Alabama Phenology Garden Project: Using Degree-days and Plant Phenology to Predict Pest Activity

by

Raymond Albert Young

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Approved by

David Held, Chair, Associate Professor of Entomology
Gary Keever, Dodd Endowed Professor of Horticulture
Bill Klingeman, Associate Professor of Entomology, University of Tennessee Knoxville

Abstract

Accurate prediction of pest activity is crucial crucial for maintaining a successful urban integrated pest management program. Plant phenology and growing degree days can be useful tools in tracking important pest stages thus signaling the most critical treatment time. Because plant and insect development is mostly dependent upon temperature, biological calendars can be developed to help monitor key stages. The main objectives of this research were to (1) establish phenology gardens containing common taxa throughout Alabama, (2) compare the emergence, flight, or appearance of insect pests with the progression of ornamental plant bloom stages in each garden, and (3) produce a website with key phenological indicators and pest correlates.

Phenological data collected from two sentinel insect species, dogwood borer and crape myrtle aphid on five sites and eight additional landscape pests in Auburn from 2010 to 2011 were used to establish phenological bloom sequence-based prediction models for 12 plant species for landscaper management personnel, growers, and laypersons. Growing degree-days models were implemented and compared to test accuracy of each. A total of 32 phenological events were studied in correlation with key insect life stage events such as first appearance and peak stages.

The rank order of phenological events showed that there was significant correlation of bloom stages from year to year and site to site based on results of the Spearman's bivariate correlation and regression analysis. A common phenophase was not found to be consistent with activity statewide of the two sentinel pests. Variations in cumulative growing degree day and

Julian date proved no reliable statewide indicator for pest prediction. However, In future studies, recommendations could possibly be on a broader latitudinal area such as region or USDA hardiness zone.

Dedication

I would like to dedicate this thesis and its work to my parents, Charles and Becky, and brother Scott. Thanks for your unlimited support throughout this project and graduate school.

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Chapter 1

Introduction

Importance of Landscape Pest Management

The Green Industry is a major source of U.S. commerce with an estimated $175 billion (2007) in sales and employment of approximately two million persons (Hodges et al. 2011). More than 90 million American households partake in gardening as a recreational hobby (NGA 2006). Alabama's Green Industry increased from $1.9 billion in 2003 to $2.9 billion in 2007, ranking as the state's 3rd largest commodity behind poultry and cattle and employing over 20,000 people with more than 2,500 firms (Hodges et al. 2011).

As urban areas increase, so does the demand for public, commercial, and residential green spaces including lawns and landscapes. Along with the increase in plant species comes an increase in the number of arthropod pests (Raupp et al. 2001). As insect pest populations increase, potential damage to landscape ornamental plants also increases. Consequently, significant amounts of pesticides are used for pest control in landscapes. Annually, more than $172 million worth of damages occur in Georgia landscapes and costs of control to pests attacking ornamentals plants in nurseries and landscapes (Oetting et al. 2004). Landscapers, nursery personnel, and laypersons alike traditionally rely on calendar based application for predicting pest activity, often with immense failure rates in controlling landscape pests due to inconsistencies in pest activity from year to year and variations such as warmer or cooler spring temperatures. The annual timing of plant events (budding, leafing, flowering) and insect

development is driven by temperature; therefore, we can use growing degree-days to track important developmental phases (Huberman 1941). Growing degree days (GDD) account for the accumulation of heat units in a 24-hour period. The use of phenology and degree-day models can aid in forecasting key pest events, ultimately saving money in pest management programs. Degree-day models and plant phenological indicators can be used for predicting pest activity.

Growing Degree Days

Temperature can be a valid tool in predicting insect development rate (Herms 2004). The idea of using a growing-degree day model was first applied in 1735 by Réaumur, stating "plant development is proportional to the sum of temperature over time rather than to temperature during the phenological event itself" (cited by Chuine et al. 2003). Degree-day models can be used to predict temperature-driven events such as insect development. Thresholds are the upper and lower limits at which development occurs and above and below these limits, no development takes place (Pedigo and Rice 2009). Base temperature is the point at which insect development is optimal. Base temperatures are generally determined by insect development thresholds for each life stage. When developmental thresholds are unknown, the base temperature is typically determined as the lowest temperature using coefficient of variation among growing degree data (Arnold 1959). A biofix is an important date signaling when to begin recording growing degree days for a pest (Herms 2004). For some insect species, January 1 may not be the optimal starting date because some insects can start developing in late summer and fall. For example, October 1 is commonly used for dogwood borer (Bergh et al. 2009). One method to determine optimal biofix would be to monitor different starting dates, for recording temperatures, over numerous

years (Herms 2004). Growing degree-days can be calculated several ways. The average method, also known as the modified average method is calculated as:

(maximum temp + minimum temp) / 2 = mean temperature for the day

The modified sine-wave (Bakersville-Emin) method, which takes into account days when the minimum temperature falls below the base temperature, is often used. The base temperature is a lower limit at which development occurs. When low temperatures do not fall below base temperatures, GDD are calculated as follows:

$$GDD = ((W * \cos(A)) - ((BASE - TAVE) * ((3.14/2)-A)))/3.14$$

Where: GDD = Average Temperature – Base Temperature

W = (Max. temperature – Min. temperature) / 2

A = Arcsin ((BASE – TAVE) / W

The modified sine-wave method is typically more precise than the average method because it uses daily maximum and minimum temperatures and takes into account developmental thresholds (Bakersville and Emin 1968).

There are some limiting factors to using growing degree days. Degree-day models fail to take into account other factors that affect rates of development such as environmental influences because models focus strictly on heat accumulation (Higley et al. 1986). Growing degree-day models assume insect growth is a linear relationship in time. However, insect development rate may be non-linear (Allen 1976, Stinner et al. 1974) although traditionally believed to be linear, in response to temperature. Nonlinear development simply means there are cutoff temperatures where insect development stops or where temperatures are lethal. For this reason, certain degree day models include a high or low cutoff temperature. High and low temperature extremes can present problems for accurate prediction of pest activity. (Stinner et al. 1974). The actual

temperature that pests experience is influenced by behavior (i.e. thermoregulation) and microenvironments. For example, leaf surface temperature may be 10°C higher than ambient temperature under certain conditions like sunny days, leading to an underestimation of insect growth (Ferro et al. 1979). Also, developmental temperatures for endophagous insects like wood borers can vary depending on the location within the plant where they are developing or overwintering. Model temperatures have been recorded in both sunny and shaded conditions (Herms 2004). Insects on the south side of trees, for example, could experience different heat accumulation than insects on the north side, or shady side (Mussey and Potter 1997). Insects may also thermoregulate, moving to darker or lighter surfaces to cool or warm their bodies (Herms 2004).

The overall rate of development is also influenced by additional abiotic factors. Heat increases development rates and cold decreases development rate (Bonhomme 2000). Additionally, insect growth rates can be influenced by plant feeding regimens based on fertility and drought effects as in holometabolous insects (insects that have four life stages: egg, larva, pupa, adult) (Herms 2004). Other abiotic factors that could influence insect development include wind effects in relation to heat loss, as well as humidity in relation to insect moisture (Ferro et al. 1979). Most landscape pests do not have established base temperatures required for accurate optimal growth rate calculation (Mussey and Potter 1997, Herms 2004). Furthermore, accurate local temperature data and GDD calculations can often be aggravating and unavailable to landscapers and laypeople.

Phenology

Phenology is the study of natural phenomena between weather and the annual timing of biological events (Huberman 1941). Naturally occurring events such as animal migrations and

hibernations, insect activity, plant flowering, and agricultural crop stages are all examples of phenology. Phenology has been used for thousands of years to predict till, plant, and harvest dates (Schwartz 2010). Written phenology records from China date back to around 974 B.C. (Gardiner 2009). Use of phenological indicators can be valuable tools for pest managers (Mussey and Potter 1997, Hoover 2002).

Geographic location will affect the occurrence of phenological events. Mussey and Potter (1997) reported up to 28 d difference between the average data of a phenological event in Kentucky compared to the average date for the same phenological event in MI. Data from different. regional sites has the potential to predict pest activity statewide (Mussey and Potter 1997, Herms 2004, Kulhanek 2009). In a 6-year study of 34 sites across Ohio, the phenological sequence of 43 arthropod pests of woody ornamentals and plants consistently correlated between years and between sites (Kulhanek 2009).

Phenology Gardens

Plant enthusiasts usually find it easier to track "indicator plants" to correlate specific insect pests rather than study the pest solely (Schnelle and Volkert 1974). Phenology gardens can be implemented to track this phenomenon. Phenology garden networks are often composed of groups of people growing the same plants from the same sources in different locations (Chen 2003).

Phenology gardens have multiple uses ranging from predicting pest activity to monitoring climatic events (Kulhanek 2009). Phenology gardens exist throughout Asia (Schwartz 2010), Europe (Chmielewski 2008, Koch et al. 2008), and the U.S. In Europe, a phenology garden network of 13 gardens in seven countries has been monitored for 54 years. These gardens

contain 14 clonal plant species that were asexually propagated with recognizable phenophases, developmental stages that are sensitive to air temperature, and phenophases that cover the majority of the growing season (Bruns et al. 2003).

The main focus of the aforementioned systems is to collect and compare phenotype data over a wide range of locations and years (Chmielewski 2008). Phenology gardens consist of certain flowering plants that can be used to track occurrences like flower and leaf development and flowering stages. Plants are monitored and recorded yearly for first sequence of flowering (Schnelle and Volkert 1974).

Biology of the Experimental System

Lepidopteran borers:

Dogwood borer (*Synanthedon scitula*):

Dogwood borer (DWB), *Synanthedon scitula* (Lepidoptera: Sesiidae), is a multi-voltine pest of dogwoods but also develops in callus or gall tissue on other plant species including oaks and apples (Eliason and Potter 2000, Bergh and Leskey 2003). Dogwood borer has a wide host range including beech, willow, chestnut, blueberry, hickory, pecan, pine, ash, oak, and elm (Johnson and Lyon 1991). Despite the common name, DWB has the most expansive host range of any sesiid in North America (Potter and Timmons 1981).

Dogwood borer emerges from inside the plant in the spring to lay eggs on the bark. Within 8-9 d, the eggs hatch and first instar larvae enter the plant and form large feeding galleries. In certain areas of the United States, it takes approximately a year for larvae to pass through seven instars (Neal and Eichlin 1983, Bergh and Leskey 2003). In other areas, it completes several generations in a year. Overwintering occurs below the bark and spring

temperatures of 7-10°C trigger feeding the following spring. Larvae then create cocoons close to the exterior of the plant in order to pupate. Pupal cases can be seen on the bark at exit sites (Gyelthsen and Hodges 2006).

Adult male flight activity can be monitored with the sex pheromone Z, Z-3,13-ODDA (Bergh et al. 2009). Growing degree days for dogwood borer are calculated using 4 and 10°C base temperatures (Potter and Timmons 1983 Bergh et al. 2009 and Mussey and Potter 1997, Herms 2004, respectively) and using a biofix of either Jan 1 (Mussey and Potter 1997, Herms 2004) or Oct 1 (Timmons and Potter 1983, Bergh et al. 2009). October 1 biofix was used to account for the overwintering egg population. First emergence of DWB in central Kentucky occurs at about 95% flower of *Ilex opaca* (American holly) and first flower of *Crataegus phaenopyrum* (hawthorn) or 531 degree-days Celsius (DDC) with a biofix of January 1 (Mussey and Potter 1997). In Ohio, first emergence occurs with full flower of *Kalmia latifolia* (mountain laurel) or 830 DDF with a biofix of January 1 (Herms 2004). In the same year over a larger geographic area, GDD for first emergence ranged from 818 DDC in New York to Tennessee 1579 DDF with a base temperature of 4°C and a biofix of October 1 (Bergh et al. 2009).

Figure 1.1. Adult *Synathedon scitula*

Lesser peachtree borer (*Synanthedon pictipes*):

Adult lesser peachtree borer, (LPTB) *Synanthedon pictipes* (Lepidoptera: Sesiidae), emerge in the spring then females lay eggs in the fall. Eggs hatch and larvae enter the trunk and feed in the sapwood. Larval damage creates weak spots in the trunk and branches and exposes the plant to various other pest attacks. Lesser peachtree borer has at least 2 generations per year with a possible third generation reported from Georgia (Yonce et al. 1977). Adult emergence occurs as early as March but adults peak in May (Yonce et al. 1977) followed by another peak of adults in July-August (Yonce et al. 1977). Frass is usually found at exit holes on the bark when larvae are feeding (Welty 2000) and pupal skins present with each adult emergence (Yonce et al. 1977). The capture of the first male, lesser peachtree borer in traps is phenologically correlated with Kousa dogwood (*Cornus kousa*) at 224 DDC, with a base 10°C and January 1 as a biofix in central Kentucky (Mussey and Potter 1997). In Midland, MI, first male capture occurs with an average of 362 DDF and a base temperature of 50°F and is correlated with full flower of Blackhaw viburnum (*Viburnum prunifolium*). In Ohio, male capture occurs or at 372 DDF or with full flower of horse chestnut (*Aesculus hippocastanum*) (Herms 2004).

Lilac ash borer (*Podosesia syringae*):

The lilac ash borer (LAB), *Podosesia syringae* (Lepidoptera: Sesiidae), is a univoltine moth whose larvae tunnel into lilac, privet, ash, and several other similar species. Adults emerge in the spring (February in FL) with peak flights in Apr-May in southern states and June in Ohio (Purrington and Nielsen 1977). Females deposit tan eggs (0.77 mm long) into crevices and wound sites in spring where larvae enter the tree, feed, and overwinter as fully grown larvae (Purrington and Nielsen 1977). The next year, larvae enter the cambium layer and exit the

following year. Damage occurs through tunneling, therefore causing weak spots in the trunks that are easily broken. Larvae usually burrow at or just below the soil surface (Westcott 1946).

Daily male flight occurs from 9 a.m. until early afternoon (Taft et al. 2004). Male moths are monitored using the sex pheromone (Z,Z)-3,13-ODDA (Purrington and Nielsen, 1977). In Lexington and Louisville (KY), first flight occurs from April 13 to May 6, consistent with first flower of Tatarian honeysuckle (*Lonicera tatarica*) and cumulative 426 DDC (Timmons and Potter 1983, Mussey and Potter 1997). In Midland, MI, LAB first emergence is concurrent with Common lilac (*Syringia vulgaris*) full flower and 324 DDF base temp 50°F. Similarly flight occurs at 330 DDF in Ohio and is correlated with first flower of 'Winter King' Indian hawthorn (*Crataegus viridus* 'Winter King') or 330 DDF (Herms 2004). Lilac ash borer first emerges in IL coinciding with Vanhoutte spirea (*Spirea* ×vanhouttei) (Orton 1989).

Oak clearwing borer (*Paranthrene simulans*):

The oak clearwing borer (Lepidoptera: Sesiidae) is an important multivoltine pest of white oaks throughout the Eastern and Southern U.S. causing damage to the root flange, often leading to degradation and decay. First sign of injury includes sap spots and frass around the base of the trunk. Later, entrance holes, 9-15 mm diameter, appear due to mining below the bark. Galleries 9 mm x 10 cm are made my tunneling. Upon emergence from wood, females lay eggs in bark crevices in the summer (Solomon et al. 1987). Male *P. simulans* can be monitored with traps containing *(Z,Z)-3,13* octadecadien-l-01 acetate (Z,ZODDA) as well as Z,Z ODDA with minor components, Z,E and E,Z ODDA (Sharp et al. 1978, Neal and Eichlin 1983, Rogers and Grant 1991). Activity begins in early May and lasts mid–July (peak mid to late May) in TN and MD (Neal and Eichlin 1983, Rogers and Grant 1991), but males are trapped from April–July in FL with April as the peak month (Sharp et al. 1978). Activity seems to alternate between

years with odd-numbered years producing a greater numbers of males in TN and MD (Neal and Eichlin 1983, Rogers and Grant 1991) or in even-numbered years in FL (Sharp et al. 1978). This is attributed to a life cycle that requires ≥ 2 yr (Sharp et al. 1978). Male traps captures that peak in late June–July in TN (Rogers and Grant 1991) may indicate emerging adults from different species of oaks (Solomon 1995).

Mandibulate folivores:

Japanese beetle (*Popillia japonica*):

Japanese beetle, *Popillia japonica* (Coleoptera: Scarabaeidae), has a host range of about 300 plant species in 79 families and the grubs feed on roots of variety of turfgrasses, trees, shrubs, and vegetables (Potter and Held 2002). Around late May, adult beetles emerge from the soil in search of a food source. After feeding, females burrow into the ground to lay eggs. They then emerge again in search of food and a mate. This cycle of feeding and egg laying repeats throughout the summer. Egg hatch normally takes 8-9 d at an average temperature of 29°C. The larvae complete three instars and feed on plant roots of mainly grasses. Grubs overwinter in the soil and feed during the following spring. Grub feeding removes significant root mass and often turfgrass can be peeled back. During the summer months (May-Aug), adults are leaf skeletonizers and also consume flowers and fruit. Japanese beetle has a 1-year life cycle. Adult Japanese beetles are typically monitored with a trap baited with a food lure (phenethyl-propionate and eugenol plus geraniol) and a sex lure (Potter and Held 2002).

Adults emerge coincident with 50% flower of Little-leaf linden (*Tilia cordata*) and a three-year average 697 DDC (Mussey and Potter 1997). Emergence in Ohio is coincident with Panicled goldenraintree (*Koelreuteria paniculata*) or 970 DDF (Herms 2004). First adult emergence in IL occurs concurrently with Hills-of-snow hydrangea (*Hydrangea arborescens*

'Grandiflora') full flower (Orton 1989). Japanese beetle prepupal stage occurs with an average 1757 GDD (June 17) in College Park, MD (Schlar & Bergquist, Unpublished data).

Lesser canna leafroller (*Geshna cannalis*):

Lesser canna leafroller, *Geshna cannalis* (Lepidoptera: Pyralidae), is a leaf-rolling moth that attacks canna (*Canna* sp.) as larvae. Upon egg hatch, larvae enter leaves and mine throughout to feed until exiting inner leaves to feed on the upper side of the leaf. One week after hatch, groups of larvae begin rolling leaves with as many as six per leaf roll. The final instar makes a silk web before pupation. Overwintering occurs in canna leaf litter. There is very little literature on the seasonal phenology of lesser canna leafroller. Damage normally occurs on leaves that have not completely unfolded (McAuslane 2000). There are no identified pheromones for this pest but activity is generally measured by the occurrence of foliar damage.

