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# Herbarium Records Reveal Earlier Bloom Times in Three Southern Appalachian Plant Species

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# HERBARIUM RECORDS REVEAL EARLIER BLOOM TIMES IN THREE SOUTHERN APPALACHIAN PLANT SPECIES

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## ABSTRACT

Plant phenology, especially the onset of flowering in angiosperms, is a useful tool for studying the effects of climate change on native flora because it is influenced by temperatures. Numerous studies in different biomes have provided evidence of earlier bloom times in response to increasing temperatures. We examined herbarium specimen data to determine whether three spring-blooming species (*Sanguinaria canadensis*, *Iris cristata*, and *Trillium rugelii*) at the southern terminus of the Appalachians exhibit a similar change in onset of flowering over several decades. All three species exhibited significantly earlier flower onset during the past 120 years, a change that could have reproductive and ecological consequences.

***Keywords:*** phenology, climate change, herbarium specimens, flowering

## INTRODUCTION

Within the past century, global temperature has risen approximately 0.74 °C (Bertin 2008). The consequence of this climate change includes melting glaciers and the extinction of species on high elevation mountain tops and species with polar distributions (Miller-Rushing et al. 2006; Parmesan 2006; Inouye 2008). Climate change is viewed as one of the more important threats to global biodiversity (Amano et al. 2010). Scientists continue to examine widespread effects of climate change, including its effects on plants. Plants are directly dependent on temperature, light, and moisture cues for development during seasonal transitions; therefore, plant phenological shifts in relation to climate change have received increased attention because these shifts are readily observable. Authors have employed different approaches to assess changes in plant phenology, including historical records of flowering phenology (McEwan et al. 2011), onset of bud burst (Nordli et al. 2008), and case studies (Gaira et al. 2011). Because herbarium specimens represent historical records of plant bloom times, they have been increasingly used as an informative character for analysis, potentially revealing "the footprint of climate change" (Callinger et al. 2013).

Many studies across biomes have demonstrated earlier onset of flowering in response to warming over time in North America (Abu-Asab et al. 2001; Beaubien and Hamann 2011; Callinger et al. 2013; Houle 2007; Primack and Miller-Rushing 2012; Primack et al. 2004; Panchen et al. 2012; Park and Schwartz 2015), Europe (Amano et al. 2010; Fitter et al. 1995; Fitter and Fitter 2002; Menzel et al. 2006; Diskin et al. 2012; Robbirt et al. 2011; Amano et al. 2010), Asia (Gaira et al. 2011), and Australia (Keatley et al. 2004; Gallagher et al. 2009; Chambers et al. 2013; Beaumont et al. 2015). To our knowledge, no research has examined possible phenological changes in the southern Appalachian region, an area that includes the Great Smoky Mountains, one of the most botanically rich regions in the eastern United States (Jenkins 2007). To assess possible phenological response to climate change in the southern Blue Ridge (BR) of Georgia, Tennessee, and the Carolinas, we analyzed historical bloom times for three species: bloodroot (*Sanguinaria canadensis* L., Papaveraceae), dwarf crested iris (*Iris cristata* Ait., Iridaceae), and southern nodding trillium (*Trillium rugelii* Rendle, Liliaceae) (Figure 1).


***Figure 1.*** Plant species investigated. *Iris cristata* (A), *Sanguinaria canadensis* (B), and *Trillium rugelii* (C).

## MATERIALS & METHODS

The spring ephemerals we examined were chosen because they are native to the southeastern United States, bloom early in the spring, and have relatively short bloom periods. In addition, these plants are rhizomatous perennials that produce a single flower during their bloom period, thus avoiding the confound of sequential flowering within an inflorescence. Phenological bloom data (collection date and location) were collected from herbaria at the University of Georgia, University of Tennessee (Knoxville), University of North Carolina (Chapel Hill), and Clemson University (Figure 2). Available herbarium records ranged from 1886 to 2014. Only herbarium specimens collected in the counties located within the southern BR province (Figure 3) were included in the analysis. Flowering day, a conventional measure that corresponds to the number of days from the first of January to the collection date, was determined for each specimen. Leap years were accounted for. We used ANCOVA to assess overall trends and potential differences among taxa during the past 120 years using year as the covariate and taxon as the categorical independent variable.

## RESULTS

A total of 293 specimens were recorded (*I. cristata*, $N$ = 118; *S. canadensis,* $N$ = 62; *T. rugelii*, $N$ = 113), and collection dates ranged from 1886 to 2014. Analysis revealed a distinct pattern (Figure 4) of earlier bloom time (17.5 days earlier) across all species during the past century [a significant effect of year (ANCOVA, $F_{1,287} = 16.104$, $P < 0.001$)]. Significance is not a consequence of data prior to 1922. Removing these data from the analysis also resulted in a significant effect of year ($F_{1,278} = 8.69$, $P < 0.005$). There was no significant difference among species [no overall effect of taxon ($F_{2,287} = 1.487$, $P$ = 0.228)], and there were no significant differences among slopes for each species ($F_{2,287}$ = 1.63, $P = 0.197$).

