The effects of site and provenance on survival, growth, stem form and fruiting of *Sorbus aucuparia*

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Master Thesis no. 230

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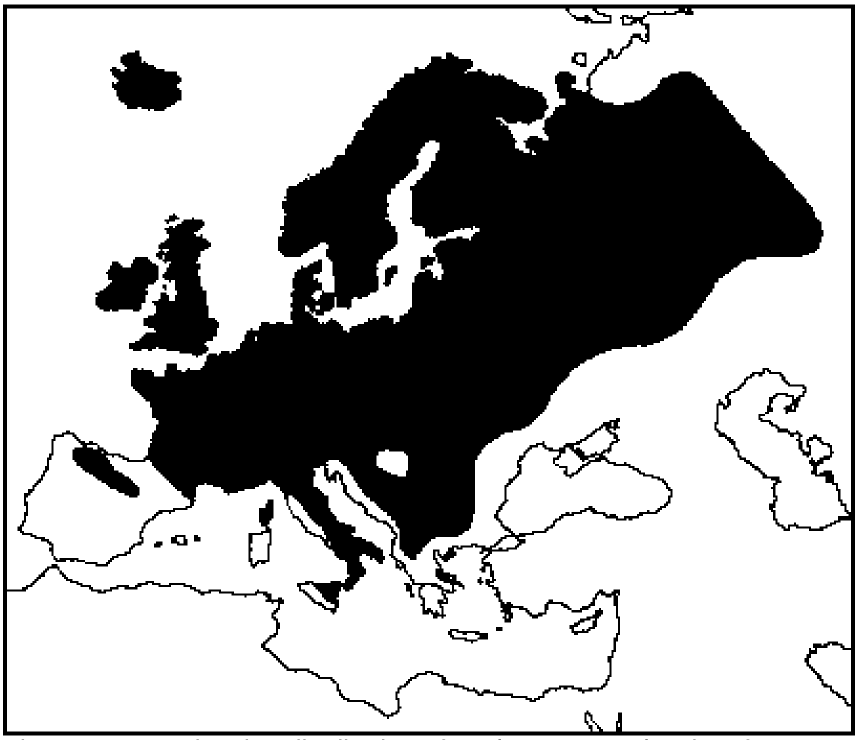
1. Abstract

Sorbus aucuparia (rowan) is a widespread and common tree in Europe, the species has a large amount of genetic diversity and provenance variation. There is little silvicultural knowledge of the species and it is rarely used in forestry. One provenance trial was visited in northern Sweden and four in Great Britain, the aim was to understand provenance and site variation. Seven main traits were studied dbh, number of corymbs or fruit clusters, stem form, number of stems per tree, fork height, percentage of forked trees and survival, in addition height was measured in Sweden. There was a lot of variation from both site and provenance; both factors had an effect on all variables except provenance on survival. One British site, North York Moor, was unsuitable for the species, which was explained by an extreme site gradient and unfavourable site vegetation such as *Vaccinium*. At other sites competition from other vegetation was found to have a large effect on rowan, resulting in higher survival at the most northerly of the British sites and many stems in the southernmost site. Trees with larger diameters and more fruits showed that productivity was higher at southern sites, however the best site overall had the highest altitude and is located in South Wales. Northern provenances generally had better attributes in northern Sweden, such as large trees and more corymbs. Northern British provenances also generally had higher rankings in northern Britain. Some provenances from southern Britain were better in all UK locations although some had very poor performance in the north and some costal provenances were even low ranking in the south. Southern provenances had more fruits in all locations. Provenance selection is important in rowan and if poorly done can lead to reduced performance. A general silvicultural recommendation would be not to use provenances from a more northern origin than their site. Provenances from high altitudes should be considered in northern locations due to higher seed quality.

1.1. Keywords

Sorbus aucuparia, provenances, genetic variation, site requirements, growth, stem form, fruiting, survival

2. Introduction



Picture 1: Map showing distribution of *Sorbus aucuparia* taken from (http://www.pennine.demon.co.uk/Arboretum/Soau.htm). Additional areas (such as Madeira) of the natural range not shown.

Sorbus aucuparia L, is commonly known as both rowan and mountain ash in Britain, however both of these names are also used to refer to species that are not *Sorbus aucuparia L..* The terms European rowan and European mountain ash are less ambiguous but not in common usage therefore for ease the term rowan will be used throughout this report.

Rowan grows throughout Britain and Scandinavia (Picture 1). It is a fast growing, pioneer species that is able to grow in a wide range of sites including hilly, rocky and exposed areas. The best soils for rowan are brown soils and fertile peats, it is tolerant of both acidic and alkaline soils but one of the site limitations for rowan are wet soils (Department of the Marine and Natural Resources, Ireland, Undated). Generally the species is light demanding although trees can grow under shade in early years, and are often found under spruce canopies (Zywiec and Ledvon, 2008). Rowan is often seen growing on exposed and rocky areas such as cliff edges and on mountains, this wind resistance is partly due to deep roots (Myking et al, 2013). Mauer and Palatova (2002) found that root morphogenesis was affected by different soil conditions or terrain. For example in flat terrain roots will branch out whereas taproots will grow against slopes. Wind endangered trees tend to have elliptical root systems to provide support.

Dry					
Intermediate					
Wet					
	Poor		Intermediate		Rich

Table 1: Soil conditions for *Sorbus aucuparia*

When there is sufficient light rowan can exhibit particularly fast early growth and grow 2m/year, typically this slows down after around 25 years and trees live to around 60 years. The species is heavily browsed by many herbivores but due to its multi stemmed nature, fast early growth and hardiness of the tree, the mortality from browsing is relatively low and populations can withstand large numbers of browsers (Myking et al, 2013). However when the terminal leader is lost, release is less likely to occur in newly formed gaps (Motta, 2002). Other secondary shoots can survive when the terminal leader shoot is lost; the multi-stemmed nature is a mechanism that helps the species survive browsers and allows growth under shade. When there is a high browsing pressure this reduces the number of young trees, consequently diameter distribution deviates from the expected reverse J-shape of old growth forests. This J-shape distribution is indicative of a large frequency of young trees and fewer old trees. Rowan has many pioneer qualities, however it differs from more traditional pioneers such as birch as it is shade tolerant when young, can grow horizontally and can take on shrub like morphology (Zerbe, 2001). This allows it to colonize areas immediately after disturbances and trees can survive under canopies for years.

Maturity is typically reached at around 10 years, rowan normally flowers in early-mid summer and fruits begin to ripe in mid-July (Myking, 2013). This timing varies due to climate, trees in northern locations will flower and fruit later. The flowers are arranged in clusters or corymbs and are white in colour, fruits are bright red and eaten by birds such as blackbirds and thrushes. Regeneration of the species is aided by disturbances such as fire and windthrow, which provide gaps in the canopy. Zywiec and Ledvon (2007) found the species growing under spruce canopies especially at forest edges, the mutli-stemmed nature and early shade tolerance allows germination. Rowan is primarily a bird dispersed species which explains the forest edge prevalence as birds often perch here after ingesting fruit where seeds then germinate. When gaps are formed in the canopy the seedlings grow rapidly due to the increase in light, this method allows the species to colonise newly formed gaps after disturbance (Zywiec and Ledvon, 2007). Rowan has difficulties germinating where there is continuous weed cover but it can grow in the vicinity of decaying and decomposing wood (Mauer and Palatova, 2002). A high density of rowan is found under canopies such as spruce that are declining (Zywiec and Ledvon, 2007). This often happens after events that can cause mortality such as bark beetle outbreaks, it is thought that such diseases will increase providing opportunities for species such as rowan. Pure strands of rowan are rare but it is commonly found growing with other species such as spruce, ash, oak and birch and is an important component of broadleaved woodlands. In Britain it is frequently found in the *Fraxinus excelsior- Sorbus aucuparia- Mercurialis perennis* woodland (W9), which is common in Wales, Northern England and Western Scotland (Rodwell, 2003).

Rowan is one of Europe's most northerly growing species and is one of the few species native to Iceland. It is also found growing at the top of tree lines at high altitudes. It can be found at 2200m in the Swiss Alps and grows the highest of British species, at 900m in the Scottish highlands (Kollas et al, 2012, Barclay and Crawford, 1984). Seeds from the coldest locations have been found to be of lower quality however this is not true of seeds that are from high altitudes that have high NSC concentrations and are better quality. Kollas et al (2012) suggested that this may be because at lower attitudes there are a greater number of species and more competition. Rowan trees can be shaded and do not receive so many nutrients that are passed onto their seeds. Barclay and Crawford (1984) found rowan seeds at high altitudes to be smaller than those from high altitudes, this is in opposition to Kollas et al (2012) who put the Barclay and Crawford result down to high altitude seeds being less mature as collection of all the seeds was done at the same time. Trees have been shown to grow faster at higher altitudes and seedling respiration is not affected by altitude. Seedlings from lower altitudes have been shown to grow at lower temperatures (Barclay and Crawford, 1984). Rowan is a tolerant tree species and can grow in fairly high temperatures however the species will suffer when high temperature is combined with a lack of water (Raspe et al, 2000).

Heide (2011) showed that like other species in the Rosaceae family such as pear and apple, rowan has been shown to respond to changes in temperature rather than changes in photoperiod. No growth was observed in temperatures of 9°C and when the temperature increased, growth occurred only after a lag period. Long periods in low temperatures will reduce the growth in lateral buds. A change in day length will not however alter growth at any temperature. It is thought that this response is due to a deficiency in transducing signals not a deficiency in light sensing (Heide, 2011). Part of rowan's distributions is in the boreal zone, this includes the north of Nordic countries. Chilling is known to be a factor that breaks dormancy in trees growing in this area, however the exact procedures that break dormancy are unknown (Linkosalo et al, 2008). Linkosalo et al (2008) found that the bud burst of boreal trees including *Sorbus aucuapria* can be fitted to a 'Thermal Time Model', which involved time and critical temperature thresholds, indicating that trees such as rowan need certain time periods in certain temperatures before bud burst or flowering can occur. This is similar to the lag response found by Heide (2011). Rowan is a species that has masting years, this is thought to be beneficial as it overloads seed predators which increases pollination rates. In Norway trees in the southwest have mast years every other year while in the southeast masting years are every three years.

