Is Arctic plant phenological sensitivity to temperature evolutionarily conserved or related to life history?

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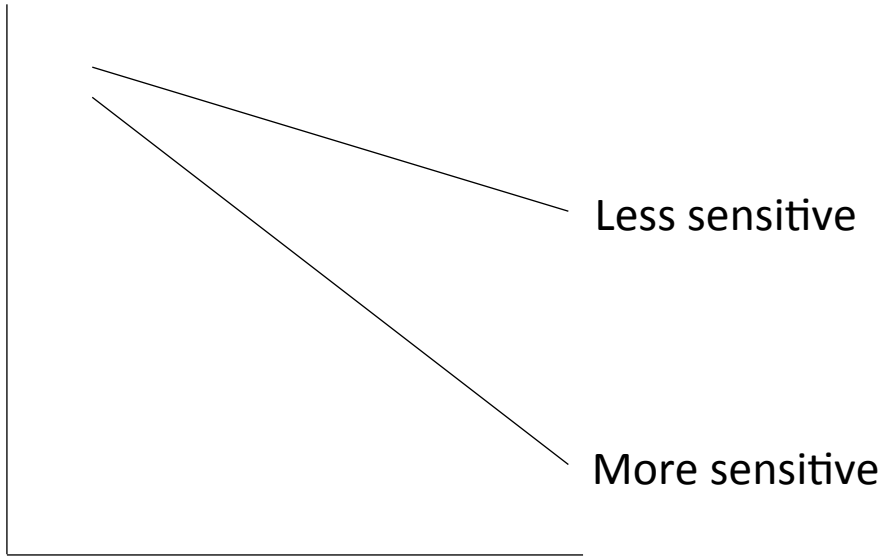
Phenology timing versus sensitivity

Time of flowering

Or

Time of green up (DOY)



Timing: Day of Year of phenological event (DOY in days)

Sensitivity: Phenological sensitivity to temperature (slope — β in days/°C)

Timing: evolutionary relatedness

Phylogenetic conservatism in plant phenology

T. Jonathan Davies[1]*, Elizabeth M. Wolkovich[2], Nathan J. B. Kraft[3], Nicolas Salamin[4,5], Jenica M. Allen[6], Toby R. Ault[7], Julio L. Betancourt[8], Kjell Bolmgren[9,10], Elsa E. Cleland[11], Benjamin I. Cook[12,13], Theresa M. Crimmins[14], Susan J. Mazer[15], Gregory J. McCabe[16], Stephanie Pau[17], Jim Regetz[18], Mark D. Schwartz[19] and Steven E. Travers[20]

"We show that more closely related species tend to flower and leaf at similar times"

A phylogenetic comparative study of flowering phenology along an elevational gradient in the Canadian subarctic

Malie Lessard-Therrien · T. Jonathan Davies · Kjell Bolmgren

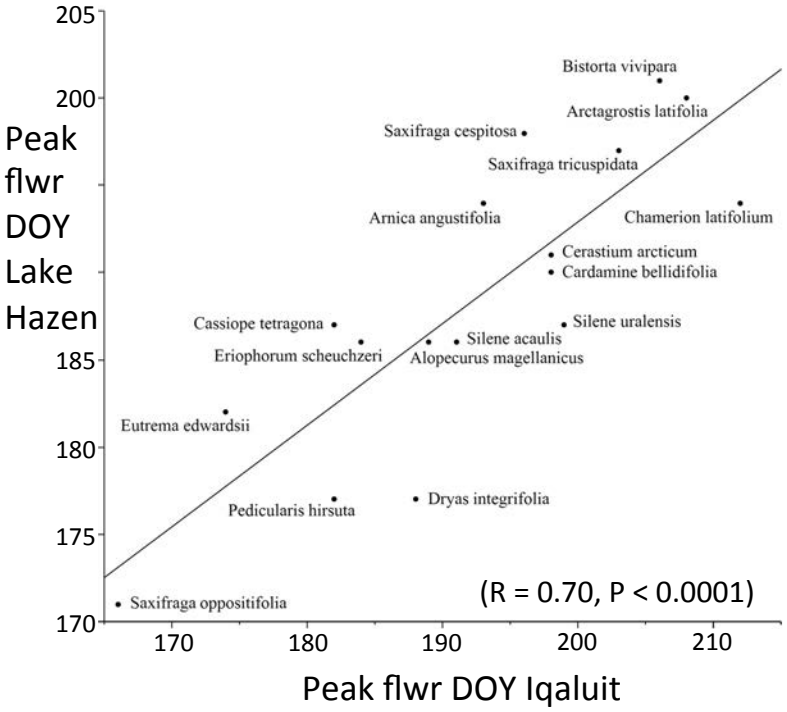
"We found that the phylogenetic signal for FFD was stronger at finer spatial scales"

Leaf out times of temperate woody plants are related to phylogeny, deciduousness, growth habit and wood anatomy

Zoe A. Panchen[1], Richard B. Primack[2], Birgit Nordt[3], Elizabeth R. Ellwood[4], Albert-Dieter Stevens[3], Susanne S. Renner[5], Charles G. Willis[6], Robert Fahey[7], Alan Whittemore[8], Yanjun Du[9] and Charles C. Davis[10]

