B4est

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Effects of future climate change on Norway spruce adaptation and growth across Europe

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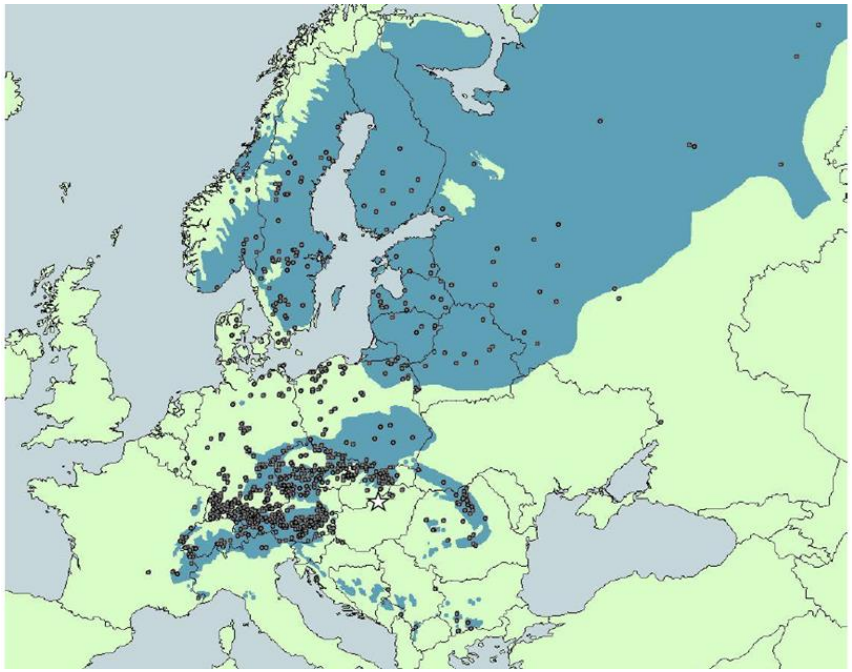
Aims of this study

- Build a universal response function (URF) by intergrating environmental and genetic effects to predict response of Norway spruce populations to the future climate change.

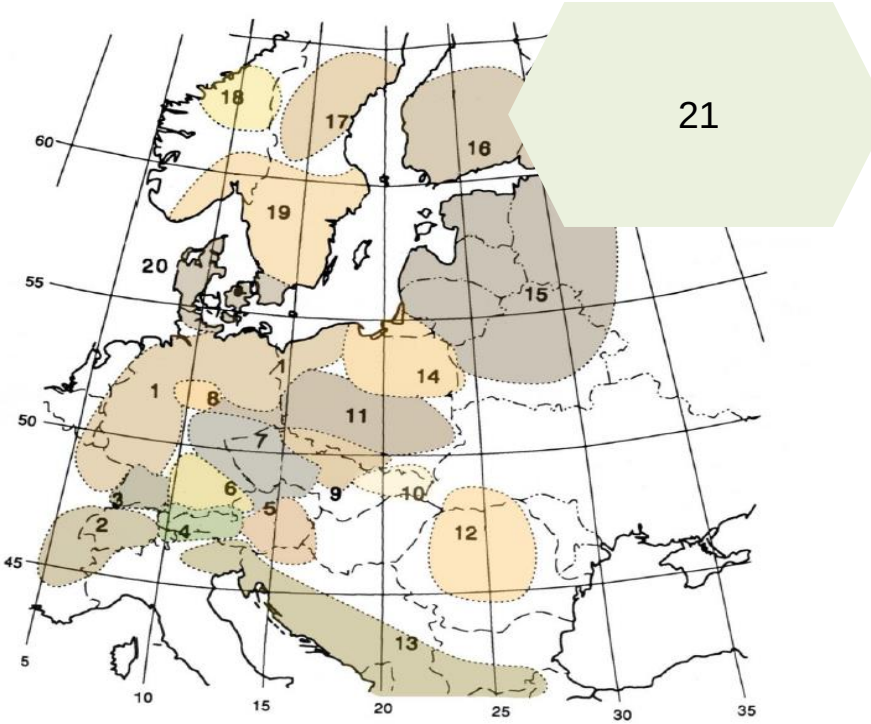
- To predict populations and species ranges for the future climate and to guide assisted migration of seeds for reforestation.

Materials

Distribution of 1100 provenances/populations for IUFRO 1964/68 trials



Number and delineation of zones refined by Fottland and Skroppa (1989)