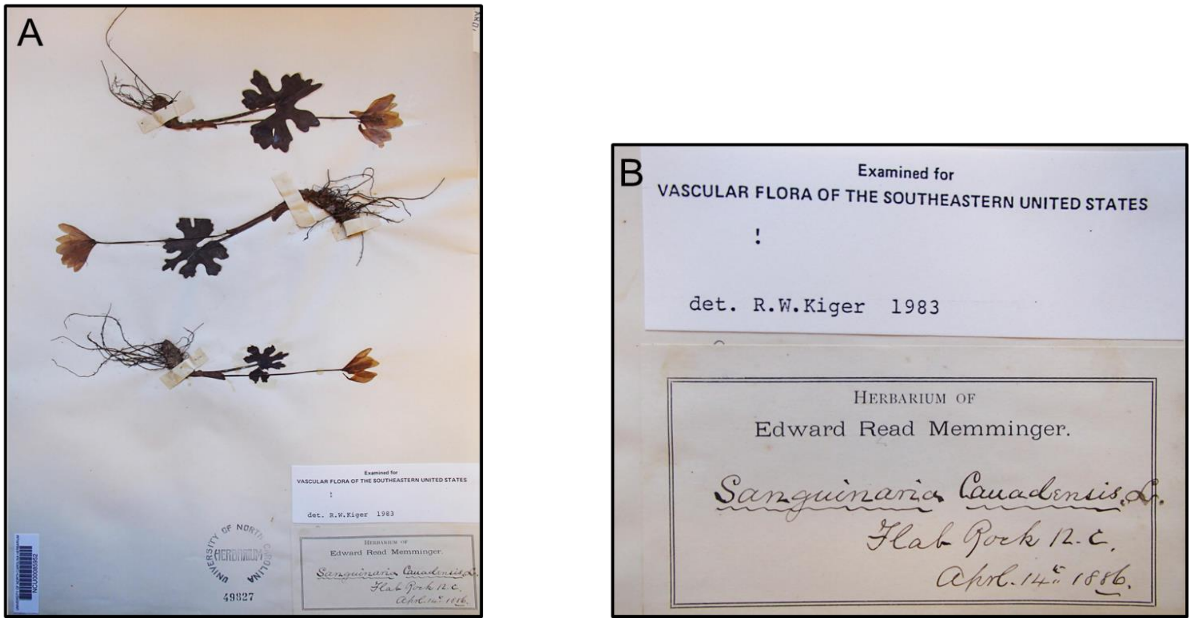


***Figure 2.*** Example of a *Sanguinaria canadensis* herbarium specimen (A) and the attached data label (B).

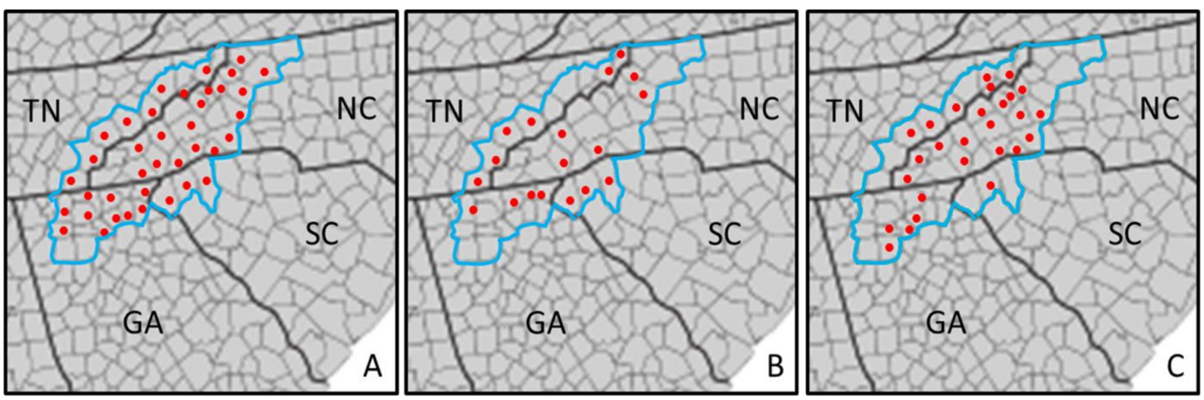


***Figure 3***. Data distribution maps. Dots indicate counties for herbarium specimen data. Maps A, B, and C represent *I. cristata*, *S. canadensis*, and *T. rugelii*, respectively. The blue line identifies the Blue Ridge physiographic region under study in Georgia (GA), Tennessee (TN), South Carolina (SC), and North Carolina (NC). (https://commons.wikimedia.org /wiki/File:Usa_counties_large.svg; the map image is in the public domain).

