

Supporting Information Appendix.

Montgomery, R.A., K.E. Rice, A. Stefanski, R. L. Rich and P. B. Reich. Phenological responses of temperate and boreal trees to warming depend on ambient spring temperatures, leaf habit and geographic range.

SI Appendix: Tables

Table S1. Mixed-effects model results for day of year that juvenile trees broke bud. Random effects of site, plot and seedling cohort not shown. The model with all five years doesn't include *Populus tremuloides* or *Pinus banksiana* due to inadequate sample size in 2013. Significant effects involving the warming treatment (heat) are in bold.

Source	2009-2012 all species				2009-2013 (8 species)			
	df	df _{den}	F	P	df	df _{den}	F	P
Year	3	3603	4551	<.0001	4	541	2576	<.0001
Habitat	1	11	1.628	0.2291	1	11	2.493	0.1425

Heat treatment	2	75	150.1	<.0001	2	76	97.29	<.0001
Species	9	5271	757.5	<.0001	7	5019	542.6	<.0001
Year*Habitat	3	3638	12.44	<.0001	4	2550	5.985	<.0001
Year*Heat treatment	6	3748	11.18	<.0001	8	3996	13.63	<.0001
Year*Species	27	5271	105.6	<.0001	28	5018	99.86	<.0001
Habitat*Heat	2	74.8	1.816	0.1698	2	76	0.7697	0.4667
Habitat*Species	9	5270	5.473	<.0001	7	5017	5.616	<.0001
Heat *Species	18	5272	6.587	<.0001	14	5022	3.785	<.0001
Year*Habitat*Heat	6	3748	4.792	<.0001	8	3996	4.308	<.0001
Year*Habitat*Species	27	5270	3.058	<.0001	28	5016	2.591	<.0001
Year*Heat*Species	54	5272	2.676	<.0001	56	5021	1.403	0.0259
Habitat*Heat*Species	18	5272	0.9076	0.5690	14	5022	0.6517	0.8228

Table S2. Mixed-effects model results for growing degree days (base temperature of 4°C) accumulated on the date juvenile trees broke bud. Random effects of site, plot and seedling cohort not shown. The model with all five years doesn't include *Populus tremuloides* or *Pinus banksiana* due to inadequate sample size in 2013. Significant effects involving the warming treatment (heat) are in bold.

Source	2009-2012 all species				2009-2013 (8 species)			
	df	df _{den}	F	P	df	df _{den}	F	P
			$R^2=0.63$				$R^2=0.60$	
Year	3	3766	289.5	<.0001	4	1846	181.9	<.0001
Habitat	1	80	10.20	0.0020	1	84	4.13	0.0453
Heat treatment	2	80	72.44	<.0001	2	81	85.48	<.0001
Species	9	5200	464.8	<.0001	7	4984	388.9	<.0001
Year*Habitat	3	3800	21.57	<.0001	4	3479	16.58	<.0001
Year*Heat treatment	6	3956	8.478	<.0001	8	4100	4.756	<.0001
Year*Species	27	5200	51.86	<.0001	28	4984	70.13	<.0001
Habitat*Heat	2	80	2.318	0.1051	2	81	1.461	0.2380
Habitat*Species	9	5199	7.021	<.0001	7	4982	6.842	<.0001

Heat *Species	18	5202	5.500	<.0001	14	4989	4.695	<.0001
Year*Habitat*Heat	6	3951	2.913	0.0078	8	4100	2.788	0.0045
Year*Habitat*Species	27	5199	3.042	<.0001	28	4981	2.847	<.0001
Year*Heat*Species	54	5201	2.218	<.0001	56	4988	1.5655	0.0046
Habitat*Heat*Species	18	5201	0.8758	0.6089	14	4989	0.6173	0.8531

Table S3. Mixed-effects model results for day of year that 1/3 of the leaves had senesced in juvenile trees. Random effects of site, plot and seedling cohort not shown. The model with all five years doesn't include *Populus tremuloides* or *Pinus banksiana* due to inadequate sample size in 2013. Significant effects involving the warming treatment (heat) are in bold.