Black cutworm (*Agrotis ipsilon*):

Black cutworm (*Agrotis ipsilon*) (Lepidoptera: Noctuidae) (BCW) is an important pest of turfgrass and at least 48 other species of cultivated plants including wheat, corn, and tobacco. Larvae chew stalks, roots, bulbs, and tubers causing major damage. Early larvae feed on foliage without actually cutting stems or leaves from its host. Black cutworm has three generations per year (Sherrod et al. 1979). Adult male moths are monitored with sticky trap or Texas cone traps (Hong and Williamson 2004) baited with the sex pheromone (Z)-7-dodenen-1-yl acetate and (Z)-9-tetradecen-1-yl acetate. In KY, first male capture averaged 557 DDC, concurrent with 95% flower of Common lilac (*Syringa vulgaris*) (Mussey and Potter 1997). However, BCW overwinters in southern states (Showers 1997), which may significantly alter the seasonal phenology in the southeast relative to northern and midwestern records (Mussey and Potter 1997).

Fall armyworm (*Spodoptera frugiperda*):

Fall armyworm, (Lepidoptera: Noctuidae) (FAW), is a major pest of all types of grasses, mainly corn and small grain, as well as legumes. These caterpillars consume foliage, and small plants can be eaten entirely. The insect has three generations per year with the last generation typically causing the most damage and forming "armies" of gregarious larvae (Nagoshi and Meagher 2004). Third instar larvae overwinter in the soil in tropical areas of North America (Texas and Florida) and the adults migrate north during the spring. Egg hatch takes 2-10 days and full development of larvae takes roughly 20 days before burrowing into the soil. Pupation then usually takes 10 days (Sparks 1979). Adult male flight is monitored with traps baited with the sex pheromone (Z)-7-dodecen-l-ol-acetete (Z7-12:AC) (Mitchell et al. 1985).

Eastern Tent Caterpillar (*Malacosoma americanum*):

Eastern tent caterpillar, (Lepidoptera: Lasiocampidae), is an important defoliator of trees and shrubs native to North America. Preferred hosts are plants in the family *Rosaceae*, and host range includes *Prunus*, *Malus*, *Crataegus*, *Pyrus*, and a number of additional hardwood species. Overwintering occurs in spumaline coated egg masses encircled on the plants that normally contain 150-350 eggs. Full-grown larvae are 50–55 mm in length (Johnson and Lyon 1991, Hyche 1996).

Larvae spin webs or tent-like structures on forked branches of trees and devour foliage of host trees. Feeding occurs only during the daytime and larvae accumulate in tents during nighttime and periods of inclement weather. Molt takes between 5–10 weeks, depending on temperature. After molting, larvae find nearby sites for pupation. In 3 to 4 weeks, moths pupate from silken cocoons. Eastern tent caterpillar has one generation per year in Auburn, AL and hatch occurs from mid-February to mid-March (Hyche 1996).

Adult male moths can be monitored using pheromone traps. However moths fly in one season and females defoliate trees the following spring. Therefore, spring larval activity is gauged by monitoring egg hatch (Potter et al. 2005). Egg hatch of ETC in central Kentucky occurs with 50% flower Border forsythia (*Forsythia* ×*intermedia*) and a three-year average of 18 DDC (Mussey and Potter 1997). In Midland, MI, egg hatch occurs at 47 DDF, in correlation with first flower of *Acer rubrum* (Herms 2004). In IL, egg hatch occurs when Saucer magnolia (*Magnolia* ×soulangiana) is in pink bud to early flower (Orton, 1989). Egg hatch in Ohio occurs on average date April 1 or with 92 GDD (Schlar & Bergquist, unpublished data).

Haustellate folivores:

Crapemyrtle aphid (*Tinocallis kahawaluokalani*):

Crapemrytle aphids (CMA), *Tinocallis* (*Sarucallis*) *kahawaluokalani*, are introduced pests of crapemyrtles that have spread throughout the southeast (Mizell and Schiffhauer 2007). Adults and nymphs have yellow-green bodies with black projections on their abdomens. All adults CMA are winged (Alverson and Allen 1992). Length ranges from 0.4–0.6 cm (Ong 2010). Crapemyrtle aphids are specific mainly to crapemyrtle. Damage from CMA is both direct and indirect. Direct damage occurs via distortion and stunting of new growth through feeding, and indirect damage occurs through production of honeydew. CMA typically feeds on the bottom of leaves. They use piercing-sucking mouthparts to remove plant sap (Alverson and Allen 1992). Cultivars such as ‘Biloxi’, ‘Hopi’, ‘Apalache’, ‘Zuni’, and ‘Comanche’ are more susceptible to CMA, while ‘Natchez’, ‘Potomac’, and ‘Victor’ are nearly resistant (Mizell and Knox 1993).

Damage includes deformed leaves and stunted growth. Additionally, production of

honeydew leaves plants aesthetically displeasing (Alverson and Allen 1992). Ultimately, the black soot shades the leaf, inhibiting photosynthesis (Mizell and Knox 1993). Aphids reproduce parthenogenically throughout the summer but sexual stages and mating occurs in fall. Eggs are deposited on the bark in fall on terminal growth up to 100 cm from the terminal. Eggs hatch in spring typically coincident with bud break (Alverson and Allen 1992). In Georgia, activity of CMA ranges from May 6 to September 8 (Stewart et al. 2002). In Texas, CMA is found from May through September, with peak populations during July and early August (Ong 2010).

There are no pheromones available for CMA so alates and apterous forms can be monitored using sticky traps or beat samples (Mizell and Schifflauer 2007). Alverson and Allen (1992) found activity of alates captured on sticky traps was generally coincident with infestations on plants. In general, sticky cards may still record activity after the peak leaf density (Alverson and Allen 1992). Adults, all winged, readily disperse especially when air temperatures are ≥30°C (Alverson and Allen 1991).

Recommendations for the aforementioned phenology correlates vary from site to site because they came from different states or regions. The method used to calculate growing degree days for each insect event applied various biofix dates and base temperatures. For example, some calculations used a 55°F base temperature, some used several years worth of temperature data from a single location, and others were calculated using data from many locations. To be able to report a consistent recommendation with each pest species and plant would require original temperature datasets. This variation is due to the lack of a standard system for calculating growing degree day, therefore making each study site unique. Ultimately, it is difficult to compare GDD information from region to region because of sampling technique.

Objectives

The use of the common calendar as a guide for predicting landscape insect pests is unreliable. The application of degree-day models and plant phenological indicators can be a more accurate tool to pinpoint control measures of these pests. The objectives of this study were to establish five phenology gardens containing 15 plant taxa across Alabama, to monitor insect activity in relation to plant phenology and growing degree-days, to compare plant phenological indicators and arthropod data collected in Auburn to occurrence in other gardens and to train Master Gardeners and other citizen scientists about phenology via meetings and a website. Ultimately a biological calendar was produced indicating growing degree data and plant phenological indicators for nursery managers, landscapers, pest control personnel, and laypersons to pinpoint key stages of landscape insect pests, producing recommendations for improved integrated pest management strategies.

Chapter II

COMPARING THE PHENOLOGY AND DEGREE-DAY MODELS FOR 12 ORNAMENTAL LANDSCAPE PLANTS

Abstract

Ornamental plant phenophases can be important tools in tracking pest events. Degree day models are often used to predict activity of specific species pest life stages. A suite of the same 15 plants replicated four times was planted at five locations across Alabama and replicated four times at each site. Flower sequences were monitored and a standardized base temperature and biofix were used to calculate GDD for each plant species in two years. The phenological sequence was significantly correlated between years and all locations across Alabama. These data indicate a plant phenological sequence even across large geographic area may be useful to predict other phenological events such as insect activity.

Introduction

Accurate predictions using phenological indicators are critical for pest management (Chmielewski 2008). Phenological methods have been used in the U.S. with over 200 agricultural and horticultural pest species (Delahaut 2010). Phenology has a useful application to pest management for predicting the timing of pest emergence and peak stages because the urban landscape contains a diversity of flowering plant species. Several studies conducted in northern states (e.g., KY, OH, MI) have documented the emergence or activity of key pests and correlated these events with flowering stage of common ornamental plants (Mussey and Potter 1997, Hoover 2002, Herms 2004).

Phenology gardens have grown popular since the 1990s. Concern about climate change and global warming has led citizens to monitor this phenology phenomenon and use plants to gauge insect activity by monitoring easily recognizable growth stages (e.g., Project Budbreak). Phenological events such as bud break, flowering, and leaf expansion are recorded coincident with the date of occurrence. These events are reported categorically using either the BBCH (Biologische Bundesanstalt, Bundessortenamt, Chemische Industrie) scale (Meier 2010) or event specific categories such as first and full flower (Herms 2004). These categories are intended to provide conspicuous, observable events that can be compared between years in the context of climate change, or used to correlate with activity of insects (Delahaut 2010).

Biological calendars are the most common application of phenology to agronomic and horticultural pests (Herms 2004, Mussey and Potter 1997, Kulhaneck 2009, Delahaut 2010). Herms (2004) gathered data and developed a calendar, monitoring 47 landscape plant species and 24 insect pests for 5 years in Midland, MI. Additionally, Mussey and Potter (1997) monitored 34 ornamental plant species and 33 insect pest species in Kentucky, with some of the

same plant species as the Herms 2004 study. Hodges and Braman (2004) studied seasonal abundance and phenological indicators of five scale species (Hemiptera: Diaspididae, Coccidae) in the landscape environment in Georgia. Kulhanek (2009) analyzed phenological data collected for 43 arthropod landscape pests from 1997–2002 to develop a model of 45 phenological events for the insect pest species. However, there is some perception that phenology is not important in southern states due to the milder climate (Jim Reinert, personal communication). In order to make accurate control recommendations for landscape pests, we monitored activity of plants and pests in each of the garden sites.

Objectives

The objective of this chapter was to record and compare Julian date and growing degree days of 12 ornamental landscape plants for 5 sites in Alabama over two years.

Materials and Methods

Study sites. Five study sites (Fig. 2.1) were established across Alabama including Huntsville Botanical Garden (Huntsville), Oak Mountain Middle School (Birmingham), Auburn University Campus (Auburn), Wiregrass Extension Center (Headland), and Mobile Botanical Garden (Mobile) (Table 2.1). In accordance with the standards of the European Phenology Network, which utilizes 13 gardens in seven countries, gardens should be planted in optimal growing conditions, on level ground, with even sun exposure, and free of obstacles or influence by man-made structures or highways that could potentially give microclimate variation (van Vliet et al. 2003, Bruns et al. 2003). Each garden contained four plot replicates approximately 0.16 ha each, spaced to avoid shading. Gardens were planted in November and December 2010, and mulched

annually with pine straw (Mobile only) (Fig. 2.2) or shredded hardwood mulch. All plants were fertilized in spring 2011 with a granular 18-8-12 (Regal Chemical, Alpharetta, GA) at label rate according to plant size. Plant species that were studied from February 2010 to October 2011 are listed in Table 1. Plant phenology was monitored at each site.

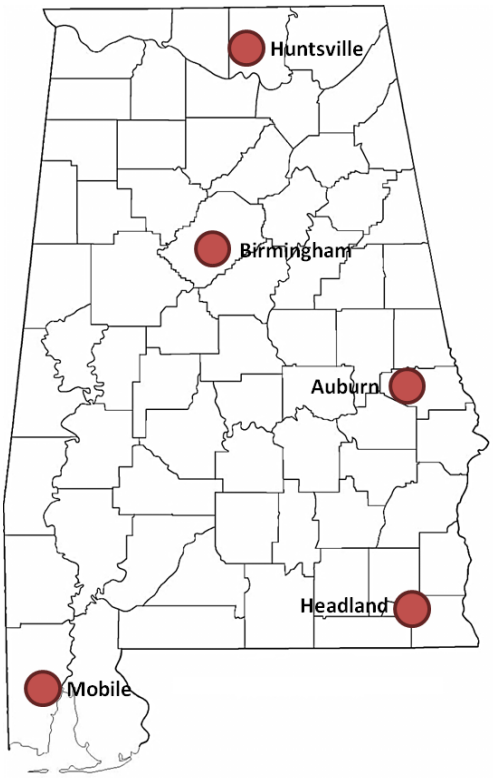


Figure 2.1. Map of five sites in Alabama Phenology Garden network

Table 2.1. Garden locations in Alabama Phenology Garden Network

Garden #	Location	Nearest city	County	Latitude	Longitude	Elevation	USDA Hardiness Zone
1	Mobile Botanical Garden	Mobile	Mobile	30.7002	-88.1596	54m	8B
2	Wiregrass Extension Center	Headland	Henry	31.3575	-85.3217	109m	8A
3	Plant Science Research Center	Auburn	Lee	32.5908	-85.487	210m	8A
4	Oak Mountain Middle School	Hoover	Shelby	33.3705	-86.713	159m	8A
5	Huntsville Botanical Garden	Huntsville	Madison	34.7129	-86.6357	200m	7B

*GPS coordinates and elevations from www.earthtools.com

Figure 2.2. One replicate in the phenology garden at the Mobile Botanical Gardens.

An annual management program was implemented at each garden to control weeds. All garden plots were treated in February with oxadiazon + prodiamine (RegalStar, oxadiazon 1% ai + prodiamine 0.2% ai G, Regal Chemical, Alpharetta, GA) at 2.17kg/100 m^2 or prodiamine (RegalKade, 0.5% ai G, Regal Chemical, Alpharetta, GA) at 39.18kg/ha. Garden plots were sprayed for control of annual and perennial weeds periodically throughout the growing season with post-emergent herbicide glyphosate (Eraser, 41% ai, L, Control Solutions, Inc., Pasadena, TX) at 15.64 ml/L. The Auburn garden was treated in summer 2011 with halosulfuron-methyl (SedgeHammer, 75% ai, G, Gowan Company, Yuma, AZ) at 0.9g/100 m^2 s for selective control of yellow nutsedge (*Cyperus esculentus*).

Additionally, fire ant (*Solenopsis invicta*) and varmit management strategies were used at some sites. Each garden was also treated for fire ants annually, and deer browsing caused vast damage to plants in the Huntsville garden. The Auburn and Huntsville gardens were treated with hydramethylnon (Amdro Fire Ant Bait, 0.73% ai G, BASF, Research Triangle Park, NC) for control of *Solenopsis invicta* at 1.7kg/ha in April 2011. In 2010, the Auburn garden was treated with fipronil (TopChoice, 0.0143% ai G, Bayer Environmental Science, Research Triangle Park,

NC) at 39kg/ha, for *Solenopsis invicta*. Plots were treated twice with dehydrated coyote urine (PredaScent, Landscape Control Products 1.5% ai, Kennesaw Georgia) at 1 capsule/m^2 in spring 2011 for varmit and nuisance animal deterrent because we could not construct a fence around the garden. Also, bars of bath soap (Ivory, P&G, Cincinnati, OH) were hung in the trees in and surrounding the garden to discourage deer (*Odocoileus* sp.) browsing because our options for control were limited. Despite preventative measures to combat deer, several plants species were lost at the Huntsville site.

Plant materials

A consistent suite of 12 plants (Table 2.2) was selected to provide a continuum of flowers from February to November. Plants were chosen based on their landscape importance and the presence of easily identifiable phenological phases in the flower stage (Delahaut 2010). Plants were also selected based on their ability to survive and thrive throughout Alabama with a reasonably short, well-defined flower period. 'Natchez' crapemyrtle (*Lagerstroemia indica* ×fauriei 'Natchez') is resistant to crapemyrtle aphid, therefore 'Biloxi' crapemyrtle (*Lagerstroemia* 'Biloxi') was also planted at Mobile and Headland since a susceptible species was not previously on site (Mizell and Knox 1993).

Table 2.2. Twelve plants established in the phenology gardens

Common Name	Scientific Name	Phenophase Recorded
'Lynwood Gold' Border Forsythia	*Forsythia* ×*intermedia* 'Lynwood Gold'	First flower 50% flower Full flower
'Ice Follies' Daffodil	*Narcissus* 'Ice Follies'	Bud tight Shepherd's crook 1st petal open Flower fully open
Yoshino Cherry	*Prunus* ×*yedoensis*	First flower 50% flower Full flower
'Ruby' Loropetalum	*Loropetalum chinense* 'Ruby'	First flower Full flower
'Eleanor Tabor' Indian Hawthorn	*Raphiolepis indica* Eleanor Tabor™	First flower 50% flower Full flower
'Ellen Huff' Oakleaf Hydrangea	*Hydrangea quercifolia* 'Ellen Huff'	First flower 50% flower Full flower
'Natchez' Crapemyrtle	*Lagerstroemia* indica ×fauriei 'Natchez'	First flower Full flower
'Happy Returns' Daylily	*Hemerocallis* 'Happy Returns'	Bud tight Shepherd's crook 1st petal open Flower fully open
'Hummingbird' Clethra	*Clethra alnifolia* 'Hummingbird'	First flower Full flower
'Majestic' Liriope	*Liriope muscari* 'Majestic'	First flower Full flower
'Crown of Rays' Goldenrod	*Solidago canadensis* 'Crown of Rays'	First flower Full flower
Swamp Sunflower	*Helianthus angustifolius* 'Swamp Sunflower'	First flower Full flower

Phenophase recording

To determine dates of first flower, 50% flower, and full flower, 10 randomly selected branches per plant were selected and the number of open flower buds was counted for plants such as forsythia, cherry, and indian hawthorn (Figure 2.3). First flower was recorded when one flower on any of the flagged branches was open. The next phase was determined by counting open flowers on each branch and when half of the branches had a single open flower, 50%

Figure 2.3. A flowering cherry tree in the phenology garden that shows the flagged shoots used to record flowering phenology on certain woody plants

flower was recorded. Full flower was recorded when each flagged branch had an open flower. For plants such as hydrangea and chrysanthemum, which did not have the appropriate branching structure to flag shoots, first flower and full flower were recorded. Additionally, plants with no apparent 50% flower period, (loropetalum, crapemyrtle, liriope, goldenrod, and swamp sunflower), first flower and full flower classifications were used. Daylily and daffodil produce a funnelform flower, so four phenophase description terms were used; 1) bud tight & upright, 2) shepherd's crook, 3) first petal open, and 4) fully open. Each plant species was represented by four replicates on each site. On each site, an average Julian date and growing degree date for each phenophase was determined. The phenological flowering sequence was determined by assigning the 32 plant events based on the average date per site. Plant phenological events were given a value and ranked, sequenced, and compared by year and site. There were cases in which we had missing data. In the case of missing variables, an M was placed in the sequence. Spearman's bivariate correlation coefficients (Statistix 2009) were used to determine correlation between years and sites.

