Changes and trends in budburst and leaf flush across Europe and North America:

A meta-analysis of local adaptation in spring phenology studies

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Acknowledgement

Dr. Lizzie Wolkovich | Temporal Ecology Lab | The University of British Columbia

Undergraduate Diversity Research Grant | Biodiversity Research Center

Background + Introduction

Phenology: timing of events.

e.g. flowering, hibernation, migration.

Common garden experiment: comparison of different populations under the exact same environment.

Background + Introduction

Most studied tree species have the highest fitness at geographical origin.

- Fall events (bud set, leaf senescence, etc.): similar trends of adaptive differentiation.
- Spring events (budburst, leaf flush, etc.): more substantial phenotypic plasticity.

Increasing interest in predicting local adaptation across different locations.

Research questions + Goals

Knowledge gap:

No study has examined the relationship between spring phenology variations observed across North America and Europe.

We ask:

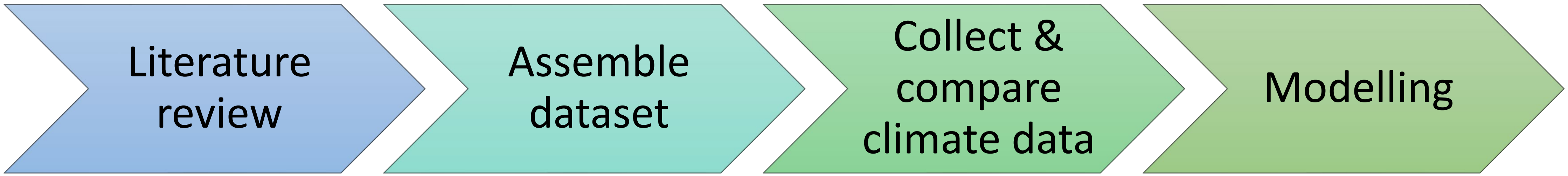
Is the local adaptation of spring phenology stronger in Europe than in North America?

Do angiosperm and gymnosperms exhibit different degree of clines?

Goals:

(1) Examine if North America and Europe show distinct interannual climate variability relative to spatial climate variability.
(2) Explore if differences in spring event local adaptation exist across the two continents.
(3) Understand if climate variability explains the similarities/differences in local adaptation.

Methods



Literature review
Assemble dataset
Collect & compare climate data
Modelling

Methods – Literature review

- Timing of spring events (budburst, leaf flush).
- Woody plant species.
- Searched on ISI Web of Science, Google Scholar, and Connected Papers:

ALL FIELDS = (budburst OR leaf out OR spring phenology OR spring events) AND (common garden) AND (latitude OR latitudinal) AND (local adaptation), yielding 1,067 results.

Methods – Assemble dataset

To be included, studies must

(a) focus on European or North American woody plants;

(b) report spring event DOY in calendar days;

(c) report geographic coordinates of provenances and gardens.

No.	Publication	Provenance Continent	Garden Continent	Garden ID	Species	Species Type	# of Provenances	Observation Year	Spring Event Definition	Fall Event	Fall Event Definition
1	Hamann et al., 1998	North America	North America	A	Alnus rubra	Angiosperm	55	1996	Bud burst	Yes	Leaf abscission
2	Rehfeldt, 1994	North America	North America	B	Picea engelmannii	Gymnosperm	103	n.d.	Bud burst	Yes	Leaf cessation
3	Bower & Aitken, 2008	North America	North America	C	Pinus albicaulis	Gymnosperm	25	2003	Leaf flush	No	n.a.
4	McKown et al., 2013	North America	North America	D	Populus trichocarpa	Angiosperm	97	2010	Bud burst Leaf flush	Yes	Bud set
5	Mimura & Aitken 2007	North America	North America	D	Picea sitchensis	Gymnosperm	17	2003	Bud burst	Yes	Bud set
6	Kuser, 1980	North America	North America	E	Tsuga heterophylla	Gymnosperm	19	1978	Bud burst	Yes	Bud set
7	Farmer, 1993	North America	North America	F	Populus balsamifera	Angiosperm	4	1985 1986 1987	Bud burst	No	n.a.
8	Hannerz et al., 1999	North America	North America	G	Tsuga heterophylla	Gymnosperm	4	1998	Bud burst	No	n.a.
9	White et al., 1979	North America	North America	H	Pseudotsuga menziesii	Gymnosperm	16	1962 1963 1965	Bud burst	No	n.a.
10	Guo et al., 2021	North America	North America	I	Picea mariana	Gymnosperm	5	2015	Bud burst	No	n.a.

11	Dixit et al., 2020	North America	North America	J	Pinus ponderosa	Gymnosperm	21	2019	Bud burst	No	n.a.
12	Hawkins & Dhar 2012	North America	North America	K L M	Betula papyrifera	Angiosperm	18	1998	Bud burst	No	n.a.

Studies with provenances and common gardens on different continents were excluded from our main analysis

13	Cannell et al. 1987	North America	Europe	N	Alnus rubra	Angiosperm	12	1895	Bud burst	Yes	Bud set
14	Lavadinovic et al., 2013	North America	Europe	O	Pseudotsuga menziesii	Gymnosperm	14	2002 2003 2004	Bud burst	No	n.a.
15	Sweet, 1965	North America	Oceania	P	Pseudotsuga menziesii	Gymnosperm	23	1961	Bud burst	No	n.a.
16	Rosique-Esplugas, 2021	Europe	Europe	Q*	Fraxinus excelsior	Angiosperm	42	2013	Leaf flush	Yes	Leaf senescence
17	Petkova et al., 2017	Europe	Europe	R*	Fagus sylvatica	Angiosperm	8	2013 2016	Bud burst	Yes	Leaf senescence
18	Sogaard et al., 2008	Europe	Europe	S*	Picea abies	Gymnosperm	9	2004	Bud burst	No	n.a.
19	Gömöry & Paule 2011	Europe	Europe	T*	Fagus sylvatica	Angiosperm	32	2007 2008	Bud burst	No	n.a.
20	Alberto et al., 2011	Europe	Europe	U* V*	Quercus petraea	Angiosperm	10	2009	Bud burst	No	n.a.

	# of Angiosperms	# of Gymnosperms	# of Provenances	# of Common Gardens	Species
North American Studies	3	1	101	6	Fagus sylvatica, Fraxinus excelsior, Picea abies, Quercus petraea
European Studies	4	7	384	13	Alnus rubra, Betula papyrifera, Picea engelmannii, Picea mariana, Pinus ponderosa, Picea sitchensis, Pinus albicaulis, Populus balsamifera, Pseudotsuga menziesii, Populus trichocarpa, Tsuga heterophylla
Total	7	8	485	19	

**Seven species had fall event (i.e. leaf abscission, leaf coloring) information available.*

**mMost common gardens included in this study only had observations of one species.*

We focused on estimating species effects because we expected a larger effect from species.


