Supplementary Material: Woody plant phenological responses are strongly associated with key functional traits

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Methods

We used a phylogenetic generalized least-squares regression model (PGLS) to test the relationship between day of budburst and each trait. This analysis allowed us to test for phylogenetic non-independence in the phenology-trait relationship [1]. We obtained a rooted phylogenetic tree by pruning the tree developed by [2] and performed the PGLS analysis using the mean trait values and mean posterior estimates of the cue responses from our joint model. The PGLS was run using the "Caper" package in R [3].

Figures & Tables

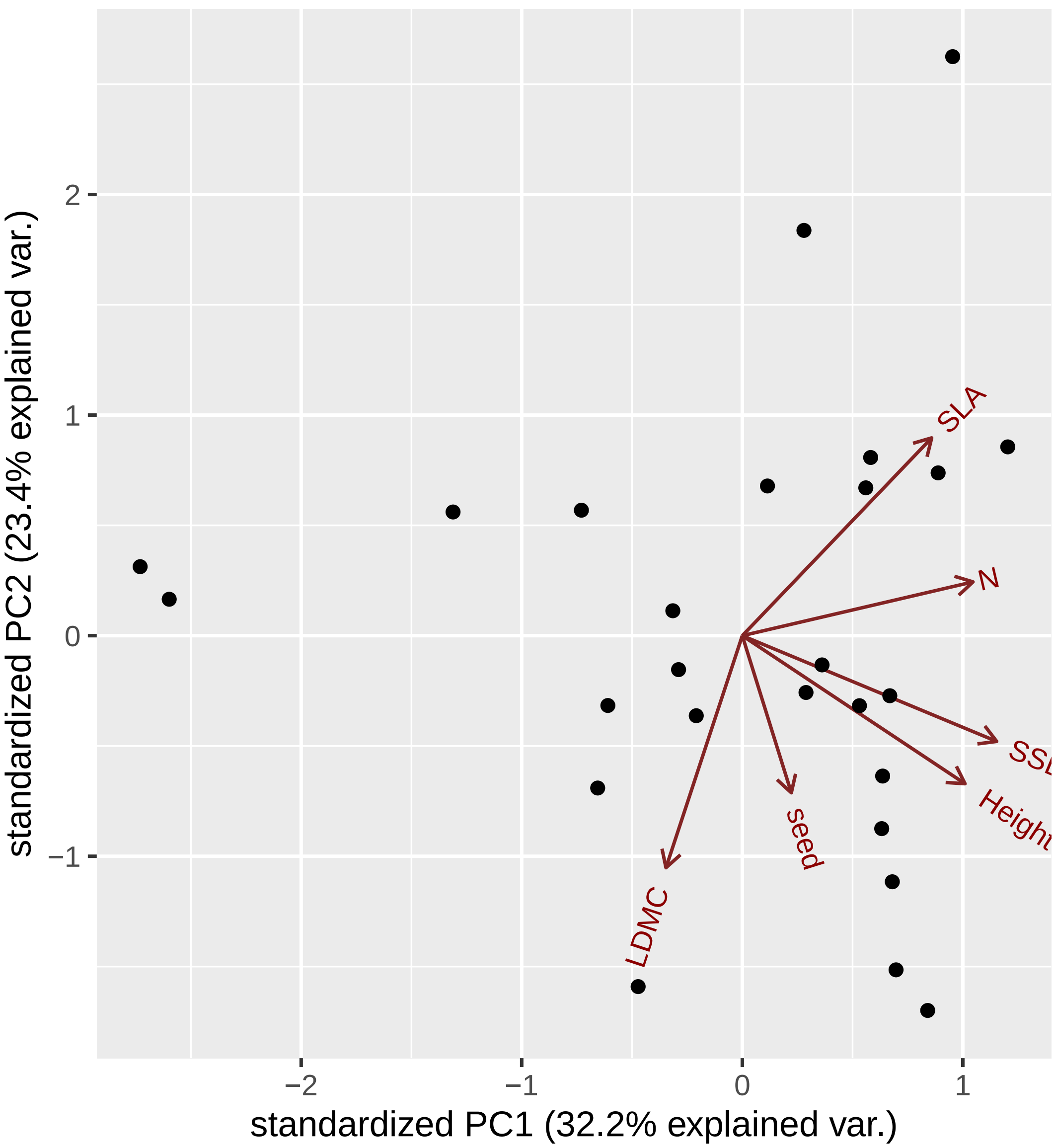

Figure S1: A projection of tree traits across the first and second principle component axis. Arrows represent the direction of vectors for six functional traits. Points represent the 26 species for which complete trait data was available

