

# Spatio-temporal analysis of flowering using LiDAR topography

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**Abstract:** Spatio-temporal patterns of flowering in forest ecosystems are hard to quantify and monitor. The objectives of this study were to investigate spatio-temporal patterns (e.g. soils, simple slope classes, slope aspect, and flow accumulation) of flowering around Lake Issaquena, South Carolina (SC, USA) using plant-flowering database collected with GPS-enabled camera (stored in Picasa 3 web albums and project website) on a monthly basis in 2012 and LiDAR-based topography. Pacolet fine sandy loam had the most flowering plants, followed by Madison sandy loam, both dominant soil types around the lake. Most flowering plants were on moderately steep (17%–30%) and gently sloping (4%–8%) slopes. Most flowering plants were on west (247.5°–292.5°), southwest (202.5°–247.5°), and northwest (292.5°–337.5°) aspects. Most flowering plants were associated with minimum and maximum flows within the landscape. Chi-square tests indicated differences in the distributions of the proportions of flowering plants were significant by soil type, slope, aspect, and flow accumulation for each month (February–November), for all months (overall), and across months. The Chi-square test on area-normalized data indicated significant differences for all months and individual differences by each month with some months not statistically significant. Cluster analysis on flowering counts for nine plant families with the most flowering counts indicated no unique separation by cluster, but implied that the majority of these families were flowering on strongly sloping (9%–16%) slopes, on southwest (202.5°–247.5°) aspects, and low flow accumulation (0–200). Presented methodology can serve as a template for future efforts to quantify spatio-temporal patterns of flowering and other phenological events.

**Keywords:** aspect; flow accumulation; Geographic Information Systems (GIS); phenology; soils

## 1 Introduction

New technological advances are increasingly used to study and record phenological events, for example: remote sensing (Wei *et al.*, 2014), digital repeat photography (Crimmins and Crimmins, 2008; Chen *et al.*, 2011; Liang *et al.*, 2012; Panchen, 2012; Nijland *et al.*, 2013), website (Bradley *et al.*, 2010), citizen science (Hill *et al.*, 2012), and others. The majority of spatio-temporal studies on phenologies focused on agricultural crops and utilized remote

Received: 2015-07-15 Accepted: 2015-10-29

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sensing techniques (Chakaborty *et al.*, 2014; Wei *et al.*, 2014). However, Andrew and Ustin (2009) used a LiDAR based DEM to study the effects of microtopography and hydrology on the phenology of an invasive herb. Caillaud *et al.* (2010) modelled the spatial distribution and fruiting pattern for *Dipteryx oleifera* in Panama using a point process model of tree spatial distribution and a generalized linear mixed-effects model of temporal variation of fruit production. According to Dahlgren *et al.* (2007), environmental properties other than temperature, photoperiod, and moisture have not received much attention. Spatio-temporal patterns of flowering of a variety of plant species in forest ecosystems are hard to quantify and monitor because of the canopy cover, and there is a need to develop methodology for assessing phenology in such environments.

The majority of previous spatio-temporal studies on phenologies focused on agricultural crops and utilized remote sensing techniques, but such analysis is complicated in forested ecosystems. It is only in the last few years that LiDAR derived digital elevation models (DEMs) have become available. These LiDAR DEMs have sufficient horizontal and vertical accuracy to detect small changes in microtopography that had previously not been possible with coarser-scale spatial data. Additionally, the LiDAR DEMs use active remote sensing that is often able to penetrate forest canopy to see the underlying ground topography (Lorenzo Gil *et al.*, 2013).

Flowering, one of many phenological events, occurs after a plant has transitioned from juvenile to adult and vegetative meristem buds change into a reproductive meristem, evocation (Gilbert, 2000). The transition of juvenile to adult occurs when the juvenile grows in size, age, and leaf number and has the right amount of water and light (photoperiod), and the right temperature (Gilbert, 2000). These factors cause a change in hormones, nutrient levels, and other chemicals (Gilbert, 2000). Plants flower at different times due to a variety of factors: pollinator availability, photoperiod (daily duration of light), temperature (thermoperiod), humidity, precipitation, and soil nutrients (especially phosphorus) (Lee and Amasino, 1995; Jones and Reithel, 2000; Gilbert, 2000; Evans, 2013a,b; Dahlgren *et al.*, 2007; Jentsch *et al.*, 2009).

Previous studies on the plant inventory and flowering around Lake Issaqueena in 1970–1971 (Pamplin, 1971) found 281 plants compared to 207 in 2011–2012 (Pamplin, 2013). Comparison of phenologies indicated 269 plant species blooming in 1970–1971 compared to 203 plants blooming in 2011–2012 (Pamplin, 1971, 2013). The blooming period was 11 months in 2011–2012 compared to 8 months in 1970–1971 (Pamplin, 1971, 2013). A majority of plants were blooming earlier and longer in 2011–2012 than in 1970–1971 (Pamplin, 1971, 2013).

