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

getwd()

1. General Survival and germination success from the western transect experiment
   (a) 2285 samples went into chilling
   (b) 2458 survived the experiment
   (c) 7.04% of the remaining samples did not budburst at all
   (d) 15.7% did not have terminal budburst, most of these were *Vaccinium membranaceum*, *Rubus parviflorus*, and *Ribes lacustre*
2. Our model found...
   (a) The root trait was 12.3 (uncertainty interval: 6.3, 18.4) and lambda was 0.8 (uncertainty interval: 0.5, 0.9)
   (b) Species cue responses were strongly phylogenetically structured.
   (c) While all cues did lead to the advance in budburst date, there were strong interactions between cues and between cues and sites.
   (d) Strong delaying interaction between forcing and chilling
   (e) Strong delaying interaction between forcing and the two eastern sites
   (f) Strong delaying interaction between chilling and the two eastern sites
   (g) moderate advancing interaction between photoperiod and our eastern sites

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

4 Supplementary Material

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

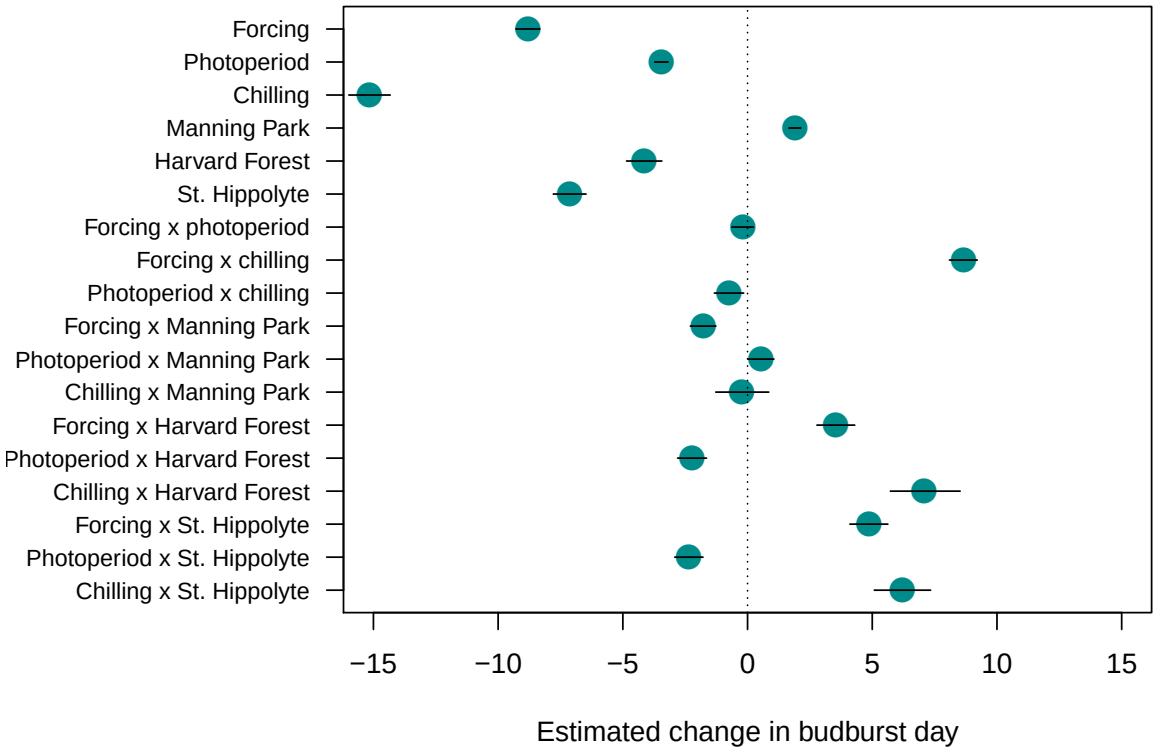

Figure 1: Estimated mean responses in budburst date of first bud to varying forcing, chilling, and photoperiod cues for 47 deciduous woody species across North America. Points represent mean budburst dates, while bars depict the 50% uncertainty interval. Negative responses represent advances budburst,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

