Counting reproductive organs:

the use of a quantitative phenological index in pheno-climatic models

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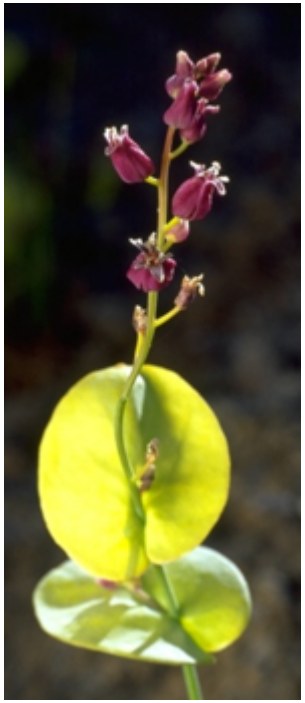


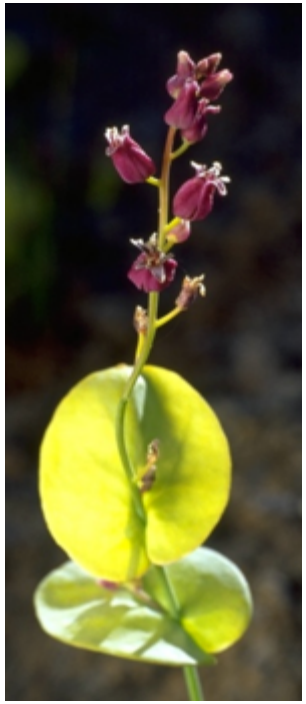
Counting reproductive organs:

the use of a quantitative phenological index in pheno-climatic models

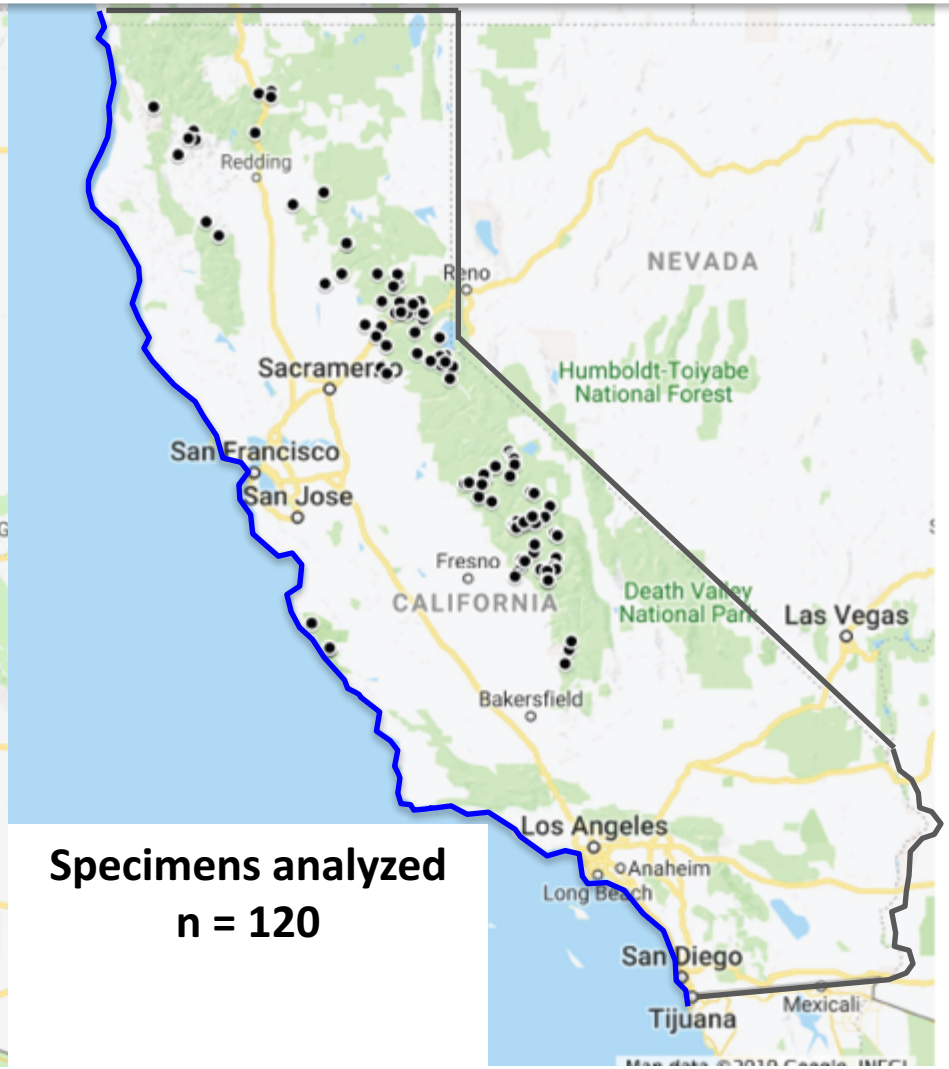
- Preliminary case study in *Streptanthus tortuosus* (California jewelflower: Brassicaceae)
- Buds, flowers, and fruits: how we count ‘em and use ‘em
- Manuscript in progress (Natalie Rossington Love & Susan Mazer)
- Other ongoing work (Isaac Park & Susan Mazer)

