

# Cue responses in woody plants of North America

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## 1 Research questions:

1. How do species in deciduous forests across North America respond to varying chilling, forcing, and photoperiod cues?
2. Do we see similar trends when we compare species eastern deciduous forests to western deciduous forests communities?
3. How do shrub species differ from tree species in their cue use?

## 2 Results

1. General Survival and germination success from the western transect experiment
  - (a) Of the 2285 samples that went into chilling, 2458 survived the duration of the experiment, with only 7% percent mortality occurring.
  - (b) We also had considerable success in the percentage of budburst, with only 7% of the surviving samples exhibiting no budburst at all.
  - (c) Terminal buds failed to open for 15.7% of samples, most of which were *Vaccinium membranaceum*, *Rubus parviflorus*, and *Ribes lacustre*.
2. General findings...
  - (a) Species cue responses were strongly phylogenetically structured (with a lambda of 0.8 (uncertainty interval: 0.6, 1), with a root trait value of 12.3 (uncertainty interval: 7.2, 17.3).
  - (b) While all cues did lead to the advance in budburst date, there were strong interactions between cues and between cues and sites.
  - (c) Forcing and chilling cues produced a strong delaying effect, with low chilling being offset by high forcing conditions(Fig. 2 a).
  - (d) Similar delaying interactions occur between forcing and the two eastern sites and between chilling and the two eastern sites.
  - (e) As illustrated for our St. Hippolyte site in Fig. 2 b and c), eastern sites has weaker responses to forcing and chilling cues, budbursting earlier than western species in response to both cues.

- (f) The interaction between photoperiod and our eastern sites in contrast support a moderate advancing effect, with longer photoperiods at our eastern sites causing budburst dates to advance (Fig. 2 d).
3. We found different trends in cue use when comparing the timing of first lateral budburst and 50% lateral budburst for our western species.
- (a) In comparison to our model of the timing of first budburst, the timing of lateral budburst had stronger responses to chilling, with 50% lateral budburst having almost equivalent responses to forcing and chilling.
- (b) However, lateral budburst also experienced a strong interaction between forcing and chilling cues as well as between forcing and photoperiod for the timing of the first lateral budburst.
- (c) Our more southern site in our western transect, Manning Park, showed delayed budburst relative to our more northern Smithers sites.
- (d) While we do observe weak interactions between photoperiod and Manning Park and chilling and Manning park, a strong advancing interactions occurred between forcing and Manning Park.
4. While there are some differences across sites, they are moderate.
5. Individual species show more distinct trends - compare the three species in both transects
6. No strong differences across plant archetypes

### 3 Tables and figures

Table 1: Summary output from a phylogenetic mixed-effect model in which species are partially pooled and phylogeny is included on the intercept. The model includes photoperiod, forcing, and site as dummy variables, while the chilling effect is included as continuous chill portions.

	mean	sd	2.5%	50%	97.5%	n_eff	Rhat
Forcing	-8.81	0.72	-10.23	-8.80	-7.38	9931.87	1.00
Photoperiod	-3.45	0.41	-4.25	-3.45	-2.63	8418.40	1.00
Chilling	-15.17	1.27	-17.71	-15.16	-12.66	5282.13	1.00
Manning Park	1.90	0.35	1.22	1.90	2.60	13833.47	1.00
Harvard Forest	-4.15	1.06	-6.26	-4.14	-2.12	1330.94	1.00
St. Hippolyte	-7.13	0.99	-9.10	-7.13	-5.23	1329.89	1.00
Forcing x photoperiod	-0.19	0.65	-1.43	-0.19	1.11	12000.48	1.00
Forcing x chilling	8.66	0.86	7.00	8.65	10.39	7759.42	1.00
Photoperiod x chilling	-0.75	0.90	-2.55	-0.75	1.01	6849.85	1.00
Forcing x Manning Park	-1.78	0.77	-3.27	-1.78	-0.25	11224.65	1.00
Photoperiod x Manning Park	0.54	0.78	-0.99	0.54	2.04	9557.53	1.00
Chilling x Manning Park	-0.23	1.63	-3.51	-0.20	2.94	5942.76	1.00
Forcing x Harvard Forest	3.54	1.14	1.31	3.52	5.82	3930.17	1.00
Photoperiod x Harvard Forest	-2.22	0.87	-3.91	-2.23	-0.50	8263.34	1.00
Chilling x Harvard Forest	7.08	2.11	2.80	7.14	11.06	2838.67	1.00
Forcing x St. Hippolyte	4.86	1.15	2.59	4.86	7.14	4048.10	1.00
Photoperiod x St. Hippolyte	-2.36	0.85	-4.02	-2.37	-0.69	7814.44	1.00
Chilling x St. Hippolyte	6.21	1.72	2.76	6.24	9.57	3335.24	1.00