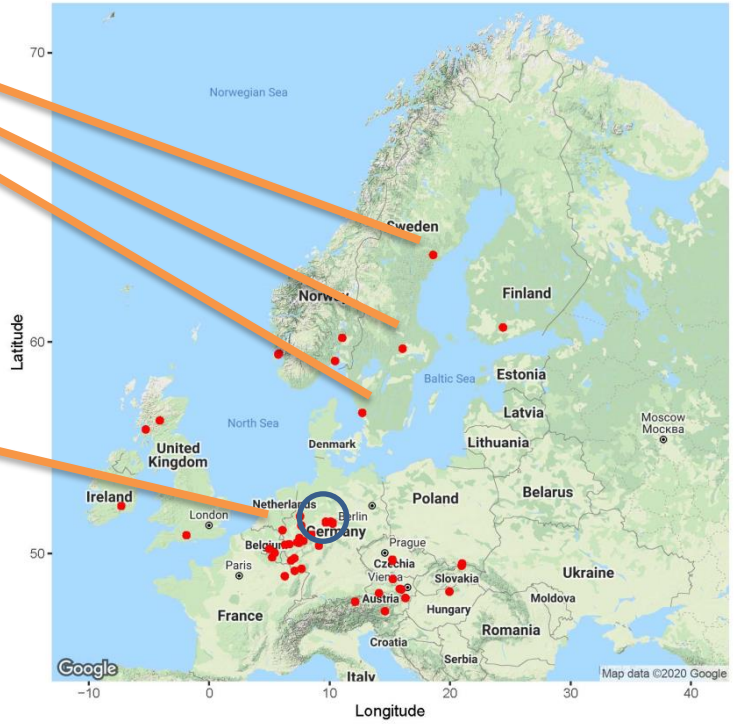
Locations of trials and blocks

Table A.1 *IUFRO IPTNS 1964/68 provenance trial locations*

Exp. no.	Locality	Country code	Lat.	Long.	Alt. m	Blocks 1	2	3	4	5	6	7	8	9	10	11
01	Bronson	CA	46° 11′	65° 47′ w	70	x	x	x	x	x	x	x	x	x	x	x
02	Castlemorris	IE	52° 28′	7° 17′ w	70	x	x	x	x	x	x	x	x	x	x	x
03	Salisbury	GB	50° 58′	1° 52′ w	170	x	x	x	x	x	x	x	x	x	x	x
04	Ilsvåg	NO	59° 31′	5° 49′ e	150	x	x	x		x		x	x	x	x	
05	Vats	NO	59° 29′	5° 45′ e	150				x		x					x
05	Overud	NO	60° 10′	11° 04′ e	200	x	x					x			x	x
05	Bjerkøy	NO	59° 12′	10° 28′ e	10			x	x	x	x		x	x		
06	Hjuleberg (Abild)	SE	56° 56′	12° 44′ e	60	x	x	x	x	x	x	x	x	x	x	x
07	Lisjö	SE	59° 43′	16° 05′ e	65	x	x	x	x	x	x	x	x	x	x	x
08	Lappkojberget	SE	63° 25′	18° 37′ e	190	x	x	x	x	x	x	x	x	x	x	x
09	Haapastansyrje*	FI	60° 36	24° 25′ e	130	x	x	x	x	x	x	x	x	x	x	x
10	Amance	FR	48° 47′	6° 18′ e	240	x	x	x	x	x	x	x	x	x	x	x
11	Herbeumont	BE	49° 48′	5° 15′ e	410		x									
11	Fagne del Borne	BE	50° 02′	5° 27′ e	560				x							
11	Rocherath	BE	50° 28′	6° 20′ e	600						x					
12	Gendron-Celle	BE	50° 15′	5° 00′ e	250	x		x		x						
13	Deuselbach	DE	49° 45′	7° 06′ e	640	x	x									
13	Kell-Nord	DE	49° 38′	6° 50′ e	620					x						
13	Brandscheid	DE	50° 30′	6° 40′ e	620		x	x			x				x	
13	Ruppertsweiler	DE	49° 11′	7° 41′ e	305							x				
13	Kindsbach	DE	49° 04′	7° 07′ e	240								x			
13	Nister	DE	50° 40′	7° 51′ e	380									x		
13	Bellerhof	DE	50° 40′	7° 51′ e	440											x
14	Holzerode	DE	51° 40′	10° 07′ e	250	x					x	x	x			
14	Rüdershausen	DE	51° 34′	10° 16′ e	235		x								x	x
14	Schoningen	DE	51° 38′	9° 42′ e	305			x						x		
14	Delliehausen	DE	51° 40′	9° 42′ e	305				x							
14	Hörden	DE	51° 37′	10° 16′ e	235					x						
15	Heltorf	DE	51° 57′	7° 34′ e	400	x										
15	Brüggen	DE	51° 14′	6° 06′ e	40		x									
15	Letmathe	DE	51° 28′	7° 40′ e	250			x								
15	Gedern	DE	50° 25′	9° 08′ e	340				x							
15	Linz	DE	50° 36′	7° 20′ e	340					x	x					
15	Sassmannshausen	DE	51° 00′	8° 30′ e	400							x	x			
15	Herrnstein	DE	50° 49′	7° 30′ e	200									x		
15	Schleiden	DE	50° 28′	6° 21′ e	625										x	
15	Reggsdorf	DE	50° 34′	7° 29′ e	290											x
16	Minard Forest**	GB	56° 10′	5° 15′ w	170								x	x		
16	Drummond Hill**	GB	56° 35′	4° 05′ w	160										x	x
17	Zahradka	CZ	49° 37′	15° 15′ e	390	x	x	x	x	x	x					
17	Dolni Kralovice	CZ	49° 40′	15° 14′ e	390							x	x	x		
17	Borovsko	CZ	49° 41′	15° 14′ e	390										x	x
18	Klein-Mariazell	AT	48° 03′	15° 58′ e	450	x	x									
18	Stollberg	AT	48° 05′	15° 51′ e	500			x	x							
18	Ottenstein	AT	48° 37′	15° 17′ e	550					x	x					
18	Landsee	AT	47° 34′	16° 19′ e	600							x	x			
18	Klaus Pyhrnbahn	AT	47° 51′	14° 07′ e	600									x		
18	Eberstein	AT	46° 50′	14° 37′ e	1150										x	
18	Kelchsau	AT	47° 22′	12° 08′ e	1050											x
19	Krynica	PL	49° 21′	20° 59′ e	750		x				x				x	
19	Krynica	PL	49° 28′	21° 01′ e	750	x		x	x	x		x	x	x		x
20	Gyöngyössolymos (Nyirjes)	HU	47° 56′	19° 58′ e	600	x	x	x	x	x	x	x	x	x	x	x

* non experimental; **six-plant plots design was used

sources: *Krutzsch* (1992); *Lines* (1973); *Dietrichson* et al. (1976)



20 trials
52 sites

20 trials, 13 countries, phenotypic data from two of them are not collected based on B4EST

Table 1. List of trial sites and persons in charge in 1968 (Krutzsch 1973)

No	Country	Location of site	Responsible
01	Canada	Bronson, New Brunswick	D. P. Fowler
02	Ireland	Castlemorris, SW of Dublin	J. O'Driscol
03	England	Salisbury, SW of London	L. Pearce
04	Norway	Ilsvag, near Haugesund[1]	H. Robak
05	Norway	Near Kongsvinger and Tönsberg[2]	J. Dietrichson
06	Sweden	Abild, near the West coast	P. Krutzsch
07	Sweden	Lisjö, Central Sweden	P. Krutzsch
08	Sweden	Lappkojberget, N. Sweden, Lat. 63° 25´	P. Krutzsch
09	Finland	Haapastensyrjä, near Helsinki[3]	L. Kärki
10	France	Amance, near Nancy	P. Bouvarel
11	Belgium	blocks 2, 4 and 6[1, 2]	A. Nanson
12	Belgium	Gendron-Celle (blocks 1, 3 and 5)[1]	A. Jamblinne
13	Germany	Near Kaiserslautern[2]	W. Langner
14	Germany	Near Hildesheim-Kassel[2]	W. Langner
15	Germany	NW Germany[2]	W. Langner
16	Scotland	blocks 8, 9, 10 and 11[1, 2]	R. Lines
17	Czech Rep.	SE of Praha[2]	B. Vinš
18	Austria	blockwise, throughout the country[2]	L. Günzl
19	Poland	Kraków (Krynica)	S. Balut
20	Hungary	Nyírjes, NE of Budapest	L. Szönyi

[1] incomplete trial; [2] trial spread over numerous sites; [3] non experimental

No data at all

No data at all

Height phenotypic data

	tree age and year at measurement time																	
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Trial_No	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
T19		yes, blocks 2, 6, 10			yes, blocks 2, 6, 10			yes, blocks 2, 6, 10			yes, blocks 2, 6, 10					yes, blocks 2, 6, 10		
T19		yes, blocks 1,3,4,5,7,8,9,11			yes, blocks 1,3,4,5,7,8,9,11			yes, blocks 1,3,4,5,7,8,9,11			yes, blocks 1,3,4,5,7,8,9,11					yes, blocks 1,3,4,5,7,8,9,11		
T20					yes, all blocks					yes, all blocks			yes, blocks 7, 8, 9					

