Final Report to Meg and Bert Raynes Wildlife Fund

Date: January 6, 2016

Project title: For everything there is a season – but the seasons, they are a changing: Phenology shifts in the Tetons

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Project Objectives:

The objectives for this one-year pilot project were:

1. Extract and put into digital format usable, quantitative data from Frank Craighead Jr.'s original phenology notes. The specific output will be a table of species with date and location data for each observation.
2. From this data, identify a set of species (tied to specific locations) that will be used for further research – to compare contemporary phenology against baseline phenology. The specific output will be a data collection plan / protocol for the second phase of the project.
3. Develop two pilot phenology walks in easily-accessible locations and begin using them for citizen science data collection and education.

Project Activities:

Objective 1:

- In June 2015, I worked with Charlie Craighead and Shirley Craighead to locate and scan nearly 100 pages of Frank Craighead's notes and phenological observations from the 1970s and 80s. Some of the pages were easily legible and some were in bad condition, with either badly faded type-written ink or difficult to read hand writing, and some were smoke-damaged from a fire in 1978 that burned Frank's cabin to the ground.
- With the help of a U.S. Geological Survey volunteer, Lindsey Bargelt, we identified all of the plant-related observations in these notes and entered them into a series of excel spreadsheets.
- We entered nearly 800 observations from 258 species of plants. All genus and species names were cross-checked using the USDA Plants database (plants.usda.gov).
- Plant observations were scored as representing first presence of leaves, first presence of buds, first flower, peak flower, and occurrence of fruits or seeds. Where available, location data and any other notes were recorded.
- Data were cleaned up as much as possible to ensure consistent entries.
- The objective laid out in the proposal was fully met.

Objective 2:

- All data were sorted by species, year, and ecological event. I identified the species that had at least two (preferably three) observations from the 1970s – sufficient replication to make contemporary comparisons. This resulted in a list of 54 species suitable for future analysis of first flowering date and 7 species suitable for analysis of first buds or leaf-out.
- Many of these species also had observations from 1988, an unusually dry and hot spring / summer that is often considered a harbinger of future conditions under a warming climate.

- This prompted me to analyze the available first flowering data to examine (a) how well spring temperatures predicted first flowering time, and (b) whether differences in flowering time were significantly different between 1988 and the available dates from the 1970s.
- Specifically, I:
    - Calculated the average minimum and maximum temperatures for March-June of each year
    - Used linear regressions to relate temperature to first flowering date for each species. Average minimum temperature was consistently a better predictor, so I report only results from that variable.
    - Within each species, I calculated the difference in first flowering date between the following pairs of years (years for which there was adequate data): 1988-1975, 1988-1976, 1988-1979
    - I then calculated the average difference in first flowering date across all species and related it to the difference in mean minimum temperature for each year pair.
- The results of these analyses (see Results, below) demonstrate effectively that the Craighead data are robust and can be used to examine the effects of temperature change on first flowering time for a wide variety of plants. This essentially provides "proof of concept" that we can proceed to the next phase of the project and compare first flowering time from the 1970s to current patterns.
- The objective laid out in the proposal was exceeded.

Objective 3:

- This objective was postponed due to the unexpected closure of the Teton Research Institute of Teton Science Schools and lack of matching funds and staff resources to achieve this objective.
- This change in plans was approved by the board of the Meg and Bert Raynes Wildlife Fund.

Other project activities:

- In summer 2015, I contacted Dr. Richard Primack, a professor at Boston University who has pioneered the use of historical data to examine how climate change impacts phenology. He has successfully compared phenology observations made by Henry David Thoreau to contemporary phenology patterns in the Concord, MA area. After extensive correspondence, Dr. Primack decided to come visit Jackson and the GYE. Geneva Chong and Frances Clarke and I hosted his visit.
- While here, Dr. Primack gave a public talk at the Teton County Library, detailing his findings about the impacts of climate change on plants, birds, and insects from 15 years of work with historical phenology data in the Concord region.
- We also discussed the Craighead data and lessons that Primack has learned from his work with other historic data sets that will benefit our project.
- We discussed the larger idea of searching for and assembling historic data from around the GYE on plants, migratory bird arrivals, and other ecological events. We also met with and discussed these ideas with Ann Rodman, who is leading climate change work at Yellowstone National Park.

Results

Spring (March-June) average minimum temperature data ranged from 25.0 °F to 30.2 °F (Table 1).

Table 1. Mean spring (March-June) minimum and maximum temperatures, derived from TopoWx-corrected data from the Philip's Bench weather station. Temperatures are presented for the years for which flowering time data were available.

Year	Mean min temp (°F)	Mean max temp (°F)
1975	25.05	42.47
1976	26.54	46.87
1977	28.67	48.95
1979	28.79	48.08
1988	30.24	51.19

First flowering date for the majority of plant species was negatively correlated with mean spring minimum temperature (Figure 1). In many cases there were only 3 data points available, reducing the power to detect statistically significant trends; nevertheless, many regressions were statistically significant and had high R^2 values, indicating that a large amount of variation in flowering time could be explained by mean minimum temperatures. Some species had remarkably tight correlations with temperature data (e.g. *Amelanchier alnifolia; Epilobium angustifolium; Heracleum lanatum; Hydrophyllum capitatum; Potentilla gracilis*). Some species did not show much relationship at all with temperature (e.g. *Prunella vulgaris; Prunus virginiana; Shepherdia canadensis*).

