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

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## Figures & Tables

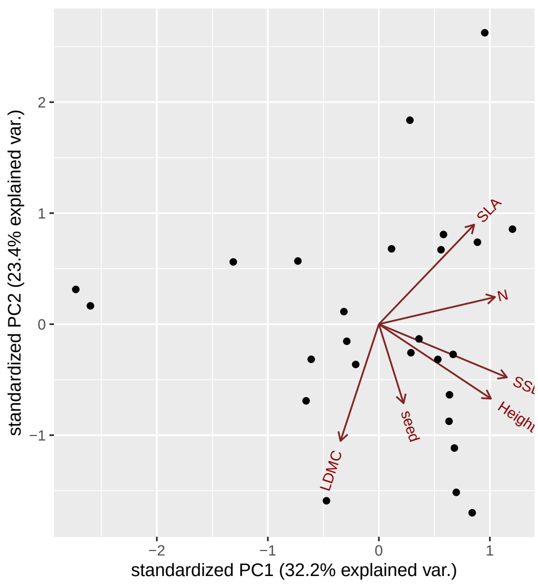


Figure S1: A projection of tree traits across the first and second principle component axis. Arrows represent the direction of vectors for six functional traits. Points represent the 26 species for which complete trait data was available

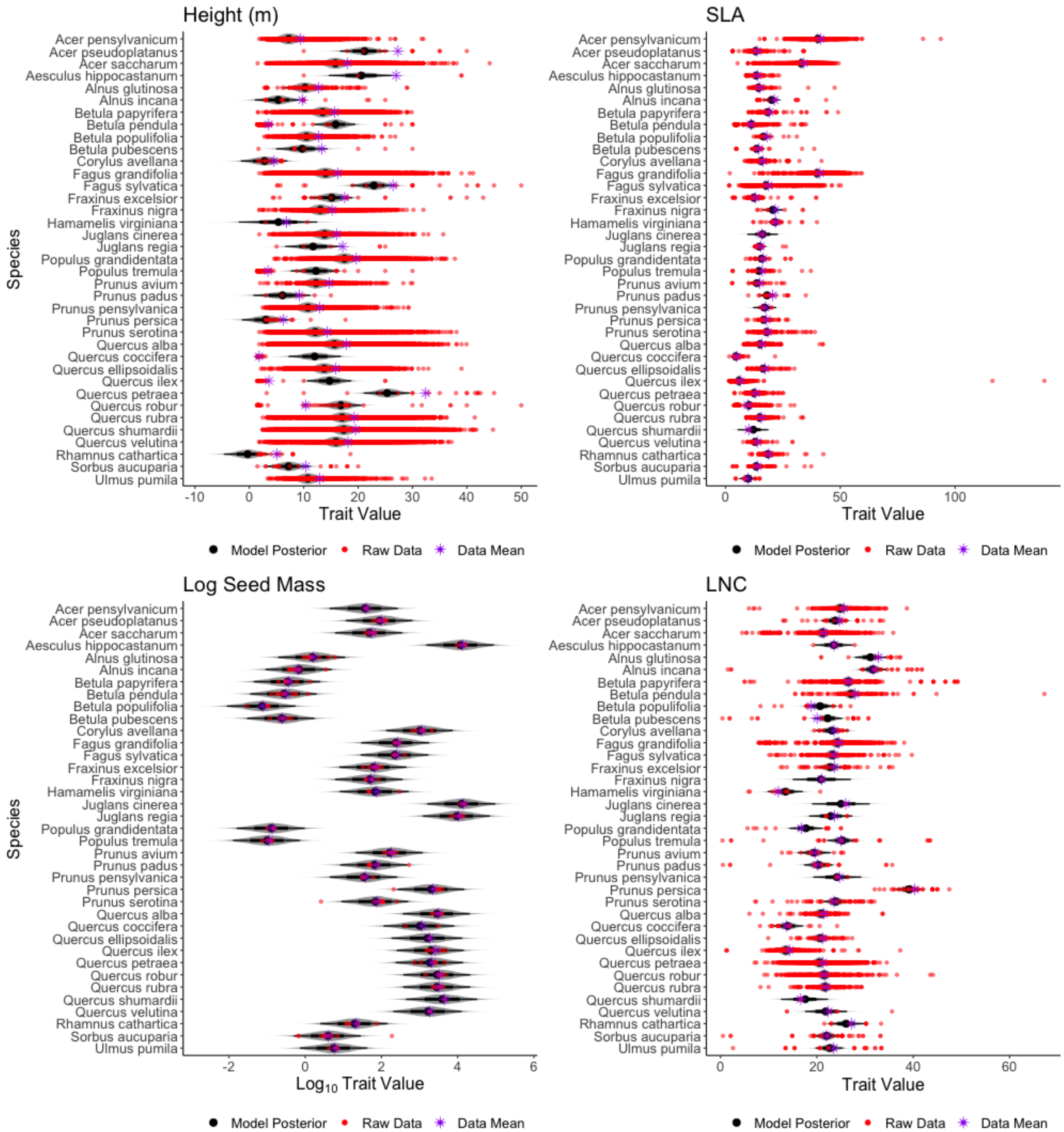


Figure S2: Comparisons of estimated model fits and raw data from joint models of trait effects on budburst phenological cues for 37 species of woody deciduous plants. Four functional traits – a. height, b. SLA, c. seed mass, and d. LNC – were modeled individually, with the calculated trait value being 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.

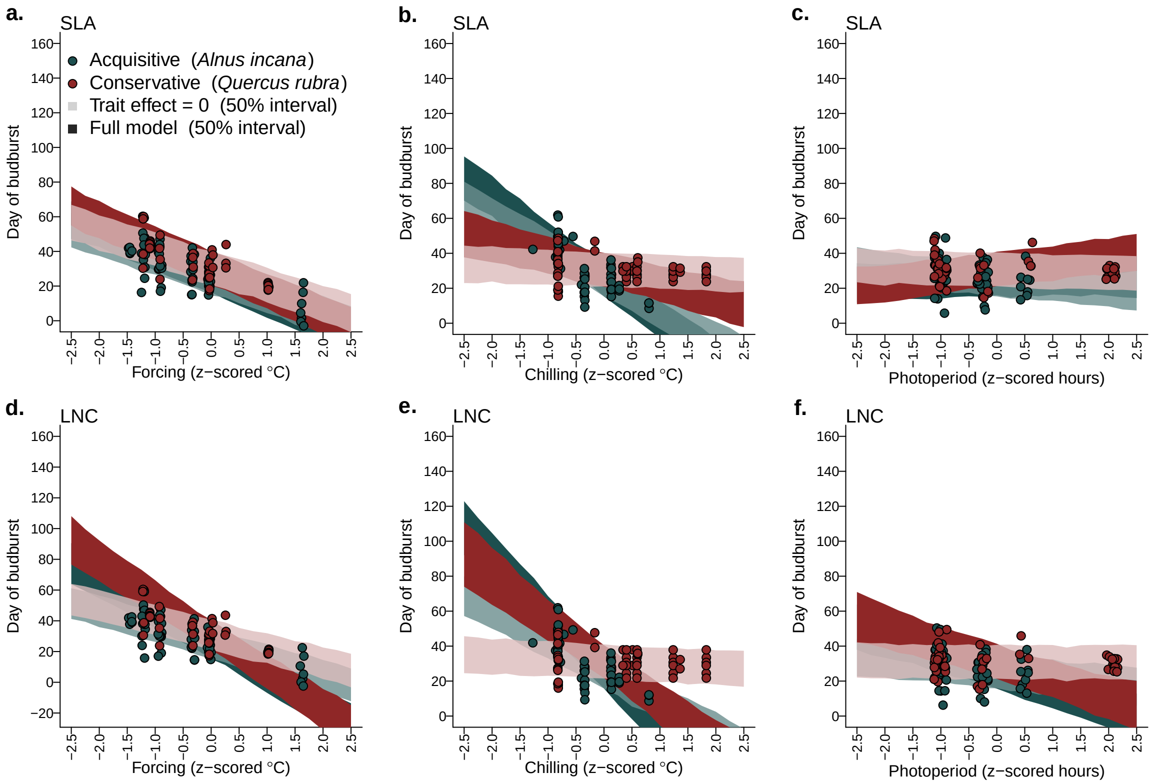


Figure S3: We expected species with traits associated with acquisitive (e.g, low specific leaf area, SLA, and leaf nitrogen content, LNC) versus conservative (e.g., high SLA and LNC) growth strategies would have different budburst responses to phenological cues. Our joint model allows traits of species to influence their responses to cues. We show an example here with an acquisitive 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 trait measurements.