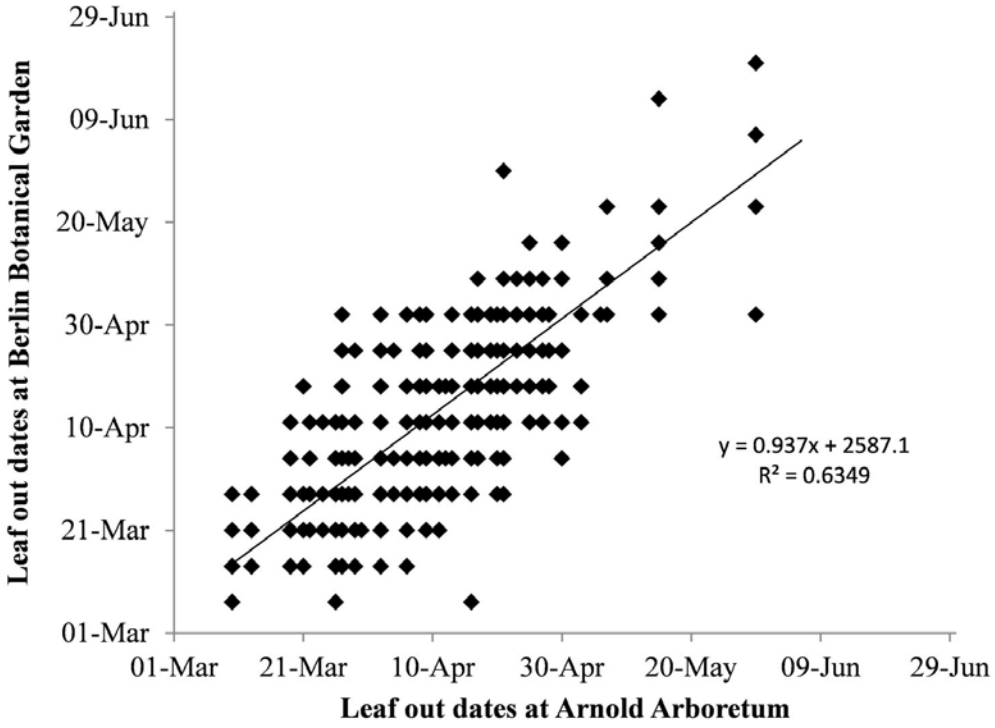
Species' flowering/leaf out sequence

Flowering times L. Hazen vs Iqaluit 2014



Panchen & Gorelick (2016)

Leaf out times Berlin vs Boston 2012



Panchen et al. (2014)

Species flower & leaf out in roughly the same order each year and at different locations

Sensitivity: evolutionary relatedness

Phenological responses to climate change do not exhibit phylogenetic signal in a subalpine plant community

Paul J. CaraDonna[1,2,4] and David W. Inouye[1,3]

Flowering date of taxonomic families predicts phenological sensitivity to temperature: Implications for forecasting the effects of climate change on unstudied taxa[1]

Susan J. Mazer[2,3,13], Steven E. Travers[4], Benjamin I. Cook[5,6], T. Jonathan Davies[7], Kjell Bolmgren[8,9], Nathan J. B. Kraft[10], Nicolas Salamin[11], and David W. Inouye[10,12]

"Family membership can be used to identify taxa of high and low sensitivity to temperature"

Phylogenetic patterns of species loss in Thoreau's woods are driven by climate change

Charles G. Willis[a], Brad Ruhfel[a], Richard B. Primack[b], Abraham J. Miller-Rushing[b], and Charles C. Davis[a,1]

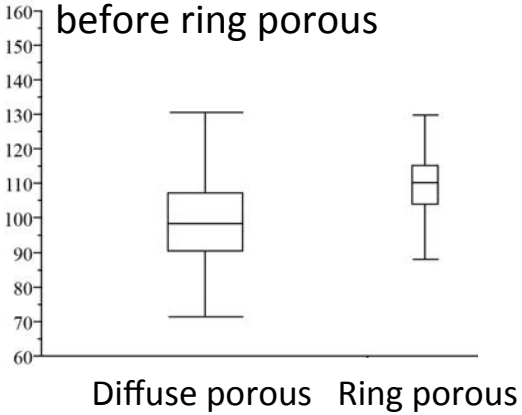
".....flowering-time response traits are shared among closely related species....."

Life history

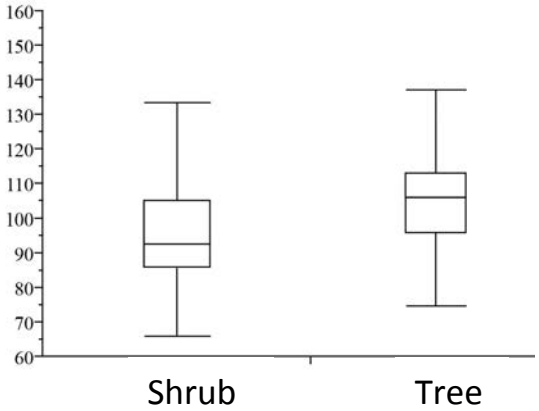
Timing ✓

Deciduous leaf out before evergreen

Diffuse porous leaf out before ring porous



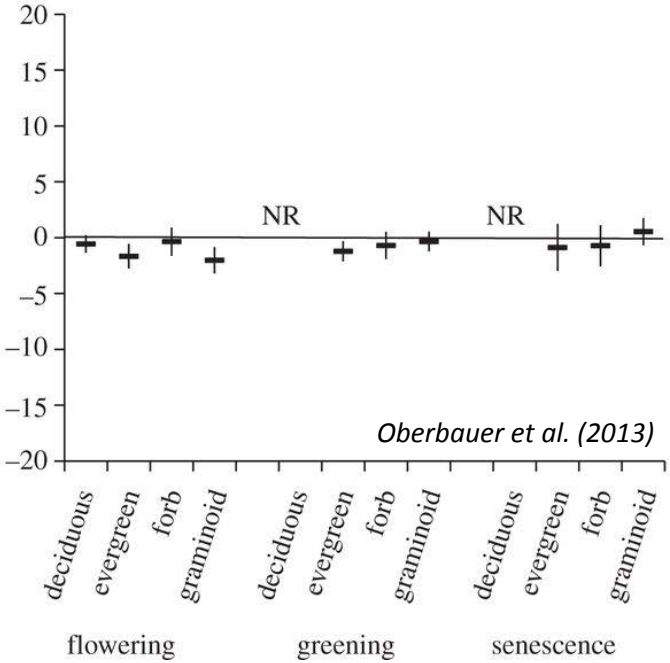
Shrubs leaf out before trees



Panchen et al. (2014)

