Provenance variation in subalpine fir grown as an exotic tree species in Denmark and Iceland

Ph.D. thesis, Brynjar Skulason

Paper I: Damage by *Neonectria neomacrospora* and *Adelges piceae* in provenance trials of subalpine fir (*Abies lasiocarpa*) in Denmark. Forest Pathology.

Paper II: Provenance variation in adaptability and Christmas tree characteristics in subalpine fir (*Abies lasiocarpa*) planted in Denmark and Iceland. Scandinavian Journal of Forest Reserach

Paper III: Provenance variation in phenology and frost tolerance in subalpine fir (*Abies lasiocarpa*) planted in Denmark and Iceland. (Unpublished manuscript)

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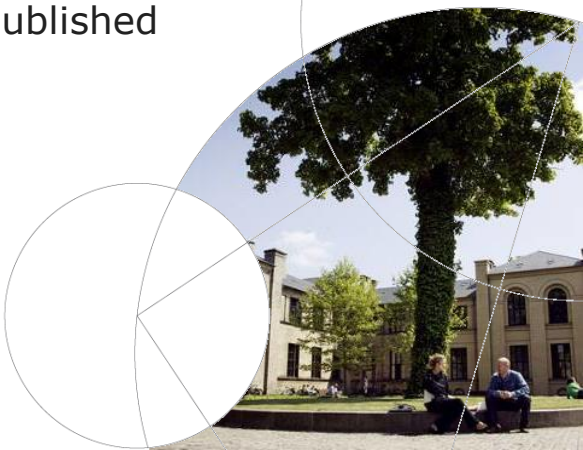


Distribution of subalpine fir

- **Northern limit 64° 30’ N**
- **Southern limit 32° N**
- South eastern Alaska
- Central Yukon Territory
- Through British Columbia
- Alberta,Washington, Oregon
- More eastern and continental at high elevations in Idaho, Montana, Wyoming, Utah, Colorado New Mexico and Arizona

Two varieties of subalpine fir are recognised

Corkbark fir (*A. lasiocarpa* var. *arizonica* (Merriam) Lemmon)

- Scattered mountain populations in southern Colorado, Arizona, New Mexico
- White, corky bark and blue needles

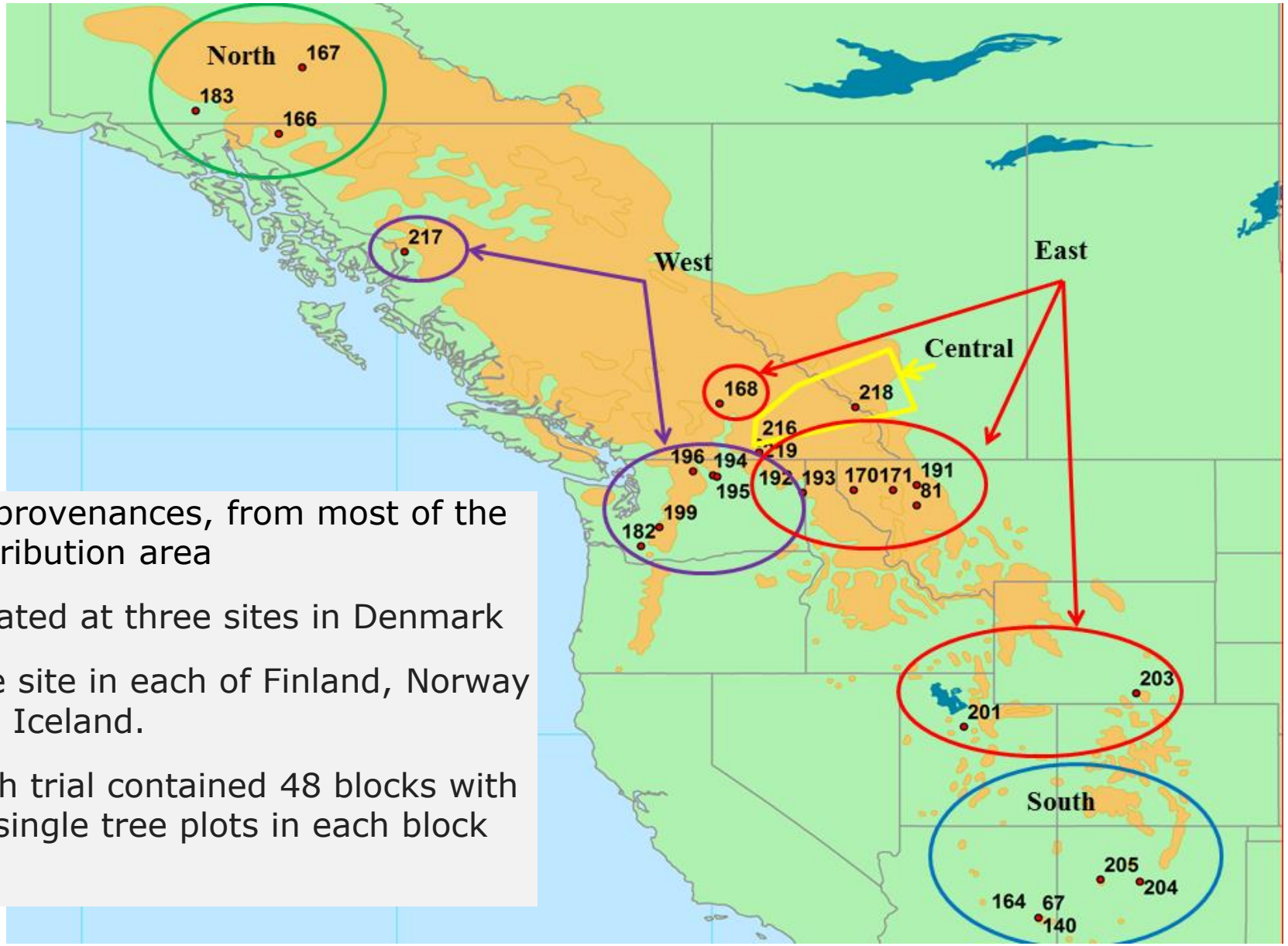
Photo: Ole Kim Hansen

Photo: Brynjar

Subalpine fir *(A. lasiocarpa* var. *lasiocarpa* (Hook.) Nutt.

- Northern part of distribution area down to northern Colorado
- Brown bark and usually green needles

The joint Nordic provenance test, established 1999



- 26 provenances, from most of the distribution area
- Located at three sites in Denmark
- One site in each of Finland, Norway and Iceland.
- Each trial contained 48 blocks with 28 single tree plots in each block

Proposition of regional division by Hansen et al. (2004)

Earlier results from the joint Nordic provenance test

Scand. J. For. Res. 19: 112–126, 2004

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Nordic Provenance Trials with *Abies lasiocarpa* and *Abies lasiocarpa* var. *arizonica:* Three-year Results

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Scandinavian Journal of Forest Research

Hansen, O. K.[1,2], Nielsen, U. B.[2], Edvardsen, Ø. M.[3], Skúlason, B.[3] and Skage, J.-O.[4] ([1]The Arboretum, The Royal Veterinary and Agricultural University, Kirkegaardsvej 3A, DK-2970 Hørsholm, Denmark, [2]Danish Forest and Landscape Research Institute, Hørsholm Kongevej 11, DK-2970 Hørsholm, Denmark, [3]Icelandic Forest Research, Bugardur, Oseyri 2, 603 Akureyri, Iceland, and [4]Norwegian Forest Research Institute, Fanaflaten 4, NO-5244 Fana, Bergen, Norway). *Nordic provenance trials with Abies lasiocarpa and Abies lasiocarpa var. arizonica: three-year results.* Received Jan. 10, 2003. Accepted Nov. 27, 2003. Scand. J. For. Res. 19: 112–126, 2004.

