Forest Research

Summary of FR Seed Origin Trials on red oak (*Quercus rubra* L.)

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Front cover picture: Experiment Alice Holt 428 being assessed in 2010.

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Executive summary

Red oak is attracting interest as a forest species because it can produce valuable timber, grow faster than native oaks, is well-suited to a warming climate, has good wood properties and its foliage produces beautiful autumn colour. However, in some parts of Europe the species has attracted controversy because of reports it is invasive.

To help build an evidence base for the use of this species in British forestry this study aimed to identify suitable seed origins based on a series of seed origin experiments established in 1992. The current recommendation on the Forest Research (FR) species and provenance webpage is:

'Very few provenance trials in Britain and few forest plots; seed should be sourced either from southern Canada or from good stands in north western Europe.'

Four experiments were established and contained 13 different seed origins that had been collected in the Great Lakes region of North America. Analysis of the data after 28 years showed that there were no clear trends for survival, form score or diameter growth. However, height growth from the southerly seed origins (between latitudes of 41°N and 44°N) was significantly greater compared with more northerly ones. Based on this finding it is recommended that the FR web-page should be revised to read:

'A recent analysis of seed origin experiments planted in 1992 in England showed that seed origins between latitudes of 41°N and 44°N from the Great Lakes region showed significantly better growth compared to more northerly seed origins and should be the preferred source of direct-import seed. Seed from stands in the northwest of Europe have not yet been tested alongside native-range sources in the UK but evidence from elsewhere indicates European sources can be superior.'

Other findings from the study were:

1. Red oak achieved GYC 6-10 on three lowland sites which is at the upper end/above what would be expected from our native oaks. However, productivity at the fourth upland site was much lower (GYC 4).

2. Each red oak experiment has an adjacent seed origin experiment of native oaks and further work could compare the experiments at the species level.

3. At sites with high local density of grey squirrels, frequency of damaged trees was high (56-75%).

1.0 Introduction

Red oak is attracting interest as a forest species because it can produce valuable timber, grow faster than native oaks, is well-suited to a warming climate, has good wood properties and its foliage produces beautiful autumn colour (Wilson, 2018). This interest is reflected in a recently published review of the species and its history in Europe (Nicolescu *et al*., 2020) from which the following extract is the summary.

Red oak is a valuable broadleaved tree species originating from the eastern half of the USA and Canada. It was introduced to Europe in 1691 and currently covers over 350 000 ha, being found all over the continent, except the coldest part of Scandinavia. It is a fast-growing and valuable broadleaved tree due to its ecological characteristics, good wood properties and high economic value. Northern red oak[1] prefers deep, loose, moderately humid and acid soils, without compact horizons and of at least moderate fertility. It does not grow well on dry, calcareous soils as well as waterlogged or poorly drained soils. It is either naturally regenerated using a group shelterwood system or planted using seedlings of European provenance, collected in certified seed stands. As red oak is light-demanding, its management should be 'dynamic' and includes heavy interventions (cleaning–respacing and thinning from above), in order to minimize crown competition between the final crop trees. These should produce large diameter trees for valuable end uses (e.g. veneer, solid furniture, lumber, etc.) within a rotation period generally of 80–100 years. The necessity for pruning (both formative and high) depends on the stand stocking at establishment, the subsequent silvicultural interventions as well as the occurrence of forking. The adaptation potential of red oak to predicted climate change, especially drought, seems to be higher than for European native oaks, the importance of the species is expected to increase in the future.

One negative factor of the species is that some authorities consider it to be invasive (EUFORGEN, 2022).

The objective of the work described in this report is to identify suitable origins for growing in Britain based on a series of seed origin experiments established in 1992. The current recommendation on the Forest Research (FR) species and provenance webpage is (Forest Research, 2022):

'Very few provenance trials in Britain and few forest plots; seed should be sourced either from southern Canada or from good stands in north western Europe.'

1.1 Objective of study

In 1992 a series of 5 experiments were established to examine the effects of seed origin on survival and growth of red oak to identify origins suitable for Britain. Four of these experiments were reassessed in 2020/21 to provide an objective basis for recommendations based on the seed origin of this species.

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[1] Northern red oak is a synonym for red oak

2.0 Seed origin variation in red oak

2.1 Experiments

A collection of red oak seed sources in North America was made by Dr. A Kremer of INRA, Bordeaux, France in 1988. Some of this seed was made available to the Forestry Commission and was planted in the Bush nursery in 1989. The seed collection was the result of increasing interest in the species in Europe and a recognition of its potential in Britain, where it can grow faster than both native oak species. Red oak has an extensive natural range and is likely to show considerable variation in commercially important traits.

Seed was made available from 13 locations in the northern part of the native range in North America and initially five experiments were established: Alice Holt 428 (had all 13 seed origins), Dean 168 (12 seed origins), Arden 3 (9 seed origins), North York Moors 60 (6 seed origins) and Neroche 33 (5 seed origins). A maximum of 36 trees were planted from each seed origin at each experiment (representing a 6 x 6 tree plot) and replicated up to 3 times (block) per site.

