



LINK BETWEEN LOCAL PHENOLOGY AND CLIMATE CHANGE

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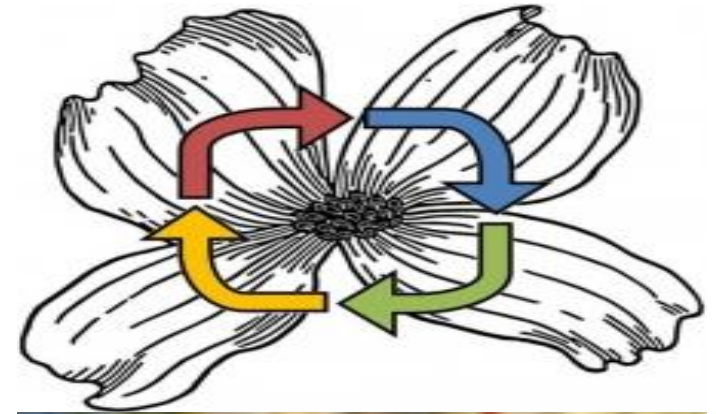
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INTRODUCTION

- Phenology is the study of cyclic and seasonal biological phenomena of plants and animals.
 - 20-1,200 years of data is used to make conclusions in **Europe and Japan** (Menzel *et al.* 2006; Aono and Kazui, 2008; and Primack *et al.* 2009).
- The Southeastern Virginia Phenology Network is a partnership between Old Dominion University (ODU) and Norfolk Botanical Gardens.
 - Started in 2010 with the purpose of assessing phenological change in native plants in respect to climate change.
- **Objectives:**
 1. Determine which plants' phenophases are sensitive to temperature changes.
 2. Show which plants' phenophases are shifting over time as the climate changes.
 3. Interpret the impact of these shifts on the ecosystem, human health, and recreation.



SE Virginia Phenology Network Logo (top) Flowers of Red Maple (*Acer rubrum*, bottom)



MATERIALS AND METHODS: SPECIES SELECTION

- A taxonomically diverse set of 7 native species were chosen:

1. *Acer rubrum* (Red maple), n = 3.
2. *Podophyllum peltatum* (Mayapple), n = 1.
3. *Panicum virgatum* (Switchgrass), n = 1.
4. *Cornus florida* (Flowering dogwood), n = 3.
5. *Cephalanthus accidentalis* (Common buttonbush), n=3.
6. *Vaccinium corymbosum* (Highbush blueberry), n = 3.
7. *Pinus taeda* (Loblolly pine), n = 3.

Location

- All three sites are located in the Norfolk

Botanical Garden:

1. Mirror Lake (36.90° N, 76.21° W),
2. VA Native Garden (36.90° N, 76.20° W),
3. Enchanted Forest (36.91° N, 76.20° W).



MATERIALS AND METHODS: LOCATION

Mirror Lake	1 Red Maple	1 Mayapple	2 Common Buttonbushes	1 Highbush Blueberry	1 Loblolly Pine	2 Flowering Dogwoods
VA Native Garden	1 Red Maple	1 Switchgrass	1 Common Buttonbush	1 Highbush Blueberry	1 Loblolly Pine	X
Enchanted Forest	1 Red Maple	X	X	1 Highbush Blueberry	1 Loblolly Pine	1 Flowering Dogwood
						Total = 16

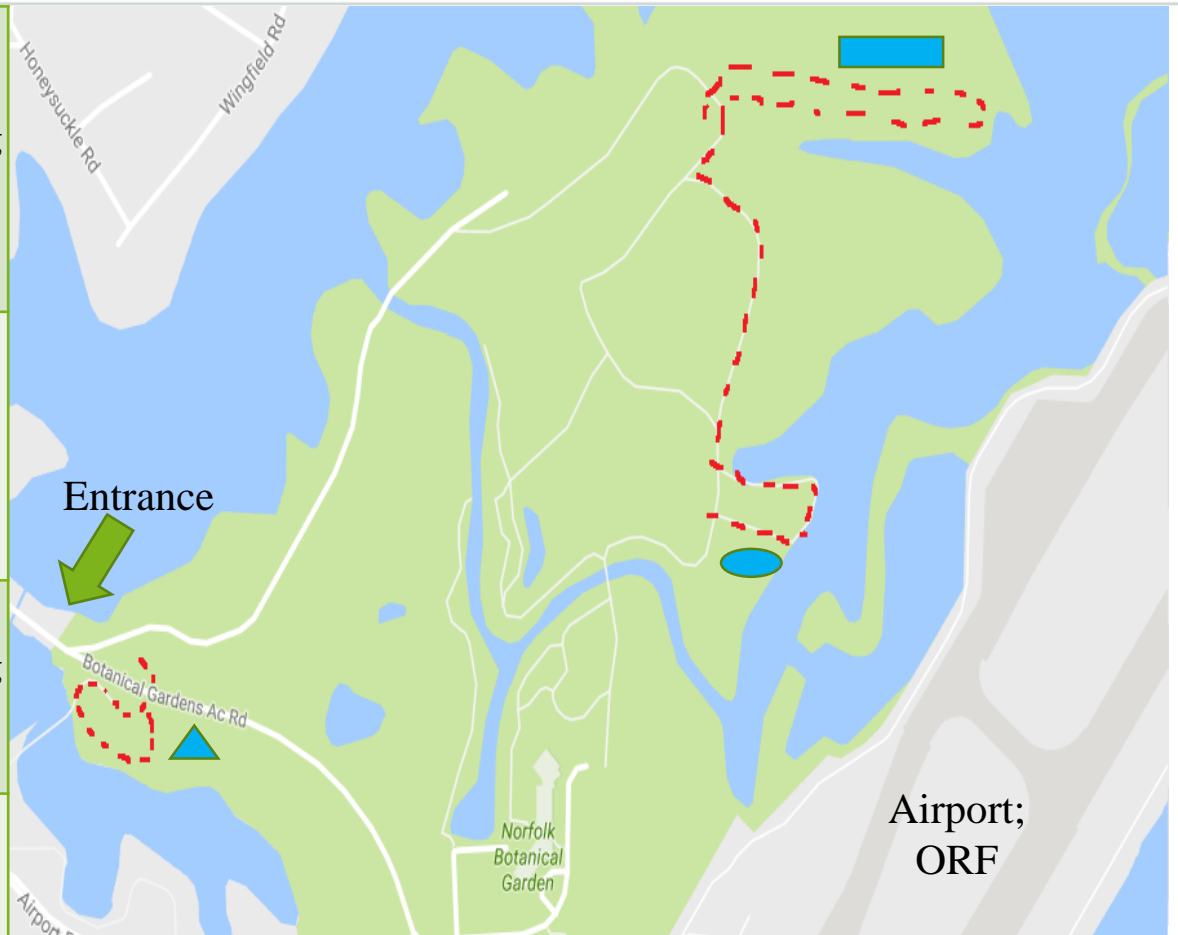


Table and Map of the three study sites with observed individuals in the Norfolk Botanical Garden where triangle = Mirror Lake; Oval = VA Native; and rectangle = Enchanted Forest.

MATERIALS AND METHODS: PHENOPHASE AND TEMPERATURE

SAMPLE DATASHEET

- Adopted the USA National Phenology Network's (USA-NPN) methodology.
- Looked for four phenophases:
 1. First Flowering Date (FFD)
 2. First Leafing Date (FLD)
 3. First Fruiting Date (FFrD)
 4. First Date of Senescence (FDS).
- Used average daily temperature data from NOAA's Norfolk INTL Airport Station (36.90°N, 76.19°W).