Arctic Ocean
NORTH AMERICA
North Pacific Ocean
North Atlantic Ocean
EUROPE
Gardens
A,NA ALNURU Hamann et al. 1998
B,NG PICEEN Rehfeldt 1994
C,NG PINUAL Bower and Aitken 2008
D,NA POPUTR McKown et al. 2013
D,NG PICESI Mimura & Aitken 2007
E,NG TSUGHE Kuser 1980
F,NA POPUBA Farmer 1993
G,NG TSUGHE Hannerz et al. 1999
H,NG PSEUME White et al. 1979
I,NG PICEMA Guo et al 2021
J,NG PINUPO Dixit et al 2020
K,NA BETUPA Hawkins & Dhar 2012 K
L,NA BETUPA Hawkins & Dhar 2012 L
M,NA BETUPA Hawkins & Dhar 2012 M
Q*,EA FRAXEX Rosique-Esplugas 2021
R*,EA FAGUSY Petkova et al 2017
S*,EG PICEAB Sogaard et al. 2008
T*,EA FAGUSY Gömöry & Paule 2011
U*,EA QUEPET Alberto et al 2011 Garden U
V*,EA QUEPET Alberto et al 2011 Garden V
Provenances
A,NA ALNURU Hamann et al. 1998
B,NG PICEEN Rehfeldt 1994
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U*,EA QUEPET Alberto et al 2011 Garden U
V*,EA QUEPET Alberto et al 2011 Garden V

Methods – Collect & compare climate data

Coarse metrics:

- Provenance/common garden latitude.
- Mean annual temperature (MAT).

Climate WNA (Wang et al., 2012), Climate Information Tool (FAO, 2022)

***Latitude and MAT ultimately represent how similar the climates are between the provenances and gardens in times that matter for the events*.**

⇨ We estimated climate overlap in relevant months (March to May) to further test how much climate similarity, between provenance and common garden, predicts local adaptation.

- Extracted gridded daily climate data (2011-2020)

E-OBS, Daymet package in R

- Calculated climate overlap percentage and standard deviation
  - Overlap package in R

Methods – Modelling

One predictor:

Spring event DOY ~ (Provenance latitude| Species)

Spring event DOY ~ (MAT| species)

Spring event DOY ~ (Climate overlap percentage| Species)

Spring event DOY ~ (Climate overlap standard deviation| species)

Fall event DOY ~ (Provenance latitude| Species)

Fall event DOY ~ (MAT| Species)

Fall event DOY ~ (Climate overlap percentage| Species)

Fall event DOY ~ (Climate overlap standard deviation| species)

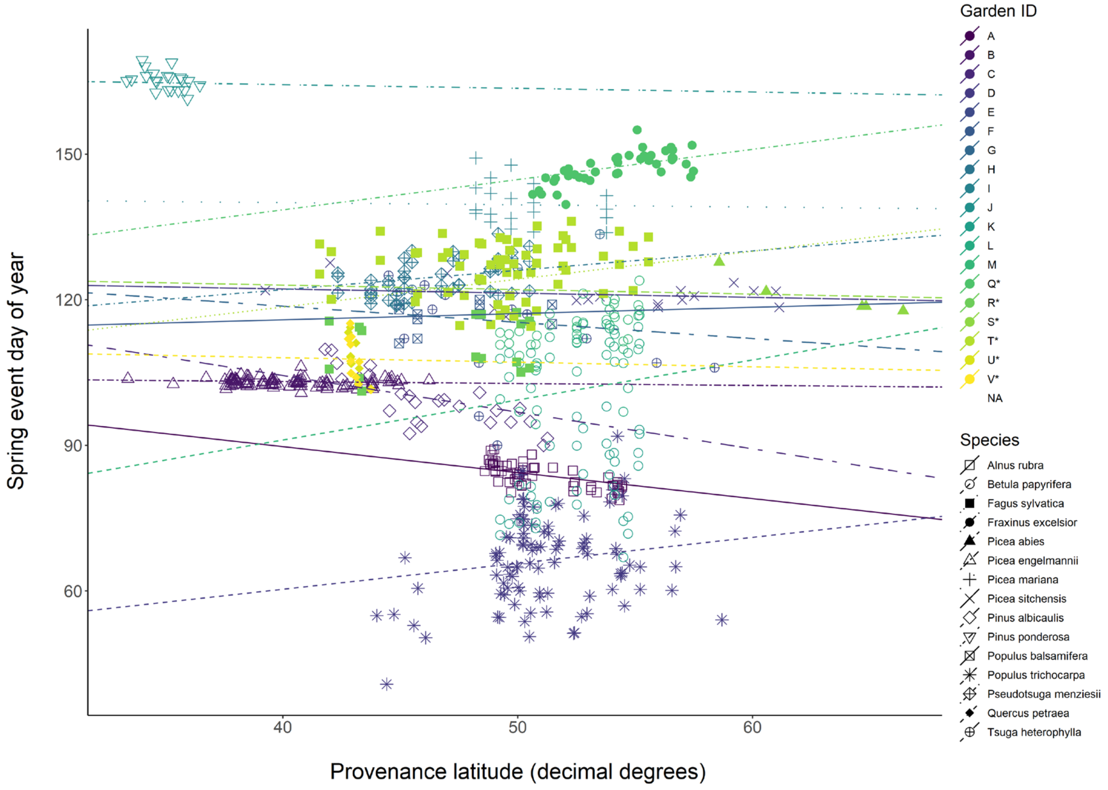
Two predictors:

Spring event DOY ~ ((Climate overlap percentage * Climate overlap standard deviation) | Species)

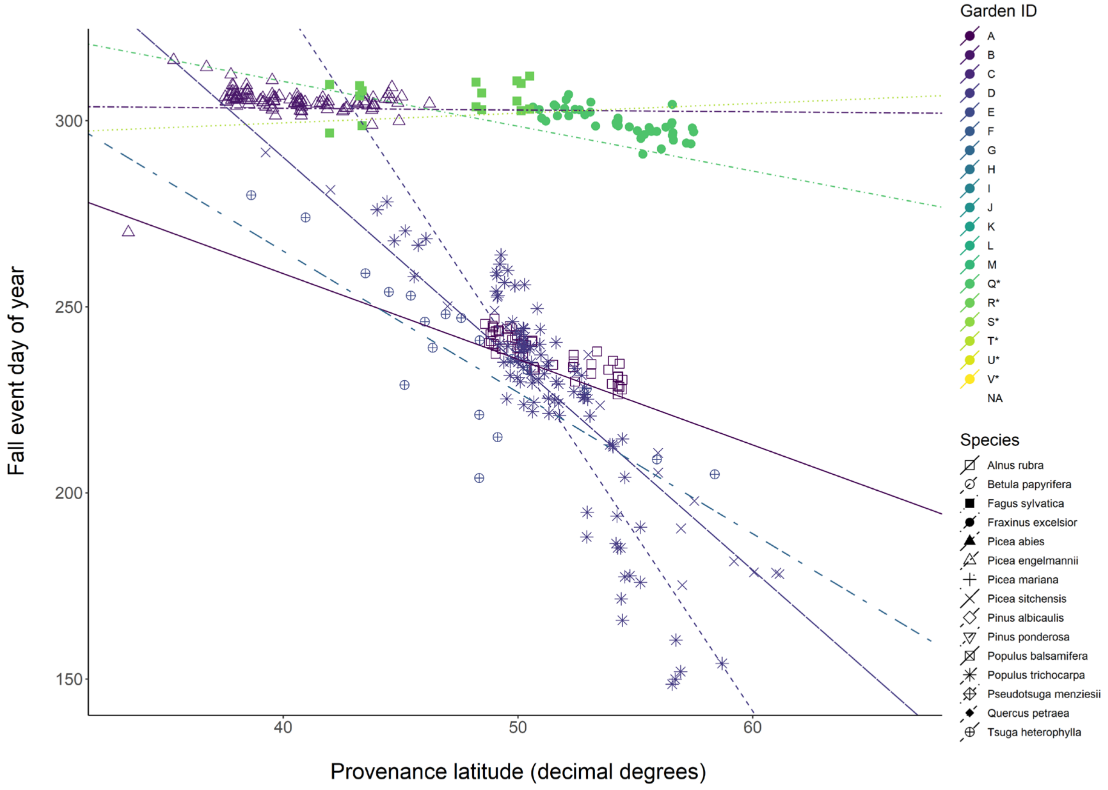
Fall event DOY ~ ((Climate overlap percentage * Climate overlap standard deviation) | Species)

