the experiment (Figure 2.3). In most plots, plants had earlier first flowering and earlier maximum flowering peaks in the cone treatment than in controls. The first fruiting and peak fruiting also occurred earlier in the cones than in the controls. The maximum fruiting peak was greater in the cone than the control for four of the seven plots. In addition, the first flowering and peak in number of flowering species occurred earlier in the cones (Figure 2.4). The average week of first flowering occurred significantly earlier in the cone treatments than in the control treatments, using the Wilcoxon signed-rank test and an alpha of 0.05 (Table 2.2).

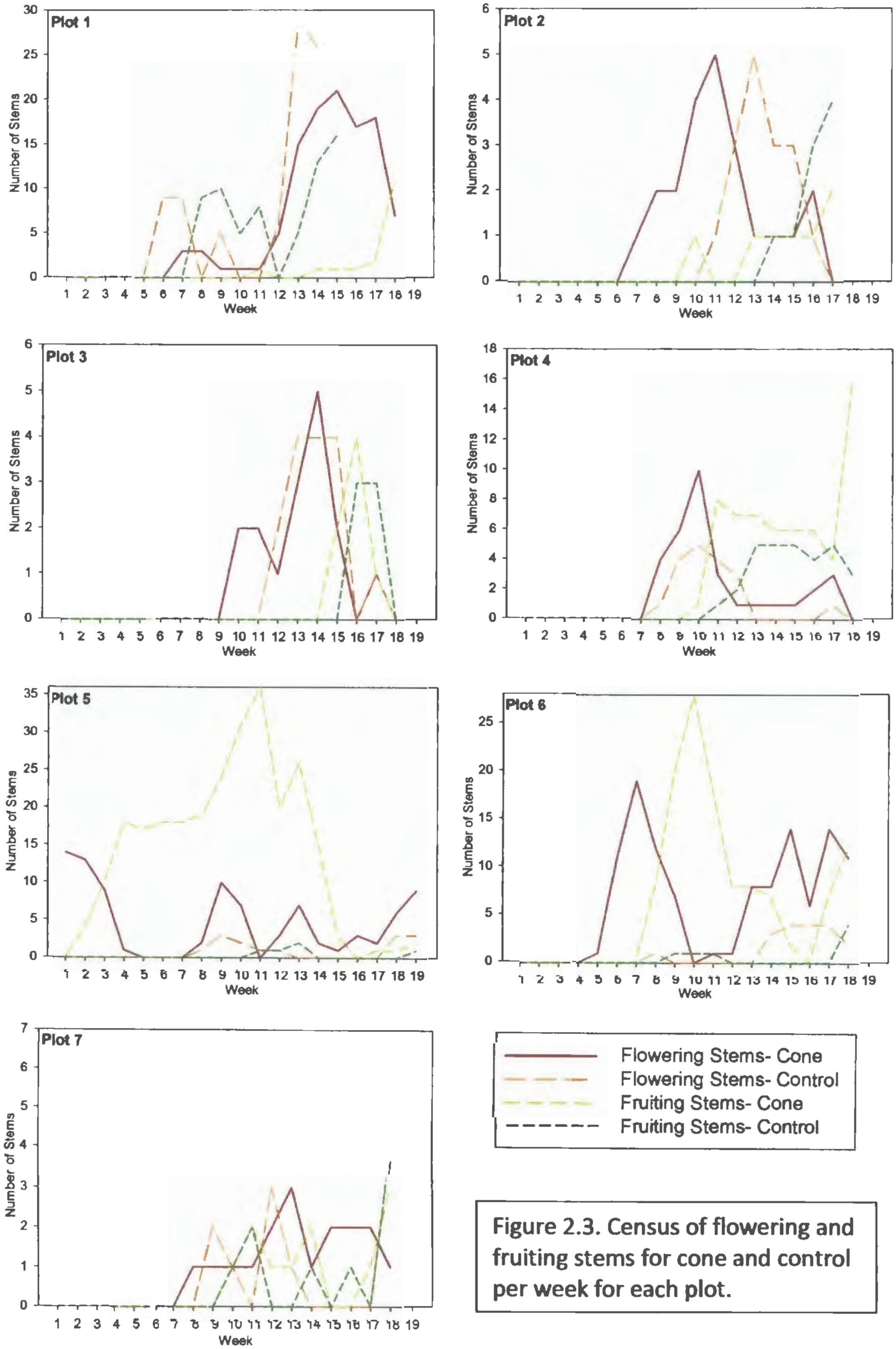
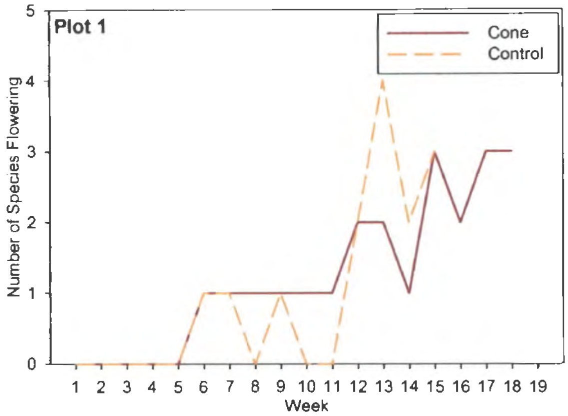
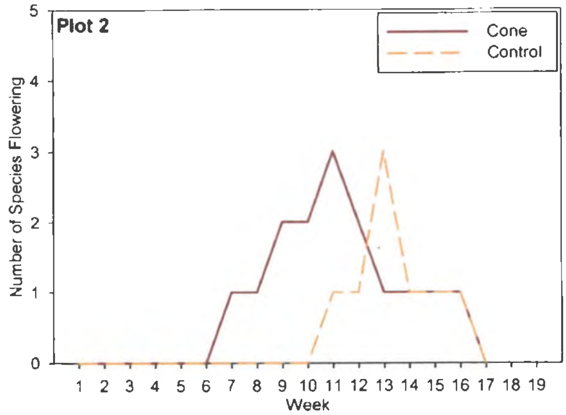
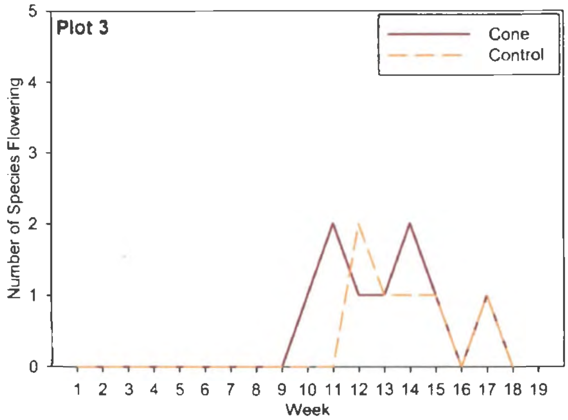
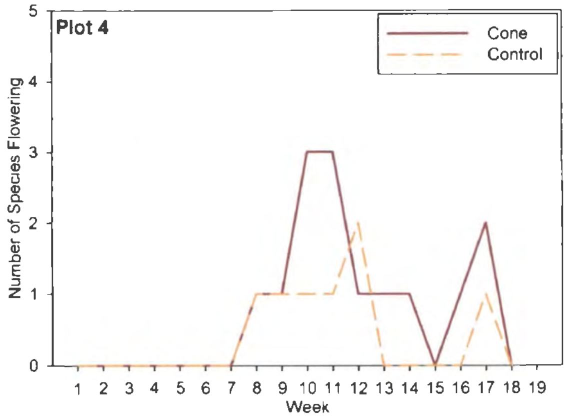


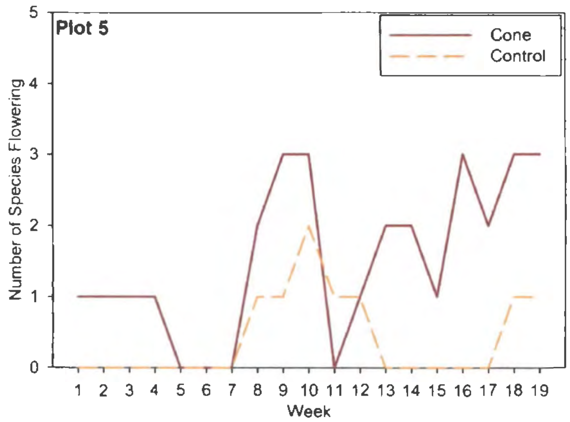
Figure 2.3. Census of flowering and fruiting stems for cone and control per week for each plot.

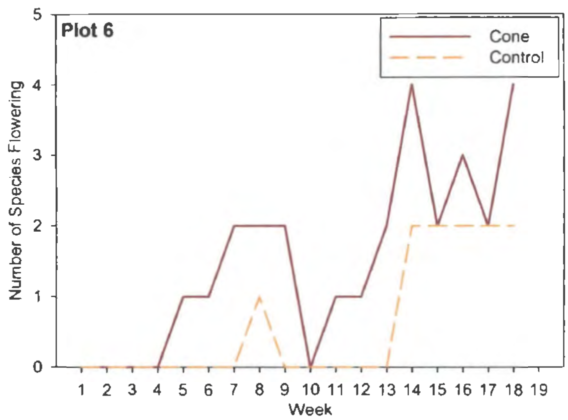












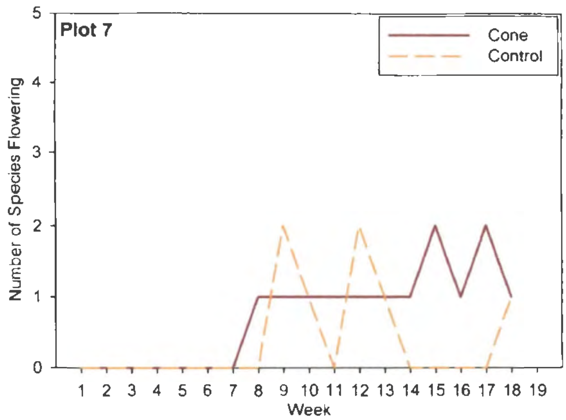


Figure 2.4. Census of flowering species for cone and control per week for each plot.

Table 2.2. Summary of census data results.