Degree-day Accumulations

Air temperature was recorded at each of the five gardens using an on-site weather station (Fig. 2.4) (HOBO, model # U23-003, Onset Computer Corporation, Bourne, MA), similar to

Figure 2.4. Data loggers were used on all sites to record weather data loggers were housed in radiation shields.

Herms (2004). Ambient temperature was recorded above ground at a height of 15–30 cm inside a radiation shield. A base temperature of 10°C was used to calculate growing degree day accumulations (Klein 2002) coincident with the phenological events of the concurrent plant species, consistent with similar studies. The average method was primarily used because ambient temperature typically did not fall below base temperature for the majority of the year (Herms 2004). Growing degree-day calculations for all plants and insects were obtained with a biofix of January 1.

Data collection

Volunteer citizen scientists and members of the Alabama Master Gardeners Association collected data at three sites (Mobile, Huntsville, Birmingham) for two growing seasons from February 2010 to November 2011. Volunteers were trained through on-site meetings in each year of the study. These meetings included yearly presentations on the importance of phenology applications to pest management, scouting and trapping procedures, and methods of rating plant flower stages. Also each participant was given a color manual with detailed information on monitoring pests and plants and a map depicting plants and traps in the garden (www.auburn.edu/phenology). Each plant in the garden was labeled and mapped, and gardens were checked three times each week from February to November of each year. Master Gardeners also did routine maintenance and watering of their local gardens. The Auburn and Headland gardens were monitored and maintained by R. Young and Agricultural Experiment Station staff.

Statistical analyses

Julian date and GDD for each phenological event were compared among sites and between years using an ANOVA (Stastix 2009). Following the ANOVA, the mean JD and GDD were compared using Tukey's HSD test ($P< 0.05$). Spearman's bivaraiate correlation coeffiecients were used to determine differences among plant phonological events across all sites over two years.

Results

Location-to-Location variation in phenological sequences over two years

Some plants failed to produce adequate flower data due to a lack of flowering, plant death, or severe damage or death from deer browsing. In Huntsville, Indian hawthorn, hydrangea, liriope, sedum, and forsythia were severely damaged in both years by deer, which led to little or no flower stage data. All preventative measures (PredaScent and soap bars) were unsuccessful. Plants were replaced but deer continued to damage plants at that location. Hydrangeas at Headland phenology garden died likely due to lack of shade in 2010 and were not replaced.

The phenological sequences statewide were significantly correlated, ($P < 0.001$) between sites and years with most sites (75%) occurring at greater than 0.90 and lowest value was 0.85. Spearman's bivariate correlation coefficients was used to determine these correlates (Table 2.4).

Table 2.3. Julian days to event of plant flowering sequences in Alabama Phenology Garden network, five sites 2010-2011

PLANT	PHEN EVENT	AUB10	AUB11	HVL10	HVL11	BHA10	BHA11	HEA10	HEA11	MOB10	MOB11
Yoshino cherry	1st flower	83	76	88	73	M	77	82	77	84	75
Yoshino cherry	50% flower	85	79	90	76	M	80	86	80	88	80
Yoshino cherry	Full flower	88	82	93	81	91	84	91	83	92	84
Daffodil	Bud tight	79	63	81	60	94	61	62	57	68	60
Daffodil	Shep. crook	84	66	88	62	99	65	66	60	72	62
Daffodil	1st petal open	85	69	91	66	103	70	71	62	76	65
Daffodil	Full flower	88	70	92	73	106	76	77	65	82	68
Forsythia	1st flower	70	53	88	56	M	57	82	52	68	61
Forsythia	50% flower	73	56	92	59	M	64	84	60	77	67
Forsythia	Full flower	77	59	99	62	91	77	90	63	92	71
Loropetulum	1st flower	78	62	90	60	92	58	59	55	54	61
Loropetulum	Full flower	88	69	100	80	99	80	67	61	92	63
Indian hawthorn	1st flower	105	91	M	M	113	96	102	83	96	82
Indian hawthorn	50% flower	108	95	M	M	116	100	106	85	99	84
Indian hawthorn	Full flower	111	98	M	M	120	107	113	87	105	87
Hydrangea	1st flower	124	111	M	M	121	109	M	M	118	101

Hydrangea	50% flower	129	115	M	M	132	117	M	M	121	106
Hydrangea	Full flower	132	117	M	M	144	122	M	M	129	112
Daylily	Bud tight	132	125	133	123	124	117	125	114	125	107
Daylily	Shep. crook	141	128	140	131	132	124	128	118	131	117
Daylily	1st petal open	144	130	146	136	138	129	132	123	134	121
Daylily	Full flower	147	132	155	141	143	132	137	126	140	125
Crapemyrtle	1st flower	151	143	162	148	148	142	144	128	143	132
Crapemyrtle	Full flower	170	153	207	162	172	155	153	146	161	143
Clethra	1st flower	179	186	M	M	176	184	144	182	164	M
Clethra	Full flower	186	197	M	M	191	195	160	193	176	M
Liriope	1st flower	M	187	199	213	218	192	199	175	224	191
Liriope	Full flower	M	195	210	220	222	199	210	193	235	204
Sunflower	1st flower	177	193	205	159	185	161	199	209	M	M
Sunflower	Full flower	186	200	216	184	220	180	214	223	M	M
Goldenrod	1st flower	148	184	174	176	M	140	177	M	M	M
Goldenrod	Full flower	173	190	181	206	M	148	M	M	M	M

Table 2.4. Spearman's bivariate correlation coefficients generated from phenological sequence of five sites, two years.

	AUB10	AUB 11	BHA10	BHA11	HEA10	HEA11	HUN10	HUN11	MOB10
AUB10	0.99								
BHA10	0.90	0.88							
BHA11	0.92	0.91	0.78						
HEA10	0.88	0.90	0.78	0.97					
HEA11	0.91	0.93	0.81	0.96	0.99				
HUN10	0.88	0.86	0.78	0.97	0.93	0.92			
HUN10	0.97	0.97	0.84	0.98	0.95	0.96	0.94		
MOB10	0.90	0.89	0.78	0.99	0.97	0.96	0.98	0.96	
MOB11	0.88	0.90	0.78	0.96	0.99	0.99	0.94	0.95	0.96

*All p-values are <0.001

In general, JD and GDD for each phenophase were greater in 2010 than in 2011 (Tables 2.6–2.14). Phenophases of spring flowering species cherry, daffodil, forsythia, loropetalum, indian hawthorn, and daylily occurred at significantly different growing degree days and JD at each site. Interestingly, first flower (JD) for these same plants didn't occur first in Mobile (the southernmost location) was not the first site for most events to occur in the spring. Phenophases occurred at different Julian dates between each site in both years. When there was sufficient data for three plants, we used the data, noting the occurrence in the appropriate table. However, in instances that there were only two plants on a site, that plant was thrown out of the dataset.

Table 2.5. Julian date conversion for common year

Month	Calendar	JD
Jan	1-30	1-30
Feb	1-28	31-59
Mar	1-31	60-90
Apr	1-30	91-120
May	1-31	121-151
Jun	1-30	152-181
Jul	1-31	182-212
Aug	1-31	213-243
Sept	1-30	244-273
Oct	1-31	274-304
Nov	1-30	305-334
Dec	1-31	335-365

(Excludes leap years)

For each site in 2010, the first event in the sequence was bud tight of daffodil or first bloom of forsythia. In 2011, there was no significant difference among Julian day for daffodil for all sites. In Headland, bud tight of daffodil was the first phenological event in both years. Daffodil bloom period from bud tight to full bloom range was 8-15 days. In 2010, Headland and Mobile were more advanced until full bloom of daffodil. Huntsville and Birmingham were always different from the other sites. Daylily averaged 11 days from bud tight to full bloom. In 2010, forsythia first bloom was earliest, similar to Headland, Huntsville, and Birmingham. This event occurred significantly later in Mobile. In 2010, each site had the same phenological indicator. For Huntsville, 50% bloom was significantly later than all other sites. For full bloom, Auburn, Mobile, and Headland had consistent bloom stages and length of blooms was 7 days on average. Huntsville averaged 21 days from first to full. The cherry first bloom to full bloom range was 5-10 days with the southern-most sites at the long range, shortening as progression occurred North throughout the state. The average full sequence was 7.3 days. Cherry at Headland in 2010 bloomed first of all plant phenophases at the site. Headland and Auburn had very similar bloom occurrences in 2010 and Huntsville was the last to bloom. Auburn site had the fastest bloom progression from first to 50% bloom. The loropetulum first flowered in Mobile and last bloomed in Huntsville. Mobile had significantly earlier first bloom than Huntsville. Auburn differed significantly from all other sites for full flower in 2010. Mobile differed significantly from Huntsville. This plant showed spurious blooms throughtout the 2-year study. Loropetulum had a 3-36 day blooming period, which averaged 17.3 days. The first flower through 50% bloom of Indian hawthorn occurred in Mobile and Headland consistently. The 4-11 day bloom period for sites averaged 7 days first to full bloom. Full bloom did not differ statewide, therefore an excellent statewide correlate.

TABLE 2.6. GDD and Julian date for flowering events for Yoshino cherry, *Prunus* ×yedoensis

2011						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	72.5 ± 1.5a	146.25 ± 5.75a	76.25 ± 0.75b	167 ± 5d	80 ± 0.0e	203 ± 0.0b
Birmingham	77 ± 0.0a	208 ± 0.0a	80.5 ± 0.5a	240 ± 0.0c	84 ± 0.0d	274 ± 0.0a
Auburn	76.25 ± 1.25a	235.75 ± 11.75a	79 ± 1.22ab	261.5 ± 13.34c	82 ± 0.81c	292 ± 7.54ab
Headland	55 ± 0.0b	289 ± 0.0b	60.25 ± 0.75c	324 ± 0.0b	63 ± 1.0b	361 ± 0.0c
Mobile	74.5 ± 0.95a	308.25 ± 8.1a	80.5 ± 0.5ab	369.25 ± 6.25a	84 ± 0.0a	405 ± 0.0a
SITE	F= 72.36 df= 4 *P* < 0.001	F= 84.89 df= 4 *P* < 0.001	F= 111.74 df= 4 *P* < 0.001	F= 121.22 df= 4 *P* < 0.001	F= 236.4 df= 4 *P* < 0.001	F= 540.57 df= 4 *P* < 0.001
2010						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	88 ± 0.0a	170d ± 0.0	90.5 ± 0.50ab	186.75 ± 4.75d	93.5 ± 0.86a	216.5 ± 8.94c
Birmingham	na	na	na	na	91 ± 0.0b	224 ± 0.0c
Auburn	83 ± 0.0bc	196 ± 0.0b	85 ± 0.0b	202 ± 0.0c	88.5 ± 0.5c	220 ± 3c
Headland	82 ± 0.0c	180 ± 0.0c	86.5 ± 0.86c	208 ± 6.92b	91 ± 0.0b	245 ± 0.0b
Mobile	83.75 ± 0.75b	265.5 ± 4.5a	87.5 ± 0.5a	290.25 ± 3.75a	92 ± 0.0ab	325 ± 0.0a
SITE	F= 49.59 df= 3 *P* < 0.001	F= 366.96 df= 3 *P* < 0.001	F= 18.07 df= 3 *P* < 0.001	F= 103.94 df= 3 *P* < 0.001	F= 19 df= 4 *P* < 0.001	F= 127.13 df= 4 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

TABLE 2.7. GDD and JD for flowering events for flowering for daffodil, *Narcissus* 'Ice Follies'

2011								
	BUD TIGHT		SHEPHERDS CROOK		FIRST PETAL OPEN		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC	JD	DDC
Huntsville	59 ± 1de	100.5 ± 5.5d	62.5 ± 0.5d	118 ± 2ef	66.25 ± 0.75ef	125.5 ± 0.5d	73.5 ± 3.2de	159.75 ± 18.63c
Birmingham	61.5 ± 0.86de	144.5 ± 5.48c	65.5 ± 1.65cd	159 ± 3.31de	70.75 ± 2.28def	176 ± 10.83cd	76 ± 2.12cde	206 ± 14.74bc
Auburn	63 ± 0.0d	175 ± 0.0b	65.5 ± 0.5cd	182.25 ± 0.75cd	67.25 ± 0.47def	189 ± 2.44c	69 ± 0.57e	195 ± 1.15bc
Headland	57.75 ± 1.1e	169 ± 10.55bc	60.5 ± 0.5d	192 ± 3bcd	61.5 ± 0.5f	198.75 ± 3.25bc	65 ± 1e	214 ± 4bc
Mobile	60.5 ± 0.95de	221.5 ± 6.18a	62.75 ± 1.18d	234 ± 6.27ab	65.5 ± 1.65ef	249.75 ± 8.25ab	68.75 ± 1.7e	267.25 ± 11.01ab
SITE	F= 5.44 df= 4 *P* < 0.001	F= 46.73 df= 4 *P* < 0.001	F= 4.71 df= 4 *P* < 0.001	F= 142.94 df= 4 *P* < 0.001	F= 6.15 df= 4 *P* < 0.001	F= 49.33 df= 4 *P* < 0.001	F= 4.93 df= 4 *P* < 0.001	F= 10.75 df= 4 *P* < 0.001
2010								
	BUD TIGHT		SHEPHERDS CROOK		FIRST PETAL OPEN		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC	JD	DDC
Huntsville	81 ± 0.0b	145 ± 0.0c	87.5 ± 1.25ab	169.75 ± 5.1cd	90.25 ± 0.85ab	186 ± 6.59c	92.25 ± 1.03ab	204 ± 10.35bc
Birmingham	91 ± 1a	226.75 ± 6.25a	94.75 ± 1.49a	260.5 ± 14.37a	98.5 ± 2.5a	299.5 ± 22.5a	102.75 ± 3.75a	334.5 ± 33.5a
Auburn	79.5 ± 0.86b	185 ± 3.46b	83 ± 0.81b	196.25 ± 2.25bcd	85 ± 0.4bc	202.25 ± 1.43	87.25 ± 0.75bc	213.25 ± 3.75bc
Headland	60.5 ± 1.5de	78.5 ± 0.5d	68.25 ± 4.69cd	104.5 ± 25.16f	72.5 ± 4.17de	127.75 ± 22.9d	75.75 ± 4.4cde	147.5 ± 28.42c
Mobile	68 ± 0.57c	187 ± 2.3b	72.5 ± 0.86c	214 ± 4.04abc	76 ± 0.81cd	229.25 ± 3.47bc	82 ± 2.3bcd	258.5 ± 11.83ab
SITE	F= 163.41 df= 4 *P* < 0.001	F= 277.55 df= 4 *P* < 0.001	F= 21.52 df= 4 *P* < 0.001	F= 18.73 df= 4 *P* < 0.001	F= 22.08 df= 4 *P* < 0.001	F= 18.05 df= 4 *P* < 0.001	F= 13.06 df= 4 *P* < 0.001	F= 11.17 df= 4 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

TABLE 2.8. GDD and JD for flowering events for forsythia, *Forsythia ×intermedia* 'Lynwood gold'

2011						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	56 ± 0.0b	84 ± 0.0d	60 ± 0.0bc	106d ± 0.0d	62 ± 0.0c	116 ± 0.0d
Birmingham	57 ± 0.0b	110 ± 0.0cd	66.25 ± 1.43ab	160.5 ± 2.87cd	77 ± 0.0cd	208 ± 0.0b
Auburn	53 ± 0.57b	106 ± 4.61c	56.25 ± 1.03c	131.25 ± 8.06bc	59.5 ± 0.5c	156 ± 3c
Headland	55 ± 0.0b	143 ± 0.0b	60.25 ± 0.75c	189 ± 3.46b	63 ± 1bc	206.5 ± 4.5b
Mobile	64 ± 2.17a	242.75 ± 11.8a	67.5 ± 2.59a	260.75 ± 15.43a	68.5 ± 2.59b	266.5 ± 15.16a
SITE	F= 18.98 df= 4 *P* < 0.001	F= 122.37 df= 4 *P* < 0.001	F= 10.59 df= 4 *P* < 0.001	F= 55.18 df= 4 *P* < 0.001	F= 30.39 df= 4 *P* < 0.001	F= 63.04 df= 4 *P* < 0.001
2010						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	88.33 ± 4.37a	189.67 ± 33.68a	98.33 ± 4.48a	262.67 ± 42.04a	109.33 ± 6.06a	353.67 ± 49.36a
Birmingham	na	na	na	na	91 ± 0.0b	224 ± 0.0b
Auburn	70.75 ± 2.68a	154.75 ± 8.6a	73.5 ± 2.1b	165 ± 6.36b	77 ± 2.12c	176.5 ± 5.1b
Headland	76 ± 3.46a	144.5 ± 20.49ab	80 ± 2.67b	171 ± 12.92ab	83.75 ± 2.65bc	193.5 ± 16.19b
Mobile	68 ± 1a	189 ± 6b	77.25 ± 3.72b	237.75 ± 19.29ab	81.75 ± 3.88bc	193.5 ± 22.77ab
SITE	F= 8.26 df= 3 *P* < 0.001	F= 1.69 df= 3 *P* < 0.001	F= 16.2 df= 3 *P* < 0.001	F= 5.28 df= 3 *P* < 0.001	F= 13.66 df= 4 *P* < 0.001	F= 9.51 df= 4 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

TABLE 2.9. GDD and JD for flowering events for loropetalum, *Loropetalum chinense* 'Ruby'