The objectives of this study were to investigate spatio-temporal patterns (e.g. soils, simple slope classes, slope aspect, and flow accumulation) of flowering around Lake Issaqueena, SC using plant-flowering database collected with GPS-enabled camera and LiDAR topography.

## 2 Materials and methods

### 2.1 Study area

Lake Issaqueena (Figure 1) was built by the Works Progress Administration (WPA) in a

Land Use Project introduced in 1934 that covered thousands of acres (Pamplin, 1971).

Lake Issaqueena is 116-acres in size, maintained by Issaqueena Dam in the northern part of Clemson Experimental Forest, and it was built for boating, swimming, and fishing. Clemson University acquired this land in 1954 and many research projects are undertaken within Clemson Experimental Forest (Pamplin, 1971).

## 2.2 Weather data

Long-term weather data were obtained from U.S. Historical Climatology Network– Monthly Data, Site 381770, Clemson University, South Carolina (Table 1).

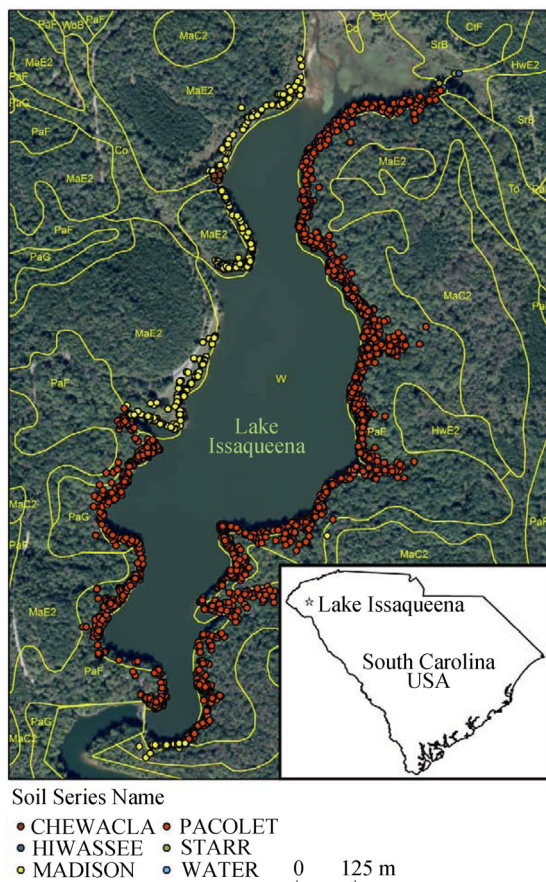
## 2.3 Spatial analysis

A 3-m LiDAR derived DEM was obtained from Pickens County, SC and with an Issaqueena lake polygon from NHD USDS and an aerial photo of the study site from USDA-NRCS (Table 2; ESRI, 2013). The DEM is based on data acquired in 2011 at a 1.4 m point spacing with a horizontal

accuracy of better than 1 m and a vertical accuracy of approximately 0.23 m. Slope was calculated using the ArcGIS 10.1 slope tool which reported the slope as the maximum rate of change in elevation of each 3.048 m by 3.048 m cell to its eight neighboring cells. Slopes were classified into simple slope classes based on definition and slope gradient limits defined by the Soil Survey Manual (2015) developed by United States Department of Agriculture and Natural Resources Conservation Service (USDA/NRCS). Aspect was found using the ArcGIS 10.1 aspect tool which identified the downslope direction of the maximum rate of change in elevation for each 3.048 m by 3.048 m cell. Flow accumulation was calculated using the ArcGIS 10.0 flow accumulation tool and was calculated as the number of cells expected to drain into each 3.048 m by 3.048 m cell.

## 2.4 Soil inventory

Soil map units were identified using Web Soil Survey (Table 2; Soil Survey Staff, 2015). The following soil types were identified around Lake Issaqueena: Chewacla soils, frequently flooded (Co) (Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts); Hiwassee sandy loam, 10 to 25% slopes eroded (HwE2) (Very-fine, kaolinitic, thermic Rhodic Kanhapludults); Madison sandy loam, 10 to 25% slopes, eroded (MaE2) (Fine, kaolinitic, thermic Typic Kanhapludults); Pacolet fine sandy loam, 25 to 40% slopes (PaF) (Fine, kaolinitic,



**Figure 1** Soil types and flowering occurrences around Lake Issaqueena, SC

thermic Typic Kanhapludults); Pacolet fine sandy loam, 40 to 80% slopes (PaG) (Fine, kaolinitic, thermic Typic Kanhapludults); Rabun cobbly loam, 25 to 40% slopes (RaF) (Fine, kaolinitic, mesic Typic Kanhapludults); Starr loam, 0 to 6% slopes (SrB) (Fine-loamy, mixed, semiactive, thermic Fluventic Dystrudepts); Toccoa soils (To) (Coarse-loamy, mixed, active, nonacid, thermic Typic Udifluvents).