The slope of these regressions also varied (Table 2; Figure 1). Species with particularly steep slopes – indicating high sensitivity to temperature – were *Orogenia linearifolia, Viola adunca, Lomatium ambiguum, Galium boreale, Geum triflorum, Taraxacum officinale, Arnica cordifolia*, and *Cirsium foliosum*.

Across all species analyzed, first flowering time was, on average, 25.1 days earlier in 1988 compared to 1975 (Figure 2). Even 1979, which was only 1.4 °F cooler than 1988, had first flowering dates averaging 12 days later than in 1988.

Table 2. List of species suitable for analysis of first flowering date, with slope of regression against spring temperature depicted in Figure 1. Particularly steep slopes are highlighted.

Scientific name	Common name	Slope of regression
Actaea rubra	red baneberry	-3.22
Agastache urticifolia	giant hysop	-3.73
Amelanchier alnifolia	saskatoon serviceberry; western serviceberry	-3.45
Arnica cordifolia	heartleaf arnica	-6.34
Balsamorhiza sagittata	arrowleaf balsamroot	-3.64
Calypso bulbosa	fairy slipper	-4.06
Cirsium foliosum	elk thistle	-3.99
Cirsium vulgare	bull thistle	-6.18
Claytonia lanceolata	spring beauty	-1.63
Clematis columbiana	rock clematis	-2.62
Clematis hirsutissima	hairy clematis; sugarbowl	-2.20

Corallorhiza striata	stripted coralroot; hooded coralroot	-5.10
Delphinium nelsonii	larkspur	-3.09
Disporum trachycarpa	fairy bells	-2.15
Dodecatheon pauciflorum	shooting star	-4.39
Epilobium angustifolium	fireweed	-3.27
Fragaria vesca	woodland strawberry	-4.94
Fritillaria atropurpurea	leopard lily; spotted fritillary	-4.07
Fritillaria pudica	yellow fritillaria	-3.73
Galium boreale	northern bedstraw	-7.31
Geranium viscosissimum	sticky purple geranium	-4.99
Geum triflorum	old man's whiskers; long-plumed avens	-6.96
Gilia aggregata	scarlet gilia	-4.52
Helianthus annuus	common sunflower	-3.06
Heracleum lanatum	cow parsnip	-4.27
Hydrophyllum capitatum	waterleaf; ballhead waterleaf	-3.42
Linum lewisii	Lewis/blue/prairie flax	-4.49
Lithophragma parviflorum	star flower	-4.13
Lithospermum incisum	narrowleaf stoneseed; Gromwell; puccon	-3.09
Lomatium ambiguum	Wyeth biscuitroot	-8.45
Lupinus parviflorus	lodgepole lupine	-2.06
Mahonia repens	creeping barberry; Oregon grape, holly grape	-4.26
Orogenia linearifolia	snow drops, Indian potato	-10.23
Pedicularis groenlandica	elephant's head; elephantshead lousewort	-3.77
Potentilla fruticosa	shrubby cinquefoil	-1.74
Potentilla gracilis	slender cinquefoil	-4.23
Prunella vulgaris	prunella, common selfheal	-1.51
Prunus virginiana	black chokecherry	0.40
Purshia tridentata	antelope bitterbrush	-2.98
Ranunculus glaberrimus	sagebrush buttercup	-4.04
Ranunculus sp.	snowbank buttercup	0.39
Rosa woodsii	woods' rose	-2.36
Shepherdia canadensis	buffalo berry	-0.87
Sisyrinchium sarmentosum	pale blue-eyed grass; mountain blue-eyed grass	-4.53
Smilacina stellata	wild lily of the valley	-3.38
Taraxacum officinale	dandelion	-6.33
Valeriana dioica	tobacco root; valerian	-4.64
Viola adunca	early blue violet, or hookedspur violet	-9.04
Viola nuttallii	yellow violet; Nuttall's violet	-1.74

Based on these results, we have identified a list of common, recognizable, and ecologically important species that we recommend as highest priority for future monitoring and/or citizen scientist data collection (Table 3). For a complete list of possible species for future monitoring (species with adequate data from the 1970s), see Appendix I.

Scientific name	Common name	Attribute to monitor
Acer glabrum	mountain maple	First leaves and buds
Populus tremuloides	aspen	First leaves and buds
Amelanchier alnifolia	saskatoon serviceberry; western serviceberry	First flowers

Arnica cordifolia	heartleaf arnica	First flowers
Balsamorhiza sagittata	arrowleaf balsamroot	First flowers
Calypso bulbosa	fairy slipper	First flowers
Delphinium nelsonii	larkspur	First flowers
Epilobium angustifolium	fireweed	First flowers
Fragaria vesca	woodland strawberry	First flowers
Geranium viscosissimum	sticky purple geranium	First flowers
Gilia aggregata	scarlet gilia	First flowers
Mahonia repens	creeping barberry; Oregon grape, holly grape	First flowers
Orogenia linearifolia	snow drops, Indian potato	First flowers
Pedicularis groenlandica	elephant's head; elephantshead lousewort	First flowers
Prunus virginiana	black chokecherry	First flowers
Purshia tridentata	antelope bitterbrush	First flowers
Rosa woodsii	woods' rose	First flowers
Shepherdia canadensis	buffalo berry	First flowers
Taraxacum officinale	dandelion	First flowers

Conclusions and Next Steps

We found a range of variation in how sensitive plant flowering times in the Tetons are to temperature. Some species shifted their date of first flower dramatically in response to small differences in average spring temperature, while others shifted somewhat and still others not at all. This degree of variation is consistent with the results of other studies of plant phenology in other locations, such as the Concord, MA and the Rocky Mountain Biological Laboratory, CO (Miller-Rushing and Primack, 2008; Primack et al., 2009; Calinger et al., 2013; CaraDonna et al., 2014).