How to deal our such heterogenous data

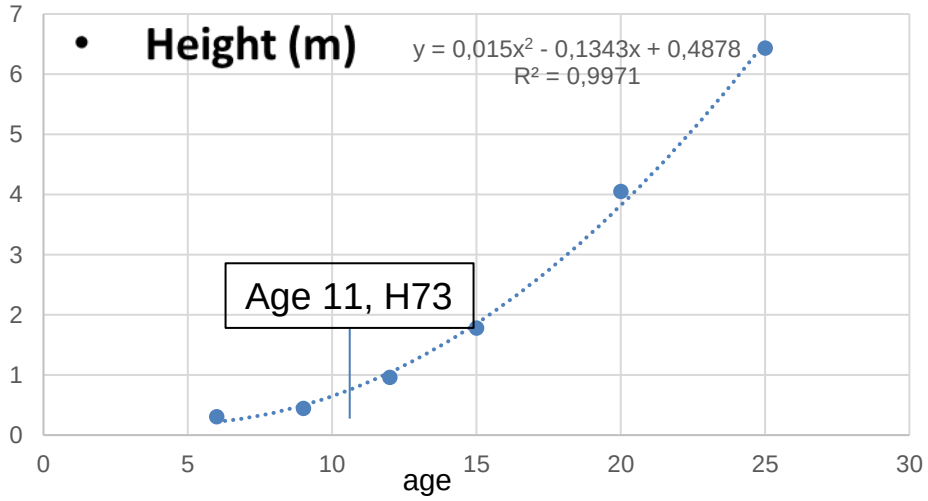
Step 1: Adjust the age effects

Step 2: Adjust block effects

Step 3: Filter the redundancy of provenances

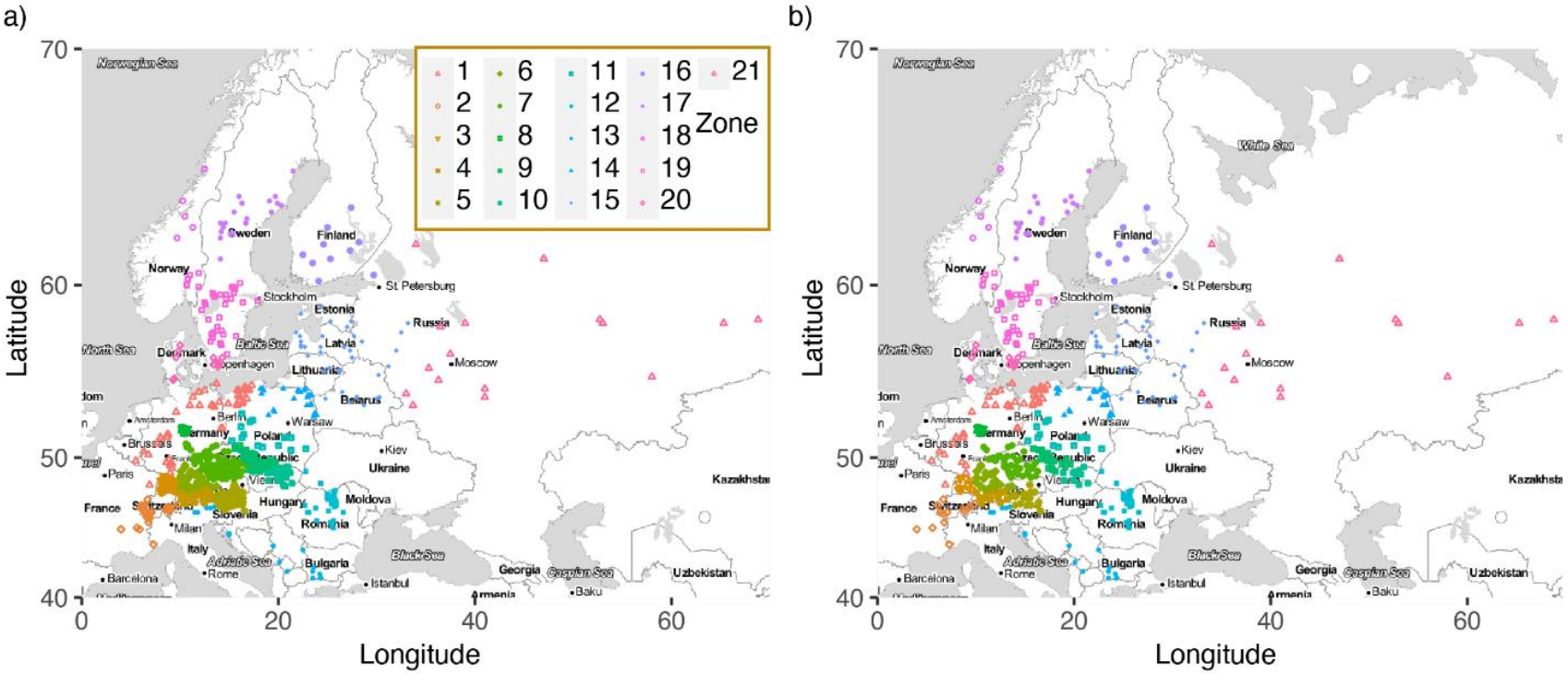
Step 1: Adjusting age effects

Polish trial



No provenance	No Block	H69	H72	H75	H78	H83	H88
0	1	0.30	0.43	0.80	1.57	3.54	5.67
1	1	0.37	0.54	1.07	2.07	4.59	7.06
2	1	0.31	0.48	1.09	2.00	4.56	6.81
3	1	0.39	0.56	1.08	2.08	4.66	6.81

Step 3 Filtering redundancy of provenances in Alpine area



Climate data

Climate DT (ClimateDT - Climate Downscaling Tool - Institute of Biosciences and Bioresources (cnr.it)) developed by B4EST project

- 1100 provenance climate data
- 52 sites climate data
- 101 climate variables

Methods

Individual Response Function

$$Y_i = b_0 + b_1 X_{1i} + b_2 X_{1i}^2 + e_i$$

Individual Genecology Function

$$Y_j = b_0 + b_1 X_{2j} + b_2 X_{2j}^2 + e_j$$

Universal Response Function (URF)