2011				
	FIRST FLOWER		FULL FLOWER	
SITE	JD	DDC	JD	DDC
Huntsville	80 ± 0.0b	203 ± 0.0ab	106 ± 0.0a	357 ± 0.0a
Birmingham	57.5 ± 2.06cd	115.25 ± 14ef	84.83 ± bc	238 ± 30abc
Auburn	62 ± 2.48c	165.5 ± 13.47cd	70.25 ± 3.4cde	203.5 ± 15.05c
Headland	55 ± 0.0d	143 ± 0.0de	60.75 ± 1.75cde	195.25 ± 8.72c
Mobile	61 ± 0.0c	224 ± 0.0a	63.75 ± 0.75de	241 ± 3bc
year*site	F= 46.48 df= 4 *P* < 0.001	F= 25.65 df= 4 *P* < 0.001	F= 51.42 df= 4 *P* < 0.001	F= 17.32 df= 4 *P* < 0.001
2010				
	FIRST FLOWER		FULL FLOWER	
SITE	JD	DDC	JD	DDC
Huntsville	90.5 ± 0.95a	188.5 ± 7.62bc	99.75 ± 0.75ab	273.75 ± 5.75abc
Birmingham	92.25 ± 1.97a	238 ± 19.69a	99 ± 0.0ab	301 ± 0.0ab
Auburn	78 ± 0.0b	179 ± 0.0bcd	87 ± 1.22cde	214 ± 7.03bc
Headland	59 ± 1.77cd	78 ± 0.57g	68 ± 1.22abc	94.75 ± 9.72d
Mobile	45.75 ± 4.81e	91.25 ± 4.87fg	81.5 ± 3.86bcd	259.5 ± 20.9abc
year*site	F= 65.7 df= 4 *P* < 0.001	F= 49.4 df= 4 *P* < 0.001	F= 47.2 df= 4 *P* < 0.001	F= 53.67 df= 4 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

TABLE 2.10. GDD and JD for flowering events for indian hawthorn, *Rhaphiolepis indica* Eleanor Tabor™

2011						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	na	na	na	na	na	na
Birmingham	96 ± 0.0a	330 ± 0.0a	100.33 ± 0.66a	384.67 ± 6.38ab	105 ± 0.0a	426 ± 0.0ab
Auburn	91.75 ± 0.75b	350 ± 6b	95.5 ± 0.95b	376.5 ± 9.64b	98.5 ± 1.44b	405 ± 17.32ab
Headland	83 ± 0.0c	361 ± 0.0c	85 ± 0.0c	377 ± 0.0b	87 ± 0.0c	396 ± 0.0b
Mobile	82 ± 0.0c	388 ± 0.0c	84 ± 0.0c	405 ± 0.0a	87 ± 0.0c	445 ± 0.0a
SITE	F= 206.6 df= 3 *P* < 0.001	F= 44.97 df= 3 *P* < 0.001	F= 71.60 df= 3 *P* < 0.001	F= 6.88 df= 3 *P* < 0.001	F= 96.87 df= 3 *P* < 0.001	F= 4.97 df= 3 *P* < 0.001
2010						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	na	na	na	na	na	na
Birmingham	114.75 ± 1.75a	438.25 ± 13.25a	118 ± 2a	471.5 ± 20.5a	121.5 ± 1.5a	498 ± 20a
Auburn	105 ± 0.57b	366 ± 6.35a	107.75 ± 0.75ab	395.25 ± 7.28a	110 ± 0.57a	414 ± 4.04ab
Headland	102.5 ± 4.33b	364.5 ± 43.59a	106 ± 4.04b	400 ± 41.59a	113 ± 4.52a	480.5 ± 54.74ab
Mobile	96 ± 0.0b	365 ± 0.0a	98.75 ± 0.75b	390.5 ± 5.5a	104.5 ± 0.5a	441 ± 5b
SITE	F= 1.68 df= 3 *P* < 0.001	F= 2.25 df= 3 *P* < 0.001	F= 9.6 df= 3 *P* < 0.001	F= 2.18 df= 3 *P* < 0.001	F= 7.19 df= 3 *P* < 0.001	F= 1.39 df= 3 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

TABLE 2.11. GDD and JD for flowering events for oakleaf hydrangea, *Hydrangea quercifolia* 'Ellen Huff'

2011						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	na	na	na	na	na	na
Birmingham	107.67 ± 1.33a	448.67 ± 11.33c	117 ± 1b	554.33 ± 9.66b	122 ± 0.0a	552.67 ± 63.33b
Auburn	111 ± 0.57a	522.5 ± 7.79b	114.75 ± 1.03b	570.75 ± 0.0a	117.5 ± 0.95b	601.5 ± 10.13b
Headland	na	na	na	na	na	na
Mobile	101.5 ± 0.5b	601 ± 5a	106 ± 1.77a	650.25 ± 20.89a	112 ± 0.0ac	732 ± 0.0a
SITE	F= 36.32 df= 2 *P* < 0.001	F= 82.04 df= 2 *P* < 0.001	F= 17.54 df= 2 *P* < 0.01	F= 9.85 df= 2 *P* = 0.007	F= 63.7 df= 2 *P* < 0.001	F= 9.87 df= 2 *P* =0.06
2010						
	FIRST FLOWER		50%		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC
Huntsville	na	na	na	na	na	na
Birmingham	120c ± 0.0c	478c ± 0.0c	131.5 ± 1.5a	619.25 ± 15.33a	143.5 ± 2.02a	774 ± 26.55a
Auburn	124 ± 0.57b	555.5 ± 7.79b	128.33 ± 0.67ab	602.67 ± 15.33a	129.5 ± 1.65b	624.25 ± 20.37a
Headland	na	na	na	na	na	na
Mobile	118 ± 0.0a	578 ± 0.0a	121.75 ± 1.75b	623.25 ± 26.25a	129.5 ± 1.44b	733.5 ± 18.18b
SITE	F= 0.5 df= 2 *P* < 0.001	F= 135.91 df= 2 *P* < 0.001	F= 10.6 df= 2 *P* < 0.001	F= 0.21 df= 2 *P* = 0.81	F= 0.05 df= 2 *P* < 0.001	F= 11.92 df= 2 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

TABLE 2.12. GDD and JD for flowering events for flowering for ‘Happy Returns’ daylily, *Hemerocallis* 'Happy Returns'

2011								
	BUD TIGHT		SHEPHERDS CROOK		FIRST PETAL OPEN		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC	JD	DDC
Huntsville	123 ± 0.0abc	536 ± 0.0bc	131 ± 1abc	615 ± 13bc	136 ± 1.95abc	665.75 ± 7.75bc	142 ± 2.48abc	729 ± 34.41ab
Birmingham	117.5 ± 0.86bcd	562 ± 9.24abc	124.75 ± 2.25cd	633.25 ± 21.75bc	129.5 ± 0.5cd	692.75 ± 7.75bc	132 ± 0.57cde	728.5 ± 7.21ab
Auburn	125.75 ± 1.18ab	684 ± 11.05a	127.75 ± 1.37bcd	704.25 ± 17.39ab	129.75 ± 1.49bcd	730.25 ± 20.48ab	132.25 ± 1.49cde	759.75 ± 17.98ab
Headland	114.75 ± 1.84cd	493.75 ± 19.72c	118.5 ± 2.9d	539 ± 37.66c	123 ± 2.44d	598.5 ± 33.98c	126.75 ± 2.83de	650.5 ± 42.07b
Mobile	107.67 ± 5.69d	680 ± 74.22a	117.33 ± 2.33d	807.33 ± 31.33a	121.67 ± 1.45d	862 ± 17.76a	125 ± 2.08e	902.67 ± 24.23a
SITE	F= 9.41 df= 4 *P* < 0.001	F= 9.68 df= 4 *P* < 0.001	F= 10.18 df= 4 *P* < 0.001	F= 7.89 df= 4 *P* < 0.001	F= 18.44 df= 4 *P* < 0.001	F= 10.82 df= 4 *P* < 0.001	F= 10.11 df= 4 *P* < 0.001	F= 9.12 df= 4 *P* < 0.001
2010								
	BUD TIGHT		SHEPHERDS CROOK		FIRST PETAL OPEN		FULL	
SITE	JD	DDC	JD	DDC	JD	DDC	JD	DDC
Huntsville	132.75 ± 2.13a	558.5 ± 27.79a	140 ± 40.2a	690 ± 55.64ab	146 ± 4.26a	772.75 ± 65ab	151.25 ± 4.67a	857.25 ± 76.7a
Birmingham	124.25 ± 3.25abc	532.5 ± 39.5bc	133 ± 2.12abc	641.75 ± 25.27bc	138 ± 2.12abc	707 ± 29.69bc	143.5 ± 2.72ab	784.5 ± 40.18ab
Auburn	132 ± 0.0a	655 ± 0.0ab	136.25 ± 0.75ab	719 ± 11ab	140.5 ± 1.5ab	779.25 ± 21.63ab	145.5 ± 0.95ab	853.75 ± 14.5a
Headland	125.75 ± 1.49ab	635 ± 22.15ab	129.25 ± 1.43bc	689 ± 20.74ab	133 ± 1.77bc	746.5 ± 28.84ab	137.5 ± 0.5bcd	819.5 ± 7.5b
Mobile	125.25 ± 1.75ab	675.75 ± 26.25a	131.25 ± 1.49abc	748.25 ± 18.94ab	134.75 ± 1.49abc	800.5 ± 23.89ab	140 ± 0.57e	880.5 ± 9.52a
SITE	F= 3.99 df= 4 *P* < 0.001	F= 4.69 df= 4 *P* < 0.001	F= 4.09 df= 4 *P* < 0.001	F= 1.25 df= 4 *P* < 0.001	F= 4.32 df= 4 *P* < 0.001	F= 0.92 df= 4 *P* < 0.001	F= 4.56 df= 4 *P* < 0.001	F= 0.89 df= 4 *P* < 0.001

Means within column followed by the same letter were not significantly different (*P* < 0.05, Tukey’s HSD test).

TABLE 2.13. GDD and JD for flowering events for ‘Natchez’ crapemyrtle, *Lagerstroemia indica* ×fourieri 'Natchez'

2011				
	FIRST FLOWER		FULL FLOWER	
SITE	JD	DDC	JD	DDC
Huntsville	148 ± 0.0bc	813 ± 0.0cd	162.25 ± 1.25bcd	1078 ± 23b
Birmingham	142.5 ± 2.46c	840.5 ± 33.48cd	155.75 ± 4.64cde	1069.3 ± 88.75b
Auburn	143 ± 1.77c	880.25 ± 26.78bcd	157.5 ± 3.01def	1143.8 ± 60.91b
Headland	128 ± 1.15d	850.5 ± 13.56cd	146.75 ± 1.18def	1114.3 ± 22.44b
Mobile	132.75 ± 1.75d	1003.3 ± 19.25ab	142.5 ± 0.5f	1149 ± 0.0b
SITE	F= 11.53 df= 4 *P* < 0.001	F= 24.66 df= 4 *P* < 0.001	F= 9.7 df= 4 *P* < 0.001	F= 0.53 df= 4 *P* = 0.71
2010				
	FIRST FLOWER		FULL FLOWER	
SITE	JD	DDC	JD	DDC
Huntsville	162.5 ± 2.5a	1039.8 ± 43.25a	207.25 ± 5.48a	1033.8 ± 235.66a
Birmingham	148 ± 0.0bc	785.75 ± 66.25d	172.5 ± 2.02b	1297.5 ± 41.85b
Auburn	151.25 ± 1.18b	966.5 ± 30.63abc	167 ± 2.54bc	1264.8 ± 46.65b
Headland	144 ± 0.0bc	931 ± 0.0abcd	153.5 ± 0.5def	1092.8 ± 8.75b
Mobile	143.5 ± 1.44c	939.5 ± 24.53abcd	161 ± 0.57bcd	1231.5 ± 10.68b
SITE	F= 5.49 df= 4 *P* < 0.001	F= 30.83 df= 4 *P* < 0.001	F= 52.47 df= 4 *P* < 0.001	F= 11.57 df= 4 *P* < 0.001

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey’s HSD test).

TABLE 2.14. GDD and JD for flowering events for Majestic liriope, *Liriope muscari* 'Majestic'

2011				
	FIRST FLOWER		FULL FLOWER	
SITE	JD	DDC	JD	DDC
Huntsville	213 ± 0.0a	1999 ± 0.0ab	220 ± 0.0a	2134 ± 0.0a
Birmingham	192.25 ± 2.25ab	1708.5 ± 44.5b	198 ± 4a	1838 ± 95.75a
Auburn	188.75 ± 1.18ab	1717.5 ± 23.17b	195.25 ± 1.49a	1857.3 ± 40.12a
Headland	175 ± 1b	1740 ± 22ab	193 ± 0.0a	2119 ± 0.0a
Mobile	191.33 ± 9.82ab	2114.3 ± 193.23a	204 ± 9.68a	2208 ± 191a
SITE	F= 5.8 df= 4 $P < 0.001$	F= 4.32 df= 4 $P < 0.001$	F= 2.46 df= 4 $P < 0.001$	F= 4.25 df= 3 $P = 0.71$
2010				
	FIRST FLOWER		FULL FLOWER	
SITE	JD	DDC	JD	DDC
Huntsville	199.25 ± 3.88b	1735.8 ± 79.09c	210.5 ± 2.46c	1965.3 ± 49.02d
Birmingham	218 ± 0.0a	2585 ± 0.0a	222 ± 0.0b	2893 ± 0.0a
Auburn	na	na	na	na
Headland	199.5 ± 0.5b	1996 ± 10b	209.25 ± 0.75c	2207 ± 16c
Mobile	224.75 ± 1.75a	2487.3 ± 34.25a	235.5 ± 2.1a	2698 ± 40.15b
SITE	F= 36.78 df= 3 $P < 0.001$	F= 86.4 df= 3 $P < 0.001$	F= 54.02 df= 3 $P < 0.001$	F= 172.12 df= 3 $P < 0.001$

Means within column followed by the same letter were not significantly different ($P < 0.05$, Tukey's HSD test).

Discussion

For virtually all phenophases evaluated, there was significant variation in Julian data and GDD among sites and between years. In many instances, a phenophase was significantly different among sites in one year but not another (e.g., crapemyrtle). With crapemyrtle (Table 2.13), there was a significant difference at first flower but not at full flower. It is clear that the bloom period (first to full) also varied widely by site. With crapemyrtle, likely warmer temperatures at one site may have enabled flowers on that plant to 'catch up' phenologically to plants that bloomed earlier. In Mobile, for example, first to full flower was much faster (10 d compared to 14–18 d) at other sites in 2011 (Table 2.13).

Interestingly, the sequence of flowering did not necessarily progress from south to north as would be expected (Tables 2.6-2.14). For many phenophases, Mobile or Headland was the first site but others such as Auburn were often not significantly different from Mobile. It was common, though, that a particular event in Mobile was significantly different from the same event in Huntsville. In Ohio, the progression of spring was measured a 7–16 km per day from south to north by tracking the occurrence of first bloom of forsythia in Ohio phenology garden sites (Kulhanek 2009). The southern sites (Mobile, Headland, and Auburn) were likely more phenologically similar due to similarity in temperatures.

Despite variation in JD and GDD for each event, plant phenology across five sites showed a significant correlation in flower sequence from site-to-site and from year-to-year. This suggests that the sequence statewide progresses similarly irrespective of the absolute date or GDD for the event. These data reinforce the relative utility of phenology compared to GDD or calendar date for use in pest management (Mussey and Potter 1997, Herms 2004). Mobile

Alabama, the southern part of the state, is coastal and in USDA hardiness zone 8b (United States National Arboretum, 2012). However, the data presented here suggest that the sequence of bloom in Mobile is no different than the sequence at other locations in the state. This would indicate that plant phenological indicators identified from work at Auburn may be applicable for pests in other parts of the state. This hypothesis will be further investigated in Chapter 3.

Chapter III

PHENOLOGY AND DEGREE-DAY MODELS IN ALABAMA

Abstract

Plant phenophases of 12 plants were monitored in five replicated gardens established in Mobile, Headland, Auburn, Birmingham, and Huntsville, Alabama, the main climate regions of the state. Coincident with phenophase recording, first capture and seasonal flight periods were monitored. Two sentinel landscape pests, crapemyrtle aphid (CMA) and dogwood borer (DWB) were tracked across the state, and flower stages were compared with important pest activities. No single phenological indicator existed for all sites. Emergence of DWB or CMA was consistent statewide. First emergence and\or seasonal flight period for an additional eight pest species were monitored in Auburn. First peak and seasonal trap capture of CMA and male DWB were graphed for each site relative to GDD and JD for two years. The sequence of phenophases to pests was not consistent statewide. However, the order in which plants flowered maintained a consistent pattern from Mobile to Huntsville.

Introduction

As urban areas increase, so does the demand for public, commercial, and residential green spaces including lawns and landscapes. Along with the increase in plant species comes an increase in the number of arthropod pests (Raupp et al. 2001). As insect pest populations increase, potential damage to landscape ornamental plants also increases. Consequently, significant amounts of pesticides are used for pest control in landscapes. Annually, more than $172 million worth of damages occur in Georgia landscapes and costs of control to pests attacking ornamentals plants in nurseries and landscapes (Oetting et al. 2004). Landscapers, nursery personnel, and laypersons alike traditionally rely on calendar based application for predicting pest activity, often with immense failure rates in controlling landscape pests due to inconsistencies in pest activity from year to year and variations such as warmer or cooler spring temperatures. Plant and insect development is based on temperature; therefore, we can use growing degree-days to track important developmental phases (Huberman 1941). The use of phenology and degree-day models can aid in forecasting key pest events, ultimately saving money in pest management programs. Degree-day models and plant phenological indicators can be used for predicting pest activity. When available to pest managers, degree-day information to pinpoint control measures, has led to a 28% reduction in pesticide use over two years (Suchanic and Vorodi 1993) and a 41% decrease in pesticides over an 8-year period (Hoover 2002).

Borers are among the most important pests of ornamental plants in production or in the landscape. At least 151 species in 19 genera of clearwing borers (Lepidoptera: Sesiidae) exist in North America, North of Mexico (Heppner 1987). Of these, 22 species in 8 genera have significant economic importance (Rogers and Grant 1990). Dogwood borer, *Sinathedon scitula*,

Figure 3.1. Sooty mold on crapemyrtle

occurs from SE Canada to Eastern U.S. with one of the longest reproductive activity periods of clearwings (Drooz 1985, Davidson et al. 1992). This species also has the broadest host range of any North American clearwing borer (Rogers and Grant 1990).

Crapemyrtle has grown to be one of the most prevalent ornamental landscape plants in the Southeastern U.S. (USDA hardiness zones 7-10). Crapemyrtles offer wide array of aesthetic attributes with its lustrous foliage, long-lasting flowers, extravagant fall color, and unique showy bark (Dirr 1998). However, all varieties are vulnerable to sooty mold (Fig. 3.1) due to crapemyrtle aphid infestations (Allen and Alverson 1991, Mizell and Knox 1993). Crapemyrtle aphid, *Tinocallis kahawaluokalani* is the only key insect pest of crapemyrtles. All adult crapemyrtle aphids are winged and on tree activity is correlated with captives on sticky cards (Allen and Alverson 1991).

Objective

The objective of this work was to determine the phenological phases of 12 ornamental plants for five sites in Alabama in two years.