Sensitivity X

Flower, green up, senescence sensitivity to temperature (Days/°C)



Oberbauer et al. (2013)

Questions

Arctic plant flower/green up timing and sensitivity

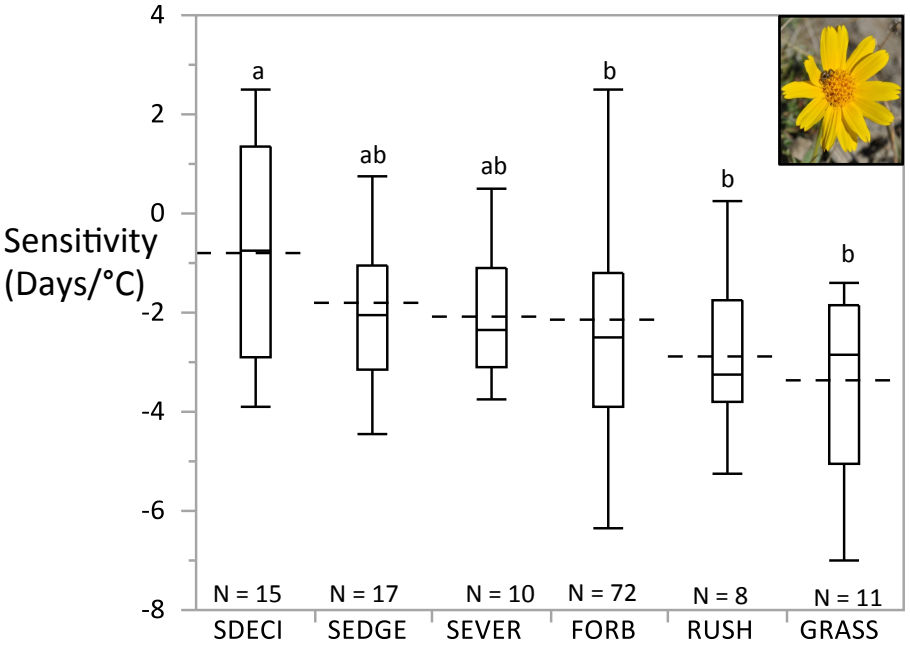
- evolutionarily conserved?
- related to life history?

Preliminary analysis

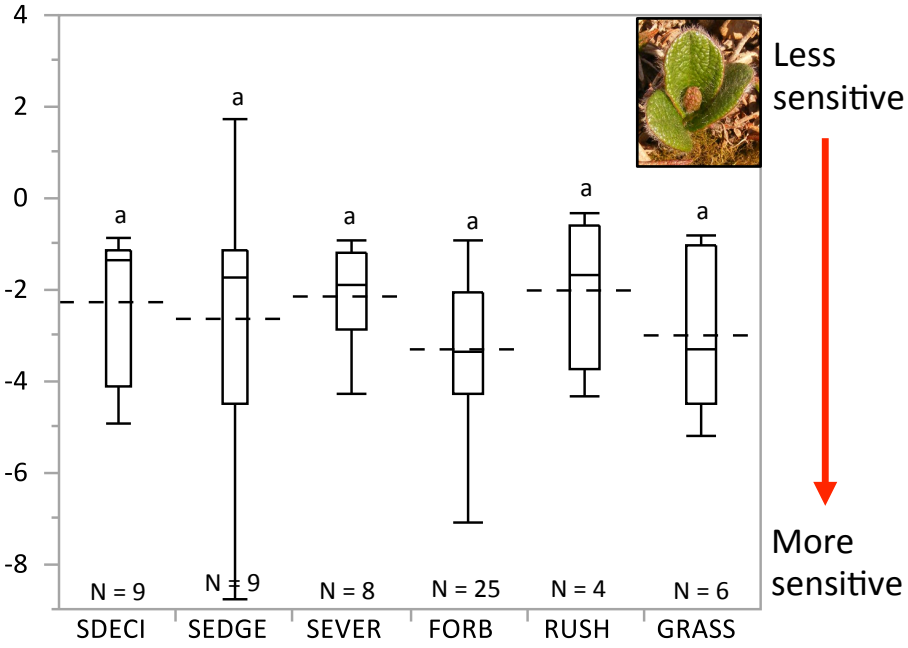
- Sensitivity to temperature (May, June, July) per species
  - DOY ~ α + (β * monthly temp.) + (site[plot])
  - ITEX first flower & green up data set (Prevey et al. 2017)
  - β - most sensitive monthly temp. (June similar results)
- Life history patterns
- Bayesian hierarchical model

Flowering/green up β: Growth form

Flowering sensitivity
Deciduous shrubs least sensitive
Grass & rush most sensitive