**Table 1** Monthly total precipitation (cm) and monthly average temperature (°C) for 2012, and 50-year mean (Source: U.S. Historical Climatology Network-Monthly Data, Site 381770, Clemson University, South Carolina)

Month	2012		50-year mean	
	Mean temp., °C	Precip., cm	Mean temp., °C	Precip., cm
January	9	11	5	13
February	9	5	7	12
March	17	6	11	14
April	18	6	16	10
May	22	8	20	10
June	24	16	24	10
July	27	12	26	11
August	25	21	25	12
September	22	6	22	10
October	16	7	16	10
November	10	2	11	10
December	9	13	7	12
Total precip.		112		134
Mean temp.	17		16	

**Table 2** Data sources and descriptions

Data layer	Source	Coordinate system	Spatial resolution	Date
DEM (LiDAR)	Pickens County GIS	NAD State Plane 1983 SC	3.048 m	2011
Lake Polygon	NHD USGS	NAD State Plane 1983 SC	na	2013
NAIP Aerial Photo	USDA-NRCS	NAD State Plane 1983 SC	1 m	2013
SSURGO Soils Data	USDA-NRCS	Geographic	na	na

2.5 Floristic inventory, identification, and storage

Flowering plants were recorded via GPS enabled camera for future identification on a monthly basis. Flowering plants were identified using the USDA Plants Database (USDA, NRCS, 2014) and through the use of expert knowledge. Picasa 3 and Google Website were used to archive photos (Google, Inc., 2010).

2.6 Statistical analysis

Chi-square tests were used to examine the difference in distribution of proportions between flowering and soils, simple slope classes, slope aspects, and flow accumulations within each month, among the months, and overall when sample size was large enough to meet the as-

sumptions. The Chi-square test was also performed using the normalized area percentages to examine the proportions within each month, among the months, and overall (SAS v. 9.3). Copyright, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA. Exploratory k-means cluster analysis was used to examine groups of slope classes, slope aspects, and flow accumulations by flowering families. Cluster analyses were performed using R Statistical Software (R Statistical Software, 2012).

### 3 Results and discussion

#### 3.1 Soils and flowering

The Chi-square test (Table 3) indicated differences in the distribution of proportions of flowering counts among Chewacla, Madison, and Pacolet soil types were significant for all months ( $\chi^2(2)=4885.4$ ,  $p=0.000$ ) and for each individual month ( $p=0.000$  for all tests, respectively). For the area-normalized data, the Chi-square test indicated that the differences in the distribution of proportions of flowering counts were significant over all months ( $\chi^2(2)=126.0$ ,  $p=0.000$ ), and for each individual month, significant differences were found in May ( $\chi^2(2)=53.5$ ,  $p=0.000$ ) and June ( $\chi^2(2)=71.5$ ,  $p=0.000$ ).

The soil series Pacolet fine sandy loam had the most flowering plants while Madison sandy loam had the second most (Figure 1 and Table 3). This is most likely due to the fact that Pacolet and Madison are the most dominant soil types in terms of area of the study site. Loam has been determined to be the best soil texture for agricultural crop growth (Brady and Weil 2004), and is the most conducive to plant growth around Lake Issaquena. Chewacla, Starr loam and Hiawassee sandy loam soil series had very few flowering plants while Rabun cobbly loam and Toccoa had no flowering plants (Figure 1 and Table 3). The cobbly texture in the Rabun soil is problematic for retention of nutrients that would be beneficial to plant growth (USDA/NRCS, 2014). The Toccoa soil series had too small of an area in the study site to account for flowering plants.

#### 3.2 Simple slope classes and flowering

The largest number of flowering plants was found on moderately steep slopes of 17%–30% followed by strong slopes of 9%–16% and gentle slopes of 4%–8% (Figure 2 and Table 4). The Chi-square test (Table 4), indicated that the differences in the distribution of proportions of flowering counts were significant for all months ( $\chi^2(4)=1905.6$ ,  $p=0.000$ ), across months ( $\chi^2(40)=232.2$ ,  $p=0.000$ ), and for each individual month March through November ( $p=0.000$  for all tests, respectively). For the area-normalized data, the Chi-square test indicated that the differences in the distribution of proportions of flowering counts were significant over all months ( $\chi^2(4)=139.3$ ,  $p=0.000$ ), across months ( $\chi^2(59)=3176.8$ ,  $p=0.000$ ), and for each individual month, significant differences were found for all months examined except September ( $\chi^2(4)=8.5$ ,  $p=0.075$ ).