The sites covered a wide geographical range and also had varying rainfall (760-1100 mm yr^{-1}), temperate (1396-1903 day degrees), soil nutrient regimes (very poor to rich) and soil moisture regimes (slightly dry to very moist); two of the experiments were planted on free-draining mineral soils and two were on gleys (Table 2). Good establishment practice was used at each of the sites and only a small amount of beating-up was required.

The experiments were visited in 2020/21 to ascertain their condition. Unfortunately, the integrity of the small experiment at Neroche was found to have lapsed too far to warrant formal assessment; however, the other four sites were assessed.

2.2 Assessments and analyses

2.2.1 Assessments

The four sites were assessed in winter 2020/21 using a standard assessment:

1. The diameter at breast height (DBH) of each tree.

2. The total height of the two largest DBH trees per plot.

3. The form of each live tree was scored using the system: 1 = single, straight clear stem and leader ('potentially excellent timber tree'); 2 = single stem and leader but some kinks in main stem and/or heavy branching ('potential timber tree'); and 3 = neither 1 nor 2 ('candidate to remove in early thinning').

The mean of the height measurements for each seed origin at each site was taken as an estimate of top height and from this an assessment of General Yield Class (GYC) was made using the top height-age models for red oak in Matthews *et al*. (2013).

The presence of dead tops as a result of grey squirrel damage was recorded at Alice Holt and Dean.

In addition to the 2020 data, the 2005 assessment was also available for analysis.

Initial exploration of the data revealed problems with the data from North York Moors 60 and as there were only trees from six seed origins available, it was removed from the analysis. The trees from the following seed origins (*Auburn*, *Bancroft*, *Point Albino* and *Ridgeway/Point*) were also removed prior to analysis as they had only been planted at 1-2 of the 3 sites.

2.2.2 Effects of seed origin and site

Analysis was conducted in R (version 4.1.0, R Core Team 2020), with graphics produced using ggplot2 (Wickham, 2016) as follows:

Mean height and diameter were analysed for 2005 and 2020 separately using mixed linear models in the 'lme4' package (Bates et al, 2015). Site and seed origin were fit as fixed effect covariates and block and site as random effects. Type II Anova tests were used to test the statistical significance of fixed effects and pairwise comparisons made (if $p \leq 0.05$) made using the 'multcomp' package (Hothorn et al, 2008). The Tukey method was used to correct for multiple comparisons Interactions between site and seed origin were tested and retained if significant. Adjusted marginal means were extracted from models using the 'emmeans' package (Lenth, 2021).

Form score and survival were analysed using generalized mixed linear models with a binomial distribution and logit link function with the same covariate structure as previously described. Prior to analysis form score was converted into a binary variable with '1' representing scores of 1 and 2 (good form), and '0' representing a score of 3 (poor form).

To test differences between 'northerly' and 'southerly' seed origins, latitude 44°N was used to separate the two regions (see Figure 1). For this analysis an additional random effect (seed origin) was added to the linear model.

2.3 Results: seed origin and site

2.3.1 Survival in 2005

- This was generally high (overall mean = 76%) but there were significant differences between the sites at Dean (86%), Arden (80%) and Alice Holt (60%).
- Tree survival in 2005 is shown for the three different sites in Figure 2. There was a significant effect of seed origin, site and the interaction between these two terms. Survival was much lower at Alice Holt and higher at Dean and Arden; however, the lower survival at Alice Holt was in part due to scorching caused by agricultural refuse being dumped in the experiment at a young age. Generally it was difficult to identify seed origins with consistently good survival as this differed according to site. The only seed origins that did not achieve >75% survival at two sites were *Maywood, Twin Springs* and *Plaines de Kazabazua*, both of which were from the northern region.
- The seed origin from *Plaines de Kazabazua* had a very poor survival at Alice Holt (14%) and therefore the mean height (9.3 m) could not be used as a basis for the estimation of GYC.

2.3.2 Mean diameter (2005) and (2020)

- In 2005 there was a significant main effect of site and seed origin on diameter (data not shown). After correction for multiple testing there were no pairwise differences in diameter according to site; however, two of the seed origins from Ontario (*Chatham District* and *Aylmer/Simcoe*) had significantly greater diameters than some of the other seed origins.
- By 2020 there was a significant effect of site but the differences between seed origins were no longer significant (Figure 3). Diameters at Arden were significantly larger than those at Dean.

2.3.3 Top height in 2005 and 2020

- In 2005 there was a significant effect of seed origin on height with trees from *Chatham District* and *Alymer/Simcoe* having a greater height than two origins (*Plaines de Kazabazua* and *Maywood - Twin Springs*) in the north (Figure 4). Tree height was not significantly different between the three sites.
- In 2020 there was a significant effect of both site and seed origin on height (Figure 5). Trees grown at Arden which had suffered no squirrel damage (mean height = 18.6 m) were significantly taller than those at Dean (15 m) or Alice Holt (13 m). For seed origins averaged over the sites, trees originating from the *Aylmer/Simcoe* and *Angola* were significantly taller than trees from *Maywood - Twin Springs*.

