Phenological cue use varies with functional traits in North American woody plan communities

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[1] "/Users/deirdreloughnan/Documents/github/Treetraits/docs"
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Research questions

1. Do phenological cue-trait relationships change across transects? Populations?
2. How do budburst cues relate to functional traits in temperate woody species?
3. How do shrub and tree species differ in their cue-trait relationships?

Materials and Methods

These plots and tables are using the model output from the model with a dummy variable for transect (east = 1) and an interaction between transect and latitude. Latitude is included as a continuous variable, but based on the prior predictive checks, I decided to z-scored it. 90% UI given in text.

Results

1. Our study = one of the first to combine trait data with phenological cue responses for the same individuals and across species distributions.
   (a) Includes plant communities in eastern and western deciduous forests of North America
   (b) Samples collected from multiple populations—modelling approach that accounts for variation across populations and transects
   (c) Joint modelling approach = use sp-level estimates for traits to understand phenological cue responses and budburst timing
   (d) Taking a community-level approach—with woody tree and shrub species = different growth strategies and presumably suites of traits
2. Most traits small population effects—but some traits show strong interaction between pop and transect
   (a) Found differences between our transects for height and DBH— smaller for eastern species

   (b) Moderate to strong interaction between leaf traits across latitude and transects
   (c) Both LMA and C:N = larger trait values with increasing latitude in eastern transect, but smaller values in western transect species (0.9, UI: 0.8,1.1 for LMA, 1.1, UI: 1.0,1.3 for C:N)
   (d) No relationships between transect or latitude for SSD
   (e) Fig. 1

3. All traits related to one or more budburst cue—but responses were variable across cues and traits
   (a) Wood and structural traits all showed similar cue relationships but differed in strength
   (b) Height only related to photoperiod—taller trees stronger photoperiod responses = earlier bb under high cues (-3.4, UI: -2.7, -0.3)—no response to forcing or chilling.
   (c) Cues had a moderate relationship to DBH—found weakest cue responses of large diameter trees to forcing (3.3, UI: -0.7, 7.4) and chilling (2.7, UI: -5.3, 10.4) = later budburst than smaller trees—but strong responses to photoperiod with greater advances in bb with longer photoperiods (-3.5, UI: -5.5, -1.0)
   (d) Strongest cue responses found for SSD—increasing stem specific density lead to weaker cue responses to forcing (12, UI: 1.8, 21.8) and chilling (19.3, UI: 1.1, 36.5) = later budburst under high cues—but strong responses to photoperiod with greater advances in bb with longer photoperiods (-3.4, UI: -10.1, 2.2)
   (e) Ref Fig. **??** and Fig. 5
   (f) But no correlation between between ring porosity of wood with our three cues—based on spp means using posterior estimates 3.

4. leaf traits varied more in the direction of cue responses
   (a) LMA showed weak relationships with forcing and chilling—larger LMA stronger responses under high forcing (-3, UI: -8.8, 3.2) and chilling (-3.9, UI: -14.9, 7)—but strong responses to photoperiod with larger LMA species advancing in bb with longer photoperiods (-4.1, UI: 0.1, 6.6)
   (b) In contrast—C:N strong responses to forcing and chilling but not photoperiod—high C:N species weaker responses to forcing (5.7, UI: 1.0, 10.3), chilling (10.5, UI: 2.3, 18.7) and photoperiods (-3.7, UI: -2.3, 3.7)—with high temperatures and longer daylengths all leading to later budburst in high C:N species.