Study by Komac *et al.* (2011) reported that plant expansion rates were faster on steeper slopes than shallow slopes. Steep slopes of 30%–45% and nearly level slopes of 0–3% had far fewer flowering plants than the other slopes with the exception of steep slopes of 45% and above (Figure 2 and Table 4). Andrew and Ustin (2009) reported an association between

**Table 3** Flowering counts and area (m<sup>2</sup> and %) by soil type around Lake Issaqueena, SC in 2012

Parameters	Area (m <sup>2</sup> )	Area (%)	All months	Across months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Soils <sup>a</sup>																
Chewacla soils (Co)	707	1	15	—	0	0	0	0	1	0	5	8	0	1	0	0
Hiwassee sandy loam (HwE2)	409	0	1	—	0	0	0	0	0	0	0	0	0	1	0	0
Madison sandy loam (MaE2)	29571	20	503	—	0	2	84	20	52	29	123	149	2	37	4	0
Pacolet fine sandy loam (Pa)	113904	79	3271	—	0	17	383	427	545	477	575	517	156	127	46	1
Rabun cobbly loam (RaF)	0	0	0	—	0	0	0	0	0	0	0	0	0	0	0	0
Starr loam (SrB)	413	0	2	—	0	0	1	0	0	0	0	0	0	1	0	0
Toccoa soils (To)	0	0	0	—	0	0	0	0	0	0	0	0	0	0	0	0
Total:	145003	100	3792	—	0	19	468	447	598	506	703	674	158	167	50	1
Chi-Square	—	—	4885.4	<sup>b</sup>	—	27.3	520.7	779.4	905.7	848.0	772.6	614.8	304.2	153.2	78.0	—
DF	—	—	2	—	—	2	2	2	2	2	2	2	2	2	2	—
Pr > ChiSq	—	—	0.000	—	—	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	—
Area-normalized																
Chi-Square	—	—	126.0	<sup>b</sup>	—	<sup>b</sup>	<sup>b</sup>	<sup>b</sup>	53.5	71.5	3.48	2.18	<sup>b</sup>	<sup>b</sup>	<sup>b</sup>	—
DF	—	—	2	—	—	—	—	—	2	2	2	2	—	—	—	—
Pr > Chi-Square	—	—	0.000	—	—	—	—	—	0.000	0.000	0.175	0.336	—	—	—	—

<sup>a</sup> The statistical analysis was performed for Chewacla, Madison, and Pacolet, because other soils had almost no flowering counts.

<sup>b</sup> Chi-square analysis not reported due to small expected cell counts.

more mature phenology and shallower slopes. On the steepest slopes, there is less organic matter in the soil as it is washed down the slope gradient with the rain and less organic matter leaves fewer nutrients necessary for plants to flower (Corral-Nunez *et al.*, 2014). On less steep slopes, plants can be in competition with grasses (Komac *et al.*, 2011), and it may explain the fewer flowering plants found on the nearly level slopes.

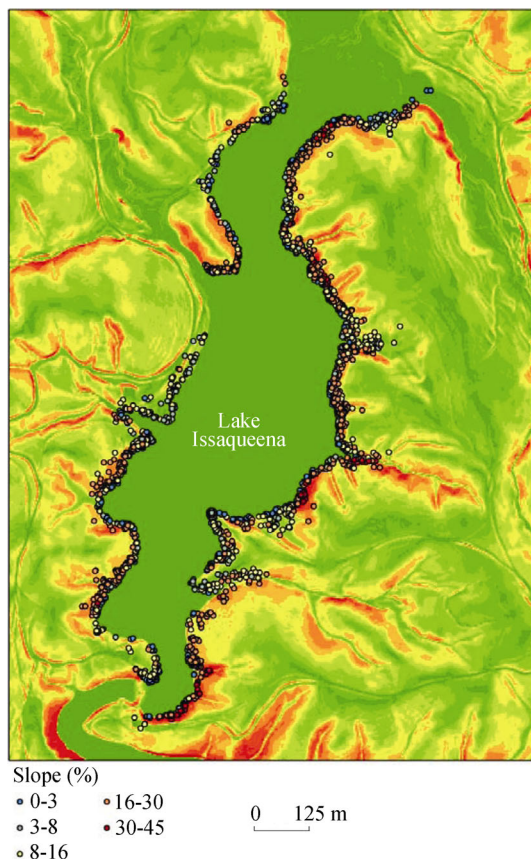
### 3.3 Slope aspect and flowering

The highest number of flowering plants was found on the western aspect, followed by southwestern and northwestern aspects (Figure 3 and Table 5). The next most productive slope aspects, in order of descending number of flowering plants were the southeastern, southern, and eastern aspects (Figure 3 and Table 5). The Chi-square test (Table 5) indicated that the differences in the distribution of proportions of flowering counts were significant for all months ( $\chi^2(8) = 1141.1$ ,  $p=0.000$ ), across months ( $\chi^2(80) = 534.3$ ,  $p=0.000$ ), and for each individual month ( $p=0.000$  for all tests). For the area-normalized data, the Chi-square test indicated that the differences in the distribution of proportions of flowering counts were significant over all months ( $\chi^2(8) = 297.4$ ,  $p=0.000$ ), across months ( $\chi^2(107) = 3997.1$ ,  $p=0.000$ ) and for each individual month, significant differences were found for all months examined except March ( $\chi^2(8) = 13.4$ ,  $p=0.099$ ).

