

# Online Supplemental Materials:

## Phenology and plant invasions: Climate change contributes to exotic species' success in temperature-limited systems

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### 1 Overview of Phylomatic and PHLAWD model results

Results of comparing exotic and native species in linear models (LM) and phylogenetic general linear models (PGLM) at five sites considering mean flowering date (day of year), climate sensitivities, flowering time shift (not available for Konza, see main text) in two different tree flavors (Phylomatic and PHLAWD). The following are the variables evaluated and their shorthand in tables S1 to S6 and S8-S13, we explain the models briefly here and provide a more complete description of each in the main text.

- mean FFD: mean first flowering day of year
- flowering time shift: how much a species has shifted its flowering date over time
- sensitivity (gdd): temperature sensitivity from growing degree day model based on 3 month windows regressed against flowering time each year
- sensitivity (gdd w/ prec): as in sensitivity (gdd) but taken as main effect of temperature from model which also includes 3 month summations of precipitation and interaction between precipitation and temperature
- sensitivity (prec w/ gdd): same model as described for sensitivity (gdd w/ prec) but showing the main effect of precipitation
- sensitivity (intxn): same model as described for sensitivity (gdd w/ prec) but showing the interaction term of precipitation and temperature
- sensitivity (soil moisture): sensitivity to monthly soil moisture based on regression of soil moisture against flower time each year (for Konza only)
- sensitivity (3 month): sensitivity to temperature based on 3 month (monthly means)
- sensitivity (MAT): the main temperature sensitivity presented in the main text, based on mean annual temperature (MAT)

## 2 Results using Phylomatic trees

Table S1: Results of LMs and PGLMs for Concord data using USDA Plants to establish native status.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	475	167.66	175.45	0.042	0.944	152.99	158.96	0.052
flowering time shift	360	-5.73	0.25	0.002	0.000	-5.73	0.25	0.002
sensitivity (3 month)	475	-6.22	-4.30	0.039	0.044	-6.80	-4.79	0.034
sensitivity (MAT)	475	-4.36	-2.95	0.057	0.040	-4.66	-3.16	0.046

Table S2: Results of LMs and PGLM for Konza data using USDA Plants to establish native status.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	196	139.55	163.33	0.118	0.989	126.49	124.03	0.827
sensitivity (gdd)	196	-3.97	-3.60	0.848	0.000	-3.97	-3.60	0.848
sensitivity (gdd w/prec)	196	-1.85	-3.34	0.512	0.000	-1.85	-3.34	0.512
sensitivity (intxn)	196	-0.87	0.80	0.420	0.000	-0.87	0.80	0.420
sensitivity (prec w/gdd)	196	5.39	-1.37	0.138	0.000	5.39	-1.37	0.138
sensitivity (soil moisture)	196	2.58	-1.02	0.118	0.000	2.58	-1.02	0.118
sensitivity (3 month)	196	-3.31	-2.85	0.779	0.000	-3.31	-2.85	0.779
sensitivity (MAT)	196	-2.29	-3.06	0.522	0.266	-2.30	-3.55	0.296

Table S3: Results of LMs and PGLMs for Fargo data using USDA Plants to establish native status, including all species.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	304	160.21	160.09	0.974	0.763	155.53	155.54	0.995
flowering time shift	104	3.30	1.02	0.329	0.000	3.30	1.02	0.329
sensitivity (gdd)	304	-4.43	-3.47	0.325	0.025	-4.25	-3.33	0.351
sensitivity (gdd w/prec)	304	-3.49	-3.15	0.740	0.000	-3.49	-3.15	0.740
sensitivity (prec w/gdd)	304	-0.85	1.13	0.059	0.058	-0.60	1.36	0.064
sensitivity (intxn)	304	-1.11	-0.13	0.334	0.000	-1.11	-0.13	0.334
sensitivity (3 month)	304	-2.00	-2.63	0.166	0.000	-2.00	-2.63	0.166
sensitivity (MAT)	304	-0.39	-1.67	0.025	0.000	-0.39	-1.67	0.025

Table S4: Results of LMs and PGLMs for Fargo data using USDA Plants to establish native status, excluding *Chenopodium* species that is an outlier.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	303	159.63	160.09	0.897	0.757	155.41	155.55	0.962
flowering time shift	104	3.30	1.02	0.329	0.000	3.30	1.02	0.329
sensitivity (gdd)	303	-3.99	-3.47	0.582	0.074	-3.68	-3.20	0.617
sensitivity (gdd w/prec)	303	-2.83	-3.15	0.735	0.000	-2.83	-3.15	0.735
sensitivity (prec w/gdd)	303	-0.97	1.13	0.047	0.050	-0.72	1.34	0.054
sensitivity (intxn)	303	-0.80	-0.13	0.507	0.000	-0.80	-0.13	0.507
sensitivity (3 month)	303	-2.33	-2.63	0.472	0.000	-2.33	-2.63	0.472
sensitivity (MAT)	303	-1.00	-1.67	0.131	0.000	-1.00	-1.67	0.131