	Date:	Date:	Date:	Date:	Date:	Date:	Date:	Date:
Do you see...	Time:	Time:	Time:	Time:	Time:	Time:	Time:	Time:
Breaking leaf buds	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Leaves	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Increasing leaf size	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Colored leaves	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Falling leaves	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Flowers or flower buds	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Open flowers	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Fruits	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Ripe fruits	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Recent fruit or seed drop	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___	y n ? ___
Check when data entered online:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Comments:								



MATERIALS AND METHODS: ANALYSIS

- For sensitivity:
 - Used a 3-mo summed temperature window (threshold = 0°C) from 2009-2016 (Cook *et al.*, 2012).
 - $GDD_{\text{daily}} = \max(T_{\text{mean}} - GDD_{\text{thresh}}, 0)$
 - $GDD_{\text{sum}}(\text{years}) = \sum GDD$
 - These values were standardized.
 - Dates of occurrence was averaged as number of days in the year. (Mazer *et al.*, 2013).
 - If regression was significant ($F < 0.05$), then there is a strong relationship between date of occurrence and growth based on temperature (GDD).
- For determining a phenophase shift:
 - The average temperature for the 3-mo window for each year, respective to each phenophase.
 - If there were multiple individuals, the average date of occurrence was used per year.
 - If phenophase showed a significant ($F < 0.05$) regression over time, then it was concluded that a shift was occurring.
- Univariate and multivariate linear regression in Microsoft Excel (2016) was used for statistical analysis.

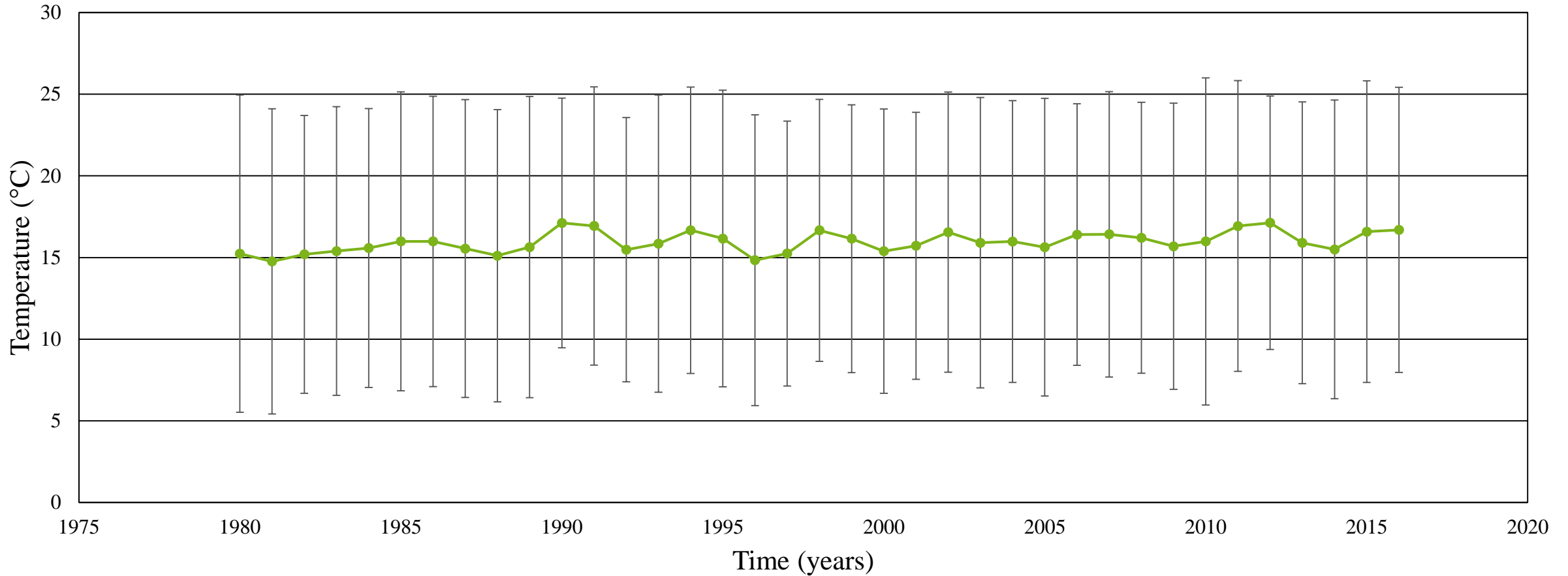


**RESULTS:
SENSITIVITY**










TEMPERATURE RESULTS

ANNUAL AVERAGE TEMPERATURE, ORF



- *This graph displays the annual average temperature for the past 36 years ($F=0.0045$). Specifically, it shows the annual average temperature during the time of this study. In our area, it as been getting warmer with a rate of about $0.0265^{\circ}\text{C}/\text{year}$.*