5. Regardless of trait effects—our joint modeling approach still estimated phenological cue responses in line with previous work.
   (a) All models showed earlier budburst in response to all three cues
   (b) Individual spp varied in both their timing and cue responses.
   (c) But in general spp responses were strongest for chilling and weakest for photoperiod.
   (d) ref Fig. 4 and Fig. 5

6. Including trait effects better informed spp level estimates of phenology
   (a) Estimates bb using our model parameters show clear differences in bb timing between tree and shrub spp (Fig. 6)
   (b) Shrub spp were estimated to bb earlier—especially under stronger cues—tree spp were later
   (c) But species-level effects vary across traits = unique effects on cue responses—estimated order of spp bb order differs between the two models

Figures

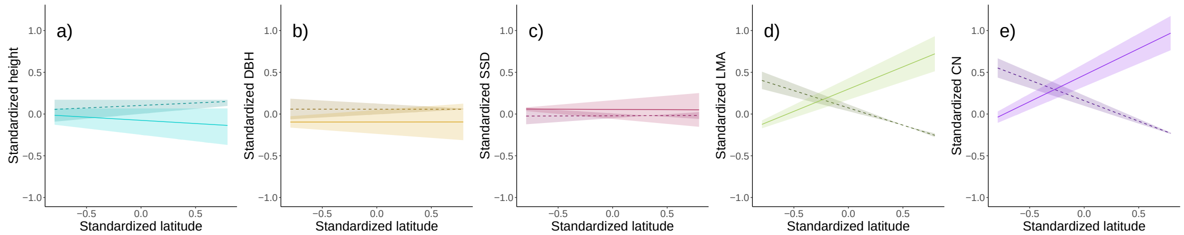

Figure 1: We only found biogeographic differences for four of our functional traits, with the direction of the relationship varying across traits. Both height a. height and b. diameter at base height showed strong interactions between latitude and trait values, while c. leaf mass area has the weakest response, and d. stem specific density, and e. carbon:nitrogen moderate interactive effects.

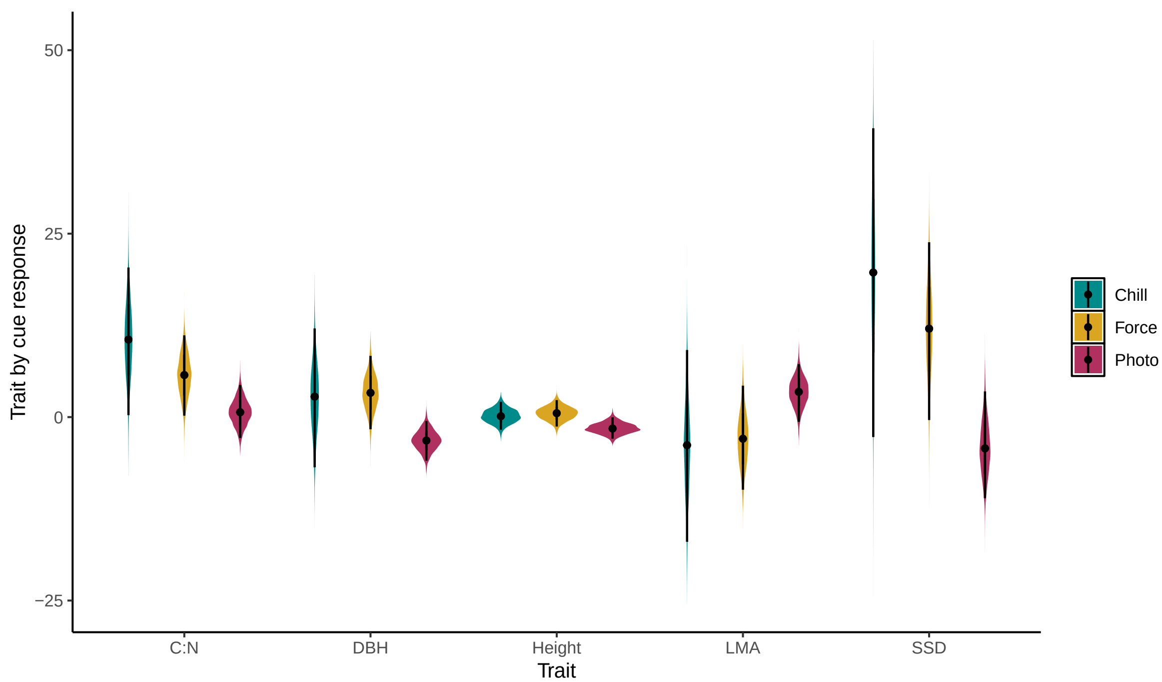

Figure 2: Only some traits were related to budburst phenological cues. For leaf mass area, stem specific density, and the ratio of carbon to nitrogen, traits no effect on budburst timing.