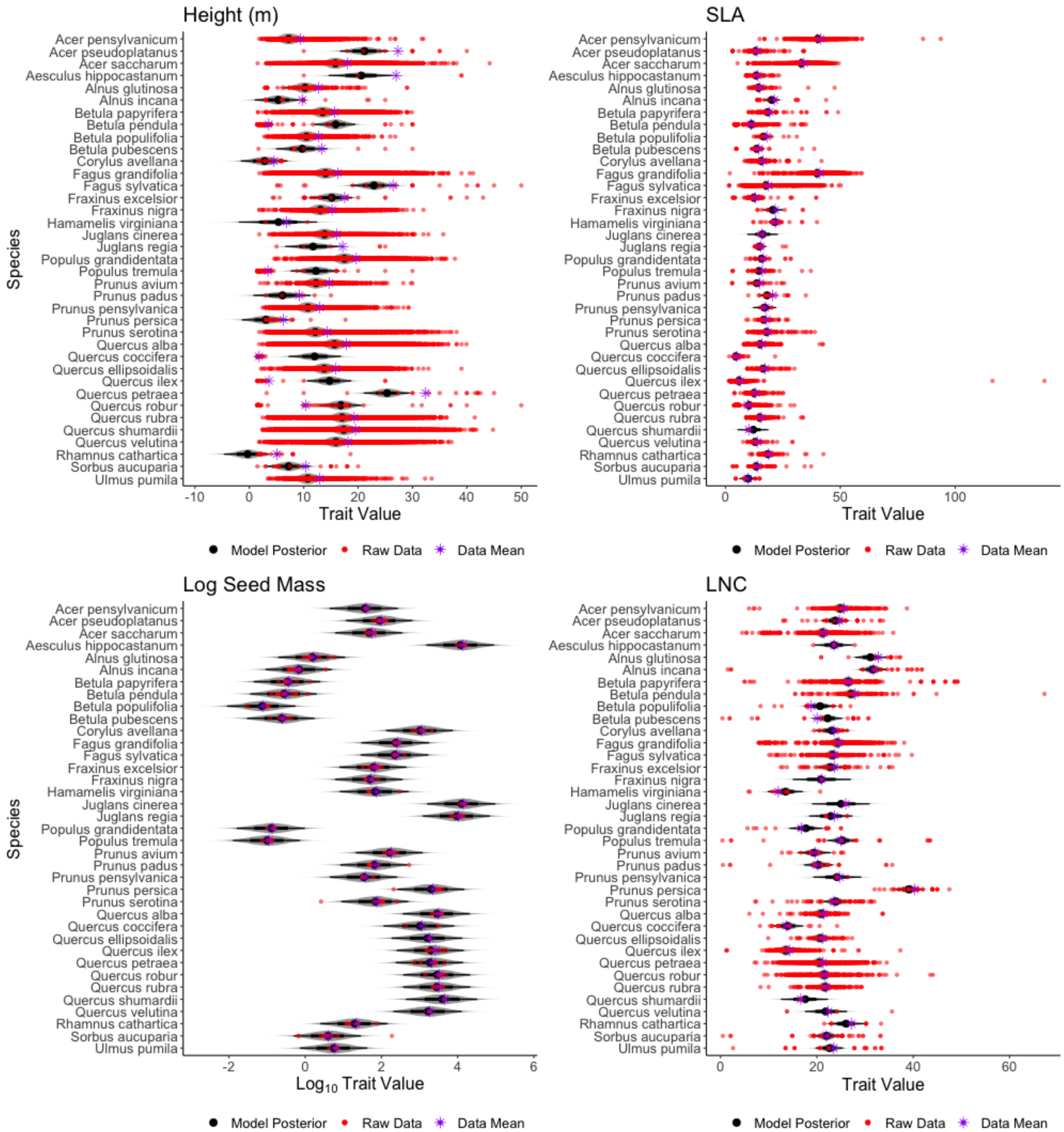

Figure S2: Comparisons of estimated model fits and raw data from joint models of trait effects on budburst phenological cues for 37 species of woody deciduous plants. Four functional traits – a. height, b. SLA, c. seed mass, and d. LNC – were modeled individually, with the calculated trait value being used to jointly model species responses to standardized chilling, forcing, and photoperiod cues. Model posteriors are shown in black, with the thicker line depicting the 66% interval and the thinner black line the 97% interval. Overall species level model posterior distributions were well aligned with the raw data, shown in red, and the species level means from the raw data, denoted as a purple stars.