Results – Event DOY~ Provenance latitude

Spring



Fall

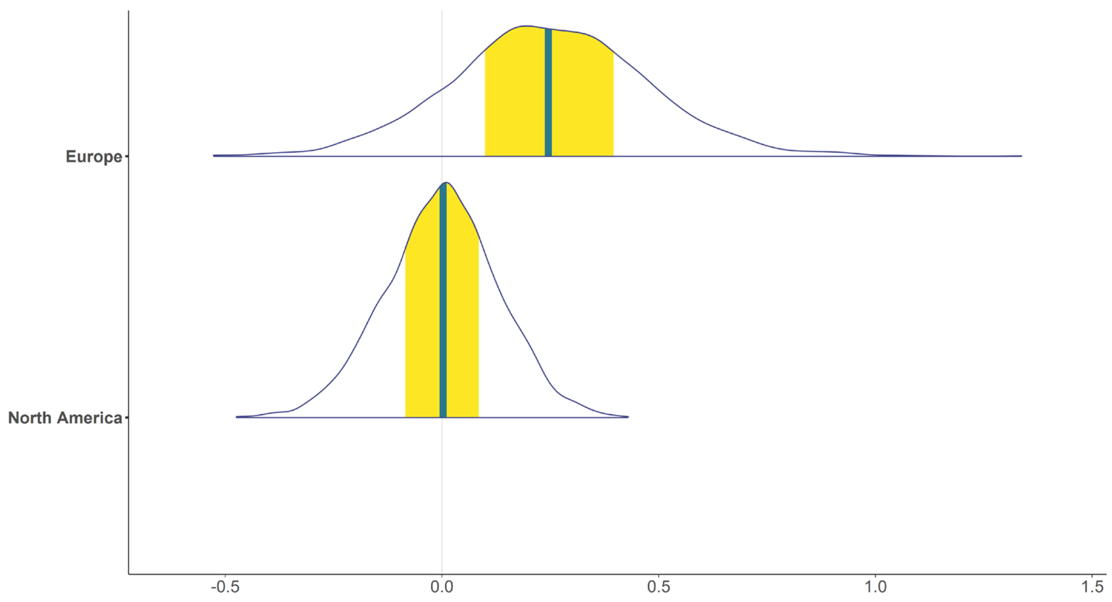


Stronger plasticity in spring events than fall

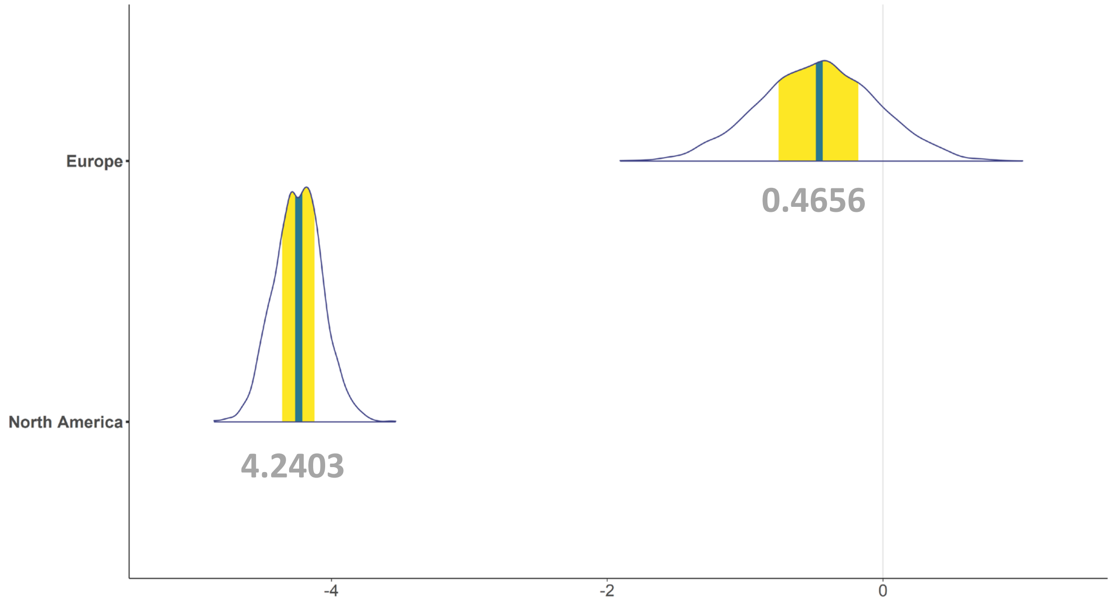
Regarding spring events, slightly stronger relationships in Europe than in North America

Results – How it relates to continents?

Spring



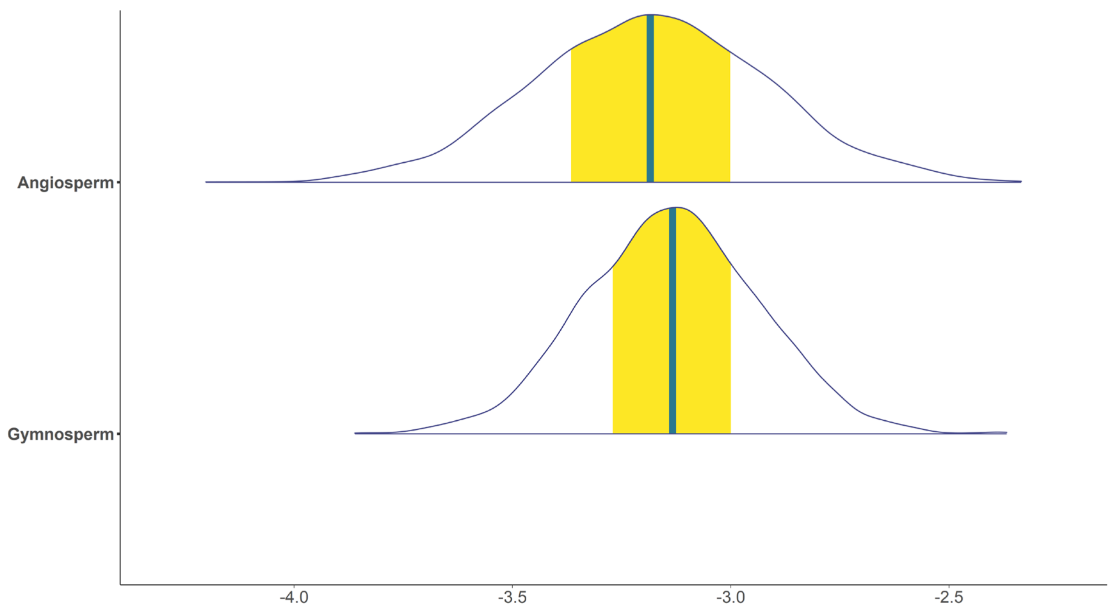
Fall



Results – How it relates to leaf types?