2.3.4 Form score/squirrel damage 2020

- In general most seed origins had <50% of trees judged to have been of good form (see front cover).
- The analysis showed that there was a significant effect of seed origin and a significant interaction between seed origin and site (Figure 6). Trees from some seed origins had better form scores when growing at Dean (*Constance Bay*, *Plaines de Kazabazua*, *Angola*, *Chalk River*). Trees from the *Aylmer/Simcoe* had better form score when grown at Alice Holt.
- The sites were assessed by different people and it is likely that the interpretation of the form scores was different. Therefore, not too much emphasis should be placed on differences between sites. If this variation is removed then the range of form scores was between 55% of trees with good form (*Ridgeway*) and 28% of trees with good form (*Maywood - Twin Springs*) and is statistically significant.
- Grey squirrel damage was 56% at Alice Holt and 76.5% at Dean; it was not recorded at Arden but reports show that little was observed.

2.3.5 Comparison of 'north' and 'south' seed origins

- The nine seed origins that were analysed were divided into those to the north of latitude 44°N (*Mission Hill*, *Chalk River*, *Plaines de Kazabazua*, *Constance Bay*, *Maywood- Twin Springs*) and those to the south (*Angola*, *Chatham District*, *Ridgeway*, *Aylmer/Simcoe*).
- Analysis found that top height in plots of trees originating from Southern seed origins was significantly greater than those of Northern seed origins in 2005 and 2020 across all sites (Figure 7).

2.4 Discussion and conclusions

2.4.1 Seed origins

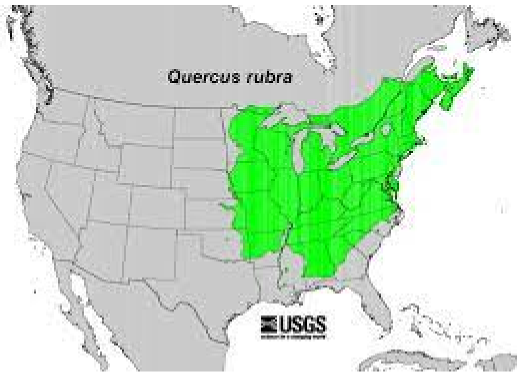
1. The native range of red oak is shown in the figure below and covers a vast area of eastern North America. The seed origins tested in these experiments, and most of the red oak introduced to, or remaining in Europe (Merceron *et al*., 2017, Pettenkofer et al., 2019), all come from the northern part of the natural range around the Great Lakes, and hence constitute only part of the natural range. A reason for this may be due to past taxonomy which recognised a distinct variety of red oak in the northeastern part of the range up until the 1950s (Merceron *et al*., 2017). However, the results support the present advice on the FR web-page that: 'Very few provenance trials in Britain and few forest plots; seed should be sourced either from southern Canada or from good stands in north western

Europe'. However, based on the results of this study it is suggested that the text should be revised to read:

'A recent analysis of seed origin experiments planted in 1992 in England showed that seed origins between latitudes of 41 and 44°N from the Great Lakes region showed significantly better growth compared to more northerly seed origins and should be the preferred source of direct-import seed. Seed from stands in the northwest of Europe have not yet been tested alongside native-range sources in the UK but evidence from elsewhere indicates European sources can be superior.'

2. The main source of evidence for direct comparisons of European provenances with these from the native range are from German experiments described by Westergren (2016) [cited in Wilson (2016)], who states that after 10 years, most European provenances were better than material from the native range. The reasons for this may be because there is some evidence suggesting that adaptive differentiation in leaf phenology has begun, possibly due to natural selection against frost prone origins (Daubree and Kremer, 1993), and because pests of acorns in the native range are not present in Europe (Nicolescu *et al*., 2018).

3. Conversion of the Arden experiment (which suffered little squirrel damage), into a select seed stand through a heavy thinning could potentially be considered for a future treatment. For example, if all trees with poor form (score 3) and with DBH <15 cm were removed, 152/752 trees would be retained. The mean form score of the stand would be 1.86 (versus site mean of 2.44). Mean DBH of the site would be 17.2 cm (versus site mean of 13.7), which represents a 25% improvement over the average.



The natural range of Quercus rubra

2.4.2 Silviculture and wood properties

1. The experiments demonstrated that red oak can grow well on a range of lowland sites and achieve GYC 6-10, which is at the upper end/above the productivity of our native oaks. Productivity was far lower at the upland site in the North York

Moors (GYC 4) but our understanding of how the species reacts to a number of potential constraining factors such as exposure is not well developed.

2. Grey squirrel damage was evident throughout the trials at Alice Holt and Dean, where 56% and 76.5% of trees had damaged tops.
3. The wood properties of red oak are compared with native white oaks in Table 3. In general, the wood of red oak is denser, stronger and harder than that of native oaks, although the data were obtained from small sample sizes so may not be representative.