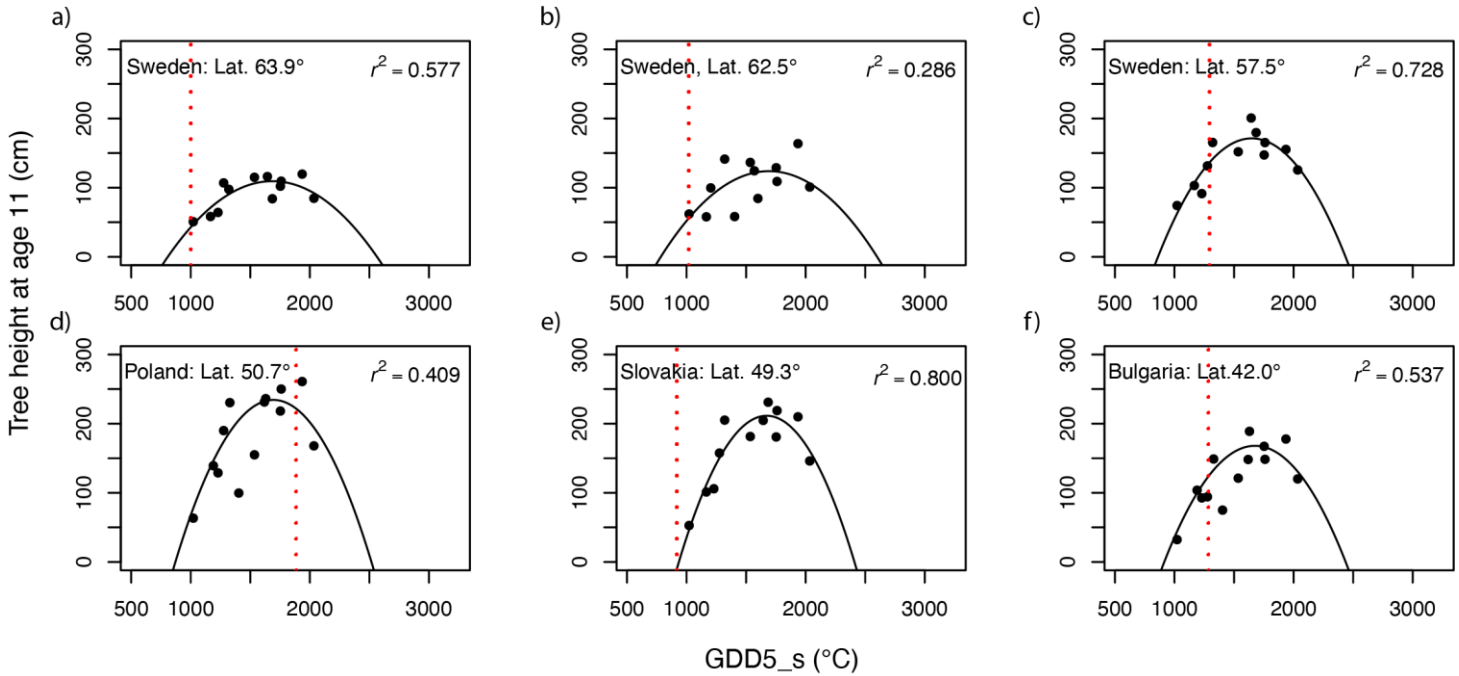
$$Y_{ij} = b_0 + b_1 X_{1i} + b_2 X_{1i}^2 + b_3 X_{2j} + b_4 X_{2j}^2 + b_5 X_{1i} X_{2j} + e_{ij}$$

Table 1: Variance components and their percentages for the block adjusted tree height at tree age 11, including four years in the nursery, based on 1086 populations (left side) and 475 populations (right side).

Source of variation	Variance component (SE)	Percentage (%)	Sig.	Variance component (SE)	Percentage (%)	Sig.
Site	2042.7 (512.4)	67.8	***	1927.6 (484.5)	66.2	***
Zone	552.0 (176.5)	18.3	***	547.0 (176.6)	18.8	***
Site x Zone	116.1 (8.4)	3.9	***	129.9 (10.2)	4.5	***
Pop. (Zone)	78.0 (4.0)	2.6	***	74.8 (6.0)	2.6	***
Residuals	223.7 (25.1)	7.4	***	232.7 (43.3)	8.0	***

Significant level (sig.) was tested using the wald F test in ASReml-R v4.0. *** represent extremely significant (P<0.01).

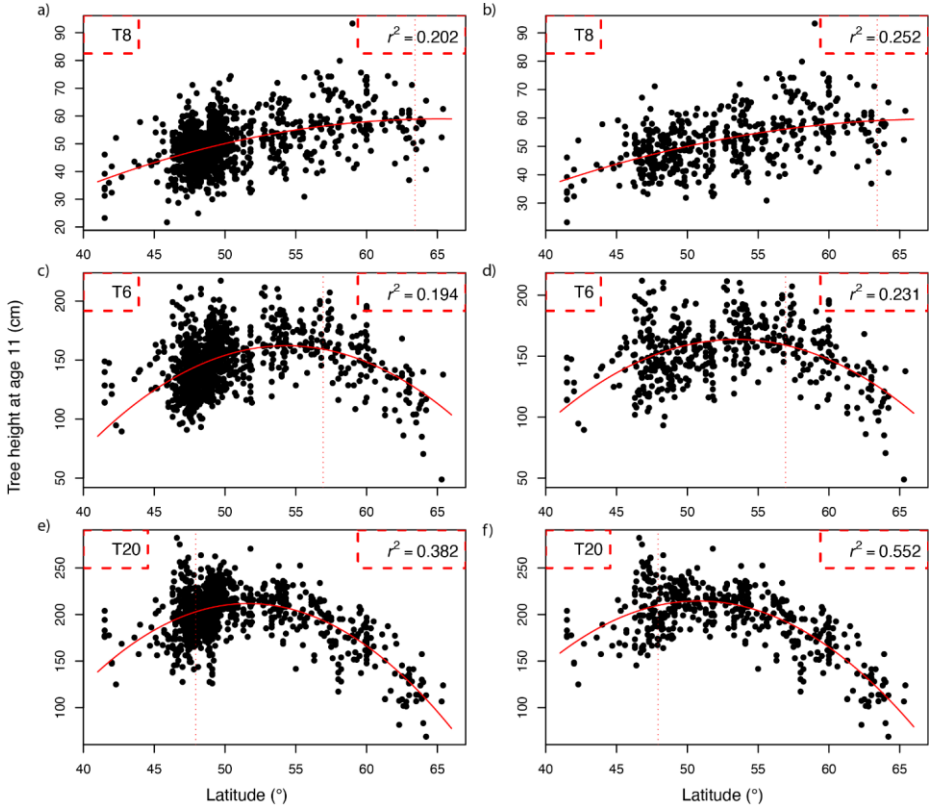
Individual response curves for populations



Individual genecology functions for three provenance trials.