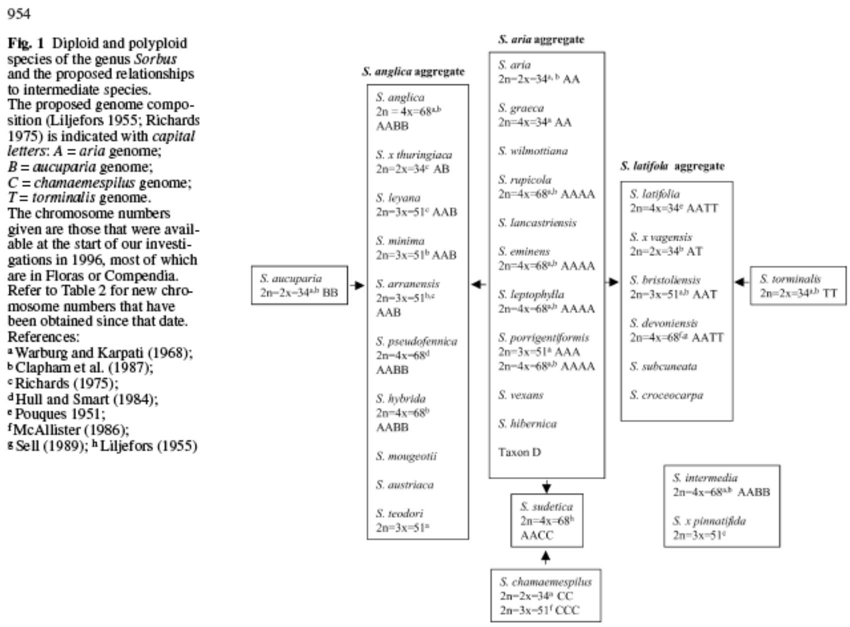
Satake and Bjornstad (2008) explained this as a productivity gradient caused by local adaptation and not due to biological parameters.

While not widely used, the timber from rowan is hard and dense and can be used for small traditional items such as bows, spinning wheels and tool handles. The main use of the wood is for measuring sticks. The relatively small size of trees means that the timber is rarely used for larger items. Due to the multi-stemmed nature of the species it is suitable for coppicing. Following clipping rowan will produce heavier and thicker shoots and more stems. If no mechanical clipping has occured then multi-stems and heavy shoots suggest browsing pressure (Hester et al, 2004). Rowan makes good firewood and the fast growing and coppice nature of the species means it has potential as a biofuel.

2.1. Genetic Variation in Sorbus aucuparia

As a species rowan exhibits a high amount of genetic diversity, however there are not always significant differences between populations from different regions. Raspe and Jacquemart (1998) showed that Finnish populations are separate from South Western and Central Europe populations. This difference is either due to the populations being from distinct glacial refugia or a more recent isolation event. Genetic differences are not dependent on geographical distances. Populations from the Tailles plateau in Belgium showed this, which were shown to have heterogeneity despite small physical distances. This is typical of bird-dispersed species, which do not show population bottlenecks due to long distance dispersal (Raspe and Jacquemart, 1998). The cpDNA is also indicative of long dispersal events and differs from what is commonly found in forest trees that are not animal dispersed (Raspe and Jacquemart, 1998; Myking et al, 2013). The high genetic diversity of rowan is also due to self-incompatibility, which makes it an interesting and suitable species for studying genetic diversity.

Sorbus torminalis and *aria* are more genetically similar than either species is to *Sorbus aucuparia*, all three species have different unique multilocus genotypes (Robertson et al, 2010; Nelson-Jones et al, 2002). It is possible these three groups are actually different genuses. Throughout the Sorbus genus there is evidence of a large amount of hybridization and backcrossing which gives rise to the large number of species (Robertson et al, 2010). Today new species are still being found such as *Sorbus busambareius* and *Sorbus madoniesis,* these were both recently discovered in Sicily and are in the aria subgroup (Castellano et al, 2012). There are hotspots of genetic diversity throughout Europe, including SW Britain and Scandinavia, this is a result of niche colonisation (Robertson et al, 2012). The Avon Gorge in South West Britain has one of the highest diversities of *Sorbus* in the world, however *S. aucuparia* is only a minor component of this area and does not hybridise so freely with *S.torminalis* and *S. aria.* (Ludwig et al, 2012). *Sorbus torminalis* has greater diversity than *S. aucuparia* which Demesure (2000) explained as the result of rowan populations being the result of many small glacial refugia.



Picture 2: Genetics of *Sorbus* genus taken from from Nelson-Jones et al, 2002.

2.1.1. Genetic Variation in Trees

There is less genetic diversity in trees than annual plants due to the longevity of trees and the fact that tree populations are generally more stable. Unlike annual plants, trees exhibit similar diversity in newly established and older populations. Annuals have more diverse younger populations due to the nature of regeneration (Austerlitz et al, 1999). Species that are bird or animal dispersed, such as rowan, tend to have higher genetic diversity (Raspe and Jacquemart, 1998). The long-term health of forests relies on high genetic diversity, for instance pest and disease response is linked to genetic diversity (Evoltree, 2010). There are threats to forest health and genetic diversity such as climate change, landuse and habitat fragmentation (Kremer, 2006). Poor silvicultural practices and selection of unsuitable provenances can also have negative impacts on tree populations.

2.2. Climate Change and Forests

The exact consequences of climate change are unknown, there are however some likely outcomes. Predictions include an increase in extreme weather events such as storms and forest fires. On the positive side forest productivity is likely to increase, on the other hand there will be a northwards spread of pests and diseases, and water availability is likely to decrease in coniferous forests (Lindner, 2006). There are also predictions of how forests and tree populations will adapt. There is some evidence that trees are already adapting to an increase in carbon dioxide and it is thought that adaptation of forest trees can occur in as little as two generations. For species such as rowan this could happen in as little as 15 years. Tree species migration is, however, a very slow process, slower than projected climate change even for bird dispersed species. It is likely that the rate of anthropegenic climate will be faster that tree evolution or migration. Fragmented populations, which often have the greatest diversity, are less likely to adapt to changing conditions and are likely to be most threatened (Savolainen, 2006). Large and diverse populations are more likely to adapt.

The geographical distribution of trees is likely to change, however envelopes will remain fairly constant which could result in a northwards shift in populations (Kremer, 2006). As native European tree species have been subjected to many previous extinction events, our tree species are 'survivors' and it is unlikely that entire populations will become extinct. Human intervention will however be important in aiding tree response to ensure health and productivity, landscape fragmentation means that human intervention is even more important (Matyas, 2006 Kremer, 2006). Climate change will cause trees to be out of equilibrium with their environment, this will threaten forest biodiversity which is often said to be a by product of equilibrium (Kramer, 2006). Group selection is an adaptive response and will aid the maintenance of genetic diversity (Kramer, 2006). Provenance trials indicate that trees do have an adaptability to a range of climatic and moisture conditions (Matyas, 2006). Genetically set limits mean that species will be threatened by climate change; populations that are most at risk are fragmented ones or those at limits, which highlights the importance of human interference for maintaining genetic diversity and forest health.

2.3. Rationale

Despite being one of Europe's most widely distributed and hardiest trees, *Sorbus aucuparia* is under used in forestry and silviculture. There are however many potential applications such as for biofuel, in mixtures and in changing climates. The large genetic variation and relatively short life span mean that the species could have wide applications. A lack of knowledge of provenance variation could result in a poor seed selection, especially considering the large number of ornamental varieties.

The aim of this study is to look into how provenance and site affect growth, stem form, fruiting and survival and what the provenance variation is. The exact cause of provenance variation will be interesting for example there could be a geographical gradient relating to factors such as longitude or there could be a scattered variation caused by a variable such as rainfall. Rowan is thought to be a tree species that can grow almost anywhere in Northern Europe, however there are some site limitations such as waterlogging. Links and correlations between measured variables will also help to give an overview of the species and may have silvicultural applications.

2.3.1. Hypotheses

Using knowledge of the tree species and productivity gradients in Europe mean that a number of assumptions or hypotheses can be formed. These are as follows:

1. The provenance will have a large effect on survival, growth, stem form and fruiting as there is lots of genetic variation in the species.
2. Provenances with northern climates will not be suited to southern sites and will have poorer stem form.

3. When grown close to their origin provenances will have better growth, stem form, survival and more fruits.
4. Provenances from the north will flower and produce fruits earlier than provenances from the south.
5. Southern sites will be more productive and trees will have higher survival here.
6. There will be little difference in the survival of the species between different sites.

3. Materials and Methods

3.1. Data Collection

3.1.1. Sites

Data was collected in June-August 2013 from the Swedish site Innertavle (1 site) and Great Britain (4 Sites). The site in Sweden was visited 11-14th June 2013 and data was collected, it is situated close to Umea in Vasterbotten Country, Northern Sweden. Alice Holt is a site near Farnham in Surrey, Southern England it was visited and data was collected 15-16th July. The third site, North York Moor, near Pickering, North Yorkshire was visited and data was collected 26th-27th July. Data was collected from Dornoch, near Lairg, Sutherland in the Scottish Highlands on 8-9th August 2013. Llandovery, near Brecon, Carmarthenshire, mid Wales was visited and data was collected 12-13th August 2013. In Sweden December 2012 was cold followed by a mild January, early spring was cold and sunny. Mid- late spring was warm and rainfall was high in early June (smhi, 2014). In Britain, July 2013 was the sunniest since 2006, this followed a late winter and spring and the coldest spring since 1962. The rainfall and temperature were not exceptional despite the seasons being more extreme (Annual, 2013). See tables for additional information such as soil conditions at all sites.

3.1.2. Measurements and Variables

The variables recorded were:

- diameter at breast height (mm)
- number of fruits (Britain only)
- number of corymbs (Sweden only)
- stem form (0-3)
- number of stems (per tree)
- fork height (cm)
- height (Sweden only).

Missing/dead trees and if the tree had a fork were recorded as well as some observations. DBH of the largest stem was measured with electronic callipers in mm at breast height (130cm). Trees under 160cm in height were recorded as having a diameter of zero as when measuring at breast height there will not be a sufficient stem to measure. Clusters of fruits were counted and only those that were significant in size were counted, an example of this is shown below. Clusters were counted in ones up to ten, in twos from 10-20 and in fives above 20. If there was dispute about the number of fruits then an in between number was chosen (eg some trees recorded as 102 fruits). The number of stems per tree was counted, only living stems were counted. Stem form was recorded on a scale of 0-3 with 0 being the worst. The straightness and lean were taken into account, examples can be seen below.