Materials and Methods

Pests were monitored in five phenology gardens established as part of the Auburn Phenology Garden Project (Chapter 2). Plant phenophases were recorded as described in

Chapter 2. Also on these sites, the seasonal phenology of two key landscape pests (crapemyrlte aphid and dogwood borer) was monitored at all five sites statewide in 2010 and 2011.

Flight activity of male dogwood borer was monitored with two 1C wing traps (Pherocon, Inc. Adair, OK) hung 1.5-1.8m high in baited rubber septa containing a trinary blend of purified dogwood borer pheromone (<0.05% Z, Z-3, 13-ODDA) obtained from Dr. A. Zhang (USDA-ARS) (Bergh et al. 2004). Two traps were hung 1.5-1.8m off the ground within the garden and lures were replaced every 4 wk. Wing traps at satellite sites with captured moths were sent to the lab biweekly, stored in the freezer, and labeled with the location and Julian date. All traps were inspected three times per week from March to late October. The first male capture and cumulative seasonal capture were recorded.

Crapemyrtle aphids were monitored with two 7.6 cm x 12.7 cm yellow sticky cards (Olson Products, Medina, OH) hung 1.5-1.8 m above the ground on susceptible crapemyrtle species, beginning in March and sampled weekly at Auburn and biweekly at other sites. A crapemyrtle variety susceptible to crapemyrtle aphids were not present at Mobile and Headland so four 'Biloxi' crapemyrtles were planted within 5 m of each garden at the time the gardens were established in 2010. Sticky cards from remote sites were harvested from the trees and stuck to thin clear acetate transparency sheets then mailed to the lab for identification and counting. First occurrence and duration of activity on sticky cards was recorded for CMA at all sites.

At the Auburn garden in 2010 and 2011, additional pests were monitored to establish their activity in relation to plant phenological indicators (Table 3.1). Flight activity of lesser peachtree borer, lilac ash borer, and oak clearwing was monitored with 1C traps as mentioned for dogwood borer (Pherocon, Inc. Adair, OK). Traps were hung 1.5-1.8 m high within 15 m of the garden. Traps for lesser peachtree borer were baited with commercially available lure

(LPTB3140 and LILA3224, Trece, Adair, OK). Lilac ash borer and oak clearwing borer were both monitored with the commercial lure for lilac ash borer (LILA3224, Trece, Adair, OK). Traps were inspected three times per week from March to late October and lures were replaced every 4 weeks. Captured moths were stored in the freezer and labeled with the location and Julian date. The first male capture and cumulative seasonal capture were recorded.

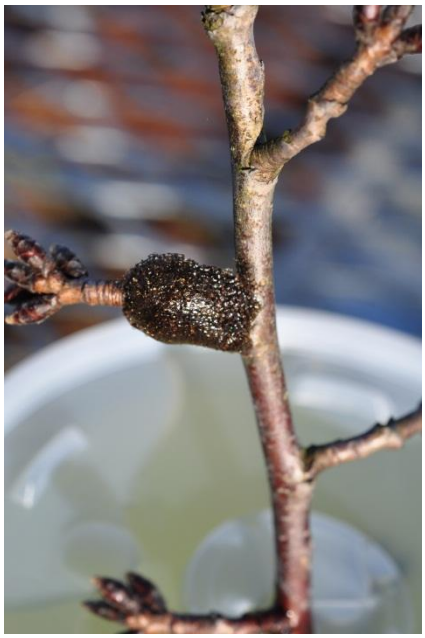
The flight activity of black cutworm and fall armyworm, two turf-infesting moths, were monitored at the Auburn site. First emergence was monitored with one 1C wing trap (Pherocon, Inc. Adair, OK) hung 1.5–1.8m high near the garden. Two traps were in each garden. Commercially-available pheromones (3141 or BCW and 3143 for FAW, Trece) were used in traps and replaced every 4 wk. Traps were inspected coincident with monitoring of the other moths. BCW was monitored from January–May and FAW from Mar–October and the Julian date for first moth capture of each species recorded. Adult Japanese beetles were monitored using a Japanese beetle trap (Trece) baited with the food and the pheromone lures. Traps were inspected coincident with servicing the other traps. First trap capture and seasonal abundance were recorded.

First emergence of adult Canna leafroller moth was recorded using caged *Canna* 'Tropicana' plants infested. Five plants with signs of previous damage and infested with immature canna leafrollers were planted into the garden in 2009 (Fig. 3.2). In January 2010 metal, screen cages (61 x 61 x 61 cm, Bioquip Products, Rancho Dominguez, CA) were used to cover each plant to trap emerging adults. First adult emerged and emergence period were recorded as adults were caught fluttering around in the cages.

Infested twigs of *Malacosoma americanum* (F.) were obtained at sites in Auburn and surrounding areas from wild and cultivated cherry (*Prunus*) and crabapple (*Malus*) trees. In

spring 2010, twig collections included: AL CR. 30, near Auburn University Field Crops Research Farm, Tallassee, AL – 3 twigs; Dr. Mike William's property, Notasulga, AL – 3 twigs; Intersection of Gateway Dr. & Thompson Dr., Opelika, AL – 4 twigs; Memorial Park Cemetery – 2 twigs; Moore's Mill Rd. near Stonehenge Dr. – 1 twig; Keesal Park, Auburn – 1 twig. In spring 2011, 12 egg masses were collected from five large cherry trees (*Prunus serotina*) growing in a fencerow in Sharpsburg, GA. Additionally, three egg masses were collected from two large cherry trees (*Prunus serotina*) growing in a fencerow in Auburn, AL.

Figure 3.2. Cherry twig with an egg mass of *Malacosoma americanum*



Infested twigs were cut and placed in 1:3 antifreeze/water solution in plastic cups to prevent water from freezing (473 ml, Solo Cup Company, Lake Forest, IL) in the Auburn phenology garden in January (Figure 3.2). Cups with twigs were placed in metal screen cages (61 x 61 x 61 cm, Bioquip Products, Rancho Dominguez, CA) to prevent damage from wildlife. Samples were monitored and the number of larvae that hatched was recorded daily.

Eight additional arthropod species were monitored in the Auburn garden (Table 3.1).

Table 3.1. Arthropods monitored in Auburn, AL, 2010-2011

Common Name	Scientific Name	Order: Family	Life Cycle	Stage Monitored
Lepidopteran borers				
Dogwood borer	*Synanthedon scitula*	Lepidoptera: Sesiidae	typically bivoltine generalist on many trees & shrubs	1st emergence[a], 1st peak
Lesser peachtree borer	*Synanthedon pictipes*	Lepidoptera: Sesiidae	univoltine specialist on ornamental trees & shrubs	1st emergence[a], 50% flight
Lilac ash borer	*Podosesia syringae*	Lepidoptera: Sesiidae	univoltine specialist of *Fraxinus*	1st emergence[a]
Oak clearwing borer	*Paranthrene simulans*	Lepidoptera: Sesiidae	semivoltine generalist, primarily oaks of red & white groups, elm, & American chestnut	1st emergence[a]
Mandibulate folivores				
Lesser canna leafroller	*Geshna cannalis*	Lepidoptera: Pyralidae	univoltine specialist of *Canna*	1st emergence[b]
Japanese beetle	*Popillia japonica*	Coleoptera: Scarabaeidae	univoltine generalist on >79 plant families	1st emergence[a], peak
Eatern tent caterpillar	*Malacosoma americanum*	Lepidoptera: Lymantridae	univoltine specialist on *Malus* sp. & *Prunus* sp. (Rosaceae family)	1st emergence[b]
Black cutworm	*Agrotis ipsilon*	Lepidoptera: Noctuidae	multivoltine generalist of turfgrass, nearly all vegetable crops	1st emergence[a]
Fall armyworm	*Spodoptera frugiperda*	Lepidoptera: Noctuidae	univoltine generalist of turgrass, and over 80 other plants	1st emergence[a]
Haustellate folivores				
Crapemyrtle aphid	*Sarucallis kahawaluokalani*	Hemiptera: Aphididae	multivoltine specialist on crapemyrtle	1st emergence[a], 50% flight, peak

[a] - data for trap collections

[b] - data for direct observation

Statistical analyses

Five potential base temperatures, 35°F (1.6°C), 40°F (4.4°C), 45°F (7.2°C), 50°F (10°C) and 55°F (12.7°C), were used to determine the most appropriate base temperature for dogwood borer and crapemyrtle aphid. For the additional insect species, a base temperature of 1.6°C and a biofix of January 1 were used for GDD calculations (Klein 2002) for all plants and the additional insect species.

Cumulative GDDC for first, last, and peak occurrence of CMA was analyzed for each location using ANOVA with Tukey's LSD test to show variation in GDD among sites. Also, cumulative abundance of CMA was compared with cumulative GDD. Similar to Mussey and Potter (1997), the 2-year average was calculated for first emergence.

Results

Sentinel pests first emergence, two year average

Analysis of total cumulative capture for dogwood borer from first peak using GDD (Figure 3.3) proved Mobile was not significantly correlated with the four other sites in 2010. In 2011, Huntsville showed no significant correlation compared to four other sites that were correlated (Figure 3.3). In JD analysis, for 2010 (Figure 3.4) showed no significant correlation with the four other sites as well as 2011 analysis (Figure 3.5).

GDDC and JD monitored CMA first emergence and seasonal abundance in 2010 and 2011 at all garden sites over two years. In 2010 (Figure 3.6) GDD for Mobile were not significantly correlated with the other four sites; however in 2011 (Figure 3.7) were better correlated among five sites.