If we consider 1988 to represent the conditions of the present and/or future, our preliminary analyses indicate that plant flowering times are likely quite different, on average, now compared to the 1970s. Of the past 10 springs, five have had average minimum temperatures as warm or warmer than 1988 spring minimum temperatures. Given how closely many plant species' flowering times track spring temperatures, we can expect that plants are now flowering substantially earlier in many years than they were in the 1970s.

Shifts in plant phenology due to a warming climate are often considered a first indicator of the impacts of climate change. Plants that are less "plastic" (changeable) in their response to temperature have been shown to be more likely to go locally extinct (Primack et al., 2009). Changes in phenology can also lead to "ecological mismatches" or asynchronies between events that were once more synchronized. For example, migratory birds often arrive at the same time of year regardless of temperature (since their migrations are cued on day length), but if plants flower earlier and insects emerge earlier, migratory birds may miss important sources of spring food.

Based on our findings to date, it is clear that the Craighead data provide a valuable baseline against which we can compare contemporary patterns of plant flowering time and leaf-out time. By collecting contemporary data, we can improve our understanding of how climate change is impacting the flora and fauna of the Tetons. It is also a valuable way to engage with and educate citizens of the Tetons region. Plant phenology data collection is well-suited to citizen science, and many resources exist to facilitate this (e.g. the National Phenology Network's Nature's Notebook initiative – https://www.usanpn.org/natures_notebook). By creating citizen science opportunities, we can educate residents of the Tetons region about the changes that climate change is causing in this area.

We plan to take the following next steps towards collecting contemporary (and potentially long-term) phenology data and creating opportunities for citizen science:

1. In spring and summer 2016, begin looking for flowering plants of the top priority species (Table 3). Searching will focus on the area around Blacktail Butte, covering these major habitat areas: sage flats, dry aspen woodlands, south-facing slopes, and riparian / moist forested areas.
2. In summer 2016, we hope to engage a USGS intern to assist with searching for flowering plants of these key species.
3. Record precise locations for all flowering plants of these key species.
4. Based on this information, the intern will put together maps and recommendations for where to search for each species, as well as a brochure with instructions for data collection for any future citizen scientist volunteers. This information will be vital to planning a true field season of data collection in 2017.
5. We will also present this project to biologists at Grand Teton National Park and begin the process of applying for a permit to collect data.
6. We will also seek more funds for the 2017 spring-summer season and plan to begin actual data collection then.

Acknowledgements

We thank the Craighead family for permission to access and copy Frank Craighead, Jr.'s data and Charlie Craighead and Shirley Craighead for their help in locating and scanning all data sheets. We are deeply grateful to Lindsey Bargelt for volunteering many hours of her time to help enter data. We are also grateful to Frances Clarke for her thoughtful input and encouragement, and to Richard Primack for his practical advice and enthusiasm for phenology data. Finally, we thank Sara Fagan for her support and grant administration.

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Appendix I: Possible Species for Current / Future Monitoring

Non-flowering phenology

- Acer glabrum (mountain maple) – maybe – first leaves and buds
- Alnus tenuifolia (Alder) – first leaves
- Frasera speciosa (green gentian) – first leaves
- Populus balsamifera supsp. trichocarpa (black cottonwood) – first leaves
- Populus (cottonwood) – budding – if we can decide that this is not black cottonwood
- Populus tremuloides (aspen) – green leaves, budding
- Urtica gracilis (nettle) – green leaves

First flower

- Actaea rubra (red baneberry)
- Agastache urticifolia (giant hyssop)
- Amelanchier alnifolia (serviceberry)
- Arnica cordifolia (heartleaf arnica)
- Balsamorhiza sagittata (arrowleaf balsamroot)
- Calypso bulbosa (fairy slipper)
- Cirsium foliosum (elk thistle)
- Cirsium vulgare (bull thistle)
- Claytonia lanceolata (spring beauty)
- Clematis columbiana (rock clematis)
- Clematis hursutissima (hairy clematis)
- Corallorhiza striata (striped coralroot)
- Delphinium nelsonii (larkspur)
- Disprum trachycarpa (fairy bells)
- Dodecatheon pauciflorum (shooting star)
- Epilobium angustifolium (fireweed)
- Fragaria vesca (woodland strawberry)
- Fritillaria atropurpurea (spotted fritillary / leopard lily)
- Fritillaria pudica (yellow fritillaria)
- Gallium boreale (northern bedstraw)
- Geranium viscosissimum (sticky geranium)
- Geum triflorum (old man's whiskers)
- Gilia aggregata (scarlet gilia)
- Helianthella uniflora (one-flower sunflower)
- Helianthus annus (common sunflower)
- Heracleum lanatum (cow parsnip)
- Hydrophyllum capitatum (waterleaf)
- Linum lewisii (blue flax)
- Lithophragma parviflorum (star flower)
- Lithospermum incisum (narrowleaf stoneseed / Gromwell)
- Lomatium ambiguum (Wyeth biscuitroot)
- Lupinus parviflorus (lodgepole lupine)
- Lupinus sericeus (silky lupine)
- Mahonia repens (Oregon grape / barberry)
- Mertensia ciliata (mountain bluebell)
- Oenothera caespitosa (tufted evening primrose)