Isaac Park

Natalie Love



Distribution of *Streptanthus tortuosus*



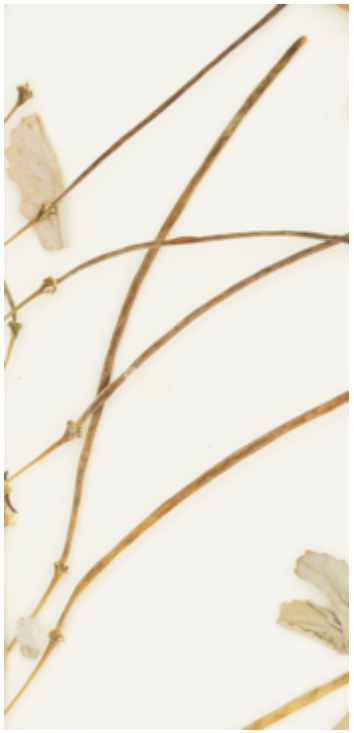
Specimens analyzed
n = 120

Actual: based on all electronic herbarium records now in Consortium of California Herbaria

Bud

Open flowers

Immature fruits



Mature fruits

Using ImageJ and its "Cell Counter" plug-in:

Point-and-click to record and to count all visible reproductive objects:

Buds
Open flowers
Immature fruits (or spent flowers)
Mature fruits

Cell Counter provides a final count of each class of reproductive organs

These counts can be used to obtain a quantitative index of the specimen's phenological status (*wait* for it…)


a.
CALIFORNIA ACADEMY OF SCIENCES
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a.
b.
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Phenological Index:

$$\sum_{i=1}^{4} (p_i)(i)$$

Where:

p_1 = proportion of all reproductive organs that are buds

1 = score of buds

p_2 = proportion of all organs that are open flowers

2 = score of open flowers

p_3 = proportion of all organs that are immature fruits

3 = score of immature fruits

p_4 = proportion of all organs that are mature fruits

4 = score of mature fruits

Phenological Index (PI):