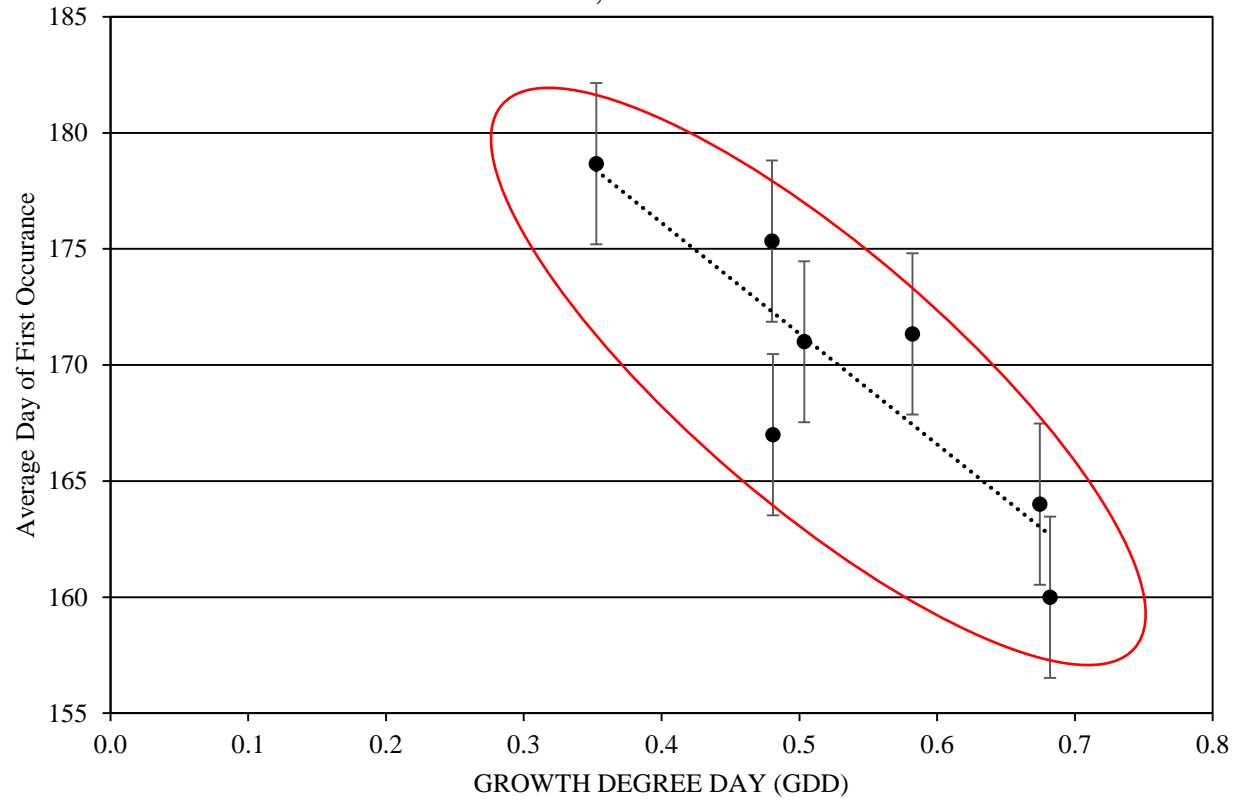
SENSITIVITY RESULTS

Species	N	Phenophase <i>F</i> -value (<i>F</i> <0.05)				Phenophase R ² (SE)			
		FLD	FFD	FFrD	FDS	FLD	FFD	FFrD	FDS
 <i>A. rubrum</i> (Red maple)	3	0.5027	0.4278	0.8085	0.3471	0.0944 (6.843)	0.1295 (8.820)	0.0165 (15.71)	0.1771 (18.87)
 <i>P. peltatum</i> (Mayapple)	1	0.3555	0.4583	0.0056	X	0.1716 (10.50)	0.1143 (7.111)	0.8803 (4.298)	X
 <i>P. virgatum</i> (Switchgrass)	1	0.0901	0.2002	0.0940	X	0.4679 (9.109)	0.3033 (8.088)	0.5446 (8.093)	X
 <i>C. florida</i> (Flowering dogwood)	3	0.2190	0.8015	0.0155	0.0073	0.2831 (8.124)	0.0139 (21.80)	0.8040 (9.801)	0.7911 (7.501)
 <i>C. occidentalis</i> (Common buttonbush)	3	0.4675	0.0107	0.0372	0.0368	0.1099 (11.25)	0.7590 (3.473)	0.7024 (8.069)	0.6152 (14.51)
 <i>V. corymbosum</i> (Highbush blueberry)	3	0.4104	0.0120	0.2444	0.0013	0.1388 (10.89)	0.7478 (5.367)	0.3173 (13.25)	0.8936 (7.116)
		FLD	FPCD	FSCD					
 <i>P. taeda</i> (Loblolly pine)	3	0.0688	0.4465	0.3111	X	0.4197 (12.26)	0.1200 (16.61)	0.3300 (14.16)	X

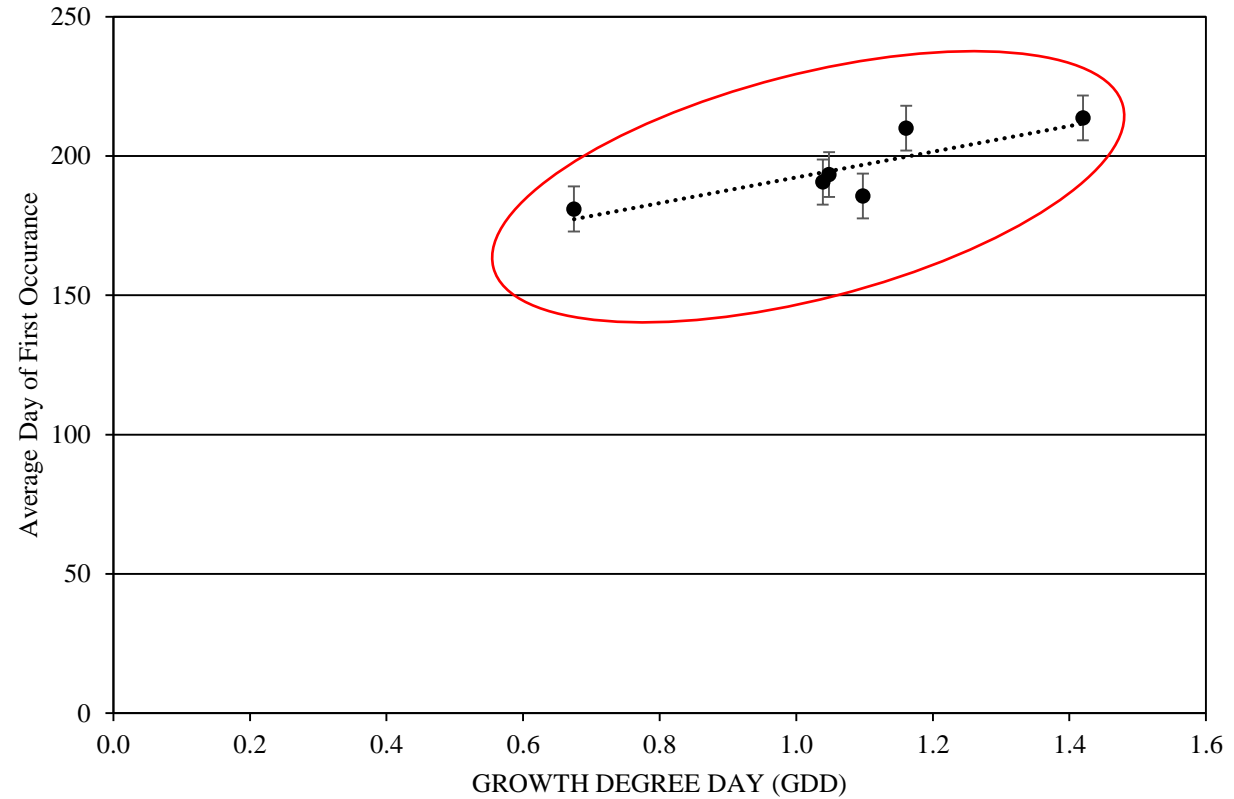
- Results of the sensitivity linear regression tests. Bold-faced species and numbers represent a significant relationship between average date of occurrence and growth degree day (GDD). © from top to bottom: Norfolk Botanical Garden (NBG, Red Maple), Wplynn (Mayapple), Bob Klips (Switchgrass), Larry Korhnak (Flowering Dogwood), NBG (Common Buttonbush), Francis Carpenter (Highbush Blueberry), and University of Texas (Loblolly Pine).

SENSITIVITY RESULTS CONT.