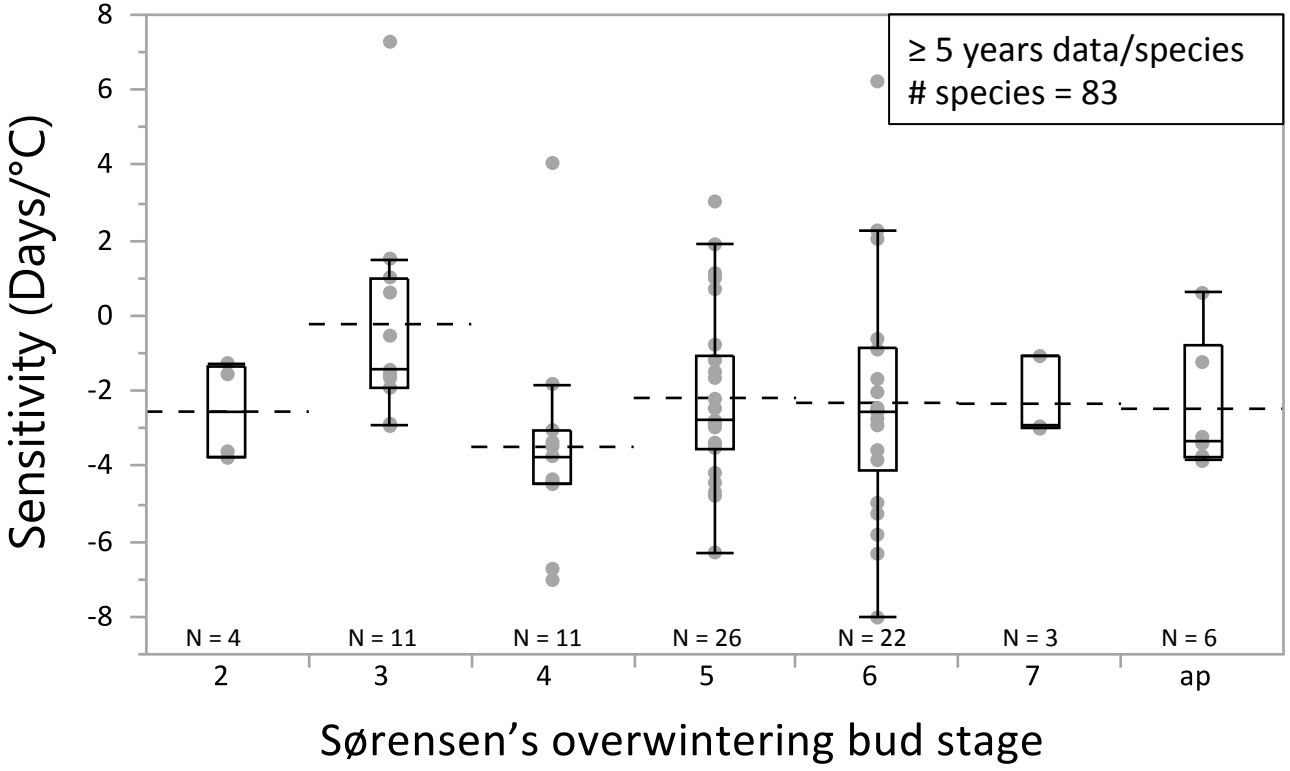
Green up sensitivity
Little dif. between growth forms
Sensitivity differs from flowering

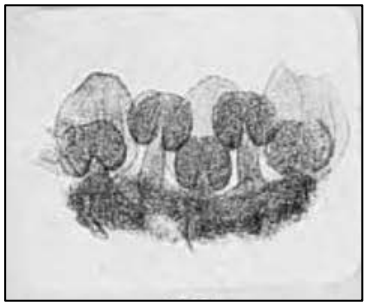


SDECI – Deciduous shrub
SEDGE – Cyperaceae
SEVER – Evergreen shrub
FORB – Forbs
GRASS – Poaceace
RUSH – Juncaceae

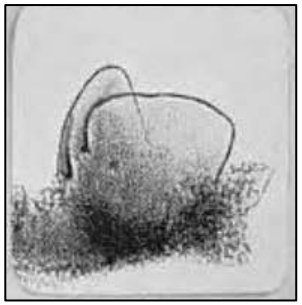
Flwr ≥ 10; Green up ≥ 5 years of data
Flowering # species = 133
Green up # species = 61

Flowering sensitivity: Sørensen's overwintering bud stage





Saxifraga oppositifolia (stage 6)



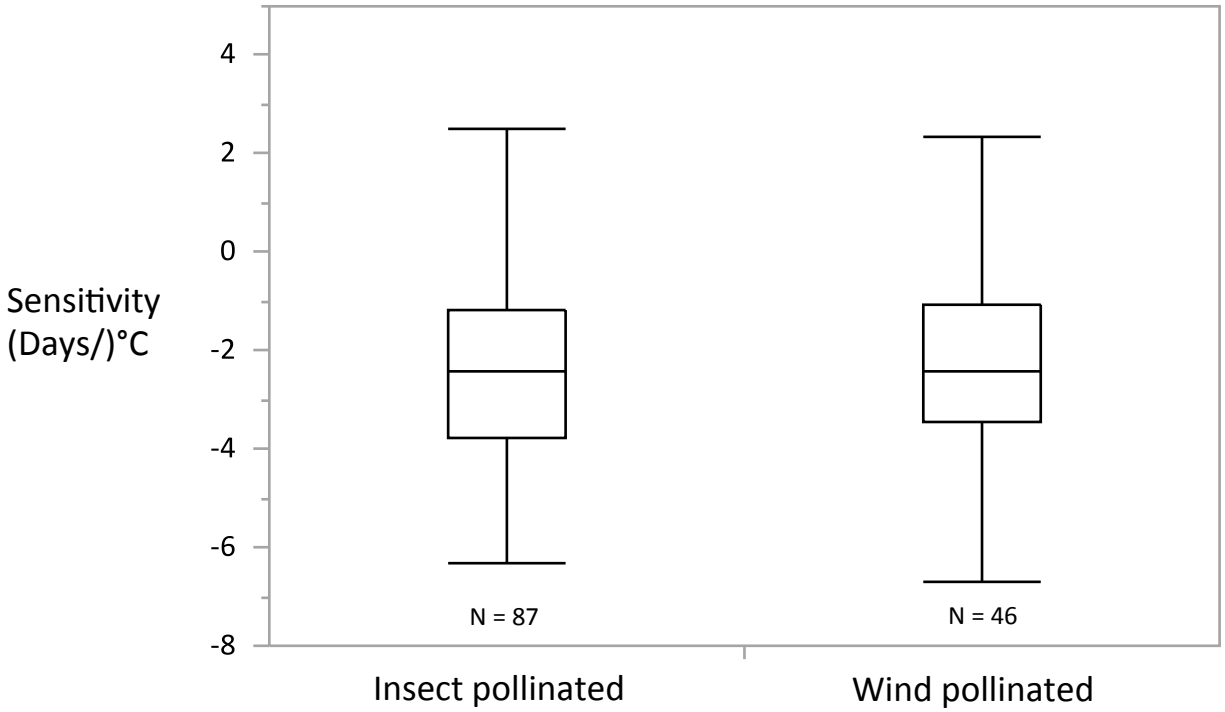
Pinguicula vulgaris (stage 2)