3.0 Tables and Figures

Table 1: Summary of the red oak seed origin productivity at the experiment sites

						Top height (m) and GYC			
Seed ident	Location	State	Country	Latitude	Longitude	Alice Holt	Arden	Dean	N York M
ROK14005	Maywood -Twin Springs	Michigan	USA	45.83	86.98	10.6	17.1	14.1	*
ROK14006	Mission Hill	Michigan	USA	46.47	84.67	13.8	18.5	16.5	*
ROK14007	Constance Bay	Ontario	Canada	45.5	76.08	12.3	18.6	14.9	10.3
ROK14008	Bancroft	Ontario	Canada	45.28	77.68	11.4	*	13.9	*
ROK14009	Chalk River	Ontario	Canada	46.05	77.37	12.7	18.2	14.8	9.7
ROK14019	Angola	Indiana	USA	41.67	85.02	14.3	19.1	15.9	10.1
ROK14020	Auburn	Indiana	USA	41.38	85.03	15.1	*	13	*
ROK14021	Plaines de Kazabazua	Quebec	Canada	45.93	76.1	**	19	12.9	9.8
ROK14025	Ridgeway	Ontario	Canada	42.9	79.03	15.9	19.6	13.7	*
ROK14026	Point Albino	Ontario	Canada	42.85	79.1	15.3	*	*	*
ROK14030	Chatham District	Ontario	Canada	42.5	82.25	14.1	18.8	15.5	10.1
ROK14031	Ridgeway - Point	Ontario	Canada	42.83	79.07	15.6	19.6	13.7	*
ROK14032	Aylmer - Simcoe	Ontario	Canada	42.83	81	14.6	18.7	16.2	10.8

Colour codes for GYC	
(dark green)	10
(light green)	8
(yellow)	6
(red)	4

* Not planted

** Poor survival; no GYC estimate

Table 2: Summary of experimental sites **(from ESC version 4* and experimental files)**

Site	NGR	P. Year	DAMS	AT5	SMR	SNR	Soil	Suitability	Ann. rainfall (mm)
Alice Holt	SU990361	1992	9	1903	3 (v. moist)	3 (medium)	SW gley	0.61 Suitable	760
Arden	SP357702	1992	13	1706	3 (v. moist)	3 (medium)	SW gley	0.61 Suitable	850
Dean	SO636147	1992	13	1612	6 (s. dry)	1 (v. poor)	Podzol	0.18 Not Suit	1060
N York Moors	SE948860	1992	14	1396	5 (fresh)	4 (rich)	Brown earth	0.80 V. suit	1100

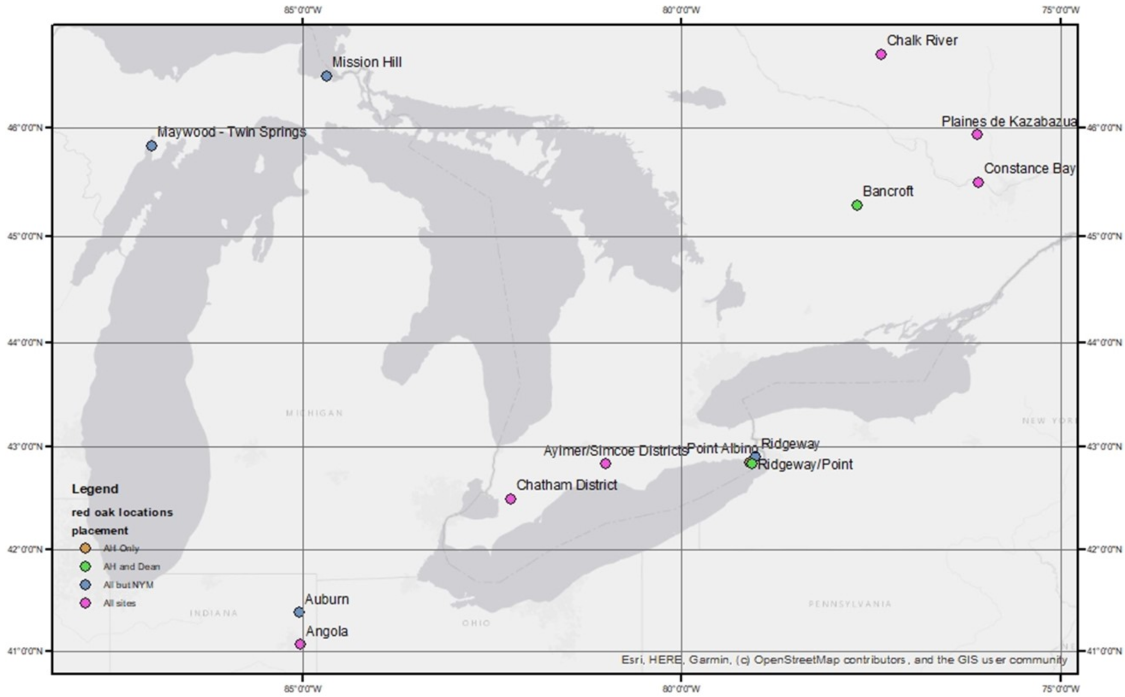
* ESC v4 returned values of 0 for these sites and Stephen Bathgate carried out a more localised appraisal. The 0 values were returned due to soil mapping problems and/or the fact that for GF (and other species) if a site value is outside the tolerance range then suitability declines rapidly.