Table 2: Summary output from a phylogenetic mixed-effect model for the day of budburst of the first lateral bud for western species. In this model, species are partially pooled and phylogeny is included on the intercept. The model includes photoperiod, forcing, and site as dummy variables, while the chilling effect is included as continuous chill portions.

	mean	sd	25%	50%	75%	n_eff	Rhat
Forcing	-12.55	0.99	-13.17	-12.54	-11.91	2286.03	1.00
Photoperiod	-2.29	0.57	-2.66	-2.28	-1.93	3873.11	1.00
Chilling	-12.54	1.26	-13.39	-12.55	-11.70	4735.75	1.00
Manning Park	2.44	0.45	2.13	2.43	2.74	7934.30	1.00
Forcing x photoperiod	0.16	1.05	-0.54	0.16	0.83	4950.07	1.00
Forcing x chilling	5.62	1.30	4.78	5.61	6.47	3921.71	1.00
Photoperiod x chilling	-0.62	1.50	-1.61	-0.59	0.39	2753.68	1.00
Forcing x Manning Park	-2.22	1.13	-2.97	-2.21	-1.46	4797.06	1.00
Photoperiod x Manning Park	0.15	1.01	-0.53	0.14	0.82	7029.58	1.00
Chilling x Manning Park	0.88	1.40	-0.04	0.87	1.77	3742.14	1.00

Table 3: Summary output from a phylogenetic mixed-effect model for the day of 50 percent lateral budburst of species from our western transect. In this model, species are partially pooled and phylogeny is included on the intercept. The model includes photoperiod, forcing, and site as dummy variables, while the chilling effect is included as continuous chill portions.

	mean	sd	25%	50%	75%	n_eff	Rhat
Forcing	-13.16	1.29	-14.01	-13.17	-12.33	2179.45	1.00
Photoperiod	-1.69	0.61	-2.09	-1.70	-1.30	6774.36	1.00
Chilling	-10.47	1.33	-11.37	-10.49	-9.61	5047.62	1.00
Manning Park	1.17	0.60	0.75	1.18	1.58	7519.30	1.00
Forcing x photoperiod	2.02	1.18	1.22	2.03	2.83	6463.12	1.00
Forcing x chilling	4.93	1.63	3.88	4.96	5.98	3690.31	1.00
Photoperiod x chilling	-0.64	1.44	-1.57	-0.67	0.24	4810.07	1.00
Forcing x Manning Park	-3.78	1.75	-4.92	-3.79	-2.64	4200.16	1.00
Photoperiod x Manning Park	0.63	1.41	-0.31	0.61	1.52	4991.98	1.00
Chilling x Manning Park	1.29	2.50	-0.27	1.23	2.91	2181.64	1.00

