Supplemental Materials: Photoperiod and temperature interactively drive spring phenology in multiple species

Flynn, Wolkovich...

The Arnold Arboretum of Harvard University

Literature Review

We conducted a literature review, finding 109 studies which investigated effects of photoperiod, temperature, or their interaction on the timing of bud burst or flowering for woody or semi-woody plants. No study varied chilling period, photoperiod, and temperature simultaneously across multiple species at multiple sites. Of those studies, eight simultaneously manipulated photoperiod and temperature. Basler & Koerner [1] found a negative tradeoff between sensitivity to photoperiod and sensitivity to warming for four species, for example with *Fagus sylvatica* advanced on average in leafout by 12 days in response to experimentally lengthened photoperiod, but only ca. 8 days in response to warmer temperatures, while *Acer pseudoplatanus* advanced in leafout by 17 days in response to warming but essentially had no change in response to photoperiod. The current study expands on this work by including 28 species, across two sites, with addition manipulations of chilling temperature.

References Cited

References

[1] Basler, D. & Körner, C. Photoperiod and temperature responses of bud swelling and bud burst in four temperate forest tree species. *Tree physiology* **34**, 377–388 (2014). URL `http://treephys.oxfordjournals.org/content/34/4/377.full.pdf`.

Supplemental Figures and Tables

Table S1: Mean leafout and budburst days for the 28 species at both Harvard Forest, USA and St. Hippoltye, Canada

Species	Budburst.HF	Budburst.SH	Leafout.HF	Leafout.SH
Acer pensylvanicum	16.40	18.33	40.88	46.94
Acer rubrum	22.40	25.15	40.59	44.40
Acer saccharum	44.96	36.48	57.07	46.88
Alnus incana subsp. rugosa	32.91	25.36	45.15	44.36
Aronia melanocarpa	13.62		29.83	
Betula alleghaniensis	19.67	20.77	33.51	34.64
Betula lenta	29.83		50.57	
Betula papyrifera	16.89	18.04	28.71	35.63
Corylus cornuta	24.86	19.04	33.95	30.38
Fagus grandifolia	41.82	43.13	48.54	46.90
Fraxinus nigra	38.00	38.00	52.28	46.91
Hamamelis virginiana	43.67		47.38	
Ilex mucronatus	15.80	15.49	26.97	25.15
Kalmia angustifolia	30.25	32.48	37.80	42.20
Lonicera canadensis	16.91	15.75	28.26	25.08
Lyonia ligustrina	30.87		49.50	
Nyssa sylvatica	31.65		52.87	
Populus grandidentata	33.43	31.23	46.21	45.17
Prunus pensylvanica	17.81	16.21	32.13	29.65
Quercus alba	45.23		52.91	
Quercus rubra	36.43	33.57	45.02	42.80
Quercus velutina	52.09		59.16	
Rhamnus frangula	32.38		37.29	
Rhododendron prinophyllum	29.25		52.14	
Spiraea alba	18.00	20.21	25.94	24.62
Vaccinium myrtilloides	13.12	17.27	27.00	28.95
Viburnum cassinoides	15.41	18.46	16.80	18.71
Viburnum lantanoides	31.25	27.54	32.02	26.41

Table S2: Summary of mixed effect model of budburst day by species.