Figure 3.3. DWB Cumulative GDD trap capture for 2010, 5 sites statewide

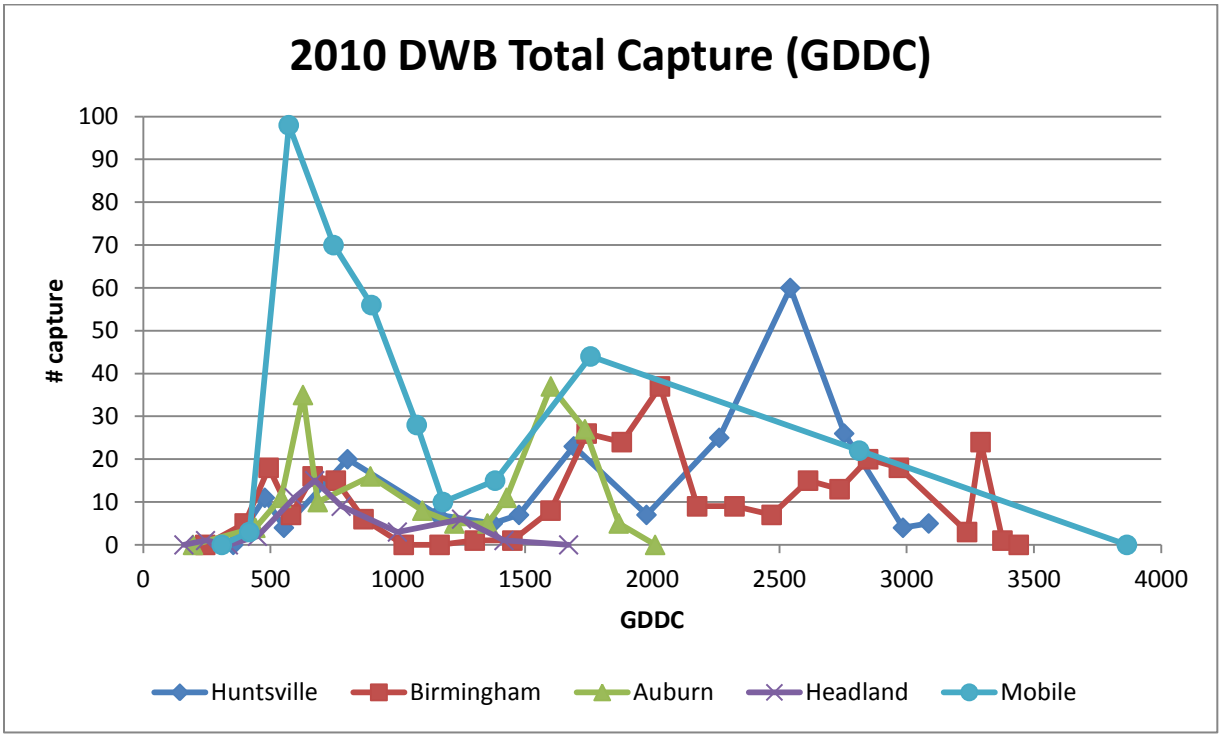


Figure 3.4. DWB Cumulative GDD trap capture for 2011, 5 sites statewide

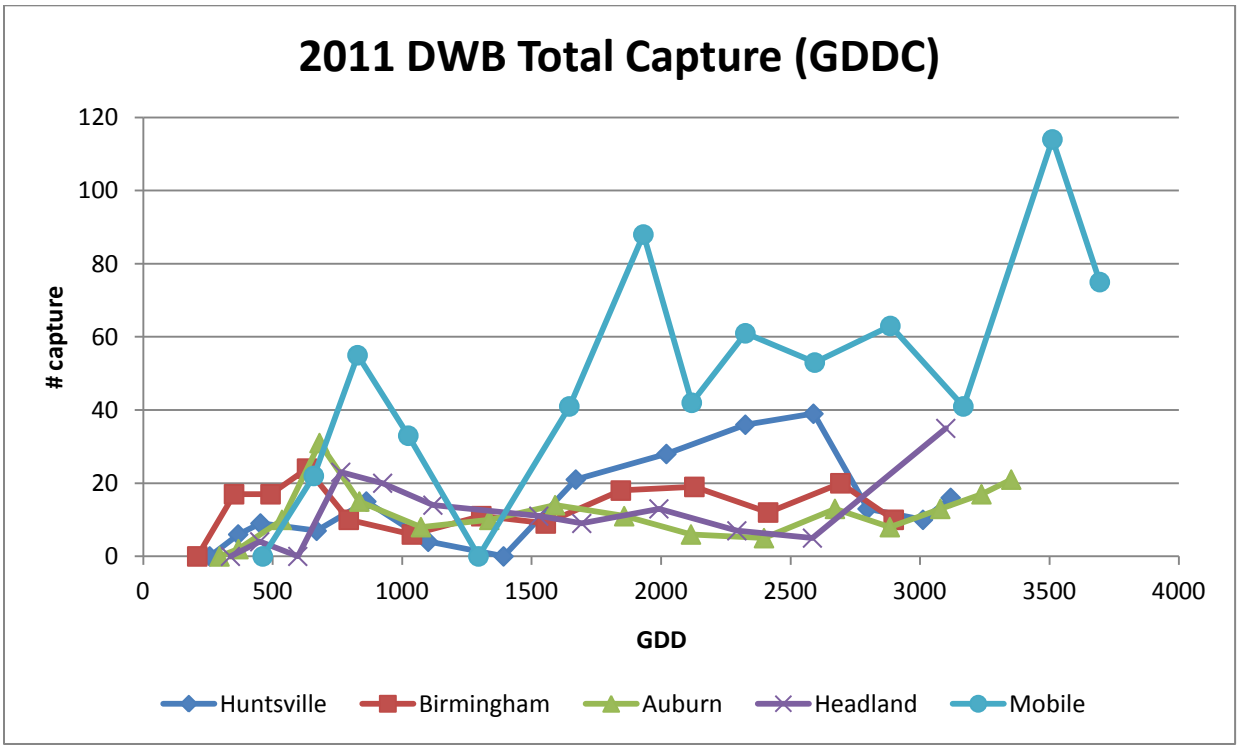


Figure 3.5. DWB Cumulative JD trap capture for 2010, 5 sites statewide

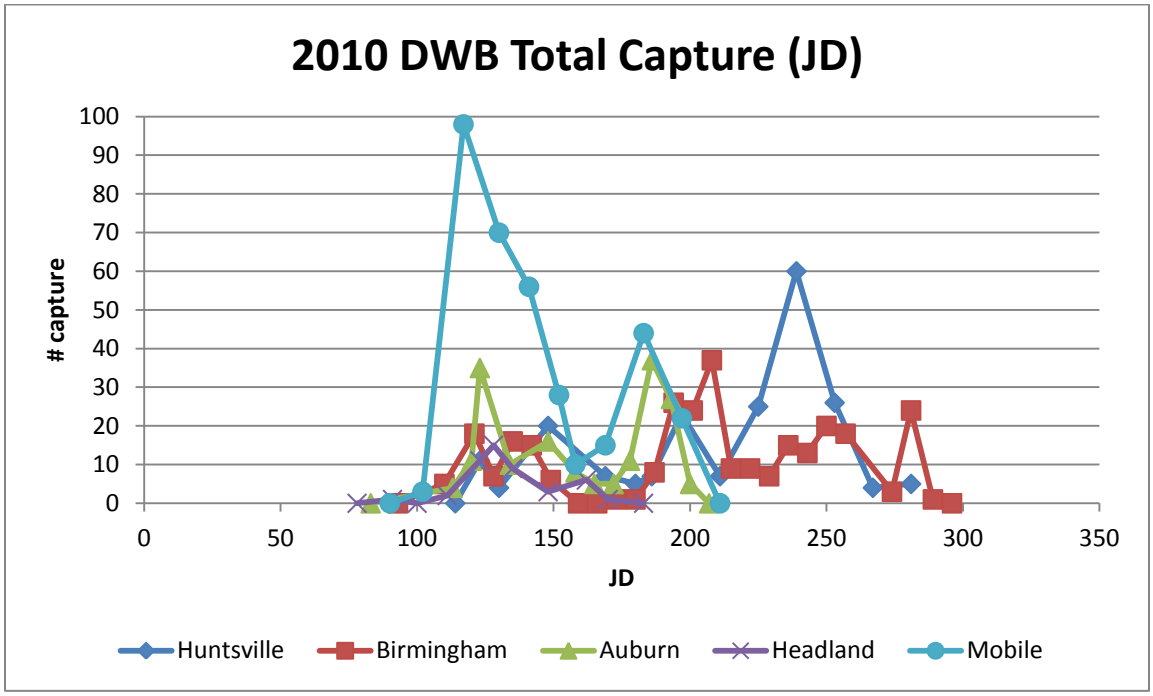


Figure 3.6. DWB Cumulative JD trap capture for 2011, 5 sites statewide

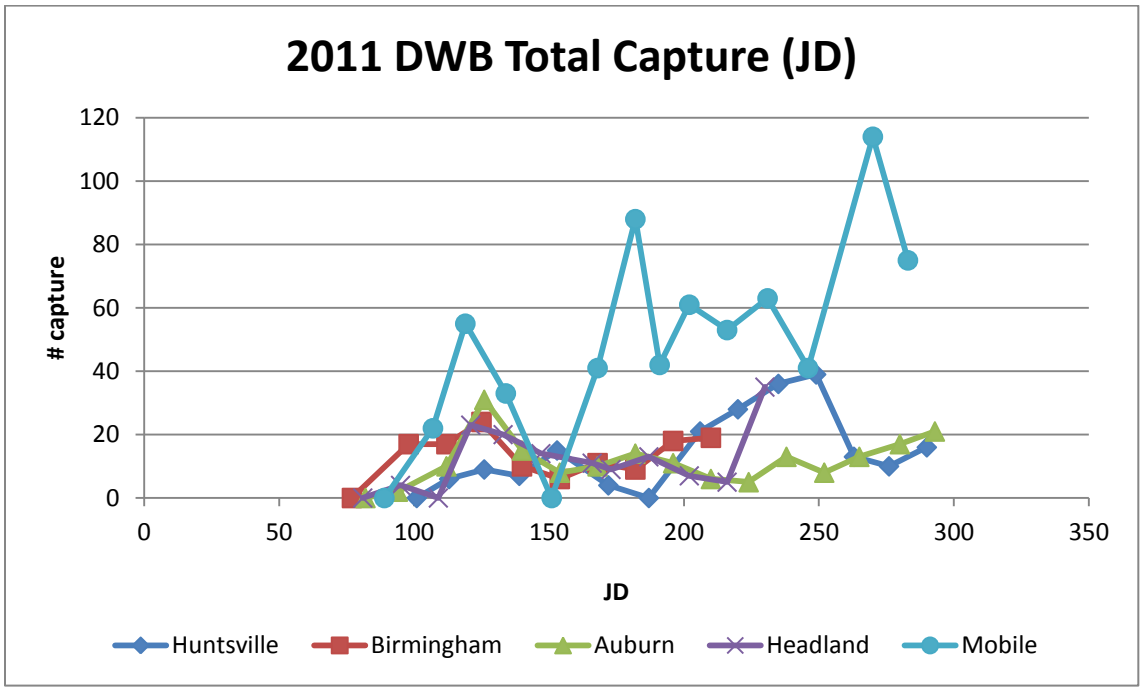


Figure 3.7. CMA Cumulative GDD trap capture for 2010, 5 sites statewide

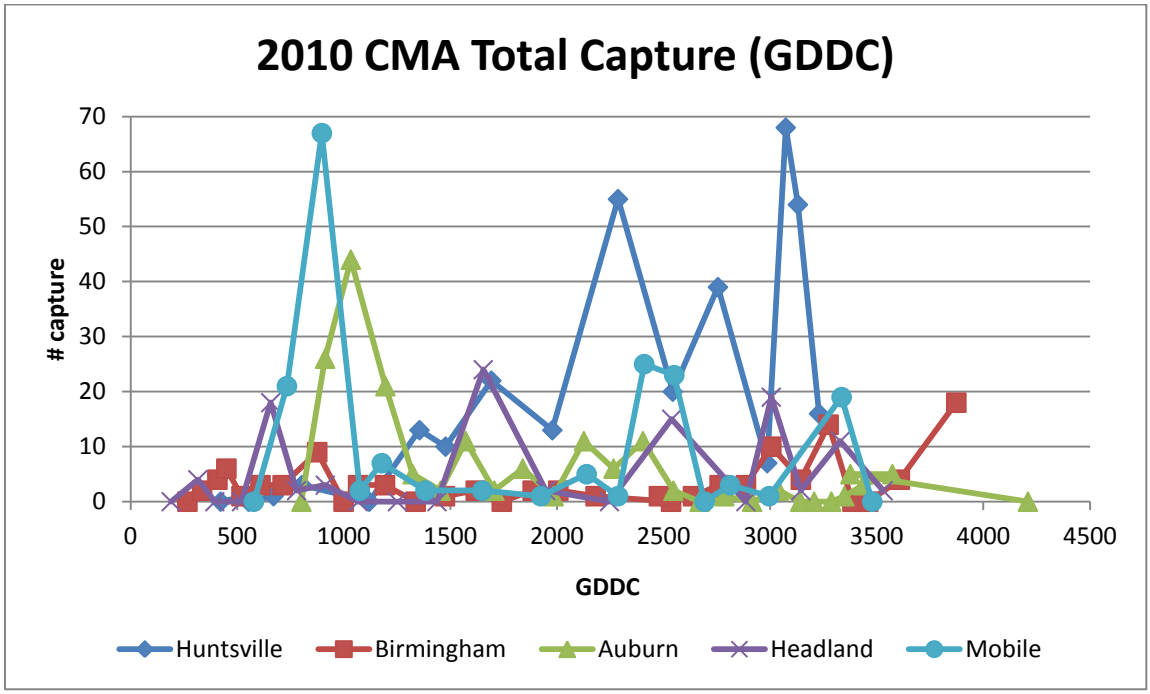


Figure 3.8. CMA Cumulative GDD trap capture for 2011, 5 sites statewide

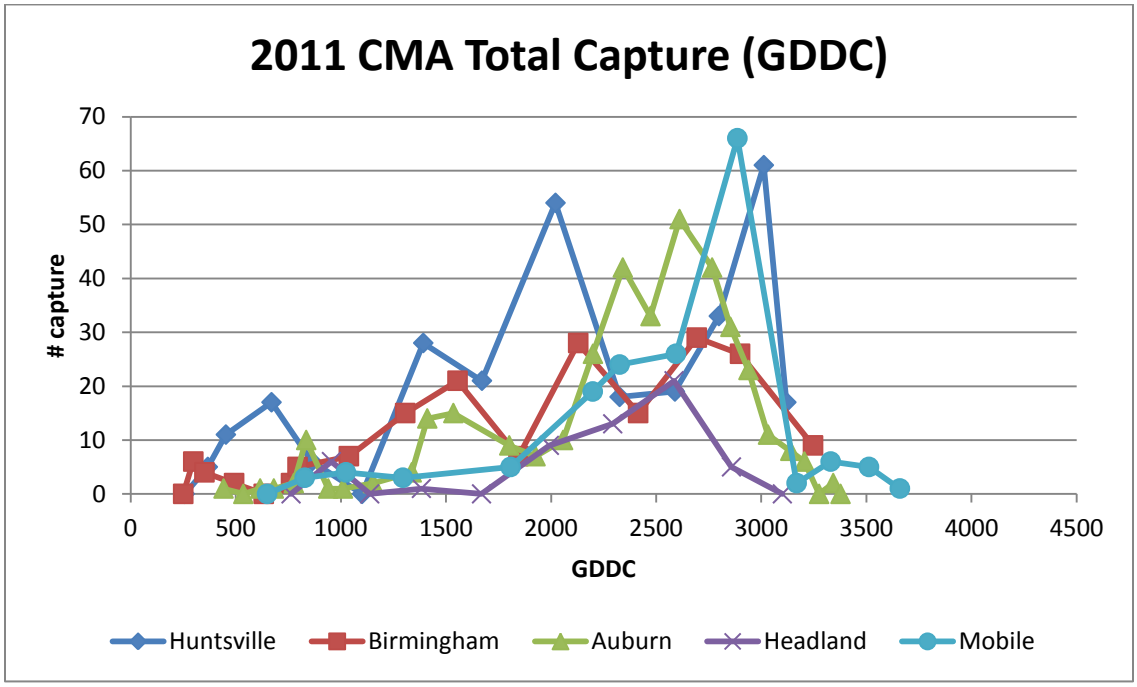


Figure 3.9. CMA Cumulative JD trap capture for 2010, 5 sites statewide

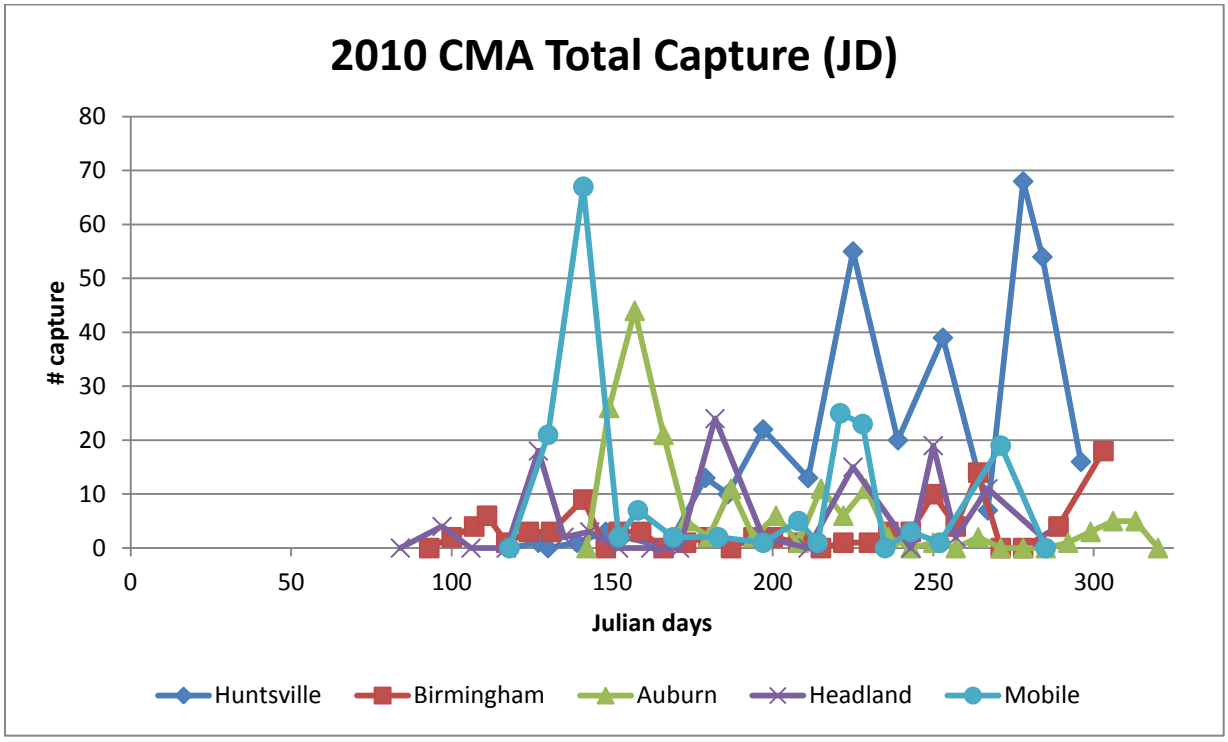


Figure 3.10. CMA Cumulative JD trap capture for 2011, 5 sites statewide

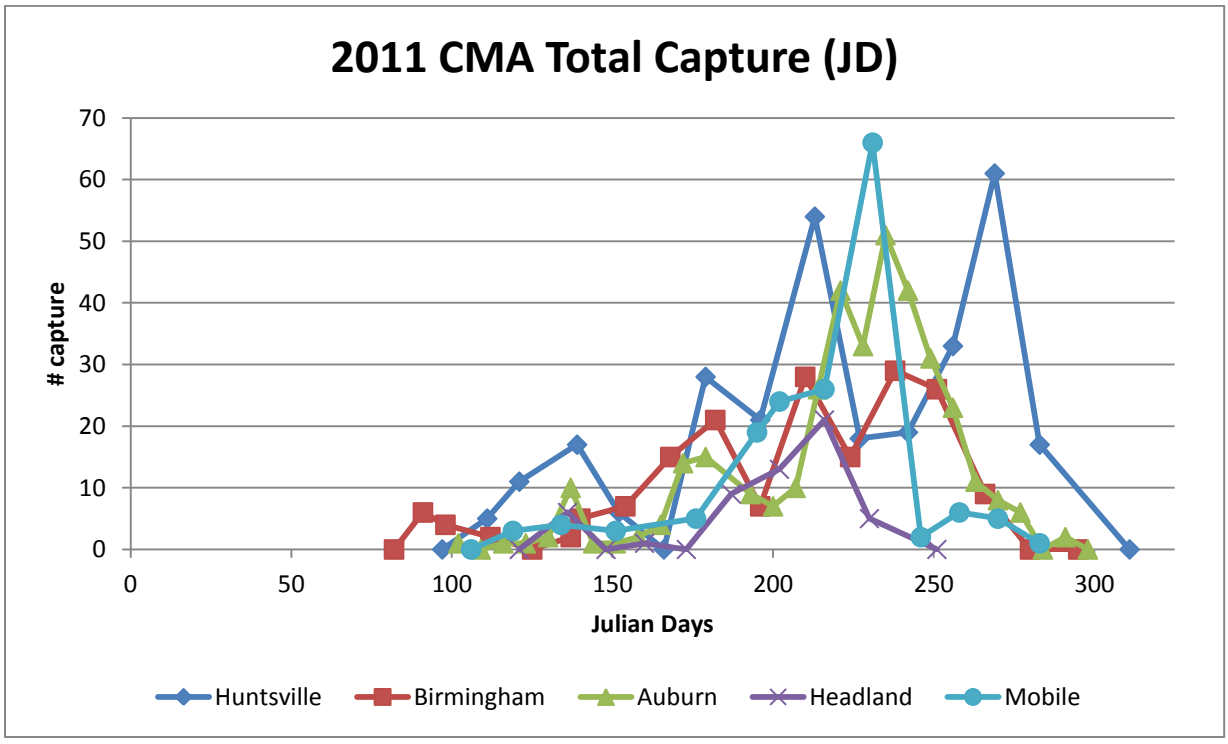


Table 3.2. Sentinel insect species data across 5 sites and 2 years comparing GDD(C) and calendar date

Huntsville							
Insect	Insect event	GDD 2010	GDD 2011	GDD 2 yr avg	Calendar date 2010	Calendar date 2011	Calendar date 2 yr avg
CMA	1st emergence	536	367	451	7-Apr	15-May	26-Apr
DWB	1st emergence	478	670	574	3-May	23-Apr	28-Apr
DWB	1st peak	803	1334	1068	28-May	1-Jun	30-May
Birmingham							
Insect	Insect event	GDD 2010	GDD 2011	GDD 2 yr avg	Calendar date 2010	Calendar date 2011	Calendar date 2 yr avg
CMA	1st emergence	335	286	310	7-Apr	1-Apr	4-Apr
DWB	1st emergence	399	351	375	20-Apr	8-Apr	14-Apr
DWB	1st peak	666	633	649	15-May	5-May	10-May
Auburn							
Insect	Insect event	GDD 2010	GDD 2011	GDD 2 yr avg	Calendar date 2010	Calendar date 2011	Calendar date 2 yr avg
CMA	1st emergence	912	442	677	29-May	12-Apr	4-May
DWB	1st emergence	441	244	342	23-Apr	4-Apr	13-Apr
DWB	1st peak	628	681	654	10-May	6-May	8-May
Headland							
Insect	Insect event	GDD 2010	GDD 2011	GDD 2 yr avg	Calendar date 2010	Calendar date 2011	Calendar date 2 yr avg
CMA	1st emergence	315	955	635	7-Apr	15-May	26-Apr
DWB	1st emergence	245	419	664	1-Apr	5-Apr	3-Apr
DWB	1st peak	674	925	799	8-May	13-May	10-May
Mobile							
Insect	Insect event	GDD 2010	GDD 2011	GDD 2 yr avg	Calendar date 2010	Calendar date 2011	Calendar date 2 yr avg
CMA	1st emergence	733	828	780	10-May	16-May	13-May
DWB	1st emergence	417	659	538	12-Apr	17-Apr	14-Apr
DWB	1st peak	572	828	700	27-Apr	29-Apr	28-Apr

Growing degree day and calendar date for 5 sites over the two year study were noted and averaged (Table 3.2). Base temperatures for the two sentinel insects were determined using the lowest coefficient of variation for each site (Tables 3.6, 3.7). Base temperature of 1.6°C was consistently the lowest predictor for CMA in Auburn and Birmingham. Coefficients varied for all other sites and there was no consistent base temperature for DWB or the CMA in Huntsville, Headland, and Mobile.

First emergence of DWB in both years was earlier in Headland and Birmingham than all other sites (Table 3.3). No single plant correlate was consistent statewide for first emergence; however, Indian hawthorn, daffodil, and daylily were three plants that pinpointed the occurrence. For DWB, the range of first flower to full flower of Indian hawthorn was coincident with five of the ten emergence dates for 3 sites over the two year study (Table 3.3). Huntsville had missing data for Indian hawthorn due to deer damage, no bloom stage was recorded in 2011. Average first emergence of CMA was greatly earlier in Birmingham than all other sites (Table 3.2). Plant correlates included daylily, Indian hawthorn, daffodil, and crapemyrtle. Various stages of Indian hawthorn were the most common phenological indicator, for CMA. Huntsville had missing data due to deer damage, no bloom stage was recorded in 2010.

Table 3.3. DWB first emergence, 2 year average and 2 year date with plant correlate, 5 sites statewide, 2010, 2011

Site	2 year average (2010, 2011)	Plant correlate 2010	Plant correlate 2011
Mobile	April 14 (April 12, April 17)	Full flower indian hawthorn	Daylily bud tight, upright
Headland	April 3 (April 1, April 5)	1st flower indian hawthorn	Full flower indian hawthorn
Auburn	April 13 (April 23, April 4)	1st flower indian hawthorn	1st flower indian hawthorn
Birmingham	April 4 (April 7, April 1)	Daffodil tight, upright	Daffodil tight, upright
Huntsville	April 28 (April 23, May 5)	Daylily Shepherd's crook	N/A

Table 3.4. CMA first emergence, 2 year average and 2 year date with plant correlate, 5 sites statewide, 2010, 2011

Site	2 year average (2010, 2011)	Plant correlate 2010	Plant correlate 2011
Mobile	May 13 (May 10, May 16)	Bud tight, daylily	1st flower crapemyrtle
Headland	April 26 (April 7, May 15)	First flower indian hawthorn	Full flower daylily
Auburn	May 5 (May 29, April 12)	Full flower daylily	Full flower indian hawthorn
Birmingham	April 14 (April 20, April 8)	Full flower daffodil	1st flower indian hawthorn
Huntsville	April 29 (April 7, April 11)	N/A	Daffodil tight, upright

Auburn temperature averages

Mean monthly temperatures in Auburn were recorded from January to October in both years of the study. January to March 2010 was much cooler than the 30-year average. Most phenological events occurred earlier in 2010 than 2011, probably due to the unseasonably warmer temperatures in February 2010.