- Orogenia linearifolia (snow drops)
- Pedicularis groenlandica (elephant's head lousewort)
- Potentilla fruticosa (shrubby cinquefoil)
- Potentilla gracilis (slender cinquefoil)
- Prunella vulgaris (prunella / common selfheal)
- Prunus virginiana var melanocarpa (black chokecherry)
- Purshia tridentata (antelope bitterbrush)
- Pyrola asarifolia (pink pyrola)
- Ranunculus glaberrimus (sage buttercup)
- Ranunculus sp. (snowbank buttercup)
- Rosa woodsii (wood rose)
- Shepherdia canadensis (buffaloberry)
- Sisyrinchium sarmentosum (blue-eyed grass)
- Smilacina racemosa (feather false lily of the valley / false Solomon's seal)
- Smilacina stellata (wild lily of the valley)
- Taraxacum officinale (dandelion)
- Valeriana dioica (tobacco root / valerian)
- Viola adunca (early blue violet)
- Viola nuttallii (yellow violet / Nuttall's violet)

Height of bloom

- Balsamorhiza sagittata (arrowleaf balsamroot)
- Eriogonum heracleoides (parsnipflower / buckwheat / umbrella plant)
- Helianthella uniflora (one-flower sunflower)

Figure 1 (page 1/6)

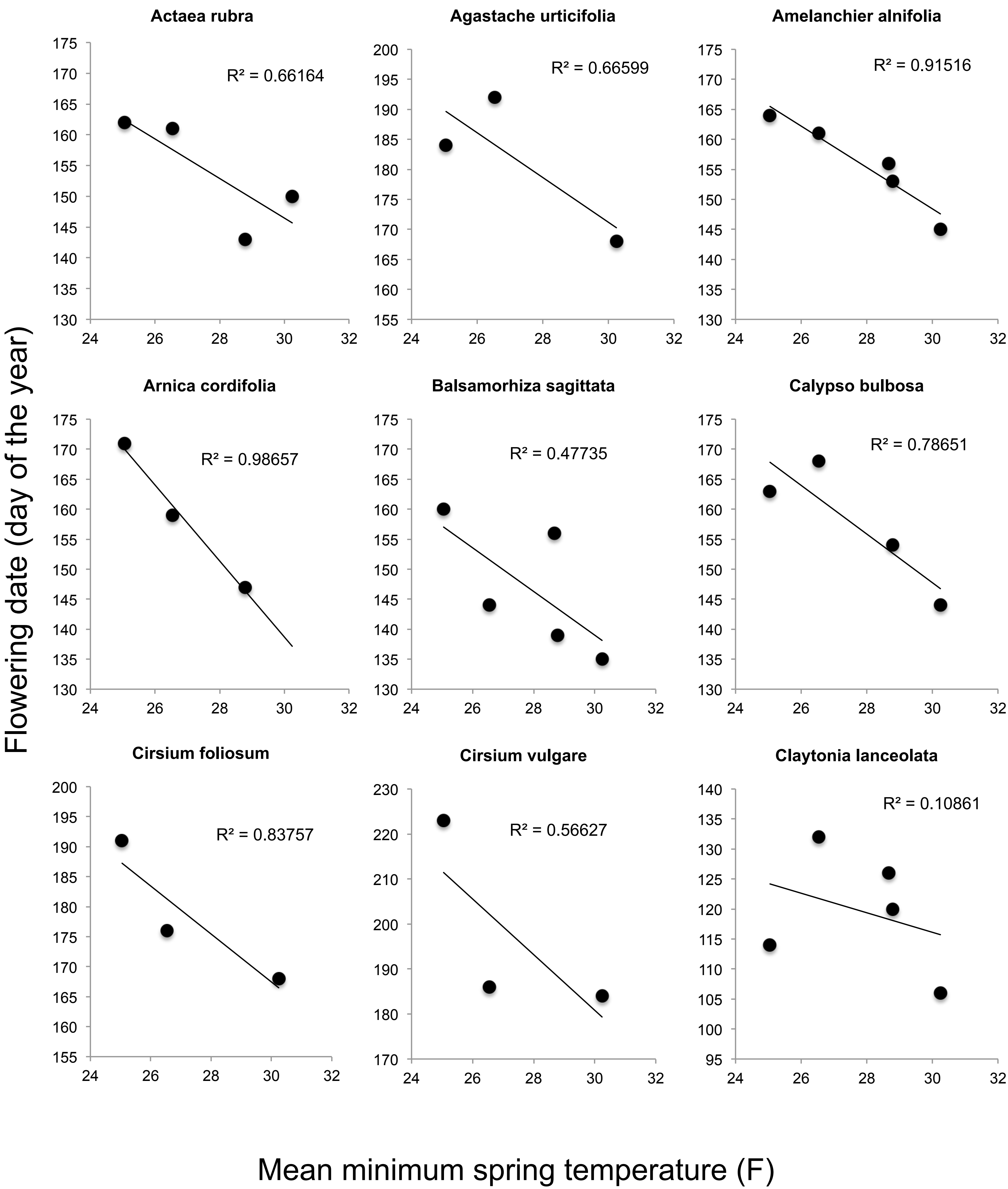
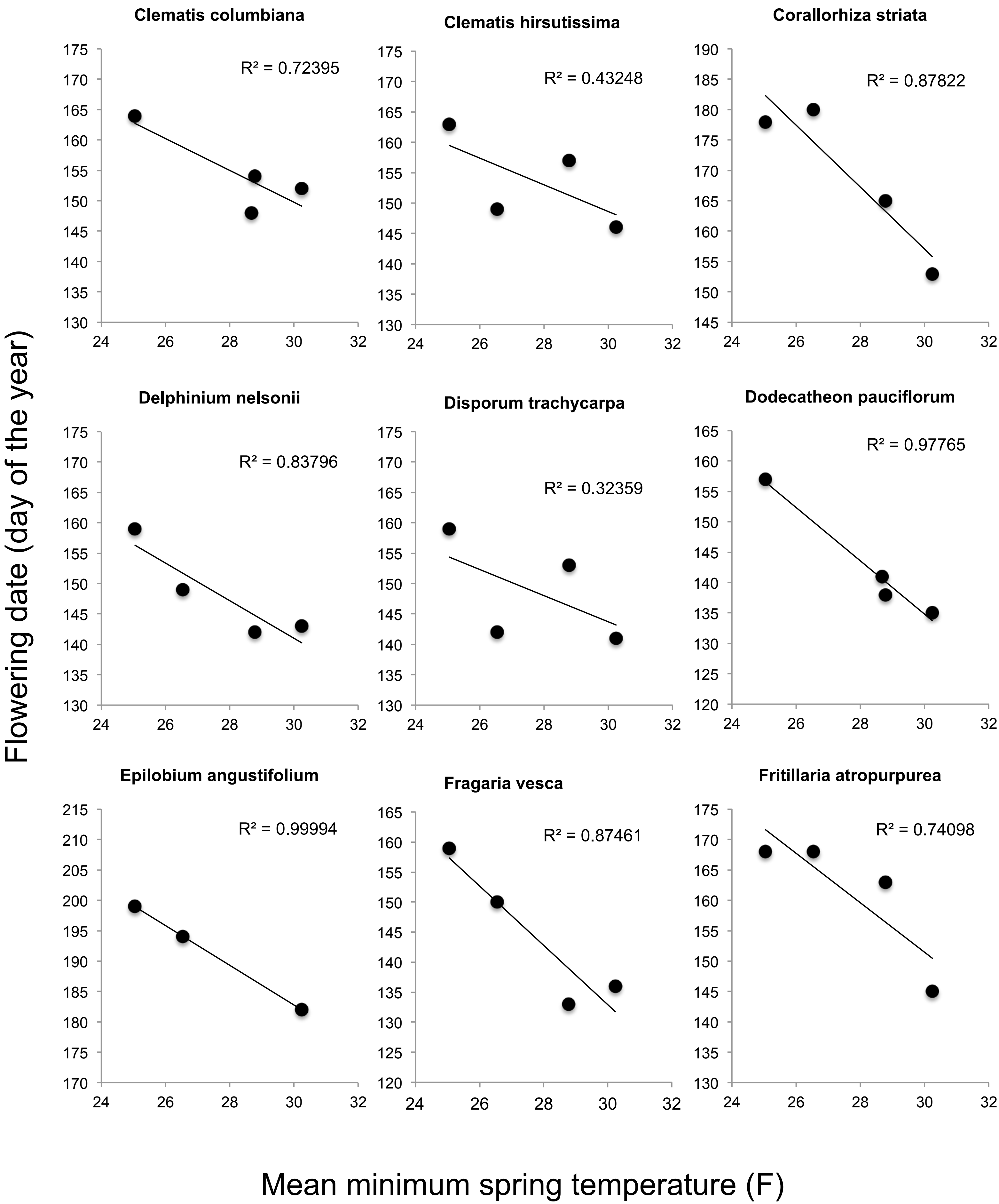