	Week of first flowering		Week of max # of flowering stems		Max # of flowering stems		Max # of fruiting stems		Max # of flowering species	
Plot	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control
1	7	6	15	13	21	29	11	16	3	4
2	7	11	11	13	5	5	2	4	3	3
3	10	12	14	13	5	4	4	3	2	2
4	8	8	10	10	10	5	16	5	3	2
5	1	8	1	9	14	3	36	2	3	2
6	5	8	7	15	19	4	28	4	4	2
7	8	9	13	18	3	4	3	4	2	2
mean	6.571	8.857	10.143	13.000	11.000	7.714	14.286	5.429	2.857	2.429
	W = -18	P < 0.05	W = -14	P > 0.05	W = 10	P > 0.05	W = 11	P > 0.05	W = 6	P > 0.05

At the end of the experiment the proportion of vegetation cover, percent cover by species, species richness, and standing biomass were assessed at a single time point. There were no significant differences in the vegetative cover of cone circles versus control circles (Figure 2.5).

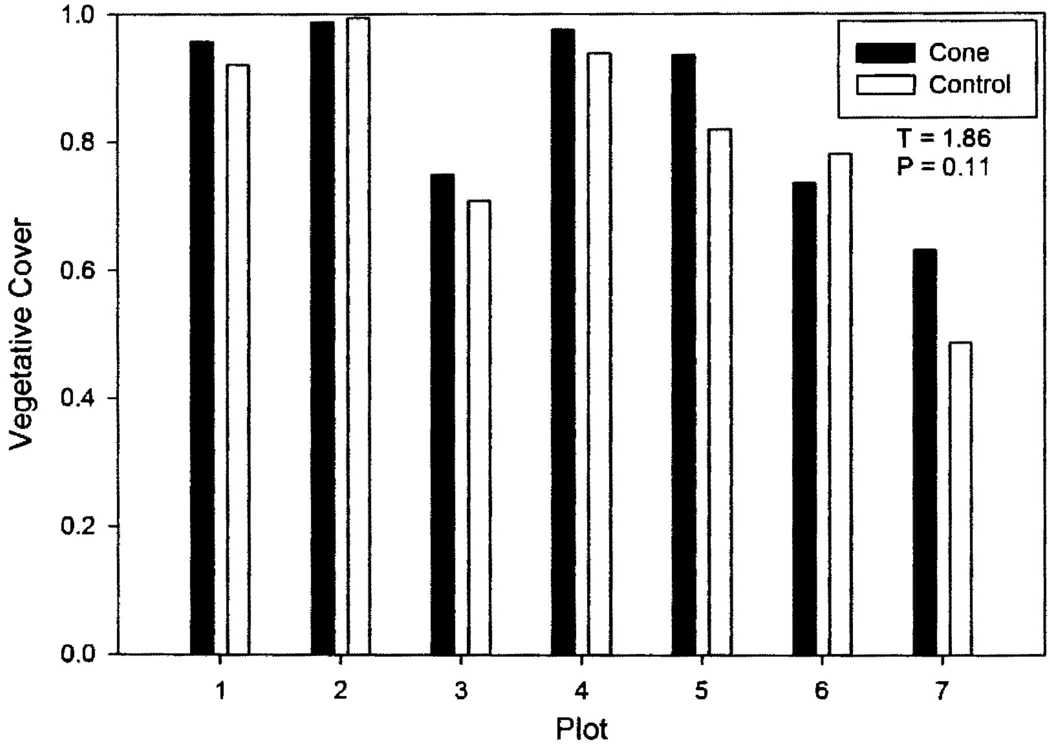


Figure 2.5. Proportion of total intercepts that contained plants rather than bare ground by plot.

The species proportion counts showed variations in the number of species within each plot and each treatment (Table 2.3). The total number of species in the cone and control treatments ranged from five to 17. There were clear dominant species in each treatment. The species with the highest proportion cover was always greater than 20 percent of the total cover and was as high as 75 percent depending on plot and treatment. Moreover, species evenness estimates were relatively low indicating some species were much more common overall than other species. As is typical of the tallgrass prairie, all plots were dominated by grass species with the exception of plot 6 control. The most dominant species overall included *Andropogon gerardii, Poa pratensis, Bouteloua gracilis, Dichanthelium wilcoxianum*, and *Sorghastrum nutans*. Although an invasive species, Kentucky bluegrass, *Poa pratensis,* was the dominant in a number of plots it did not seem to respond to warming in a consistent pattern. However, species richness was on average higher in the cone treatments than in controls (Figure 2.6). There were no significant differences in biomass between treatments (Figure 2.7).

Table 2.3. By species proportion counts broken down by plot and by treatment. Yellow highlighted species are non-native. Dark blue is the dominant species and light blue includes the 2nd and 3rd most dominant species in treatment.

PLOT:	1		2		3		4		5		6		7	
Species	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control
Allium stellatum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000
Ambrosia psilostachya	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.019	0.000	0.000
Amorpha canescens	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.041	0.000	0.000	0.000	0.000
Andropogon gerardii	0.104	0.264	0.288	0.181	0.364	0.276	0.139	0.000	0.000	0.000	0.000	0.000	0.128	0.000
Anenome patens	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.041	0.000	0.000	0.000	0.000
Apocynum cannabinum	0.000	0.000	0.031	0.031	0.023	0.019	0.055	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Asclepias incarnata	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Asclepias syriaca	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013
Asclepias viridiflora	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bouteloua gracilis	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.652	0.000	0.233	0.184
Calamagrostis stricta	0.000	0.000	0.006	0.013	0.000	0.000	0.030	0.148	0.000	0.000	0.000	0.000	0.000	0.000
Calylophus serrulatus	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Carex spp.	0.000	0.000	0.006	0.075	0.000	0.114	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cirsium flodmanii	0.052	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000
Crepis runcinata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000
Dalea purpurea	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.035	0.039
Dichanthelium wilcoxianum	0.000	0.000	0.194	0.200	0.038	0.048	0.018	0.452	0.038	0.041	0.148	0.288	0.070	0.000
Echinacea angustifolia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000
Equisetum spp.	0.060	0.016	0.038	0.006	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eragrostis spectabilis	0.000	0.000	0.000	0.000	0.015	0.038	0.000	0.000	0.023	0.008	0.009	0.135	0.000	0.000
Erigeron strigosus	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000
Helianthus pauciflorus ssp. *p auciflorus*	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.107	0.041	0.000	0.000	0.000	0.000
Helianthus maximiliani	0.000	0.000	0.019	0.019	0.083	0.000	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heterotheca villosa var. villosa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.029	0.000	0.000

Table 2.3. (continued)

Liatris punctata	0.000	0.000	0.000	0.000	0.008	0.000	0.012	0.000	0.008	0.000	0.000	0.000	0.000	0.000
Linum sulcatum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.010	0.000	0.000
Lithospermum canescens	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000	0.000	0.000
Melilotus officinalis	0.037	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000
Oligoneuron rigidum var. rigidum	0.037	0.062	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Packera plattensis	0.000	0.000	0.019	0.050	0.030	0.162	0.000	0.000	0.031	0.024	0.000	0.000	0.000	0.000
Phalaris arundinacea	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Physalis virginiana	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.013
Poa pratensis	0.627	0.535	0.181	0.231	0.167	0.210	0.255	0.200	0.573	0.366	0.000	0.000	0.000	0.000
Polygala verticillata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000
Pycnanthemum virginianum	0.000	0.000	0.025	0.063	0.030	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ratibida columnifera	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000
Rosa arkansana	0.000	0.000	0.044	0.031	0.083	0.105	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000
Schizachyrium scoparium	0.067	0.054	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.309	0.000	0.000	0.000	0.000
Solidago canadensis	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Solidago missouriensis	0.000	0.000	0.000	0.000	0.030	0.000	0.000	0.000	0.069	0.049	0.000	0.000	0.000	0.000
Sorghastrum nutans	0.000	0.000	0.031	0.000	0.000	0.000	0.194	0.032	0.000	0.000	0.000	0.000	0.523	0.750
Sisyrinchium montanum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.009	0.000	0.000	0.000
Symphyotrichum ericoides var. *ericoides*	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.006	0.038	0.057	0.087	0.010	0.000	0.000
Symphyotrichum ericoides var. *pansum*	0.000	0.000	0.000	0.000	0.000	0.000	0.067	0.000	0.000	0.000	0.000	0.452	0.000	0.000
Thalictrum dasycarpum	0.000	0.000	0.013	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Viola nephrophylla	0.000	0.008	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zizia spp.	0.000	0.000	0.081	0.069	0.129	0.019	0.097	0.135	0.000	0.000	0.000	0.000	0.000	0.000

Table 2.4. Species composition indices.

Plot:	1		2		3		4		5		6		7	
	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control	Cone	Control
Simpsons Diversity Index	2.394	2.742	5.998	6.852	5.116	5.715	6.757	3.499	2.847	4.123	2.185	3.244	2.853	1.671
Equitability	0.299	0.343	0.353	0.457	0.426	0.572	0.483	0.437	0.190	0.344	0.218	0.324	0.476	0.334
Species Richness	8	8	17	15	12	10	14	8	15	12	10	10	6	5
Number Shared Species	7	7	13	13	9	9	7	7	9	9	6	6	3	3
Proportion Shared Species	0.875	0.875	0.765	0.867	0.750	0.900	0.500	0.875	0.600	0.750	0.600	0.600	0.500	0.600

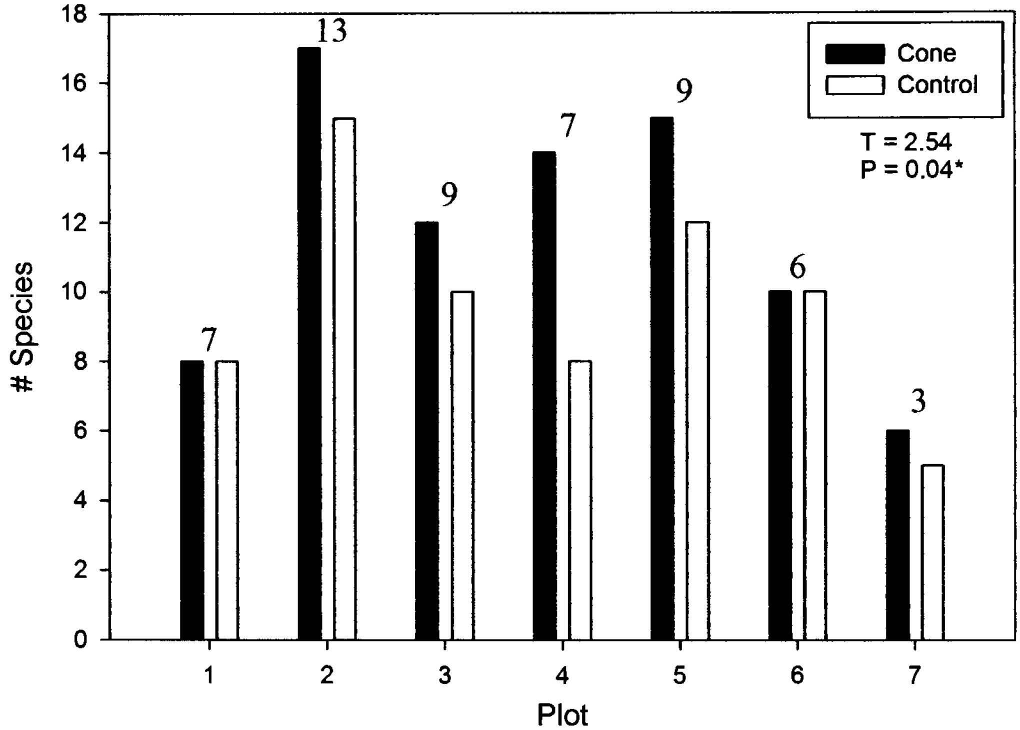


Figure 2.6. Species richness per plot.