Table 3.5. Mean monthly temperatures for monitoring period 2010-2011 & 30-year average for Auburn, AL

	2010	2011	*30-yr avg.
Month	°F (°C)	°F (°C)	°F (°C)
Jan.	39.2 (4)	42.8 (6)	44.7 (7.1)
Feb.	42.8 (6)	51.8 (11)	48.4 (9.1)
March	51.8 (11)	59 (15)	55.8 (13.2)
Apr.	66.2 (19)	66.2 (19)	62.5 (17)
May	75.5 (23)	72.2 (22)	70.6 (21.4)
June	82.4 (28)	83.7 (28)	77.2 (25.1)
July	84.2 (29)	83.1 (28)	79.9 (26.9)
Aug.	86 (30)	83.3 (29)	79.9 (26.6)
Sept.	80.6 (27)	72.5 (23)	74.7 (23.7)
Oct.	67.5 (20)	60.9 (16)	64.5 (18.1)

*30-yr avg. data from National Climatic Data Center.

Table 3.6. Comparison of degree-day requirements for first capture of CMA in five sites in Alabama; calculated from Jan 1 using eight potential base temperatures

		Base temperature (°C)							
Year	Date	0	1.6	2	4	6	8	10	12.7
		Mobile							
2010	10 May	1820	1630	1583	1351	1128	920	733	516
2011	16 May	2309	2101	2051	1802	1566	1342	1132	876
CV		16.78	17.85	18.21	20.23	22.99	26.38	30.26	36.57
		Headland							
2010	7 Apr	1057	916	881	712	554	421	315	211
2011	15 May	2094	1889	1839	1594	1363	1147	947	708
CV		46.54	49.06	49.81	54.09	59.68	65.48	70.82	76.48
		Auburn							
2010	29 May	2021	1816	1767	1525	1298	1093	912	702
2011	12 Apr	1545	1374	1333	1132	944	771	616	441
CV		18.88	19.60	19.80	20.92	22.33	24.43	27.40	32.29
		Birmingham							
2010	7 Apr	824	710	683	559	453	363	290	216
2011	1 Apr	902	784	756	621	499	391	298	200
CV		6.39	7.00	7.17	7.43	6.83	5.25	1.92	5.44
		Huntsville							
2010	7 May	982	854	824	683	559	454	367	280
2011	21 Apr	1172	1023	987	816	662	530	416	287
CV		12.47	12.73	12.73	12.55	11.93	10.92	8.85	1.75

Table 3.7. Comparison of degree-day requirements for first capture of DWB in five sites in Alabama; calculated from Jan 1 using eight potential base temperatures

		Base temperature (°C)							
Year	Date	0	1.6	2	4	6	8	10	12.7
		Mobile							
2010	12 Apr	1225	1080	1044	868	701	549	417	274
2011	17 Apr	1547	1386	1346	1156	977	811	659	477
CV		16.43	17.54	17.87	20.12	23.26	27.24	31.81	38.23
		Headland							
2010	1 Apr	927	785	763	605	460	339	245	155
2011	5 Apr	1131	997	964	807	664	534	419	287
CV		14.02	16.82	16.46	20.32	25.67	31.59	37.06	42.23
		Auburn							
2010	24 Apr	1213	1051	1029	858	701	565	453	333
2011	4 Apr	1057	926	894	742	603	477	368	248
CV		9.72	*8.94	9.93	10.25	10.63	11.94	14.64	20.69
		Birmingham							
2010	20 Apr	1055	921	889	739	608	494	399	298
2011	8 Apr	1016	888	857	709	574	454	351	241
CV		2.66	*2.57	2.59	2.93	4.07	5.97	9.05	14.96
		Huntsville							
2010	3 May	1209	1062	1027	862	715	586	478	362
2011	23 Apr	1196	1045	1009	836	680	546	430	298
CV		0.76	1.14	1.25	2.17	3.55	5.00	7.48	13.71

*Denotes base temperature with the lowest Coefficient of Variation

Auburn biological calendar

Phenophases of 15 landscape ornamental plants were correlated with pest activity of nine ornamental landscape plant pests, and data were organized into a biological calendar for each site (Tables 3.7 – 3.11). Phenological events for plants and insect pests in both years are presented and organized by the 2 year average for each event (Mussey and Potter, 1997). Notable plant events such as first flower can be associated with key insect activities like first appearance to more accurately time control measures. Important life stages of the additional 8 pests that were monitored in the Auburn phenology garden are also included in the calendar (Table 3.9). First emergence of lesser canna leafroller was observed and recorded in 2010 but no moths were captured in 2011. First emergence of fall armyworm, black cutworm, lesser peachtree borer, oak clearwing borer, and Japanese beetle was monitored in 2010 and 2011. Bagworms were also collected and monitored in both years but no emergence was detected. The unseasonably cold temperatures of the 2010 winter killed the overwintering population of Florida wax scale on Foster's #2 hollies in the garden. A biological calendar was created for the Auburn phenology garden (Table 3.9), which states average dates of plant and insect phenological events for 2010 and 2011 and each year independently.

Table 3.8. Biological calendar for Huntsville, AL, 2010-2011

Plant/Insect	Phenological Event	2010	2011	2 year
		Average	Average	Average
Daffodil	Bud tight, upright	22-Mar	1-Mar	11-Mar
Forsythia	1st flower	29-Mar	25-Feb	13-Mar
Daffodil	Shepherd's crook	29-Mar	3-Mar	16-Mar
Forsythia	50% flower	2-Apr	28-Feb	16-Mar
Loropetulum	1st flower	31-Mar	1-Mar	16-Mar
Daffodil	1st petal open	1-Apr	7-Mar	19-Mar
Loropetulum	Full flower	9-Apr	2-Mar	21-Mar
Yoshino Cherry	1st flower	29-Mar	14-Mar	22-Mar
Daffodil	Full flower	2-Apr	14-Mar	23-Mar

Yoshino Cherry	50% flower	31-Mar	17-Mar	24-Mar
Yoshino Cherry	Full flower	3-Apr	21-Mar	28-Mar
Dogwood borer	1st emergence	3-May	23-Apr	28-Apr
Crapemyrtle aphid	1st emergence	7-May	21-Apr	29-Apr
Daylily	Bud tight, upright	13-May	3-May	8-May
Daylily	Shepherd's crook	20-May	11-May	15-May
Daylily	1st petal open	26-May	16-May	21-May
Daylily	Full flower	4-Jun	21-May	28-May
Crape myrtle	1st flower	12-Jun	28-May	4-Jun
Goldenrod	1st flower	23-Jun	25-June	24-Jun
Sunflower	1st flower	25-Jul	8-Jun	24-Jun
Sunflower	Full flower	26-Jul	11-Jun	3-Jul
Liriope	1st flower	18-Jul	10-Sep	14-Aug
Liriope	Full flower	29-Jul	N/A	N/A

Table 3.9. Biological calendar for Birmingham, AL, 2010-2011

Plant/Insect	Phenological Event	2010	2011	2 year
		Average	Average	Average
Forsythia	1st flower	N/A	26-Feb	N/A
Forsythia	50% flower	N/A	5-Mar	N/A
Yoshino Cherry	1st flower	N/A	18-Mar	N/A
Yoshino Cherry	50% flower	N/A	21-Mar	N/A
Goldenrod	1st flower	N/A	21-May	N/A
Goldenrod	Full flower	N/A	28-May	N/A
Loropetulum	1st flower	2-Apr	27-Feb	16-Mar
Daffodil	Bud tight, upright	4-Apr	2-Mar	18-Mar
Daffodil	Shepherd's crook	9-Apr	6-Mar	23-Mar
Forsythia	Full flower	1-Apr	18-Mar	25-Mar
Daffodil	1st petal open	13-Apr	11-Mar	27-Mar
Yoshino Cherry	Full flower	1-Apr	25-Mar	28-Mar
Loropetulum	Full flower	9-Apr	21-Mar	30-Mar
Daffodil	Full flower	16-Apr	17-Mar	1-Apr
Indian Hawthorn	1st flower	23-Apr	6-Apr	4-Apr
Crapemyrtle aphid	1st emergence	7-Apr	1-Apr	4-Apr
Dogwood borer	1st emergence	20-Apr	8-Apr	14-Apr
Indian Hawthorn	50% flower	26-Apr	10-Apr	18-Apr
Indian Hawthorn	Full flower	30-Apr	16-Apr	23-Apr
Hydrangea	1st flower	1-May	19-Apr	25-Apr
Daylily	Bud tight, upright	4-May	27-Apr	30-Apr
Hydrangea	50% flower	12-May	27-Apr	4-May
Daylily	Shepherd's crook	12-May	2-May	8-May
Dogwood borer	1st peak	15-May	5-May	10-May

Hydrangea	Full flower	25-May	2-May	13-May
Daylily	1st petal open	18-May	9-May	13-May
Daylily	Full flower	24-May	12-May	18-May
Crapemyrtle aphid	1st peak	8-Apr	1-Jul	21-May
Crape Myrtle	1st flower	28-May	22-May	25-May
Crape Myrtle	Full flower	22-Jun	4-Jun	13-Jun
Sunflower	1st flower	4-Jul	10-Jun	22-Jun
Clethra	1st flower	25-Jun	3-Jul	29-Jun
Clethra	Full flower	10-Jul	14-Jul	12-Jul
Goldlace	Full flower	8-Aug	29-Jun	19-Jul
Liriope	1st flower	6-Aug	11-Jul	25-Jul
Liriope	Full flower	11-Aug	18-Jul	29-Jul

Table 3.10. Biological calendar for Auburn, AL, 2010-2011

Plant/Insect	Phenological Event	2010	2011	2 year
		Average	Average	Average
Eastern tent caterpillar	1st emergence	8-Mar	24-Feb	2-Mar
Forsythia	1st flower	11-Mar	22-Feb	2-Mar
Forsythia	50% flower	14-Mar	25-Feb	5-Mar
Forsythia	Full flower	18-Mar	28-Feb	9-Mar
Loropetulum	1st flower	19-Mar	3-Mar	11-Mar
Daffodil	Bud tight, upright	21-Mar	4-Mar	12-Mar
Daffodil	Shepherd's crook	25-Mar	7-Mar	16-Mar
Daffodil	1st petal open	26-Mar	9-Mar	17-Mar
Daffodil	Full flower	29-Mar	10-Mar	19-Mar
Loropetulum	Full flower	29-Mar	10-Mar	19-Mar
Yoshino Cherry	1st flower	24-Mar	17-Mar	20-Mar
Yoshino Cherry	50% flower	26-Mar	20-Mar	23-Mar
Yoshino Cherry	Full flower	29-Mar	23-Mar	26-Mar
Black cutworm	1st emergence	10-Apr	14-Mar	27-Mar
Lesser canna leafroller	1st emergence	7-Apr	N/A	N/A
Fall armyworm	1st emergence	16-Apr	18-Mar	1-Apr
Indian Hawthorn	1st flower	15-Apr	1-Apr	8-Apr
Indian Hawthorn	50% flower	18-Apr	5-Apr	11-Apr
Dogwood borer	1st emergence	23-Apr	4-Apr	13-Apr
Indian Hawthorn	Full flower	21-Apr	8-Apr	14-Apr
Oakleaf hydrangea	1st flower	4-May	21-Apr	27-Apr
Hydrangea	50% flower	9-May	25-Apr	2-May
Hydrangea	Full flower	12-May	27-Apr	4-May
Crapemyrtle aphid	1st emergence	29-May	12-Apr	5-May
Daylily	Bud tight, upright	12-May	5-May	8-May

Dogwood borer	1st peak	10-May	6-May	8-May
Oak clearwing borer	1st emergence	14-May	11-May	12-May
Daylily	Shepherd's crook	21-May	8-May	14-May
Daylily	1st petal open	24-May	10-May	17-May
Lesser peachtree borer	1st emergence	11-May	23-May	17-May
Daylily	Full flower	27-May	12-May	19-May
Japanese beetle	1st emergence	24-May	18-May	21-May
Crapemyrtle	1st flower	31-May	23-May	27-May
Crapemyrtle aphid	1st peak	6-Jun	17-May	27-May
Crapemyrtle	Full flower	19-Jun	2-Jun	10-Jun
Goldenrod	1st flower	28-May	4-Jul	15-Jun
Goldenrod	Full flower	22-Jun	22-Jun	22-Jun
Clethra	1st flower	28-Jun	7-Jul	1-Jul
Sunflower	1st flower	26-Jun	12-Jul	5-Jul
Liriope	1st flower	N/A	7-Jul	N/A
Goldlace Sunflower	Full flower	5-Jul	19-Jul	12-Jul
Clethra	Full flower	6-Jul	16-Jul	18-Jul
Liriope	Full flower	N/A	14-Jul	N/A

Table 3.11. Biological calendar for Headland, AL, 2010-2011

Plant/Insect	Phenological Event	2010	2011	2 year
		Average	Average	Average
Loropetulum	1st flower	28-Feb	24-Feb	26-Feb
Daffodil	Bud tight, upright	3-Mar	26-Feb	28-Feb
Daffodil	Shepherd's crook	7-Mar	1-Mar	3-Mar
Loropetulum	Full flower	8-Mar	2-Mar	5-Mar
Daffodil	1st petal open	12-Mar	3-Mar	7-Mar
Forsythia	1st flower	23-Mar	21-Feb	8-Mar
Daffodil	Full flower	19-Mar	6-Mar	13-Mar
Forsythia	50% flower	25-Mar	1-Mar	13-Mar
Forsythia	Full flower	1-Apr	4-Mar	17-Mar
Yoshino Cherry	First flower	23-Mar	18-Mar	20-Mar
Yoshino Cherry	50% flower	27-Mar	20-Mar	23-Mar
Yoshino Cherry	Full flower	1-Apr	24-Mar	28-Mar
Indian Hawthorn	1st flower	12-Apr	24-Mar	2-Apr
Dogwood borer	1st emergence	1-Apr	5-Apr	3-Apr
Indian Hawthorn	50% flower	16-Apr	26-Mar	5-Apr
Indian Hawthorn	Full flower	23-Apr	28-Mar	10-Apr
Indian Hawthorn	Full flower	21-Apr	8-Apr	14-Apr
Crapemyrtle aphid	1st emergence	7-Apr	15-May	26-Apr
Daylily	Bud tight, upright	5-May	24-Apr	29-Apr

Daylily	Shepherd's crook	8-May	28-Apr	3-May
Daylily	1st petal open	12-May	2-May	7-May
Dogwood borer	1st emergence	8-May	13-May	10-May
Daylily	Full flower	17-May	6-May	11-May
Crapemyrtle	1st flower	24-May	8-May	16-May
Crapemyrtle	Full flower	2-Jun	26-May	29-May
Crapemyrtle aphid	1st peak	7-May	21-Jul	13-Jun
Liriope	1st flower	18-Jul	24-Jun	6-Jul
Liriope	Full flower	29-Jul	12-Jul	20-Jul

Table 3.12. Biological calendar for Mobile, AL, 2010-2011

Plant/Insect	Phenological Event	2010	2011	2 year
		Average	Average	Average
Loropetulum	1st flower	23-Feb	2-Mar	26-Feb
Daffodil	Bud tight, upright	9-Mar	1-Mar	5-Mar
Forsythia	1st flower	9-Mar	2-Mar	5-Mar
Daffodil	Shepherd's crook	14-Mar	3-Mar	8-Mar
Daffodil	1st petal open	17-Mar	6-Mar	11-Mar
Forsythia	1st flower	23-Mar	21-Feb	8-Mar
Daffodil	Full flower	23-Mar	9-Mar	16-Mar
Loropetulum	Full flower	2-Apr	4-Mar	18-Mar
Yoshino Cherry	First flower	25-Mar	16-Mar	20-Mar
Forsythia	Full flower	22-Mar	12-Mar	22-Mar
Yoshino Cherry	50% flower	29-Mar	21-Mar	25-Mar
Yoshino Cherry	Full flower	22-Apr	25-Mar	29-Mar
Indian Hawthorn	First flower	6-Apr	23-Mar	30-Mar
Indian Hawthorn	50% flower	9-Apr	25-Mar	4-Apr
Indian Hawthorn	Full flower	15-Apr	28-Mar	6-Apr
Dogwood borer	1st emergence	12-Apr	17-Apr	14-Apr
Hydrandea	1st flower	28-Apr	11-Apr	19-Apr
Hydrandea	50% flower	1-May	16-Apr	23-Apr
Daylily	Bud tight, upright	5-May	22-Apr	28-Apr
Dogwood borer	1st emergence	27-Apr	29-Apr	28-Apr
Hydrangea	Full flower	9-May	22-Apr	30-Apr
Daylily	1st petal open	12-May	2-May	7-May
Dogwood borer	1st peak	8-May	13-May	10-May
Daylily	Full flower	17-May	6-May	11-May
Crapemyrtle aphid	1st emergence	10-May	16-May	13-May
Crapemyrtle	1st flower	24-May	8-May	16-May
Crapemyrtle	Full flower	2-Jun	26-May	29-May
Crapemyrtle aphid	1st peak	7-May	21-Jul	13-Jun

Liriope	1st flower	12-Aug	10-Jul	26-Jul
Liriope	Full flower	23-Aug	23-Jul	7-Aug

Discussion

The sequence of phenophases to pests was not consistent statewide. However, the order in which plants flowered maintained a consistent pattern from Mobile to Huntsville. No common plant phenological indicator was correlated with pest activity from location to location. In further studies, perhaps recommendations could be based on regional phenophases or possibly categorized by USDA Hardiness Zone. Sequence of plants from location to location and year to year showed significant consistencies according to Spearman's bivariate correlation and regression analysis, (Chapter 2) similar to Kulhanek (2009), which had significant correlation from year to year for all phenological sequences and location to location.

Some of the sequences of plants flowering to pests emerging from year-to-year in the Auburn garden can be extrapolated statewide. Hydrangea data was inadequate in Headland and Huntsville due to plant loss. The pest emergences occurred before first flower of indian hawthorn, with lesser canna leafroller emergence very close to indian hawthorn flower. Additionally, dogwood borer first emergence always preceded crapemyrtle aphid first emergence at each site, statewide. Eastern tent caterpillar emergence was similar to Mussey and Potter (1997), with consistent correlation to first flower to 50% flower of *Forsythia.*

In 2011, additional landscape plants with similar phenophase sequences to the plants in the Auburn Phenology Garden were observed. The similar plants were established in the landscape throughout Auburn, Alabama. Bridal wreath spiraea first flower (*Spiraea prunifolia* Siebold & Zucc.) and flowering dogwood (*Cornus florida)* first flower were consistent with Yoshino cherry (*Prunun* ×yedoensis) first flower. Chinese fringetree (*Chionanthus retusus*) was

consistent with ‘Ellen Tabor’ indian hawthorn (*Raphiolepis indica* Eleanor Tabor™) first flower. Glossy abelia (*Abelia* x grandiflora) was consistent with 50% flower of ‘Ellen Tabor’ indian hawthorn (*Raphiolepis indica* Eleanor Tabor™) indian hawthorn. Southern catalpa (*Catalpa* bignonioides) first flower was coincident with dogwood borer first peak.