	mean	sd	25%	50%	75%	Rhat
Temperature	-6.80	1.71	-7.95	-7.02	-5.63	1.05
Photoperiod	-3.96	1.67	-5.13	-4.13	-2.80	1.05
Chilling 4 °C	-22.09	2.84	-24.05	-21.75	-20.26	1.03
Chilling 1.5 °C	-19.79	2.96	-22.32	-19.90	-17.78	1.13
Site	2.59	1.88	0.93	2.54	3.93	1.13
Temperature × Photoperiod	-0.60	0.72	-1.07	-0.46	-0.24	1.02
Temperature × Site	9.17	1.00	8.50	9.32	9.77	1.03
Photoperiod × Site	9.68	1.06	9.11	9.57	10.33	1.00
Temperature × Chilling 4 °C	-0.18	0.96	-0.82	-0.06	0.47	1.04
Temperature × Chilling 1.5 °C	-0.02	1.03	-0.67	0.14	0.48	1.02
Photoperiod × Chilling 4 °C	-1.48	0.76	-1.99	-1.35	-1.00	1.04
Photoperiod × Chilling 1.5 °C	0.05	0.79	-0.52	0.09	0.76	1.10
Site × Chilling 4 °C	-1.96	1.33	-2.84	-1.86	-0.85	1.09
Site × Chilling 1.5 °C	-3.49	1.23	-4.14	-3.55	-2.78	1.01

Table S3: Summary of mixed effect model of leafout day by species.

	mean	sd	25%	50%	75%	Rhat
Temperature	-21.91	1.72	-23.05	-21.90	-20.75	1.01
Photoperiod	-13.68	1.69	-14.79	-13.71	-12.56	1.02
Chilling 4 °C	-26.37	3.09	-28.41	-26.41	-24.41	1.01
Chilling 1.5 °C	-26.14	3.09	-28.29	-26.23	-24.03	1.01
Site	3.00	2.05	1.67	3.00	4.43	1.02
Temperature × Photoperiod	3.54	0.77	2.99	3.54	4.07	1.02
Temperature × Site	10.19	1.16	9.47	10.12	10.93	1.00
Photoperiod × Site	11.29	1.25	10.44	11.26	12.09	1.01
Temperature × Chilling 4 °C	0.77	1.05	0.08	0.79	1.48	1.00
Temperature × Chilling 1.5 °C	2.41	1.27	1.60	2.41	3.24	1.01
Photoperiod × Chilling 4 °C	-0.59	0.82	-1.11	-0.58	-0.04	1.03
Photoperiod × Chilling 1.5 °C	-1.00	0.83	-1.55	-1.01	-0.42	1.02
Site × Chilling 4 °C	-1.87	1.26	-2.67	-1.92	-1.05	1.01
Site × Chilling 1.5 °C	-3.46	1.38	-4.39	-3.44	-2.52	1.01

Figure S1: Model estimates of budburst, including species-level effects.