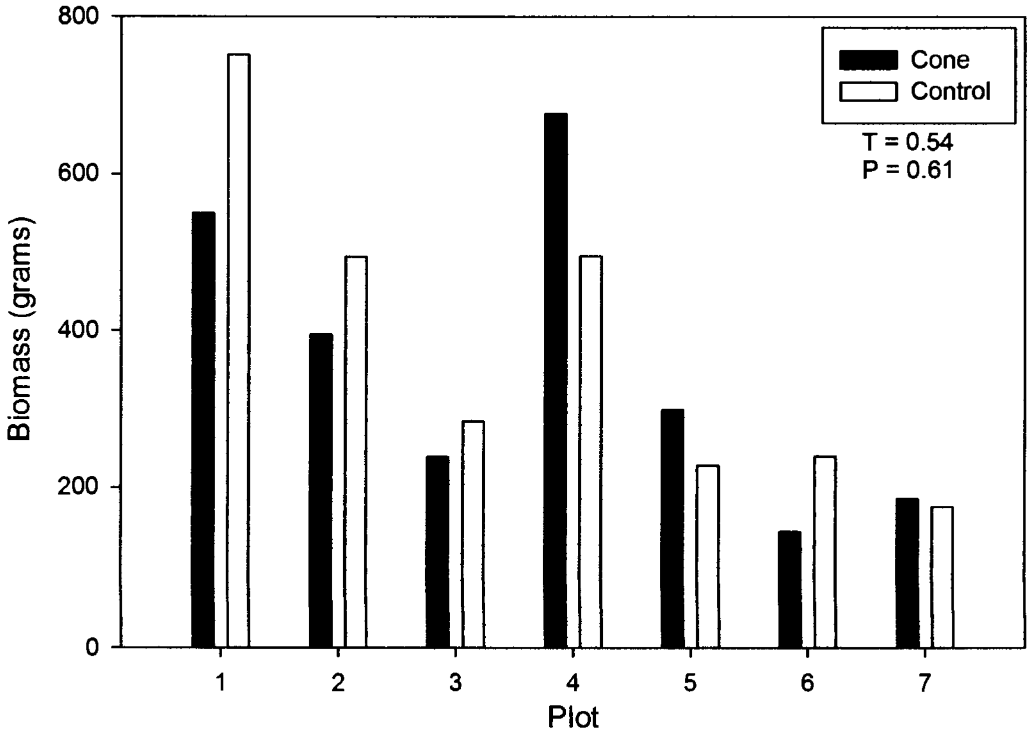


Figure 2.7. Biomass per plot.

Discussion

The results of this experiment indicate that the flowering phenology of multiple flowering plant species is affected by warming. The mean first flowering and maximum flowering occurred earlier in the cone than control treatments. Warming affected the seven plots differently. The differences in the responses to the warmed treatment are most likely due to the differences in habitat and plant communities in each plot.

Warming also affected the final species composition at the end of the summer. Significantly higher species were found in the cone treatments than control. It is unclear if these differences in species richness were manifested early on in the experiment since we only estimated percent cover at the end of the summer. However, there is an indication that at least in some plots there were more species flowering in cones than in controls after the experiment was half over. In three of the seven plots the number of species flowering in the cone circle exceeded the maximum number in the control circle as early as the tenth week (Figure 2.3). The mechanism of increased species richness under warmer conditions is not clear. Based on the percent cover data there is no evidence for a complete shift of species from one treatment to another. Rather the same species seem to be in both treatments, however, a few additional ones are present in the cones at the end of the summer. The prediction from this study is that the degree to which warming can change tallgrass prairie composition will vary from habitat to habitat. A wetter site could have much different changes than a drier site. Additional years of observation will be informative regarding warming effects on species composition.

There is little evidence from this single year experiment that invasive species will thrive under warming conditions in the tallgrass prairie. Two invasive species were identified within the plots. *Poa pratensis* is already a dominant species in both treatments in five of seven plots. Other studies have found that invasive species are increasing in population size in concert with increasing temperatures (Willis et al. 2010) suggesting that this may be a long term response that we could not detect.

Productivity, as measured by standing biomass at the end of the experiment, was not significantly affected by increased temperature. Productivity could have been affected earlier in the growing season particularly when there were clear differences in temperature between the cone and control treatments. The pattern of earlier flowering and fruiting as well as higher levels of fruit production in cones throughout the season imply that early productivity differences ultimately decreased towards the end of the growing season.

A study by Post et al. in 2008 showed that over a two-year period of warming at a low-artic site, aggregate life history events shifted. My experiment used the same ITEX cone design and showed similar results. In their experiment they looked at emergence, flower bud set, blooming, and fruit set. They found the mean aggregate life history of each species from those phenological events and compared them between warmed and control treatments. They found that some species were more affected by warming than others, but overall there was a shift to earlier occurrence of these events (Post et al. 2008).

Since my experiment only showed general trends of earlier flowering and fruiting, a longer study period may show greater shifts in phenological events.

There are many implications of climatic warming. Invasive species could survive better under warming conditions since the results of our experiment shows that warmer conditions lead to higher species richness and some of those species could be invasive. Higher species richness could be the result of more species germinating and surviving. This study indicates that there is the potential for disruption in ecological relationships by species that do or do not shift phenological patterns with increasing temperatures. The extent to which the composition and nature of the tallgrass prairie has been shaped by well-timed phenological responses in the past will ultimately determine how climate change shapes the tallgrass prairie in the future.

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GENERAL CONCLUSIONS

The results of these two studies imply that as the planet has warmed and continues to warm we can expect changes in the phenology of tallgrass prairie plants, which could change many aspects of that ecosystem. The first study provides correlative evidence that increasing air temperatures since the late 1970s have led to earlier springs and earlier flowering in some years. There is also evidence that some plant species are flowering later than ever as a result of the lengthening growing season. In addition, year to year variation from 1910 to 1961 in spring temperature, specifically April temperature, was correlated with the timing of first flower in plant species in the Northern Great Plains. There was little statistical evidence that precipitation changes, including rainfall and previous winter's snowfall, over the same period were correlated with first flowering time. The second study provides experimental evidence that increasing air temperatures are leading to earlier flowering. The prediction from these two studies is that as temperatures continue to rise plant communities in the Northern Great Plains will not retain the same phenological patterns. The consequences of these shifts in phenology will depend on the importance of the timing of life history events for the successful reproduction and survival of native species.

APPENDIX I

Scientific Name	2007	Z-score 2007	2008	Z-score 2008	2009	Z-score 2009
Acer ginnala					152	0.67
Acer negundo			121	0.61	114	-0.16
Acer saccharinum			107	0.95	104	0.58
Achillea millefolium	155	-1.87	168	0.24	168	0.24
Actaea rubra			148	1.19		
Agoseris glauca			161	0.42		
Allium stellatum	205	-0.91	225	1.26	216	0.28
Allium textile					152	1.31
Amelanchier alnifolia			139	1.06	136	0.68
Amorpha canescens	177	-1.37	194	1.31	188	0.36
Andropogon gerardii			225	1.74		
Androsace occidentalis			120	-0.26	119	-0.36
Anemone canadensis	151	-1.03	161	0.53		
Anemone cylindrica			174	0.12	175	0.27
Apocynum cannabinum			177	0.38	177	0.38
Aquilegia canadensis					143	-0.29
Artemisia biennis			233	-1.06		
Asclepias ovalifolia			185	2.39	175	1.00
Asclepias syriaca			185	1.68	185	1.68
Berteroa incana					155	0.23
Betula papyrifera					116	-1.28
Caltha palustris	127	0.22	132	0.96	124	-0.22
Calylophus serrulatus			203	2.42	181	0.55
Campanula rapunculoides			172	-0.64		
Campanula rotundifolia	159	-1.72			175	-0.39
Capsella bursapastoris			107	-1.09		
Castilleja sessiliflora	151	-0.09	158	0.82	152	0.04
Catalpa speciosa			192	2.23	188	1.70
Cerastium arvense			132	-0.32	134	-0.07
Chrysopsis villosa					175	-0.68
Cicuta maculata	177	-0.15			188	1.85
Comandra umbellata			148	0.38	147	0.28
Conringia orientalis			153	0.64		
Convolvulus arvensis			177	0.37	188	1.94
Corylus americana			106	0.35	105	0.24
Crataegus chrysocarpa			148	0.76		
Cypripedium candidum	151	-0.22	147	-0.75	147	-0.75
Dalea candida			195	0.33	196	0.42
Dalea purpurea			199	1.01	197	0.81
Delphinium carolinianum ssp. virescens	165	-1.48	178	0.14	181	0.51