Provenances are listed in order of latitude, with the most northern provenances at the top. Key climate estimations for provenances origin (period 1961-1990)

Provenance / Locality	Id. no.	State	Elev. m	Lat. °N	Long. °W	MAT °C	MWMT °C	MCMT °C	TD °C	MAP mm
Canol Road	**167**	Yukon	900	62°	120°	**-3.4**	13.5	**-23.5**	**37**	472
Skagway	**183**	Alaska	800	60°	136°	0.2	12.5	-12.2	24.6	1861
Atlin	**166**	Br. Col.	800	60°	134°	-1.2	12	-16.8	28.8	476
White River	**217**	Br. Col.	320	56°	130°	4.0	12.3	-4.7	17	**3969**
Adams Plateau	**168**	Br. Col.	1400	51°	120°	3.0	13.8	-7.7	21.6	494
Albert River	**218**	Br. Col.	1525	51°	115°	1.6	13.1	-10.3	23.4	914
Blue Joint	**216**	Br. Col.	1970	50°	119°	1.1	12.1	-8.1	20.2	1068
Okanogan N.F.	**196***	Wash.	-	49°	121°	2.1	13.2	-6.9	20.2	1170
Name unknown	**219**	Br. Col.	1300	49°	119°	4.0	15.3	-7	22.3	569
Kootenai N.F.	**170**	Montana	-	48°	116°	4.8	15.7	-5.4	21.1	996
Flathead N.F.	**171**	Montana	-	48°	114°	5.8	17.7	-5.1	22.8	498
Flathead N.F., West of Marias Pass	**191***	Montana	1200	48°	114°	4.5	16.8	-9.3	26	1226
Mt. Spokane	**192***	Wash.	1400	48°	117°	5.0	15.6	-4.6	20.3	1148
Mt. Spokane	**193***	Wash.	1500	48°	117°	4.5	15.1	-4.9	20	1148
Okanogan N.F.,For. Rd. 42, L. Camp	**194***	Wash.	1300	48°	120°	6.4	17.4	-4.1	21.5	671
Okanogan N.F., For. Rd. 42	**195***	Wash.	1500	48°	120°	5.6	17.2	-5.4	22.5	565
Flathead N.F., Hungry Horse	**81**	Montana	-	48°	114°	2.1	14.3	-9.2	23.5	1477
Mt. Rainier N.F.	**199***	Wash.	-	47°	122°	4.4	12.8	-2.3	**15.2**	2299
Seed zone 440, SW of Mt. St. Helens	**182**	Wash.	1200-1400	46°	122°	6.5	15.3	**-0.9**	16.2	2879
Medicine Bow N.F.	**203***	Wyoming	2400	41°	107°	4.6	16.4	-6	22.4	726
Wahsatch N.F.	**201***	Utah	-	40°	112°	**8.6**	**21.7**	-4.2	25.9	**303**
Cibola N.F., Sandria Crest	**204***	New Mex.	2900	35°	106°	6.6	17.4	-3.5	20.8	588
Cibola N.F., Mt. Taylor	**205***	New Mex.	2900	35°	108°	6.1	16	-3.4	19.4	323
Apache N.F., H. Meadows + Big Lake	**140**	Arizona	2900-3200	34°	110°	2.4	**11.4**	-5.4	16.8	778
Apache N.F.	**164**	Arizona	2900-3200	34°	110°	2.4	**11.4**	-5.4	16.8	778
Apache N.F., Hannigan Meadows	**67**	Arizona	-	34°	110°	2.4	**11.4**	-5.4	16.8	778

Made by using the programs ClimateWNA v4.80 (locations in USA) (Wang et al. 2014) and ClimateBC v5.00 (locations in Canada) (Wang et al. 2013)

The test sites Hønning, Thorsø, Vilsbøl in Denmark, Hallormsstadur in Iceland

Average key climate values for the period of 1998 to 2010

Test site	Elevation m a.s.l.	Lat. °N	Long. °W	MAT[1)] °C	MWMT[2)] °C	MCMT[3)] °C	TD[4)] °C	MAP[5)] mm
Hønning	27	57°01′	8°35′	8.7	16.9	1.9	15.0	867
Thorsø	100	56°09′	9°32′	8.2	16.3	1.5	14.8	784
Vilsbøl	48	55°10′	8°57′	8.6	16.6	2.1	14.5	835
Hallormsstadur	35	65°14´	14°67´	3.9	11.0	-1.4	12.0	510

1)MAT - Mean annual temperature, 2)MWMT - Mean temperature of warmest month, 3)MCMT - Mean temperature of coldest month, 4)TD - Difference between coldest and warmest month, 5)MAP - Mean annual precipitation

Objective - study provenance variation in subalpine fir in Danish and Icelandic forestry – special emphasis on Christmas tree production

Adaptive characteristics:

- Survival
- Height growth
- Forking frequency

Christmas tree characteristics:

- Christmas tree classification
- Christmas tree prices
- Postharvest needle retention

Phenology and hardiness:

- Flushing
- Bud set
- Spring frost hardiness
- Autumn frost hardiness

Susceptibility to pests and pathogens:

- Susceptibility to *Neonectria neomacrospora*
- Susceptibility to *Adelges piceae*

Photo: Ole Kim Hansen

Statistical models

- The statistical program R (R Core Team 2015) was used to analyse the data.
- Models A and C were used for normally distributed data while B was applied for binomial data.
- Y is the measurement of the individual tree variable and P is the probability of the binomial variables.
- Site, Block (Site) and Time (Site) were assumed to be fixed effects, whereas Provenance, Provenance * Site and Error were considered random.

A. Y = Site + Block (Site) + Provenance + Provenance * Site + Error

B. Logit (P) = Site + Block (Site) + Provenance + Provenance * Site

C. Y = Site + Block (Site) + Time (Site) + Provenance + Provenance * Site + Error

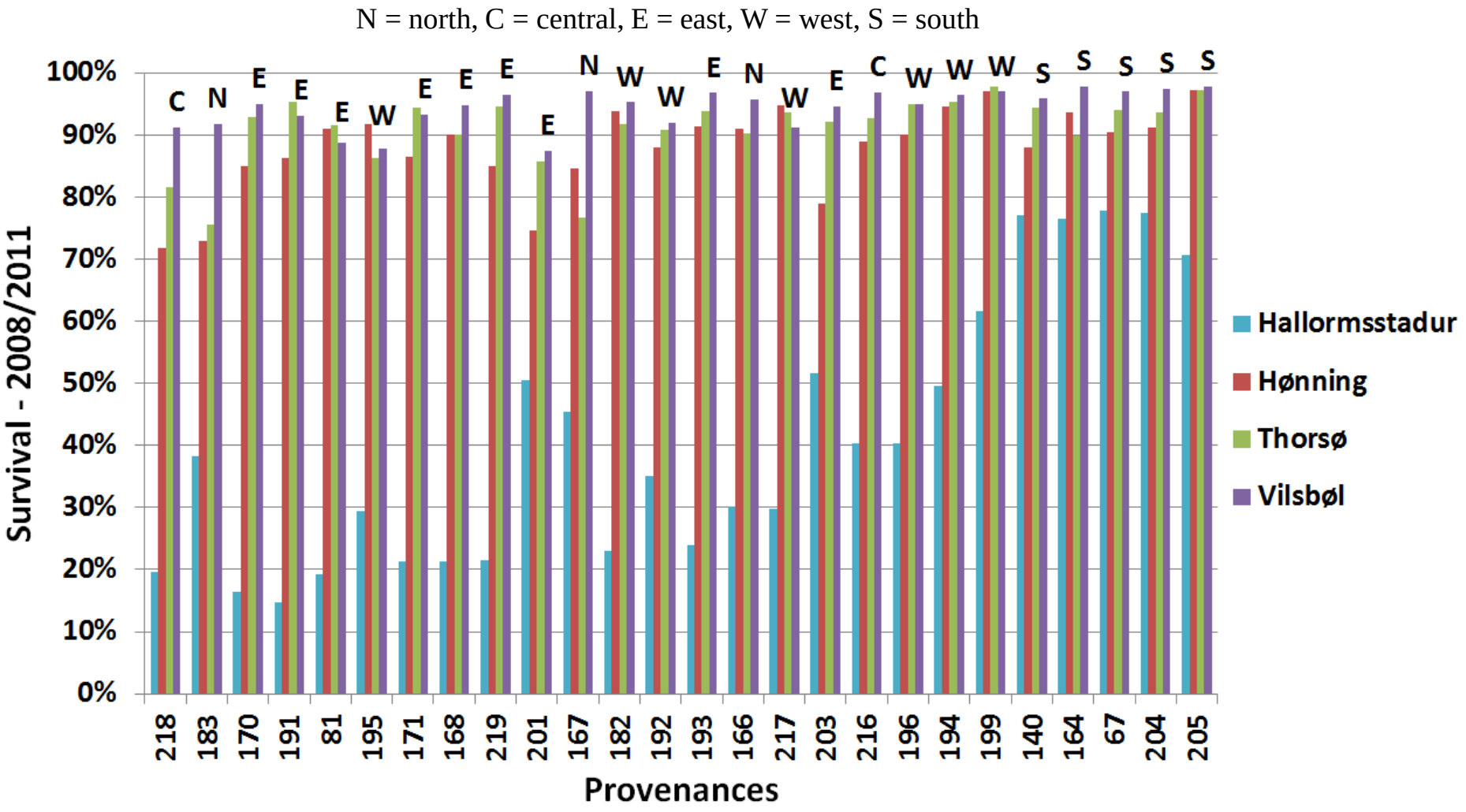
Overview of the main characteristics measured