Source	2009-2012 all species				2009-2013 (8 species)			
	df	df _{den}	F	P	df	df _{den}	F	P
			$R^2=0.55$				$R^2=0.55$	
Year	3	1874	113.4	<.0001	4	18	99.42	<.0001
Habitat	1	10	1.060	0.3271	1	10	4.495	0.0597
Heat Treatment	2	59	32.60	<.0001	2	59	20.76	<.0001
Species	9	4541	304.1	<.0001	7	4513	311.6	<.0001
Year*Habitat	3	1969	2.217	0.0842	4	359	1.840	0.1207
Year*Heat Treatment	6	3012	7.605	<.0001	8	3408	5.310	<.0001
Year*Species	27	4540	22.15	<.0001	28	4512	37.67	<.0001
Habitat*Heat	2	58	0.1467	0.8639	2	59	0.2245	0.7996
Habitat*Species	9	4541	15.50	<.0001	7	4513	26.60	<.0001

Heat *Species	18	4543	10.00	<.0001	14	4514	11.66	<.0001
Year*Habitat*Heat	6	3006	1.391	0.2142	8	3407	1.914	0.0537
Year*Habitat*Species	27	4541	1.417	0.0747	28	4512	5.911	<.0001
Year*Heat*Species	54	4543	1.774	0.0004	56	4513	1.372	0.0349
Habitat*Heat*Species	18	4541	2.200	0.0025	14	4513	2.221	0.0055

Table S4. Mixed-effects model results for growing season length for deciduous species (n=5). Random effects of site, plot and seedling cohort not shown. Significant effects involving the warming treatment (heat) are in bold.

2009-2013 (5 species)				
$R^2=0.69$				
Source	df	df _{den}	F	P
Year	4	180	367	<.0001
Habitat	1	10	4.863	0.0510
Heat Treatment	2	75	86.94	<.0001
Species	4	2710	87.22	<.0001
Year*Habitat	4	1283	3.795	0.0045
Year*Heat Treatment	8	2508	6.855	<.0001
Year*Species	16	2711	57.20	<.0001
Habitat*Heat	2	75	1.072	0.3476
Habitat*Species	7	2700	16.77	<.0001
Heat *Species	8	2713	2.073	0.0352
Year*Habitat*Heat	8	2507	2.949	0.0028
Year*Habitat*Species	16	2712	6.051	<.0001
Year*Heat*Species	32	2711	1.342	0.0954
Habitat*Heat*Species	8	2713	2.609	0.0077

Table S5. Contribution of earlier budburst versus delayed start of senescence to extension of the growing season in deciduous species grown in +1.7°C and +3.4°C warming.

Year	Species	N	+1.7°C		+3.4°C	
			Budburst	Start of Senescence	Budburst	Start of Senescence
2009	<i>Acer rubrum</i>	12	21%	79%	22%	78%
	<i>Acer saccharum</i>	12	42%	58%	24%	76%
	<i>Betula papyrifera</i>	12	39%	61%	38%	62%
	<i>Populus tremuloides</i>	12	30%	70%	23%	77%
	<i>Quercus macrocarpa</i>	12	27%	73%	42%	58%
	<i>Quercus rubra</i>	12	40%	60%	53%	47%
	Mean	6	33%	66%	33%	66%
2010	<i>Acer rubrum</i>	12	43%	57%	47%	53%
	<i>Acer saccharum</i>	12	50%	50%	50%	50%
	<i>Betula papyrifera</i>	12	46%	54%	41%	59%
	<i>Populus tremuloides</i>	12	52%	48%	55%	45%
	<i>Quercus macrocarpa</i>	12	75%	25%	68%	32%
	<i>Quercus rubra</i>	12	57%	43%	56%	44%
	Mean	6	54%	46%	53%	47%
2011	<i>Acer rubrum</i>	12	6%	94%	39%	61%