Before filtering provenances

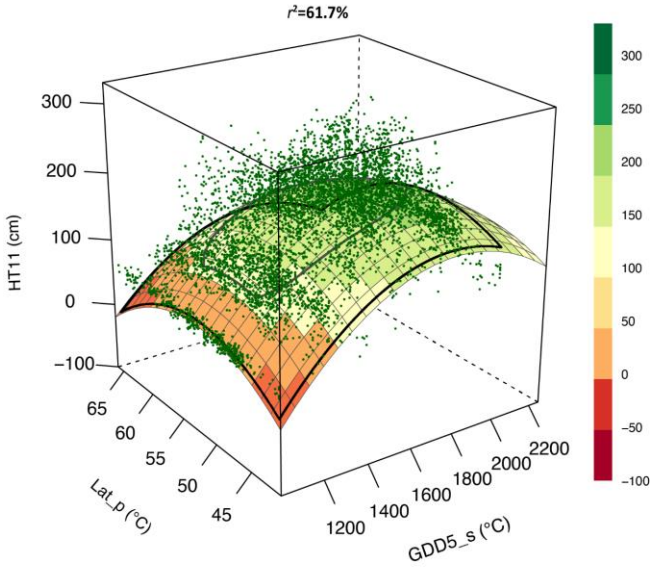
After filtering provenances



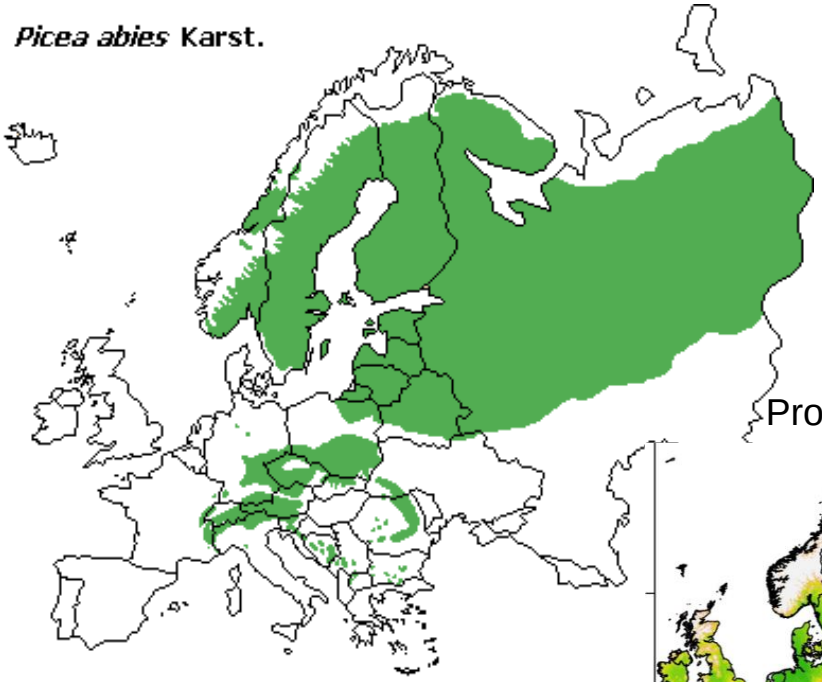
Final Universal Response Function (URF): 72.3% of the total phenotypic variation for tree height

Table 2 Results of multiple regression analysis predicting Norway spruce using site and provenance climate variables in a universal response function.

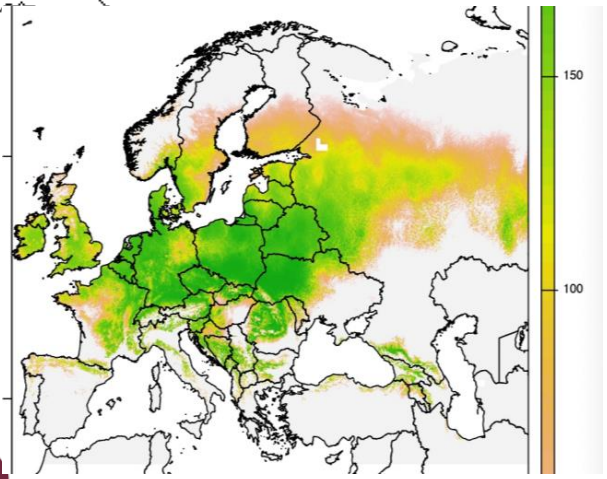
	Estimate	SE	T value	Pr (>|t|)	Significance
(Intercept)	-2332.8420	48.79288	-47.8	2.00E-16	***
GDD5_s	0.8833	0.02020	43.7	2.00E-16	***
SHM_s	7.8570	0.43260	18.2	2.00E-16	***
Lat_p	51.0940	1.40764	36.3	2.00E-16	***
TD_p	26.9627	1.80448	14.9	2.00E-16	***
GDD5_s^2	-0.0002	0.00000	-43.1	2.00E-16	***
SHM _s^2	-0.1156	0.00294	-39.4	2.00E-16	***
Lat_p^2	-0.4124	0.01440	-28.6	2.00E-16	***
TD_p^2	-0.2357	0.02165	-10.9	2.00E-16	***
GDD5_s x Lat_p	-0.0034	0.00026	-13.1	2.00E-16	***
SHM_s x Lat_p	0.0469	0.00625	7.5	7.13E-14	***
Lat_p x TD_p	-0.2733	0.03433	-8.0	2.08E-15	***