Sørensen, 1941

Species with less advanced bud stage 3 less sensitive than more advanced bud stages 4, 5, 6
BUT more data required

Flowering sensitivity: Pollination

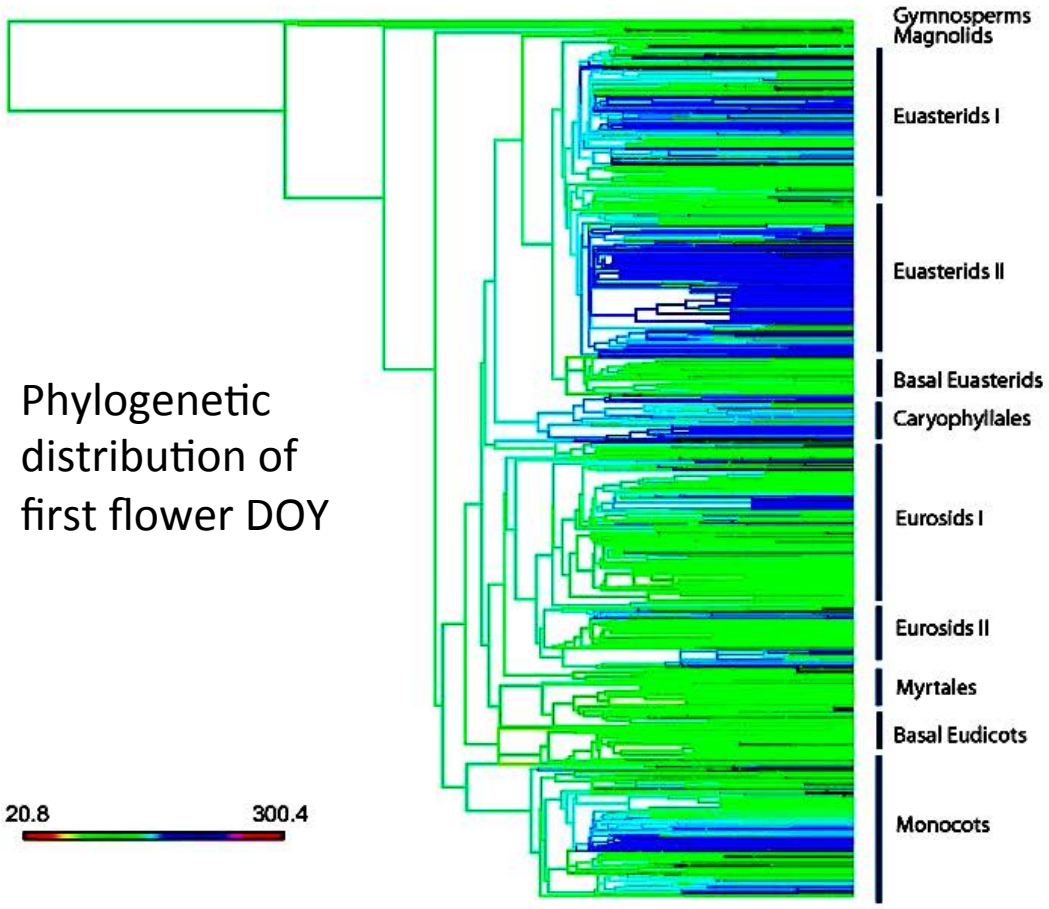
No difference in flowering time sensitivity of wind vs insect pollinated species