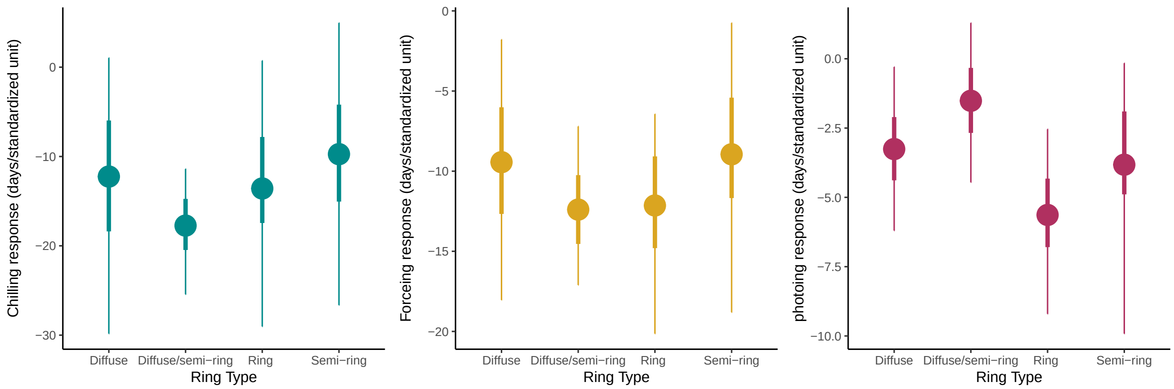

Figure 3: Ring porosity and height.

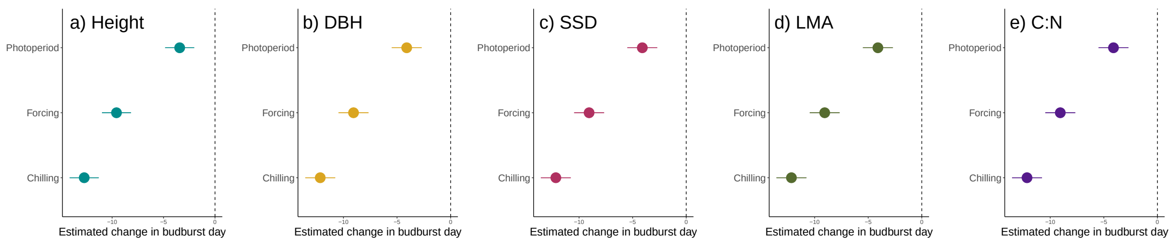

Figure 4: We found consistent estimates for budburst cue responses to chilling, forcing, and photoperiod for each of our trait models: a. height, b. diameter at breast height, c. stem specific density, d. leaf mass area, and e. carbon:nitrogen. Lines represent 90% uncertainty intervals.

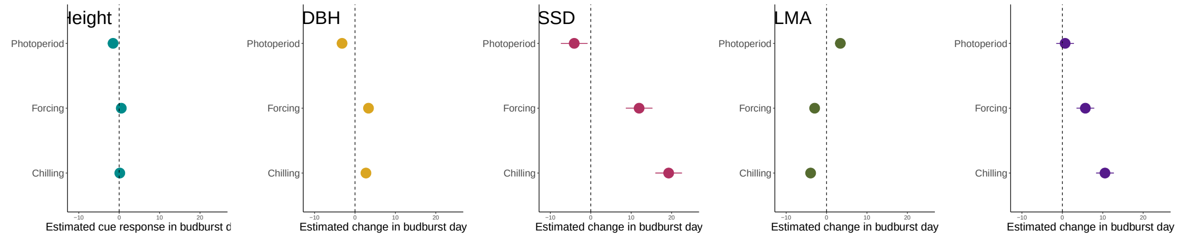

Figure 5: The relationships between traits and cue responses varied considerably across each of our trait models, a. height, b. diameter at breast height, c. stem specific density, d. leaf mass area, and e. carbon:nitrogen, and for individual cues. Lines represent 90% uncertainty intervals.