Table S1: Bibliographic information for trait data sources from both BIEN and Try trait databases. Datasets without references or incomplete references are denoted below as 'unreferenced'.

| Database | Reference | Trait name | Unit | No. observations | No. Species |
|---|---|---|---|---|---|
| bien | Mchugh et al. (2015) | Height | m | 26 | 8 |
| bien | Marx et al. (2016) | Height | m | 2 | 2 |
| bien | Price et al. (2014) | Height | m | 27 | 19 |
| bien | Unreferenced | Height | m | 18 | 16 |
| bien | Kleyer et al. (2008) | Height | m | 90 | 19 |
| bien | Unreferenced | Height | m | 10 | 10 |
| bien | Moles, Angela; unreferenced | Height | m | 21 | 14 |
| bien | Reams, Greg; unreferenced | Height | m | 47036 | 19 |
| bien | Grime, Hodgson, & Hunt; unreferenced | Height | m | 5 | 5 |
| bien | Unreferenced | Height | m | 8 | 5 |
| bien | Pérez-de Lis et al. (2017) | Height | m | 18 | 1 |
| bien | Robinson et al. (2015) | Height | m | 120 | 1 |
| bien | Anderson-teixeira et al. (2015) | Height | m | 20 | 1 |
| try | Bond-Lamberty et al. (2002) | Height | m | 2 | 1 |
| try | Unpublished | Height | m | 275 | 3 |
| try | Wright et al. (2004) | Height | m | 28 | 19 |
| try | Prentice et al. (2011) | Height | m | 2 | 2 |
| try | Schweingruber and Landolt (2010) | Height | m | 21 | 21 |
| try | Unpublished | Height | m | 35 | 2 |
| try | Moles et al. (2004) | Height | m | 5 | 5 |
| try | Cavender-Bares et al. (2006) | Height | m | 1 | 1 |
| try | Diaz et al. (2004) | Height | m | 11 | 10 |
| try | Craine et al. (2009) | LNC | mg/g | 287 | 12 |
| try | Wilson et al. (2000) | LNC | mg/g | 44 | 2 |
| try | Wenxuan et al. (2012) | LNC | mg/g | 7 | 4 |
| try | Yahan et al. (2013) | LNC | mg/g | 7 | 3 |
| try | Wright et al. (2004) | LNC | mg/g | 65 | 32 |
| try | Prentice et al. (2011) | LNC | mg/g | 3 | 2 |
| try | Vergutz et al. (2012) | LNC | mg/g | 120 | 20 |
| try | Atkin et al. (2015) | LNC | mg/g | 24 | 8 |
| try | Marie et al. (2015) | LNC | mg/g | 72 | 22 |
| try | Cornelissen et al. (2003) | LNC | mg/g | 2 | 1 |
| try | Unpublished | LNC | mg/g | 3216 | 37 |
| try | Wang et al. (2017) | LNC | mg/g | 6 | 2 |
| bien | Marx et al. (2016) | Seed mass | mg | 3 | 3 |
| bien | Unreferenced | Seed mass | mg | 4 | 2 |
| bien | Liu et al. (2018) | Seed mass | mg | 250 | 37 |
| bien | Ameztegui et al. (2017) | Seed mass | mg | 12 | 12 |
| bien | Paine et al. (2015) | Seed mass | mg | 12 | 7 |
| try | Wilson et al. (2000) | SLA | mm2 mg-1 | 44 | 2 |
| try | Unpublished | SLA | mm2 mg-1 | 204 | 3 |
| try | Wright et al. (2004) | SLA | mm2 mg-1 | 93 | 33 |
| try | Prentice et al. (2011) | SLA | mm2 mg-1 | 2 | 2 |
| try | Kleyer et al. (2008) | SLA | mm2 mg-1 | 102 | 18 |
| try | Unpublished | SLA | mm2 mg-1 | 83 | 2 |
| try | Atkin et al. (2015) | SLA | mm2 mg-1 | 40 | 11 |
| try | Marie et al. (2015) | SLA | mm2 mg-1 | 86 | 23 |
| try | Cornelissen et al. (2003) | SLA | mm2 mg-1 | 615 | 14 |
| try | Unpublished | SLA | mm2 mg-1 | 6307 | 37 |
| try | Wang et al. (2017) | SLA | mm2 mg-1 | 6 | 2 |
| try | Shipley and Vu (2002) | SLA | mm2 mg-1 | 20 | 2 |
| try | Cavender-Bares et al. (2006) | SLA | mm2 mg-1 | 42 | 2 |
| try | Unpublished | SLA | mm2 mg-1 | 1 | 1 |
| try | Diaz et al. (2004) | SLA | mm2 mg-1 | 11 | 10 |