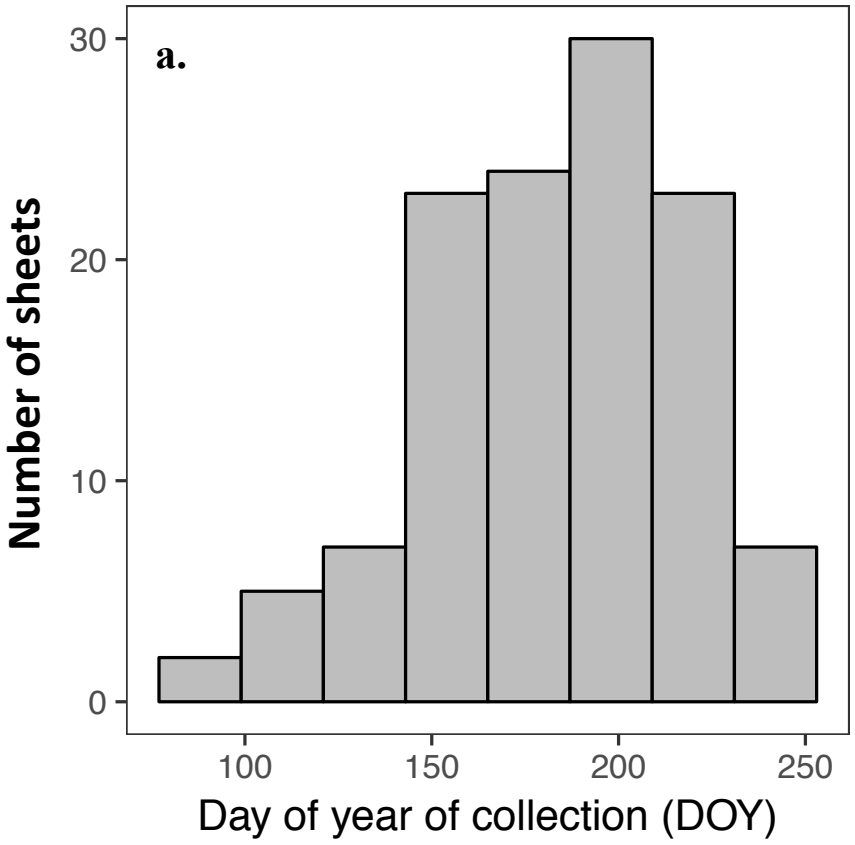
$$\sum_{i=1}^{4} (p_i)(i)$$

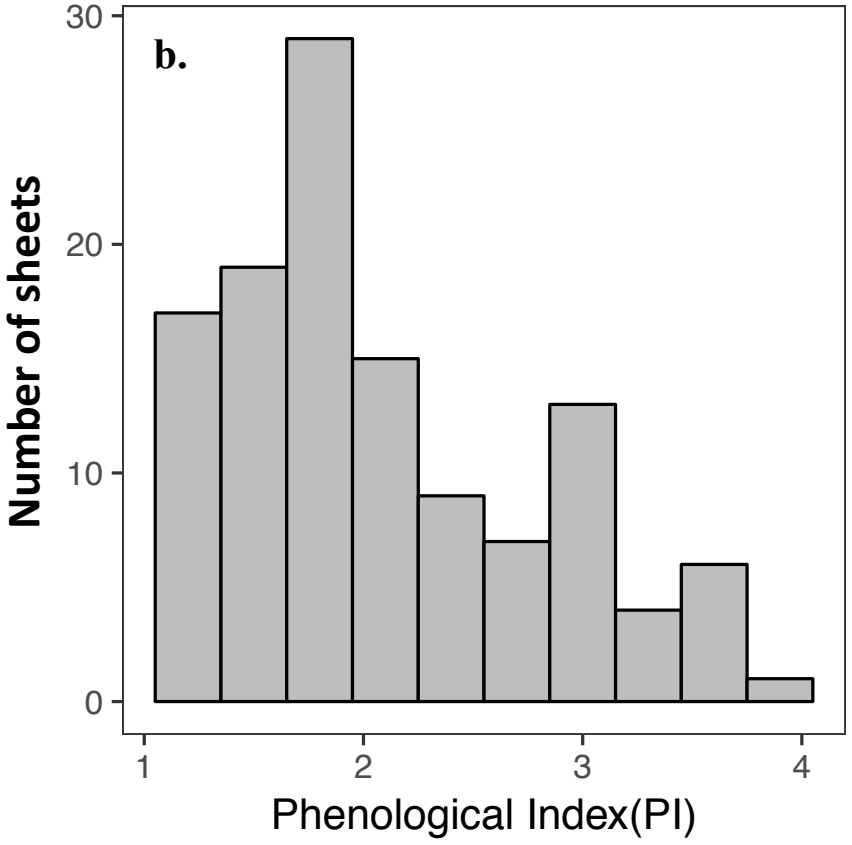
And:

PI = 1 for a specimen comprised only of buds

PI = 4 for a specimen comprised only of ripe fruits

Distributions of collection date and phenological index of 120 *S. tortuosus* sheets