	<i>Acer saccharum</i>	12	14%	86%	32%	68%
	<i>Betula papyrifera</i>	12	39%	61%	27%	73%
	<i>Populus tremuloides</i>	12	35%	65%	44%	56%
	<i>Quercus macrocarpa</i>	12	66%	34%	55%	45%
	<i>Quercus rubra</i>	12	42%	58%	47%	53%
Mean			34%	66%	41%	59%
2012	<i>Acer rubrum</i>	12	26%	74%	60%	40%
	<i>Acer saccharum</i>	12	33%	67%	54%	46%
	<i>Betula papyrifera</i>	12	100%	0%	100%	0%
	<i>Populus tremuloides</i>	12	84%	16%	100%	0%
	<i>Quercus macrocarpa</i>	12	43%	57%	78%	22%
	<i>Quercus rubra</i>	12	97%	3%	95%	5%
Mean		6	64%	36%	81%	19%
2013	<i>Acer rubrum</i>	12	40%	60%	5%	95%
	<i>Acer saccharum</i>	12	16%	84%	19%	81%
	<i>Betula papyrifera</i>	12	6%	94%	28%	72%
	<i>Populus tremuloides</i>	6	30%	70%	20%	80%
	<i>Quercus macrocarpa</i>	12	19%	81%	32%	68%
	<i>Quercus rubra</i>	12	28%	72%	32%	68%
Mean		6	23%	77%	23%	77%
Grand Mean		5	42%	58%	46%	54%

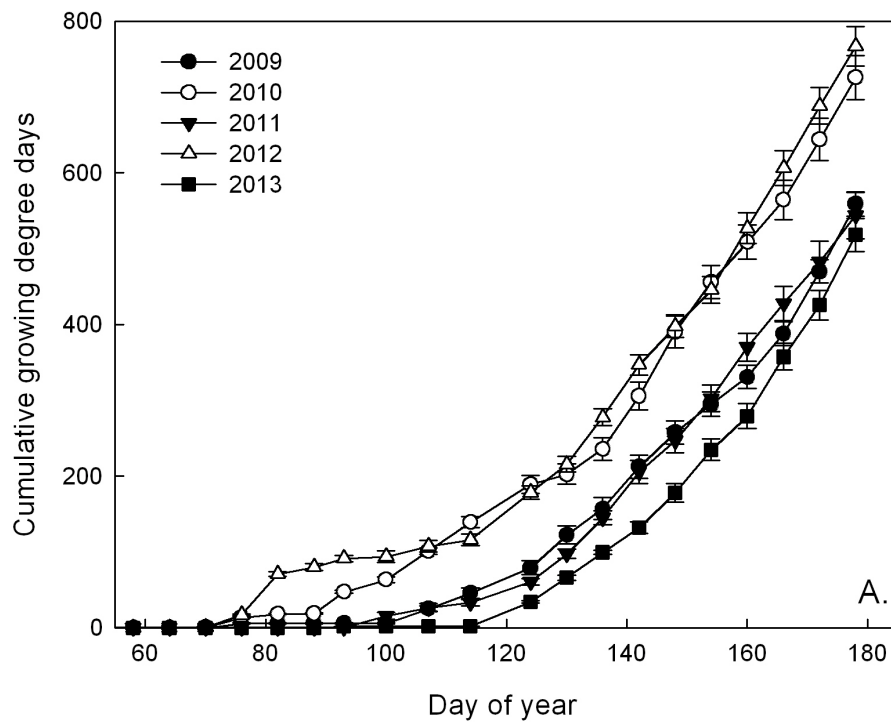
Table S6. Study species with shade tolerance rankings (Niinemets & Valladares 2006), geographic range center (Reich et al. 2015) and leaf habit.