Descurainia pinnata			140	-0.89		
Echinacea purpurea	171	-2.31	190	4.14	189	3.80
Erigeron philadelphicus			161	0.59		
Erysimum asperum			148	-0.05		
Fragaria virginiana			132	1.17		
Fraxinus lanceolata					115	-1.49
Fraxinus pennsylvanica			131	0.45		
Gaillardia aristata	158	-1.20	175	0.28	170	-0.16
Galium aparine			148	-0.11	149	0.07
Galium boreale			168	1.48		
Gaura coccinea	151	-1.29	166	-0.13	170	0.18
Helianthus maximiliani	197	-1.48				
Heracleum maximum					176	1.54
Hesperis matronalis			150	0.29	148	0.02
Heterotheca villosa var. villosa			175	-0.68		
Heuchera richardsonii			168	0.52	152	-0.60
Hydrophyllum virginianum			148	0.17	148	0.17
Hypoxis hirsuta	146	-0.30	149	0.12	152	0.53
Juglans nigra			159	1.66		
Koeleria macrantha					173	0.35
Lactuca pulchella					205	2.73
Liatris aspera	191	-5.29	225	1.47		
Liatris punctata			225	1.89		
Liatris pycnostachya					210	1.91
Lilium philadelphicum	171	-0.90	181	1.68	181	1.68
Lithospermum canescens	127	-1.54	136	-0.42	134	-0.67
Lithospermum incisum			148	1.00	147	0.86
Lobelia spicata					197	2.02
Lonicera tatarica					148	0.97
Lygodesmia juncea			194	0.96		
Maianthemum stellatum					134	-0.53
Malus sylvestris			139	0.57		
Melilotus officinalis					168	1.33
Medicago lupulina			164	0.36		
Oenothera biennis	197	0.37				
Oenothera nuttallii	200	1.81	195	1.41		
Oenothera serrulata			175	0.04		
Oligoneuron rigidum					223	0.45
Onosmodium occidentale			178	0.11	175	-0.07
Osmorhiza longistylis			161	1.17		
Ostrya virginiana					133	0.28
Oxalis stricta			164	0.99	152	-0.38
Oxalis violacea	130	-1.90	140	-0.23	141	-0.06
Oxytropis lambertii					152	-0.28

Packera plattensis			153	1.41	152	1.23
Panicum virgatum			175	-2.17		
Parnassia palustris	213	2.34				
Pedicularis canadensis	130	-3.02	144	-0.38	141	-0.94
Pediomelum argophyllum	167	-1.65				
Pediomelum esculentum	158	-2.73	172	0.10		
Penstemon albidus	146	-1.48	167	1.34	161	0.54
Penstemon gracilis	151	-2.19	172	-0.23	168	-0.60
Penstemon grandiflorus	151	-1.93	168	0.37	168	0.37
Petalostemum candidum	180	-1.08				
Petalostemum purpurea	184	-0.44				
Populus deltoides			113	-0.35	113	-0.35
Populus tremuloides					106	-0.42
Potentilla arguta			177	0.00	181	0.47
Prunus americana			138	1.05	138	1.05
Prunus triloba					140	0.72
Psoralea argophylla			203	2.40	188	0.71
Ranunculus abortivus			132	0.64	139	1.20
Ranunculus rhomboideus	116	-0.17	125	0.53	114	-0.32
Ratibida columnifera	172	-1.35	190	0.42	196	1.00
Rhus glabra			194	1.61		
Ribes americanum			139	0.74		
Ribes missouriense			138	0.28	133	-0.43
Ribes rubrum			138	1.24	136	0.93
Rosa arkansana	153	-2.69	168	0.47	175	1.94
Rudbeckia hirta			177	3.46	175	2.31
Sanguinaria canadensis					115	-0.18
Scrophularia lanceolata			169	0.44	161	-0.06
Senecio plattensis	146	0.16				
Shepherdia argentea			131	2.19	117	0.59
Sisyrinchium angustifolium	151	1.05	147	0.61	138	-0.38
Smilacina stellata			142	0.59		
Smilax herbacea					154	0.26
Solidago canadensis					223	0.57
Solidago missouriensis			225	1.39	216	0.61
Solidago rigida	222	0.24				
Symphoricarpos occidentalis					175	-0.46
Thalictrum dasycarpum	171	-0.25			175	0.15
Thlaspi arvense			132	1.43		
Tragopogon dubius	153	-0.98	163	0.81	168	1.71
Trillian cernuum			145	0.73	143	0.50
Ulmus americana			114	0.43	107	-0.34
Uvularia grandifolia			132	0.31	134	0.64
Viburnum lentago			158	1.53	159	1.69

Vicia americana			161	1.54		
Viola papilionacea					129	0.54
Viola pedatifida	127	-0.93	144	0.65	134	-0.28
Viola pubescens var. pubescens			132	0.84	143	2.31
Zanthoxylum americanum			148	1.50	138	0.26
Zigadenus elegans	171	-0.94	177	0.84	172	-0.64
Zizia aptera			148	0.68	147	0.55
Zizia aurea	151	0.55	143	-0.49	147	0.03

APPENDIX II

Species	Years sampled	Mean 1st flower time	Top predictors	Partial R2	P-value	Equation
Taraxacum officinale	48	128	April temp	0.730	<0.0001	y=-1.23x+101.29
			May temp	0.030	0.031	y=-0.29x+101.29
Ellisia nyctelea	39	140	April temp	0.431	<0.0001	
			May temp	0.133	0.002	
Thlaspi arvense	34	111	April temp	0.216	0.006	y=-2.33x+861.14
			Year	0.336	0.013	y=-0.34x+861.14
			March temp	0.518	0.025	y=-1.21x+861.14
Hydrophyllum virginianum	32	147	May temp	0.394	0.000	y=-1.05x+334.72
			April temp	0.379	<.0001	y=-0.91x+334.72
Chrysanthemum uliginosum	32	255	None P < 0.05			
Actaea rubra	25	141	May temp	0.537	<0.0001	y=-1.15x+399.54
			April temp	0.649	0.015	y=-0.42x+399.54
Melilotus officinalis	22	159	April temp	0.289	0.010	y=-0.76x+567.16
			Year	0.272	0.003	y=-0.17x+567.16
			May temp	0.160	0.005	y=-0.77x+567.16
Stellaria media	23	158	None P < 0.05			
Zizia aurea	21	147	Year	0.287	0.012	y=0.17x-109.20
			May temp	0.219	0.011	y=-0.86x-109.20
			April temp	0.149	0.015	y=-0.53x-109.20
Androsace occidentalis	21	122	April temp	0.793	<0.0001	y=-1.65x+225.91
Sonchus arvensis	22	182	May temp	0.306	0.008	y=-0.94x+556.55
Veronica peregrina	21	139	April temp	0.376	0.003	y=-1.01x+654.76
			year	0.150	0.028	y=-0.25x+654.76
Vicia americana	21	150	May temp	0.370	0.003	y=-1.45x+274.11
			April temp	0.151	0.028	y=-0.78x+274.11

Bromus inermus	18	164	May temp	0.423	0.004	y=-0.66x+529.21
			year	0.200	0.013	y=-0.17x+529.21
Poa pratensis	18	155	May temp	0.465	0.002	y=-1.35x+650.38
			year	0.156	0.025	
			April temp	0.162	0.006	
Aster novae-angliae	17	225	April temp	0.486	0.002	y=-0.94x+341.89
Brassica arvensis	16	150	April temp	0.354	0.015	y=-0.50x+297.43
			May temp	0.273	0.009	y=-1.72x+297.43
Descurainia pinnata	16	148	Last day 32	0.326	0.010	y=0.59x+141.98
Lycoris squamigera	17	234	April temp	0.130	0.009	y=-0.73x+2715.63
			Last day 32	0.360	0.011	y=-0.57x+2715.63
			Snowfall	0.159	0.019	y=-0.29x+2715.63
Tragopogon dubius	16	158	April temp	0.351	0.016	y=-0.65x+324.99
Oxalis violacea	15	141	None P < 0.05			
Asparagus officinalis	15	154	May temp	0.407	0.011	y=-1.46x+692.00
Galium aparine	15	149	April temp	0.418	0.009	y=-0.93x+386.79
			May temp	0.170	0.046	y=-0.88x+386.79
Helianthus maximiliani	15	211	None P < 0.05			
Iva xanthifolia	15	229	None P < 0.05			
Lappula echinata	15	150	Last day 32	0.349	0.020	y=0.92x-28.03
Lepididium densiflorum	15	147	April temp	0.302	0.034	y=-2.07x+652.60

Sanguinaria canadensis	16	117	April temp	0.500	0.003	y=-1.26x+189.18
			March temp	0.155	0.039	y=-0.34x+189.18
Viola rugulosa	15	123	April temp	0.458	0.006	y=-1.16x+367.10
Capsella bursa-pastoris	15	119	Last 32 low	0.347	0.027	y=0.69x-215.20
			April temp	0.261	0.020	y=-1.29x-215.20
Carex pennsylvanica	14	121	April temp	0.596	0.001	y=-1.19x+211.68
Convolvulus repens	14	168	April temp	0.307	0.022	y=-0.85x-141.69
Heliopsis helianthoides	14	178	None P < 0.05			
Medicago sativa	14	160	April temp	0.464	0.007	y=-1.15x+55.97
Apocynum hypericifolium	13	174	None P < 0.05			
Aquilegia canadensis	13	145	May temp	0.589	0.002	y=-1.85x+311.83
Aralia nudicaulis	14	150	May temp	0.497	0.005	y=-2.04x-49.44
Lactuca scariola	13	198	None P < 0.05			
Lysmachia ciliata	13	186	Year	0.311	0.048	y=0.25x-201.08
Ranunculus rhomboideus	13	118	Year	0.476	0.009	y=0.29x-396.71
Agropyron repens	12	172	May temp	0.463	0.015	y=-1.37x+340.57

Ambrosia trifida	12	197	April temp	0.344	0.045	y=-1.54x+235.12
						y=1.18x+235.12
Anemone canadensis	12	158	May temp	0.348	0.043	y=-1.96x+277.27
Astragalus hypoglottis	12	142	April temp	0.432	0.020	y=-1.35x-67.97
Chenopodium strictum	13	229	Feb temp	0.564	0.003	y=-0.32x+199.92
Galium boreale	12	160	May temp	0.453	0.016	y=-1.17x+249.54
			April temp	0.283	0.013	y=-0.44x+249.54
			Feb temp	0.102	0.013	y=-0.28x+249.54
Lappula redowski	12	148	None P < 0.05			
Melilotis alba	12	172	Last day 32	0.713	0.001	y=0.45x+483.03
Oenothera biennis	12	194	None P < 0.05			
Oxalis europea	13	158	April temp	0.326	0.042	y=-2.08x+1064.95
Polygonatum commutatum	12	167	May temp	0.538	0.007	y=-1.01x+273.75
			Last day 32	0.195	0.031	y=-0.37x+273.75
Potentilla norvegica	12	171	Year	0.616	0.003	y=0.31x-437.12
Rumex mexicanus	12	158	None P < 0.05			
Solidago canadensis	12	218	May temp	0.378	0.033	y=-0.30x+333.32
Boltonia latisquama	11	216	None P < 0.05			
Cerastium arvense	11	135	April temp	0.561	0.008	y=-0.82x+845.52
			May temp	0.220	0.022	y=-2.07x+845.52