Chapter IV

FINAL CONCLUSIONS

Phenological data provide a practical method for predicting pest control measures, and many biological calendars have been produced from the sequences, (Mussey and Potter 1997, Herms 2004) including the Auburn University Phenology Network website. The Auburn study compiles data collected from five garden sites, while some of the aforementioned studies typically use data from one location. Few inconsistencies existed in the flower sequences from year-to-year and location-to-location.

When considering the consistency of phenological indicators, a number of environmental factors can play a role in plant and insect development (Orton 1989, Mussey and Potter 1997, Herms 2004). One factor to consider when comparing statewide plant correlates in regard to climate is the geographic variation from Mobile to Huntsville. Mobile and Headland tend to be more temperate than north Alabama field sites, or what is often referred to as a Maritime Climate. Characteristics of this factor may include warmer winters, warmer periods during flower and development, more annual rainfall, more constant cloud cover, lower radiation intensity, lower rate of evapotranspiration, and less weather variation from year to year. This in essence provides a more diffuse life cycle (Orton 1989). Auburn, Birmingham, and Huntsville tend to be more moderate in climate with characteristics of a Continental Climate like colder winters, warmer temperatures during flower and development, less annual rainfall, less constant cloud cover, higher radiation intensity, higher rates of evapotranspiration, and more variation in

weather from year to year. These factors therefore provide more brief and variable life cycles (Orton 1989). As previously mentioned plant and insect development can also be influenced by soil moisture and temperature, plant fertility, photoperiod, and atmospheric composition (Broome 2011) (as well as elevation and wind influence influencing plant development) (Orton 1989). Additionally, plants' response to environmental influences may also affect the accuracy of regional recommendations for pest predicitons (Mussey and Potter 1997).

Master Gardener participation varied over the two years of the study. For example, the Master Gardener that recorded data on Monday may have been a different Master Gardener than showed up on Wednesday, possibly leading to some variation due their interpretation of in flower stage (Kulhanek 2009). Plants in Auburn and Headland progressed faster from first flower to full flower. This is probably due to the fact that one person monitored phases at each of these gardens, versus multiple participants at the other three garden sites. Phenology gardens worldwide have reported similar fluctuations in data due to variations in volunteer participation and lack of adequate data due to issues such as plant death (Kulhanek 2009).

Differences in methodology probably give various results among similar studies of Herms (2004) and Mussey and Potter (1997). For example, differences in biofix and base temperatures among each of the 3 studies produces different growing degree day accumulations. Much of the variability among data collection can be attributed to the number of personnel collecting data. Two-year averages are more closely matched with each individual site with less people recording data.

In order to implement necessary control of key landscape pests using phenology and growing degree days, knowledge of the life history and biology of the pest will be important. Being able to pinpoint vulnerable life stages will help in phenology application for control

measures. Scouting and inspection is the first step to maintaining pest free landscapes.

Phenology is a simpler indicator for tracking ornamental pests than growing degree days. When available, plant phenophases are more reliable and easier to evaluate with pest stages. Mussey and Potter 1997, Herms 2004, and Kulhanek 2009 have shown comparable results in similar phenology garden studies. At least one year of additional data is needed to be able to obtain phenology data over a broad range of climatically different years.

Literature Cited

Allen, J.C., 1976. A modified sine wave method for calculating degree days. Environ. Ent. 5, 388-396.

Alverson, D.R. and R. K. Allen. 1991. Life history of the crapemyrlte aphid. Proc. Southern Nurseryman's Association. 36: 164-167.

Alverson, D.R. and R. Allen. 1992. Bionomics of the crapemyrtle aphid (Homoptera: Aphididae). Journal of Entomological Science. 27:445-457.

Arnold, C.Y. 1959. The determination and significance of the base temperature in a linear heat unit system. Proc. American Socicety of Horticultural Science. 74: 430-445.

Bakersville, G.L. and P. Emin. 1968. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50(3): 514-517.

Bergh, J.C. and T.C. Leskey. 2003. Biology, ecology, and management of dogwood borer in eastern apple orchards. Canadian Entomologist. 135: 615–635.

Bergh, J.C., T.C. Leskey, J.F. Walgenback, W.E. Klingeman, D.P. Kain, and A. Zhan. 2009. Dogwood borer (Lepidoptera: Sesiidae) abundance and seasonal flight activity in apple orchards, urban landscapes, and woodlands in five eastern states. Environmental Entomology. 38(3): 530-538.

Bonhomme, R. 2000. Bases and limits of using 'degree-day' units. Eur. Journal of Agronomy. 13: 1-10.

Broome, S. 2011. Fertilizers and Soil Fertility. (http://www.soil.ncsu.edu/lockers/Broome_S/ssc051/Lec3.htm)

Bruns, E., Chmielewski, F.M., and J.H. vanVliet, 2003. The Global Phenologicical monitoring concept towards international standardization of phenological networks. Phenology: An Environmental Science. 2.

Chen, X. 2003. East Asia, pp. 11-25. In: M.D. Schwartz (ed.), Phenology: an integrative tauenvironmental science. Kluwer Academic Publ., Dordrecht, The Netherlands.

Chmielewski, F.M. 2008. The international phenological gardens in Europe. In: J. Nekorvář, E.Koch, E. Kubin, P. Nejedlik, T. Sparks, and F. Wielgolaski (eds.), COST Action 725-the history and current status of plant phenology in Europe.Vammalan Kirjapaino Oy, Finland. pp. 17-21.

Chuine, I., Kramer, K., and H. Hannonen. 2003. Plant development model, pp. 217-235. In: M.D. Schwartz (ed.), Phenology: An Integrative Environmental Science. Kluwer Academic Publ. Dordrecht, The Netherlands.

Davidson, J.A., S.A. Gill, and M.J. Raupp. 1992. Controlling clearwing moths with entomopathogenic nematodes: The dogwood borer case study. Journal of Arboriculture. 18(2).

Delahaut, K. 2010. Insects. In: M.D. Schwarts (ed.) *Phenology: An Integrated Environmental Science*. pp. 405-420. Kluwer, Boston, MA.

Dirr, M. 1998. Manual of Woody and Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation, and Uses. Stipes Publishing Co. Champaign, IL.

Drooz, A.T. (Editor). 1985. Insects of Eastern Forests. Misc. Pub. No. 1426. U.S. Gov. Printing Office, Washington, D.C. 20402, 608 pp.

Eliason, E.A. and D.A. Potter. 2000. Dogwood borer (Lepidoptera: Sesiidae) infestation of horned oak galls. Journal of Econoic Entomology. 93:757–762.

Ferro, D.N., R.B. Chapman, and D.R. Penman. 1979. Observations on insect microclimate and insect pest management. Environmental Entomology. 8:1000-1003.

Gardiner, L. 2009. What is Phenology. From: Window to the Universe: (http://www.neoninc.org/budburst/phenology_history.php).

Gyelthsen, J. and A. Hodges, 2006. Featured Creatures: Dogwood borer. (http://entomology.ifas.ufl.edu/creatures/trees/moths/dogwood_borer.htm).

Heppner, J.B. 1987. Sesiidae (Sesiidae). pp. 411-414. In: Immature Insects Ed. Frederick W. Stehr. Kendall Hunt Pub. Co., Dubuque, Iowa, 754 pp.

Herms, D.A. 2004. Using degree-days and plant phenology to predict pest activity. In: V. Krischik and J. Davidson, eds. *IPM (Integrated Pest Management) of Midwest Landscapes*, pp. 49-59. Minnesota Agricultural Experiment Station Publication SB-07645, 316 pp.

Higley, L.G., Pedigo, L.P., and K.R. Ostlie. 1986. DEGDAY: A Program for Calculating Degree days, and Assumptions Behind the Degree-day approach. Environmental Entomology 15: 999-1016.

Hodges, A.W., Hall, C.R., and M.A. Palma, 2011. Economic Contributions of the Green Industry in the Unites States, 2007. *Southern Cooperative Series Bulletin.*

Hodges, G.S. and S.K. Braman. 2004. Seasonal occurrence, phenological indicators, and mortality factors affecting five scale insect species (Hemiptera: Diaspididae, Coccidae) in the urban landscape setting. Journal of Entomological Science. 39: 584-597.

Hong, S.C. and R.C. Williamson. 2004. Comparison of sticky wing and cone henomena traps for monitoring seasonal abundance of black cutworm adults and larvae on golf courses. Journal of Economic Entomology. 97(5): 1666-1670.

Hoover, G. 2002. Collaborative for integrated pest management. Tree Care Ind. 13: 19–24.

Huberman, M. A. 1941. Why phenology? *Journal of Forestry*. 39:1007-1013.

Hyche, L.L., 1996. The Eastern Tent Caterpillar: A Guide to Recognition and Habits in Alabama. (http://www.ag.auburn.edu/enpl/bulletins/easterntentcaterpillar/easterntentcaterpillar.htm)

Johnson W. and H. Lyon 1991. Insects that Feed on Trees and Shrubs. Comstock Publishing Associates, Cornell University Press, Ithaca and London.

Klein, B. 2002. "Growing Degree Day Calculator" in Spreadsheet downloads for Excel97, AgBioResearch, Michigan State University. **(**http://agbioresearch.msu.edu/nwmihort/excel.html)

Koch, E., Demairée, G., Lipa, W., Zach, S., and K. Zimmermann. 2008. History of international phenology networks, pp. 12-16. In: J. Nekorvář, E. Koch, E. Kubin, P. Nejedlik, T. Sparks, and F. Wielgolaski (eds.), COST Action 725- the history and current status of plant phenology in Europe.Vammalan Kirjapaino Oy, Finland.

Kulhanek, A. 2009. User-Friendly Methods for Timing Integrated Pest Management Strategies: An Analysis of Degree-Day Models and Biological Calendars. MS Thesis Ohio State University.

McAuslane, H.J. 2000. Featured Creatures: Lesser canna leafroller. (http://entomology.ifas.ufl.edu/creatures/orn/L_canna_leaf_roller.htm)

Meier, Uwe. 2003. Phenological growth stages pp. 269-283. *In* M.D. Schwartz (ed), Phenology: An integrated environmental science. Kluwer, Boston.

Mitchell, E.R., J.H. Tumlinson, J.N. Mcneil. 1985. Field Evaluation of Commercial Pheromone Formulation Traps Using a More Effective Sex Pheromone Blend for

Armyworm (Lepidoptera: Noctuidae). Journal of Economic Entomology. 78(6):1364-1369.

Mizell III, R.F. and D.E. Schiffhauer. 2007. Seasonal abundance of the crapemyrtle aphids, *Sarucallis kahawaluokalanii*, in relation to the pecan aphids, *Moniella caryella* and *Monolliopsis pecanis* and their common predators. Entomophaga 32: 511–520.

Mizell III, R.F. and G.W. Knox. 1993. Susceptibility of crapemyrtle, *Lagerstroemia indica* L., to the crapemyrtle aphids (Homoptera: Aphididae) in North Florida. Journal of Entomological Science 28: 1-7.

Mussey, G.J. and D.A. Potter. 1997. Phenological correlations between flowering plants and activity of urban landscape pests in Kentucky. Journal of Economic Entomology. 90:1615–1627.

Nagoshi, R.N. and R.L. Maegher. 2004. Behavior and distribution of the two fall armyworm host strains in Florida. Florida Entomologist. 87: 440-449.

NGA[National Gardening Association]. 2006. (www.garden.org).

Neal, J.W. and T.D. Eichlin. 1983. Seasonal response of six male Sesiidae of woody ornamentals to clearwing borer (Lepidoptera: Sesiidae) lure. Environmental Entomology. 12: 206-209.

Oetting, R., Hudson, W. and Braman, K. 2004. Summary of losses from insect damage and costs of control in Georgia/2004. Ornamental, Lawn, and Turf Insects (http://wiki.bugwood.org/Summary_of_Losses_from_Insect_Damage_and_Costs_of_Control_in_Georgia/2004)

Ong, K. 2010. Powdery Mildew on Crape Myrtles. (http://www.crapemyrtletrails.org/pest).

Orton, D. 1989. Coincide: The Orton System of Pest Management. Plantsmen's Publishing.

Pedigo, L. & L. Rice. 2009. Entomology and Pest Management. Pearson, Prentice Hall.

Potter, D.A. and G.M. Timmons. 1981. Flight phenology of the Dogwood Borer (Lepidoptera: Sesiidae) and Implications for Control in *Cornus florida* L. Journal of Economic Entomology. 76: 1069-1074.

Potter, D.A. and G.M. Timmons. 1983. Forecasting Emergence and Flight of the Lilac Borer (Lepidoptera: Sesiidae) Based on Pheromone Trapping and Degree-Day Accumulations. Environmental Entomology. 12: 400-403.

Potter, D.A. and D.W. Held. 2002. Biology and management of the Japanese Beetle. Annual Review of Entomology. 47:175-205.

Potter, D.A., L. Foss, R.E. Baumler, and D.W. Held. 2005. Managing Eastern tent caterpillars *Malacosoma americanum* (F) on horse farms to reduce risk of mare reproductive loss syndrome. Pest Management Science. 61:3-15.

Purrington, F.F., and D.G. Nielsen. 1977. Biology of *Podosesia* (Lepidoptera: Sesiidae) with description of a new species from North America. Annals of Entomological Society of America. 70: 906-910.

Raupp, M.J., J.A. Davidson, C.S. Koehler, C.S. Sadof, and K. Reichelderfer. 1988. Decision-making considerations for aesthetic damage caused by pests. Bulletin of Entomological Society of America. 34: 27–32.

Raupp, M.J., P.M. Shrewsbury, J.J. Holmes, and J.A. Davidson. 2001. Plant species diversity and abundance affects the number of arthropod pests in residential landscapes. Journal of Arboriculture. 27: 221–229.

Reinert, Jim 2009. Personal communication.

Rogers, L.E. and J.F. Grant. 1990. Infestation levels of dogwood borer (Lepidoptera: Sesiidae) larvae on dogwood trees in selected habitats of Tennessee. Journal of Entomological Science. 25(3): 481-485.

Rogers, L.E. and J.F. Grant. 1991. Seasonal incidence of male dogwood borer (Lepidoptera: Sesiidae) and other species of clearwing moths in selected habits in Tennessee. *Environmental Entomology* 20: 520-525. CSA

Schnelle, F. and E. Volkert. 1974. International phenological gardens in Europe the basic network for international phenological observations. Phenology and seasonal monitoring. 383-387. In: H. Leith (ed.), Phenology and seasonal modeling. Springer-Verlag New York, New York.

Schwartz, M.D.(ed). 2010. Phenology: An Integrative Environmental Science. Kluqer Academic Publishers, Dordrecht, The Netherlands.

Schlar, C. and Jackie Bergquist, unpublished data. 2006. Advanced Monitoring: Methods Used to Predict Pests.

Sharp, J.L., J.R. McLaughlin, J. James, T.D. Eichlin, and J.H. Tumlinson. 1978. Seasonal occurrence of male Sesiidae in north central Florida determined with pheromone trapping methods. Florida Entomologist. 61(4): 245-250.

Sherrod, D.W., J.T. Shaw, and W.H. Luckmann. 1979. Concepts on Black Cutworm Field Biology in Illinois. Environmental Entomology. 8: 191-195.

Showers, W.B., 1997. Migratory ecology of the black cutworm. Annual Review of Entomology. 42: 393-425.

Solomon, J.D., F.L. Anderson, R.L. Lewis, Jr., F.L. Olivera, T.H. Filer, P.J. Barry, 1987. Oak Pests: A Guide to Major Insects, Diseases, Air Pollution, and Chemical Injury.

Protection Report R8-PR7. USDA Forest Service, Southern Forest Experiment Station. 69 p.

Solomon, J.D. 1995. Guide to insect borers in North American broadleaf trees and shrubs. U.S. Department of Agriculture Forestry Service Handbook AH-706. 735 pp.

Sparks, A.N., 1979. A Review of the biology of the fall armyworm. The Florida Entomologist. 62(2): 82-86.

Statistix, 2009.

Stinner, R.E., G.D. Butler, Jr., J.S. Bacheler, and C. Tuttle, 1974. Simulation of temperature-dependant development in population dynamics models. Canadian Entomologist. 107: 1164-1174.

Stewart, C.D., K.S. Braman, B.L. Sparks, J.L. Williams-Woodward, G.L. Wade, and J.G. Latimer. 2002. Comparing an IPM Pilot Program to a Traditional Cover Spray Program in Commercial Landscapes. Economic Entomology. 95(4): 789-796.

Suchanic, D.J. and E. Vorodi. 1993. Is there a better way to predict ornamental insect problems. Regulatory Hort. 19:8-12.

Taft, W., D. Smitley, and J. Snow. 2004. A guide to Clearwing Borers (Sesiidae) of the North Central United States.

United States National Arboretum. 2012. USDA Hardiness Zone Map. http://www.usna.usda.gov/Hardzone/ushzmap.html

van Vliet, A.J.H., R.S. de Groot, Y. Bellens, P. Braun, R. Bruegger, E. Bruns, J. Clevers, C.Estreguill, M. Flechsig, F. Jeanneret, M. Maggi, P. Martens, B. Menne, A. Menzel, T. Sparks. 2003. The European phenology network. International Journal of Biometeorology. 47: 202-212.

Welty, C. 2000. Lesser Peachtree Borer. Ohio State University Extension Fact Sheet. (http://ohioline.osu.edu/hyg-fact/2000/2033.html).

Westcott, C. 1946. The Gardener's Bug Book: 1,000 Insect Pests and their Control. The American Garden Guild, Inc., New York, NY. 158, 173, 350.

Yonce, C.E. C.R. Gentry, J.H. Tumlinson, R.E. Doolittle, and J.R. McLaughlin. 1977. Seasonal distribution of the lesser peachtree borer in central Georgia as monitored by pupal skin counts and pheromone trapping techniques. Environmental Entomology 6: 203-206.