Pictures 3 and 4: left hand side a fruit cluster that would be counted. Right hand side a small fruit cluster that would not be counted.

Picture 5, 6, 7 and 8; examples of stems form scoring 0, 1, 2 and 3

Fork height was measured with a 2m stick in 5cm increments. A fork was defined as a branch at an acute angle that is at least one third of the main stem. For very small trees this definition was not applied and a fork was considered to be something entirely split from the stem. This definition was mainly used at North York Moor where there were a large number of very small trees. Trees that were dead or missing were recorded, in the final analysis dead and missing were given the same value. Other observations recorded were nearly dead, dying, main stem dead and spotted leaves. Nearly dead trees were those with dry lifeless stems and few leaves, these trees often looked dead at first sight. Dying trees were unhealthy looking often with wilted leaves, this condition did not appear as bad as nearly dead trees. Main stem dead were multi stemmed trees where the largest stem was dead and the only living parts were a few small stems. Spotted leaves was recorded when leaves were covered in small dead, brown dead patches which appeared to be detrimental to the trees health. The cause of this is unknown but is possibily mountain ash ring spot.

3.1.3. Swedish Sites

The experiment at Innertavle was one of three rowan provenance trials set up in northern Sweden. This experiment was planted in autumn 1993, there were 651 trees in total from 35 different provenances from all over Sweden (see map). Rowan trees were grown in rows and provenances were randomly distributed along these rows. Provenances were distributed unevenly some provenances such as 62 and 12 had over 100 trees while others had only 1 or 2 trees. All trees were measured at Innertavle because of this uneven distribution, there were between 1 and 250 trees of each provenance. Every row apart from the first two of the experiment had had all additional stems removed, mechanically.

3.1.4. British Sites

The British experiment was set up by the forestry commission in 2006 and was in the four sites listed above. Each site contained between 34-42 provenances collected from all over Britain, see map. The sites were arranged in 3x3 plots, these plots were replicated approximately 3 times per site and were randomly distributed over the site. Trees were 2m x 2m apart and every site was surrounded by a two tree wide buffer zone. All the sites were fenced at the start of the experiment although the fencing had been taken away at Alice Holt and Llandovery a few years previously due to the fact the trees were large and established and did not need protection from browsers any longer.

3.1.4.1. Data Collection

Due to time constrictions, the aim was to collect data from one plot of each provenance at each site. However this was not possible in all sites, some provenances were not measured at Alice Holt and more than one of some provenances was measured at Alice Holt, North York Moor and Llandovery. Considering that site was also an interesting variable in this study, plots were measured from all ends of the sites, in order that any effects of site were recorded. Certain provenances were measured more than once at North York Moor due to the poor survival, as in some instances only 3 trees had survived. Each plot contained 9 trees however some trees were dead or missing meaning that fewer than 9 trees were measured for some provenances. Between 5 and 26 trees per provenance per site were measured at all British sites. An additional study looking at survival was done at North York Moor to record the effects of site, which appeared to have a gradient. The site maps and data plot that were recorded are attached.

3.1.4.2. Survival at North York Moor

Due to the poor survival at North York Moor, an attempt was made to ensure that at least 5 trees from each provenance were sampled- this resulted in the selection of an additional plot to measure for some provenances. An additional study was done at North York Moor looking into the survival and site gradient. Every tree was recorded as being either over 160cm (and therefore measured as having a diameter), a tree under 160cm – which was any tree that looked healthy, vigorous and sizable, or not a tree – this category is different from dead or missing as it also included trees that were very unhealthy and appeared to be dying. Dominant site ground floor vegetation was recorded at all four British sites as well as any other tree species regeneration

3.2. British Sites and Provenances

The four British sites were selected to provide coverage of the island in both a North-South and East-West direction. These are the two main factors that influence the climate, the west of the country is wetter than the east and the north is colder than the south. In addition to climatic variation at the sites there is also variation in geography and plant communities at each of the four sites. Dornoch is the most extreme of the four sites, it is in the Highlands (north Scotland), which is characterised by low temperatures and fairly high rainfall. There are few tree species, especially broadleaves here and the productivity is low in this area. North York Moor is a coastal location, approximately 10km inland from the North East coast of England. This is a fairly dry but elevated site, much of the habitat in this area is Vaccinium- or Calluna-rich moorland. Llandovery is on the edge of the hilly Brecon Beacons National Park; of the four locations it has the highest elevation and most rainfall. Due to the fresh soils this is listed as the most suitable site for rowan by the Forestry Commission much of this area is home to *Fraxinus excelsior-Sorbus aucuparia-Mercurialis perennis* woodland. Alice Holt is the most mild of the four British locations, it is fairly dry and warm and in an area rich in temperate broadleaved woodland.

Provenances were selected to represent the variation within Britain and also in accordance with Forestry Commission seed zones, see accompanying map and tables for detailed information. Locations in the South East of Britain should have the most favourable conditions for tree growth and the highest productivity. Provenances from this location are Seal Chart and Saxonbury Hill. The North West of Scotland should have the most unfavourable conditions for growth and the lowest productivity. Assynt and Add Valley are from this location; Allt Volagir is from the Outer Hebrides a very northwesterly group of islands with few trees.

In accordance with the Met Office, Britain can be divided into 9 regions. Below is a map and table describing the rainfall, temperature and hours of sunshine and in which region each provenance lies.

Region	Annual Rainfall (mm)	Max temp (°C)	Min temp (°C)	Sunshine (days)	Provenances
Scotland North	1609.4	10.4	4.1	1161.0	Assynt, Inverpolly Craigdarroch, Bunchrew, Tokavig, Allt Volagir, Glen Loy, Salen
Scotland East	1073.7	11.0	3.8	1288.1	Cleanhill Wood, Birks of Aberfeldy, Pressmennan Wood, Ettrick Water

Scotland West	1717.5	11.4	4.9	1271.3	Add Valley, Strathlachlan, Mugdock Country Park, Falls of Clyde, Glenlee, Stroan Bridge, Lochwood
England East and North East	705.5	12.5	5.2	1505.2	Castle Eden Dene, Ashberry and Reins Wood, Forge Valley and Raincliffe Woods, Moor Farm, St Helens Wood
England North-West and Wales North	1198.8	12.2	5.4	1405.3	Gelt Wood, Duddon Valley, Ugly House, Beddgelert
Midlands	758.7	13.2	5.5	1512.7	Brignall Banks, The Ercall, Pepper Wood, Chestnuts Wood
East Anglia	561.6	13.8	5.9	1589.5	Felbrigg Great Wood, Cutler's Wood
England South-West and Wales South	1224.5	13.2	6.2	1584.4	Brechfa, Mynydd Du, Horner Wood, Holford/Hodders Combe, Kings Bottom
England South East and Central South	805.7	14.0	6.1	1588.3	Seal Chart, Saxonbury Hill

Table 2 showing British regions and annual rainfall, maximum and minimal annual temperatures and days of sunshine for 2013.

3.2.1. Tight Data Set

Due to the irregular site conditions at North York Moor and the fact that not all provenances were represented at all sites a new data set was created. This data contains the three British sites that can easily be compared (Alice Holt, Dornoch and Llandovery) without any effects of the extreme factors that appeared to be present at North York Moor. Any provenances that were not represented at all three sites were also eliminated- leaving 26 provenances at three sites. The provenances in the tight data set are Add Valley, Ashberry and Reins Wood. Beddgelert, Brechfa, Castle Eden Dene, Chestnuts Wood, Cutler's Wood, Duddon Valley, Ettrick Water, Falls of Clyde, Felbrigg Great Wood, Forge Valley, Gelt Wood, Holford/Hodder's Combe, Horner Wood, King's Bottom, Moor Farm, Mynydd Du, Naddle Forest, Pepper Wood, Presmennan Wood, Saxobury Hill, Seal Chart, St Helen's Wood, Stroan Bridge and The Ercall. Due to the experimental layout there is a lack of provenances from Scotland in this data.

3.3. Data Analysis

Data was recorded on an allegro electronic field computer then analysed using Microsoft Excel and R Studio. The aim was to look at how site and provenance affected the seven variables. Quadratic mean diameter (QMD), number of fruit clusters, number of stems, stem form, fork height, presence of forks and survival. Quadratic mean diameter was calculated using the formula Dg = Σ√(Di2)÷n, where Dg is QMD and Di is the dbh of tree number i. This value is preferable as trees with larger diameters are given a higher weighted value, therefore this measurement is closer to basal area.

3.3.1. All Data

Mean values were calculated for the seven variables for each site, each provenance and each provenance at each site (where represented). The lowest and highest value, the 25%, 50% and 75% quantile and the standard deviation for each variable (except fork% and survival) were calculated for each site and box plots were drawn. This was not done for provenance as there were too many different provenances with too few replications for the data to be meaningful.

In order to compare the provenances with one another a ranking system was devised for the provenances. This involved finding the best mean value for each variable per provenance and site and calculating each mean as a percentage of that best variable. Where a lower number was preferable, eg number of stems, this value was taken away from 100. After this was calculated every variable for every combination of site and provenance was obtained. These seven variables were then added together and divided by seven to get on overall percentage of tree health. Height was also used at Innertavle. This produced a provenance ranking between all provenances as well as for the sites combined. A larger QMD is favourable as are a higher number or fruit clusters, a fewer number of stems, a higher stem form, a greater fork height, a low presence of forked trees and high survival. Presence of forked trees and survival were both measured as percentages of site, provenance or site and provenance.

More fruits and flowers are favoured as this increases the number of seeds produced. It is also aesthetically pleasing and encourages seed predators such as birds, which has positive biodiversity impacts. Fewer stems are preferred as this is likely to result in single larger stems. If more stems are being produces as a result of browsing, then fewer stems may be an indication that browsers do not favour the provenance. In the provenance ranking all variables are calculated as a percentage and therefore given equal weight. However there is likely to be less variation in survival than number of fruits, therefore this may have an unfair weighting. In addition some variables are possibility not as silviculturally important in the selection of rowan provenance or reflect different management objectives. For example if the objective is to increase biodiversity then more fruits would be favoured over stem form, if high quality timber was the objective dbh is likely to be the most important variable.