Cirsium arvense	11	185	May temp	0.421	0.031	y=-1.39x+816.41
Erigeron canadensis	11	196	None P < 0.05			
Grindelia squarrosa	11	205	None P < 0.05			
Lathyrus ochroleucus	11	153	May temp	0.587	0.006	y=-2.21x-6.02
Malva rotundifolia	11	170	Snowfall	0.358	0.040	y=-0.51x+314.65
Mertensia virginica	12	130	April temp	0.825	<.0001	y=-1.26x+219.57
			Snowfall	0.059	0.042	y=-0.21x+219.57
Monolepsis nuttalliana	12	137	April temp	0.648	0.002	y=-1.10x+450.30
Penstemon gracilis	11	175	None P < 0.05			
Psoralea argophylla	11	182	None P < 0.05			
Solidago gigantea	11	208	February temp	0.481	0.018	y=0.40x+650.76
Trifolium repens	11	153	Snowfall	0.367	0.048	y=-0.23x+447.47
Allionia nyctaginea	10	170	Snowfall	0.299	0.028	y=-0.36x-149.55
			Year	0.426	0.041	y=0.24x-149.55
Allium textile	10	139	None P < 0.05			
Chenopodium album	10	171	May temp	0.613	0.007	y=-1.58x+893.65
Eleocharis palustris	10	147	Feb temp	0.314	0.029	y=-2.02x+377.94

Helianthus petiolaris	10	185	Last 32 low	0.198	0.016	y=-0.79x+186.96
Hesperis matronalis	11	148	April temp	0.732	0.001	y=-0.64x+1248.58
Lactuca pulchella	10	185	None P < 0.05			
Lathyrus venosus	10	165	None P < 0.05			
Ranunculus sceleratus	11	150	May temp	0.534	0.011	y=-1.06x+220.51
			Feb temp	0.215	0.031	y=0.36x+220.51
Senecio plattensis	10	145	March temp	0.258	0.017	y=-0.79x+876.16
Sisyrinchium angustifolium	10	141	Snowfall	0.406	0.048	y=-0.53x+203.47
			April temp	0.331	0.021	y=-1.88x+203.47
Smilacina stellata	10	138	Feb temp	0.382	0.000	y=-0.73x+293.51
			Last 32 low	0.550	0.014	y=-0.27x+293.51
			Year	0.026	0.028	y=-0.05x+293.51
Solidago rigida	10	221	None P < 0.05			
Amaranthus retroflexus	9	185	None P < 0.05			
Arenaria lateriflora	9	144	April temp	0.689	0.006	y=-1.04x-28.21
Cardaria draba	10	157	None P < 0.05			
Cirsium undulatum	9	185	None P < 0.05			
Euphorbia serpyllifolia	9	162	Last 32 low	0.179	0.004	y=0.62x+4.36
			May temp	0.695	0.005	y=-1.07x+4.36
Hesperis matronalis	11	148	April temp	0.730	0.001	

Delphinium virescens	9	177	None P < 0.05			
Gaura coccinea	10	168	April temp	0.004	0.016	y=0.30x-541.60
			Year	0.031	0.019	y=0.21x-541.60
			Feb temp	0.195	0.022	y=-0.52x-541.60
Hackelia americana	9	164	March temp	0.274	0.020	y=-2.34x-651.81
			May temp	0.561	0.020	y=-1.63x-651.81
			Feb temp	0.057	0.033	y=-0.33x-651.81
Hierochloa odorata	9	133	April temp	0.778	0.002	y=-5.35x-1862.05
Polygonum aviculare	9	162	Feb temp	0.411	0.006	y=-1.04x+368.74
Portulaca oleracea	9	188	None P < 0.05			
Ranunculus abortivus	9	124	Snowfall	0.143	0.036	y=-0.73x-757.23
			March temp	0.454	0.047	y=-0.66x-757.23
Sisymbrium altissimum	9	157	April temp	0.319	0.011	y=-1.99x+946.55
			May temp	0.535	0.025	
Smilax herbacea	9	152	May temp	0.491	0.036	y=-3.54x-1097.46
Stachys palustris	9	180	May temp	0.604	0.014	y=-3.60x+1263.57
Tradescantia bracteata	9	150	None P < 0.05			
Vernonia fasciculata	9	206	None P < 0.05			
Lithospermum canescens	6	139	None P < 0.05			
Cypripedium candidum	3	153	Year	0.994	0.048	y=0.62x-1065.46
Corylus americana		103	None P < 0.05			

Acer saccharinum	50	99	March temp	0.473	<.0001	y=-0.87x+126.24
			April temp	0.138	0.000	y=-0.71x+126.2
Sheperdia argentea	43	112	April temp	0.479	<.0001	y=-1.22x+99.14
			March temp	0.222	<.0001	y=-0.68x+99.14
Ulmus americana	48	110	April temp	0.504	<.0001	y=-1.33x+180.30
			March temp	0.171	<.0001	y=-0.60x+180.30
Populus tremuloides	16	111	April temp	0.552	0.001	y=-1.41x+214.06
			March temp	0.254	0.001	y=-0.76x+214.06
Populus deltoides	41	116	April temp	0.695	<.0001	y=-1.47x+273.25
			March temp	0.076	0.001	y=-0.45x+273.25
Acer negundo	46	115	April temp	0.553	<.0001	y=-1.44x+192.40
			March temp	0.146	<.0001	y=-0.59x+192.40
Shepherdia argentea	43	112	April temp	0.479	<.0001	y=-1.22x+99.14
			March temp	0.222	<.0001	y=-0.68x+99.14
Salix discolor	9	111	April temp	0.589	0.016	y=-1.85x+259.08
Salix cordata	12	112	April temp	0.734	0.000	y=-1.64x-50.20
Juniperus virginiana	25	119	April temp	0.580	<.0001	y=-1.26x+316.23
			March temp	0.078	0.035	y=-0.42x+316.23
Juniperus scopulorum	36	129	April temp	0.305	0.001	y=-0.71x+43.78
			May temp	0.135	0.008	y=-0.74x+43.78
Salix vitellina	23	127	April temp	0.753	<.0001	y=-1.40x+242.12
			May temp	0.095	0.001	y=-0.81x+242.12
Celtis occidentalis	26	127	April temp	0.735	<.0001	y=-1.37x+424.21
			March temp	0.063	0.013	y=-0.55x+424.21
			May temp	0.046	0.019	y=-0.46x+424.21
Crataegus mollis	10	135	April temp	0.734	0.002	y=-1.29x+212.32
Prunus tomentosa	11	127	April temp	0.792	0.000	y=-1.21x-660.98
			May temp	0.077	0.033	y=-1.23x-660.98

Prunus armeniaca	16	125	April temp	0.615	0.000	y=-1.13x+223.96
			March temp	0.219	0.001	y=-0.91x+223.96
			May temp	0.052	0.036	y=-0.58x+223.96
Prunus americana	50	130	April temp	0.569	<.0001	y=-1.44x+380.03
			May temp	0.073	0.003	y=-0.82x+380.03
			March temp	0.106	<.0001	y=-0.52x+380.03
Ribes odoratum	34	130	April temp	0.605	<.0001	y=-1.42x+430.18
			March temp	0.060	0.025	y=-0.51x+430.18
			May temp	0.097	0.002	y=-0.56x+430.18
Ribes vulgare	25	130	April temp	0.549	<.0001	y=-1.37x+196.46
			May temp	0.099	0.021	y=-0.35x+196.46
Amelanchier alnifolia	41	131	April temp	0.463	<.0001	y=-1.22x+232.18
			May temp	0.121	0.002	y=-0.80x+232.18
Sambucus pubens	24	134	April temp	0.652	<.0001	y=-1.49x+984.52
Betula papyrifera	34	126	April temp	0.448	<.0001	y=-1.12x+208.57
			May temp	0.075	0.035	y=-0.58x+208.57
Spiraea arguta	17	130	April temp	0.860	<.0001	y=-1.61x+228.55
Crataegus chrysocarpa	5	141	Year	0.856	0.024	y=1.08x-1955.73
Prunus pennsylvanica	20	132	April temp	0.644	<.0001	y=-1.41x+546.63
			May temp	0.113	0.012	y=-1.35x+546.63
			March temp	0.081	0.013	y=-0.68x+546.63
Prunus triloba	13	134	April temp	0.829	<.0001	y=-1.44x+241.13
Salix amygdaloides	6	135	None P<0.05			
Ostrya virginiana	12	130	April temp	0.770	0.000	y=-2.35x-16.27
			May temp	0.094	0.034	y=1.42x-16.27
Ribes americanum	9	134	April temp	0.747	0.003	y=-1.62x+121.95
Ribes missouriense	8	136	April temp	0.706	0.009	y=-2.29x+217.85
			snowfall	0.223	0.011	y=-0.52x+217.85

Hippophae rhamnoides	7	131	None P<0.05			
Zanthoxylum americanum	8	136	May temp	0.597	0.025	y=-1.66x+283.59
Fraxinus lanceolata	35	127	April temp	0.582	<.0001	y=-1.41x+466.16
			May temp	0.063	0.023	y=-0.70x+466.16
Daphne cneorum	9	130	April temp	0.893	0.000	y=-1.37x-1145.25
			Last 32 low	0.055	0.046	y=0.38x-1145.25
Acer ginnala	11	147	April temp	0.781	0.000	y=-1.35x-257.19
			Feb temp	0.104	0.027	y=0.44x-257.19
Prunus virginiana	37	139	April temp	0.406	<.0001	y=-1.16x+393.30
			May temp	0.249	<.0001	y=-1.14x+393.30
			March temp	0.079	0.004	y=-0.46x+393.30
Quercus macrocarpa	31	140	April temp	0.409	0.000	y=-1.15x+479.10
			May temp	0.238	0.000	y=-1.05x+479.10
Syringa vulgaris	45	139	April temp	0.499	<.0001	y=-1.36x+458.86
			May temp	0.183	<.0001	y=-0.97x+458.86
			March temp	0.036	0.027	y=-0.31x+458.86
Syringa persica	11	141	April temp	0.854	<.0001	y=-0.86x-582.51
Syringa villosa	17	153	May temp	0.631	0.000	y=-1.98x+561.88
			March temp	0.108	0.030	y=-0.56x+561.88
Euonymus nanus	9	145	March temp	0.242	0.005	y=0.57x-1306.61
Berberis thunbergii	19	140	April temp	0.814	<.0001	y=-1.84x+206.82
Lonicera tatarica	31	141	April temp	0.422	<.0001	y=-1.36x+490.41
			May temp	0.255	<.0001	y=-1.22x+490.41
			March temp	0.074	0.009	y=-0.43x+490.41
Lonicera dioica	22	145	April temp	0.483	0.000	y=-1.02x+461.96
			May temp	0.314	<.0001	y=-1.29x+461.96
			Feb temp	0.035	0.047	y=-0.21x+490.41
Cotoneaster acutifolius	21	147	April temp	0.453	0.001	y=-1.41x+1164.51