It has been generally reported that south-facing aspects tend to be warmer and drier than north-facing slope aspects (Haase 1970). Dahlgren *et al.* (2007) reported that the flowering of *Actaea spicata* Linnaeus was earlier on south-facing slopes. Andrew and Ustin (2009) reported that the flowering of *Lepidium latifolium* Linnaeus was earlier on steeper north-facing slopes and that earlier flowering was more likely at higher eastness with the reverse being true in a lowland area.

### 3.4 Flow accumulation and flowering

It has been reported that phenology stages occur earlier in dry years and later in wet years with the extent of the differentiation depending on site specific conditions and regional scale hydrology (Andrew and Ustin, 2009). The highest number of flowering plants was associated with minimum flow (dry areas) followed by those with maximum flow (wet areas) while flow levels in between had the least number of flowering plants (Figure 4 and Table 6).



**Figure 2** Simple slope classes and flowering occurrences around Lake Issaqueena, SC

**Table 4** Flowering counts and area (m<sup>2</sup> and %) by simple slope classes (Soil Survey Manual, 2015) around Lake Issaqueena, SC in 2012

Parameters	Area (m <sup>2</sup> )	Area (%)	All months	Across months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Simple Slope Classes																
Nearly level (0–3%)	12830	9	302	–	0	0	23	16	44	47	59	64	16	26	7	0
Gently sloping (4%–8%)	19565	13	720	–	0	0	98	75	100	70	126	177	24	44	6	0
Strongly sloping (9%–16%)	42624	29	933	–	0	3	158	92	125	114	170	180	57	29	4	1
Moderately steep (17%–30%)	63481	44	1678	–	0	11	166	229	299	255	336	236	58	62	26	0
Steep (30%–45%)	6503	5	159	–	0	5	23	35	31	20	12	17	3	6	7	0
Very steep (>45%)	0	0	0	–	0	0	0	0	0	0	0	0	0	0	0	0
Total:	145003	100	3792	–	0	19	468	447	599	506	703	674	158	167	50	1
Chi-Square	–	–	1905.6	232.2	–	– <sup>a</sup>	207.0	313.7	385.3	339.2	444.2	244.5	77.9	52.6	32.6	–
DF	–	–	4	40	–	–	4	4	4	4	4	4	4	4	4	–
Pr > ChiSq	–	–	0.000	0.000	–	–	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
Area-normalized																
Chi-Square	–	–	139.3	3176.8	–	– <sup>a</sup>	42.8	42.9	26.6	13.4	36.6	113.2	8.5	41.1	– <sup>a</sup>	–
DF	–	–	4	59	–	–	4	4	4	4	4	4	4	4	–	–
Pr > Chi-Square	–	–	0.000	0.000	–	–	0.000	0.000	0.000	0.009	0.000	0.000	0.075	0.000	–	–

<sup>a</sup>Chi-square analysis not reported due to small expected cell counts.





**Table 5** Flowering counts and area (m<sup>2</sup> and %) by slope aspect around Lake Issaqueena, SC in 2012

Parameters	Area (m <sup>2</sup> )	Area (%)	All months	Across months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Slope Aspect																
North (0–22.5°)	9650	6	117	–	0	1	18	21	11	11	23	17	5	4	6	0
Northeast (22.5°–67.5°)	11563	8	220	–	0	3	35	16	23	17	58	46	5	17	0	0
East (67.5°–112.5°)	12022	8	284	–	0	0	46	1	32	28	50	77	22	24	3	1
Southeast (112.5°–157.5°)	20114	14	579	–	0	1	76	2	134	46	125	132	30	28	5	0
South (157.5°–202.5°)	15310	11	401	–	0	2	61	21	58	52	74	100	18	10	5	0
Southwest (202.5°–247.5°)	16806	12	671	–	0	4	60	83	128	103	135	109	22	22	5	0
West (247.5°–292.5°)	21247	15	714	–	0	0	67	123	88	132	132	99	28	29	16	0
Northwest (292.5°–337.5°)	28196	20	644	–	0	8	75	140	106	101	77	79	18	30	10	0
North (337.5°–360°)	10096	6	162	–	0	0	30	40	19	0	29	15	10	3	0	0
Total:	145003	100	3792	–	0	19	468	447	599	490	703	674	158	167	50	1
Chi-Square	–	–	1141.1	534.3	–	<sup>a</sup>	66.2	446.2	283.3	377.9	192.0	179.3	38.5	48.5	35.7	–
DF	–	–	8	80	–	–	8	8	8	8	8	8	8	8	8	–
Pr > ChiSq	–	–	0.000	0.000	–	–	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
Area-normalized																
Chi-Square	–	–	297.4	3997.1	–	<sup>a</sup>	13.4	218.6	119.9	169.1	86.8	97.6	23.6	23.9	<sup>a</sup>	–
DF	–	–	8	107	–	–	8	8	8	8	8	8	8	8	–	–
Pr > Chi-Square	–	–	0.000	0.000	–	–	0.099	0.000	0.000	0.000	0.000	0.000	0.003	0.002	–	–

<sup>a</sup> Chi-square analysis not reported due to small expected cell counts.