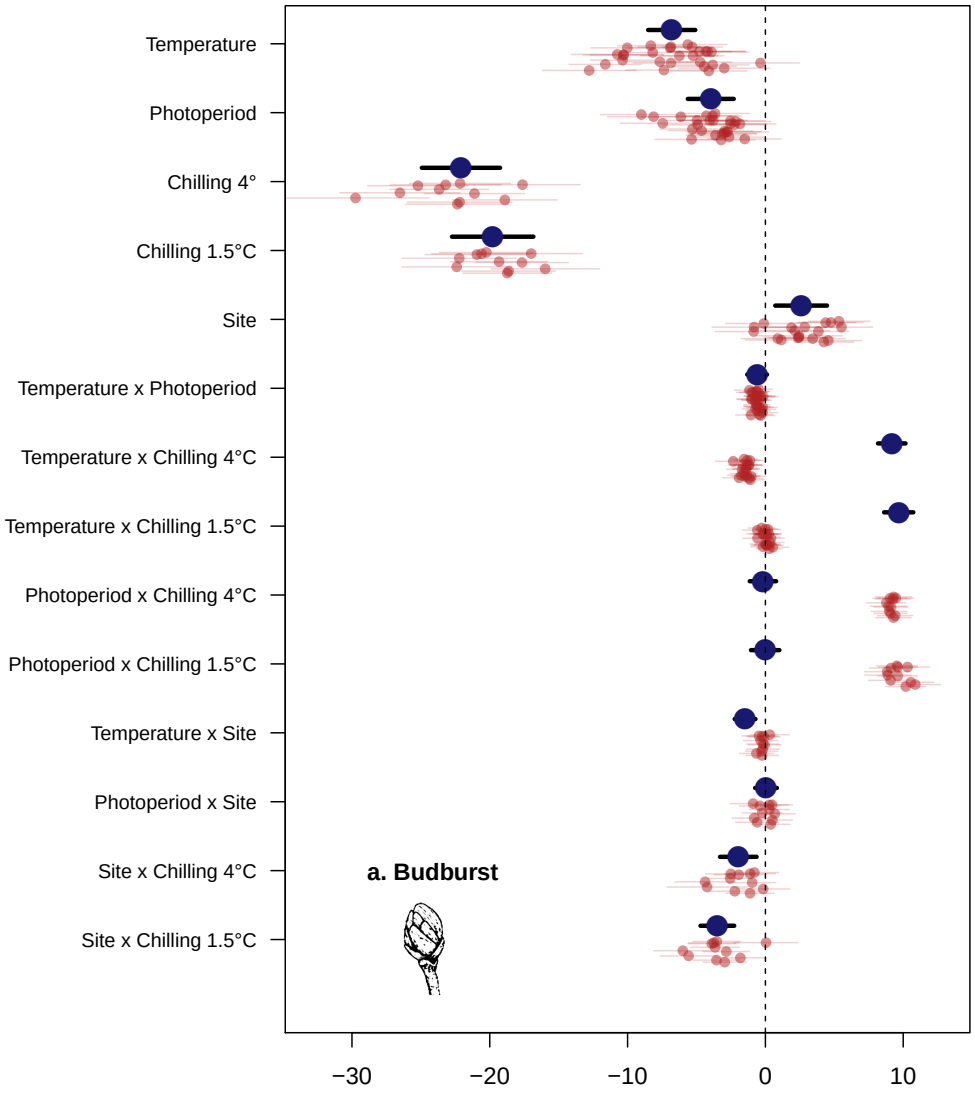

Figure S2: Model estimates of leafout, including species-level effects.