Table 3: Wood properties of red oak compared with native oak

	Wood density at 12% m.c. (kg/m^3)	Bending strength (Modulus of Rupture, mPa)	Bending stiffness (Modulus of Elasticity, mPa)	Compression strength parallel to grain (mPa)	Hardness (N)	Shear strength (mPa)
European oak *Quercus spp.*	689	97	10100	51.6	5470	13.7
Red oak *Quercus rubra*	705	123	12500	57.4	7340	17.0

Data from Lavers (1983)

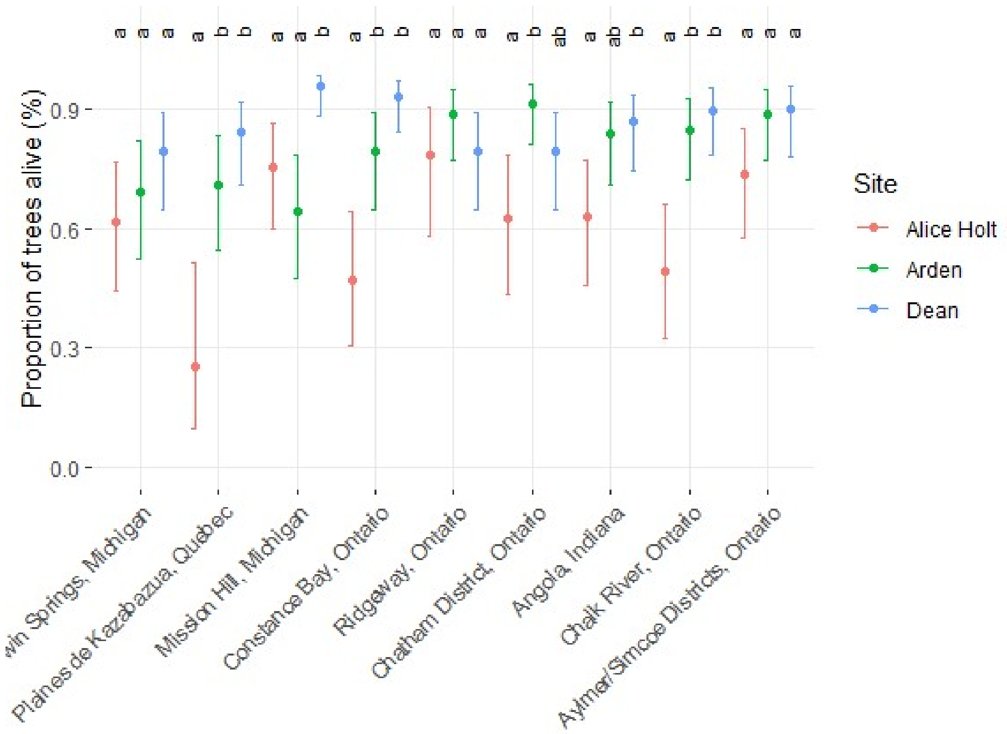
Figure 1: Location of the seed origins in the Great Lakes region



Note 1: 745 miles separates the most easterly and westerly seed origins

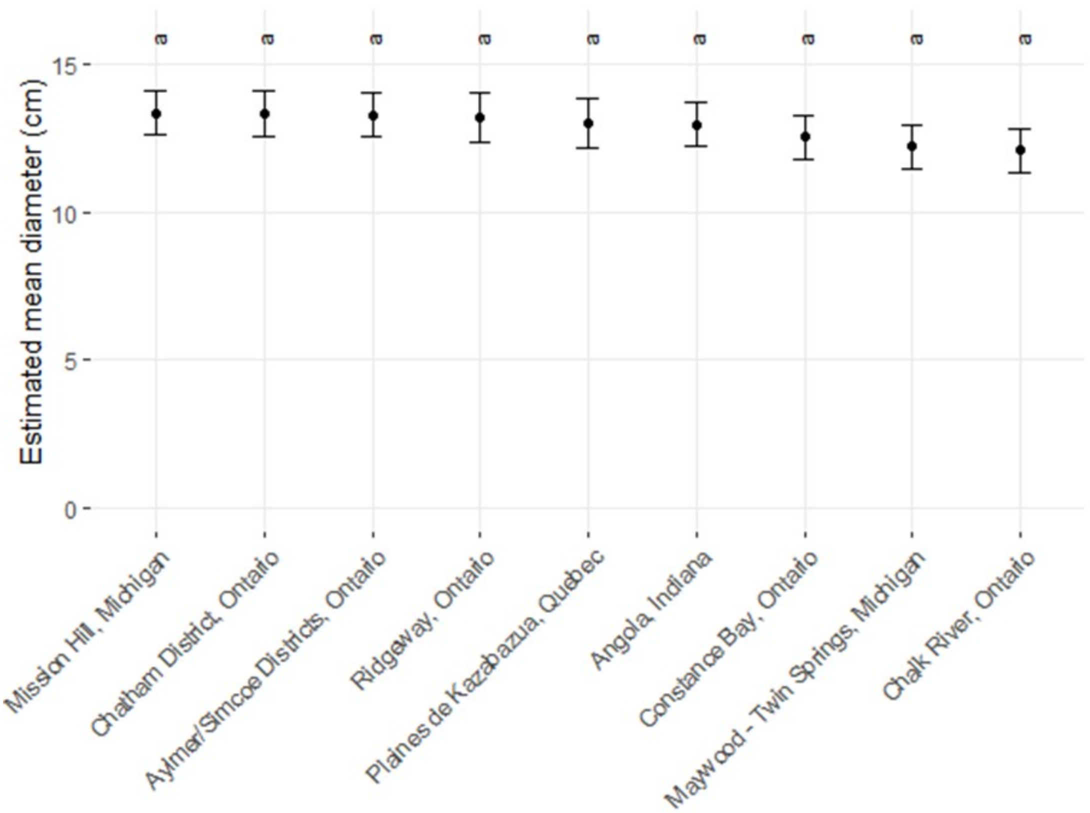
Note 2: Latitude 44°N was used to define ‘Northerly’ and ‘Southerly’ seed origins.