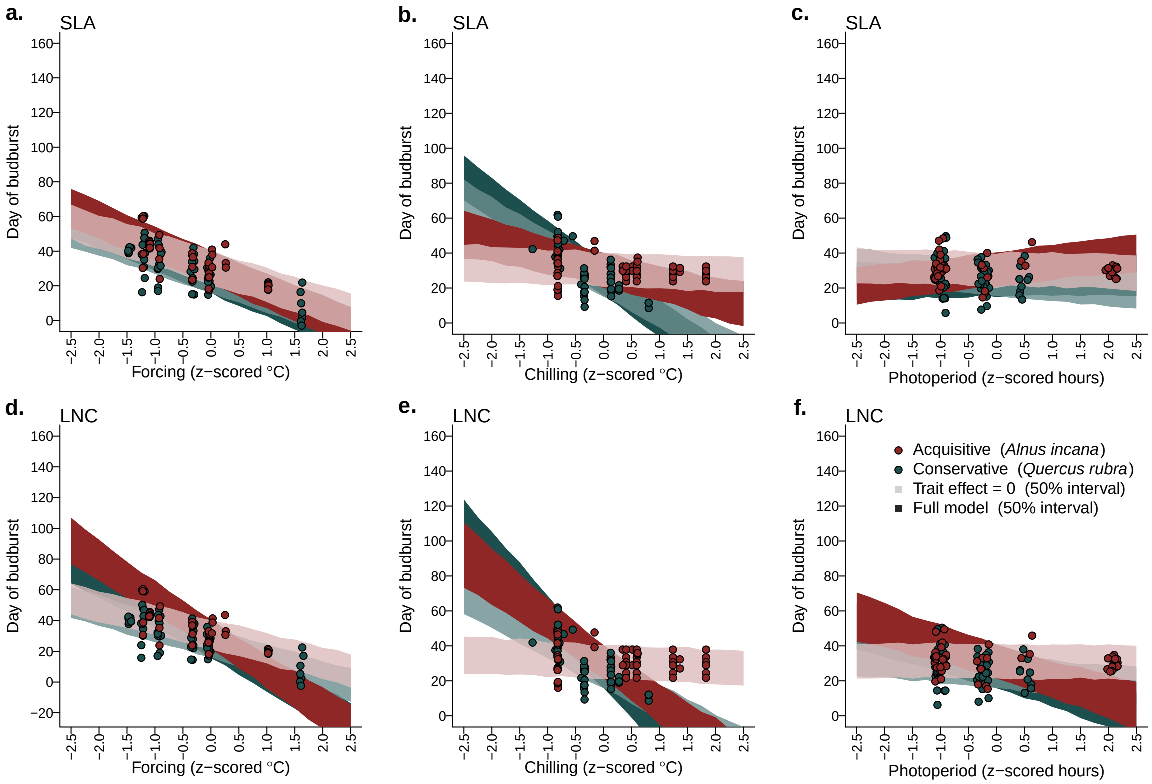

Figure S3: We expected species with traits associated with acquisitive (e.g, low specific leaf area, SLA, and leaf nitrogen content, LNC) versus conservative (e.g., high SLA and LNC) growth strategies would have different budburst responses to phenological cues. Our joint model allows traits of species to influence their responses to cues. We show an example here with an acquistive species, *Alnus incana* shown in red, and a conservative species, *Quercus rubra* shown in blue, for SLA (**a-c**) and LNC (**d-f**). Our joint model estimated later budburst due to trait effects for both SLA and LNC in response to forcing (**a, d,**) and chilling (**b, e**) and for LNC in response to photoperiod (**f**). Only in response to photoperiod did we estimate the effect of SLA to lead to slightly earlier budburst with longer photoperiods (**c**). The coloured bands represent the 50% uncertainty intervals of the model estimates and points individual trati measurements.

References

[1] R. P. Freckleton, P. H. Harvey, M. Pagel, *American Naturalist* **160**, 712 (2002).

[2] S. A. Smith, J. W. Brown, *American Journal of Botany* **105**, 302 (2018).

[3] D. Orme, The caper package: comparative analysis of phylogenetics and evolution in R. (2013).

Table S1: Bibliographic information for trait data sources from both BIEN and Try trait databases.

traitname	unitname	no.obs	no.spp	database	datasetid	reference	X
Height	m	26	8	bien	10_bien	doi:10.5061/dryad.j25t0	McHugh
Height	m	2	2	bien	12_bien	doi:10.5061/dryad.m88g7	Marx2015
Height	m	27	19	bien	14_bien	doi:10.5061/dryad.r3n45	Price2014
Height	m	18	16	bien	18_bien		
Height	m	90	19	bien	20_bien	LEDA traitbase	
Height	m	10	10	bien	21_bien		
Height	m	21	14	bien	22_bien	Moles, Angela	
Height	m	47036	19	bien	24_bien	Reams, Greg	
Height	m	5	5	bien	25_bien	Grime, Hodgson, & Hunt	
Height	m	8	5	bien	26_bien		
Height	m	18	1	bien	3_bien	doi:10.5061/dryad.1cn19	Perez-de-lis
Height	m	120	1	bien	5_bien	doi:10.5061/dryad.4q78p	Robinson20
Height	m	20	1	bien	7_bien	doi:10.5061/dryad.6nc8c	Anderson-T