## 54 4 Supplementary Material

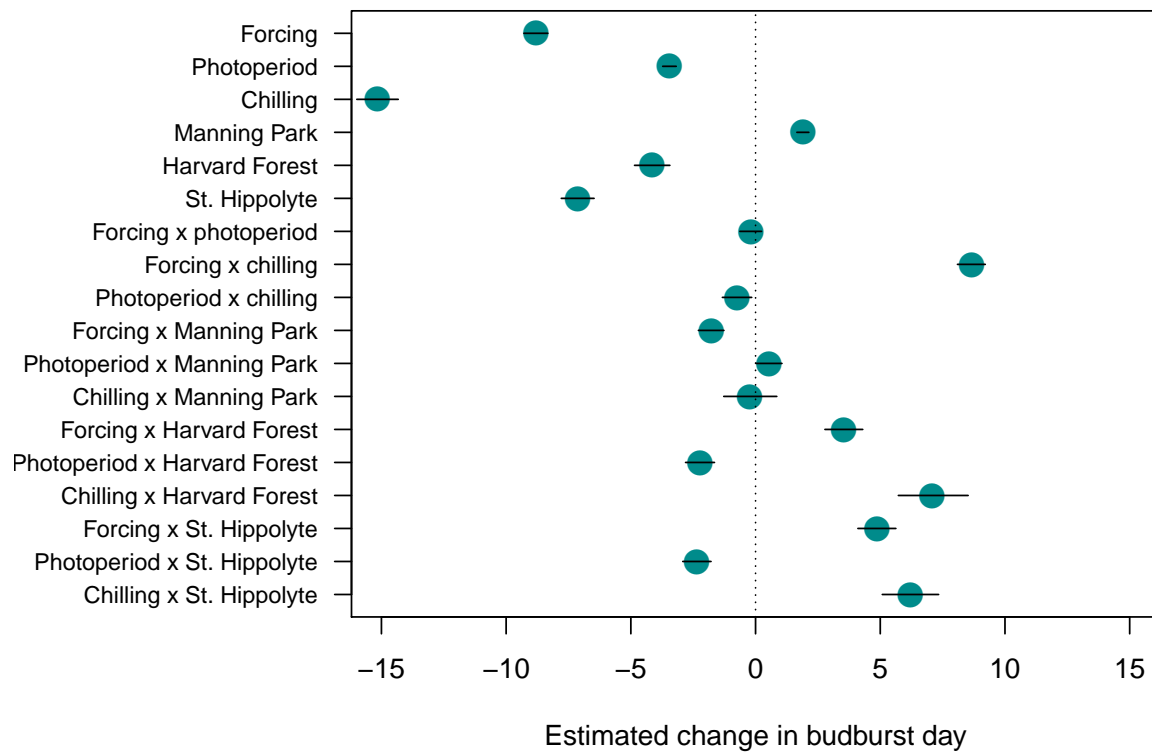


Figure 1: Estimated mean responses in budburst date of first bud to varying forcing, chilling, and photoperiod cues for 47 deciduous woody species across North America. Points represent mean budburst dates, while bars depict the 50% uncertainty interval. Negative responses represent advances budburst, while positive values represent delaying effects.