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 |
|---|---|---|---|---|---|---|
| $\mu_{grand.trait}$ | 12.71 | 1.96 | 8.73 | 12.75 | 16.46 | 1.00 |
| $\mu_{k,g}$ | 32.07 | 2.63 | 26.97 | 32.05 | 37.30 | 1.00 |
| $\mu_{force}$ | -10.74 | 2.86 | -16.63 | -10.66 | -5.38 | 1.01 |
| $\mu_{chill}$ | -4.08 | 4.13 | -12.46 | -4.02 | 3.99 | 1.01 |
| $\mu_{photo}$ | 1.11 | 2.18 | -3.37 | 1.14 | 5.27 | 1.01 |
| $\beta_{trait.force}$ | 0.16 | 0.19 | -0.21 | 0.16 | 0.55 | 1.01 |
| $\beta_{trait.chill}$ | -0.54 | 0.28 | -1.07 | -0.54 | 0.02 | 1.01 |
| $\beta_{trait.photo}$ | -0.25 | 0.15 | -0.54 | -0.25 | 0.08 | 1.00 |
| $\sigma_{species}$ | 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 |
| $\sigma_{trait}$ | 5.39 | 0.02 | 5.36 | 5.39 | 5.43 | 1.00 |
| $\sigma_{pheno}$ | 15.11 | 2.05 | 11.20 | 15.06 | 19.36 | 1.00 |
| $\sigma_{force}$ | 4.96 | 1.16 | 3.01 | 4.85 | 7.55 | 1.00 |
| $\sigma_{chill}$ | 8.53 | 2.10 | 5.21 | 8.26 | 13.38 | 1.00 |
| $\sigma_{photo}$ | 3.25 | 0.86 | 1.79 | 3.17 | 5.15 | 1.00 |
| $\sigma_d$ | 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 |
|---|---|---|---|---|---|---|
| $\mu_{grand.trait}$ | 1.87 | 0.50 | 0.89 | 1.88 | 2.84 | 1.00 |
| $\mu_{k,g}$ | 31.35 | 2.64 | 26.32 | 31.27 | 36.76 | 1.00 |
| $\mu_{force}$ | -8.17 | 1.60 | -11.35 | -8.16 | -5.07 | 1.00 |
| $\mu_{chill}$ | -9.41 | 2.82 | -15.21 | -9.43 | -3.92 | 1.00 |
| $\mu_{photo}$ | -1.26 | 1.25 | -3.72 | -1.27 | 1.19 | 1.00 |
| $\beta_{trait.force}$ | -0.30 | 0.69 | -1.61 | -0.31 | 1.06 | 1.00 |
| $\beta_{trait.chill}$ | -1.09 | 1.09 | -3.28 | -1.08 | 1.01 | 1.00 |
| $\beta_{trait.photo}$ | -0.56 | 0.58 | -1.68 | -0.56 | 0.62 | 1.00 |
| $\sigma_{species}$ | 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 |
| $\sigma_{trait}$ | 0.25 | 0.01 | 0.23 | 0.25 | 0.27 | 1.00 |
| $\sigma_{pheno}$ | 14.84 | 2.25 | 10.58 | 14.79 | 19.42 | 1.00 |
| $\sigma_{force}$ | 4.92 | 0.98 | 3.22 | 4.85 | 7.03 | 1.00 |
| $\sigma_{chill}$ | 10.67 | 2.57 | 6.55 | 10.33 | 16.65 | 1.00 |
| $\sigma_{photo}$ | 3.58 | 0.86 | 2.13 | 3.49 | 5.52 | 1.00 |
| $\sigma_d$ | 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 |