Figure 1 (page 2/6)



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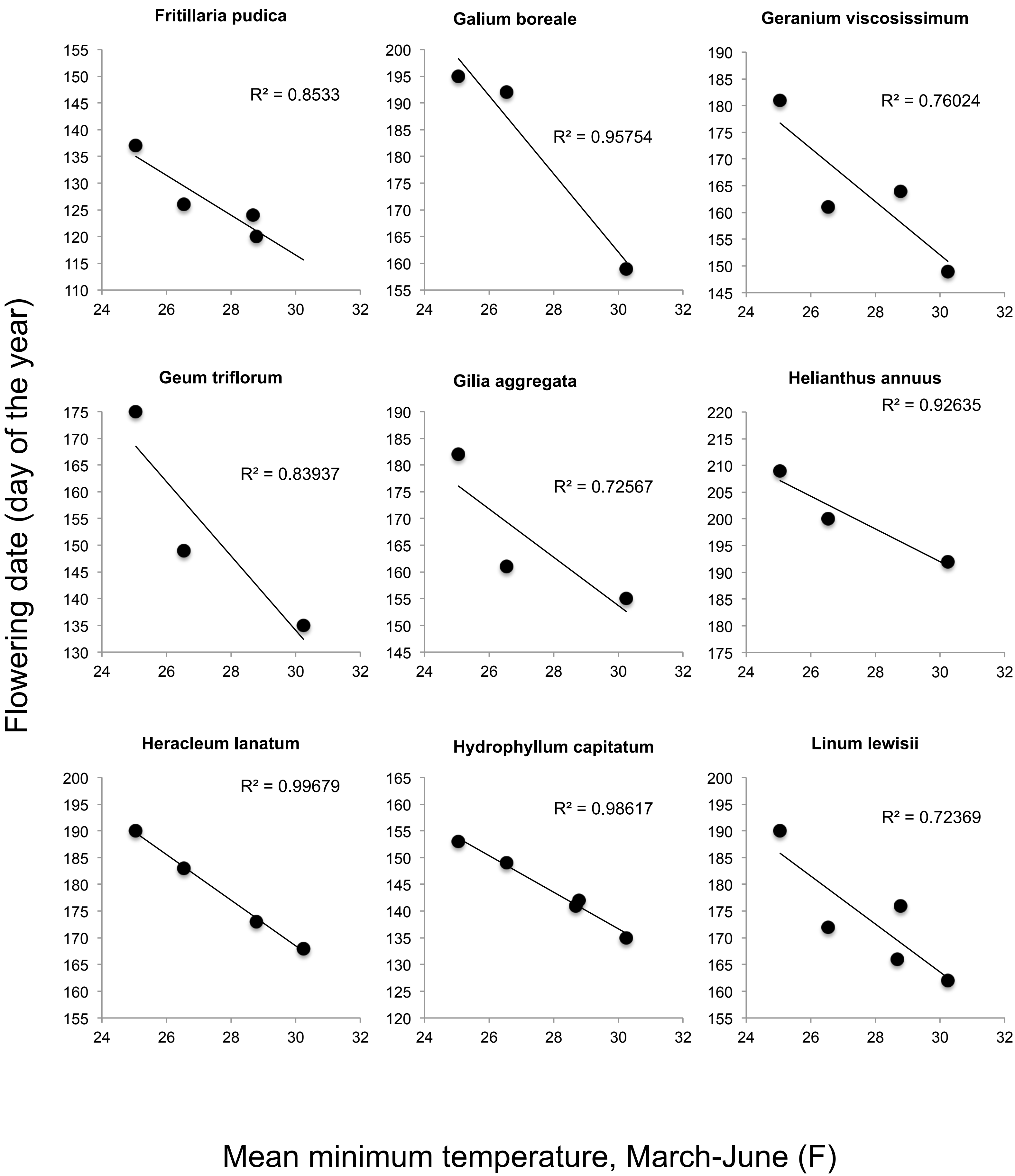

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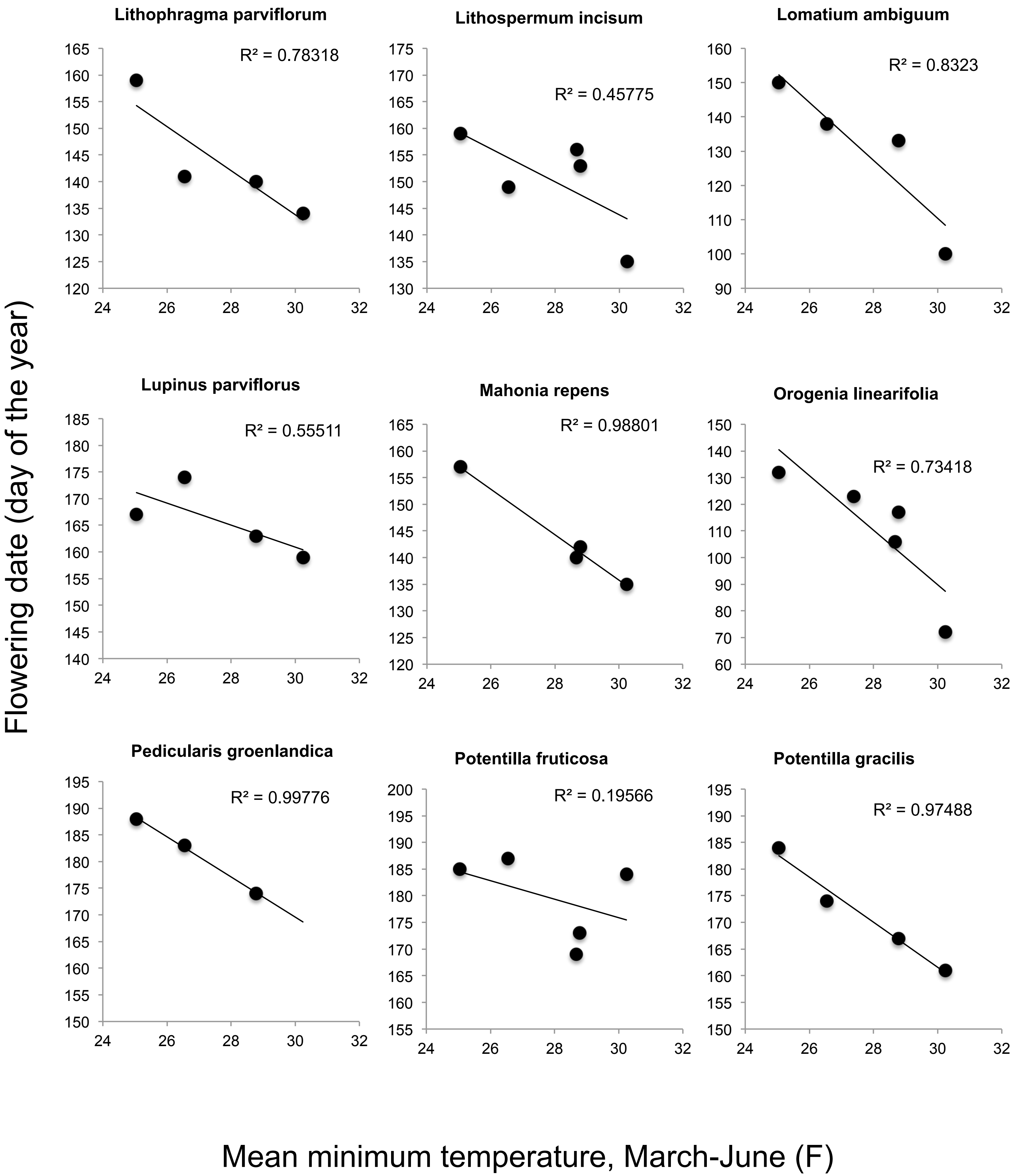