FFD vs GDD; Common Buttonbush



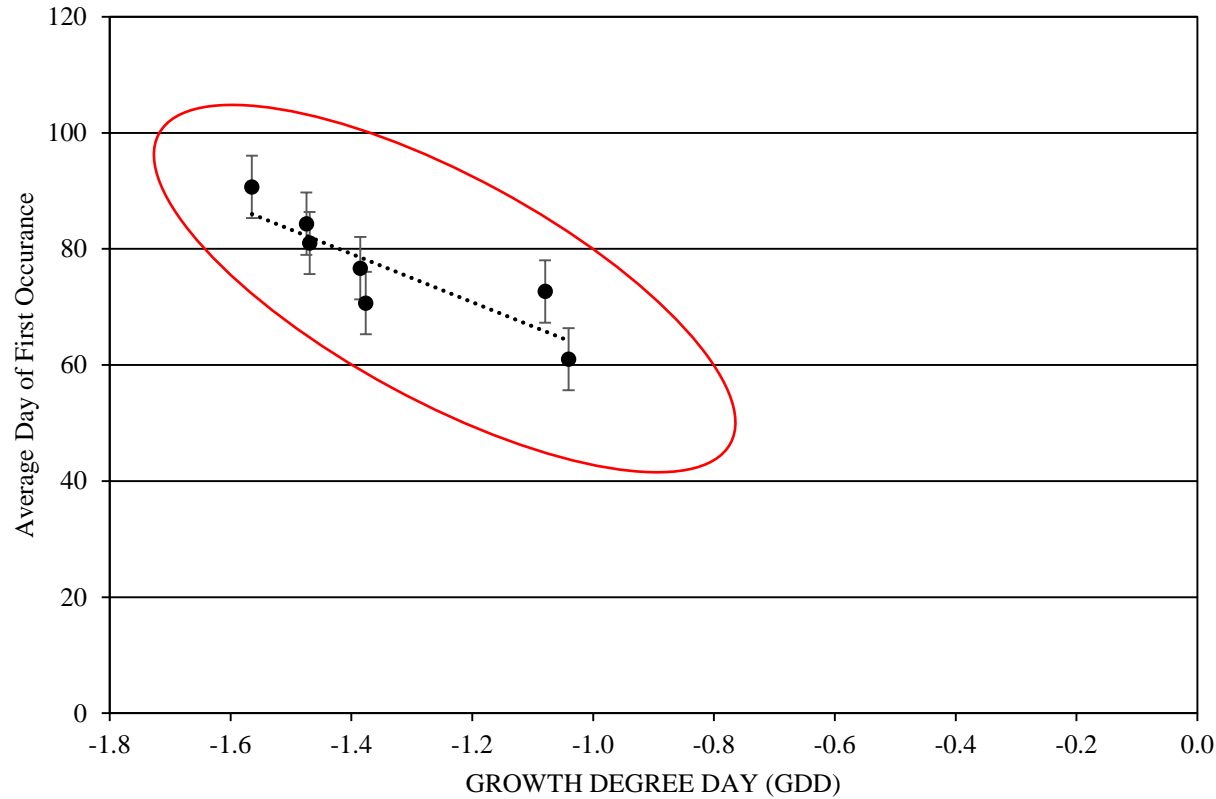
FFrD vs GDD; Common Buttonbush



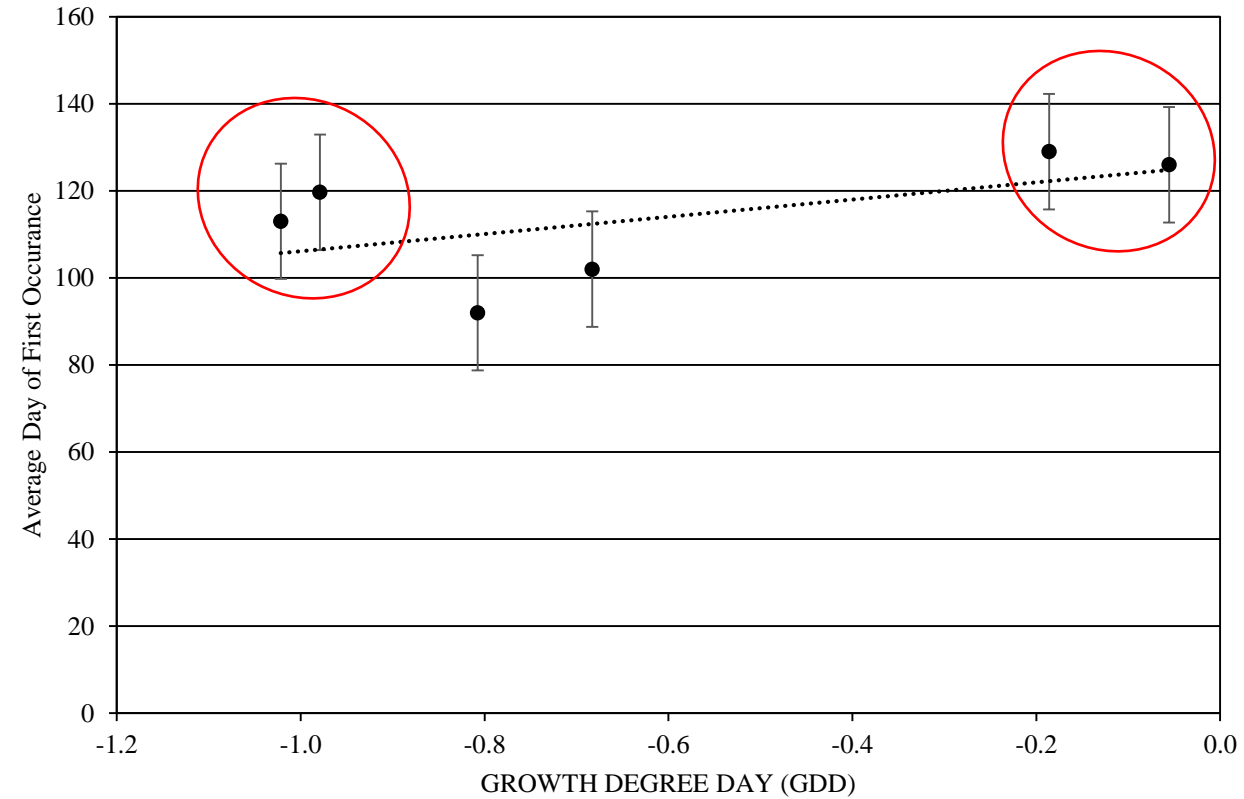
- Relationship between average day of first occurrence and GDD. For Common Buttonbush FFD, the relationship was significant ($F=0.0107$), and for FFrD it was significant ($F=0.0372$).

SENSITIVITY RESULTS CONT.

FFD vs. GDD; Highbush Blueberry



FFrD vs. GDD; Highbush Blueberry



- The relationship between average day of first occurrence and GDD. For *V. corymbosum* FFD, the relationship was significant ($F=0.0120$), and, for FFrD it was not significant ($F=0.2444$).