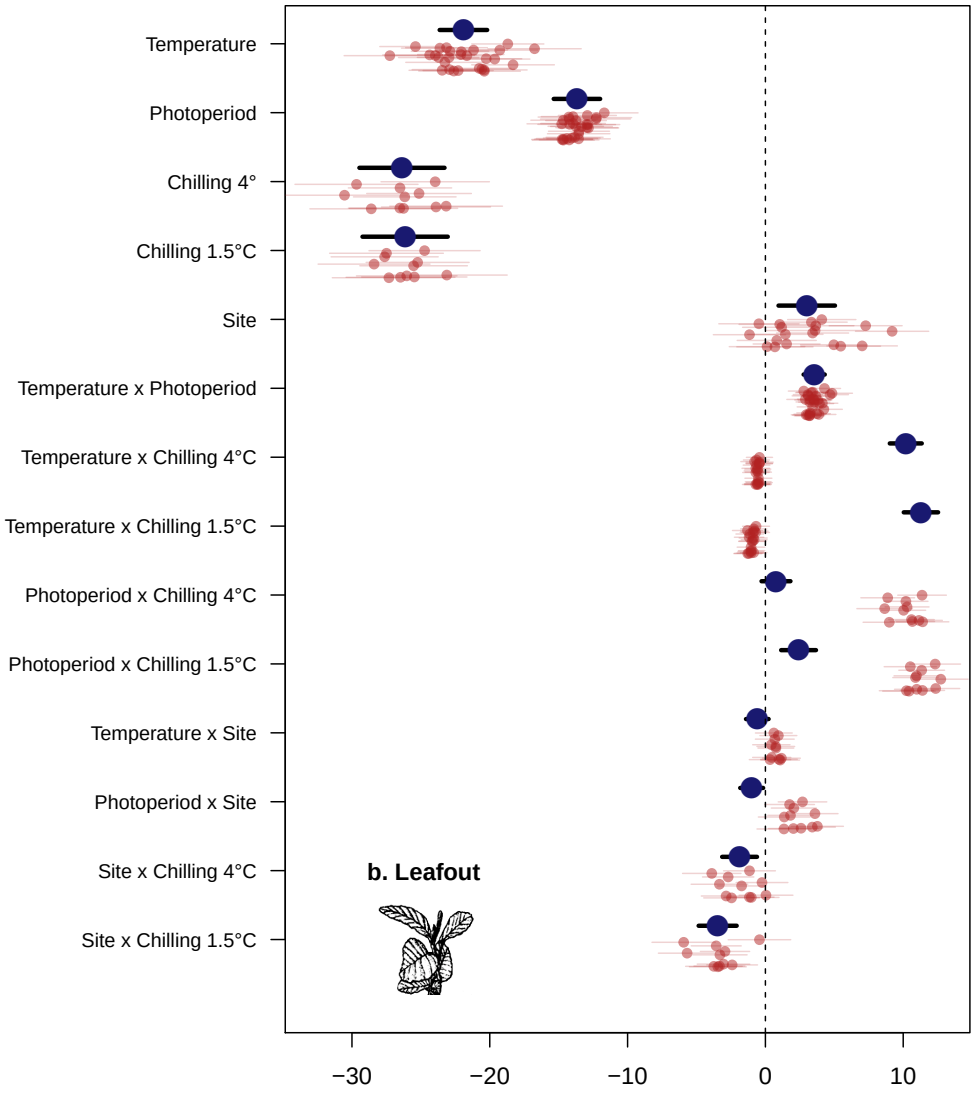

Figure S3: Model estimates of sensitivity to warming, photoperiod, and chilling, compared to day of budburst (upper panels) or leafout (lower panels) across all experimental conditions.