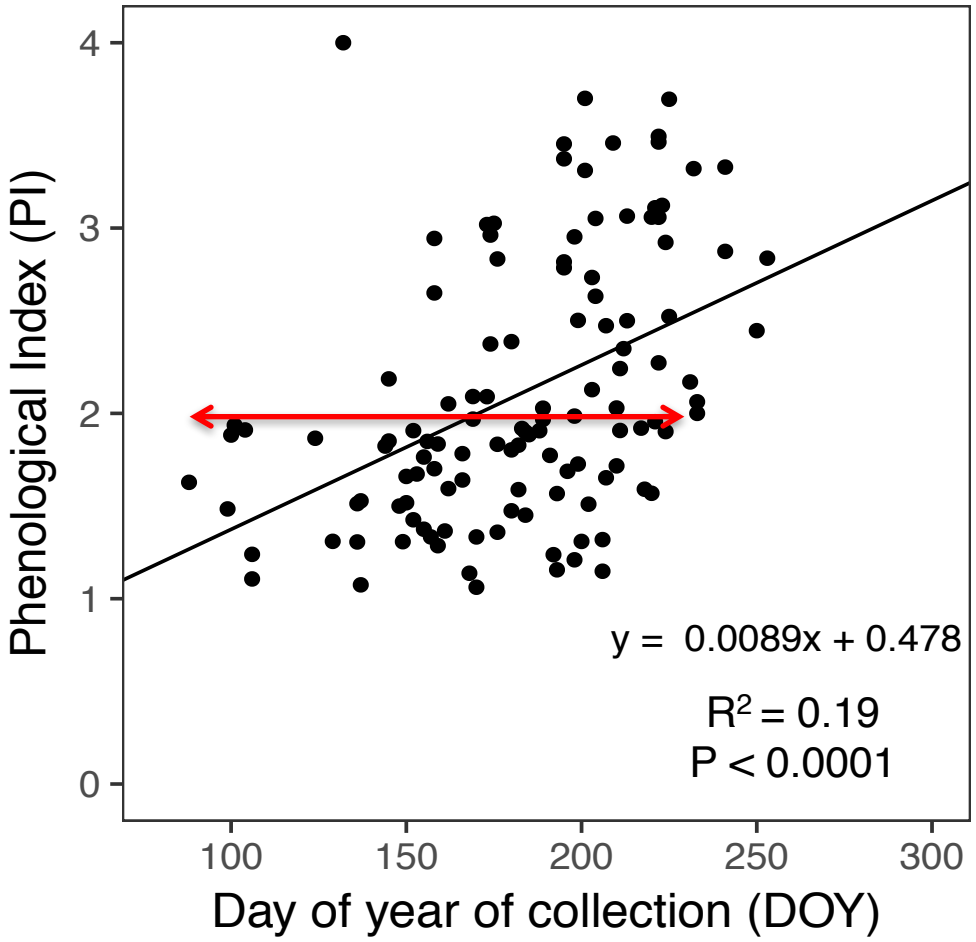


Early March ⟷ Late June

All buds ⟷ All fruits

No surprise: Specimens collected relatively late in spring/summer are phenologically more advanced

Holding PI constant, the variation in DOY could easily be influenced by climatic variation



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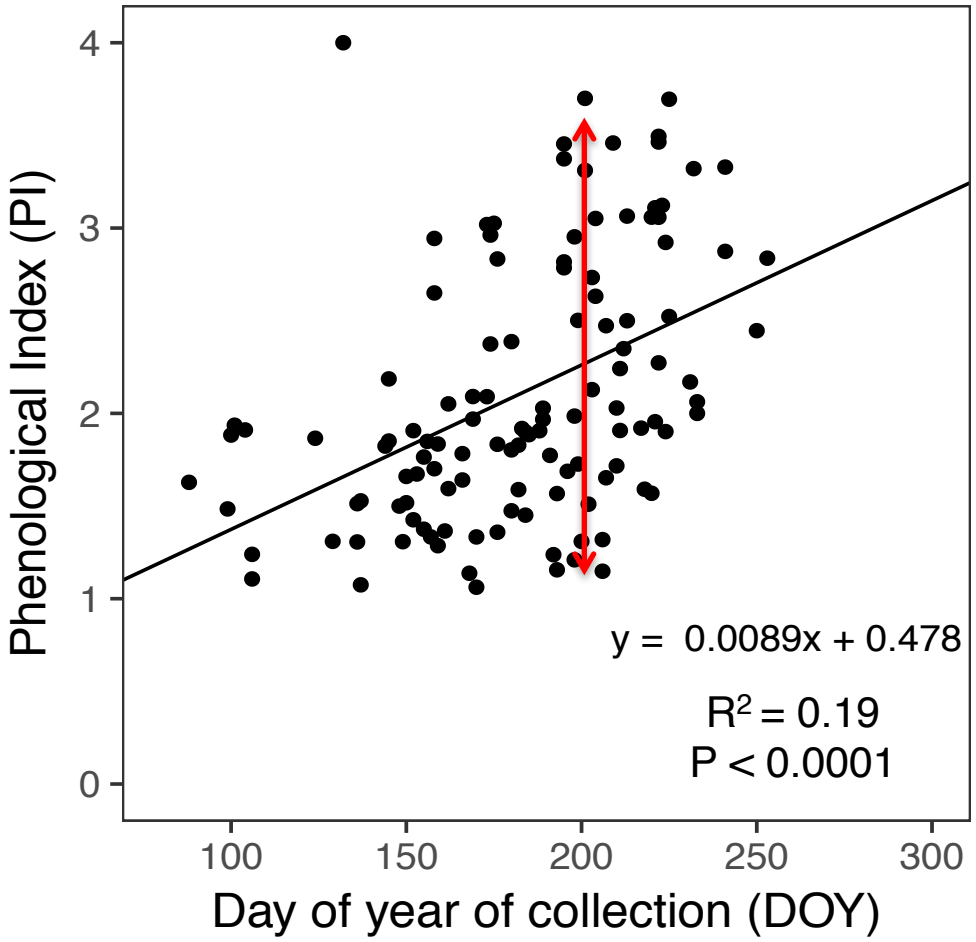
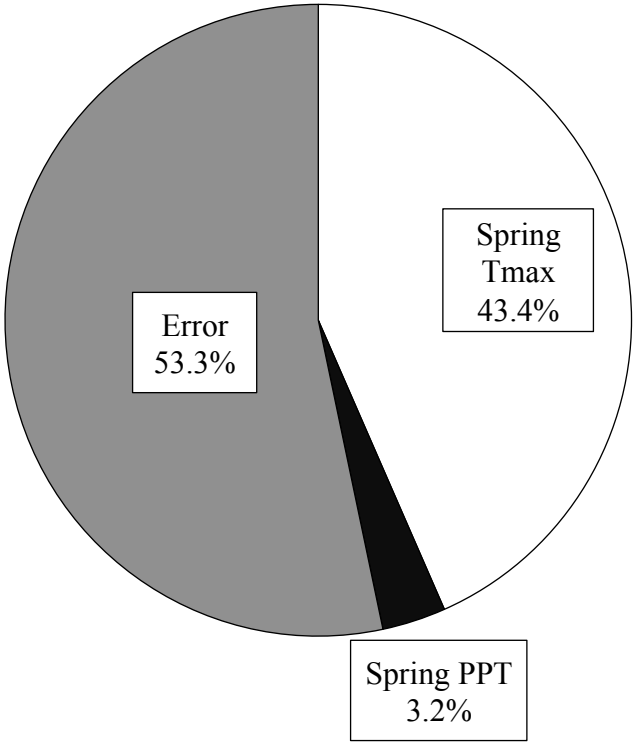