Species with ≥ 10 years of data
Number of species = 133

Phylogenetic analysis plan

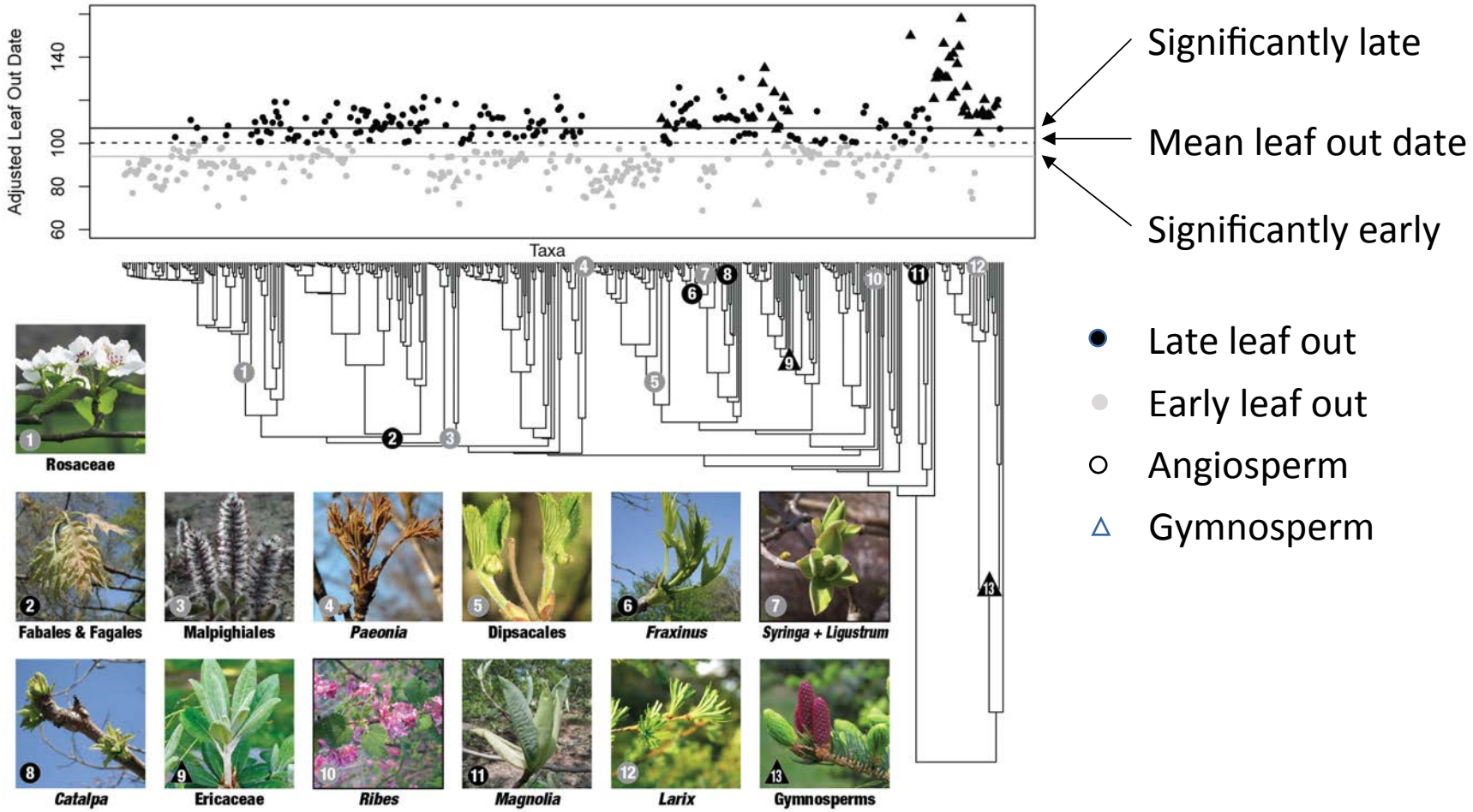
- Determine phylogenetic signal in flowering and green up timing and sensitivity



Davies et al. (2013)

Phylogenetic analysis plan

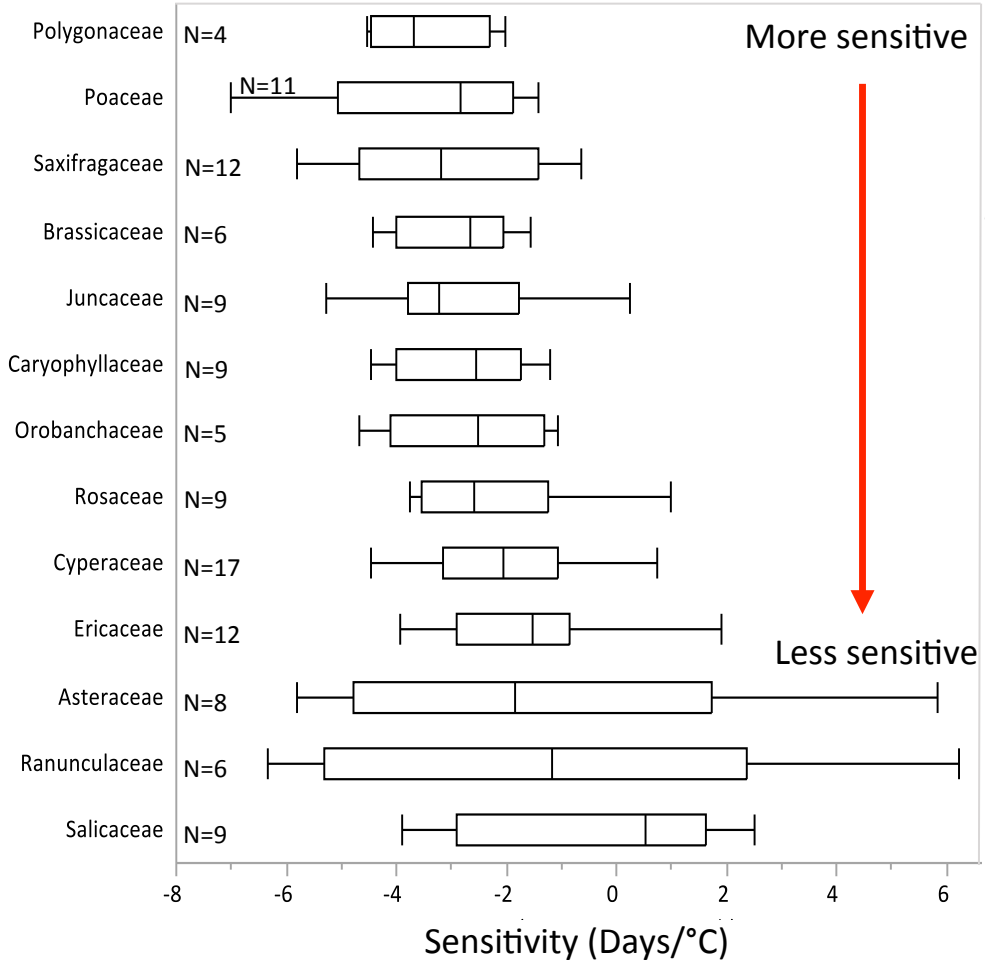
- Clades flowering/greening up significantly early/late
- Clades significantly more/less sensitive