Rhamnus cathartica	20	142	April temp	0.596	<.0001	y=-1.29x+468.49
			May temp	0.087	0.046	y=-0.77x+468.49
Elaeagnus angustifolia	5	159	None P<0.05			
Juglans cinerea	19	139	April temp	0.816	<.0001	y=-1.60x+679.61
Juglans nigra	17	150	May temp	0.416	0.005	y=-1.28x+409.39
Salix interior	8	145	April temp	0.613	0.022	y=-1.74x+703.76
			snowfall	0.250	0.030	y=-0.21x+703.76
Viburnum lentago	9	149	May temp	0.682	0.006	y=-1.37x+805.38
			April temp	0.185	0.028	y=-1.60x+805.38
Malus sylvestris	23	134	April temp	0.817	<.0001	y=-1.71x+513.48
			March temp	0.031	0.040	y=-0.41x+513.48
Malus baccata	17	132	April temp	0.673	<.0001	y=-1.46x+51.76
			May temp	0.092	0.035	y=-1.03x+51.76
Spiraea thunbergii	17	144	April temp	0.653	<.0001	y=-0.90x-253.75
			May temp	0.124	0.015	y=-1.63x-253.75
			Snowfall	0.063	0.028	y=-0.16x-253.75
Caragana arborescens	25	137	April temp	0.488	0.000	y=-1.46x+551.33
			May temp	0.142	0.008	y=-1.06x+551.33
			March temp	0.079	0.027	y=-0.55x+551.33
Caragana pygmaea	16	149	April temp	0.770	<.0001	y=-0.76x+371.16
			May temp	0.124	0.002	y=-0.98x+371.16
Potentilla fruticosa	16	157	April temp	0.529	0.001	y=-1.87x+1052.01
Amorpha fruticosa	6	155	None P<0.05			
Cornus alba	11	147	April temp	0.818	0.000	y=-0.72x+296.40
			Snowfall	0.087	0.026	y=-0.21x+296.40
Rosa hugonis	14	157	April temp	0.711	0.000	y=-1.01x+1022.65
			May temp	0.134	0.010	y=-0.98x+1022.65

Rubus occidentalis	7	151	April temp	0.602	0.040	y=-1.14x+389.35
			Snowfall	0.076	0.042	y=-0.20x+389.35
Rubus strigosus	1	167	None P<0.05			
Viburnum opulus	14	152	May temp	0.637	0.001	y=-1.00x+208.70
			April temp	0.145	0.020	y=-0.65x+208.70
Vitis riparia	11	160	May temp	0.545	0.010	y=-0.72x+236.80
			April temp	0.214	0.029	y=-0.97x+236.80
Rosa blanda	10	162	Feb temp	0.524	0.018	y=-0.46x+454.13
			Year	0.064	0.042	y=-0.10x+454.13
Rosa arkansana	13	166	None P<0.05			
Rhus glabra	12	183	Feb temp	0.410	0.025	y=-0.71x+200.88
Tamarix pentandra	8	165	May temp	0.829	0.002	y=-2.26x+650.86
			Snowfall	0.104	0.038	y=0.10x+650.86
Rhus rydbergii	4	168	Snowfal	0.965	0.018	y=-0.52x+173.18
			March temp	0.035	0.022	y=0.55x+173.18
Parthenocissus vitacea	6	185	None P<0.05			
Spiraea alba	4	181	None P<0.05			
Amorpha canescens	7	186	None P<0.05			
Catalpa speciosa	16	175	May temp	0.519	0.002	y=-1.18x+640.65
Catalpa bignoniodes	12	179	Feb temp	0.431	0.020	y=0.39x+275.25
Symphoricarpos occidentalis	8	179	May temp	0.557	0.034	y=-2.93x+310.51

Clematis virginiana	11	230	None P<0.05			
Campsis radicans	4	209	None P<0.05			

APPENDIX III

Date	Julian Date	Scientific Name	Common Name
4/17/2007	107	*Anemone patens*	Pasque flower
4/27/2007	117	*Ranunculus rhomboideus*	Prairie buttercup
5/8/2007	128	*Geum triflorum*	Prairie smoke
5/8/2007	128	*Viola pedatifida*	Prairie violet
5/8/2007	128	*Caltha palustris*	Marsh marigold
5/8/2007	128	*Antennaria campestris*	Prairie everlasting
5/8/2007	128	*Lithospermum canescens*	Hoary puccoon
5/11/2007	131	*Cerastium arvense*	Chickweed
5/11/2007	131	*Pedicularis canadensis*	Wood betony
5/11/2007	131	*Oxalis violacea*	Violet wood oxalis
5/11/2007	131	*Calvatia gigantea*	Giant puffball
5/27/2007	147	*Hypoxis hirsuta*	Yellow star grass
5/27/2007	147	*Penstemon albidus*	White beardtongue
5/27/2007	147	*Senecio plattensis*	Prairie ragwort
6/1/2007	152	*Tradescantia occidentalis*	Spiderwort
6/1/2007	152	*Sisyrinchium angustifolium*	Blue-eyed grass
6/1/2007	152	*Cypripedium candidum*	White lady's slipper
6/1/2007	152	*Zizia aurea*	Golden Alexander
6/1/2007	152	*Penstemon grandiflorus*	Large flowered penstemon
6/1/2007	152	*Castilleja sessiliflora*	Downy paintbrush
6/1/2007	152	*Gaura coccinea*	Scarlet gaura
6/1/2007	152	*Penstemon gracilis*	Lilac penstemon
6/1/2007	152	*Anemone canadensis*	Canada anemone
6/3/2007	154	*Tragopogon dubius*	Goatsbeard
6/3/2007	154	*Rosa arkansana*	Wild rose
6/3/2007	154	*Asclepias syriaca*	Milkweed
6/5/2007	156	*Achillea millefolium*	Common yarrow
6/8/2007	159	*Pediomelum esculentum*	Prairie turnip
6/8/2007	159	*Gaillardia aristata*	Blanket flower
6/9/2007	160	*Physalis sp.*	Yellow ground cherry
6/9/2007	160	*Campanula rotundifolia*	Harebell
6/15/2007	166	*Rudbeckia triloba*	Brown-eyed susan
6/15/2007	166	*Onosmodium molle*	False gromwell
6/15/2007	166	*Delphinium virescens*	Prairie larkspur
6/17/2007	168	*Pediomelum argophyllum*	Silver leaved scurf pea
6/21/2007	172	*Thalictrum dasycarpum*	Tall meadow rue
6/21/2007	172	*Zigadenus elegans*	White camas
6/21/2007	172	*Lilium philadelphicum*	Wood lily
6/21/2007	172	*Echinacea purpurea*	Purple coneflower
6/22/2007	173		Yellow flax

6/22/2007	173	*Asclepias viridiflora*	Green milkweed
6/22/2007	173	*Ratibida columnifera*	Prairie coneflower
6/27/2007	178	*Amorpha canescens*	Lead plant
6/27/2007	178	*Cicuta maculata*	Water hemlock
6/30/2007	181	*Petalostemum canidum*	White prairie clover
7/4/2007	185	*Petalostemum purpurea*	Purple prairie clover
7/4/2007	185	*Lysimachia quadriflora*	Prairie loosestrife
7/6/2007	187	*Monarda fistulosa*	Wild bergamot
7/11/2007	192	*Liatris aspera*	Tall blazing star
7/11/2007	192	*Helianthus pauciflorus*	Helianthus pauciflorus
7/17/2007	198	*Helianthus maximiliani*	Helianthus maximiliani
7/17/2007	198	*Oenothera biennis*	Common evening primrose
7/20/2007	201	*Oenothera nuttallii*	White evening primrose
7/25/2007	206	*Allium stellatum*	Wild onion
7/27/2007	208	*Lactuca sp.*	Blue lettuce
8/2/2007	214	*Parnassia palustris*	Northern grass of Parnassus
8/11/2007	223	*Solidago rigida*	Stiff goldenrod
8/14/2007	226	*Gentiana procera*	Fringed gentian
8/16/2007	228	*Gentiana andrewsii*	Closed gentian
8/31/2007	243	*Gentiana puberula*	Downy gentian

APPENDIX IV

Date	Julian Date	Scientific Name	Common Name
4/14/2008	105	*Taraxacum officinale*	Dandylion
4/16/2008	107	*Corylus americana*	Hazelnut
4/17/2008	108	*Acer saccharinum*	Silver Maple
4/17/2008	108	*Capsella bursa-pastoris*	shepherds purse
4/17/2008	108	*Anemone patens*	Pasque flower
4/23/2008	114	*Populus deltoides*	Cottonwood
4/23/2008	114	*Forsythia 'Meadowlark'*	Meadowlark Forsythia
4/24/2008	115	*Ulmus americana*	American Elm
4/25/2008	116	*Salix lutea*	willow
4/30/2008	121	*Forsythia sp.*	Forsythia
4/30/2008	121	*Androsace occidentalis*	Fairy Candelabra
5/1/2008	122	*Acer negundo*	Box Elder
5/3/2008	124	*Sanguinaria canadensis*	Bloodroot
5/5/2008	126	*Ranunculus rhomboideus*	prairie buttercup
5/5/2008	126	*Carex heterophylla*	sedge
5/5/2008	126	*Geum triflorum*	torch flower
5/8/2008	129	*Antennaria microphyla*	pussy toes
5/11/2008	132	*Shepherdia argentea*	Buffalo Berry
5/11/2008	132	*Fraxinus pennsylvanica*	Green Ash
5/12/2008	133	*Thlaspi arvense*	frenchweed
5/12/2008	133	*Cerastium arvense*	Field(Meadow) Chickweed
5/12/2008	133	*Uvularia grandifolia*	Large-flowered Bellwort
5/12/2008	133	*Viola pubescens*	Yellow Wood Violet
5/12/2008	133	*Fragaria virginiana*	Wild Strawberry
5/12/2008	133	*Asarum canadense*	Wild Ginger
5/12/2008	133	*Ranunculus abortivus*	littleleaf buttercup
5/12/2008	133	*Caltha palustris*	Common Marsh-Marigold
5/15/2008	136	*Viola sororia*	Common Blue Violet
5/16/2008	137	*Lithospermum canescens*	Hoary Puccoon
5/16/2008	137	*Calvatia gigantea*	Giant Puffballs
5/18/2008	139	*Ribes missouriense*	Gooseberry
5/18/2008	139		Honeyberry
5/18/2008	139	*Prunus americana*	American Plum
5/18/2008	139	*Ribes rubrum*	Red Lake Currant
5/19/2008	140	*Amelanchier alnifolia*	Juneberry
5/19/2008	140	*Ribes americanum*	Wild Black Currant
5/19/2008	140	*Malus sylvestris*	European Crabapple
5/20/2008	141	*Oxalis violacea*	Pink/Violet Wood Sorrel
5/20/2008	141	*Lithospermum canescens*	Hoary Puccoon
5/20/2008	141	*Astragalus missouriensis/agrestis*	Missouri or Purple milkvetch