Table S5: Results of LMs and PGLMs for Chinnor data using Botanical Society of the British Isles online database to establish native status.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	373	139.26	147.83	0.152	0.843	127.31	133.74	0.201
flowering time shift	369	-0.16	-0.10	0.058	0.000	-0.16	-0.10	0.058
sensitivity (gdd)	373	-7.08	-5.46	0.009	0.074	-7.32	-5.65	0.007
sensitivity (gdd w/prec)	373	-6.91	-5.25	0.004	0.081	-7.14	-5.41	0.003
sensitivity (prec w/gdd)	373	0.21	0.78	0.217	0.000	0.21	0.78	0.216
sensitivity (intxn)	373	0.13	0.17	0.932	0.098	0.24	0.31	0.880
sensitivity (3 month)	373	-6.33	-5.24	0.060	0.000	-6.33	-5.24	0.059
sensitivity (MAT)	373	-9.58	-7.45	0.008	0.067	-9.70	-7.61	0.010

Table S6: Results of LMs and PGLMs for Washington, DC (non-cultivated species) using USDA Plants to establish native status.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	446	115.96	115.46	0.824	0.583	115.93	118.84	0.206
flowering time shift	448	-0.18	-0.05	0.201	0.000	-0.18	-0.05	0.201
sensitivity (gdd)	446	-4.14	-2.81	0.029	0.000	-4.14	-2.81	0.029
sensitivity (gdd w/prec)	446	-3.49	-2.79	0.216	0.000	-3.49	-2.79	0.216
sensitivity (prec w/gdd)	446	1.73	0.82	0.246	0.024	1.49	0.67	0.302
sensitivity (intxn)	446	-0.77	-0.03	0.310	0.000	-0.77	-0.03	0.311
sensitivity (3 month)	446	-3.46	-2.53	0.085	0.000	-3.46	-2.53	0.085
sensitivity (MAT)	446	-3.73	-2.75	0.098	0.045	-3.50	-2.61	0.141

### 3 Results using PHLAWD trees

Table S7: Site information based on models using PHLAWD trees. Compare with Table 1 in the main text for differences between Phylomatic and PHLAWD trees in species sampling.

	exotic spp. n	native spp. n	exotic spp. n: flowering time shift models	native spp. n: flowering time shift models
Chinnor, UK	39	228	39	228
Concord, MA, USA	81	218	69	174
Fargo, ND, USA	56	134	11	65
Konza LTER, KS, USA	9	119		
Washington, DC, USA	157	215	158	215

Table S8: Results of LMs and PGLM for Concord data using USDA Plants to establish native status.

	DF	LM: ex-otic	LM: na-tive	LM: p	PGLM: lambda	PGLM: exo	PGLM: nat	PGLM: p
mean FFD	297	165.78	167.74	0.636	0.910	141.95	140.47	0.686
flowering time shift	241	-5.11	0.93	0.006	0.000	-4.57	0.93	0.014
sensitivity (3 month)	297	-6.27	-4.95	0.221	0.045	-6.93	-5.74	0.284
sensitivity (MAT)	297	-4.54	-3.28	0.151	0.000	-4.49	-3.14	0.129

Table S9: Results of LMs and PGLMs for Konza data using USDA Plants to establish native status.

	DF	LM: ex-otic	LM: na-tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	126	138.70	161.69	0.158	0.861	122.56	120.42	0.866
sensitivity (gdd)	126	-4.09	-3.70	0.844	0.000	-4.17	-3.71	0.806
sensitivity (gdd w/prec)	126	-1.86	-3.91	0.424	0.000	-1.97	-3.86	0.441
sensitivity (intxn)	126	-0.86	1.37	0.353	0.000	-0.86	1.39	0.330
sensitivity (prec w/gdd)	126	6.24	-2.80	0.089	0.000	6.25	-2.66	0.082
sensitivity (soil moisture)	126	3.12	-1.17	0.072	0.000	3.02	-1.10	0.077
sensitivity (3 month)	126	-3.40	-3.07	0.842	0.000	-3.47	-3.05	0.794
sensitivity (MAT)	126	-2.35	-3.06	0.529	0.091	-2.11	-3.24	0.311

Table S10: Results of LMs and PGLMs for Fargo data using USDA Plants to establish native status, including all species.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	188	158.86	155.20	0.379	0.827	144.78	141.51	0.342
flowering time shift	74	5.78	0.26	0.024	0.000	5.61	0.37	0.037
sensitivity (gdd)	188	-3.63	-4.44	0.375	0.158	-3.61	-4.47	0.342
sensitivity (gdd w/prec)	188	-2.13	-4.07	0.036	0.000	-2.12	-4.18	0.025
sensitivity (prec w/gdd)	188	-0.94	0.50	0.264	0.000	-0.86	0.57	0.261
sensitivity (intxn)	188	-0.40	-0.73	0.800	0.000	-0.12	-0.62	0.690
sensitivity (3 month)	188	-1.90	-2.80	0.063	0.000	-1.94	-2.83	0.060
sensitivity (MAT)	188	-1.03	-1.82	0.127	0.000	-1.05	-1.78	0.154