Height	m	2	1	try	156_try	Bond-Lamberty et al. (2002)	
Height	m	275	3	try	186_try	unpub.	
Height	m	28	19	try	20_try	Wright et al. (2004)	\{citep{Wr
Height	m	2	2	try	236_try	Prentice et al. (2011)	
Height	m	21	21	try	251_try	Schweingruber & Landolt (2005)	Schweingru
Height	m	35	2	try	275_try	unpub.	
Height	m	5	5	try	28_try	Moles et al. (2004)	
Height	m	1	1	try	54_try	Cavender-Bares et al. (2006)	
Height	m	11	10	try	86_try	Diaz et al. (2004)	
LNC	mg/g	287	12	try	130_try	Craine et al. (2009)	
LNC	mg/g	44	2	try	154_try	Wilson et al. (2000)	
LNC	mg/g	7	4	try	180_try	Wenxuan et al. (2012)	
LNC	mg/g	7	3	try	181_try	Yahan et al. (2011)	
LNC	mg/g	65	32	try	20_try	Wright et al. (2004)	
LNC	mg/g	3	2	try	236_try	Prentice et al. (2011)	
LNC	mg/g	120	20	try	240_try	Vergutz et al. 2012	
LNC	mg/g	24	8	try	286_try	Atkin et al. (2015)	
LNC	mg/g	72	22	try	342_try	Maire et al. (2015)	
LNC	mg/g	2	1	try	37_try	Cornelissen et al. (2003)	
LNC	mg/g	3216	37	try	412_try	unpub.	
LNC	mg/g	6	2	try	443_try	Wang et al. 2017	
Seed mass	mg	3	3	bien	12_bien	doi:10.5061/dryad.m88g7	Marx2015
Seed mass	mg	4	2	bien	17_bien	http://ucjeps.berkeley.edu/EFT.html	
Seed mass	mg	250	37	bien	19_bien	KEW database	
Seed mass	mg	12	12	bien	2_bien	doi:10.5061/dryad.12b0h	Ameztegui2
Seed mass	mg	12	7	bien	9_bien	doi:10.5061/dryad.h9083	Paine2015
SLA	mm2 mg-1	44	2	try	154_try	Wilson et al. (2000)	
SLA	mm2 mg-1	204	3	try	186_try	unpub.	
SLA	mm2 mg-1	93	33	try	20_try	Wright et al. (2004)	
SLA	mm2 mg-1	2	2	try	236_try	Prentice et al. (2011)	
SLA	mm2 mg-1	102	18	try	25_try	Kleyer et al. (2008)	
SLA	mm2 mg-1	83	2	try	275_try	unpub.	
SLA	mm2 mg-1	40	11	try	286_try	Atkin et al. (2015)	
SLA	mm2 mg-1	86	23	try	342_try	Maire et al. (2015)	
SLA	mm2 mg-1	615	14	try	37_try	Cornelissen et al. (2003)	
SLA	mm2 mg-1	6307	37	try	412_try	unpub.	
SLA	mm2 mg-1	6	2	try	443_try	Wang et al. 2017	
SLA	mm2 mg-1	20	2	try	50_try	Shipley et al. (2002)	
SLA	mm2 mg-1	42	2	try	54_try	Cavender-Bares et al. (2006)	
SLA	mm2 mg-1	1	1	try	65_try	unpub.	
SLA	mm2 mg-1	11	10	try	86_try	Diaz et al. (2004)	