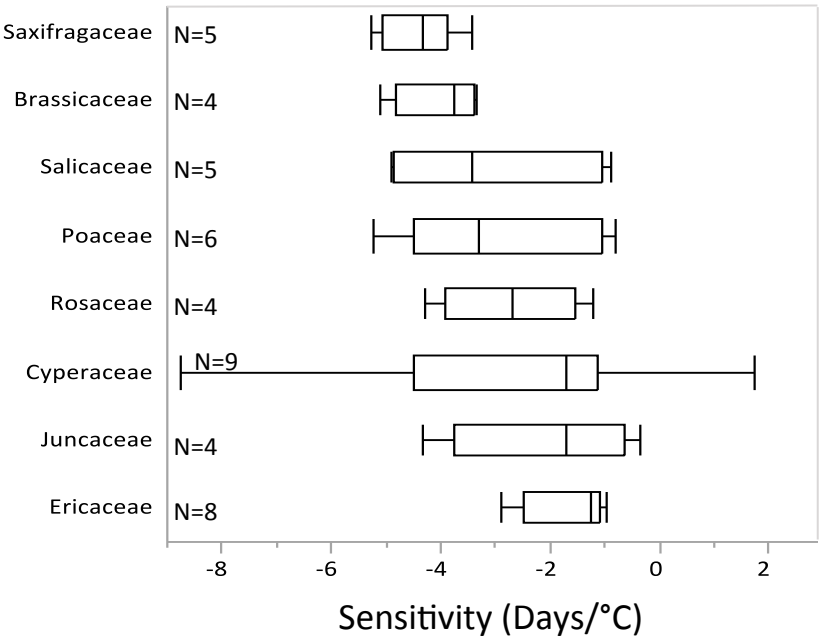
Panchen et al. (2014)

Flowering/green up β: Family

Flowering sensitivity



Green up sensitivity



Flwr ≥ 10; Green ≥ 5 years of data
Families with >3 species

Bayesian hierarchical model

- $FlwrDOY_{sp[ij]} \sim Normal\ (\mu_{sp[j]}, \sigma_{sp[j]})$
- $\mu_{sp[j]} = \alpha_{sp} + \beta_{sp} * MonthlyTemp_{site[j]}$
- $\beta_{sp} \sim Normal\ (\mu_{sp}, \sigma_{sp})$
- $\mu_{sp} = \beta_{gf[n]} + \beta_{bs[m]} + \beta_{ps[o]} + \beta_{site[j]}$
- $\beta_{site[j]} \sim Normal\ (\mu_{site}, \sigma_{site})$
- $\mu_{site} = \beta_{plot[p]} + (\alpha_{lat} + \beta_{lat} * Latitude) + (\alpha_{site} + \beta_{site} * MonthlyTemp_{site})$
- $\beta_{plot[p]} \sim Normal\ (\mu_{plot}, \sigma_{plot})$
- $\mu_{plot} = \alpha_{habitat[h]} + \beta_{habitat[h]}$

β = flowering sensitivity to temperature

α = intercept

observation = i

species (**sp**): s = (*Agrostis mertensii*, …,)

growth form (**gf**): n = (forb, grass, rush, …)

bud stage (**bs**): m = (1, 2, 3, …, 7, ap)

pollinator syndrome (**ps**): o = (insct, wnd)

Site (**site**): j = (Alex, …, Zackenberg)

plot (**plot**): p = (1, 2, …)

habitat (**habitat**): h = (dry, moist, wet)

Next Steps

- Feedback and input
- Gather/compile/add 2015-2017 ITEX phenology data
- Build phylogeny
- Run analysis using Bayesian hierarchical modelling
- Add non-ITEX datasets to the analysis