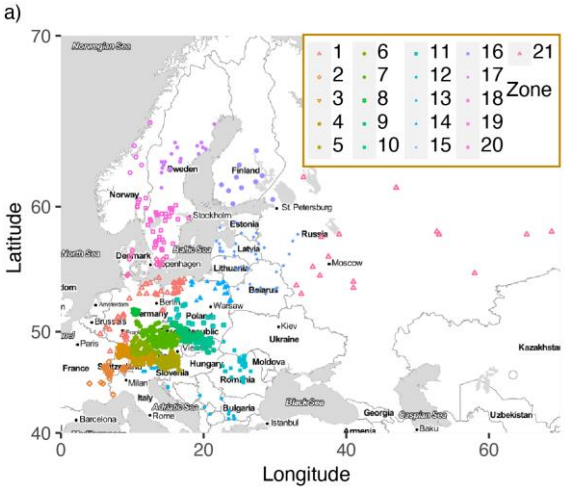


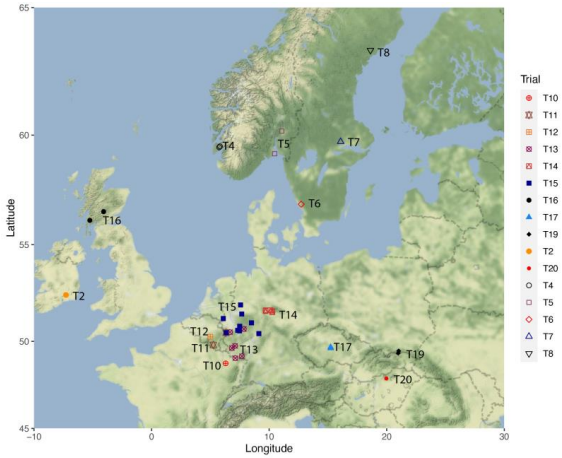
Norway spruce and distribution



Projected height in 1980s



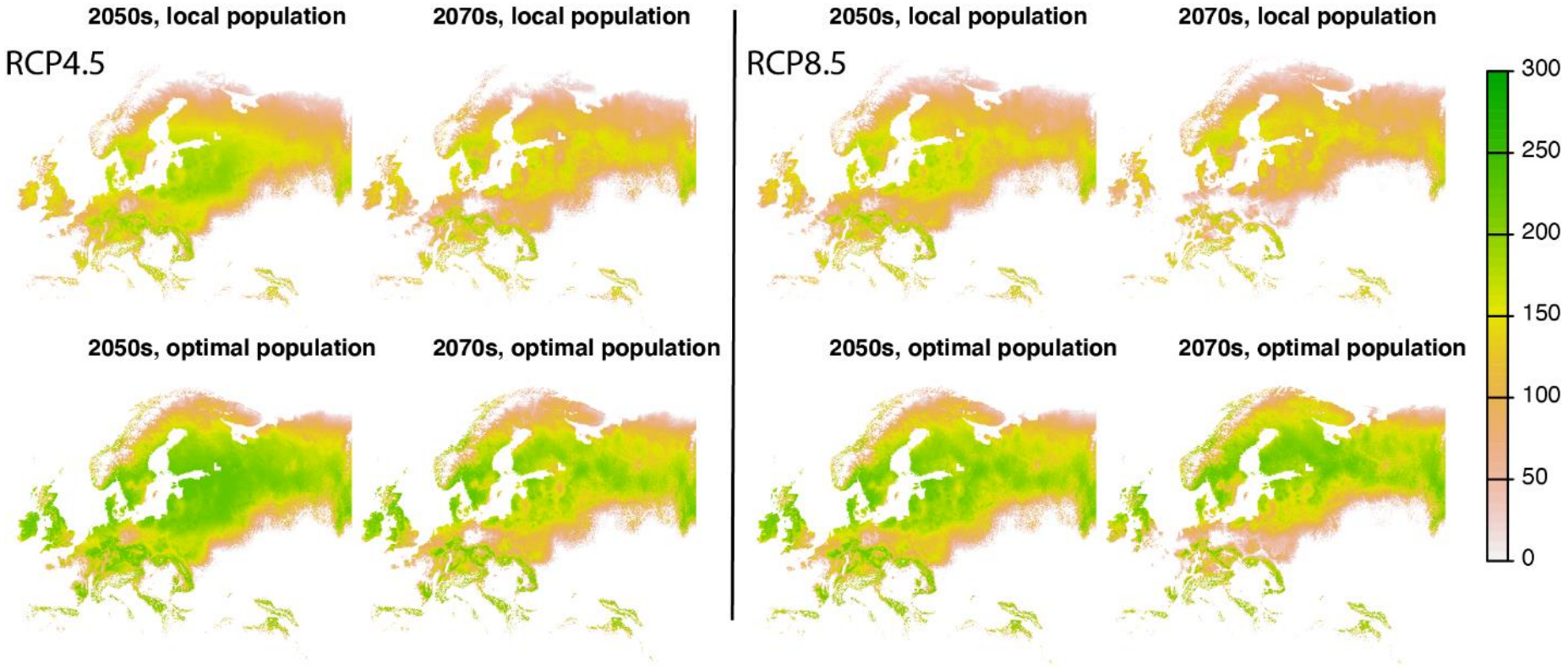




Best4

SLU Sveriges lantbruksuniversitet Swedish University of Agricultural Sciences

Umeå Plant Science Centre
a centre of excellence


2050s, local population
2070s, local population
RCP4.5
2050s, local population
2070s, local population
RCP8.5
2050s, optimal population
2070s, optimal population
2050s, optimal population
2070s, optimal population
300
250
200
150
100
50
0

Conclusions

1) Site and zone effects accounts for 66.8% and 18.2 % of phenotypic variations, respectively , indicating that Norway spruce has high plasticity and moderate local adaptation.

2) UFR explained 72.3% of the total phenotypic variation, especially, GDD5 for site explained more than 50% of phenotypic variation.

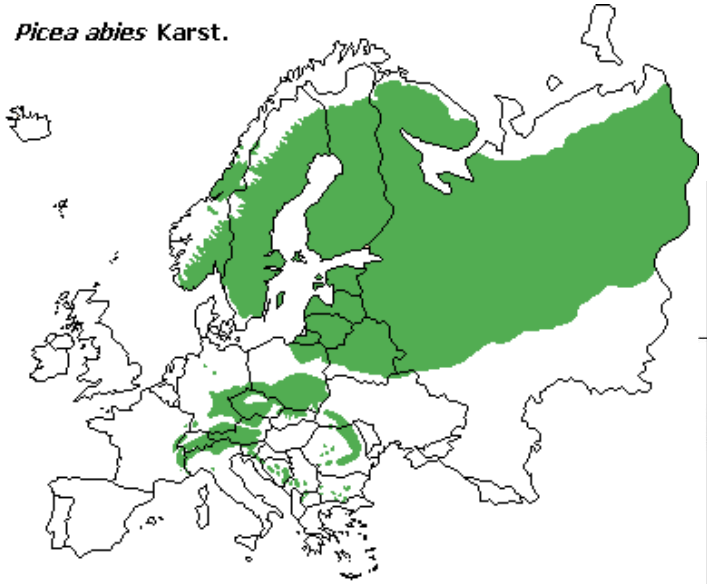
3) Under moderate climate change (1°C) in 2050s and 2070s, the tree height of local populations will increase for the whole Europe, but not in central Europe.

4) If the optimal provenance for each site was used, productivity could be improved by 51.1% and 30.7% when the temperature increases 1°C and 2°C, respectively, compared with the current period (2010s).

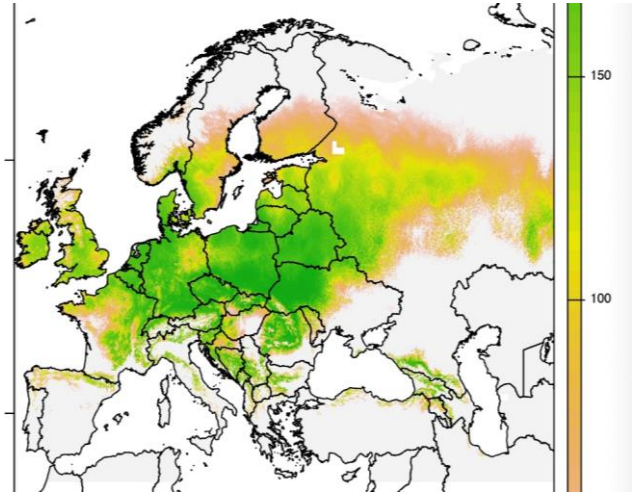
5) Productivity of local population will decrease 16.5% if the future temperature increases 2°C.

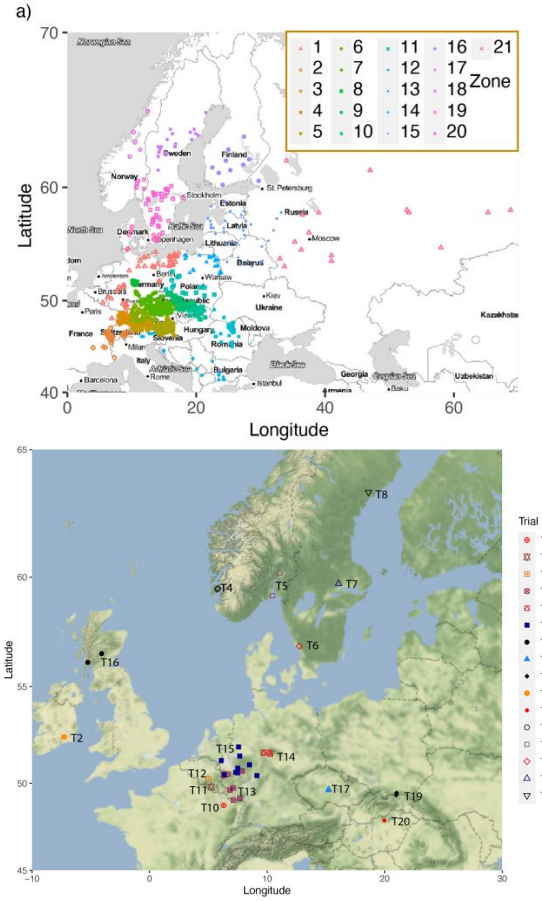
New collaborations due to lack of fit for Northern Scandinavia