Table S2: Summary of model estimates using measurements of tree height for our 37 focal species ($n = 42781$)

	mean	sd	2.5%	50%	97.5%	Rhat
mu_grand	12.71	1.96	8.73	12.75	16.46	1.00
muPhenoSp	32.07	2.63	26.97	32.05	37.30	1.00
muForceSp	-10.74	2.86	-16.63	-10.66	-5.38	1.01
muChillSp	-4.08	4.13	-12.46	-4.02	3.99	1.01
muPhotoSp	1.11	2.18	-3.37	1.14	5.27	1.01
betaTraitxForce	0.16	0.19	-0.21	0.16	0.55	1.01
betaTraitxChill	-0.54	0.28	-1.07	-0.54	0.02	1.01
betaTraitxPhoto	-0.25	0.15	-0.54	-0.25	0.08	1.00
sigma_sp	5.91	0.76	4.63	5.84	7.57	1.00
sigma_study	7.53	1.22	5.52	7.40	10.28	1.00
sigma_traity	5.39	0.02	5.36	5.39	5.43	1.00
sigmaPhenoSp	15.11	2.05	11.20	15.06	19.36	1.00
sigmaForceSp	4.96	1.16	3.01	4.85	7.55	1.00
sigmaChillSp	8.53	2.10	5.21	8.26	13.38	1.00
sigmaPhotoSp	3.25	0.86	1.79	3.17	5.15	1.00
sigmapheno_y	14.18	0.26	13.69	14.18	14.70	1.00

Table S3: Summary of model estimates using measurements of seed mass data for our 37 focal species ($n = 281$).