|---|---|---|---|---|---|---|
| $\mu_{grand.trait}$ | 16.85 | 1.47 | 14.03 | 16.85 | 19.71 | 1.01 |
| $\mu_{k,g}$ | 31.33 | 2.55 | 26.45 | 31.30 | 36.39 | 1.00 |
| $\mu_{force}$ | -11.40 | 2.71 | -17.29 | -11.33 | -6.42 | 1.01 |
| $\mu_{chill}$ | -16.66 | 4.70 | -26.35 | -16.61 | -7.84 | 1.00 |
| $\mu_{photo}$ | 1.85 | 2.47 | -3.13 | 1.98 | 6.47 | 1.00 |
| $\beta_{trait.force}$ | 0.17 | 0.15 | -0.11 | 0.17 | 0.47 | 1.01 |
| $\beta_{trait.chill}$ | 0.34 | 0.25 | -0.13 | 0.34 | 0.83 | 1.00 |
| $\beta_{trait.photo}$ | -0.23 | 0.14 | -0.50 | -0.24 | 0.05 | 1.00 |
| $\sigma_{species}$ | 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 |
| $\sigma_{trait}$ | 6.17 | 0.05 | 6.07 | 6.16 | 6.27 | 1.00 |
| $\sigma_{pheno}$ | 13.92 | 2.11 | 10.10 | 13.79 | 18.34 | 1.00 |
| $\sigma_{force}$ | 4.97 | 1.12 | 3.07 | 4.87 | 7.49 | 1.00 |
| $\sigma_{chill}$ | 10.57 | 2.30 | 6.79 | 10.33 | 15.56 | 1.00 |
| $\sigma_{photo}$ | 3.48 | 0.81 | 2.14 | 3.40 | 5.36 | 1.00 |
| $\sigma_d$ | 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 |
|---|---|---|---|---|---|---|
| $\mu_{grand.trait}$ | 22.61 | 1.37 | 19.91 | 22.60 | 25.32 | 1.01 |
| $\mu_{k,g}$ | 31.14 | 2.52 | 26.33 | 31.09 | 36.29 | 1.00 |
| $\mu_{force}$ | -19.33 | 5.37 | -30.02 | -19.45 | -8.62 | 1.02 |
| $\mu_{chill}$ | -27.10 | 7.04 | -40.56 | -27.27 | -12.84 | 1.01 |
| $\mu_{photo}$ | -9.40 | 4.67 | -18.09 | -9.41 | -0.37 | 1.02 |
| $\beta_{trait.force}$ | 0.47 | 0.23 | 0.01 | 0.47 | 0.93 | 1.02 |
| $\beta_{trait.chill}$ | 0.72 | 0.30 | 0.12 | 0.72 | 1.29 | 1.01 |
| $\beta_{trait.photo}$ | 0.31 | 0.19 | -0.06 | 0.31 | 0.68 | 1.02 |
| $\sigma_{species}$ | 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 |
| $\sigma_{trait}$ | 5.13 | 0.06 | 5.02 | 5.13 | 5.25 | 1.00 |
| $\sigma_{pheno}$ | 14.05 | 1.97 | 10.30 | 13.97 | 18.23 | 1.00 |
| $\sigma_{force}$ | 4.59 | 1.09 | 2.80 | 4.47 | 7.05 | 1.00 |
| $\sigma_{chill}$ | 8.92 | 1.97 | 5.74 | 8.71 | 13.44 | 1.00 |
| $\sigma_{photo}$ | 3.59 | 0.81 | 2.25 | 3.52 | 5.41 | 1.00 |
| $\sigma_d$ | 14.17 | 0.26 | 13.67 | 14.17 | 14.67 | 1.00 |

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