3.3.2. Swedish Data

As the distribution of provenances was uneven at Innertavle, when doing the bulk of the data analysis not all provenances were used. The provenances that are discussed in terms of means are 12, 19, 23, 43, 53 and 62 as these provenances were represented by at least 20 trees. One-way anova tests were done to look at the effects of provenance on diameter, stem form, corymb number, stem number, height and fork height.

3.3.3. North York Moor Data

Due to the poor survival of trees at North York Moor, the aim was to investigate whether this result was caused by positional effects or provenance or a mixture of the two factors. One-way anova tests were done on all of the factors first to see if they were relevant followed by two-way anovas looking at the significant factors only.

3.3.4. Tight Data Analysis

Two-way anova tests were done in the programme R Studio in order to look at the effect of site, provenance as well as the combined effect of site and provenance on all of the variables.

The formula for anova tests is

$$F = \frac{MST}{MSE}$$

Where MST= mean sum of squares due to treatment

$$MST = \frac{SST}{p-1}$$

Where SST = sum of squares due to treatment

$$SST = \Sigma n(x-\bar{x})^2$$

p = number of populations

n = number or samples in populations

MSE=mean sum of squares due to error

$$MSE = \frac{SSE}{N-p}$$

Where SSE = sum of squares due to errors

$$SSE = \Sigma n(n-1)s^2$$

Where S = standard deviation of samples

N= number of observations

In order to work out which of the sites were statistically different from one another Tukey's Honest Significant Differences (HSD) tests were carried out.

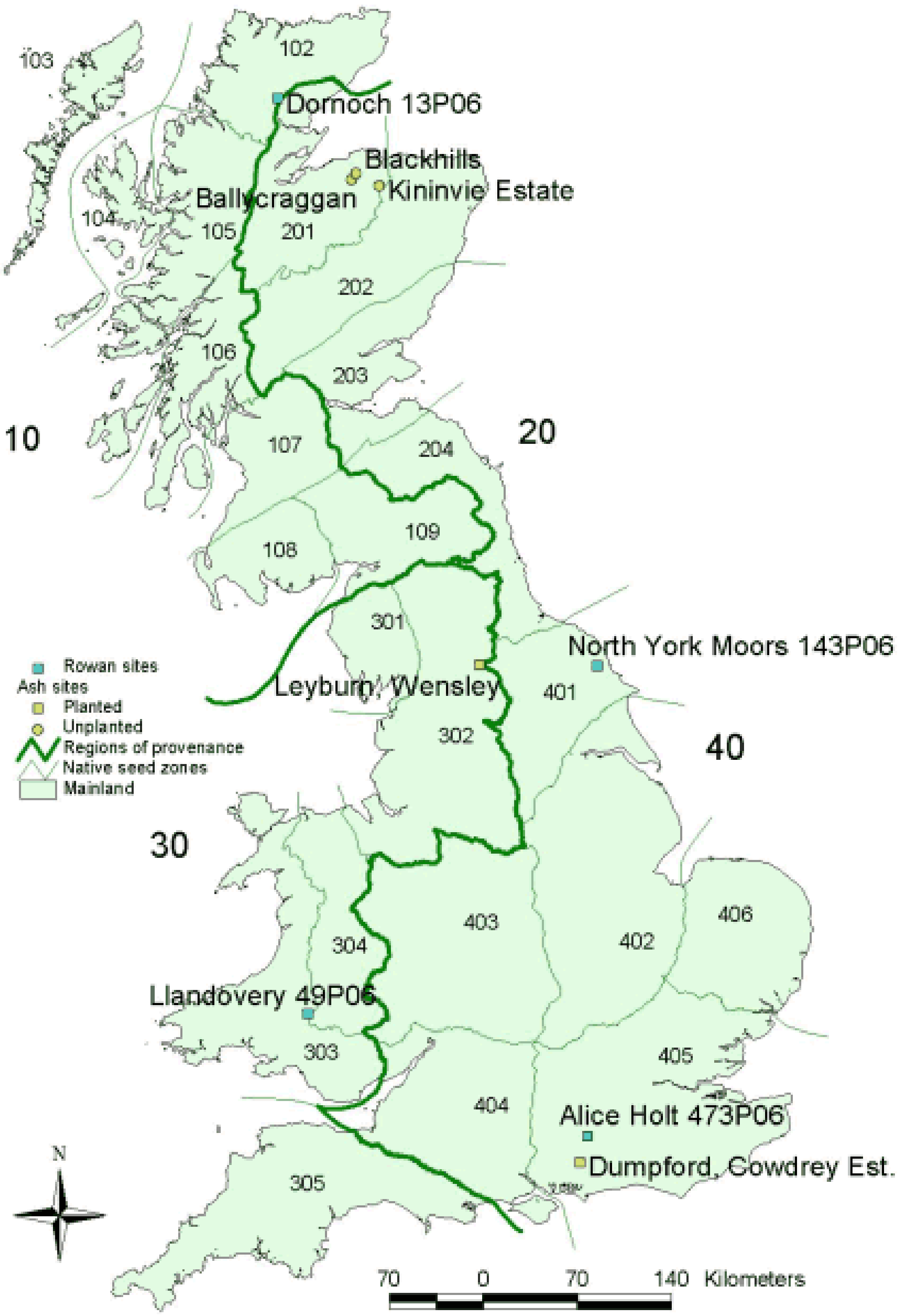
The formula for Tukey HSD test is $\frac{M_1-M_2}{\sqrt{MSw\left(\frac{1}{n}\right)}}$

Where M = treatment/group mean

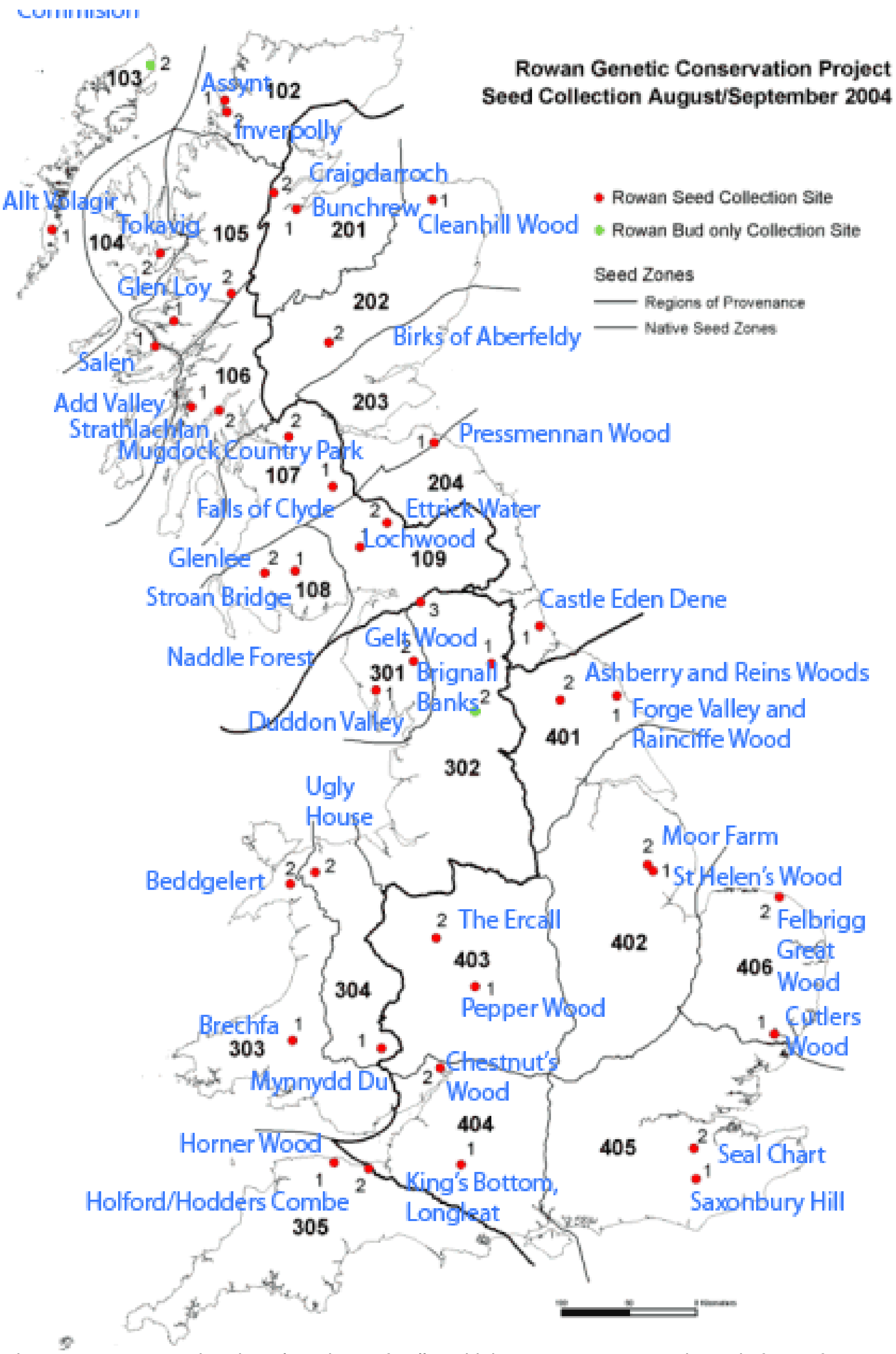
n = number per treatment

MSw= Mean squares width

This was not done for provenances due to the large number of different provenances. The data from Innertavle was not included in the anova tests as the experimental design was different and the experiments started at different times. Pearsons, Kendalls and Spearmans correlation coefficient were calculated between each of the seven variables as well as with latitude, longitude, rainfall and temperature.