Characteristic		Hønning	Thorsø	Vilsbøl	Hall	Model
Adaptive characteristics	Survival 2008/2011 (%)	88	91	94	41	B
	Survival 2014 (%)	76	83	92		B
	Height 2008/2011 (cm)	189	224	189	119	A
	Forks 1 2003 (%)	47	28	58		B
	Forks 2 2005–2007 (%)	54	24	57		B
Christmas tree characteristics	Christmas tree quality 2008/2011 (%)	3	23	28	44	B
	Christmas tree price (DKK)	78	102	93		A
	Needle loss, needles 2008, Oct. (%)	54	43	29		B
	Needle loss, needles 2007, Oct. (%)	27	21	11		B
	Needle loss, needles 2008, Nov. (%)	23	21	16		B
	Needle loss, needles 2007, Nov. (%)	10	12	11		B
Growth rhythm	Flushing 2000/2010 (score 0–6)	3.22	2.79	3.21	2.86	A
	Budset 2001 (score 0–3)		2.46		2.00	C
Susceptibility to pests and pathogens	*Neonectria neomacrospora* 2011(score 0–4)	0.96	0.55	0.33		A
	Neonectria neomacrospora 2013(score 0–4)	2.11	1.31	0.93		A
	Neonectria neomacrospora 2014(score 0–4)	2.40	1.73	1.32		A
	Adelges piceae 2007/2010 (score 0–5)	2.05	1.49	1.46		A

Analysis of variance and variance components

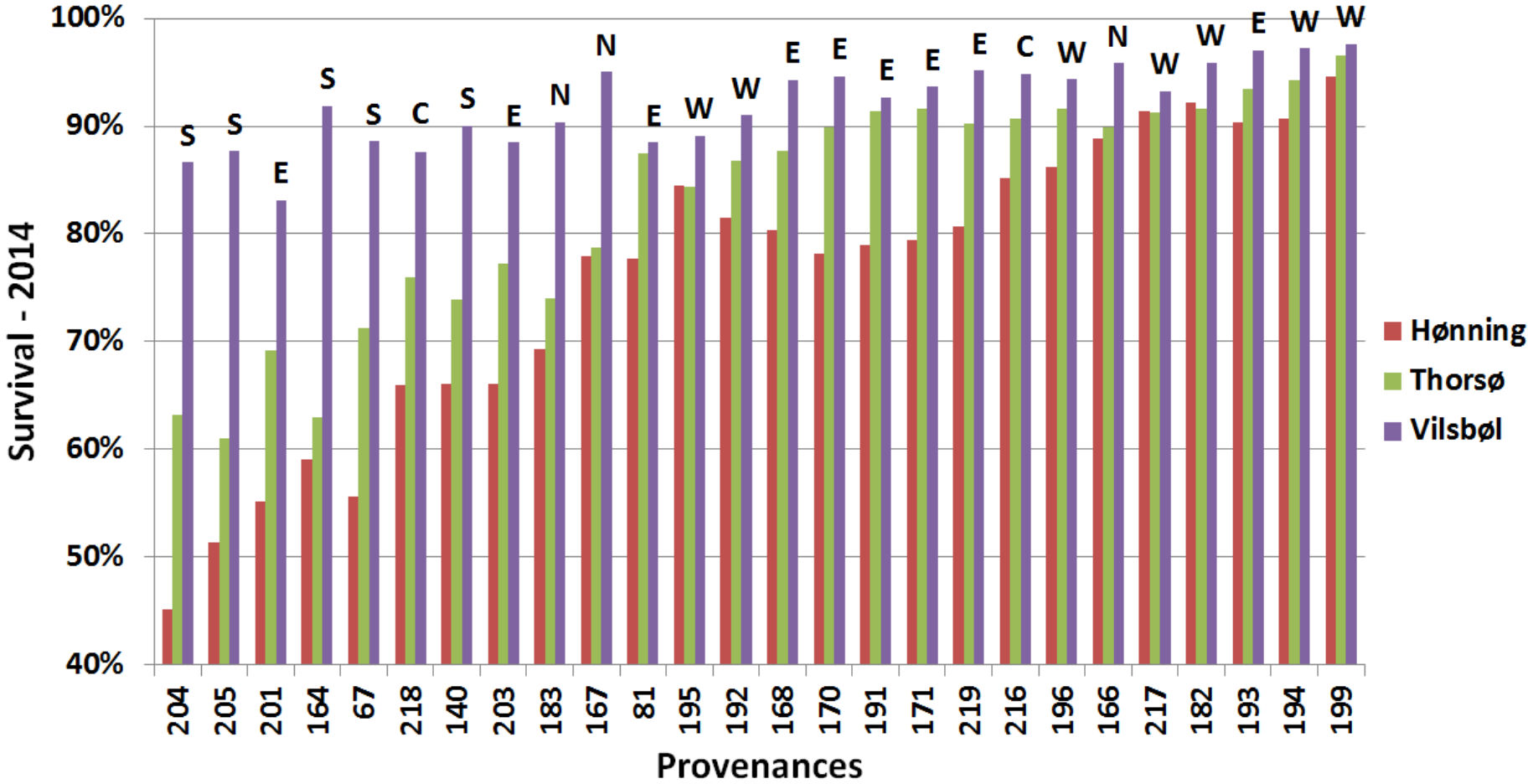
		ANOVA levels of significance p-value				Components of variance shown as % of total			
Character	**Sites included**	**Site**	**Block (Site)**	**Prov.**	**Prov. x Site**	**Prov.**	**Prov. x Site**	**MSE**	**Total MS**
Height (2008/2011)	All	<0.001	<0.001	<0.001	<0.001	9	5	86	3882.5
Survival (2008/2011)	All	<0.001	<0.001	0.012	<0.001	16	34	50	1.3832
Survival (2014)	Danish	<0.001	<0.001	<0.001	0.004	35	13	53	1.3951
Forks (2003)	Danish	<0.001	**0.053**	<0.001	0.024	32	4	64	1.7974
Forks (2005-2007)	Danish	0.012	0.007	<0.001	**0.923**	18	0	81	1.5386
Christmas tree quality (2008/2011)	All	<0.001	<0.001	<0.001	0.018	21	15	64	1.2944
Christmas tree price	Danish	<0.001	<0.001	<0.001	<0.001	11	3	86	4013.2
Needle loss (Oct 2008)	Danish	<0.001	**0.083**	<0.001	**0.968**	29	1	70	1.2388
Needle loss (Oct 2007)	Danish	0.002	**0.205**	<0.001	**0.591**	29	2	68	1.2849
Needle loss (Nov 2008)	Danish	**0.157**	**0.077**	<0.001	**0.804**	33	3	64	0.9822
Needle loss (Nov 2007)	Danish	**0.160**	**0.698**	<0.001	**0.238**	56	6	38	1.3874
Flushing	All	<0.001	<0.001	<0.001	<0.001	7	7	86	3.6675
Bud set	Thorsø Hall	<0.001	<0.001	<0.001	<0.001	23	6	71	2.6675
Neonectria neomacrospora	Danish	<0.001	<0.001	<0.001	<0.001	46	2	51	1.2574
Adelges piceae	Danish	<0.001	<0.001	<0.001	0.006	4	2	94	1.6675