**Table 6** Flowering counts and area (m<sup>2</sup> and %) by flow accumulation around Lake Issaqueena, SC in 2012

Parameters	Area (m <sup>2</sup> )	Area (%)	All months	Across months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow Accumulation																
0–200 (low)	136512	94	3329	–	0	18	403	396	537	459	623	579	135	131	47	1
200–400	1486	1	65	–	0	0	14	8	6	8	10	15	1	3	0	0
400–600	697	0.5	56	–	0	0	8	12	6	5	6	12	3	4	0	0
600–800	678	0.5	44	–	0	0	7	4	7	2	5	11	2	4	2	0
800–1000	557	0.4	29	–	0	1	2	4	2	3	4	9	0	4	0	0
1000–2000	1310	0.9	79	–	0	0	7	7	17	8	16	13	6	4	1	0
2000–3000	1468	1	46	–	0	0	6	2	7	5	7	11	5	3	0	0
3000–4000	158	0.1	33	–	0	0	7	3	5	1	8	6	0	3	0	0
4000+ (high)	2137	1.6	111	–	0	0	14	11	12	15	24	18	6	11	0	0
Total:	145003	100	3792	–	0	19	468	447	599	506	703	674	158	167	50	1
Chi-Square	–	–	22586.5	92.4	–	– <sup>a</sup>	2667.6	2718.9	3743.3	3248.7	4280.3	3818.8	886.5	769.3	348.5	–
DF	–	–	8	80	–	–	8	8	8	8	8	8	8	8	8	–
Pr > ChiSq	–	–	0.000	0.162	–	–	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
Area-normalized																
Chi-Square	–	–	480.4	– <sup>a</sup>	–	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	– <sup>a</sup>	–
DF	–	–	8	–	–	–	–	–	–	–	–	–	–	–	–	–
Pr > Chi-Square	–	–	0.000	–	–	–	–	–	–	–	–	–	–	–	–	–

<sup>a</sup> Chi-square analysis not reported due to small expected cell counts.