Species	Distribution	Shade tolerance ranking	Mean range center	Leaf habit
<i>Acer rubrum</i>	temperate	3.44±0.23	40.0°N	deciduous
<i>Quercus rubra</i>	temperate	2.75±0.18	40.5°N	deciduous
<i>Quercus macrocarpa</i>	temperate	2.71±0.27	41.2°N	deciduous
<i>Acer saccharum</i>	temperate	4.76±0.11	42.9°N	deciduous
<i>Pinus strobus</i>	temperate	3.21±0.20	47.4°N	evergreen
<i>Populus tremuloides</i>	boreal	1.21±0.18	49.3°N	deciduous
<i>Betula papyrifera</i>	boreal	1.54±0.16	50.3°N	deciduous
<i>Abies balsamea</i>	boreal	5.01±0.09	50.7°N	evergreen
<i>Pinus banksiana</i>	boreal	1.36±0.33	50.9°N	evergreen
<i>Picea glauca</i>	boreal	4.15±0.17	52.2°N	evergreen

SI Appendix: Figures

Figure S1. (A) Growing degree day accumulation in each year where one growing degree day equals $(T_{\max} + T_{\min})/2 - T_{\text{base}}$, T_{base} is 4°C, and if $(T_{\max} + T_{\min})/2 - T_{\text{base}} < 0$ then GDD=0. (B) Chilling degree day accumulation in autumn ($\text{CDD} = T_{\text{base}} - (T_{\max} + T_{\min})/2$, T_{base} is 25°C and if $T_{\text{base}} - (T_{\max} + T_{\min})/2 < 0$ then CDD=0. Day of year is counted from January 1 as day 1.

(A)



(B)

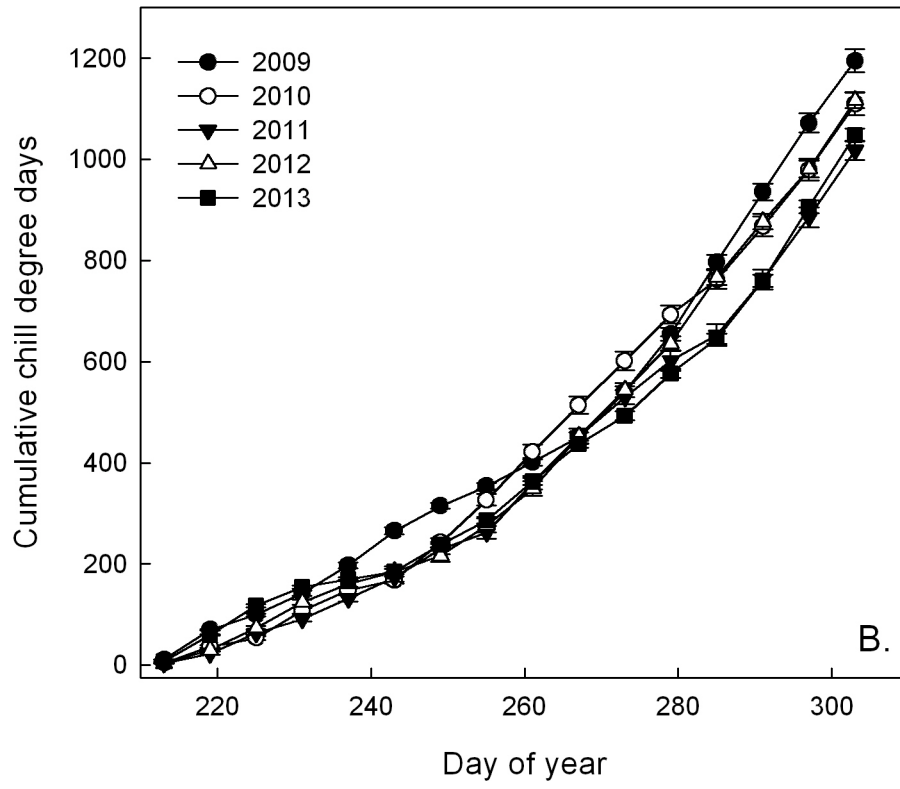


Figure S2. Average difference in budburst for saplings of ten tree species grown under ambient and elevated (+3.4 °C) temperatures. Left five species are considered temperate and right five are boreal. Each panel depicts a unique year. Error bars are standard error across plots (N=12).