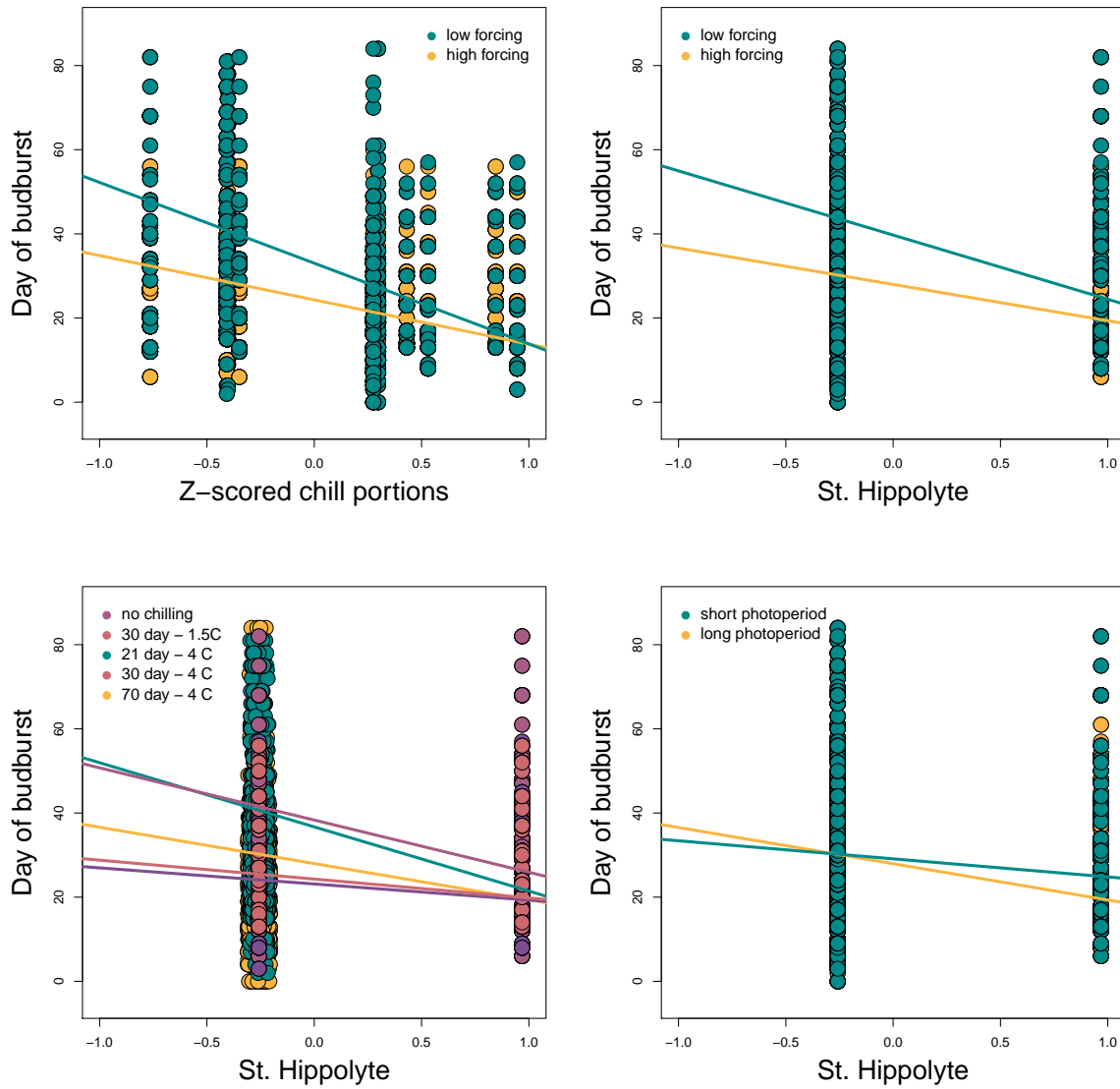


Figure 2: Interaction plots of day of budburst of first bud in response a) chill portions and forcing, b) forcing cues for species sampled from St. Hippolyte, c) chilling cues for species sampled from St. Hippolyte, and d) photoperiod cues and species sampled from St. Hippolyte.

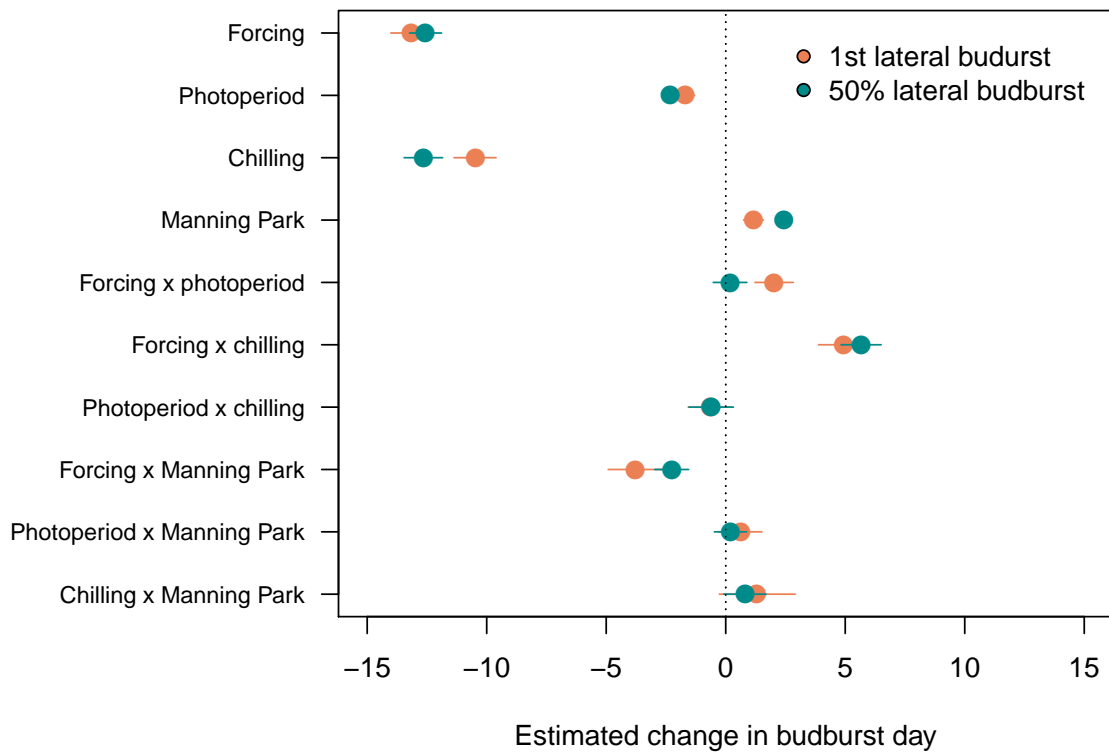


Figure 3: Estimated mean responses in lateral budburst date to varying environmental cues for 21 deciduous woody species in British Columbia. Points represent mean budburst dates, while bars depict the 50% uncertainty interval. Negative responses represent advances budburst, while positive values represent delaying effects.