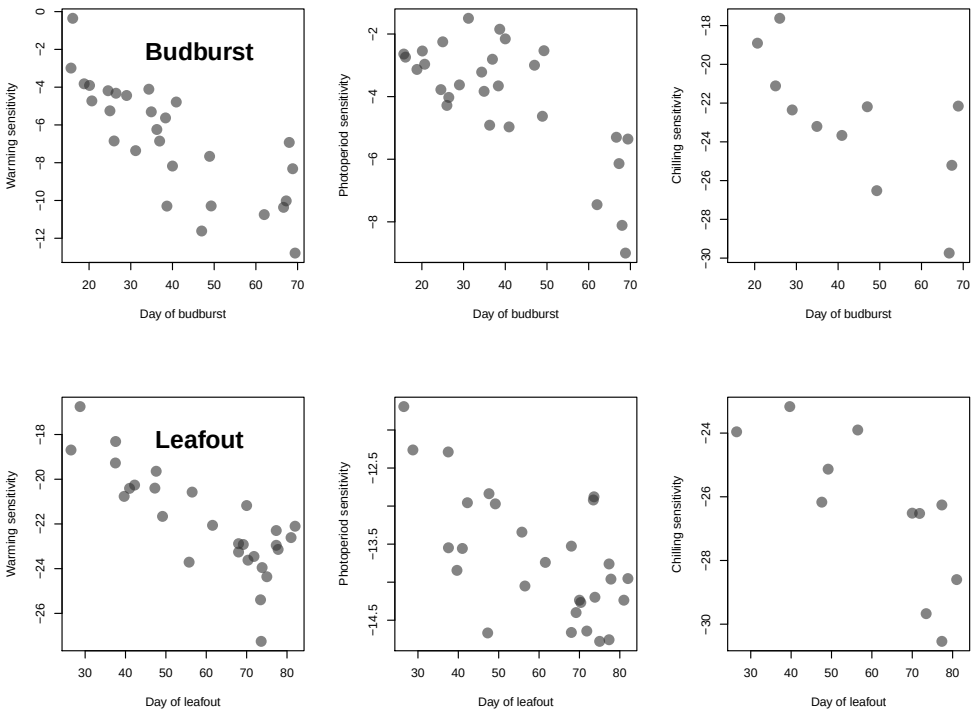

Figure S4: Trait sensitivity based on specific leaf area

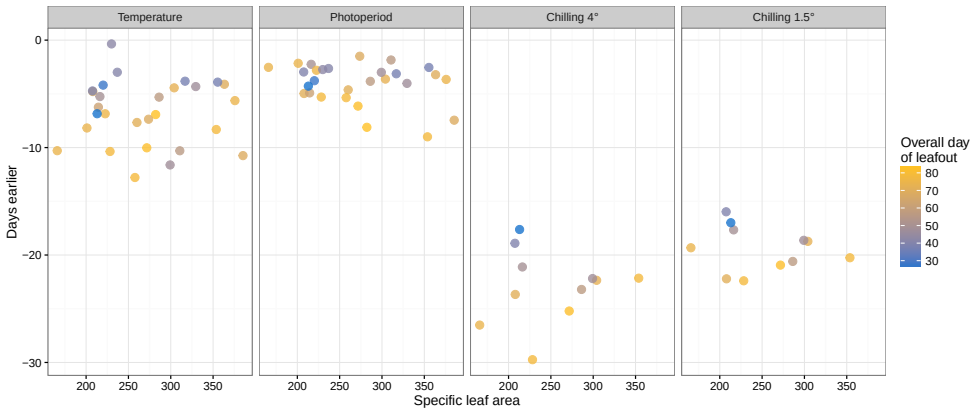

Figure S5: Trait sensitivity based on stem density

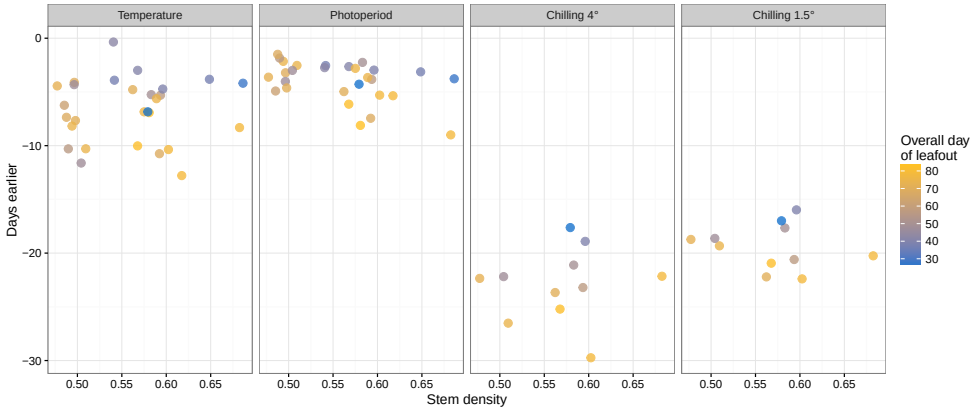

Figure S6: Trait sensitivity based on % nitrogen