Survival DK-2008, IS-2011

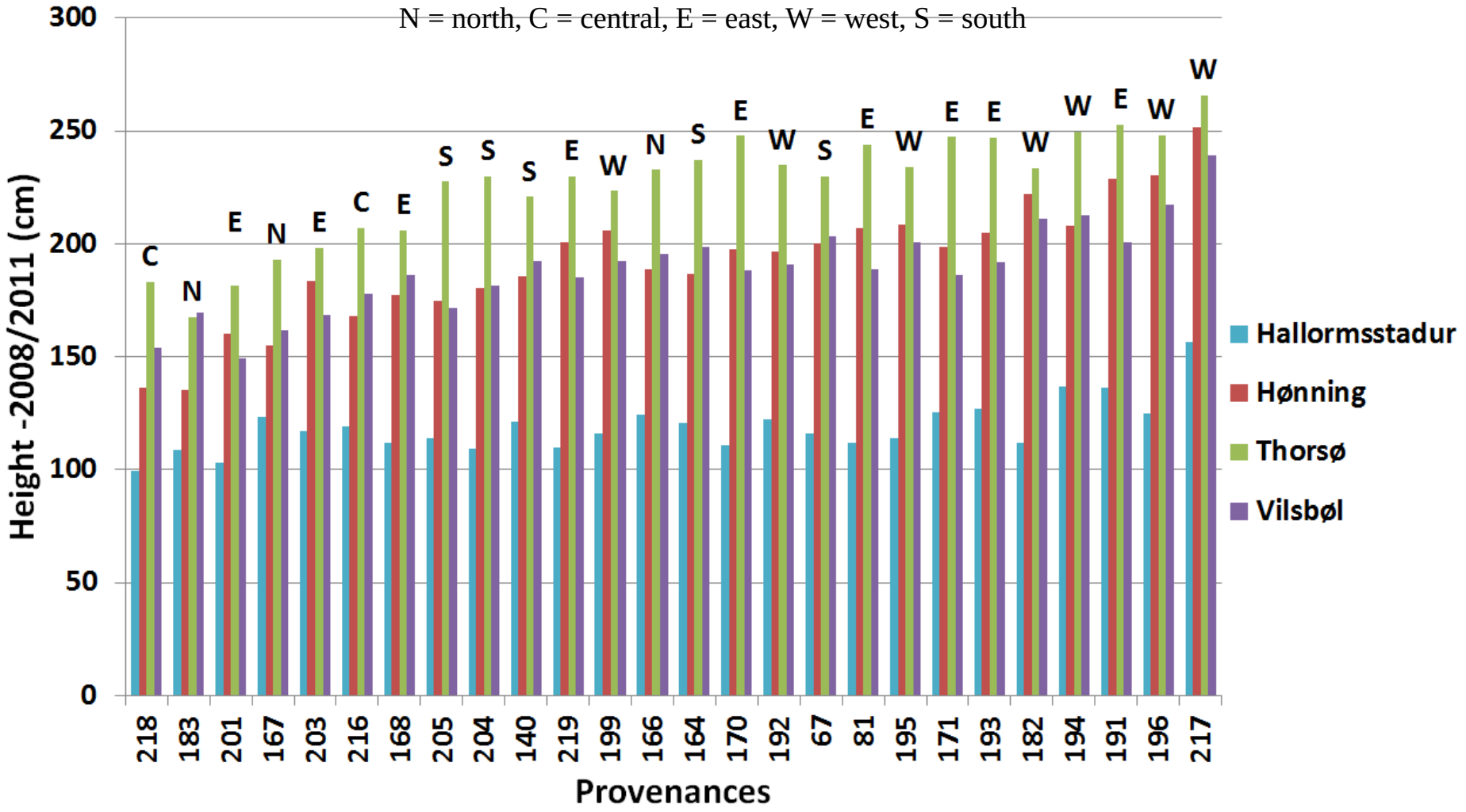


Survival DK-2014

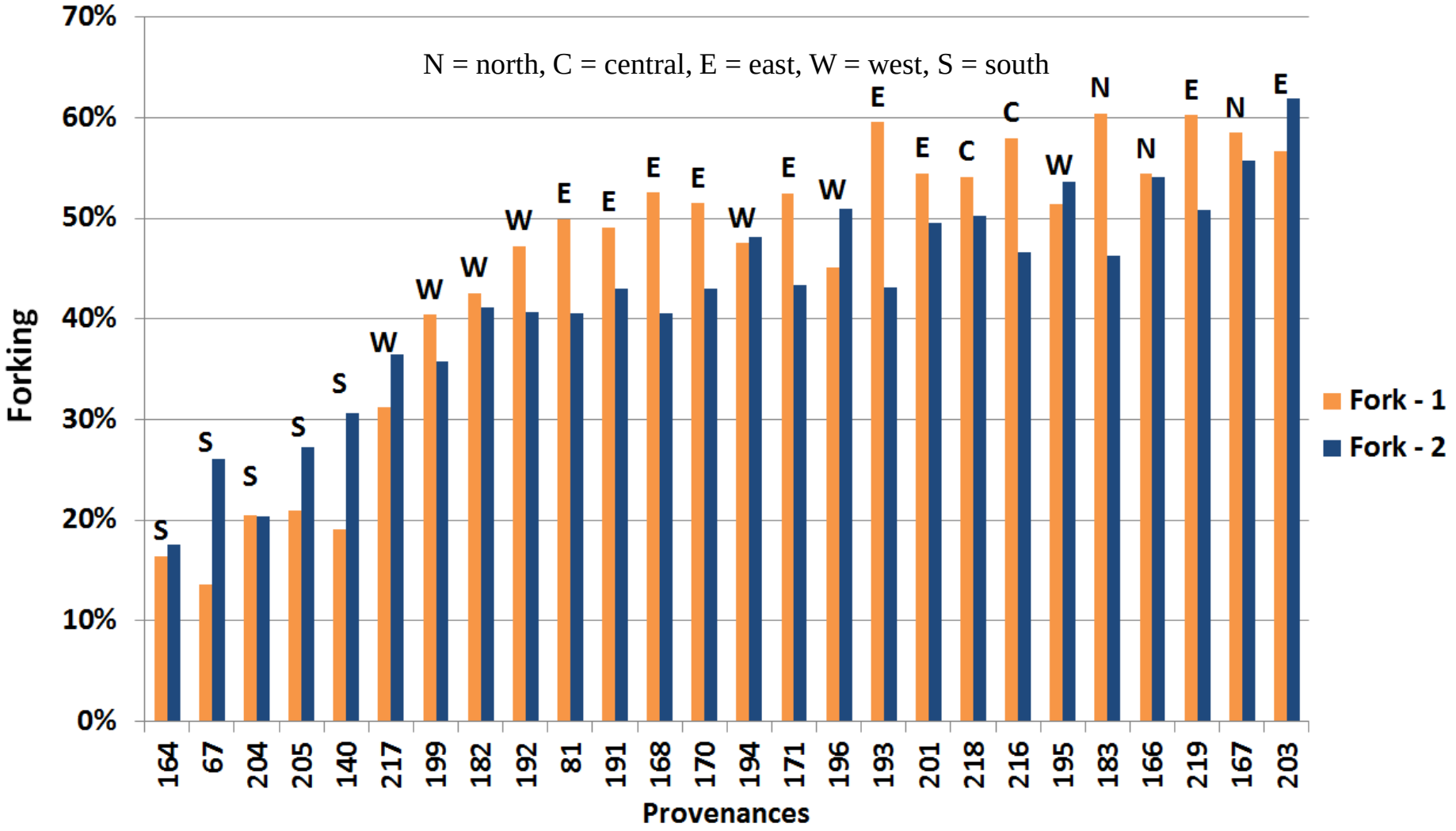
N = north, C = central, E = east, W = west, S = south