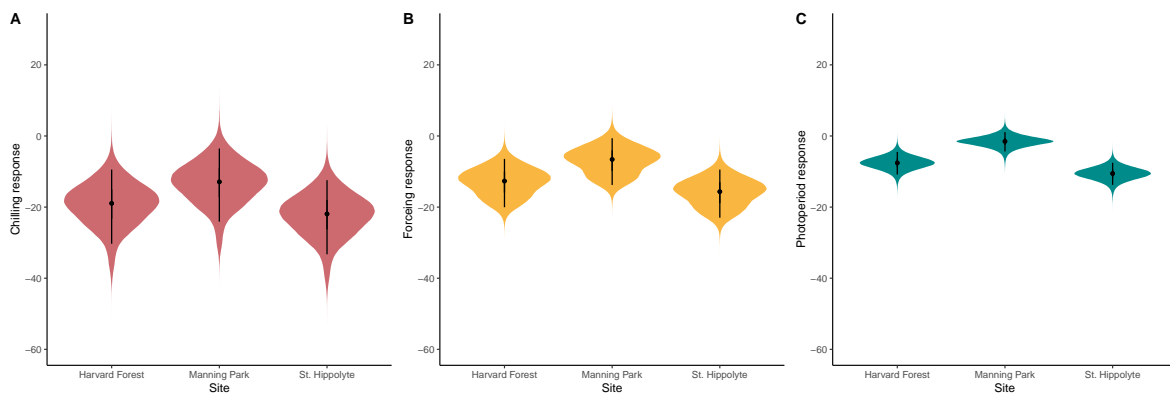


Figure 4: Posterior distributions of estimated cue responses with site level effects for individual sites, depicting a) chilling, b) forcing, and c) photoperiod cue responses. Black circles represent the median shift in phenology for a phenological event, while the thinner black line the 90% quantile interval. The coloured distribution is the the posterior density of the posteriors of the cue responses and site level responses for all species at a given site. The y-axis spans the entire range of the data.

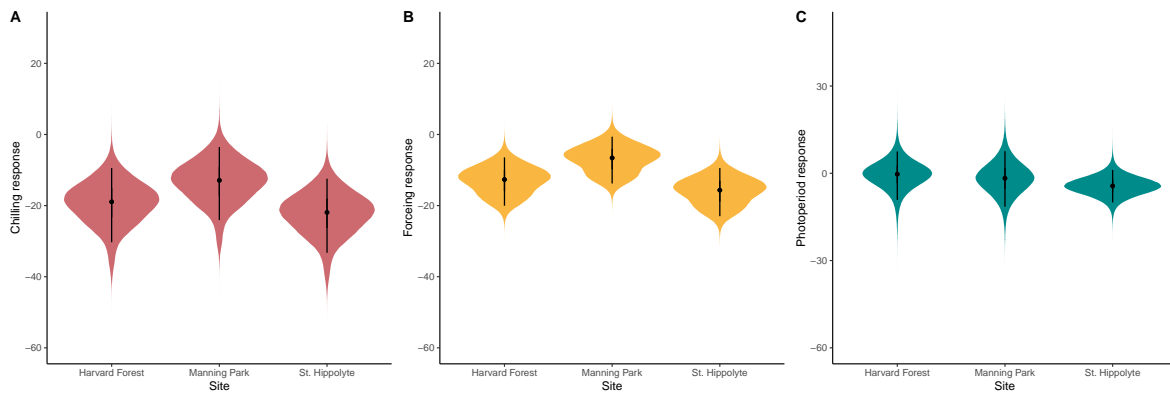


Figure 5: Posterior distributions of estimated cue responses with site level effects and site interactions for individual sites, depicting a) chilling, b) forcing, and c) photoperiod cue responses. Black circles represent the median shift in phenology for a phenological event, while the thinner black line the 90% quantile interval. The coloured distribution is the the posterior density of the posteriors of the cue responses and site level responses for all species at a given site. The y-axis spans the entire range of the data.