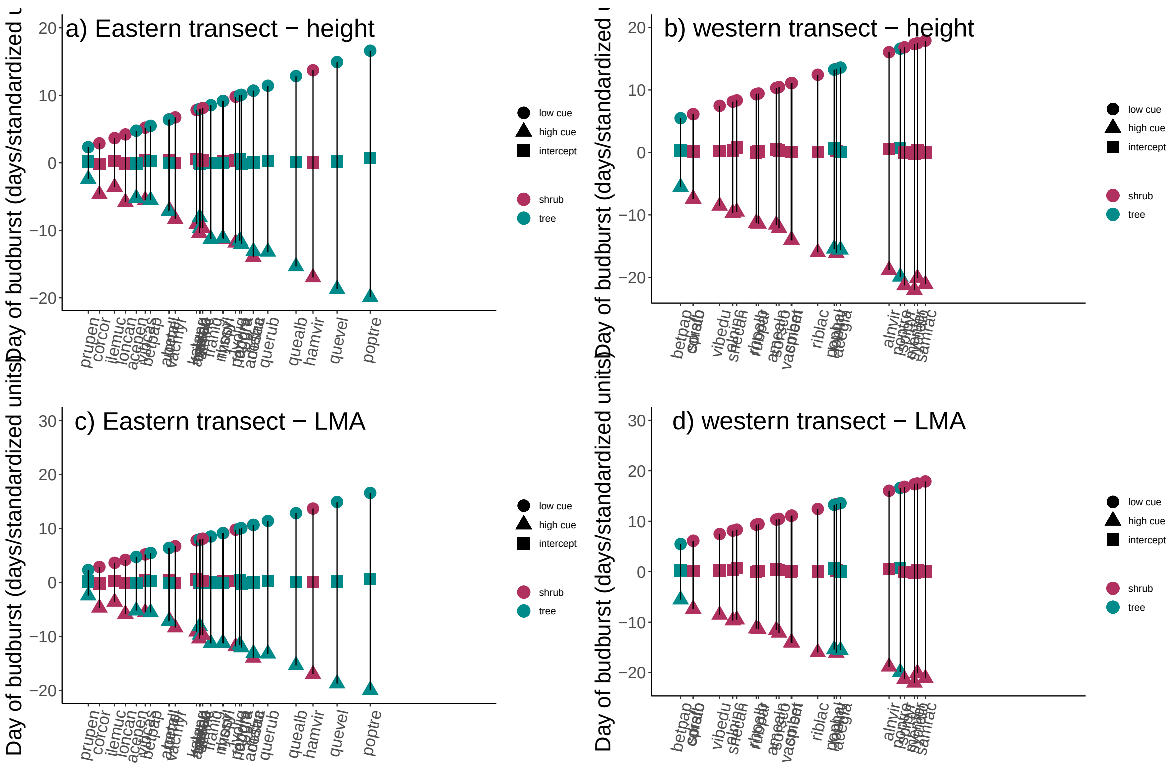

Figure 6: We found budburst estimates differed between our full model (intercept plus cues, depicted as triangles for high cues and circles for low cues), versus the intercepts only model (without cues, shown as squares). Species are ordered in increasing budburst dates for both the eastern (a and b) and western (c and d) populations, spanning from early budbursting shrubs, in red, to late budbursting trees, in blue.