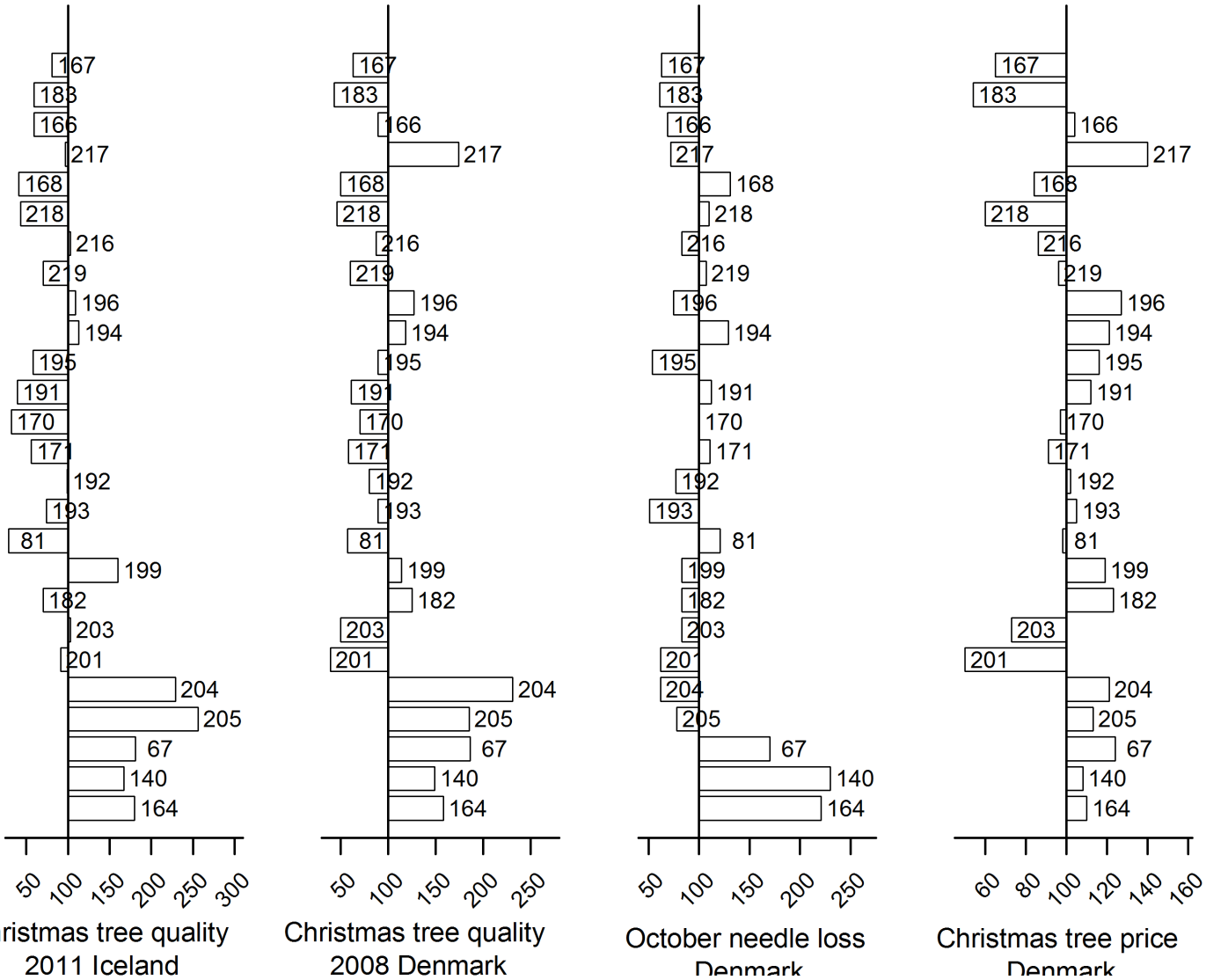
Height DK-2008, IS-2011



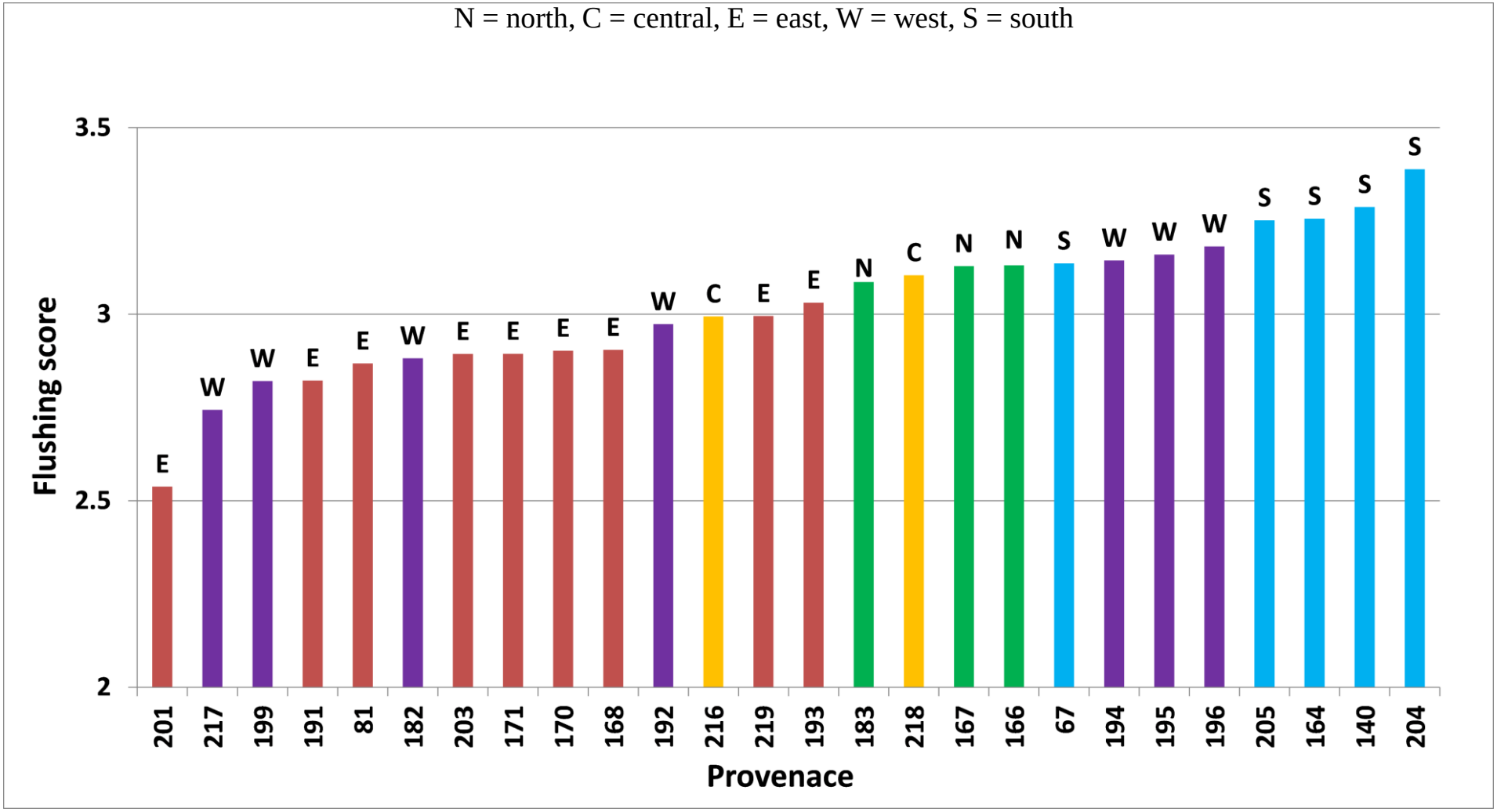
Proportion of fork-formation 4 years (Fork-1) and 6-8 years (Fork-2) after establishment at the Danish sites.