Proportion of variance in DOY explained by climate depends on whether PI is included in linear model

Without controlling for phenological status

a. Model 1

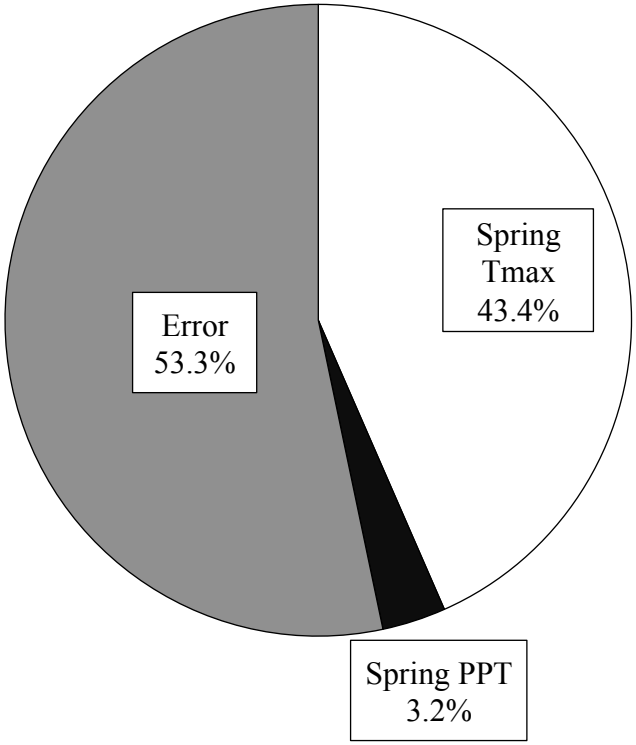


Proportion of variance in DOY explained by climate depends on whether PI is included in linear model