RESULTS: PHENOPHASE SHIFTS

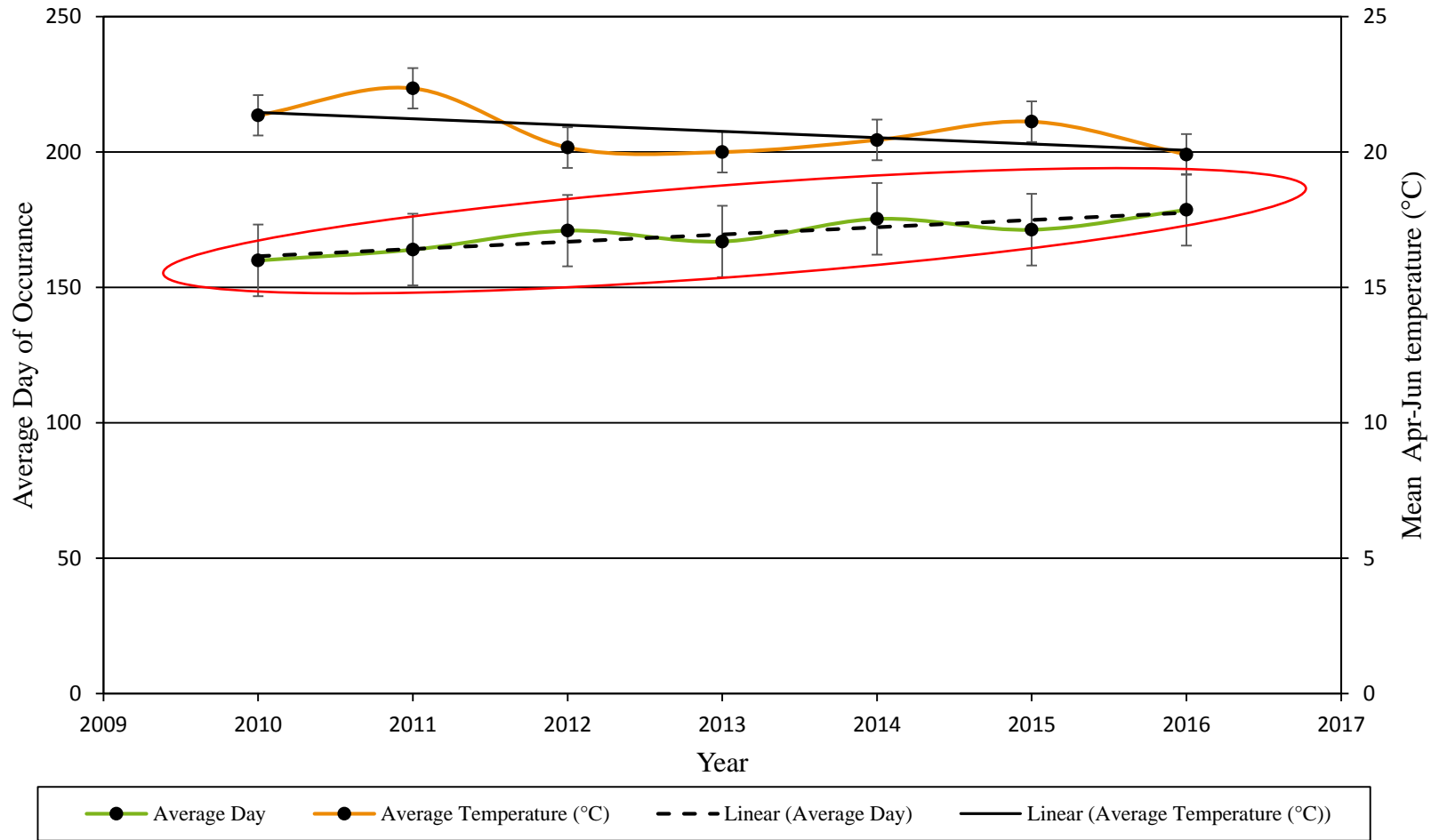
PHENOPHASE SHIFT RESULTS

Species	N	Mean phenophase date				SD of phenophase date				Sig. Pheno.	Days of Year			Temperature		
		FLD	FFD	FFrD	FDS	FLD	FFD	FFrD	FDS		Slope (d/yr)	SE	R ²	Slope (d/yr)	SE	R ²
<i>C. occidentalis</i> (Common buttonbush)	3	X	18-Jun	14-Jul	9-Oct	X	8.812	14.81	23.24	FFD, days (D,F=0.006; T,F=0.038) FFrD, days (F=0.005)	2.679 (FFD)	3.114 (FFD)	0.8026 (FFD)	-0.3106 (FFD) -	0.5849 (FFD)	0.6123 (FFD)
<i>V. corymbosum</i> (Highbush blueberry)	3	X	17-Mar	X	1-Oct	X	11.09	X	29.49	X	0.4643 (FFD) -	10.63 (FFD)	0.0106 (FFD)	0.0219 (FFD)	0.9543 (FFD)	0.0030 (FFD)
											4.405 (FDS)	19.16 (FDS)	0.2284 (FDS)	0.0397 (FDS)	0.9511 (FDS)	0.0097 (FDS)

- Phenophase-shift results compared to temperature over time. Bolded terms are when a significant shift was observed, such as the terms contained within the red rectangle. On average, Common Buttonbush is flowering 2.7 days later; it is also fruiting later by 6.7 days.

PHENOPHASE SHIFT RESULTS CONT.

FFD and Temperature Over Time – Common Buttonbush



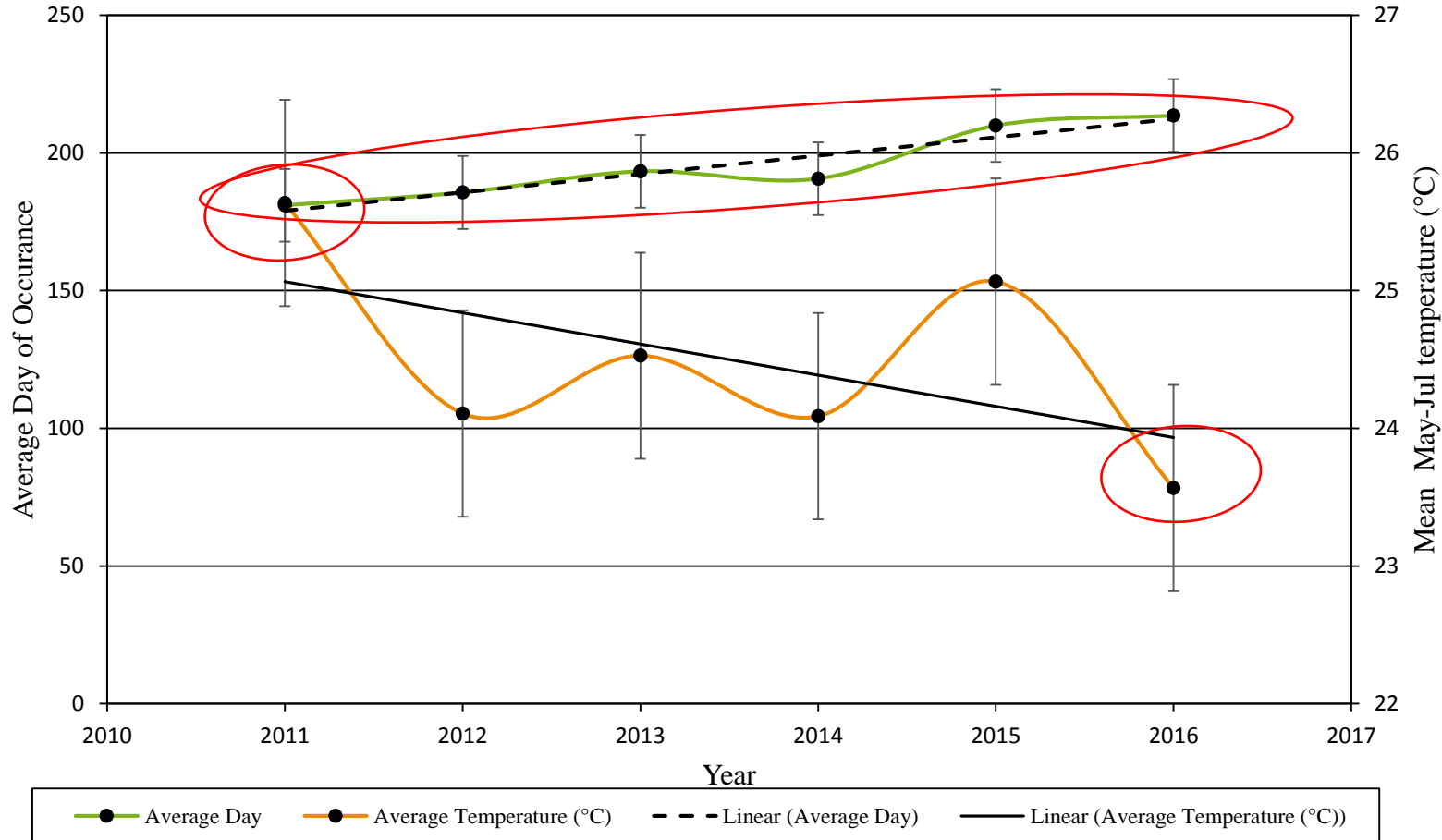
Flower of a Common Buttonbush

© Norfolk Botanical Gardens

- *FFD and temperature vs. time, as well as linear trend lines. Overall, it would appear to be getting cooler from Apr-Jun. However, the key item to note is the shift in FFD from day 160 – 178, $F=0.0064$.*

PHENOPHASE SHIFT RESULTS CONT.