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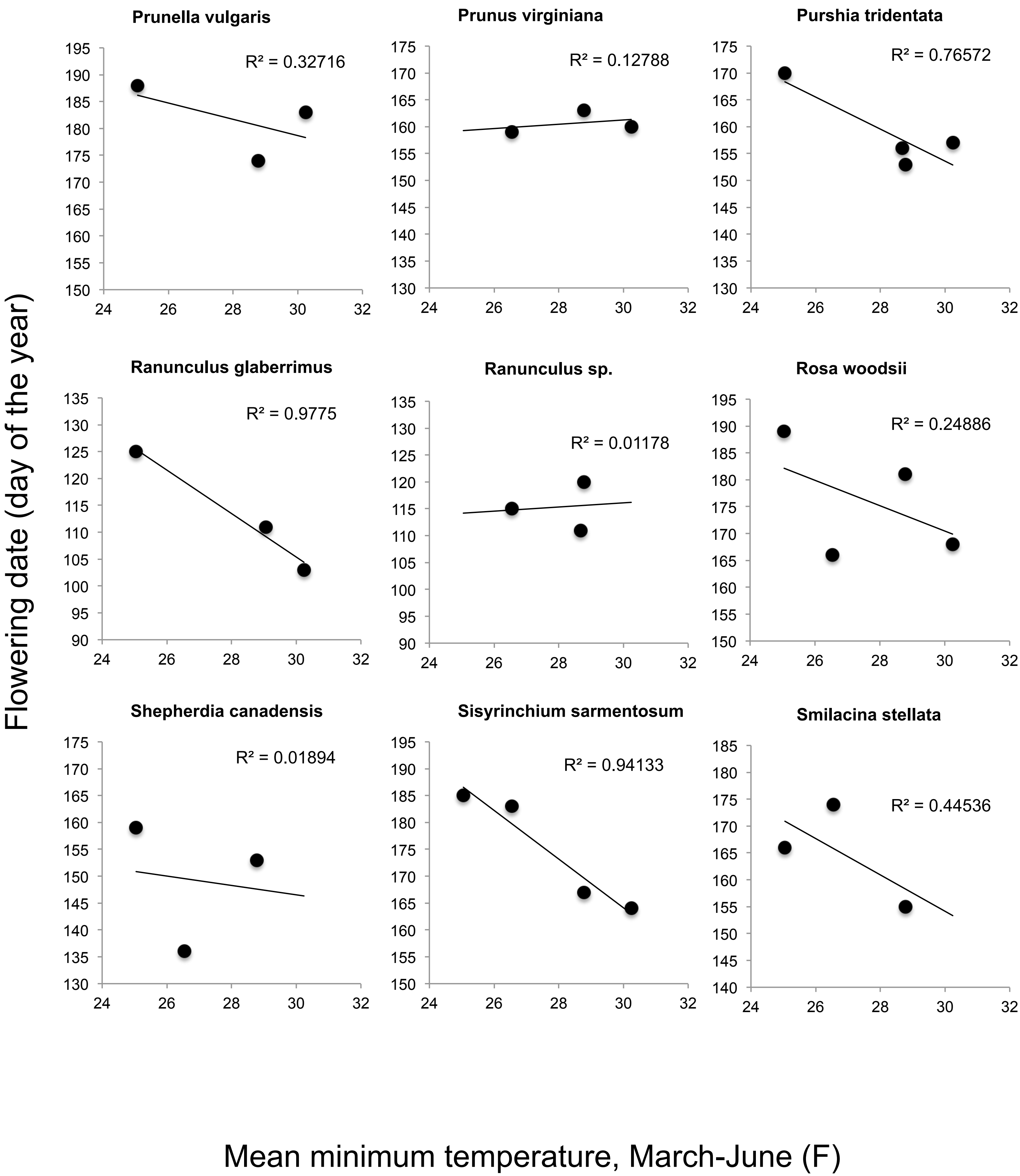