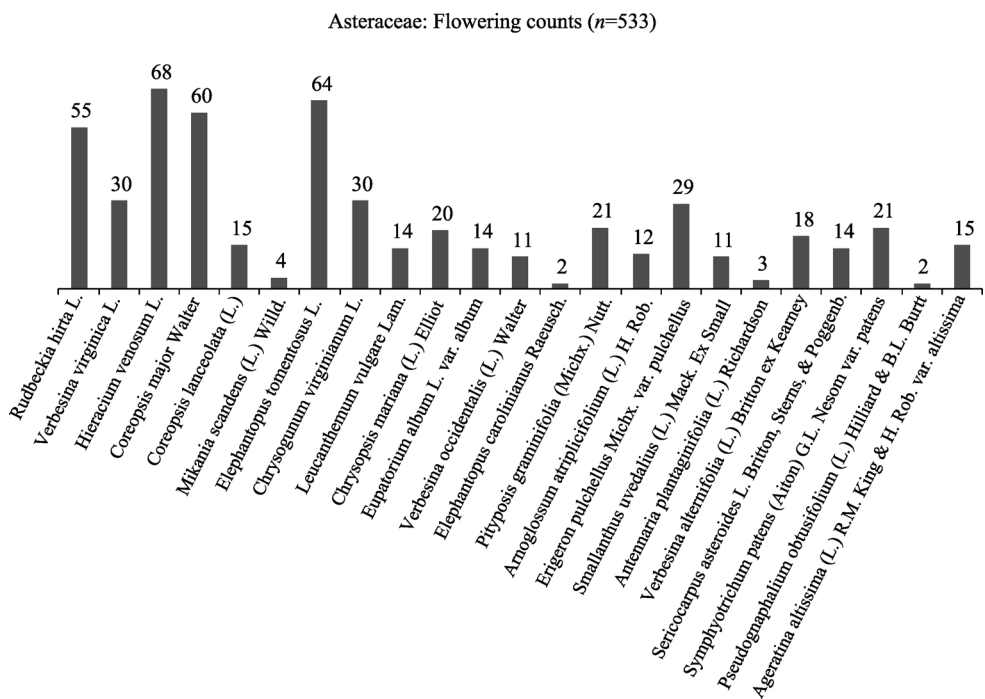


Figure 5 Flowering counts distribution within the Asteraceae family

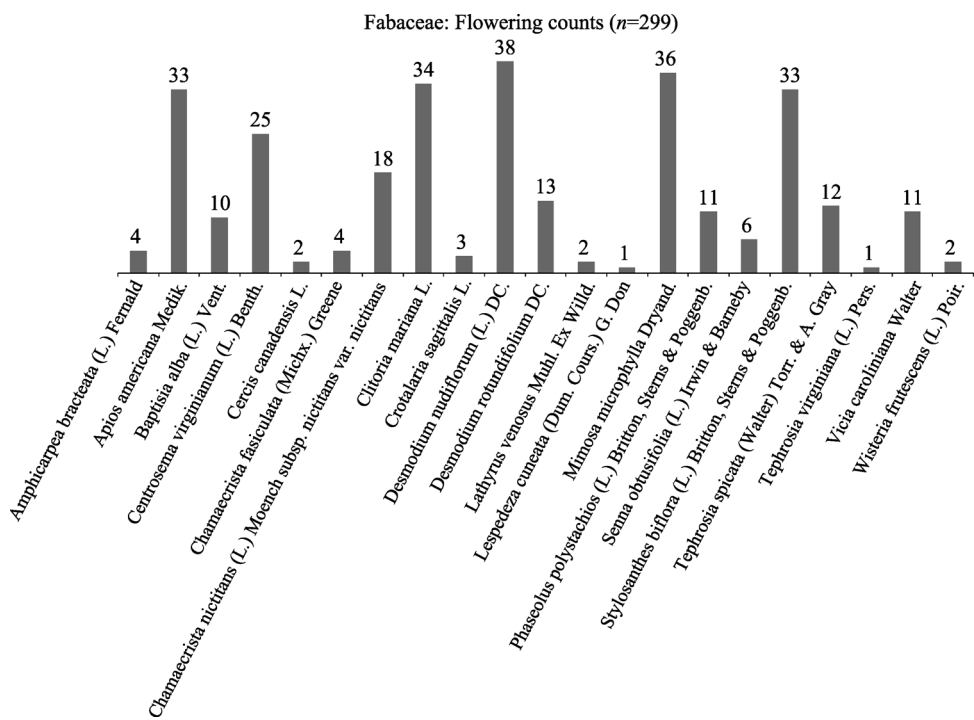


Figure 6 Flowering counts distribution within the Fabaceae family

Linnaeus ( $n=60$ ), and *Coreopsis major* Walter ( $n=60$ ). Within the second most abundantly flowering family, Fabaceae ( $n=299$ ), the most abundantly flowering species was *Desmodium nudiflorum* (Linnaeus) DC. ( $n=38$ ), followed by *Mimosa microphylla* Dryant. ( $n=36$ ), and *Clitoria mariana* Linnaeus ( $n=34$ ).

**Table 7** Landscape characteristics associated with the top nine families in terms of flowering counts around Lake Issaqueena, SC in 2012

Family	Slope aspect			Slope		Flow accumulation	
	n	Mean	St dev.	Mean	St dev.	Mean	St dev.
Overall							
Asteraceae	533	215.3	80.7	16	8	453	3392
Campanulaceae	97	180.0	97.8	14	10	223	777
Caryophyllaceae	82	229.7	93.5	19	8	448	1617
Clusiaceae	84	218.3	86.9	13	8	218	737
Ericaceae	105	249.1	80.6	18	11	293	1229
Fabaceae	304	183.6	82.7	16	8	758	6260
Lamiaceae	101	231.6	61.3	17	8	97	510
Liliaceae	132	243.4	94.9	17	8	79	276
Melastomataceae	115	192.7	78.5	11	8	2816	7502
February							
Asteraceae	2	167.0	0.0	17	0	1	0
March							
Asteraceae	52	212.9	88.9	18	9	103	257
Caryophyllaceae	26	210.6	83.7	18	8	104	313
Ericaceae	21	192.9	119.0	11	6	333	1003
Fabaceae	22	183.4	110.3	16	9	229	725
Lamiaceae	4	222.4	2.2	15	3	9	0
Liliaceae	36	222.8	116.0	16	6	46	185
April							
Asteraceae	61	270.8	42.0	21	8	287	1395
Caryophyllaceae	10	265.9	33.2	17	7	1060	2308
Ericaceae	66	274.4	52.1	20	10	341	1443
Fabaceae	7	275.3	60.3	18	10	142	247
Lamiaceae	12	257.6	87.7	17	9	417	1393
Liliaceae	52	238.1	108.1	13	7	50	161
May							
Asteraceae	64	224.4	80.8	13	8	231	695
Campanulaceae	8	125.2	21.3	27	4	9	4
Caryophyllaceae	12	309.3	34.6	22	10	950	3155
Ericaceae	7	257.1	19.4	23	7	5	7
Fabaceae	52	175.8	73.7	17	7	198	719
Lamiaceae	32	249.1	45.5	17	9	81	257
Liliaceae	8	283.4	38.2	18	8	313	378
Melastomataceae	6	123.4	36.1	7	8	2253	3092

(to be continued on the next page)

(Continued)