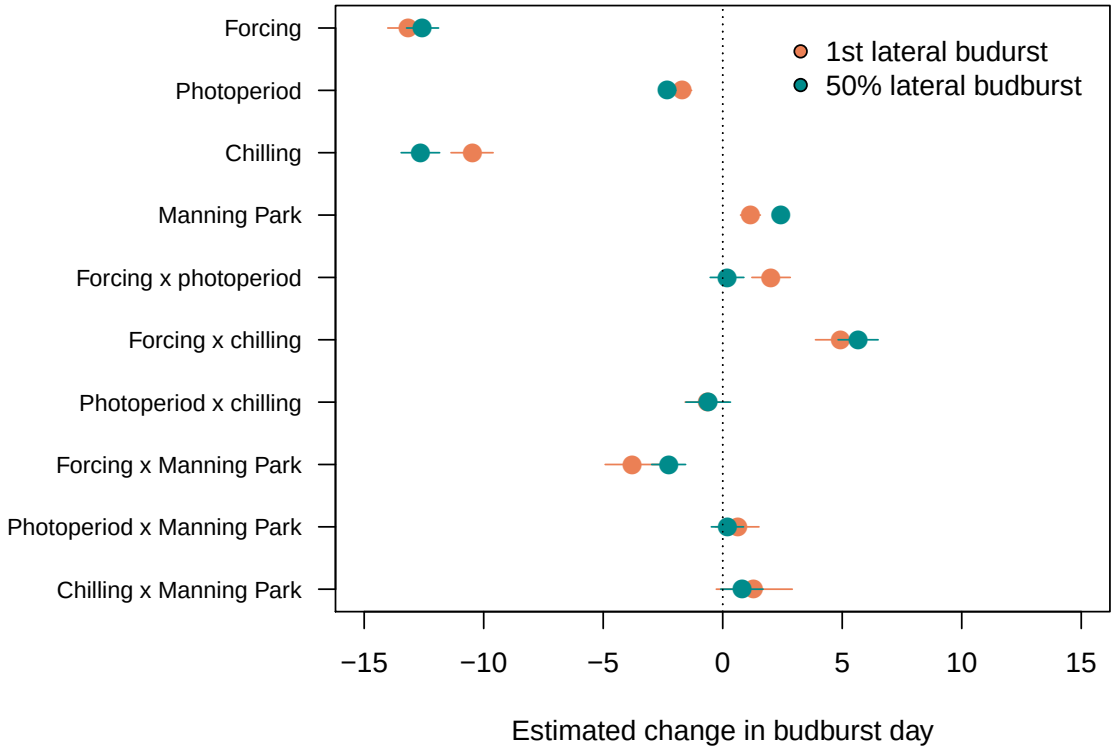

Figure 2: Estimated mean responses in lateral budburst date to varying environmental cues for 21 deciduous woody species in British Columbia. Points represent mean budburst dates, while bars depict the 50% uncertainty interval. Negative responses represent advances budburst, while positive values represent delaying effects.