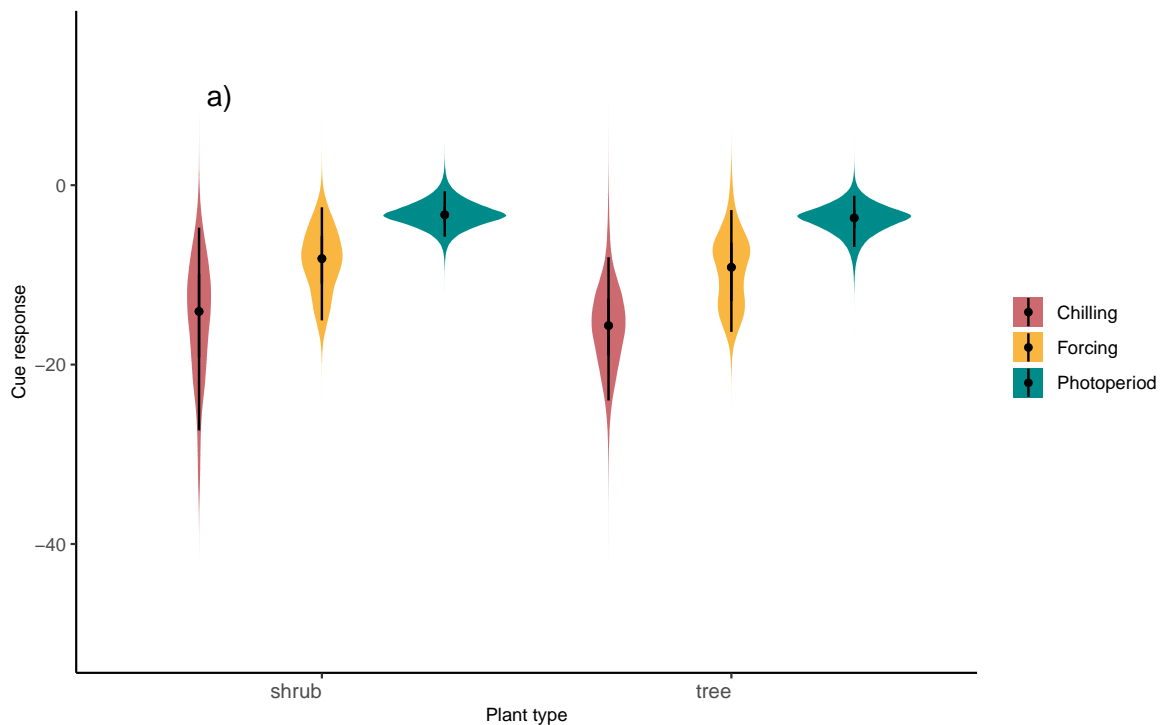


Figure 6: Interaction plots for the western transect. a) The interaction between chill portions and forcing, b) the interaction between photoperiod and chilling, and c) the relationship between forcing and site