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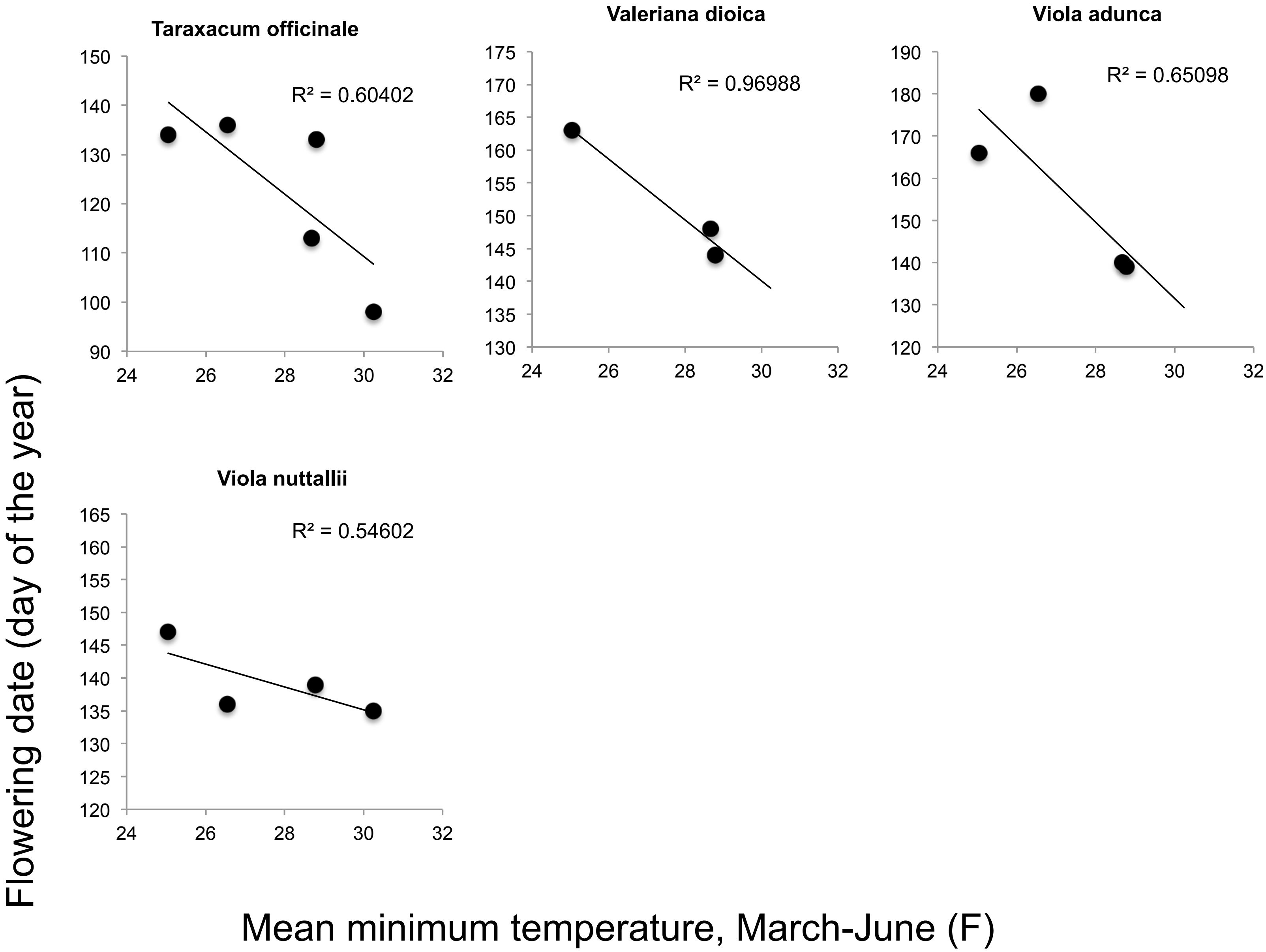

Figure 1. Regressions of first flowering date against mean mean minimum temperature during spring months (March-June). Flowering dates were sampled in five years: 1975, ‘76, ’77’, ‘79, and ’88.

Figure 2

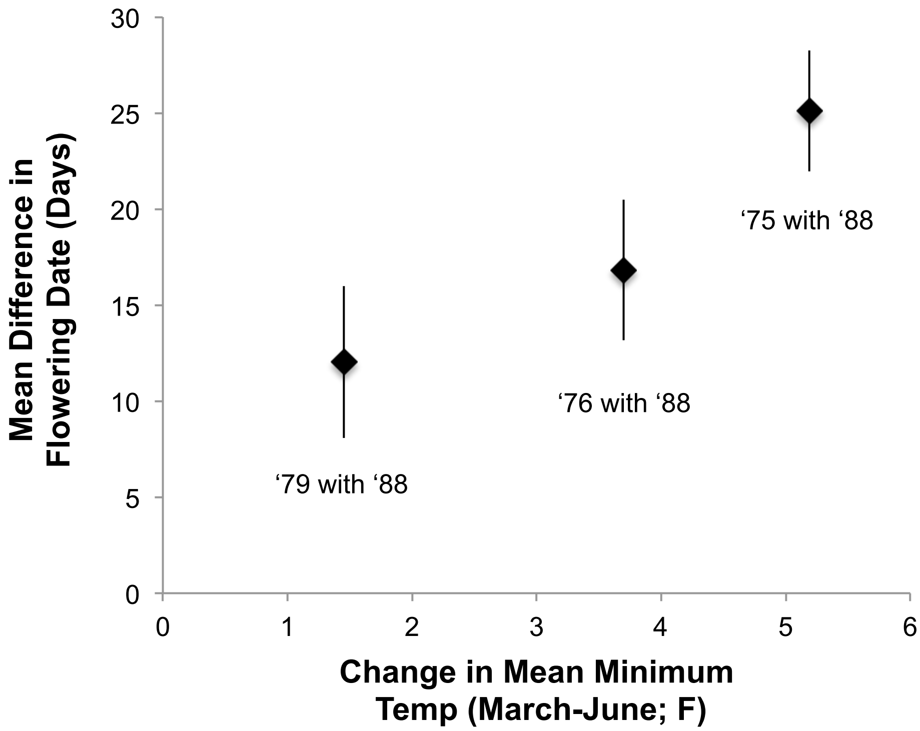

Figure 2. Mean (+-SE) difference in first fowering date (in pairwise year comparisons) for 49 species of plants as a function of difference in mean minimum temperature during spring (March-June) months. First flowering dates from 1988 are compared against earlier, cooler years.