Figure 2: Estimated proportion of trees alive in 2005 by site and seed origin.



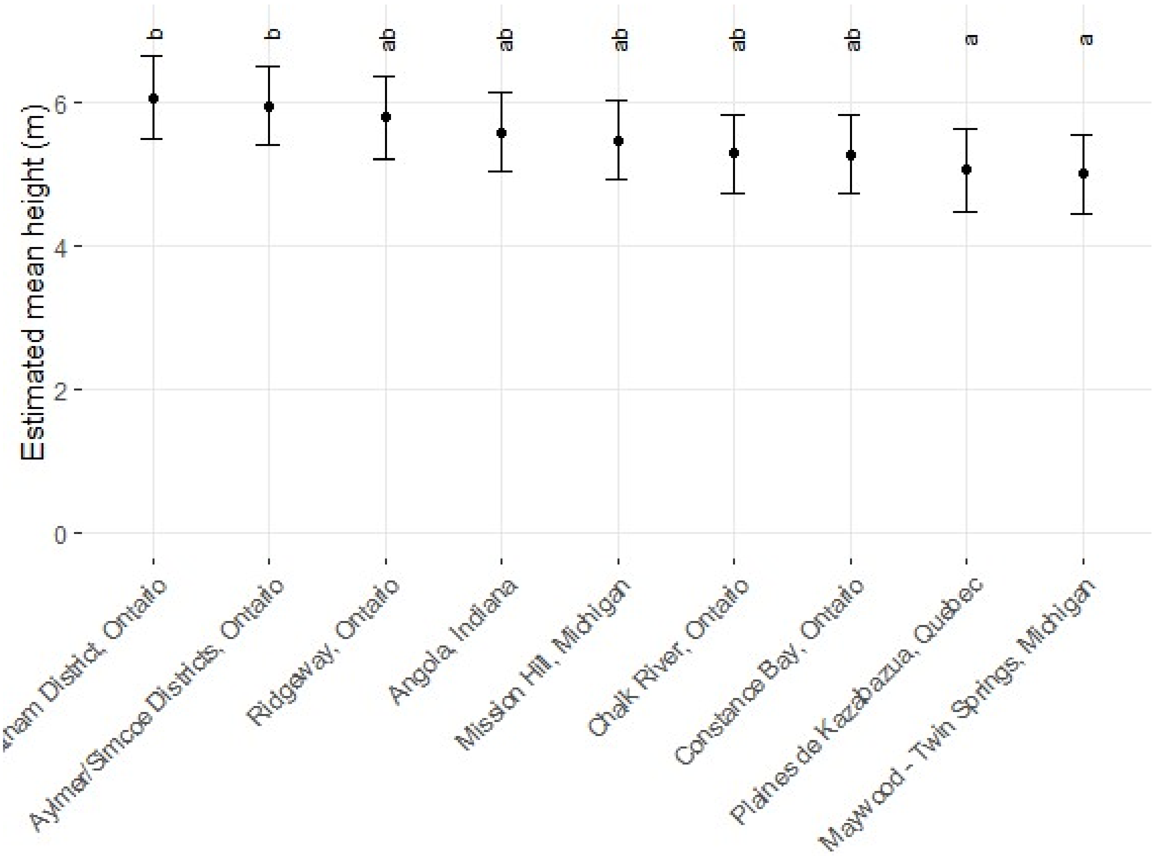
Error bars represent 95% confidence intervals and letters represent significance groupings.

Figure 3: Estimated mean diameter in 2020 at different seed origins averaged over the different sites.