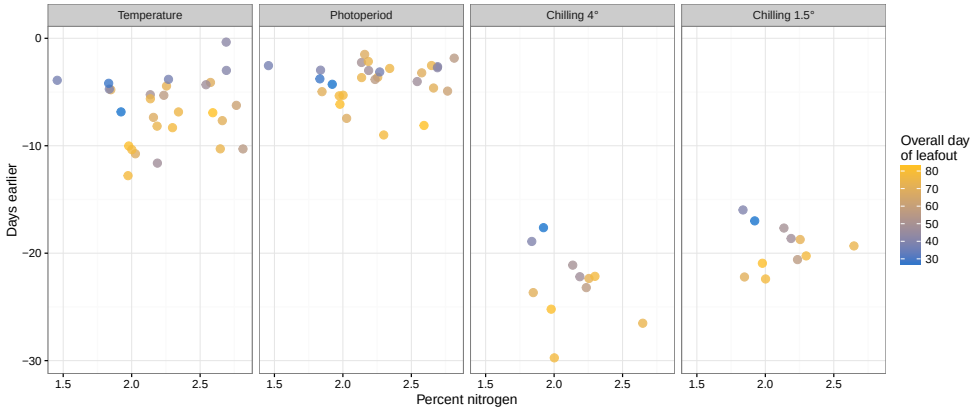

Figure S7: Specific leaf area and stem density by trees vs shrubs

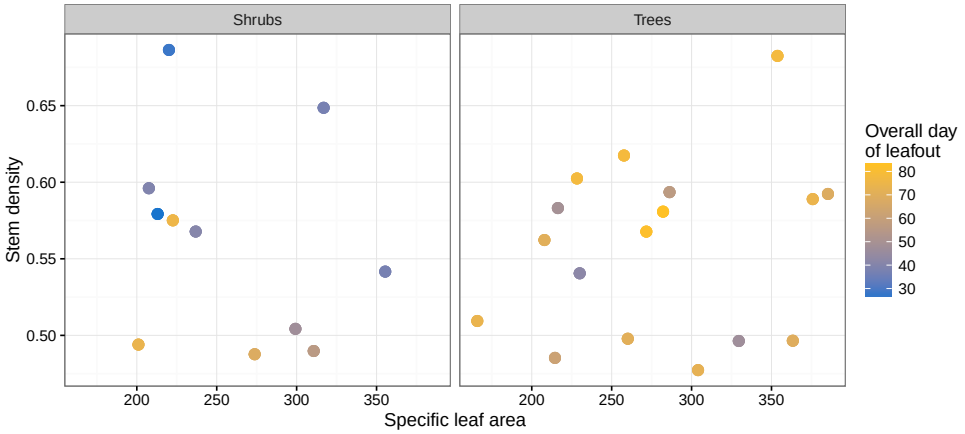

Figure S8: Specific leaf area and percent nitrogen by trees vs shrubs

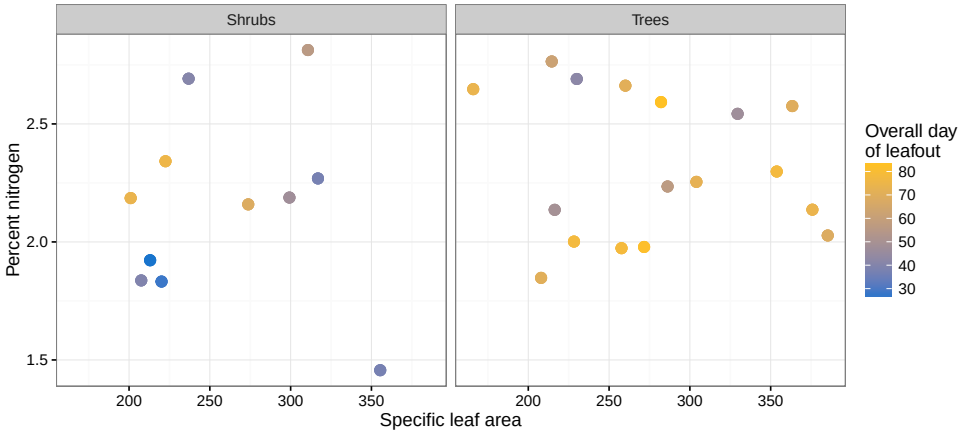