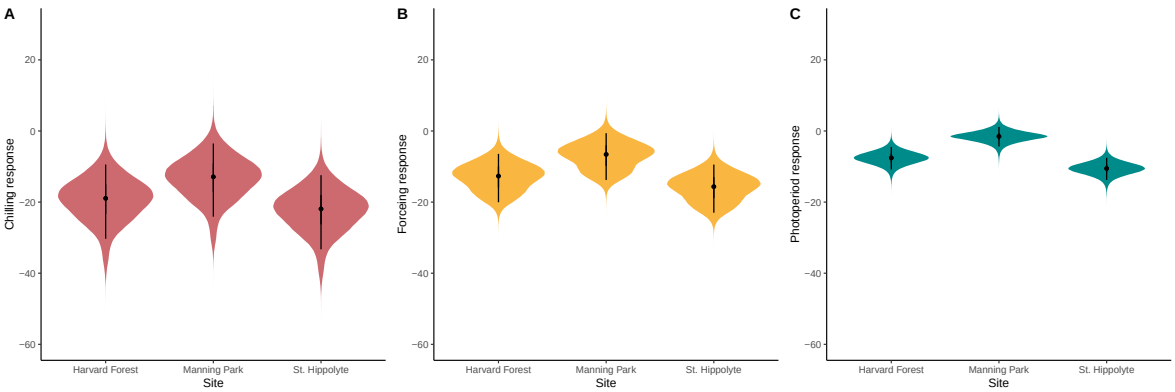

Figure 3: Posterior distributions of estimated cue responses with site level effects for individual sites, depicting a) chilling, b) forcing, and c) photoperiod cue responses. Black circles represent the median shift in phenology for a phenological event, while the thinner black line the 90% quantile 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.

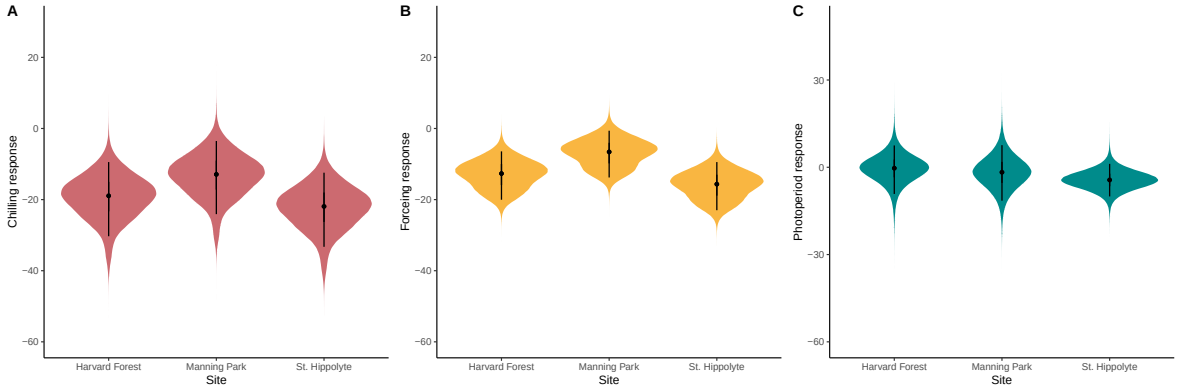

Figure 4: Posterior distributions of estimated cue responses with site level effects and site interactions for individual sites, depicting a) chilling, b) forcing, and c) photoperiod cue responses. Black circles represent the median shift in phenology for a phenological event, while the thinner black 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.