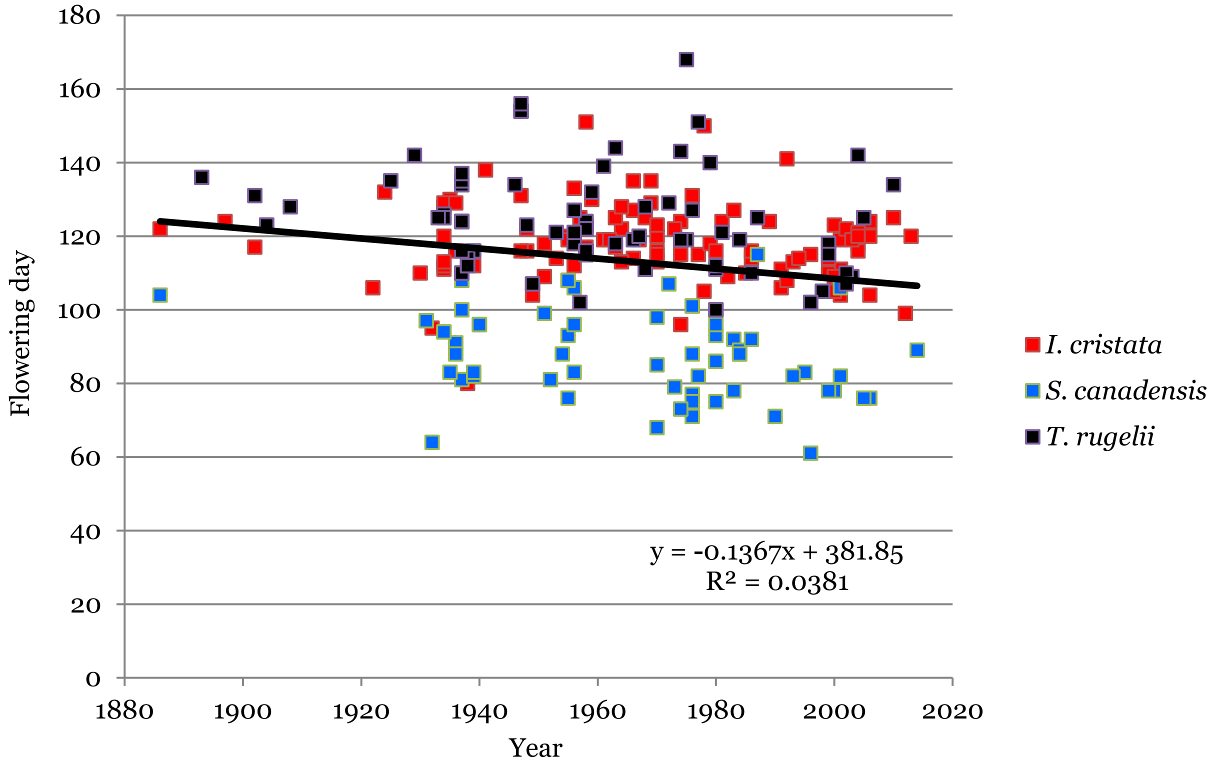


***Figure 4.*** Bloom times of three southern Appalachian species. Herbarium specimen collection dates were used to plot the flowering day of 293 specimens of species *I. cristata, S. canadensis,* and *T. rugelii* against their year of collection. The regression line indicates significantly earlier flowering dates over time (ANCOVA, $F_{1,287} = 16.104$, $P < 0.001$).

## DISCUSSION

Our results indicate a significant trend in earlier bloom times (or decrease in flowering day) for *I. cristata, S. canadensis,* and *T. rugelii* within the past century. Analysis revealed a 17.5 day earlier onset of flowering day in the past 128 years, approximately 1.4 days per decade. Our results parallel earlier blooming trends reported on different species of native plants in other regions, including trends over larger (Zalamea et al. 2011; Ellwood et al. 2013) and restricted (Primack et al. 2004; Panchen et al. 2012; Fitter and Fitter 2002; Park and Schwartz 2015; Houle 2007) geographic scales. Similar changes have also been documented in crop plants (Williams and Abberton 2004; Hu et al. 2005; Orlandi et al. 2005; Craufurd and Wheeler 2009).

To our knowledge, this is the first report of earlier onset in bloom times of native species in the southern Appalachian region. Previous studies in the U.S. have focused on species in the northeast (Primack et al. 2004; Panchen et al. 2012; Miller-Rushing et al. 2006) and northcentral regions (Callinger et al. 2013), and Rocky Mountains (Miller-Rushing et al. 2008). The study of floral phenological responses to temperature increase can help researchers assess future ecological implications resulting from climate change (Parmesan 2006), including the alteration of species interactions such as pollination, herbivory, and the formation of invasive communities (Bertin 2008). Warming trends can have far-reaching effects on flowering and fruiting (Hughes 2000) and perhaps lifetime survivorship. We do not know whether the plants in our study have experienced altered leaf emergence, seed production, or changes in other aspects of plant life history during the past twelve decades as a consequence of warming trends. We are unaware of published data on changes in flower visitors to these species during this period that might yield evidence of phenological uncoupling. Experimental study of increasing temperature on native flora in southern Appalachian ecosystems may underpredict the responses of plants to climate change (Wolkovich et al. 2012), but they can certainly broaden our understanding of the impact of climate change on these systems. With a predicted increase in global surface temperature in the next century exceeding 2 °C (Meehl et al. 2007), such studies certainly merit further attention.

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