Picture 9: Map Showing the rowan trial sites (Forestry Commission, 2014)



Picture 10: Map showing location of all British Provenances, adapted from forestry commission

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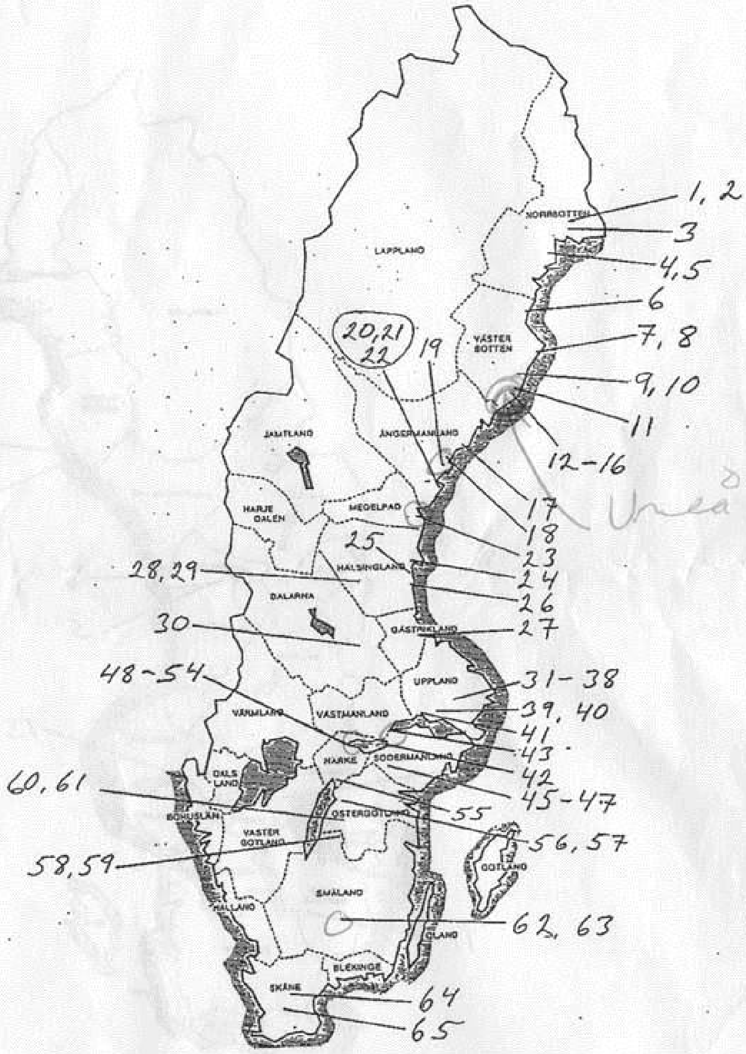


Ursprungsorter för rönn

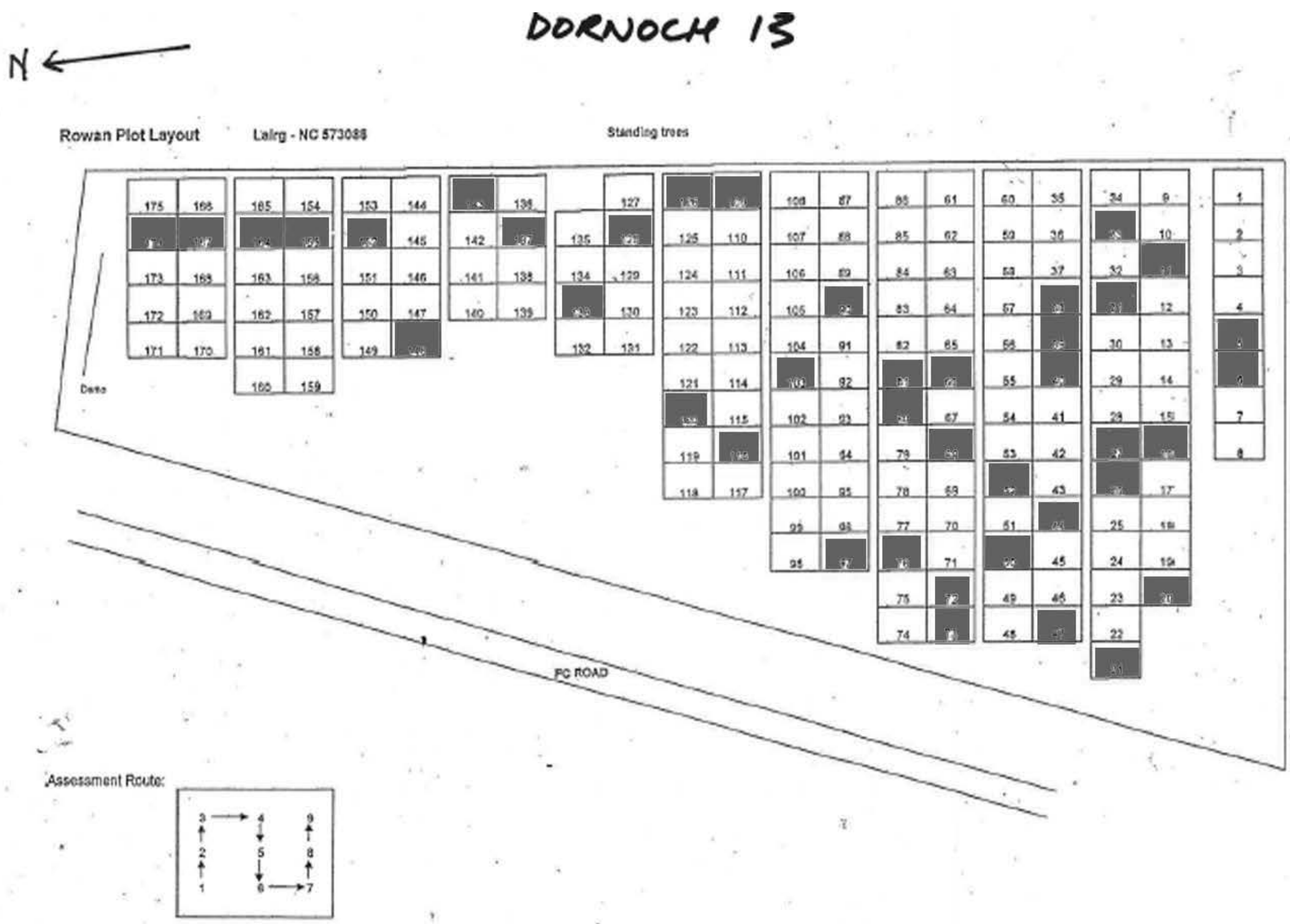
Picture 10: Map showing location of Swedish provenances

Site	Altitude (m)	Annual Rainfa	SMR	SNR	Suitability for Rowan	Habitat	Soil Depth	Organic Matter	Soil pH	Temp (°C)	Parent Material	Soil texture
Dornoch	140	1196.3	Very moist	Very Poor	Suitable	Coniferous Woodland	Deep			8.03	Glacial	Clayey loam to sandy loam
North York Moor	195	692.4	Moist	Very Poor	Suitable	Coniferous Woodland	Intermediate	Medium	Strongly acidic	9.16	Sandstone	Silty loam to sandy loam
Llandovery	245	1551.0	Fresh	Poor	Very Suitable	Coniferous Woodland	Intermediate	Medium	Strongly acidic	10.24	Sandstone and Mudstone	Sand to loam
Alice Holt	95	755.5	Very Moist	Medium	Suitable	Broadleaved Woodland	Deep	Medium	Moderately acidic	11.35	Claystone/ Mudstone	Loam to clay
Innertavle	21					Forest, coppice	Deep			3.6	Boulder Clay	Medium

Table 3 showing conditions of the five sites data tsken from Forestry Commission and mySoil, 2014

Site	Dornoch	North York Moor	Llandovery	Alice Holt
Ground Floor Vegetation	Heather (*Calluna vulgaris)* Sphagnum moss Rosebay Willowherb (*Chamerion angustifolium)* Various grasses Fern Raspberry (*Rubus occidentalis)*	Heather Gorse (*Ulex spp)* Blueberry (*Vaccinium corymbosum)* Various grasses Rosebay Willowherb Foxglove (*Digitalis purpurea)* Blackberry (*Rubus fruticosa)* – one end only Bracken fern (*Pteridium aquilinum)* – one end only	Blackberry Various grasses Rosebay Willowherb Stinging Nettles (*Urtica dioica)*	Bracken Blackberry Honeysuckle (*Lonicera)*
Tree Regeneration	Birch (*Betula)* Fir (*Abies*)	Birch Oak (*Quercus)* Fir	Birch	Birch Oak
Habitat and Classification Type	Trichophorum cespitosum - Erica tetralix wet heath (M15) Trichophorum cespitosum - Eriophorum vaginatum blanket mire (M17) Calluna vulgaria - Vaccinium myrtillus-Sphagnum capllifolim heath (H21)	Calluna vulgaris- Ulex gallii (H8) Calluna vulgaris-Erica cinerea (H10)	Quercus spp - Betula spp _ Deschampsia flexuosa woodland (W16)	Quercus robur-Pteridium aquilinum - Rubus fruticosus woodland (W10)

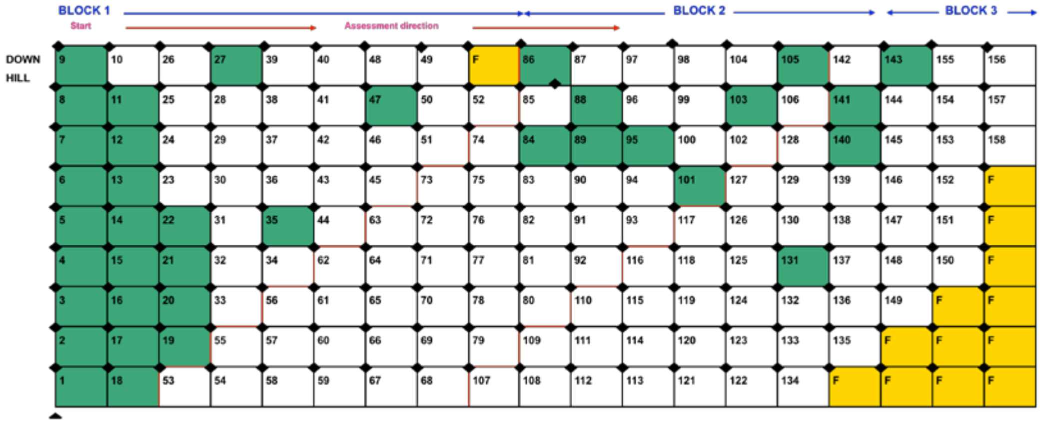
Table 5 showing observed vegetation at the four British sites