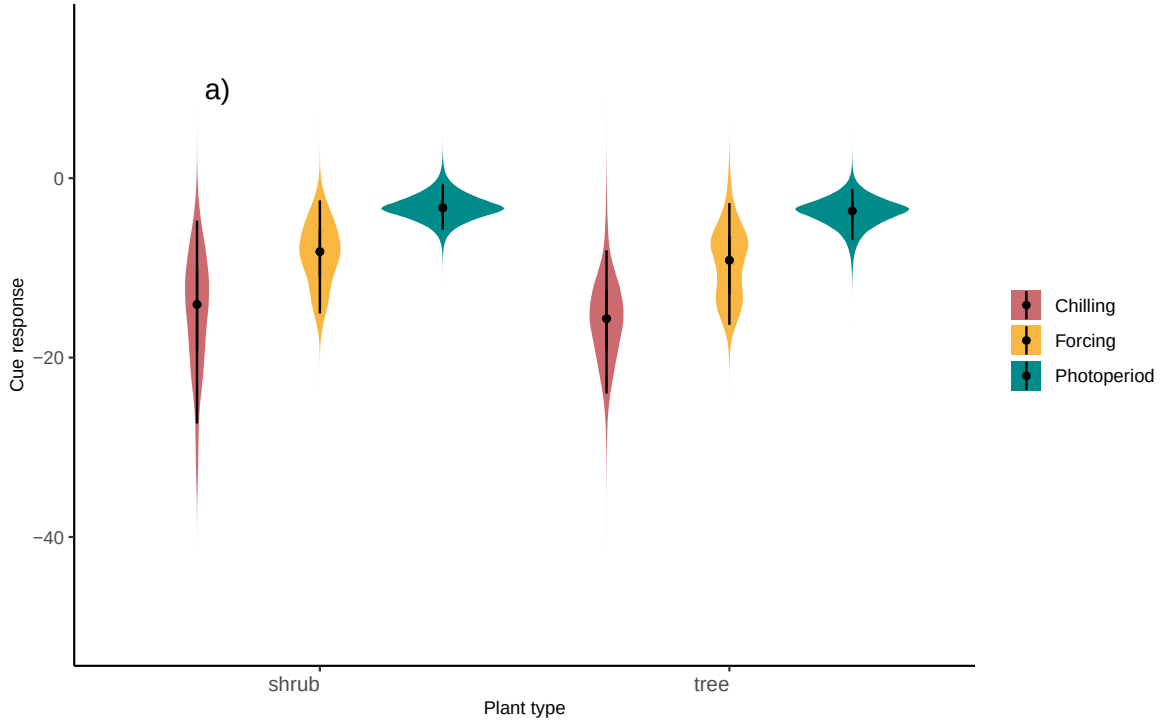

Figure 5: Interaction plots for the western transect. a) The interaction between chill portions and forcing, b) the interaction between photoperiod and chilling, and c) the relationship between forcing and site