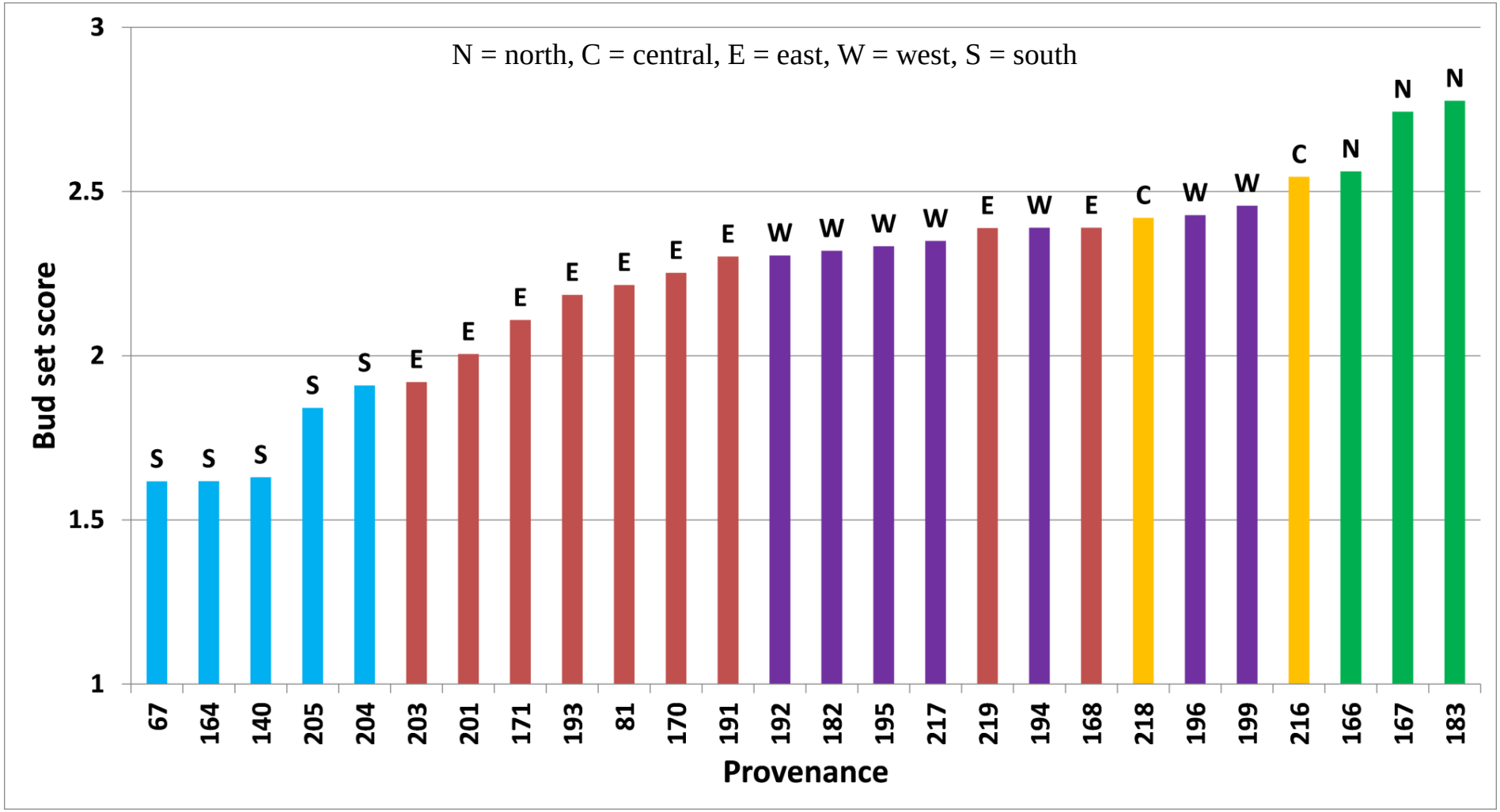
Christmas tree characteristics



Predicted flushing of 26 provenances, based on assessment in Thorsø, Hallormsstadur (spring 2001), Hønning and Vilsbøl (spring 2010)

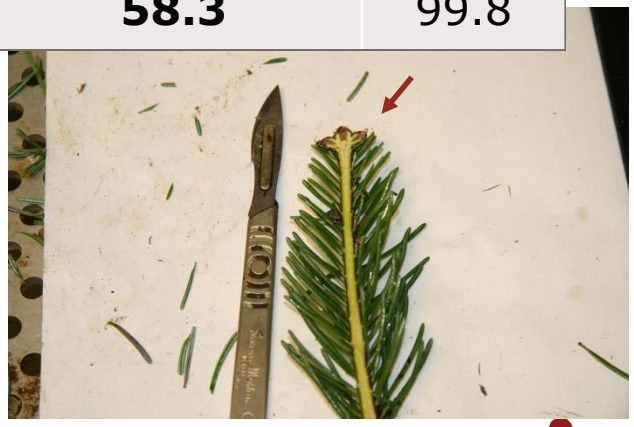


Predicted bud set of 26 provenances of subalpine fir, based on assessment in Thorsø and Hallormsstadur in the autumn of 2001

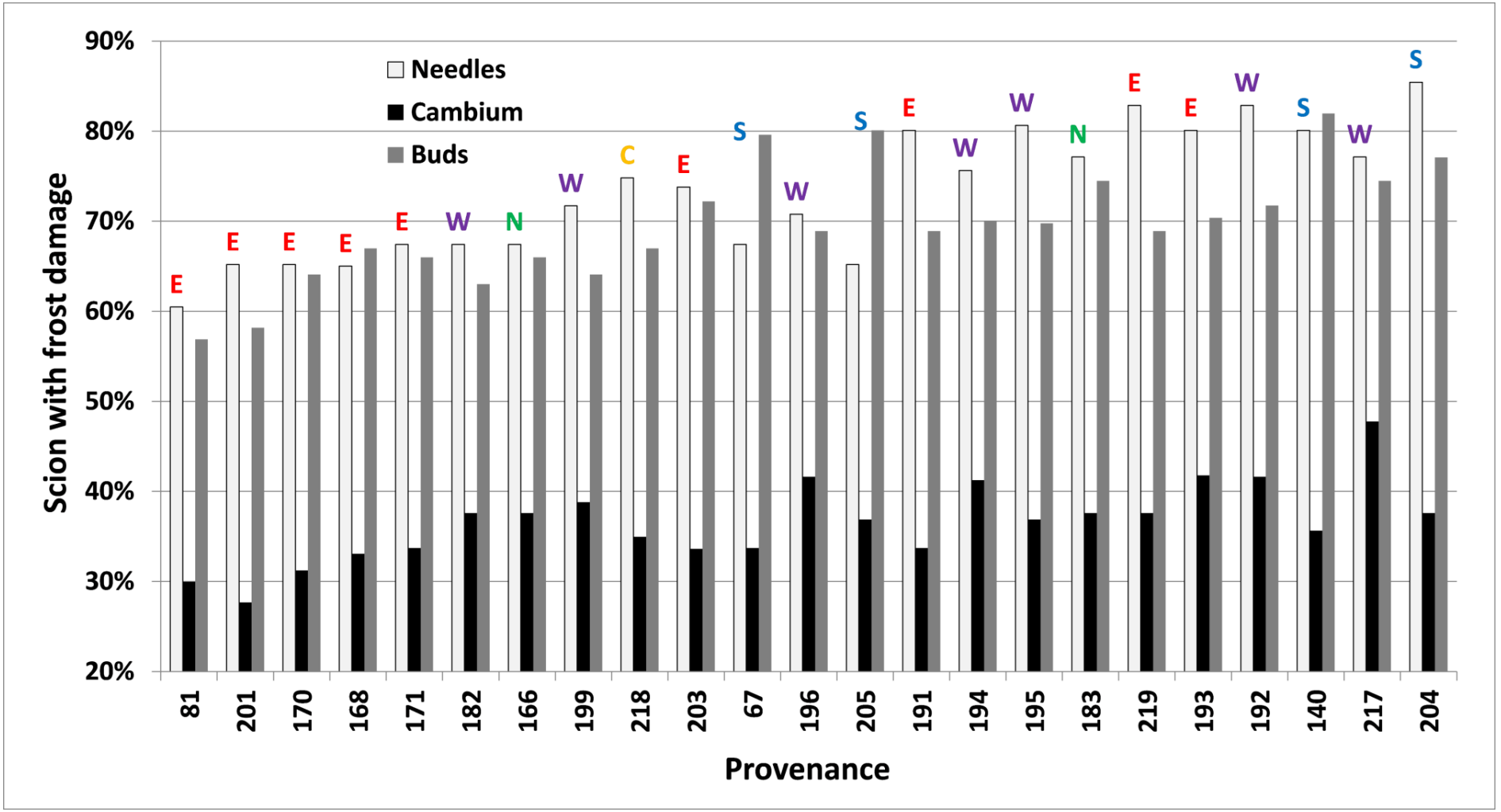


Overall per cent of frost damage to twigs, depending on tissue type, date of freezing and temperature value