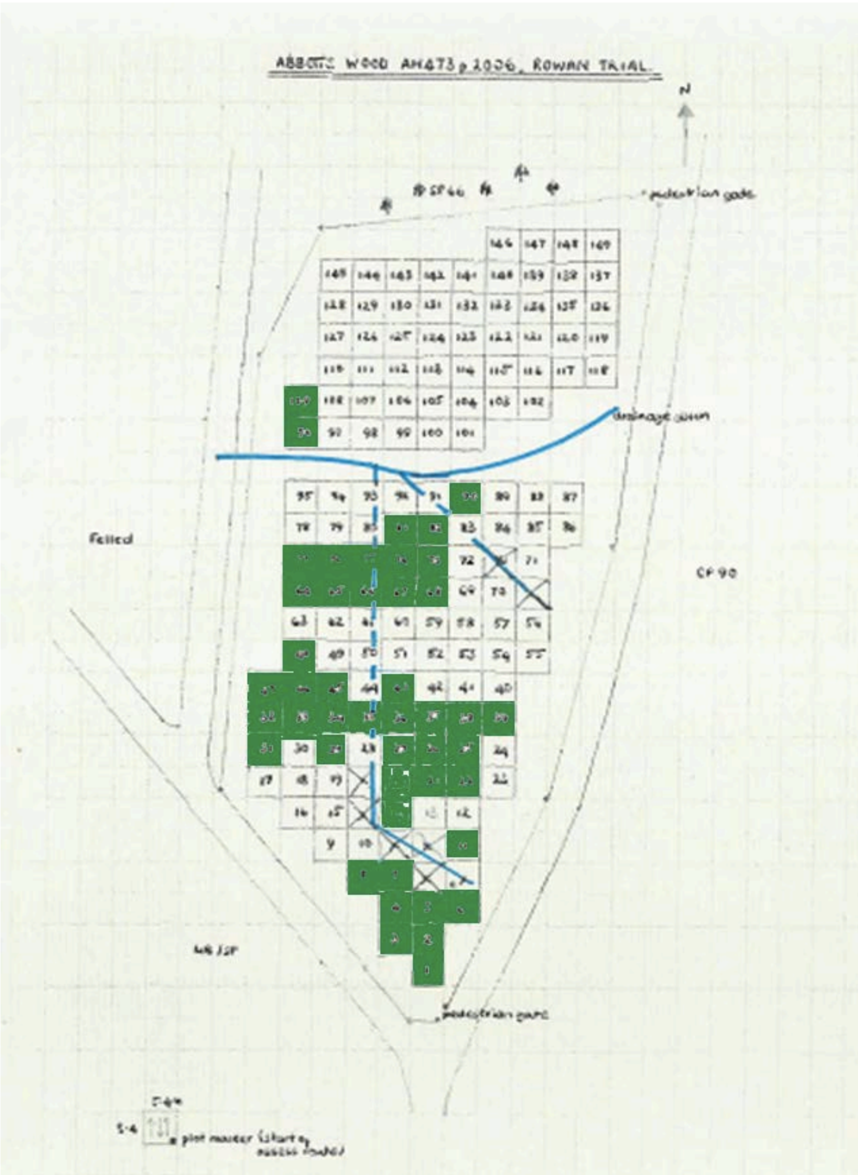
Picture 12: Site layout and plots measured (marked in green) at Dornoch

	1	2	3	4	5	6	7	8	9	10	11	12
15	15	16	45	46	75	76			133	134		
14	14	17	44	47	74	77	104	105	132	135	162	163
13	13	18	43	48	73	78	103	106	131	136	161	164
12	12	19	42	49	72	79	102	107	130	137	160	165
11	11	20	41	50	71	80	101	108	129	138	159	166
10	10	21	40	51	70	81	100	109	128	139	158	167
9	9	22	39	52	69	82	99	110	127	140	157	168
8	8	23	38	53	68	83	98	111	126	141	156	169
7	7	24	37	54	67	84	97	112	125	142	155	170
6	6	25	36	55	66	85	96	113	124	143	154	171
5	5	26	35	56	65	86	95	114	123	144	153	172
4	4	27	34	57	64	87	94	115	122	145	152	173
3	3	28	33	58	63	88	93	116	121	146	151	174
2	2	29	32	59	62	89	92	117	120	147	150	175
1	1	30	31	60	61	90	91	118	119	148	149	176

Picture 13: Site layout and plot measured (marked in gray) at North York Moor



Picture 14: Site layout and measured plot (shown in green) at Llandovery



Picture 15: Site layout and plots measures (marked in Green) at Alice Holt

Picture 16: Site at Dornoch
Picture 17: Site at North York Moor

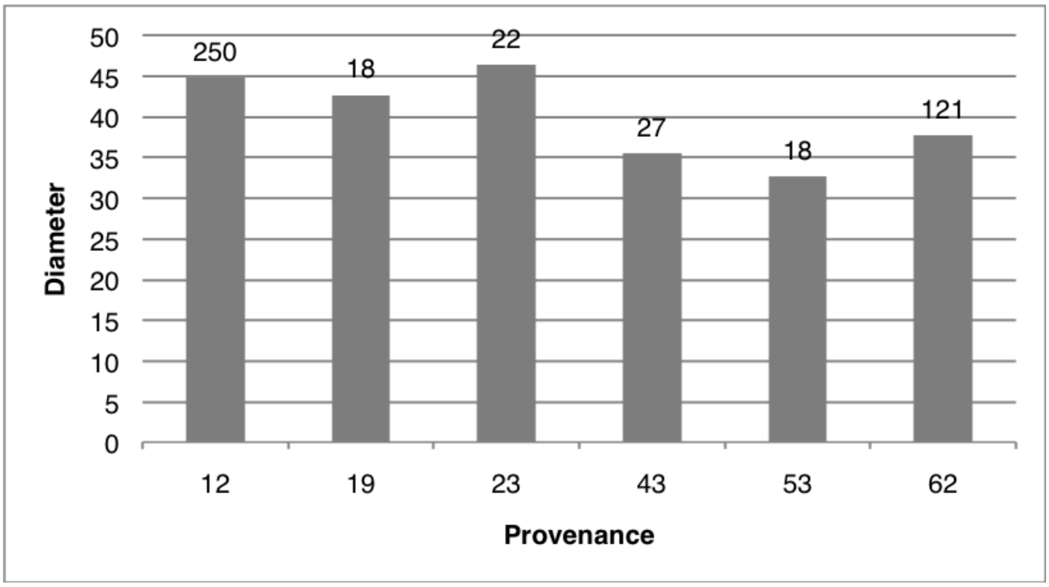
Picture 18: Site at Alice Holt

Top. Picture 19: Site Vegetation at Dornoch.
Bottom. Picture 20: Site Vegetation at Alice Holt.
Left. Picture 21: Area surrounding Llandovery.

4. Results

4.1. Innertavle

The QMD for all trees at Innertavle was 42.37; the provenance with the highest QMD was 12 (49.64) this provenance is from the most northerly location. Southern provenances such as 62 had lower QMDs (42.10). Diameter appeared to decrease with lower latitudes; the coastal position may have a larger effect as provenances 12, 19 and 23 are all from the north-east coast of Sweden. The effect of provenance on diameter was statistically significant (Table 6) The southern provenances 43, 53 and 62 are all from inland locations. One-way anova tests stated that the effect of provenance on diameter was significant. When looking at all the provenances, there is a lot of variation. The group of northern provenances 1-29 appear to be consistently larger than the southern ones, while in this group some provenances are larger there is also considerably more variation (graph 1).

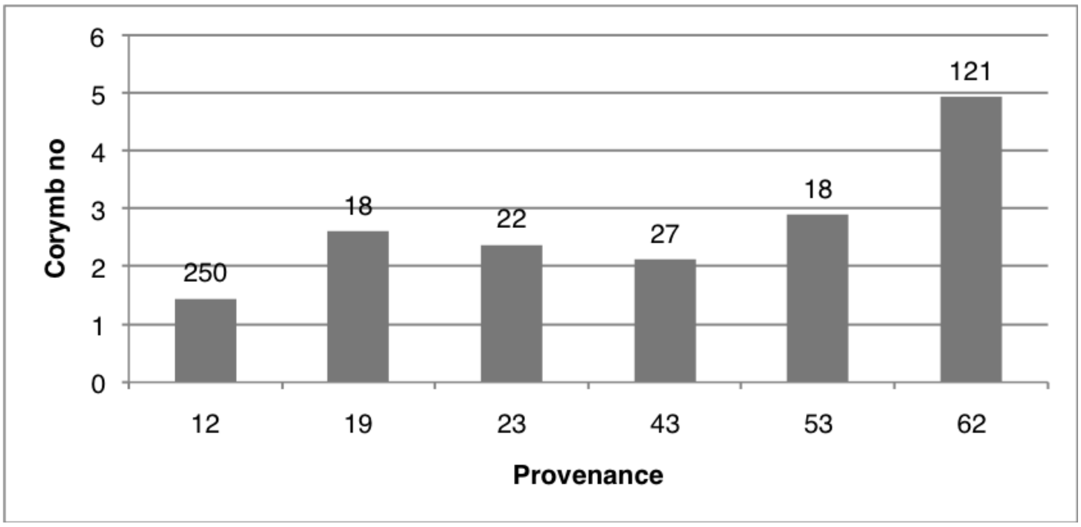


Graph 1: Bar graph showing Swedish provenances and Quadratic Mean Diameter, number of replications shown above bar

	Degrees of Freedom	Sum Square	Mean Square	F Value	P>F
Provenance	1	6203	6203	16.2	$6.53*10^{-5***}$
Residuals	541	207215	383		

Table 6: Results of anova test on diameter and provenance at Innertavle

The number of corymbs at Innertavle was 2.3, most trees had no corymbs. There were more mean corymbs on provenance 62 (5) than on provenance 12 (1.4). The southern provenances at Innertavle tended to have more corymbs than the northern ones. Provenance was a highly statistically significant factor on corymbs number (Table 7). In general the three southern inland provenances had more fruits than the northern coastal provenances (graph 2).