Changes in FFrD Over Time - Common Buttonbush



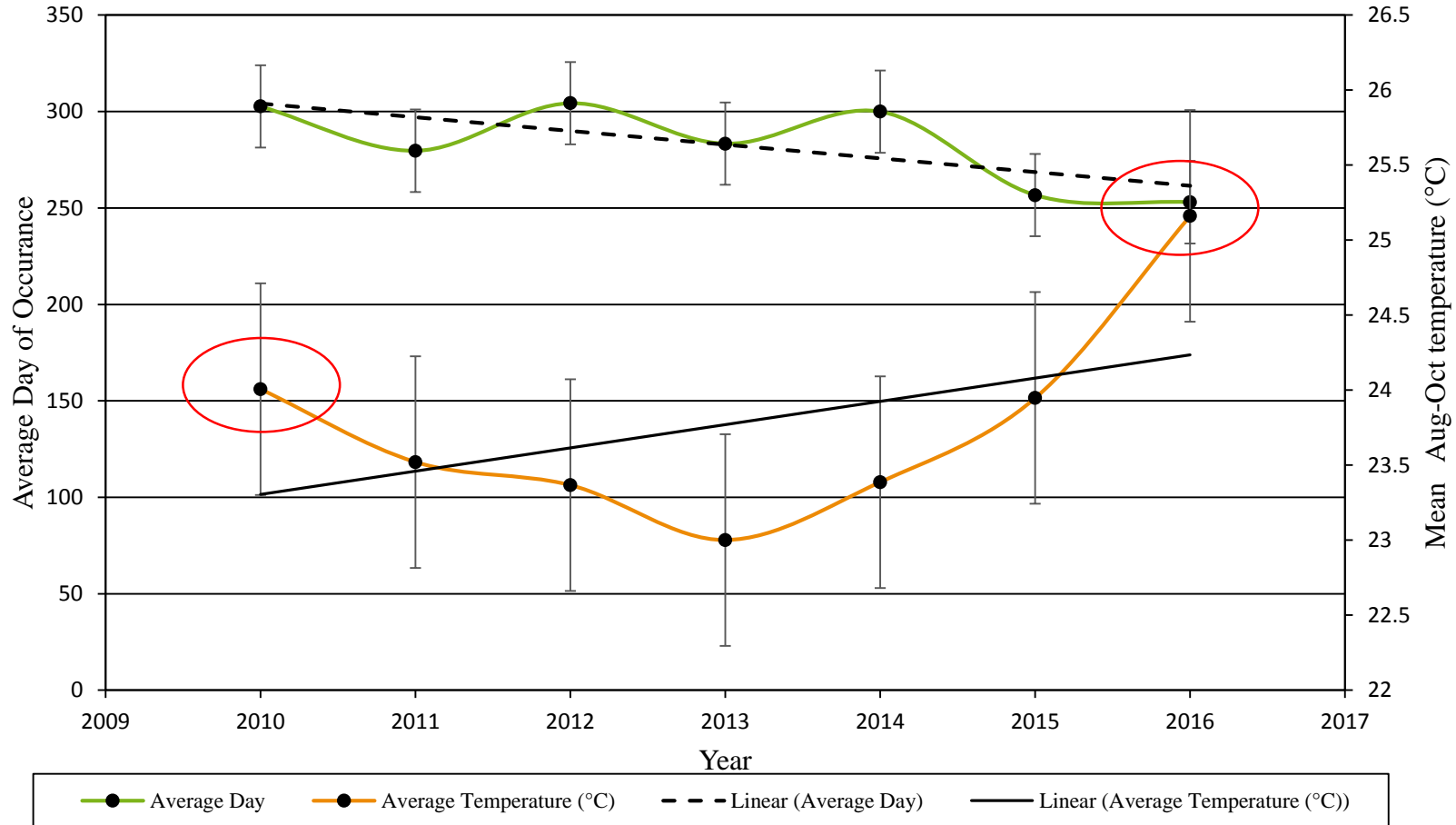
Fruits of a Common Buttonbush

© Will Cook, 2010

- FFrD and temperature vs. time, as well as linear trend lines. From May-July, there is a wide variation in temperature, with the notable exception of 2011 and 2016. However, the key item to note is the shift in FFrD from day 181 – 213, $F=0.0046$.

PHENOPHASE SHIFT RESULTS CONT.

FDS and Temperature Over Time - Common Buttonbush



Leaves of a Common Buttonbush experiencing senescence.

© Rotary Botanical Gardens

- *FDS and temperature vs. time, as well as linear trend lines. FDS did not have a significant shift, though it is close ($F=0.0679$).*



DISCUSSION

- In terms of sensitivity:
 - 4/7 species had at least one phenophase that would shift **as** the area gets warmer.
 - GDD strictly looks at temperature, not nutrient, water, or light availability (Lambers and Poorter, 1992; Cleland *et al.*, 2007).
 - However, shifts are shown to occur due to temperature (Root *et al.* 2003; Menzel *et al.* 2006).
 - 3/7 species did not show any sensitivity. This could be due to wider range of resiliency by species or a different mode of pollination.
- In terms of phenophase shift:
 - Only one species had shown a significant phenophase shift. This is most likely due to low sample size (Gunderson *et al.* 2012; Mazer *et al.* 2013).
 - Potentially, the Common Buttonbush phenophase shift could be influenced by the fact that two individuals are collated in the same microclimate.