Mats Berlin (Skogforsk), Arne Steffenrem (NIBIO), Mateusz Liziniewicz (Skogforsk)



Projected height in 1980s





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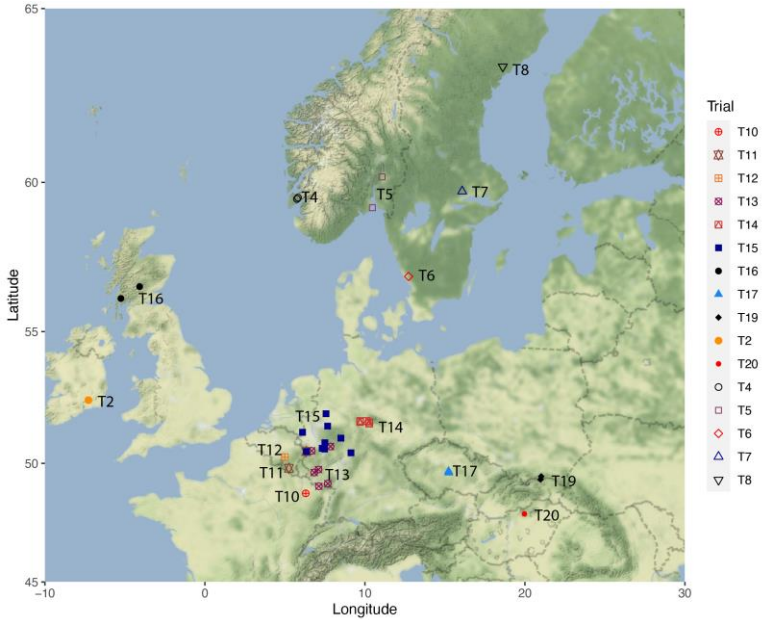
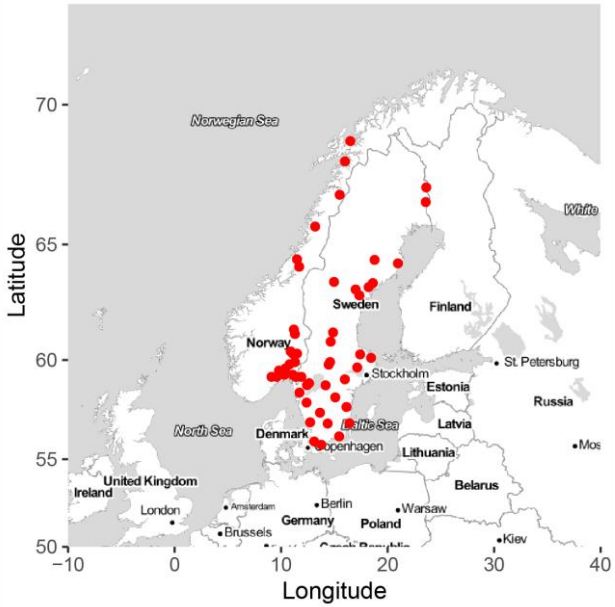
Extra trials to cover more northern Scandinavia

IUFRO 1964/68 provenance trials

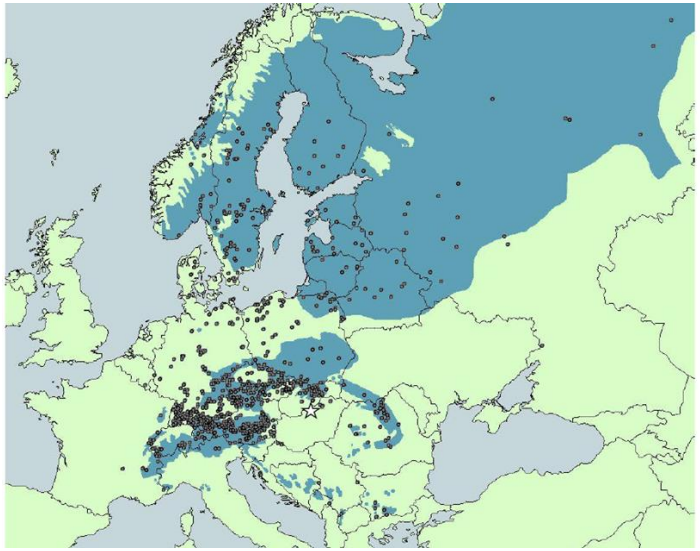


Extra Swedish and Norwegian provenance trials

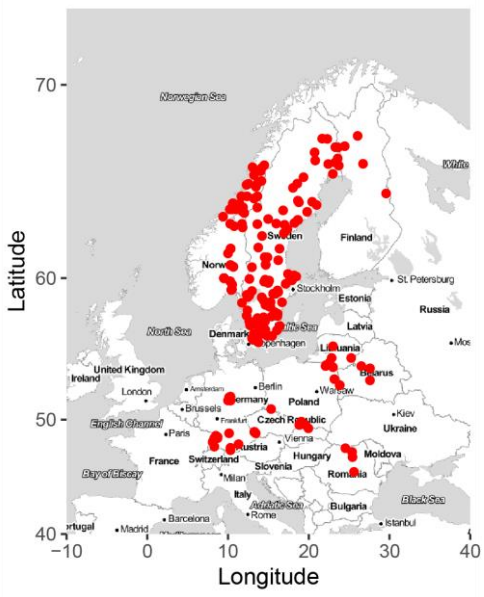


Extra provenances from Sweden and Norway

IUFRO 64/68 provenances

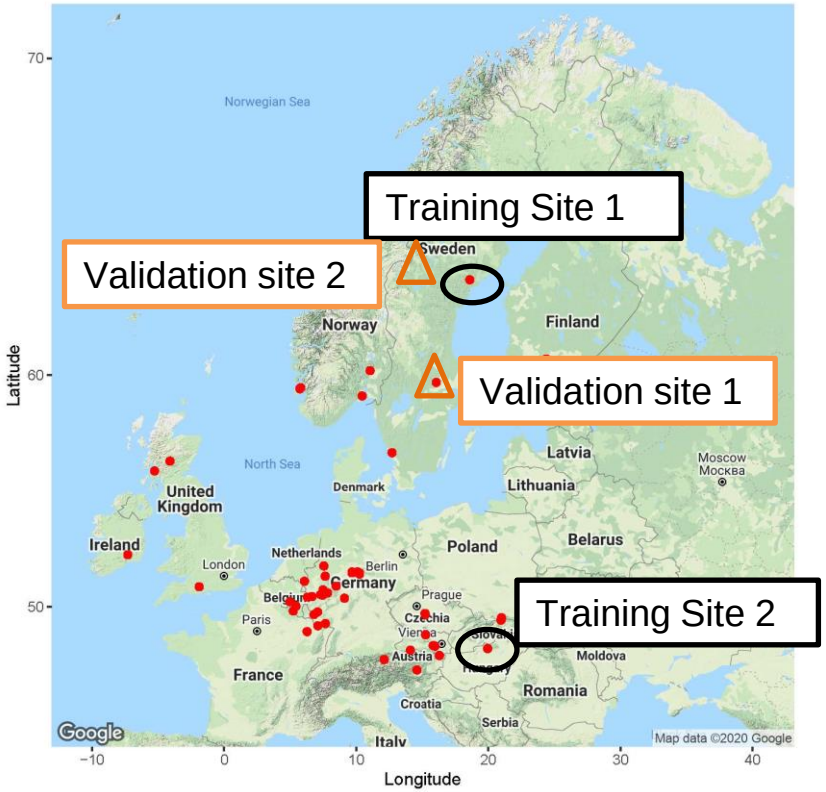


Extra provenances



Current plan

using effects of genotype data or allele frequency instead of provenance/zone effects