Table S11: Results of LMs and PGLMs for Fargo data using USDA Plants to establish native status, excluding *Chenopodium* species that is an outlier.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	188	158.86	155.20	0.379	0.827	144.78	141.51	0.342
flowering time shift	74	5.78	0.26	0.024	0.000	5.61	0.37	0.037
sensitivity (gdd)	188	-3.63	-4.44	0.375	0.158	-3.61	-4.47	0.342
sensitivity (gdd w/prec)	188	-2.13	-4.07	0.036	0.000	-2.12	-4.18	0.025
sensitivity (prec w/gdd)	188	-0.94	0.50	0.264	0.000	-0.86	0.57	0.261
sensitivity (intxn)	188	-0.40	-0.73	0.800	0.000	-0.12	-0.62	0.690
sensitivity (3 month)	188	-1.90	-2.80	0.063	0.000	-1.94	-2.83	0.060
sensitivity (MAT)	188	-1.03	-1.82	0.127	0.000	-1.05	-1.78	0.154

Table S12: Results of LMs and PGLMs for Chinnor data using Botanical Society of the British Isles online database to establish native status.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	265	140.20	146.67	0.350	0.932	107.54	109.76	0.680
flowering time shift	265	-0.19	-0.10	0.057	0.000	-0.19	-0.11	0.037
sensitivity (gdd)	265	-7.05	-5.61	0.046	0.000	-7.08	-5.69	0.052
sensitivity (gdd w/prec)	265	-6.85	-5.40	0.032	0.000	-6.87	-5.46	0.037
sensitivity (prec w/gdd)	265	0.27	0.66	0.456	0.000	0.28	0.67	0.453
sensitivity (intxn)	265	-0.07	0.25	0.558	0.109	-0.15	0.13	0.603
sensitivity (3 month)	265	-6.36	-5.36	0.134	0.030	-6.55	-5.48	0.106
sensitivity (MAT)	265	-9.36	-7.67	0.081	0.000	-9.44	-7.76	0.082

Table S13: Results of LMs and PGLMs for Washington, DC (non-cultivated species) using USDA Plants to establish native status.

	DF	LM: ex- otic	LM: na- tive	LM: p	PGLM: lambda	PGLM: exotic	PGLM: native	PGLM: p
mean FFD	370	115.49	116.49	0.690	0.546	118.73	121.03	0.378
flowering time shift	371	-0.11	-0.04	0.513	0.000	-0.10	-0.04	0.582
sensitivity (gdd)	370	-4.07	-2.68	0.042	0.000	-4.04	-2.63	0.034
sensitivity (gdd w/prec)	370	-3.21	-2.63	0.321	0.019	-2.94	-2.34	0.304
sensitivity (prec w/gdd)	370	1.24	0.89	0.647	0.000	1.11	0.78	0.653
sensitivity (intxn)	370	-0.49	-0.10	0.628	0.000	-0.50	-0.09	0.597
sensitivity (3 month)	370	-3.40	-2.41	0.103	0.000	-3.41	-2.36	0.080
sensitivity (MAT)	370	-3.72	-2.75	0.151	0.000	-3.62	-2.64	0.139

## 4 Shared species between Chinnor and Concord sites



Table S14: Latin binomials of the 42 species native to Chinnor (UK) and exotic to Concord, Massachusetts (USA). See main text for further details.

Shared species
<i>Anagallis arvensis</i>
<i>Arctium minus</i>
<i>Barbarea vulgaris</i>
<i>Chelidonium majus</i>
<i>Cichorium intybus</i>
<i>Cirsium arvense</i>
<i>Cirsium vulgare</i>
<i>Daucus carota</i>
<i>Galeopsis tetrahit</i>
<i>Glechoma hederacea</i>
<i>Hypericum perforatum</i>
<i>Iris pseudacorus</i>
<i>Leontodon autumnalis</i>
<i>Linaria vulgaris</i>
<i>Lythrum salicaria</i>
<i>Malva sylvestris</i>
<i>Myosotis arvensis</i>
<i>Myosotis scorpioides</i>
<i>Pastinaca sativa</i>
<i>Plantago lanceolata</i>
<i>Polygonum aviculare</i>
<i>Ranunculus bulbosus</i>
<i>Ranunculus repens</i>
<i>Ribes rubrum</i>
<i>Rumex acetosella</i>
<i>Rumex crispus</i>
<i>Rumex obtusifolius</i>
<i>Sagina procumbens</i>
<i>Sedum acre</i>
<i>Sisymbrium officinale</i>
<i>Solanum dulcamara</i>
<i>Sonchus asper</i>
<i>Sonchus oleraceus</i>
<i>Stellaria graminea</i>
<i>Tanacetum vulgare</i>
<i>Trifolium campestre</i>
<i>Trifolium pratense</i>
<i>Trifolium repens</i>
<i>Verbascum thapsus</i>
<i>Veronica arvensis</i>
<i>Veronica officinalis</i>
<i>Vicia cracca</i>