Family	Slope aspect			Slope		Flow accumulation	
	n	Mean	St dev.	Mean	St dev.	Mean	St dev.
June							
Asteraceae	62	222.7	78.9	17	7	146	516
Campanulaceae	21	227.7	101.4	15	11	52	102
Caryophyllaceae	4	60.5	85.5	27	2	1	1
Clusiaceae	14	191.0	77.6	12	11	21	17
Ericaceae	3	181.7	138.4	25	3	38	9
Fabaceae	46	218.4	76.8	16	7	163	699
Lamiaceae	9	231.6	71.1	17	8	122	336
Liliaceae	16	244.5	43.4	20	10	6	6
Melastomataceae	28	215.6	79.0	11	7	5330	12178
July							
Asteraceae	121	194.3	76.2	17	7	237	1541
Campanulaceae	11	163.4	135.8	9	5	3	2
Caryophyllaceae	22	232.0	101.2	18	7	417	1321
Clusiaceae	49	221.2	88.3	14	7	358	944
Ericaceae	5	244.8	37.0	18	15	11	4
Fabaceae	78	192.9	80.9	15	8	199	726
Lamiaceae	27	219.6	58.2	20	8	18	54
Liliaceae	8	264.4	49.2	30	3	6	5
Melastomataceae	52	187.6	81.7	11	9	2094	5130
August							
Asteraceae	84	203.4	79.6	13	8	610	2147
Campanulaceae	43	161.2	90.0	13	9	419	1125
Caryophyllaceae	7	195.5	91.0	18	9	405	844
Clusiaceae	21	229.6	89.9	13	7	21	40
Fabaceae	89	162.0	78.0	14	8	2145	11447
Lamiaceae	16	199.1	62.8	13	6	40	93
Liliaceae	12	286.0	16.2	18	8	295	692
Melastomataceae	29	193.8	71.4	11	8	1802	5295
September							
Asteraceae	36	195.1	92.5	14	8	1219	4083
Campanulaceae	9	221.6	75.1	14	5	8	7
Caryophyllaceae	1	273.7	NA	8	NA	39	NA
Fabaceae	8	122.3	15.7	26	4	12	8
Lamiaceae	1	236.5	NA	18	NA	1	NA
October							
Asteraceae	37	224.3	72.0	17	9	1912	11277
Campanulaceae	5	190.6	91.4	22	9	471	420
Ericaceae	2	97.4	5.8	0	0	528	152
Fabaceae	2	104.9	31.6	11	9	2	2

**Table 8** Cluster analysis for landscape characteristics associated with the top nine families in terms of flowering counts around Lake Issaqueena, SC in 2012

	Cluster				
	1	2	3	4	5
Family					
Asteraceae	8	14	510	0	1
Campanulaceae	0	5	92	0	0
Caryophyllaceae	1	5	76	0	0
Clusiaceae	0	3	81	0	0
Ericaceae	2	3	100	0	0
Fabaceae	3	12	282	1	1
Lamiaceae	0	1	100	0	0
Liliaceae	0	1	131	0	0
Melastomataceae	12	9	91	3	0
Parameter					
Slope Aspect (°)	179	141	215	262	198
Simple Slope (%)	5	7	16	2	1
Flow Accumulation	12870	3260	57	41257	81820

4 Conclusions

This study examined the effects of environmental factors (soil type, slope class, slope aspect, and flow accumulation) on spatio-temporal patterns of flowering in forest ecosystems.

(1) The spatio-temporal analysis of flowering for all plants around Lake Issaqueena indicated significant differences in flowering by plant family, soil type, slope class, slope aspect, and flow accumulation for all months ( $p=0.000$ ), across month ( $p=0.000$ ), with the exception of flow accumulation across months ( $p=0.162$ ). Area normalized differences in flowering by month for slope and slope aspect between March and October were significant ( $p=0.000$ ) with the exception of September for slope ( $p=0.075$ ), and March for slope aspect ( $p=0.099$ ). This is new evidence that flowering is influenced by microtopography and soil type.

(2) A cluster analysis using flowering counts for the nine plant families with the highest flowering numbers indicated no unique separation by cluster, but implied that the majority of these families were flowering on strongly sloping (9%–16%) areas with southwest (202.5°–247.5°) aspects, and low flow accumulation (0–200). This shows a grouping of the most predominantly flowering plants in a particular slope, aspect and flow accumulation areas.

(3) The use of GPS-enabled camera, LiDAR derived data, and GIS are important tools for phenological studies and monitoring in forested ecosystems. As demonstrated with this study, it is now possible to analyze the relationship of slope, aspect, or predicted water flow to flowering because of the availability of more accurate ground topography represented by the LiDAR based DEMs. Although, the climate is expected to change at the rates exceeding geomorphological changes, the landscape characteristics are essential in identifying and

protecting the “refugia” (habitats suitable for retreat, persistence, and potential expansion under changing environmental conditions).

## Acknowledgments

This research was made possible with funding from Clemson University. This is technical contribution No. 6345 of the Clemson University Experiment Station. This material is based upon work supported by NIFA/USDA, under project number SC-1700452.

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