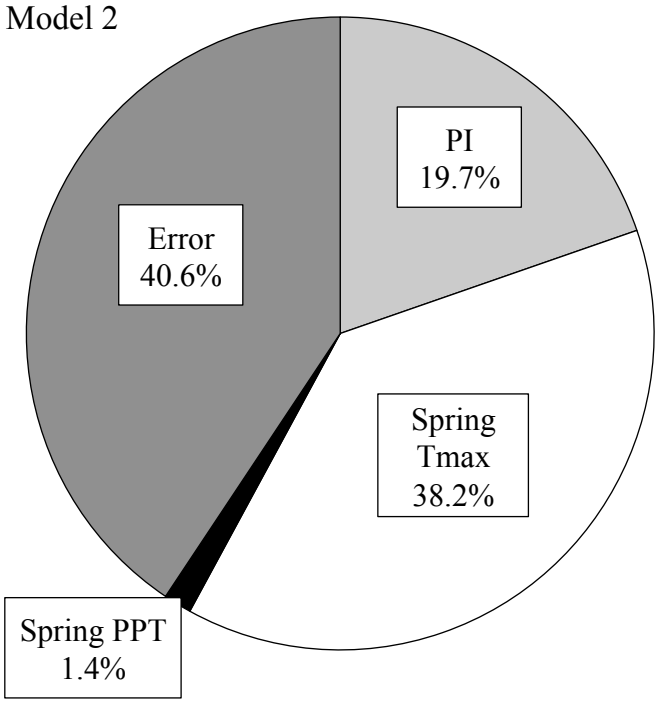
Without controlling for phenological status

With controlling for phenological status

a. Model 1



b. Model 2



Without controlling for phenological status

$R^2 = 0.46$

Analysis of Variance Source	df	Sequential SS	F ratio	P value
Spring Tmax	1	64,949.88	96.08	<0.0001
Spring Precipitation	1	4,910.65	7.26	0.0081
Error	118	79,770.80		
R2				0.46
AICc				1137

Parameter Estimates Term	Estimate	SE	t ratio	Prob > |t|
Intercept	221.25	12.02	18.41	<0.0001
Spring Tmax	-5.21	0.56	-9.3	<0.0001
Spring Precipitation	0.075	0.028	2.7	0.0081

Controlling for phenological status

$R^2 = 0.58$

Analysis of Variance Source	df	Sequential SS	F ratio	P value
Phenological Index (PI)	1	29,386.30	56.33	<0.001
Spring Tmax	1	56,984.56	109.23	<0.001
Spring Precipitation	1	2,147.62	4.11	0.0447
Error	116	60,511.87		
R2				0.58
AICc				1097

Parameter Estimates Term	Estimate	SE	t ratio	Prob > |t|
Intercept	188.11	11.88	15.83	<0.001
Phenological Index (PI)	18.2	3.01	6.07	<0.001
Spring Tmax	-5.01	0.49	-10.12	<0.001
Spring Precipitation	0.05	0.02	2.03	0.0447

Upshot for *S. tortuosus*

- Controlling for the phenological status of plants when predicting DoY from climatic conditions increased R^2 by 26%
- The direction of the effects on DoY of spring Tmax and spring rainfall remained unchanged:
  - an increase of 1°C advanced DoY by ~5 days
  - an increase of 20 mm rainfall delayed DoY by 1 day
- Including the phenological status of plants in predictive models of DoY (based on climatic conditions) can allow a new type of practical prediction…..

Predictive models

DOY = PI + α_1Climate Variable 1 + α_2Climate Variable 2 +…..

- Including the PI in predictive models reduces variance in DOY that is due to collecting plants at all stages of reproduction.
- More importantly, this kind of model enables us to predict the DOY of plants **of a specified phenological status**, under specified climatic conditions.
- In other words, we can use such models to predict the timing of specific phenophases of interest under specific climatic conditions.

Also in the works

- Collaboration with Isaac Park, using ~900,000 electronic records of specimens filtered for presence of flowers

TECHNICAL ADVANCE

WILEY Global Change Biology

Overlooked climate parameters best predict flowering onset: Assessing phenological models using the elastic net

Isaac W. Park | Susan J. Mazer

PhenoForecaster: a software package for the prediction of flowering phenology

Isaac Park[1], Alex Jones[2], Susan J. Mazer[1] *APPS, in review*

Also in the works

- Collaboration with Isaac Park, using ~60,000 electronic records of specimens filtered for presence of flowers