Tables

Table 1: Summary of a joint model for height

	mean	X2.5.	X25.	X50.	X75.	X97.5.
mu_grand	0.01	-0.13	-0.04	0.01	0.06	0.15
b_tranE	-0.18	-0.26	-0.21	-0.18	-0.15	-0.09
b_tranlat	-0.14	-0.30	-0.19	-0.13	-0.08	0.03
muForceSp	-9.58	-11.25	-10.15	-9.58	-9.00	-7.93
muChillSp	-12.72	-15.93	-13.82	-12.71	-11.64	-9.46
muPhotoSp	-3.44	-4.37	-3.73	-3.43	-3.13	-2.53
muPhenoSp	27.03	24.22	26.07	27.06	27.98	29.89
betaTraitxForce	0.52	-1.29	-0.11	0.53	1.15	2.32
betaTraitxChill	0.15	-1.72	-0.52	0.12	0.83	2.09
betaTraitxPhoto	-1.52	-2.94	-2.02	-1.56	-1.03	-0.02
sigma_traity	0.31	0.29	0.30	0.31	0.31	0.32
sigma_sp	0.46	0.37	0.42	0.45	0.49	0.57
sigmaForceSp	5.19	4.00	4.72	5.13	5.60	6.71
sigmaChillSp	9.52	7.32	8.65	9.47	10.29	12.07
sigmaPhotoSp	2.14	1.31	1.82	2.10	2.44	3.17
sigmaPhenoSp	9.77	8.01	9.03	9.70	10.44	12.02
sigmapheno_y	9.50	9.29	9.42	9.50	9.57	9.71

Table 2: Summary of a joint model for leaf mass area

	mean	X2.5.	X25.	X50.	X75.	X97.5.
mu_grand	0.17	0.08	0.14	0.17	0.20	0.27
b_tranE	0.22	0.12	0.19	0.22	0.26	0.33
b_tranlat	0.94	0.72	0.86	0.94	1.02	1.16
muForceSp	-9.06	-11.26	-9.77	-9.04	-8.36	-6.95
muChillSp	-12.17	-16.09	-13.48	-12.19	-10.85	-8.16
muPhotoSp	-4.10	-5.35	-4.50	-4.09	-3.68	-2.88
muPhenoSp	27.06	24.11	26.11	27.06	28.01	29.99
betaTraitxForce	-2.95	-9.90	-5.48	-2.95	-0.54	4.28
betaTraitxChill	-3.94	-16.99	-8.36	-3.83	0.41	9.14
betaTraitxPhoto	3.41	-0.64	2.14	3.44	4.78	7.21
sigma_traity	0.42	0.41	0.42	0.42	0.43	0.44
sigma_sp	0.26	0.21	0.24	0.26	0.28	0.33
sigmaForceSp	5.24	4.01	4.75	5.19	5.67	6.70
sigmaChillSp	9.55	7.39	8.68	9.46	10.33	12.17
sigmaPhotoSp	2.24	1.32	1.92	2.22	2.56	3.29
sigmaPhenoSp	9.76	7.94	9.03	9.67	10.36	12.12
sigmapheno_y	9.50	9.29	9.43	9.50	9.57	9.70