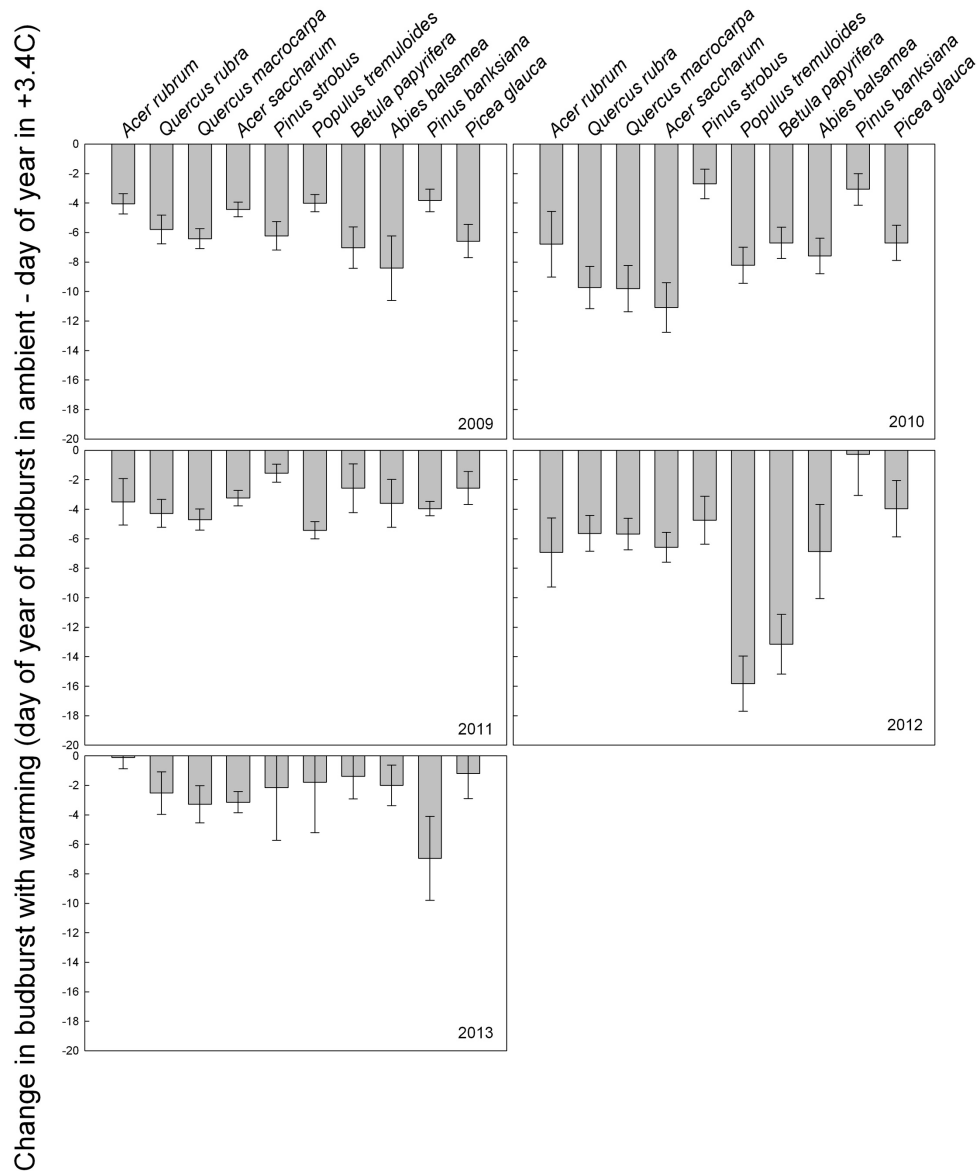


Figure S3. Average difference in day of year of start of senescence for saplings of ten tree species grown under ambient and elevated (+3.4 °C) temperatures. Left five species are considered temperate and right five are boreal. Each panel depicts a unique year. Error bars are standard error across plots (N=12).