Training Site1

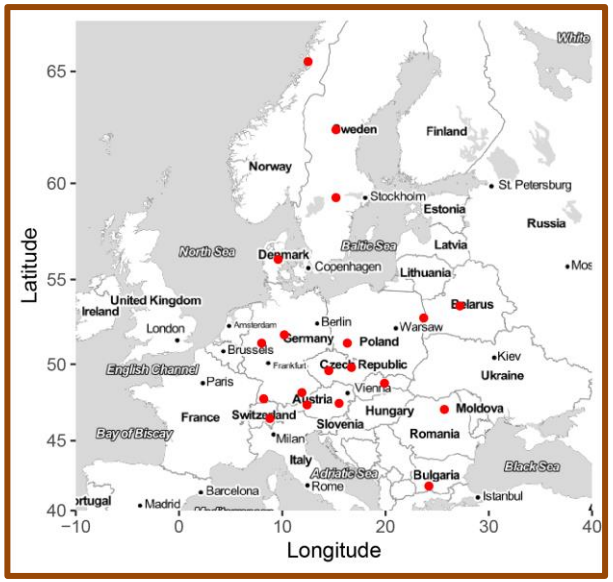
Validation site 1

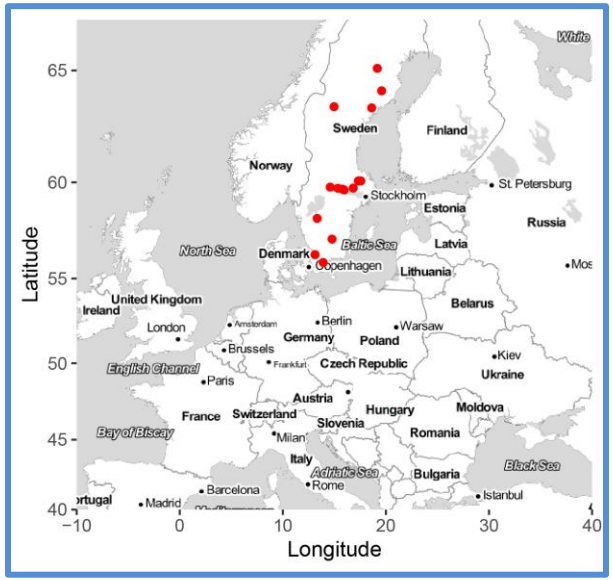
Training Site 2

		Canada	ireland	Norway	Norway	Abild	Lisjö	Lappkojberg	France	Belgium	Belgium	Germany	Gemany	Germany	Scotsland	Czech	Poland	Hungry
	Trial	T1	T2	T4	T5	T6	T7	T8	T10	T11	T12	T13	T14	T15	T16	T17	T19	T20
Canada	T1	1	0.921	0.924	0.924	0.721	0.746	-0.360	0.914	0.924	0.924	0.924	0.921	0.924	0.919	0.921	0.916	0.920
ireland	T2	0.086	1.000	0.996	0.996	0.776	0.804	-0.388	0.985	0.996	0.996	0.996	0.992	0.996	0.990	0.993	0.987	0.991
Norway	T4	0.099	0.63	1	1.000	0.780	0.807	-0.390	0.989	1.000	1.000	1.000	0.996	1.000	0.994	0.997	0.991	0.995
Norway	T5	0.066	0.499	0.539	1.000	0.780	0.807	-0.390	0.989	1.000	1.000	1.000	0.996	1.000	0.994	0.997	0.991	0.995
Abild	T6	0.356	0.179	0.068	-0.069	1.000	0.629	-0.304	0.771	0.780	0.780	0.780	0.776	0.780	0.775	0.777	0.773	0.776
Lisjö	T7	0.108	0.53	0.205	0.144	0.337	1.000	-0.314	0.798	0.807	0.807	0.807	0.804	0.807	0.802	0.804	0.800	0.803
Lappkojberg	T8	0.067	-0.039	-0.053	0.132	0.124	0.244	1.000	-0.385	-0.390	-0.390	-0.390	-0.388	-0.390	-0.387	-0.388	-0.386	-0.388
France	T10	0.301	0.512	0.299	0.195	0.249	0.274	-0.078	1.000	0.989	0.989	0.989	0.985	0.989	0.983	0.985	0.980	0.984
Belgium	T11	-0.027	0.667	-0.35	0.799	0.188	0.461	0.045	0.571	1.000	1.000	1.000	0.996	1.000	0.994	0.997	0.991	0.995
Belgium	T12	0.295	NA	0.707	0.664	0.3	0.131	-0.188	0.785	NA	1.000	1.000	0.996	1.000	0.994	0.997	0.991	0.995
Germany	T13	0.291	0.757	0.54	0.424	0.241	0.357	0.029	0.627	0.365	0.681	1.000	0.996	1.000	0.994	0.997	0.991	0.995
Germany	T14	0.305	0.666	0.517	0.427	0.274	0.358	0.061	0.577	0.342	0.826	0.743	1.000	0.996	0.990	0.993	0.987	0.991
Germany	T15	0.273	0.73	0.496	0.401	0.235	0.361	0.064	0.586	0.315	0.61	0.684	0.693	1.000	0.994	0.997	0.991	0.995
Scotsland	T16	0.357	0.784	0.607	0.623	0.29	0.393	0.083	0.635	NA	NA	0.676	0.652	0.661	1.000	0.991	0.986	0.990
Czech	T17	0.436	0.464	0.507	0.207	0.631	0.304	0.021	0.491	-0.051	0.762	0.57	0.566	0.508	0.707	1.000	0.988	0.992
Poland	T19	0.148	0.353	0.251	0.279	0.286	0.056	0.051	0.371	0.726	0.381	0.454	0.441	0.386	0.353	0.379	1.000	0.987
Hungry	T20	0.351	0.658	0.624	0.575	0.139	0.093	0.033	0.303	-0.06	0.704	0.625	0.623	0.547	0.713	0.488	0.362	1.000

Figure Zone level's correlations

Validation and prediction based on family or provenance level's genotypic data in the future





20 populations sampled in Swedish Lisjö IUFRO 1964/68 provenance trial
as a validation site

- 14 full-sib families progeny trials
- 600-1000 genotypes per trial/red dot
- >10000 genotypes

Best4

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Swedish University of Agricultural Sciences

Umeå Plant Science Centre
a centre of excellence

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