Table 3: Summary of a joint model for diameter at base height

	mean	X2.5.	X25.	X50.	X75.	X97.5.
mu_grand	-0.01	-0.12	-0.05	-0.01	0.03	0.11
b_tranE	-0.15	-0.25	-0.18	-0.15	-0.12	-0.06
b_tranlat	0.00	-0.19	-0.07	-0.00	0.07	0.20
muForceSp	-9.51	-11.20	-10.07	-9.50	-8.94	-7.83
muChillSp	-12.56	-15.48	-13.60	-12.60	-11.57	-9.35
muPhotoSp	-3.45	-4.42	-3.77	-3.45	-3.12	-2.48
muPhenoSp	27.03	24.14	26.06	27.04	27.99	29.85
betaTraitxForce	3.34	-1.65	1.72	3.31	5.04	8.34
betaTraitxChill	2.71	-6.84	-0.40	2.79	5.90	12.08
betaTraitxPhoto	-3.20	-5.94	-4.10	-3.19	-2.28	-0.52
sigma_traity	0.35	0.34	0.35	0.35	0.36	0.37
sigma_sp	0.35	0.28	0.32	0.35	0.38	0.44
sigmaForceSp	5.15	3.97	4.67	5.10	5.57	6.63
sigmaChillSp	9.56	7.28	8.61	9.45	10.38	12.46
sigmaPhotoSp	2.23	1.38	1.91	2.21	2.53	3.26
sigmaPhenoSp	9.79	7.96	9.03	9.73	10.46	12.02
sigmapheno_y	9.50	9.28	9.43	9.50	9.57	9.71

Table 4: Summary of a joint model for stem specific density

	mean	X2.5.	X25.	X50.	X75.	X97.5.
mu_grand	0.01	-0.06	-0.01	0.01	0.04	0.09
b_tranE	0.08	-0.02	0.04	0.08	0.11	0.17
b_tranlat	-0.01	-0.25	-0.09	-0.01	0.07	0.23
muForceSp	-9.72	-11.59	-10.31	-9.72	-9.11	-7.93
muChillSp	-13.08	-16.19	-14.15	-13.07	-11.98	-9.83
muPhotoSp	-3.41	-4.42	-3.74	-3.41	-3.08	-2.43
muPhenoSp	27.07	24.19	26.12	27.05	28.00	29.97
betaTraitxForce	11.97	-0.40	7.94	12.05	16.18	23.83
betaTraitxChill	19.28	-2.72	12.24	19.70	26.84	39.36
betaTraitxPhoto	-4.10	-11.06	-6.74	-4.26	-1.59	3.50
sigma_traity	0.47	0.45	0.46	0.47	0.47	0.49
sigma_sp	0.16	0.12	0.14	0.16	0.18	0.21
sigmaForceSp	4.88	3.64	4.41	4.82	5.31	6.39
sigmaChillSp	8.84	6.61	7.93	8.75	9.69	11.56
sigmaPhotoSp	2.33	1.42	1.99	2.31	2.66	3.43
sigmaPhenoSp	9.72	7.89	8.98	9.64	10.36	12.08
sigmapheno_y	9.50	9.30	9.43	9.50	9.57	9.70

Table 5: Summary of a joint model for carbon to nitrogen ratio

	mean	X2.5.	X25.	X50.	X75.	X97.5.
mu_grand	0.29	0.18	0.26	0.29	0.33	0.41
b_tranE	0.30	0.21	0.27	0.30	0.33	0.39
b_tranlat	1.12	0.94	1.05	1.12	1.18	1.30
muForceSp	-11.17	-13.47	-11.96	-11.15	-10.39	-8.88
muChillSp	-15.74	-19.87	-17.16	-15.74	-14.34	-11.73
muPhotoSp	-3.67	-5.10	-4.15	-3.66	-3.18	-2.32
muPhenoSp	27.14	24.26	26.17	27.14	28.09	30.02
betaTraitxForce	5.69	0.19	3.78	5.73	7.69	11.14
betaTraitxChill	10.55	0.26	7.05	10.57	14.01	20.39
betaTraitxPhoto	0.69	-2.84	-0.51	0.66	1.85	4.40
sigma_traity	0.35	0.34	0.34	0.35	0.35	0.36
sigma_sp	0.32	0.26	0.29	0.32	0.34	0.41
sigmaForceSp	5.00	3.87	4.54	4.96	5.40	6.47
sigmaChillSp	9.07	6.94	8.23	8.97	9.84	11.72
sigmaPhotoSp	2.47	1.57	2.13	2.44	2.78	3.54
sigmaPhenoSp	9.69	7.92	8.97	9.60	10.34	11.93
sigmapheno_y	9.50	9.30	9.43	9.50	9.57	9.71