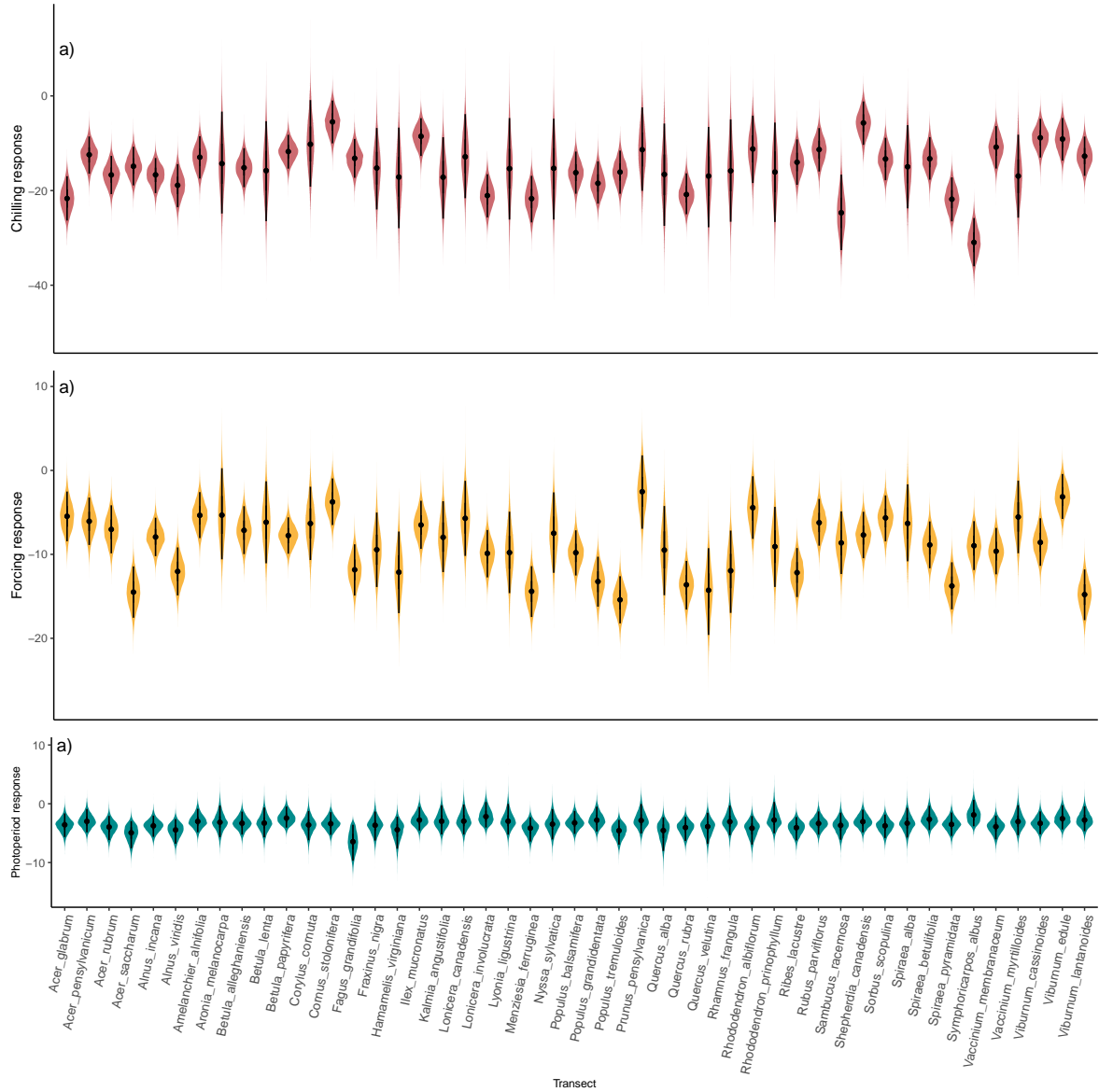


Figure 7: Interaction plots for the western transect. a) The interaction between chill portions and forcing, b) the interaction between photoperiod and chilling, and c) the relationship between forcing and site



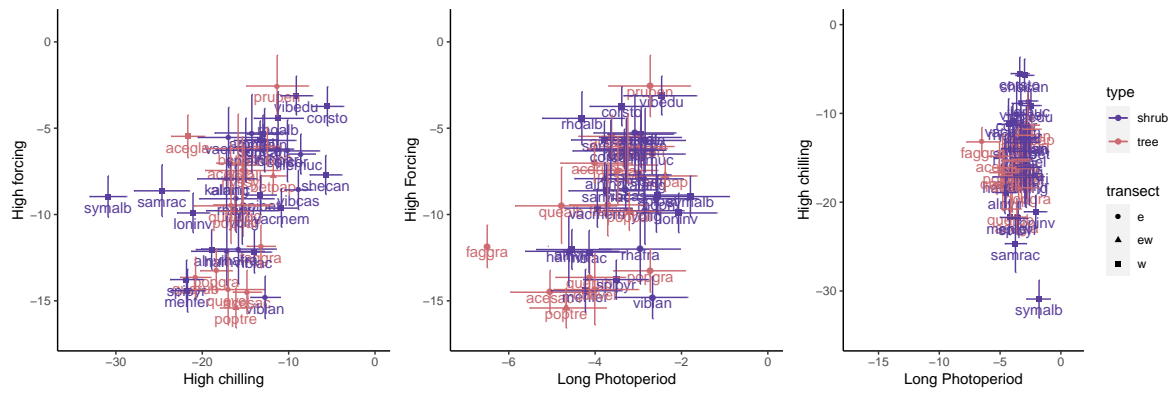


Figure 8: Interaction plots for the western transect. a) The interaction between chill portions and forcing, b) the interaction between photoperiod and chilling, and c) the relationship between forcing and site

Table 4: Mean budburst dates across all treatments from raw data for 47 species at our two western sites, E.C. Manning Park and Smither B.C., and our two eastern sites, Harvard Forest (HF) USA and St. Hippolyte (SH) Canada.