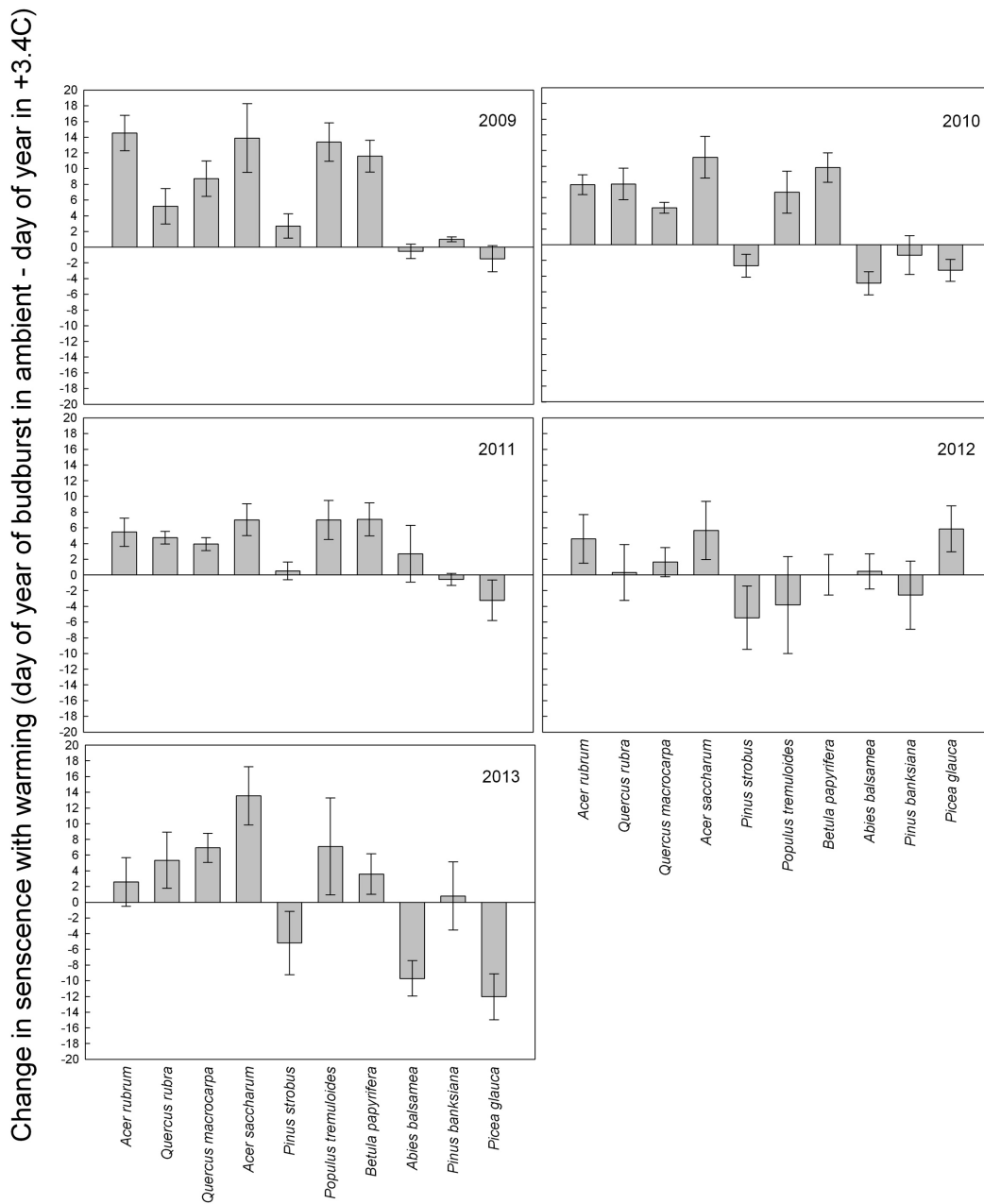


Figure S4. Average changing in growing season length for saplings of six tree species grown under ambient and elevated (+3.4 °C) temperatures. Each panel depicts a unique year. Error bars are standard error across plots (N=12).