Spring

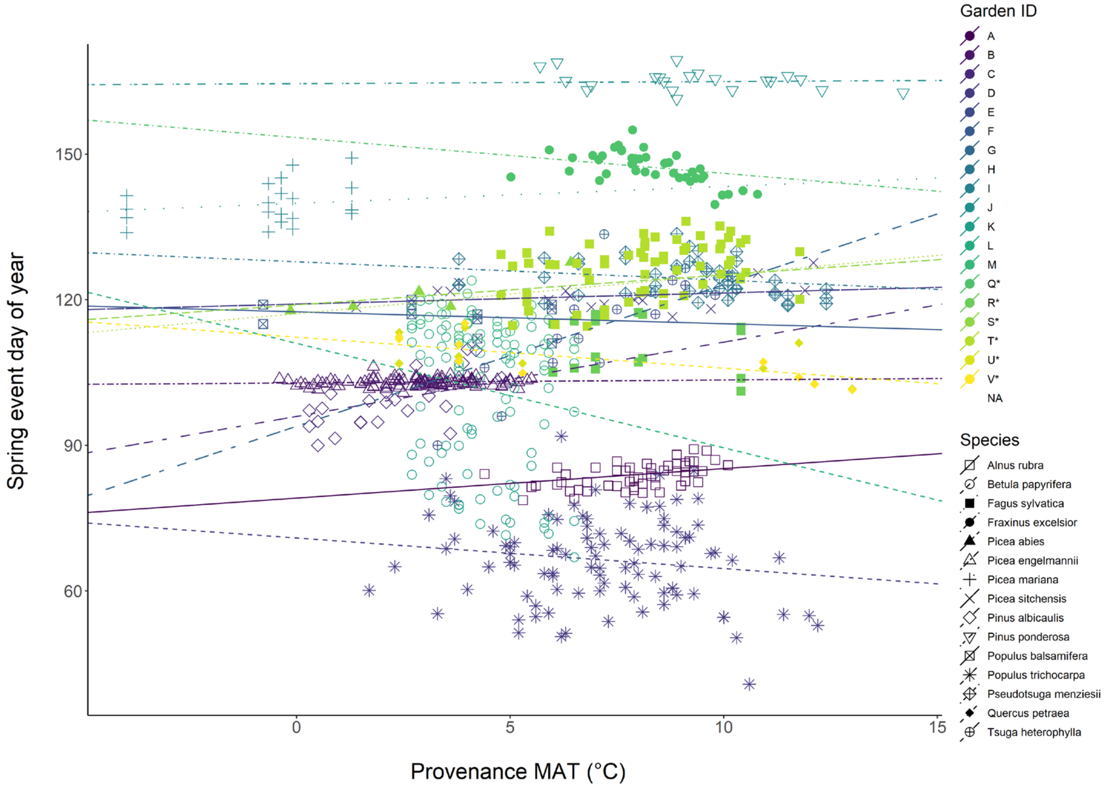
Fall



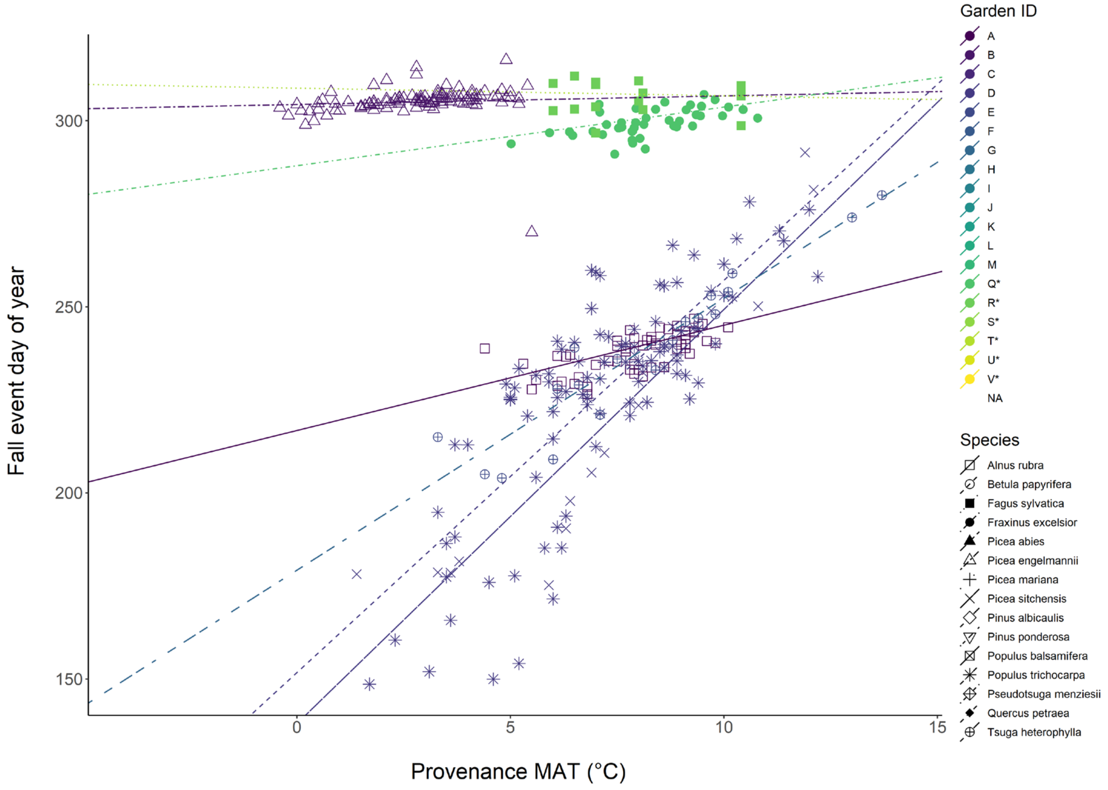
Angiosperm and gymnosperm trees both do not show a strong relationship with provenance latitude.