5/20/2008	141	*Prunus americana*	American Plum
5/20/2008	141	*Arisaema triphyllum*	Jack in the Pulpit
5/20/2008	141	*Descurainia pinnata*	Western Tansy Mustard
5/20/2008	141	*Lamiastrum galeobdolon*	yellow archangel
5/22/2008	143	*Smilacina stellata*	False Solomon's Seal
5/23/2008	144	*Euphorbia esula*	Leafy Spurge
5/23/2008	144	*Equisetum kanasanum*	Horsetail
5/23/2008	144	*Zizia aurea*	Meadow Parsnip
5/23/2008	144	*Viola canadensis* var. *rugulosa*	White/Pink Wood Violet
5/23/2008	144		Russian Honeysuckle
5/23/2008	144	*Malus spp.*	Apple Tree
5/24/2008	145	*Pedicularis canadensis*	Common Lousewort
5/24/2008	145	*Viola pedatifida*	Prairie Violet
5/25/2008	146	*Trillium cernuum*	Nodding Wake Robin
5/27/2008	148	*Zizia aurea*	Golden Alexanders
5/27/2008	148	*Sisyrinchium angustifolium*	Blue-eyed Grass
5/27/2008	148	*Cypripedium candidum*	White Lady's Slipper
5/28/2008	149	*Comandra umbellata* ssp. *pallida*	Pale Bastard Toadflax
5/28/2008	149	*Zizia aptera*	Meadow Zizia
5/28/2008	149	*Pedicularis canadensis*	Common Lousewort
5/28/2008	149	*Astragalus missouriensis*	Missouri Milkvetch
5/28/2008	149	*Galium aparine*	Bedstraw
5/28/2008	149	*Actaea rubra*	Red Baneberry
5/28/2008	149	*Trillium cernuum*	Nodding Wake Robin
5/28/2008	149	*Lithospermum incisum*	Narrow-leaved puccoon
5/28/2008	149	*Crataegus chrysocarpa*	Hawthorn
5/28/2008	149	*Lonicera sp.*	Honeysuckle
5/28/2008	149	*Erysimum asperum*	Western Wallflower
5/28/2008	149	*Hydrophyllum virginianum*	Waterleaf
5/28/2008	149	*Zanthoxylum americanum*	Prickly Ash
5/28/2008	149	*Galium aparine*	Bedstraw
5/28/2008	149	*Syringa sp.*	Lilac
5/29/2008	150	*Hypoxis hirsuta*	yellow star grass
5/30/2008	151	*Hesperis matronalis*	Dame's Rocket
6/2/2008	154	*Packera plattensis*	prairie groundsel
6/2/2008	154	*Conringia orientalis*	Hare's ear mustard
6/2/2008	154	*Castilleja coccinea*	Yellow Painted Cup
6/7/2008	159	*Viburnum lentago*	Nannyberry
6/7/2008	159	*Viburnum trilobum*	Highbush cranberry
6/7/2008	159	*Aesculus glabra*	Ohio Buckeye
6/7/2008	159	*Tradescantia occidentalis*	Spiderwort
6/7/2008	159	*Castilleja sessiliflora*	Downy Paintbrush
6/8/2008	160	*Juglans nigra*	Black Walnut

6/9/2008	161	*Sorbus decora*	Showy Mountain-ash
6/10/2008	162	*Anemone canadensis*	Canadian anemone
6/10/2008	162	*Agoseris glauca*	Pale Agoseris/False Dandelion
6/10/2008	162	*Erigeron philadelphicus*	Philadelphia fleabane
6/10/2008	162	*Vicia americana*	Wild Vetch
6/10/2008	162	*Aquilegia canadensis*	Red Columbine
6/10/2008	162	*Thalictrum venulosum*	Early Meadow Rue
6/10/2008	162	*Osmorhiza longistylis*	Sweet Cicely
6/12/2008	164	*Tragopogon dubius*	Goatsbeard
6/13/2008	165	*Trifolium repens*	White Clover
6/13/2008	165	*Oxalis stricta*	Yellow oxalis, Lady's Sorrel
6/13/2008	165	*Medicago lupulina*	black medick
6/15/2008	167	*Gaura coccinea*	Scarlet Gaura
6/16/2008	168	*Penstemon albidus*	White Penstemon
6/16/2008	168		Creeping Ground Vetch
6/17/2008	169	*Heuchera richardsonii*	Alum Root
6/17/2008	169	*Achillea millefolium*	Yarrow
6/17/2008	169	*Penstemon albidus*	White Penstemon
6/17/2008	169	*Penstemon grandiflorus*	Large Beardtongue
6/17/2008	169	*Galium boreale*	Northern Bedstraw
6/17/2008	169	*Cypripedium parviflorum*	Yellow Ladyslipper
6/17/2008	169	*Rosa arkansana*	Wild Prairie Rose
6/18/2008	170	*Sanicula marylandica*	Black Snakeroot
6/18/2008	170	*Scrophularia lanceolata*	Lanceleaf Figwort
6/21/2008	173	*Campanula rotundifolia*	bluebell/bellflower/harebell
6/21/2008	173	*Pediomelum esculentum*	large Indian breadroot
6/21/2008	173	*Penstemon gracilis*	Lilac flowered penstemon
6/23/2008	175	*Physalis virginiana*	Ground Cherry
6/23/2008	175	*Anemone cylindrica*	Candle Anemone
6/24/2008	176	*Oenothera serrulata*	Toothed Evening Primrose
6/24/2008	176	*Gaillardia aristata*	Gaillardia/Blanket Flower
6/24/2008	176	*Panicum virgatum*	Switchgrass
6/24/2008	176	*Heterotheca villosa var. villosa*	Golden Aster
6/26/2008	178	*Convolvulus arvensis*	Field Bindweed
6/26/2008	178	*Apocynum cannabinum*	Dogbane/Indian Hemp
6/26/2008	178	*Zigadenus elegans*	White Camas
6/26/2008	178	*Rudbeckia hirta*	Brown-eyed Susan
6/26/2008	178	*Potentilla arguta*	tall cinquefoil
6/27/2008	179	*Delphinium carolinianum ssp. virescens*	prairie larkspur
6/27/2008	179	*Onosmodium occidentale*	false gromwell
6/30/2008	182	*Lilium philadelphicum*	Wood Lily
7/4/2008	186	*Asclepias syriaca*	Common Milkweed

7/4/2008	186	*Asclepias ovalifolia*	Ovalleaf Milkweed
7/7/2008	189	*Cirsium flodmanii*	Flodman's Thistle
7/9/2008	191	*Ratibida columnifera*	prairie cone flower
7/9/2008	191	*Echinacea angustifolia*	purple coneflower
7/11/2008	193	*Catalpa speciosa*	Northern Catalpa
7/13/2008	195	*Amorpha canescens*	Leadplant
7/13/2008	195	*Symphoricarpos occidentalis/ albus*	Buckbrush/snowberry
7/13/2008	195	*Verbena bracteata*	Bracted Vervain
7/13/2008	195	*Verbena stricta*	Hoary Vervain
7/13/2008	195	*Lygodesmia juncea*	Skeleton Weed
7/13/2008	195	*Asclepias syriaca*	Common Milkweed
7/13/2008	195	*Asclepias ovalifolia*	Ovalleaf Milkweed
7/13/2008	195	*Heracleum maximum*	Cow Parsnip
7/13/2008	195	*Rhus glabra*	Sumac
7/13/2008	195	*Scirpus atrovirens*	Dark Green Bulrush
7/14/2008	196	*Dalea candida*	white prairie clover
7/14/2008	196	*Oenothera nuttallii*	white evening primrose
7/18/2008	200	*Dalea purpurea*	Purple prairie clover
7/22/2008	204	*Monarda fistulosa*	Wild Bergamot
7/22/2008	204	*Symphyotrichum falcatum var. commutatum*	White prairie aster
7/22/2008	204	*Calylophus serrulatus*	Yellow sundrops
7/22/2008	204	*Psoralea argophylla*	Silverleaf Scurfpea
8/13/2008	226	*Liatris aspera*	tall blazing star
8/13/2008	226	*Liatris punctata*	dotted blazing star
8/13/2008	226	*Allium stellatum*	Pink Wild Onion
8/13/2008	226	*Solidago missouriensis*	Missouri Goldenrod
8/13/2008	226	*Andropogon gerardii*	Big Bluestem
8/13/2008	226	*Amphicarpaea bracteata*	Hog Peanut
8/21/2008	234	*Artemisia biennis*	Wormwood