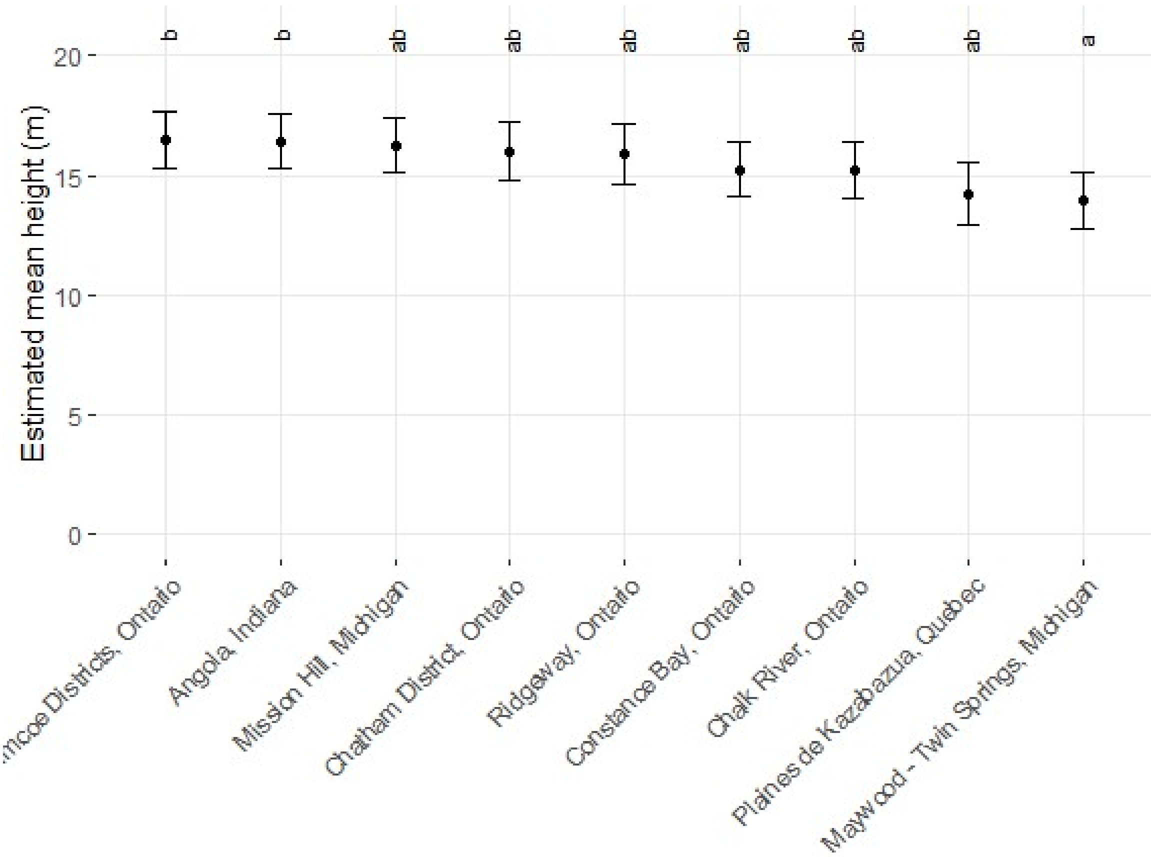
Error bars represent 95% confidence intervals and letters denote significance groupings

Figure 4: Estimated mean height in 2005 for different seed origins averaged over the three sites.



Error bars represent 95% confidence intervals and letters denote significance groupings.

Figure 5: Estimated mean height in 2020 for different seed origins averaged over the sites.



Error bars represent 95% confidence intervals and letters denote significance groupings