Results – Event DOY~ Provenance MAT

Spring



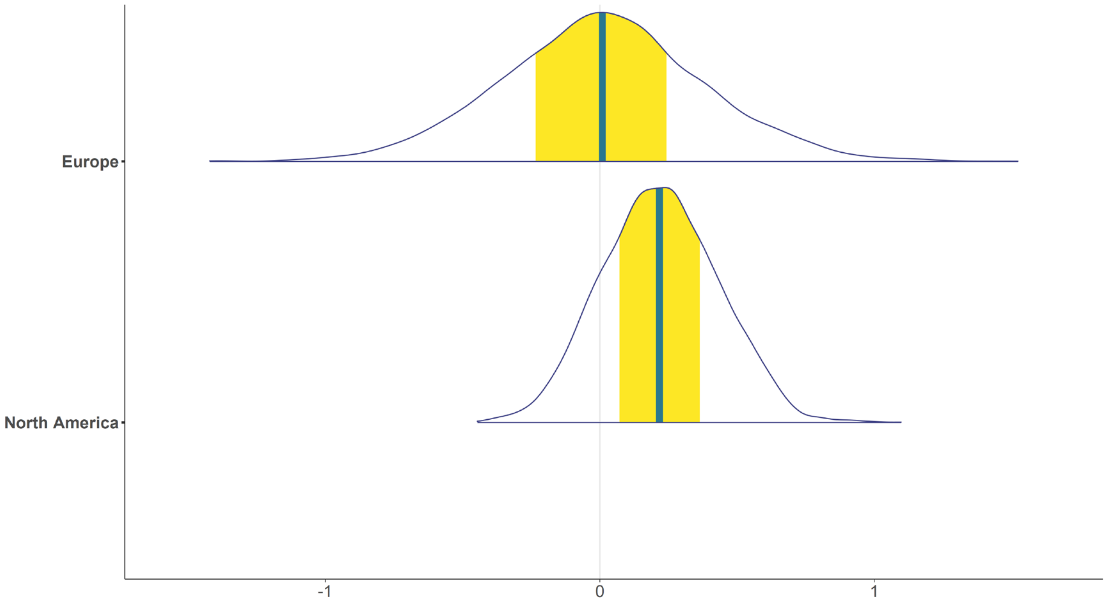
Fall



We observed little to no clines regarding mean annual temperature across gardens. This lack of effect may be explained by the similar spring climate of most provenances and gardens, but also suggests diverging latitudinal patterns in each continent.

Results – How it relates to continents?

Spring



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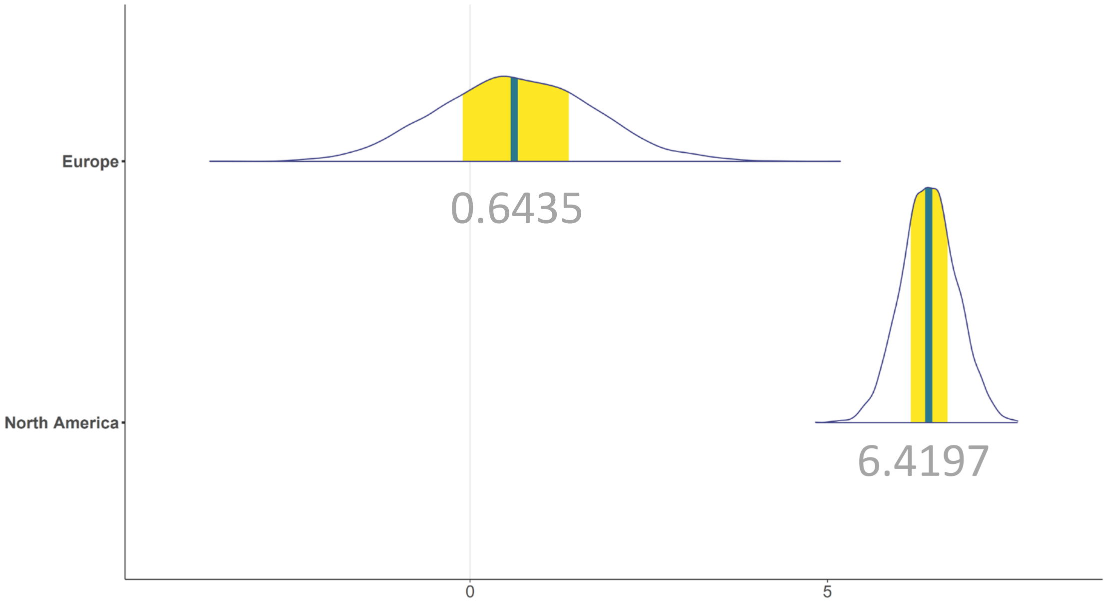
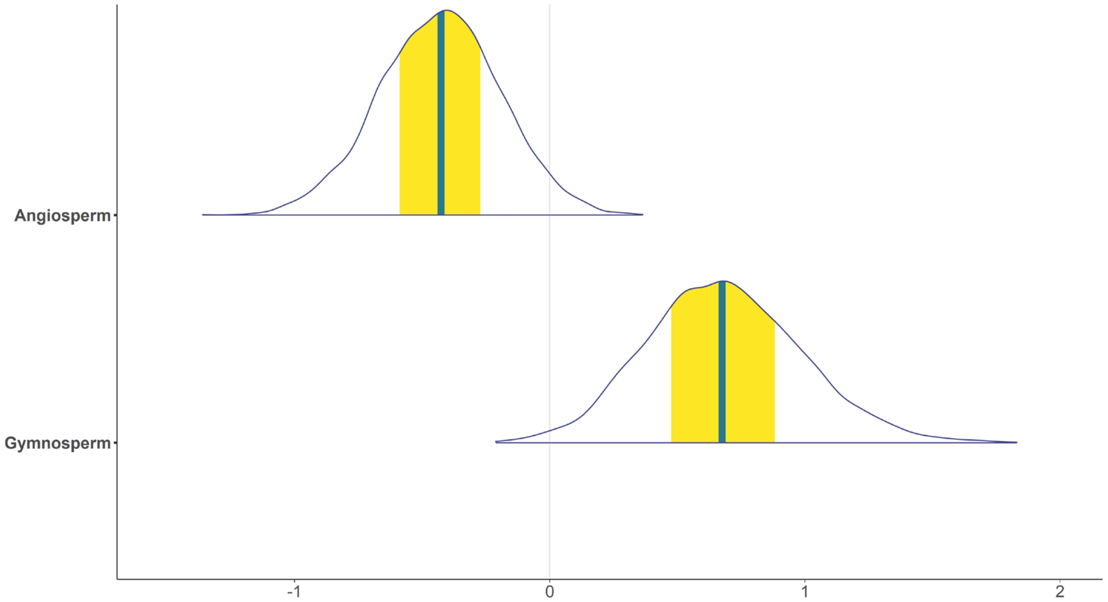


Results – How it relates to leaf types?