APPENDIX V

Date	Julian Date	*Observations*	Common Name
4/13/2009	103	*Taraxacum officinale*	Dandylion
4/14/2009	104	*Acer saccharinum*	Silver Maple
4/15/2009	105	*Corylus americana*	Hazelnut
4/16/2009	106	*Populus tremuloides*	Quaking Aspen
4/17/2009	107	*Ulmus americana*	American Elm
4/17/2009	107	*Anemone patens*	Pasque Flower
4/22/2009	112	*Stellaria media*	Common Chickweed
4/23/2009	113	*Forsythia x 'Meadowlark'*	Meadowlark Forsythia
4/23/2009	113	*Populus deltoides*	Cottonwood
4/23/2009	113	*Populus alba*	White Poplar
4/24/2009	114	*Ranunculus rhomboideus*	prairie buttercup
4/24/2009	114	*Acer negundo*	Boxelder
4/25/2009	115	*Sanguinaria canadensis*	Bloodroot
4/25/2009	115	*Fraxinus lanceolata*	Green Ash
4/26/2009	116	*Betula papyrifera*	Paper Birch
4/27/2009	117	*Shepherdia argentea*	Buffaloberry
4/29/2009	119	*Androsace occidentalis*	Fairy Candelabra
5/3/2009	123	*Asarum canadense*	Wild Ginger
5/4/2009	124	*Caltha palustris*	Marsh Marigold
5/4/2009	124	*Antennaria plantaginifolia*	Pussy Toes
5/8/2009	128	*Geum triflorum*	Prairie Smoke
5/8/2009	129	*Viola papilionacea*	Violet
5/10/2009	130	*Sanguinaria canadensis*	Bloodroot
5/10/2009	130	*Ranunculus rhomboideus*	Prairie Buttercup
5/11/2009	131	*Geum triflorum*	Prairie Smoke
5/13/2009	133	*Ribes missouriense*	Gooseberry
5/13/2009	133	*Ostrya virginiana*	Ironwood
5/13/2009	133	*Viola papilionacea*	Violet
5/13/2009	133	*Viola x wittrockiana*	Pansy
5/13/2009	133	*Lonicera caerulea var. edulis*	Honeyberry
5/14/2009	134	*Viola pedatifida*	prairie violet
5/14/2009	134	*Lithospermum canescens*	hoary puccoon
5/14/2009	134	*Calvatia gigantea*	giant puffball
5/14/2009	134	*Cerastium arvense*	common chickweed
5/14/2009	134	*Euphorbia esula*	Leafy Spurge
5/14/2009	134	*Uvularia grandiflora*	Large-flowered bellwort
5/14/2009	134	*Maianthemum stellatum*	False Solomon's Seal
5/15/2009	135	*Arisaema triphyllum*	Jack-in-the-pulpit
5/16/2009	136	*Amelanchier alnifolia*	Juneberry
5/16/2009	136	*Ribes rubrum*	Red Lake Currant
5/18/2009	138	*Astragalus missouriensis*	Missouri Milk-vetch

5/18/2009	138	*Sisyrinchium angustifolium*	Narrowleaf blue-eyed grass
5/18/2009	138	*Prunus americana*	Wild Plum
5/18/2009	138	*Zanthoxylum americanum*	Prickly Ash
5/18/2009	138	*Lamiastrum galeobdolon*	yellow archangel
5/19/2009	139	*Ranunculus abortivus*	Littleleaf Buttercup
5/19/2009	139	*Dodecathion meadia*	Shooting Star
5/20/2009	140	*Malus sp.*	Flowering Crabapple
5/20/2009	140	*Prunus triloba*	Double flowering plum
5/20/2009	140	*Cornus alternifolia*	Pagoda Dogwood
5/20/2009	140	*Fragaria virginiana*	Wild Strawberry
5/21/2009	141	*Pedicularis canadensis*	Common Lousewort
5/21/2009	141	*Oxalis violacea*	Pink/Violet Wood Sorrel
5/21/2009	141	*Castilleja coccinea*	Indian Paint-brush
5/21/2009	141	*Arabis divaricarpa*	spreadingpod rockcress
5/22/2009	142	*Alliaria petiolata*	Garlic Mustard
5/23/2009	143	*Viola pubescens*	Downy Yellow Wood Violet
5/23/2009	143	*Aquilegia canadensis*	Columbine
5/23/2009	143	*Trillium cernuum*	Nodding Trillium
5/23/2009	143	*Sisyrinchium angustifolium*	blue-eyed grass
5/23/2009	143	*Oxalis violacea*	violet wood oxalis
5/27/2009	147	*Lithospermum incisum*	Narrow-leaved puccoon
5/27/2009	147	*Cypripedium candidum*	White Lady Slipper
5/27/2009	147	*Camandra umbellata*	Bastard Toadflax
5/27/2009	147	*Zizia aurea*	Golden Alexanders
5/27/2009	147	*Zizia aptera*	Meadow Zizia
5/27/2009	147	*Sorbus decora*	Showy Mountain-ash
5/28/2009	148	*Crataegus mollis/rotundifolia*	Hawthorn
5/28/2009	148	*Lonicera tatarica*	Honeysuckle
5/28/2009	148	*Hydrophyllum virginianum*	Waterleaf
5/28/2009	148	*Hesperis matronalis*	Dame's Rocket
5/29/2009	149	*Galium aparine*	Bedstraw
6/1/2009	152	*Packera plattensis*	Prairie Groundsel
6/1/2009	152	*Hypoxis hirsuta*	Yellow stargrass
6/1/2009	152	*Allium textile*	White Wild Onion
6/1/2009	152	*Castilleja sessiliflora*	Downy Paintbrush
6/1/2009	152	*Oxalis stricta*	Yellow Oxalis
6/1/2009	152	*Heuchera richardsonii*	Alum Root
6/1/2009	152	*Oxytropis lambertii*	Lambert's locoweed
6/1/2009	152	*Cornus stolonifera*	Red-twigged Dogwood
6/1/2009	152	*Acer ginnala*	Amur Maple
6/3/2009	154	*Smilax herbacea*	Carrion Flower
6/3/2009	154	*Brassica napus*	Canola
6/4/2009	155	*Berteroa incana*	Hoary alyssum

6/4/2009	155	*Heuchera richardsonii*	Alum Root
6/4/2009	155	*Castilleja sessiliflora*	Downy Paintbrush
6/8/2009	159	*Barbarea vulgaris*	
6/8/2009	159	*Viburnum trilobum*	Upright Cranberrybush
6/8/2009	159	*Viburnum lentago*	Nannyberry
6/9/2009	160	*Silene alba*	White Campion
6/10/2009	161	*Penstemon albidus*	White Penstemon
6/10/2009	161	*Anemone canadensis*	Wood Anemone
6/10/2009	161	*Actaea rubra*	Red Baneberry
6/10/2009	161	*Scrophularia lanceolata*	Lanceleaf Figwort
6/10/2009	161	*Stellaria longifolia*	Long-leaved Stitchwort
6/17/2009	168	*Penstemon grandiflorus*	Large Beardtongue
6/17/2009	168	*Erigeron strigosus*	Daisy Fleabane
6/17/2009	168	*Pediomelum esculentum*	Indian Breadroot
6/17/2009	168	*Achillea millefolium*	Yarrow
6/17/2009	168	*Melilotus officinalis*	Yellow Sweet Clover
6/17/2009	168	*Penstemon gracilis*	Lilac flowered penstemon
6/17/2009	168	*Potentilla argentea*	Silvery Cinquefoil
6/17/2009	168	*Tradescantia occidentalis*	Prairie Spiderwort
6/17/2009	168	*Tragopogon dubius*	Goatsbeard
6/19/2009	170	*Gaillardia aristata*	Gaillardia/Blanket Flower
6/19/2009	170	*Gaura coccinea*	Scarlet Gaura
6/19/2009	170	*Amorpha nana*	Dwarf Wild Indigo
6/21/2009	172	*Zigadenus elegans*	White Camas
6/22/2009	173	*Koeleria macrantha*	Junegrass
6/24/2009	175	*Chrysopsis villosa*	Hairy goldaster
6/24/2009	175	*Anemone cylindrica*	Candle Anemone
6/24/2009	175	*Zigadenus elegans*	White Camas
6/24/2009	175	*Rosa arkansana*	Wild Prairie Rose
6/24/2009	175	*Asclepias ovalifolia*	Oval Milkweed
6/24/2009	175	*Campanula rotundifolia*	Harebell
6/24/2009	175	*Onosmodium occidentale*	false gromwell
6/24/2009	175	*Rudbeckia hirta*	Brown-eyed Susan
6/24/2009	175	*Thalictrum dasycarpum*	Tall Meadowrue
6/24/2009	175	*Prunella vulgaris*	Heal-all/Selfheal
6/24/2009	175	*Symphoricarpos occidentalis*	Western Snowberry
6/25/2009	176	*Heracleum maximum*	Cow Parsnip
6/26/2009	177	*Apocynum cannabinum*	Indian Hemp
6/30/2009	181	*Delphinium carolinianum ssp. virescens*	Prairie Larkspur
6/30/2009	181	*Lilium philadelphicum*	Wood lily

6/30/2009	181	*Calylophus serrulatus*	Yellow Sundrops
6/30/2009	181	*Physalis virginiana*	Virginia Ground Cherry
6/30/2009	181	*Potentilla arguta*	Tall Cinquefoil
7/4/2009	185	*Asclepias syriaca*	Common Milkweed
7/7/2009	188	*Amorpha canescens*	Lead Plant
7/7/2009	188	*Psoralea argophylla*	Silverleaf Scurfpea
7/7/2009	188	*Convolvulus arvensis*	Field Bindweed
7/7/2009	188	*Cicuta maculata*	Spotted water hemlock
7/7/2009	188	*Catalpa speciosa*	Northern Catalpa
7/8/2009	189	*Echinacea angustifolia*	purple coneflower
7/15/2009	196	*Ratibida columnifera*	Prairie Coneflower
7/15/2009	196	*Dalea candida*	white prairie clover
7/15/2009	196	*Potentilla sp.*	
7/16/2009	197	*Pycnanthemum virginianum*	Virginia mountain mint
7/16/2009	197	*Dalea purpurea*	Purple prairie clover
7/16/2009	197	*Asclepias incarnata*	Swamp Milkweed
7/16/2009	197	*Verbena stricta*	Hoary Vervain
7/16/2009	197	*Lobelia spicata*	Pale-spike Lobelia
7/22/2009	203	*Monarda fistulosa*	Beebalm/Wild Bergamot
7/24/2009	205	*Lactuca pulchella*	Blue Wild Lettuce
7/24/2009	205	*Asclepias verticillata*	Whorled Milkweed
7/29/2009	210	*Liatris punctata*	Narrow-leaved blazing star
7/29/2009	210	*Liatris pycnostachya*	Tall Blazing Star
8/4/2009	216	*Allium stellatum*	Pink Wild Onion
8/4/2009	216	*Solidago missouriensis*	Missouri Goldenrod
8/5/2009	217	*Eupatoriadelphus maculatus*	Spotted Joe-pye Weed
8/11/2009	223	*Oligoneuron rigidum*	Stiff Goldenrod
8/11/2009	223	*Parnassia palustris*	Northern grass of Parnassus
8/11/2009	223	*Solidago canadensis*	Canada Goldenrod