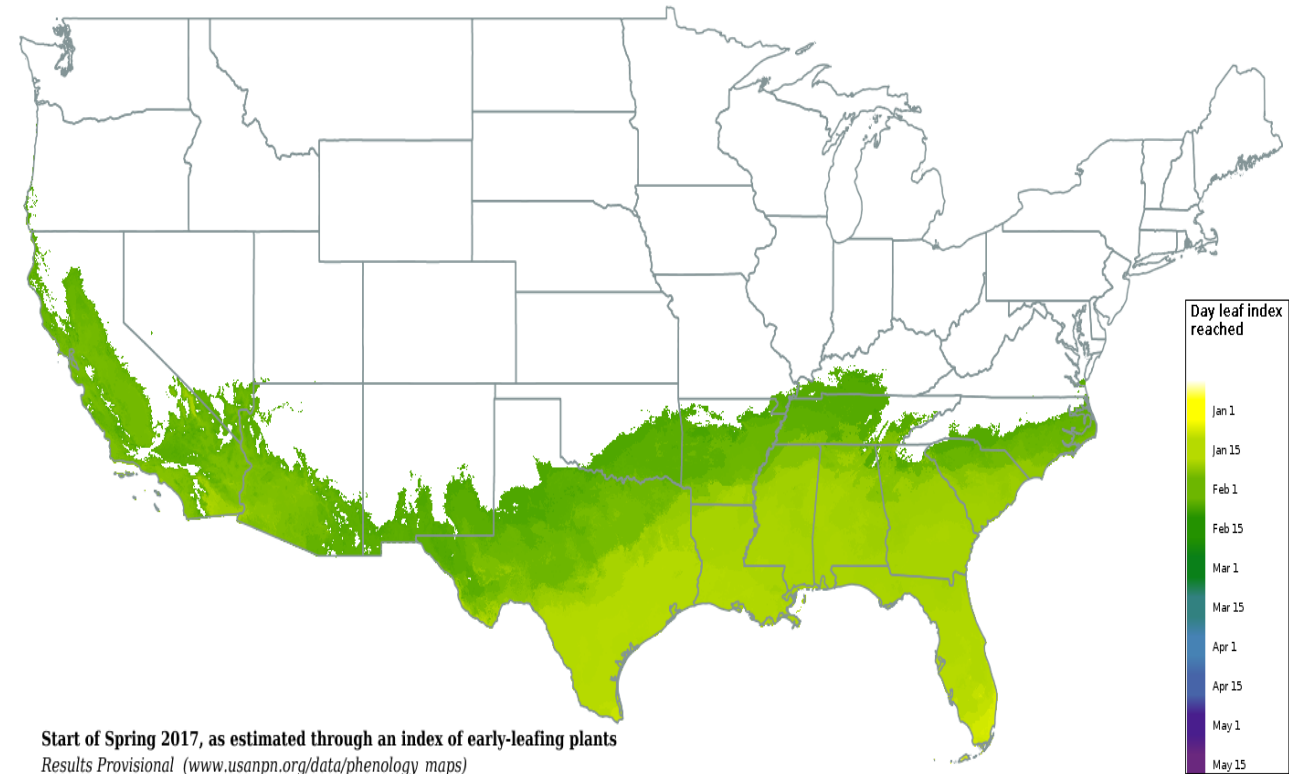


DISCUSSION

- In terms of ecosystem health:
 - Common Buttonbush is flowering and fruiting later, which has been shown to disrupt pollinators, though it is unknown as to how it affects seed dispersal.
 - Indeed, models have shown a reduction of 17-50% of pollinator reward and fruits, limiting pollinator and frugivore activity (Memmott *et al.*, 2007).
 - Phenological shifts are likely to change the composition of native pollinators, possibly with invading southern pollinators.
- In terms of human health and recreation:
 - This could mean an earlier, or longer, allergy season, especially with the understudied pines.
 - Pungo, as well as other local agricultural zones, are likely to have reduced yields (Tao *et al.*, 2006; Nahar *et al.*, 2010).

CONCLUSION AND FUTURE DIRECTIONS

- Overall, it would appear that for the past 5-6 years, the tested native plants have exhibited consistency in phenophases.
 - Mayapple, Flowering Dogwood, Common Buttonbush, and Highbush Blueberry had at least one phenophase show significant sensitivity to increasing temperature.
 - Loblolly Pine and Switchgrass are close to having significant sensitivities.
 - Only Common Buttonbush had shown a phenophase shift (FFD and FFrD).
- For the future:
 - Further observations are needed to make a more definitive assessment.
 - Training students to start observing the pollinator phenology of tested plants would help in piecing the puzzle together.
 - Genetic testing for variation would also help determine resiliency.



- First leafing date across the southern U.S. as it relates to significant shifts in FLD and temperature. © USA-NPN.*

ACKNOWLEDGMENTS

- USA-NPN for methodology.
- Norfolk Botanical Garden for collaboration.
- NOAA for climate data.
- All graduate and undergraduate volunteers: Pat Hunter Shanks, David Ingersoll, Sean, Elizabeth Kana Husa.
- Dr. Tatyana Lobova for supervising the project.



Fruit from a Highbush Blueberry

© Norfolk Botanical Gardens



QUESTIONS?