Figure 6: Form score 2020

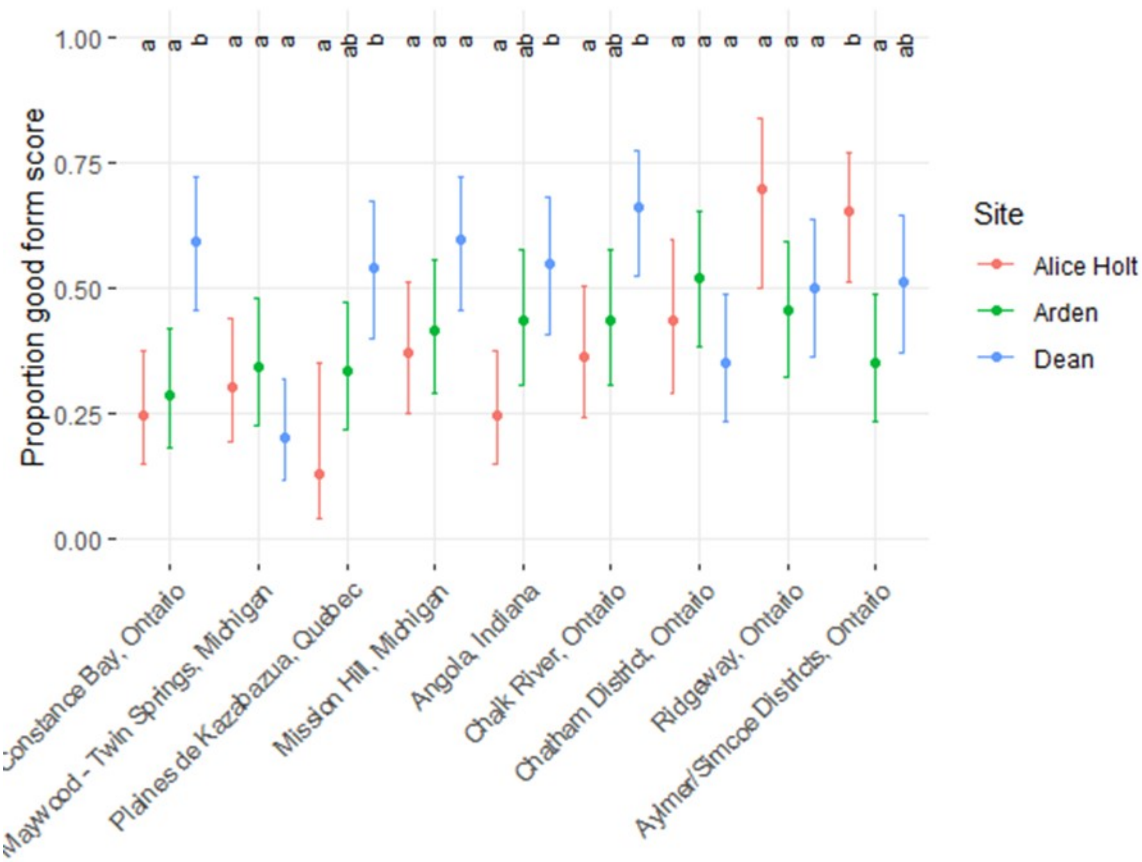
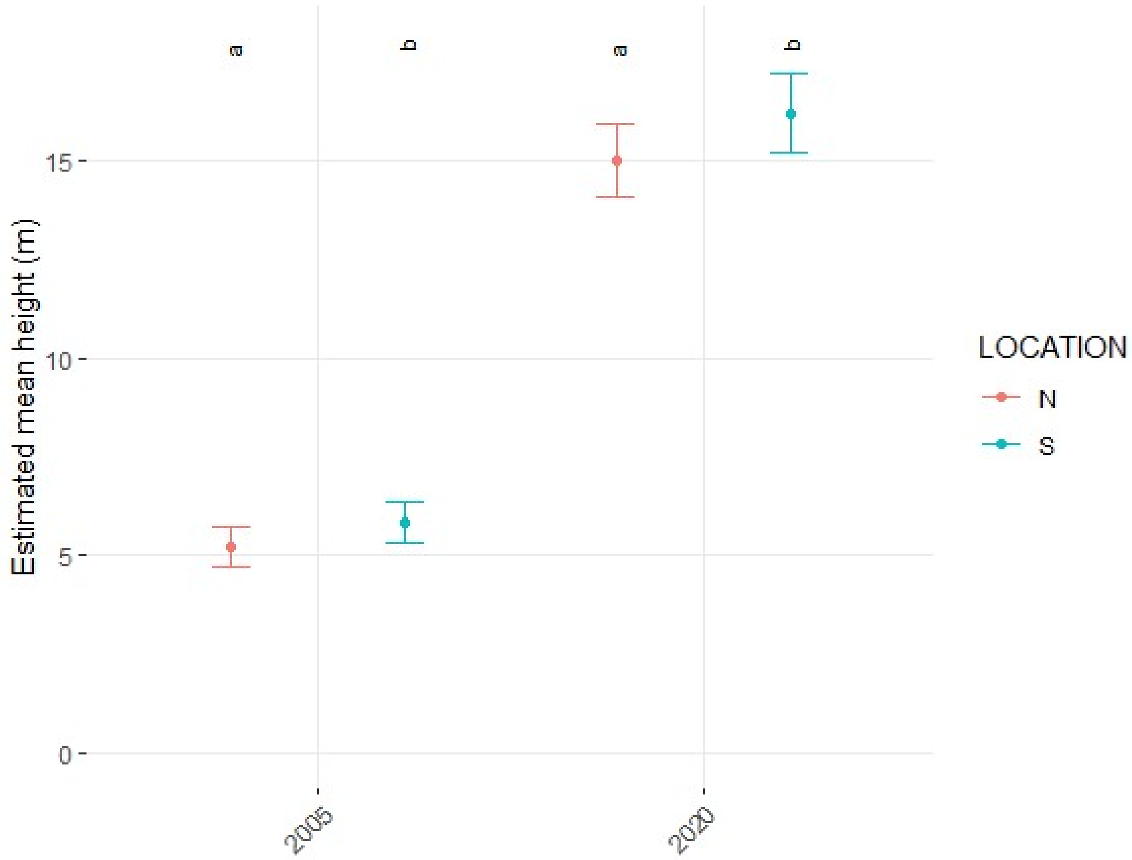


Figure 7: Mean height in 2005 and 2020 for 'north' and 'south' seed origins



Error bars represent 95% confidence intervals and letters represent significance groupings

4.0 References and acknowledgements

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