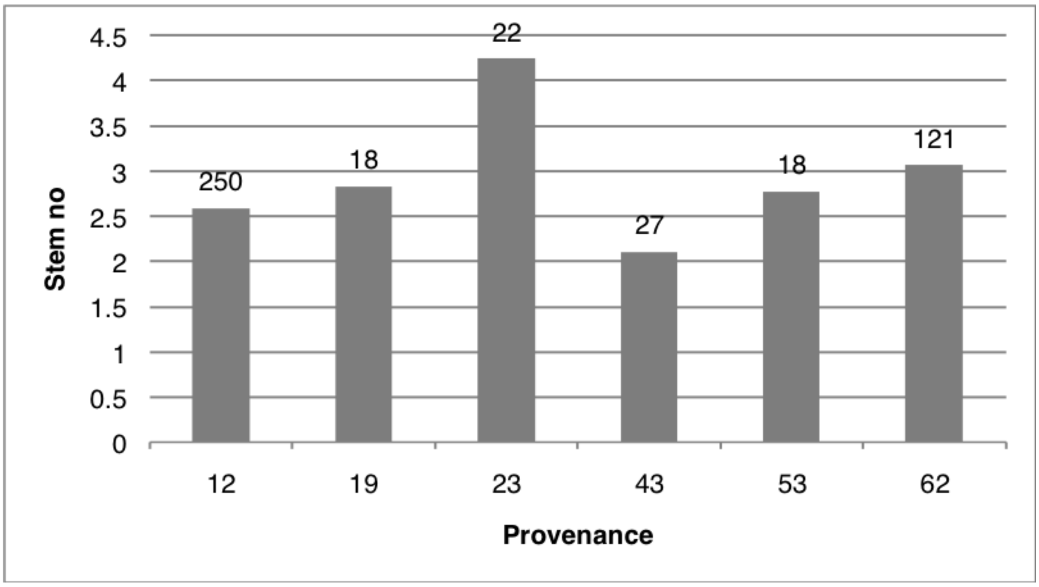
Graph 2: Bar graph showing mean number of corymbs for main provenances at Innertavle, number of replications shown above bar

	Degrees of Freedom	Sum Square	Mean Square	F Value	P>F
Provenance	1	685	685.2	23.43	$1.69*10^{-6***}$
Residuals	541	15822	29.2		

Table 7: Results of anova test on corymb number and provenance at Innertavle

The mean number of stems was 2.7 at Innertavle. At Innertavle provenance 62 had 3 stems on average more than provenance 12 with 2.5, provenance 23 had the highest mean of 4. The effect of provenance on the number of stems was not shown to be statistically significant by a one-way anova test. The three northern coastal provenances had more mean stems than the inland southern provenances. These two groups of provenances may have separate gradients with in each case the southern most provenances having the most stems. When looking at all the Swedish provenances there does appear to be a trend with the more northern provenances having more stems (Graph 3). Only one southern provenance (65) had over 5 mean stems, however this data is skewed by the fact that one tree in the provenance had 23 stems.

Many of the trees at Innertavle had previously had all but the main stem removed, with only rows one and two not having had this process done. The mean number of stems in rows one and two was 1.77 and in the other rows it was 2.97. Therefore the mechanical removal of extra stems increases the total number of stems. The stem form did not differ significantly between the trees with stems that had been removed and those that had not. It was 1.4 for rows 1 and 2 (no stem removal) and 1.3 in rows where stems had been removed. This process will however skew the data when looking at all provenances as provenances with very small replications may only be represented in one section.



Graph 3: Bar graph showing mean number of stems and Swedish provenances, number of replications shown above bar

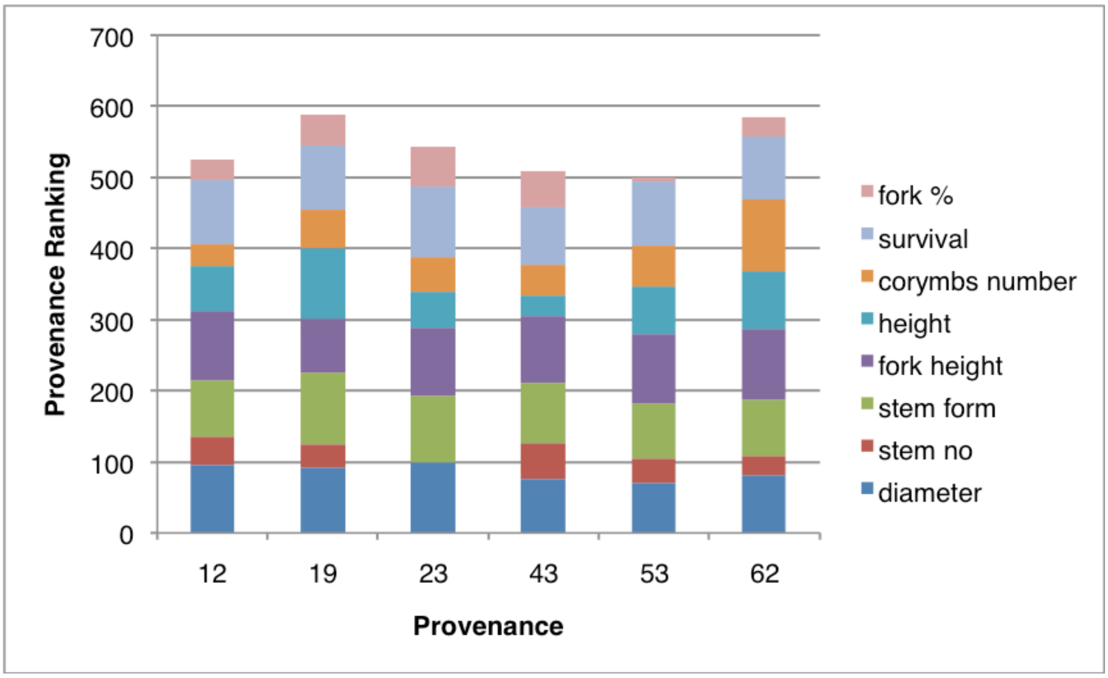
The mean stem form at Innertavle was 1.3 and there was little difference between provenances. One-way anova tests did not reveal that provenance had any significant interaction on stem form at in this location.

The mean fork height was 129cm and provenance 62 (154cm) had a higher fork height than 12 (127cm). Provenance did have a significant effect on the fork height at the 99.5% confidence level shown by 2 way anovas. Provenance 23 had 69% of trees without forks and all trees from provenance 53 had forks. Provenance 12 had 21% of trees with forks and 62 had 16%, here there were no clear geographical trends.

The survival at Innertavle was 88%, provenance 23 had the best survival at Innertavle (100%) followed by 12 (91%), 19 and 53 (90%), 62 (89%) and 43 (82%). The three southern inland provenances had lower survival than the northern coastal provenances.

4.1.1. Innertavle Provenance Ranking

Provenance 19 was ranked as the highest with 74%, closely followed by 62 with 73%. Provenance 53 and 43 were the lowest ranked provenances with 63% and 64% respectively. Provenance 19 had large diameters, tall trees and high stem form. Provenance 62 had the highest fork height and most corymbs (Graph 4).



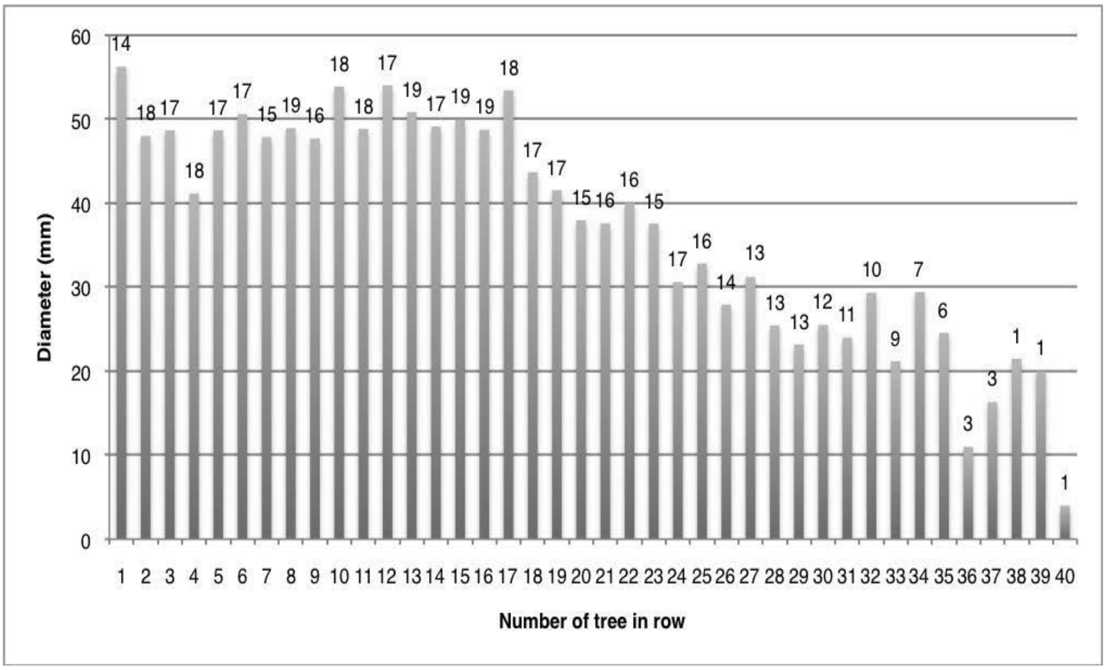
Graph 4: Stacked bar graph showing break down of ranking for Swedish provenances

Provenance	QMD	Number of corymbs	Stem Form	Number of Stems	Fork Height	% of trees without forks	Survival	Height
12	49.6	1.4	1.3	2.6	153.6	27	91	3.4
19	43.3	2.6	1.6	2.8	120.5	44	90	5.3
23	48.5	2.4	1.5	4.25	151.2	55	100	2.7
43	35.5	2.1	1.4	2.1	147.2	50	82	1.6
53	34.5	2.9	1.3	2.8	152.7	5.6	90	3.5
62	42.1	4.9	1.3	3.1	158	26	82	4.3
Innertavle	**42.4**	**2.3**	**1.3**	**2.8**	**129.4**	**15**	**88**	**3.8**