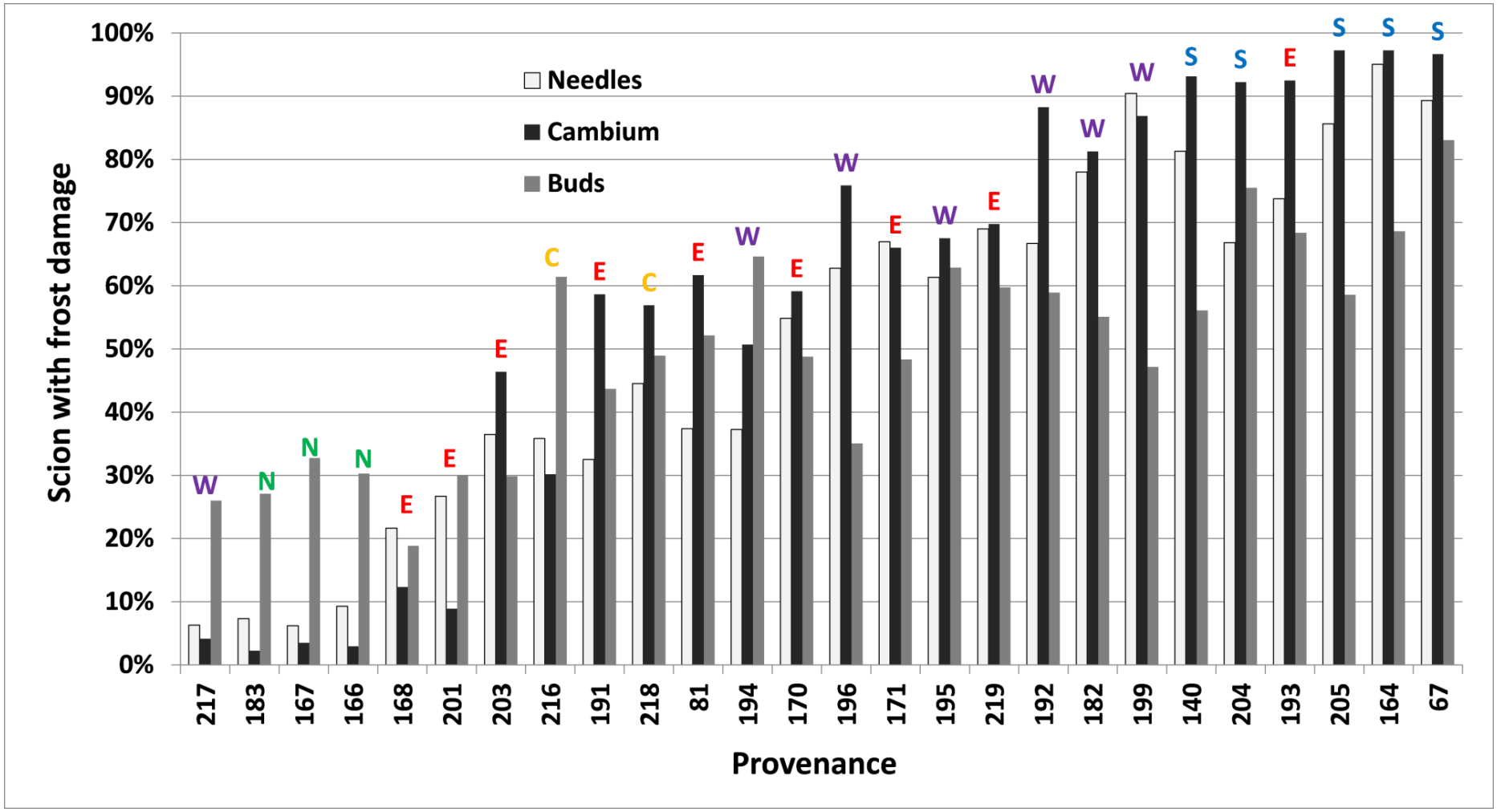
Freezing date	Temperature	Needles %	Cambium %	Buds %
Spring 2001 May 7th Iceland	-4	9.5	2.4	14.6
	-8	14.0	3.0	21.5
	-12	22.2	3.5	28.9
	-16	**73.2**	**36.7**	**69.7**
Autumn 2012 October 20th Denmark	4	1.0	1.0	1.2
	-6	0.5	0.5	0.5
	-12	2.9	3.9	9.5
	-18	21.5	29.8	**50.2**
	-24	**52.7**	**58.3**	99.8



Spring frost damage at -16 ° C



Autumn frost damage at -24° C for needles and cambium and -18° C for buds



Correlation between frost damage in spring, flushing, survival in Hallormsstadur 2011, survival in Hønning 2008 and geographical locations

	Needles -16°C	Cambium -16°C	Buds -16°C	Flushing
Cambium, -16°C	**0.52**			
Buds, -16°C	**0.49**	0.40		
Flushing	0.35	0.27	**0.67**	
Survival in Hallormsstadur	0.11	0.04	**0.63**	**0.50**
Survival in Hønning	-0.06	0.45	0.23	0.23
Latitude	0.01	0.32	-0.40	-0.27
Longitude	0.02	**0.47**	-0.20	-0.13
Elevation	0.01	-0.26	**0.54**	**0.56**

Bold values are statistically significant ($p < 0.05$)

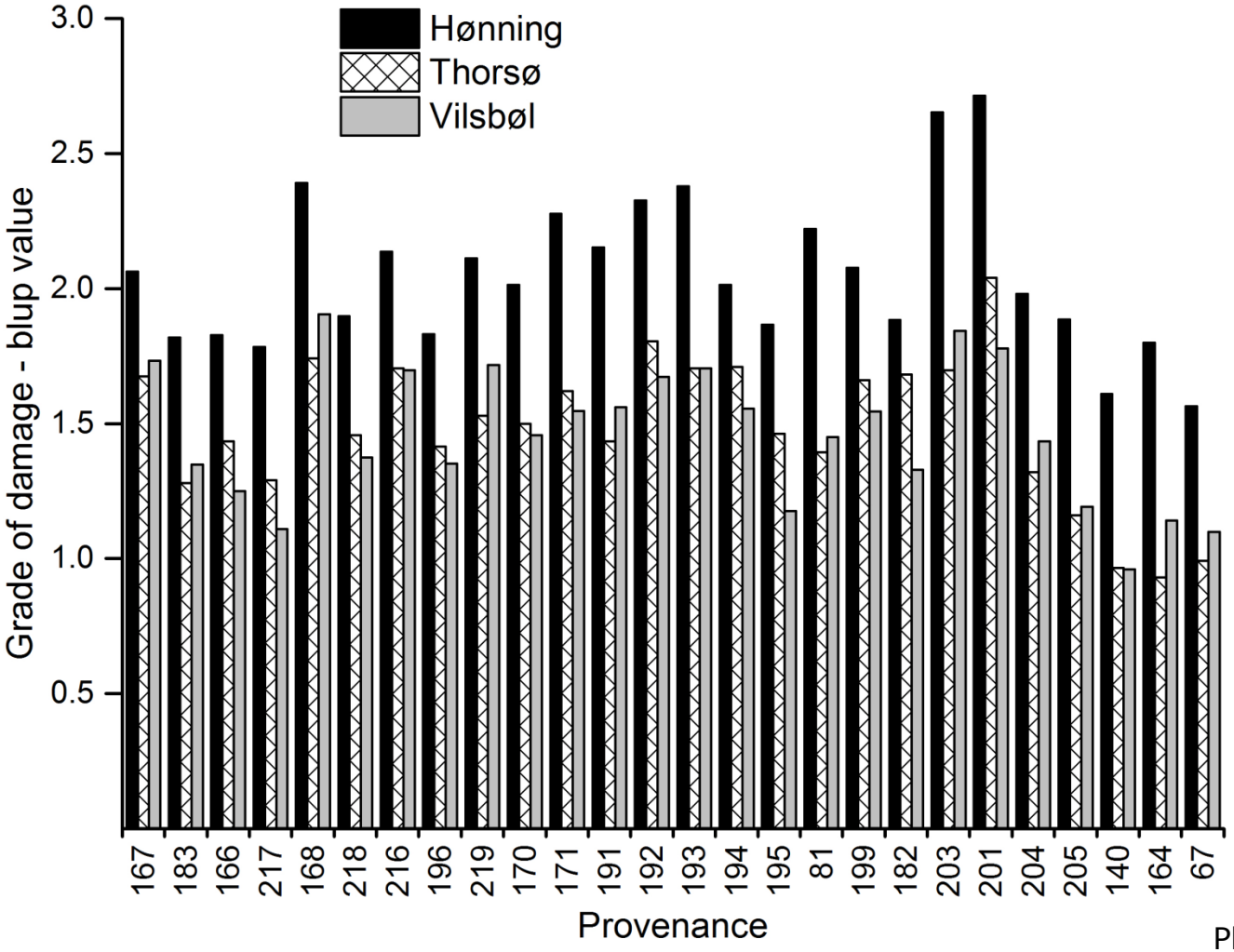
Correlation between frost damage in autumn, bud set, survival in Hallormsstadur 2011, Hønning 2008 and geographical locations