Questions - Suggestions

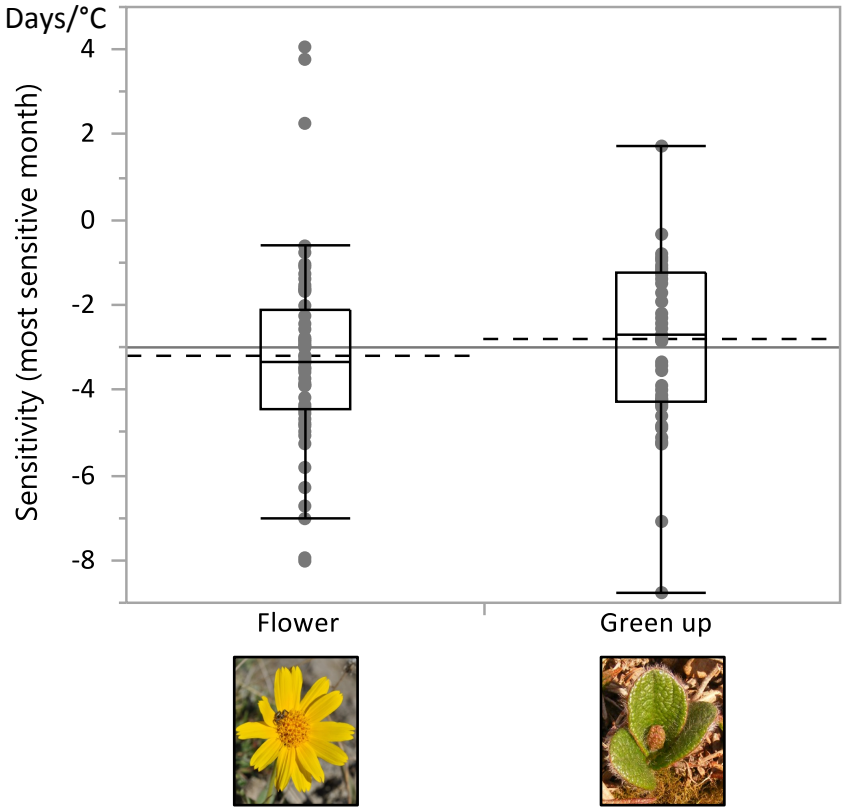
Questions

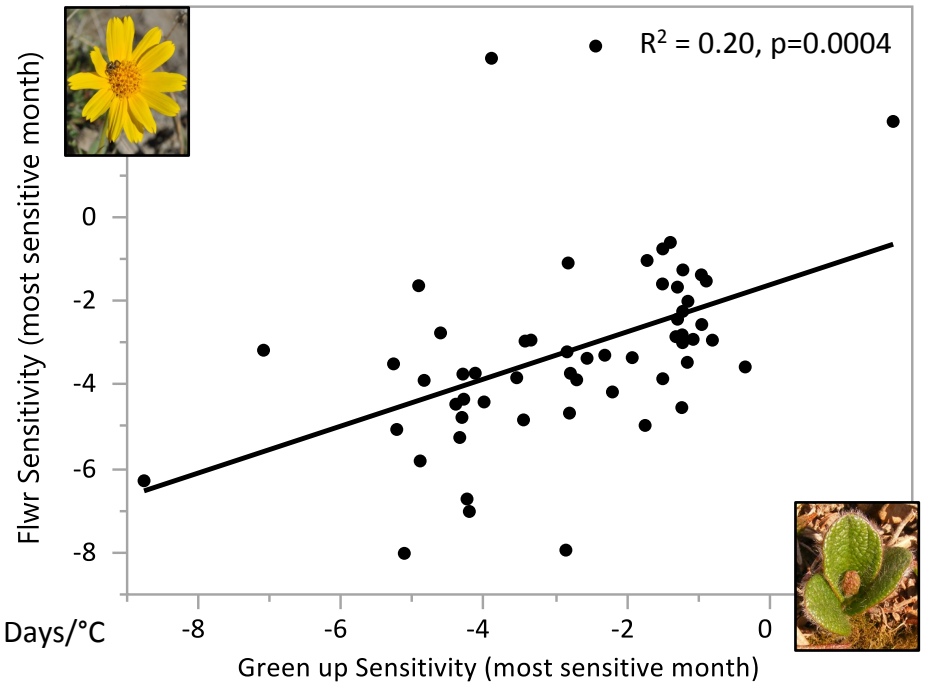
- Any comments/suggestions for Bayesian hierarchical model
- What temperatures (months) to use

Flowering versus green up time β

No significant difference in βs
Greater range flower time β

Green up time β 1.6 days/°C more sensitive than flower time β

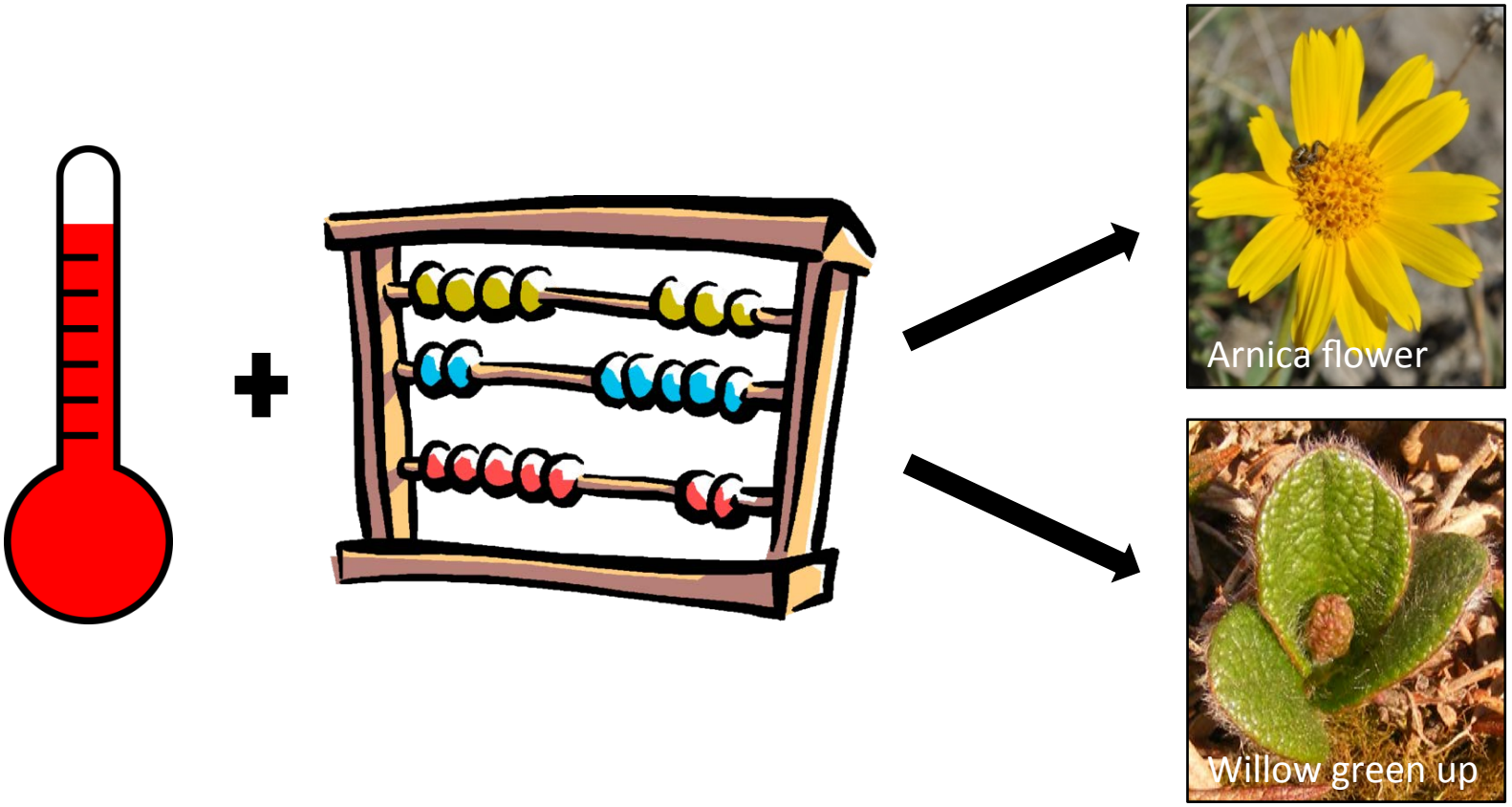




> 5 years of data
species = 57

Phenology

Timing of flowering and green up



Flowering time and green up time related to temperature (monthly temperature or growing degree days)