	mean	sd	2.5%	50%	97.5%	Rhat
mu_grand	1.87	0.50	0.89	1.88	2.84	1.00
muPhenoSp	31.35	2.64	26.32	31.27	36.76	1.00
muForceSp	-8.17	1.60	-11.35	-8.16	-5.07	1.00
muChillSp	-9.41	2.82	-15.21	-9.43	-3.92	1.00
muPhotoSp	-1.26	1.25	-3.72	-1.27	1.19	1.00
betaTraitxForce	-0.30	0.69	-1.61	-0.31	1.06	1.00
betaTraitxChill	-1.09	1.09	-3.28	-1.08	1.01	1.00
betaTraitxPhoto	-0.56	0.58	-1.68	-0.56	0.62	1.00
sigma_sp	1.62	0.19	1.30	1.61	2.05	1.00
sigma_study	0.97	0.10	0.77	0.97	1.17	1.00
sigma_traity	0.25	0.01	0.23	0.25	0.27	1.00
sigmaPhenoSp	14.84	2.25	10.58	14.79	19.42	1.00
sigmaForceSp	4.92	0.98	3.22	4.85	7.03	1.00
sigmaChillSp	10.67	2.57	6.55	10.33	16.65	1.00
sigmaPhotoSp	3.58	0.86	2.13	3.49	5.52	1.00
sigmapheno_y	14.12	0.25	13.66	14.12	14.61	1.00

Table S4: Summary of model estimates using measurements of specific leaf area for our 37 focal species (n = 7656).

	mean	sd	2.5%	50%	97.5%	Rhat
mu_grand	16.85	1.47	14.03	16.85	19.71	1.01
muPhenoSp	31.33	2.55	26.45	31.30	36.39	1.00
muForceSp	-11.40	2.71	-17.29	-11.33	-6.42	1.01
muChillSp	-16.66	4.70	-26.35	-16.61	-7.84	1.00
muPhotoSp	1.85	2.47	-3.13	1.98	6.47	1.00
betaTraitxForce	0.17	0.15	-0.11	0.17	0.47	1.01
betaTraitxChill	0.34	0.25	-0.13	0.34	0.83	1.00
betaTraitxPhoto	-0.23	0.14	-0.50	-0.24	0.05	1.00
sigma_sp	7.78	0.93	6.21	7.70	9.77	1.00
sigma_study	3.28	0.97	1.87	3.13	5.57	1.00
sigma_traity	6.17	0.05	6.07	6.16	6.27	1.00
sigmaPhenoSp	13.92	2.11	10.10	13.79	18.34	1.00
sigmaForceSp	4.97	1.12	3.07	4.87	7.49	1.00
sigmaChillSp	10.57	2.30	6.79	10.33	15.56	1.00
sigmaPhotoSp	3.48	0.81	2.14	3.40	5.36	1.00
sigmapheno_y	14.17	0.26	13.66	14.17	14.68	1.00

Table S5: Summary of model estimates using measurements of leaf nitrogen content for our 37 focal species (n = 3853.)

	mean	sd	2.5%	50%	97.5%	Rhat
mu_grand	22.61	1.37	19.91	22.60	25.32	1.01
muPhenoSp	31.14	2.52	26.33	31.09	36.29	1.00
muForceSp	-19.33	5.37	-30.02	-19.45	-8.62	1.02
muChillSp	-27.10	7.04	-40.56	-27.27	-12.84	1.01
muPhotoSp	-9.40	4.67	-18.09	-9.41	-0.37	1.02
betaTraitxForce	0.47	0.23	0.01	0.47	0.93	1.02
betaTraitxChill	0.72	0.30	0.12	0.72	1.29	1.01
betaTraitxPhoto	0.31	0.19	-0.06	0.31	0.68	1.02
sigma_sp	5.12	0.61	4.09	5.06	6.48	1.00
sigma_study	3.55	0.98	2.03	3.44	5.83	1.00
sigma_traity	5.13	0.06	5.02	5.13	5.25	1.00
sigmaPhenoSp	14.05	1.97	10.30	13.97	18.23	1.00
sigmaForceSp	4.59	1.09	2.80	4.47	7.05	1.00
sigmaChillSp	8.92	1.97	5.74	8.71	13.44	1.00
sigmaPhotoSp	3.59	0.81	2.25	3.52	5.41	1.00
sigmapheno_y	14.17	0.26	13.67	14.17	14.67	1.00