Spring



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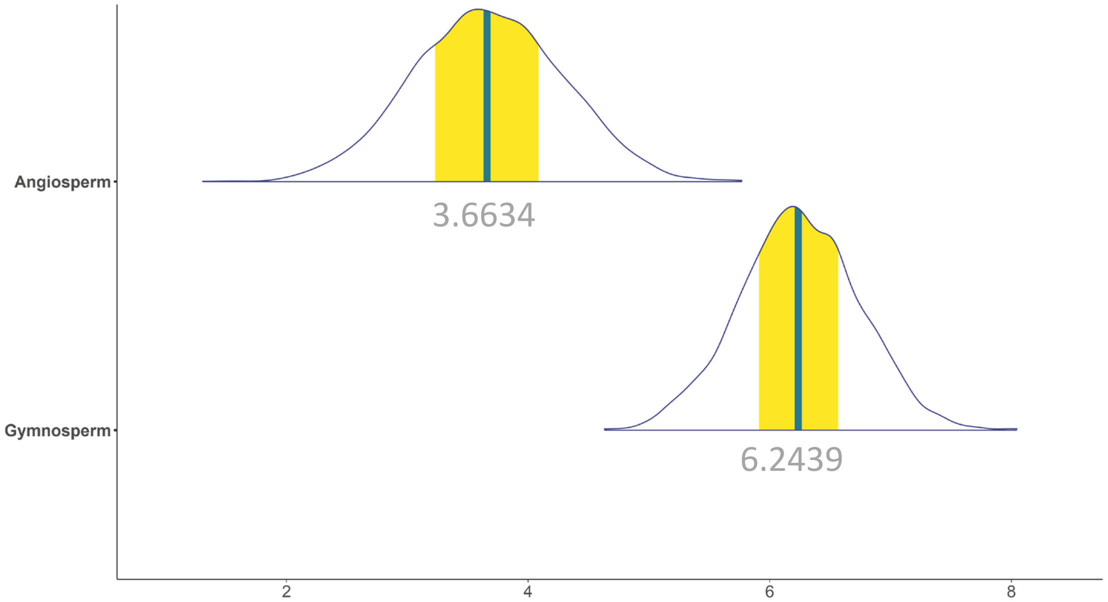
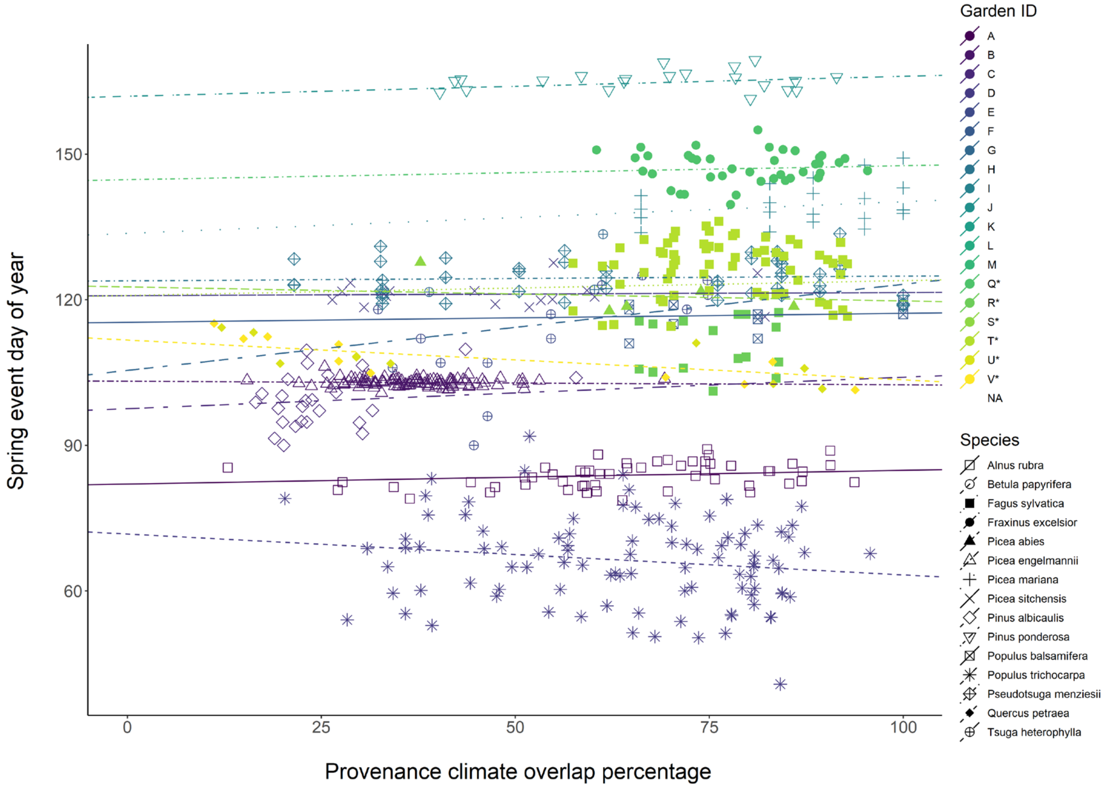


Results – Event DOY~ Climate overlap percentage