Climate affects the rate at which species successively flower:

capturing an emergent property of regional floras

Isaac W. Park[1] and Susan J. Mazer

GEB, in revision

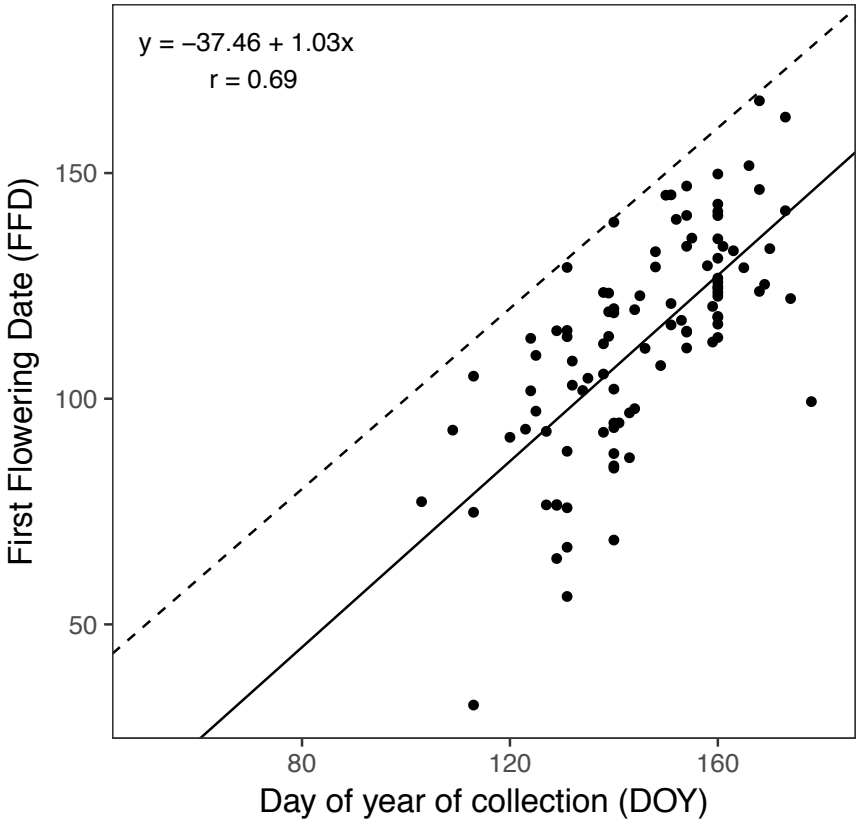
Also in the works

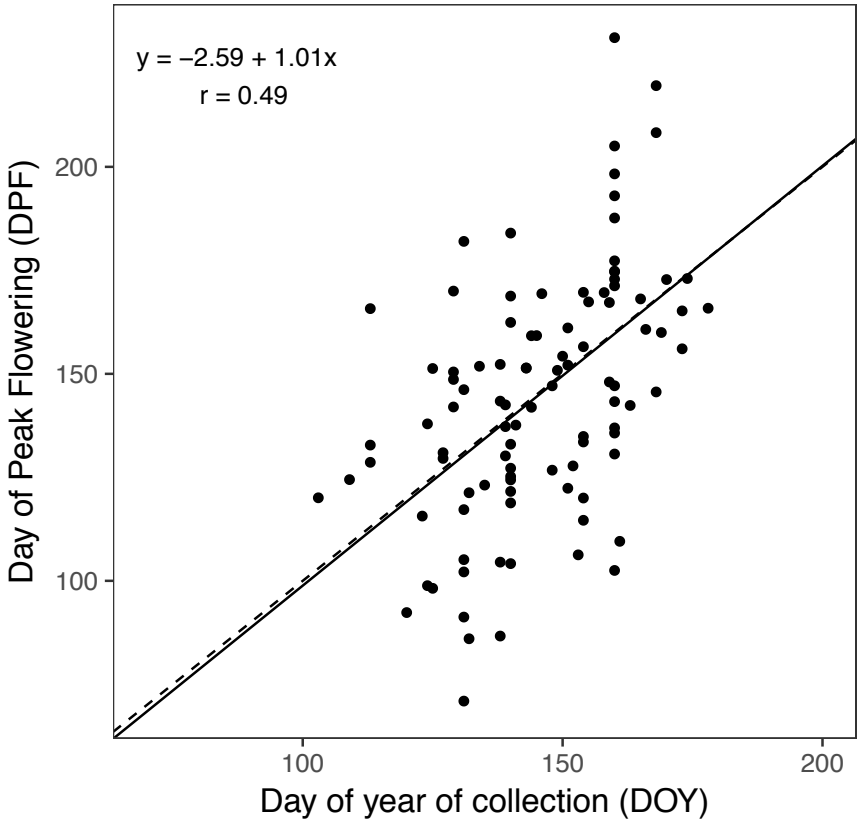
- Collaboration with Isaac Park, using ~460,000 electronic records of specimens filtered for presence of flowers