Figure S9: Stem density and percent nitrogen by trees vs shrubs

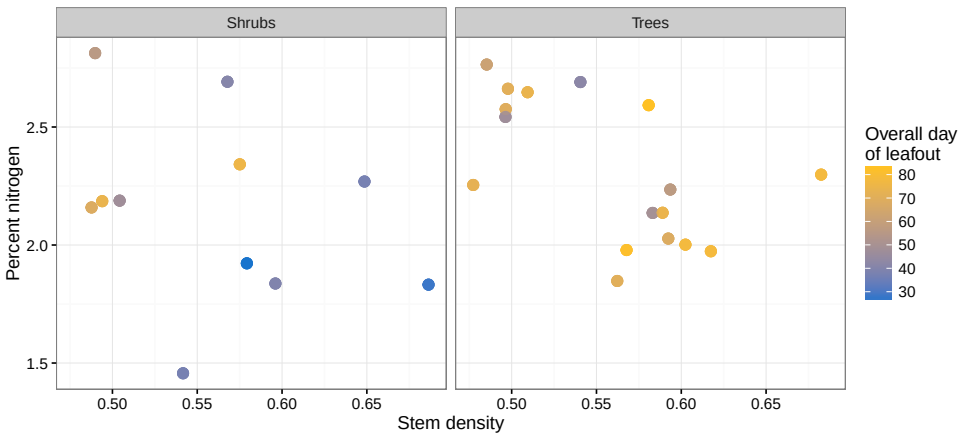

Figure S10: Leafout rank order in experimental treatments vs. O'Keefe observations

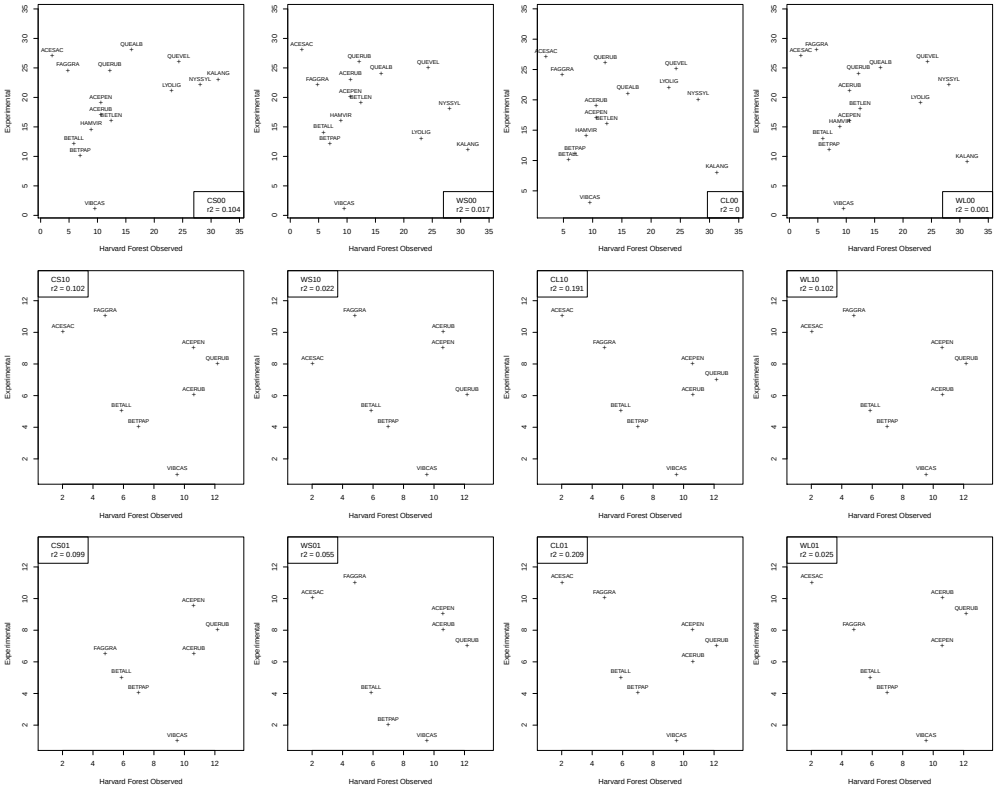

Figure S11: Leafout day of year in experimental treatments vs. O'Keefe observations