Spring



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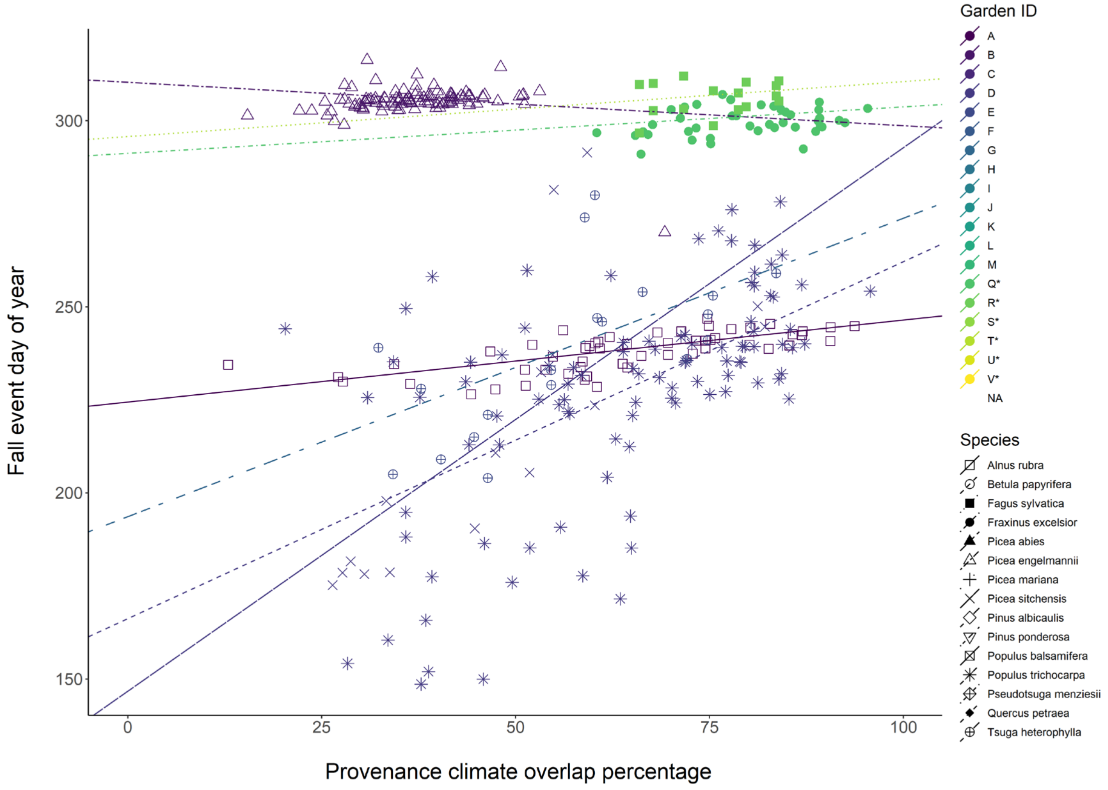
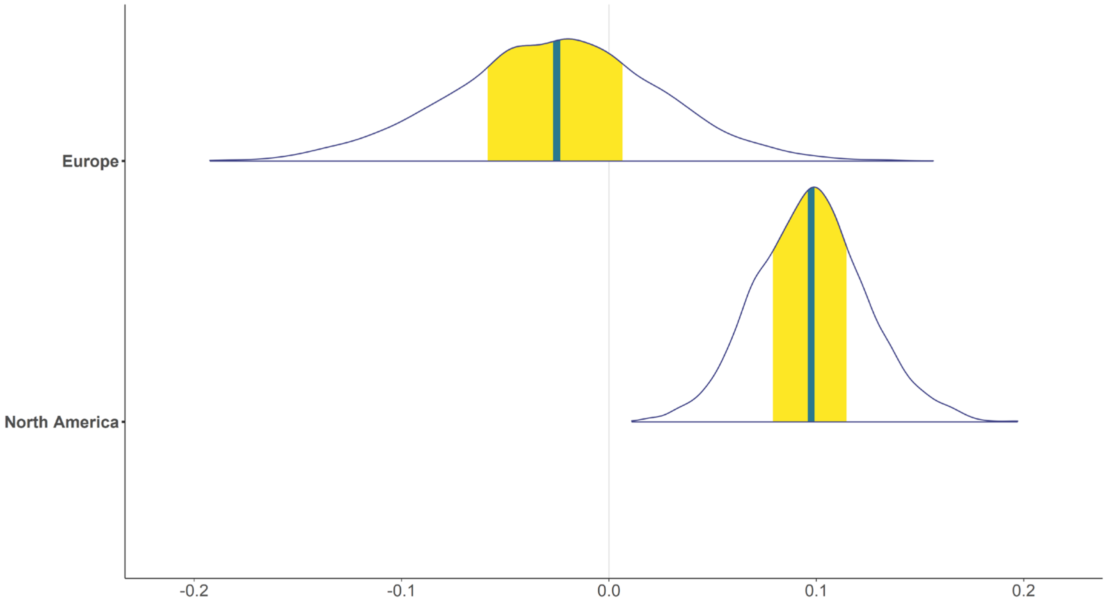
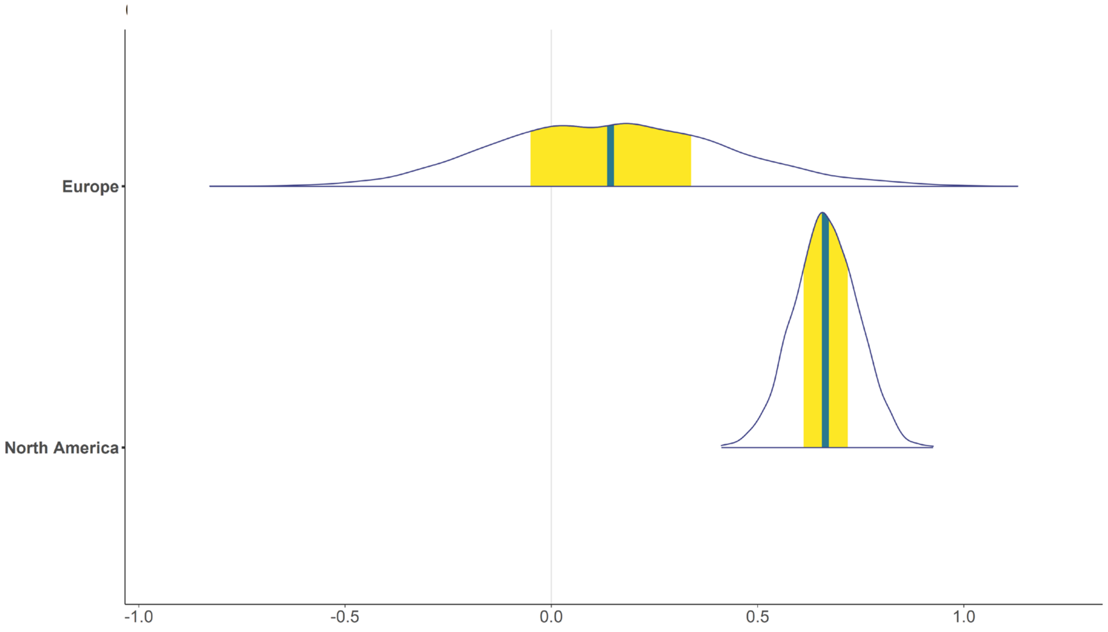