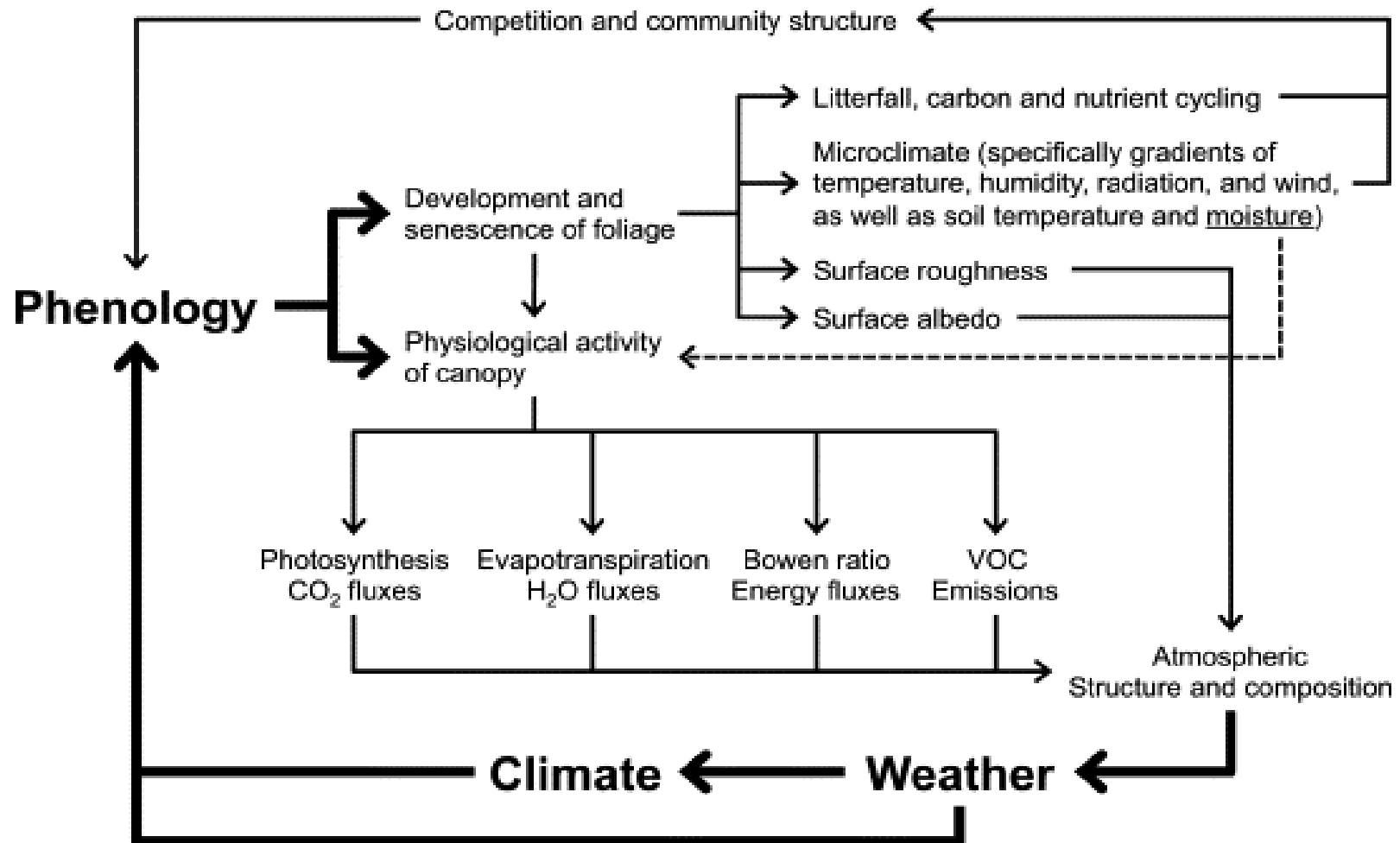
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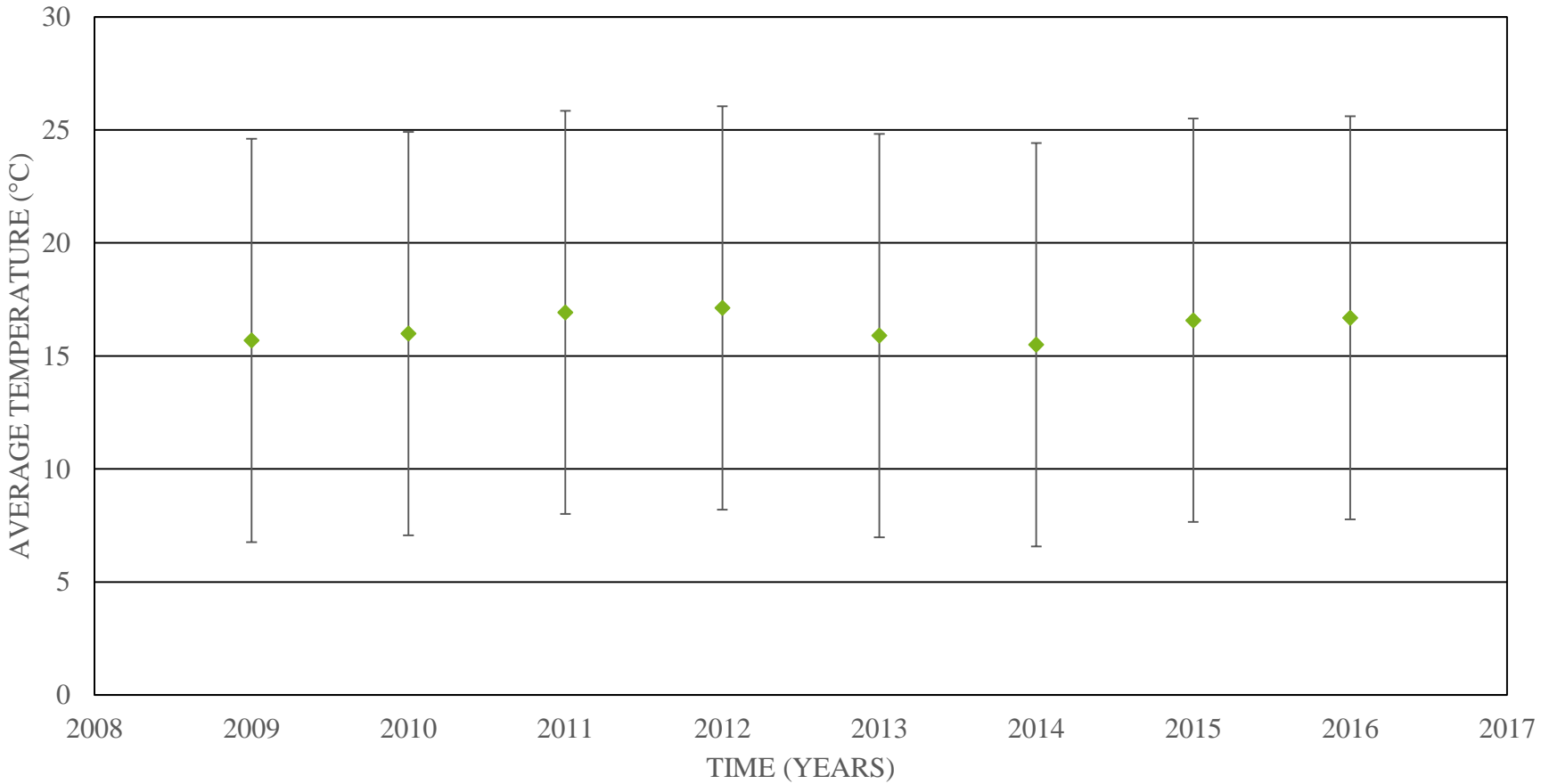
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▪ S2, a figure from Richardson et al. 2013.



ANNUAL AVERAGE TEMPERATURE, ORF



PHENOPHASE SHIFT RESULTS CHANGED

Species	N	Mean phenophase date				SD of phenophase date				Sig. Pheno.	Days of Year			Temperature			
		FLD	FFD	FFrD	FDS	FLD	FFD	FFrD	FDS		Slope (d/yr)	SE	R ²	Slope (d/yr)	SE	R ²	
<i>Podophyllum peltatum</i> (Mayapple)	1	3-Apr	20-Apr	11-May	X	10.53	6.897	11.11	X	X	-3.200 (FFrD)	10.47 (FFrD)	0.2903 (FFrD)	-0.2872 (FFrD)	1.086 (FFrD)	0.2344 (FFrD)	
<i>Cornus florida</i> (Flowering dogwood)	3	X	X	18-May	21-Sep	X	X	21.44	17.35	X	-3.143 (FFrD) - 4.238 (FDS)	21.14 (FFrD) 12.99 (FDS)	0.0882 (FFrD) 0.3734 (FDS)	-0.3011 (FFrD) 0.0254 (FDS)	1.009 (FFrD) 0.9530 (FDS)	0.2804 (FFrD) 0.0040 (FDS)	
<i>Cephalanthus occidentalis</i> (Common buttonbush)	3	X	18-Jun	14-Jul	9-Oct	X	8.812	14.81	23.24	X	FFD, days (D,F=0.006; T,F=0.038)) FFrD, days (F=0.005)	2.679 (FFD) 6.676 (FFrD)	3.114 (FFD) 4.873 (FFrD)	0.8026 (FFD) 0.8914 (FFrD)	-0.3106 (FFD) - 0.1413 (FFrD)	0.5849 (FFD) 0.8030 (FFrD)	0.6123 (FFD) 0.2691 (FFrD)
<i>Vaccinium corymbosum</i> (Highbush blueberry)	3	X	17-Mar	X	1-Oct	X	11.09	X	29.49	X	0.4643 (FFD) - 4.405 (FDS)	10.63 (FFD) 19.16 (FDS)	0.0106 (FFD) 0.2284 (FDS)	0.0219 (FFD) 0.0397 (FDS)	0.9543 (FFD) 0.9511 (FDS)	0.0030 (FFD) 0.0097 (FDS)	

■ Phenophase-shift results compared to temperature over time. These plants were chosen because they displayed significant growth sensitivity to temperature. Bolded terms are when a significant shift was observed, such as the terms contained within the red rectangle. On average, Common Buttonbush is flowering 2.7 days later; it is also fruiting later by 6.7 days. Temperature did not significantly change.