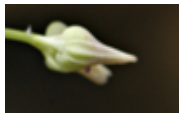
A century of frost in North America:

warming has reduced frost risk in 66% of angiosperm taxa

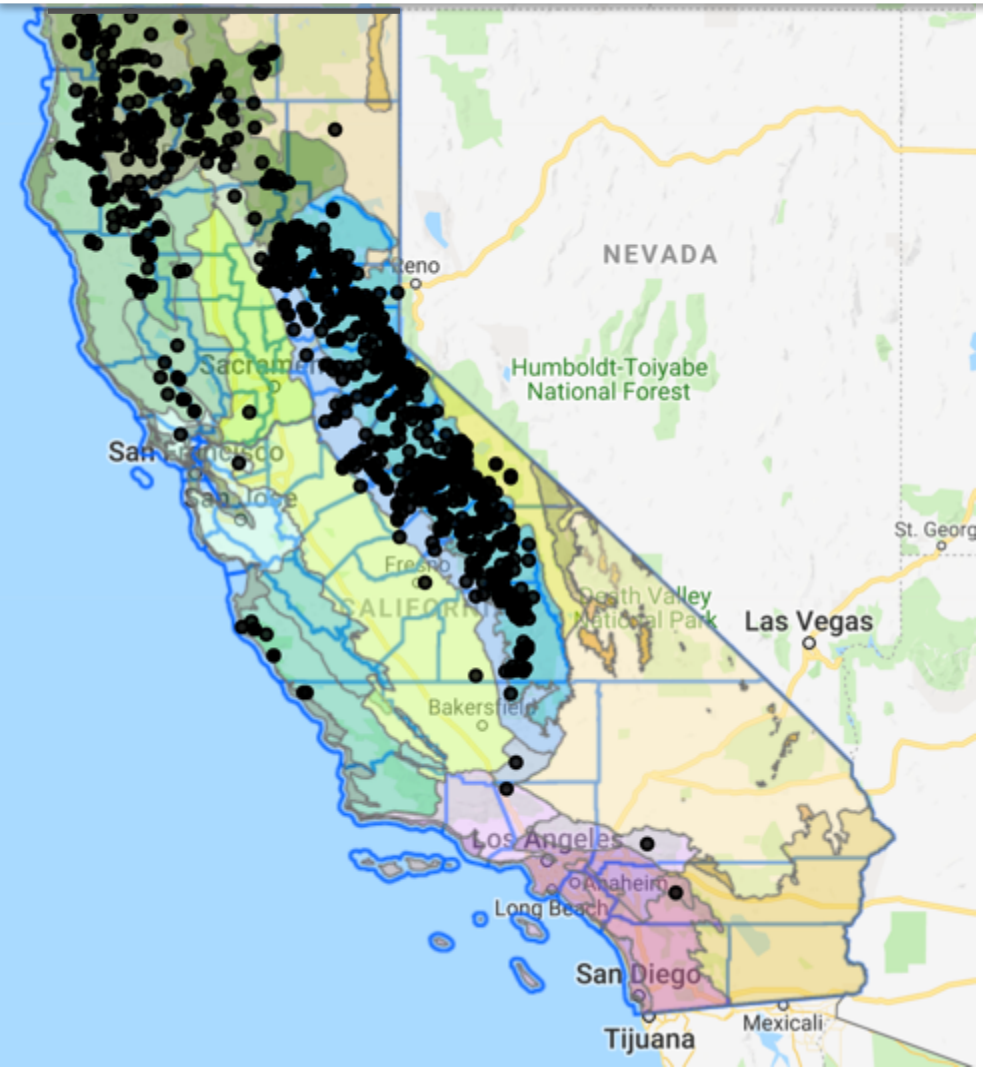
Isaac W. Park and Susan J. Mazer *Nature, in review*


y = −37.46 + 1.03x
r = 0.69
First Flowering Date (FFD)
150
100
50
80
120
160
Day of year of collection (DOY)


y = −2.59 + 1.01x
r = 0.49
Day of Peak Flowering (DPF)
200
150
100
100
150
200
Day of year of collection (DOY)

	Reproductive Unit	Definition
	Bud	Unopened flower with no perianth parts visible. Must be greater than 2mm to be counted.
	Flower	Perianth parts visible and attached to receptacle
	Immature Fruit	Immature ovary with no perianth parts attached at receptacle. Contains seeds that are not yet mature.
	Mature Fruit	Silique with mature seeds. Maturity can be determined if fruit has any evidence of dehiscence or if swollen, mature seeds cause a wavy silique margin.
		

Distribution of *Streptanthus tortuosus*



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