Results – How it relates to continents?

Spring

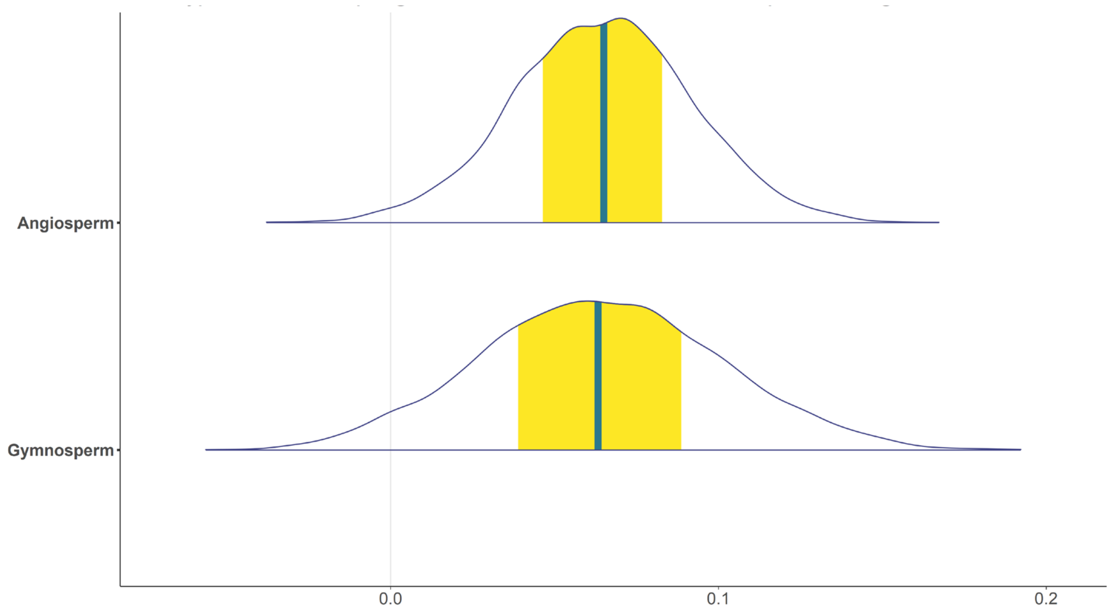


Fall

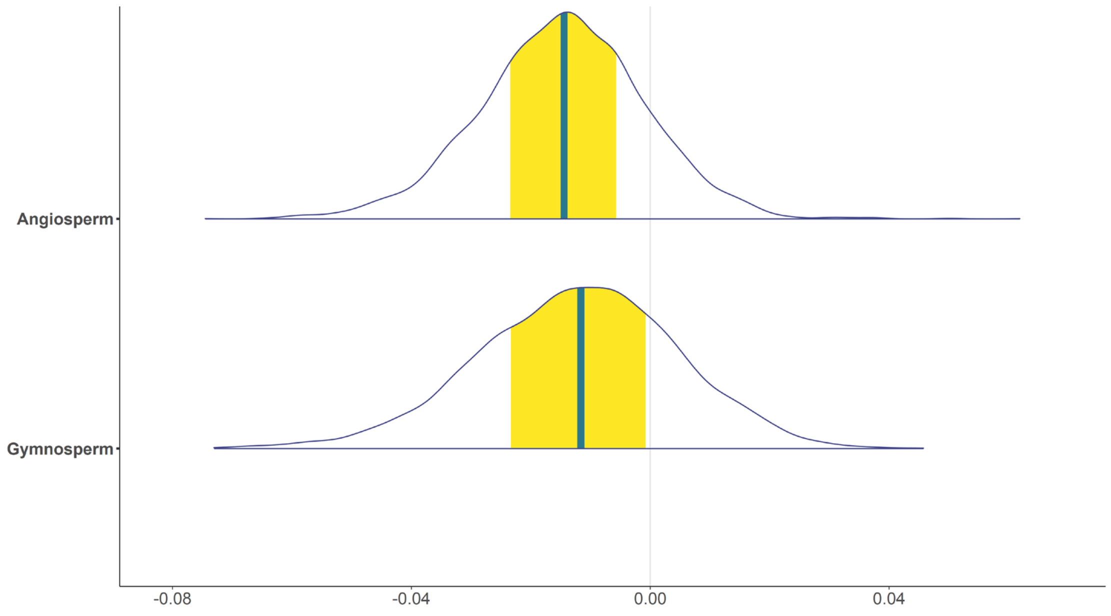


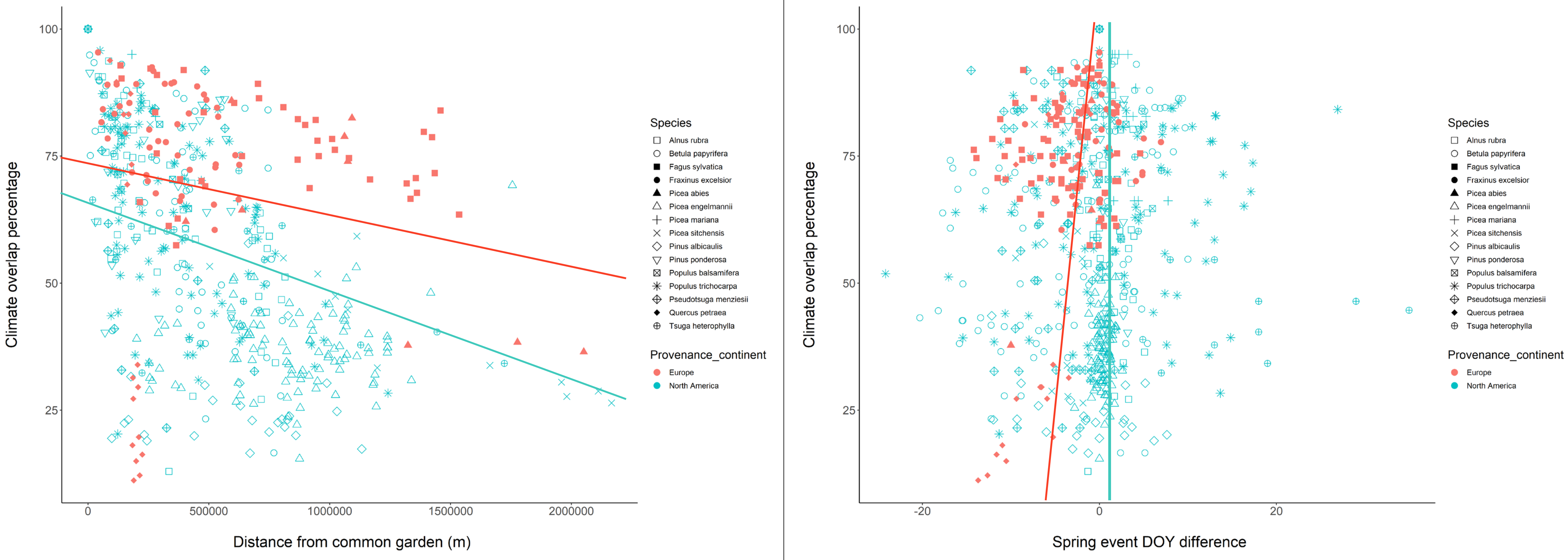
Results – How it relates to leaf types?

Spring



Fall



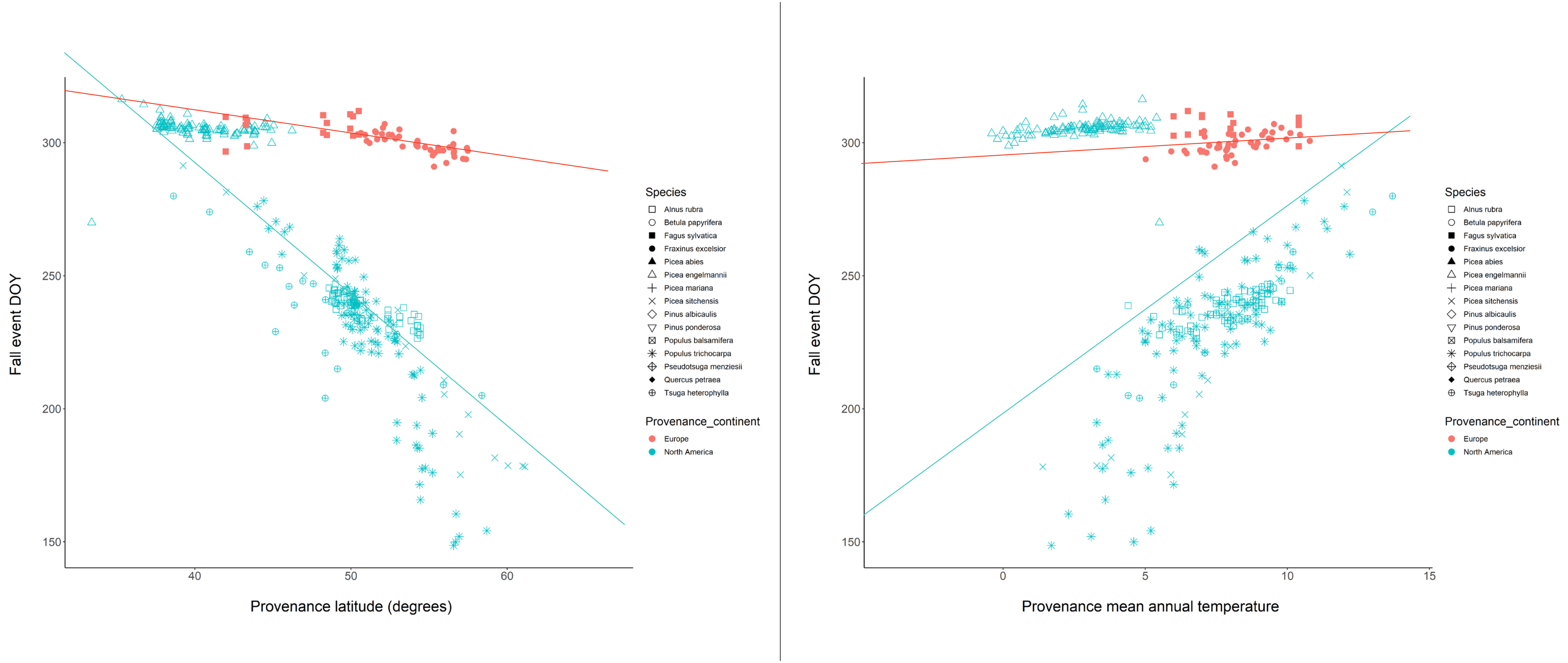


The closer a garden is to a provenance, the more overlap in temperature. The higher the percentage overlap, the less difference in spring event timing, with a stronger relationship observed in Europe.

Discussions

Stronger plasticity in spring events than fall

Our results show that spring events are highly plastic, and thus may shift with warming, but data on more species and greater information on important factors, such as their geographic location in relation to their origins and elevation, are needed for forecasting.



Local adaptation in fall events appear to be much stronger in North America than in Europe.