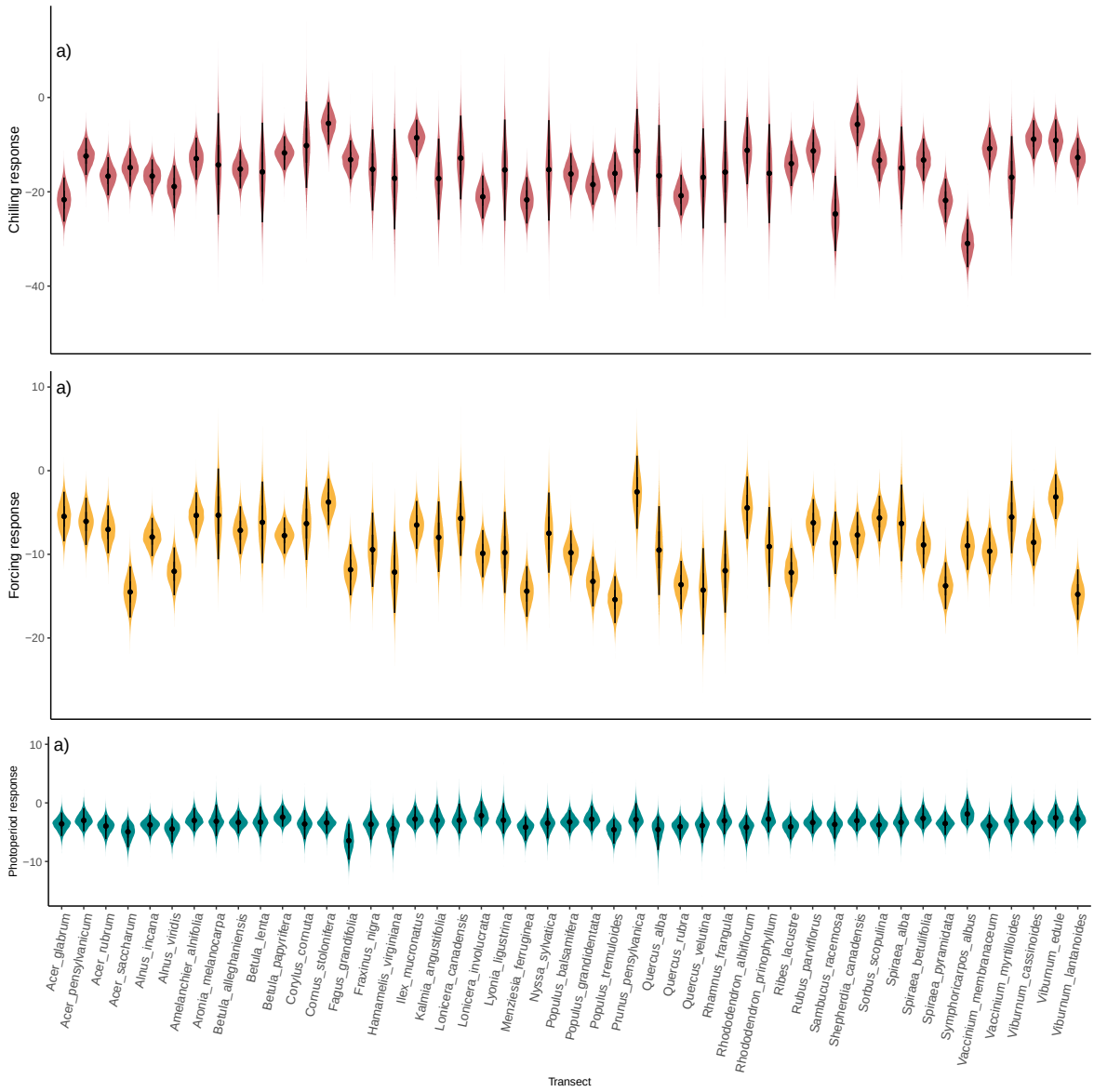

Figure 6: Interaction plots for the western transect. a) The interaction between chill portions and forcing, b) the interaction between photoperiod and chilling, and c) the relationship between forcing and site

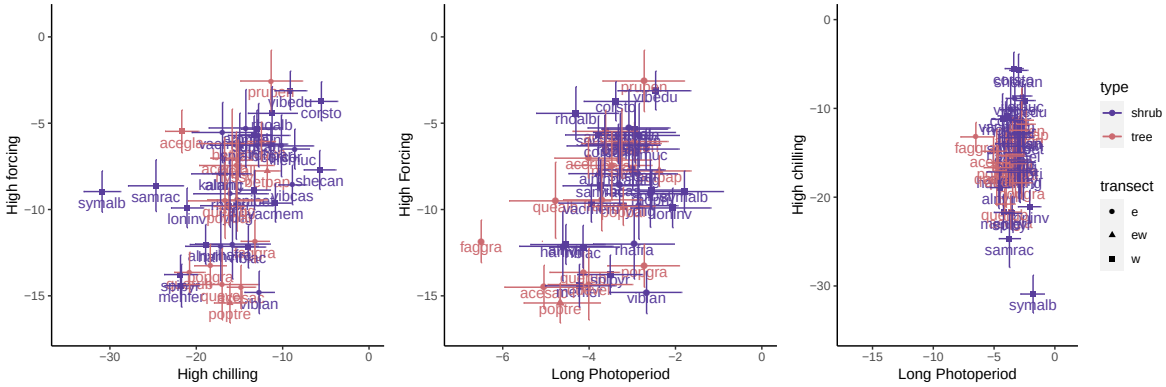

Figure 7: Interaction plots for the western transect. a) The interaction between chill portions and forcing, b) the interaction between photoperiod and chilling, and c) the relationship between forcing and site

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. Hippoltye (SH) Canada.

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

Table 5: Chill units from our two western sites, E.C. Manning Park and Smither B.C., and our two eastern sites, Harvard Forest (HF) USA and St. Hippoltye (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. Hippoltye	Field chilling	682	599.50	44.63
St. Hippoltye	Field chilling + 30 d at 4 degree C	1930	1847.50	82.06
St. Hippoltye	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: Proporation of samples with budburst per species

	Proportion Budburst	NA	NA
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