Species	Harvard Forest	St. Hippolyte	Manning Park	Smithers
<i>Acer glabrum</i>			36.00	39.00
<i>Acer pensylvanicum</i>	16.00	18.00		
<i>Acer rubrum</i>	22.00	25.00		
<i>Acer saccharum</i>	45.00	36.00		
<i>Alnus incana</i>			28.00	30.00
<i>Alnus incana</i>	33.00	25.00		
<i>Alnus viridis</i>			44.00	43.00
<i>Amelanchier alnifolia</i>			18.00	17.00
<i>Aronia melanocarpa</i>	14.00			
<i>Betula alleghaniensis</i>	20.00	21.00		
<i>Betula lenta</i>	30.00			
<i>Betula papyrifera</i>				30.00
<i>Betula papyrifera</i>	17.00	18.00		
<i>Corylus cornuta</i>	25.00	19.00		
<i>Cornus stolonifera</i>			14.00	16.00
<i>Fagus grandifolia</i>	42.00	43.00		
<i>Fraxinus nigra</i>	38.00	38.00		
<i>Hamamelis virginiana</i>	44.00			
<i>Ilex mucronatus</i>	16.00	15.00		
<i>Kalmia angustifolia</i>	30.00	32.00		
<i>Lonicera canadensis</i>	17.00	16.00		
<i>Lonicera involucrata</i>			22.00	19.00
<i>Lyonia ligustrina</i>	31.00			
<i>Menziesia ferruginea</i>			43.00	46.00
<i>Nyssa sylvatica</i>	32.00			
<i>Populus balsamifera</i>			30.00	31.00
<i>Populus grandidentata</i>	33.00	31.00		
<i>Populus tremuloides</i>			46.00	35.00
<i>Prunus pensylvanica</i>	18.00	16.00		
<i>Quercus alba</i>	45.00			
<i>Quercus rubra</i>	36.00	34.00		
<i>Quercus velutina</i>	52.00			
<i>Rhamnus frangula</i>	32.00			
<i>Rhododendron albiflorum</i>			19.00	
<i>Rhododendron prinophyllum</i>	29.00			
<i>Ribes lacustre</i>			29.00	23.00
<i>Rubus parviflorus</i>			28.00	29.00
<i>Sambucus racemosa</i>			33.00	
<i>Shepherdia canadensis</i>			25.00	23.00
<i>Sorbus scopulina</i>			21.00	18.00
<i>Spiraea alba</i>	18.00	20.00		
<i>Spiraea betulifolia</i>			24.00	18.00
<i>Spiraea pyramidata</i>			26.00	22.00
<i>Symphoricarpos albus</i>			26.00	31.00
<i>Vaccinium membranaceum</i>			22.00	23.00
<i>Vaccinium myrtilloides</i>	13.00	17.00		
<i>Viburnum cassinoides</i>	15.00	18.00		
<i>Viburnum edule</i>			19.00	8.00
<i>Viburnum lantanoides</i>	31.00	28.00		

Table 5: Chill units from our two western sites, E.C. Manning Park and Smithers B.C., and our two eastern sites, Harvard Forest (HF) USA and St. Hippolyte (SH) Canada.

Population	Chilling.treatment	Chilling.Hours	Utah.Model	Chill.Portions
Harvard forest	Field chilling	892	814.50	56.62
Harvard forest	Field chilling + 30 d at 4 degree C	2140	2062.50	94.06
Harvard forest	Field chilling + 30 d at 1.5 degree C	2140	1702.50	91.17
St. Hippolyte	Field chilling	682	599.50	44.63
St. Hippolyte	Field chilling + 30 d at 4 degree C	1930	1847.50	82.06
St. Hippolyte	Field chilling + 30 d at 1.5 degree C	1930	1487.50	79.18
Smithers	Field chilling + 30 d at 4 degree C	1965	2016.00	74.67
Smithers	Field chilling + 70 d at 4 degree C	1317	1368.00	54.95
Manning Park	Field chilling + 30 d at 4 degree C	1861	2025.00	75.33
Manning Park	Field chilling + 70 d at 4 degree C	1213	1377.00	55.09

Table 6: Proportion of samples with budburst per species

	Species name	Proportion.Budburst	Plant type
1	Acer glabrum	0.83	tree
2	Alnus incana	1.00	shrub
3	Alnus viridis	0.92	shrub
4	Amelanchier alnifolia	0.99	shrub
5	Betula papyrifera	1.00	tree
6	Cornus stolonifera	0.99	shrub
7	Lonicera involucrata	0.87	shrub
8	Menziesia ferruginea	0.80	shrub
9	Populus balsamifera	0.98	tree
10	Populus tremuloides	0.90	tree
11	Rhododendron albiflorum	1.00	shrub
12	Ribes lacustre	0.82	shrub
13	Rubus parviflorus	0.94	shrub
14	Sambucus racemosa	0.95	shrub
15	Shepherdia canadensis	1.00	shrub
16	Sorbus scopulina	0.99	shrub
17	Spiraea betulifolia	0.94	shrub
18	Spiraea pyramidata	0.92	shrub
19	Symphoricarpos albus	0.84	shrub
20	Vaccinium membranaceum	0.90	shrub
21	Viburnum edule	1.00	shrub