	Needles -24°C	Cambium -24°C	Buds -18°C	Bud set	Survival Hallormsstadur	Survival Hønning
Cambium, -24°C	**0.95**					
Buds, -18°C	**0.73**	**0.78**				
Bud set	**-0.63**	**-0.62**	**-0.50**			
Survival in Hallormsstadur	**0.43**	0.37	0.38	**-0.62**		
Survival in Hønning	**0.42**	**0.42**	0.38	-0.19	0.24	
Latitude	**-0.74**	**-0.72**	**-0.59**	**0.93**	**-0.68**	-0.22
Longitude	**-0.61**	**-0.66**	**-0.52**	**0.84**	**-0.40**	-0.05
Elevation	**0.63**	**0.64**	**0.57**	**-0.82**	**0.75**	0.17

Photo: Øyvind M. Edvardsen

Bold values are statistically significant ($p < 0.05$)

Damage by *Adelges piceae* on different subalpine fir provenances for each site sorted by provenance origin (north to south (l-r))



Photos: Ulrik Braüner Nielsen

Damage by *Neonectria neomacrospora* on different subalpine fir provenances, sorted by provenance origin (north to south (l-r))

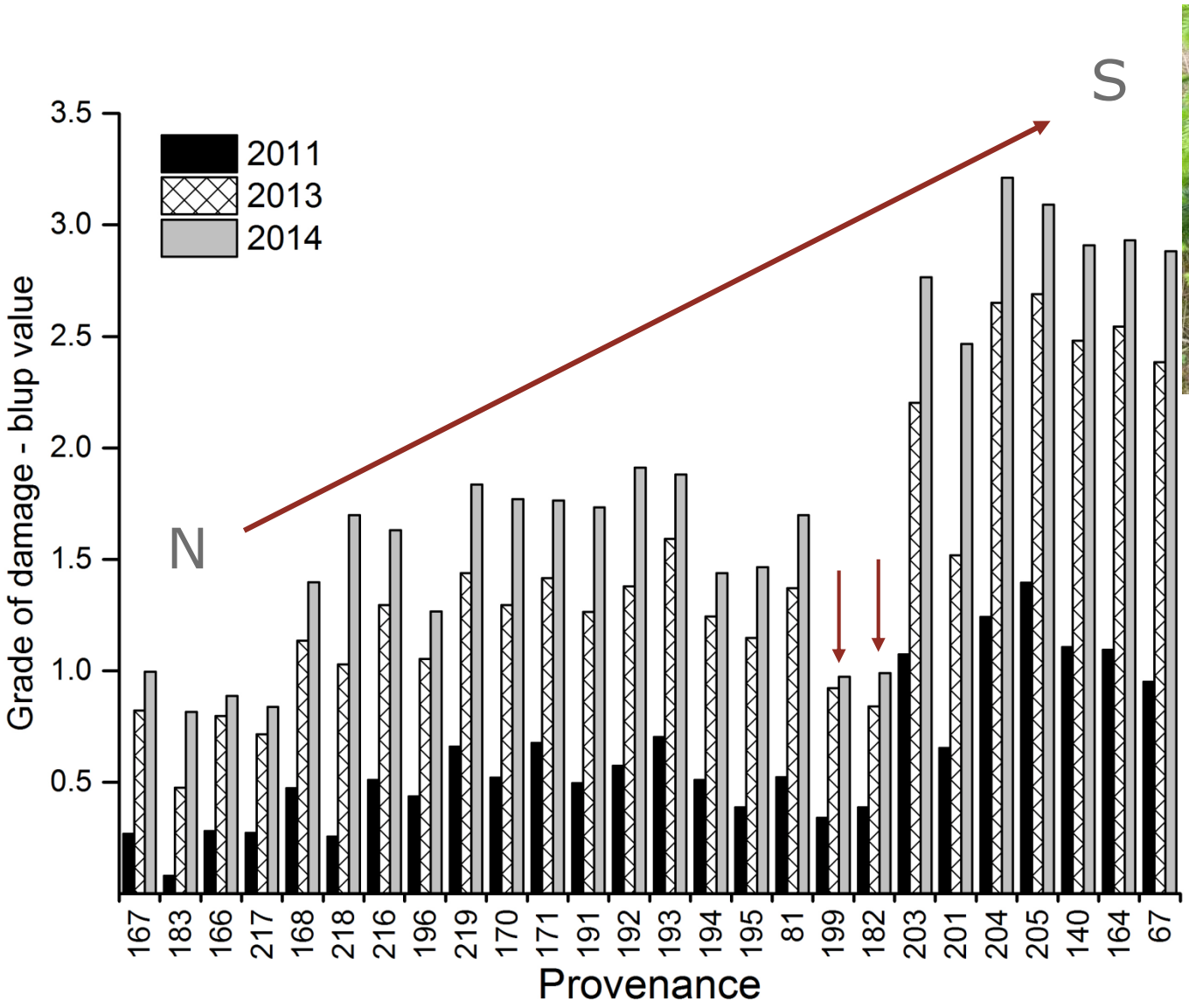


Photo: Iben M. Thomsen

Photo: Vence Talgø

Recommended provenances to use in Denmark

Provenance 217, White River in British Columbia

- High survival rate
- High needle retention
- Tallest and high Christmas tree quality
- Lowest tendency of forking formation after corkbark fir
- Rather late budburst
- Excellent tolerance to *Neonectria neomacrospora* and *Adelges piceae*

Other promising provenances belong to the western group

30 best individuals of the best provenance, White River from British Columbia, were selected from the Danish field trials and grafted in 2011 to serve as a clonal seed orchard.

Photo: Ole Kim Hansen

Recommended provenances to use in Iceland

Sandia Crest and Mount Taylor from Cibola N.F. in New Mexico (204 and 205)

- Corkbark fir showed superior results, especially for survival rate and Christmas tree quality
- The corkbark fir provenances from Arizona (67, 140 and 164) showed the poorest needle retention of all tested provenances
- Any recommendation for Iceland must be revised if *Neonectria neomacrospora* or other new pests arrive in the country
- Because the testing in Iceland was limited to one site, additional trials need to be conducted to verify the results
- 43 clones from 20 provenances were selected to become main clones in a clonal seed orchard

Else Möller and Cibola (205). Photo: Brynjar

Photo: Pétur Halldórsson

Photo: Ulrik Braüner Nielsen