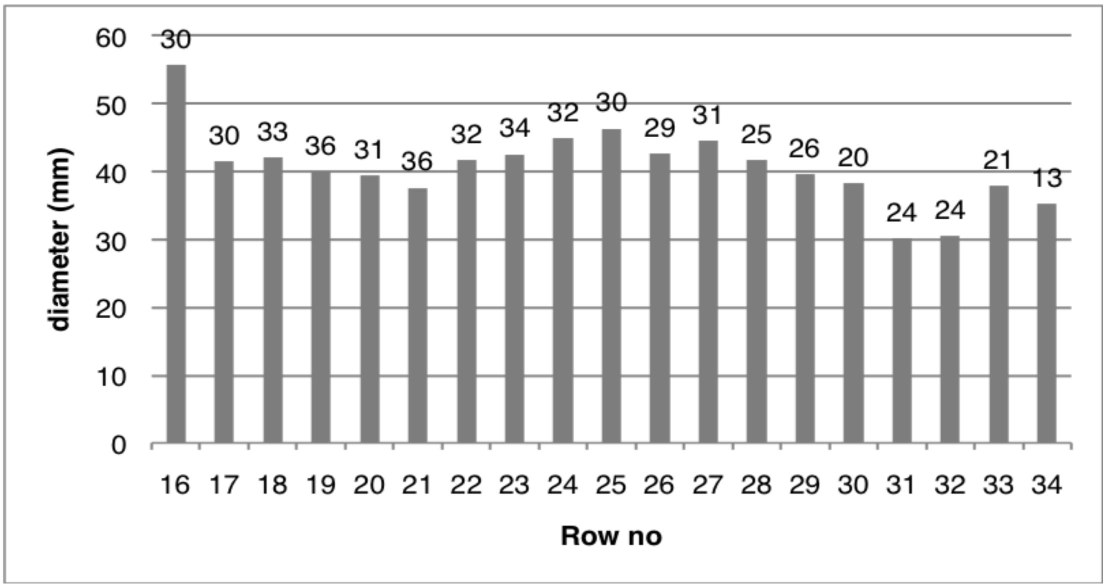
Table 8: Means of variables for main provenances at Innertavle

4.1.2. Survival and Site at Innertavle

There was a site gradient at Innertavle where at one end of the site trees had performed badly. There were lots of dead and missing trees towards this end of the site and the ones that survived were very small and often unhealthy. This effect was present in two directions, however much stronger along the rows than in different rows. Here dbh is used to illustrate the size of trees to show the positional effects (graphs 5 and 6).



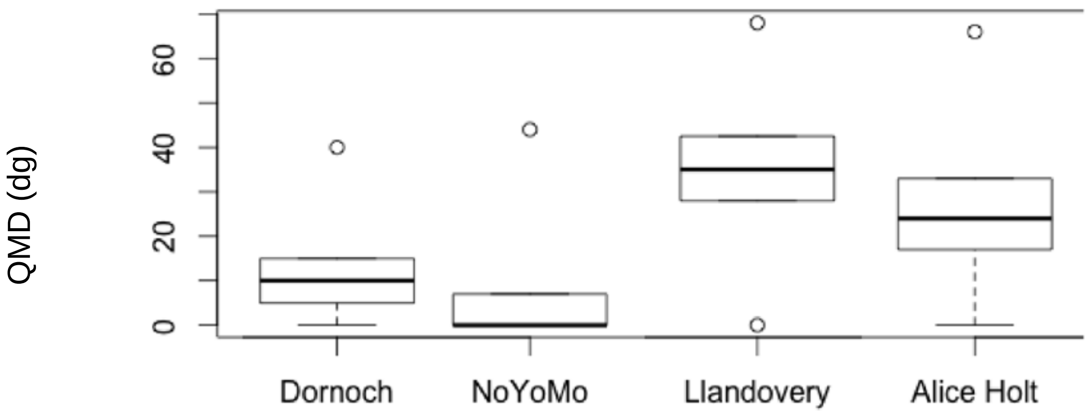
Graph 5: Bar graph showing number of tree alone row and mean tree diameter (mm) at Innertavle, number of replications shown above bar



Graph 6: Bar graph showing row number and mean tree diameter (mm) at Innertavle, number of replications shown above bar

4.2. North York Moor

The QMD was significantly lower at North York Moor than all of the other British sites, here it was 8.5. There was also a large percentage (66%) of small trees with a diameter of 0 cm (under 160 cm tall). This is nearly three times as many as the site with the next most trees with 0cm diameter this was Dornoch at 23% (Graph 7). Tukey HSD tests showed that trees at North York Moor had significantly different (smaller) diameters to all other British sites (Table 9). Provenance and the interaction of site and provenance were also shown to have a significant effect on the diameter of trees. Only one provenance, Mugdock Country Park had a QMD over 20 at North York Moor (21.79), the next highest was Seal Chart (16.82). Lochwood and Pepper Wood both had QMD of zero at North York Moor, indicating that no trees were over 160 cm tall.

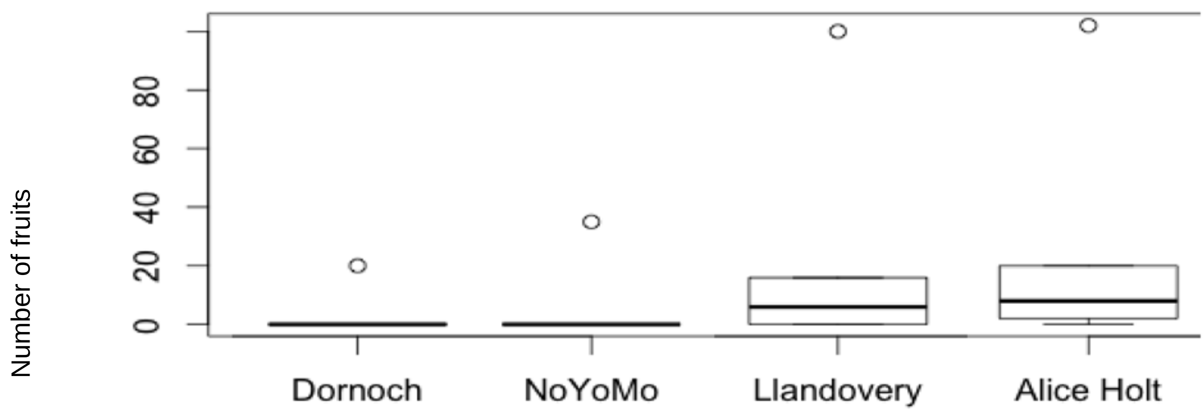


Graph 7: Boxplot showing minimum value, lower quartile, mean, upper quartile and maximum value for site and diameter for British sites

Interaction	**Difference**	**Lower**	**Upper**	**P Adj**
Dornoch-Alice Holt	-15.16	-17.05	-13.29	0
Llandovery-Alice Holt	9.55	7.57	11.53	0
North York Moor-Alice Holt	-21.15	-22.96	-19.35	0
Llandovery-Dornoch	24.72	22.74	26.70	0
North York Moor-Dornoch	-5.99	-7.79	-4.18	0
North York Moor-Llandovery	-30.70	-32.61	-28.80	0

Table 9: Results of Tukey HSD at 95% significance for interactions of site on diameter for British sites

North York Moor had the 2nd least mean fruits of all the British sites (1.4), and 78% of trees had no fruit clusters (Graph 8). This result was significantly different from the Southern sites - Alice Holt and Llandovery but not from Dornoch. Provenances with no fruits at North York Moor were Assynt, Allt Volagir, Glenlee, Lochwood, Castle Eden Dene, Pepper Wood and The Ercall.



Graph 8. Boxplot showing minimum, lower quartile, mean, upper quartile and maximum number of fruits and site for British data

The mean number of stems at North York Moor was 2.6, which was significantly more than other British sites apart from Alice Holt as shown by anova and Tukey HSD tests. Stem form was significantly lower at North York Moor (0.7) than at the other British sites, this result was the only one that differed from other sites. While provenance also had a significant effect on the stem form there was no general geographical trend.

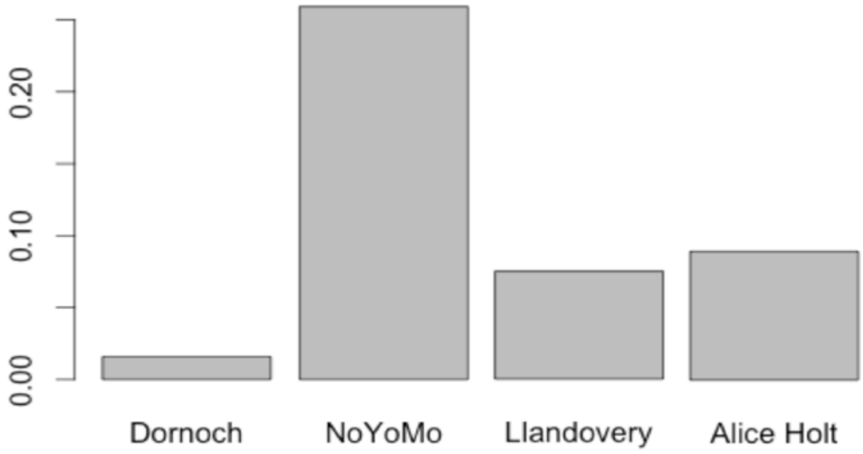
There were significantly less trees with forks at North York Moor (50%) than at the other sites which all had over 90%. This is probably due to the very small size of trees at North York Moor, where forks are harder to define. Of the trees that had forks there was no significant difference in the fork height from the other British sites again this is probably as trees were only measured as having forks when they were a certain size.

4.2.1. Local Provenances

The Provenances Forge Valley and Raincliffe Woods and Ashberry and Reins Woods have the closest origin to North York Moor. They were the 14th and 8th best provenances at the site respectively. They both had low survival at the site but more fruits than the site mean. The provenances with the highest percentage score at the site were Mugdock Country Park (West Scotland), Falls of Clyde (West Scotland) and Moor Farm (East England). The provenances with the lowest score were Pepper Wood (West England), Strathlachlan (West Scotland) and Castle Eden Dene (Notheast England). There was significant variation within the provenances.

4.2.2. Survival

North York Moor was the only site that had significantly different rates of survival to the other British sites (Table 11), provenance did not affect survival (Table 10).



Graph 9: Bar growth growing percentage of dead trees at all British sites

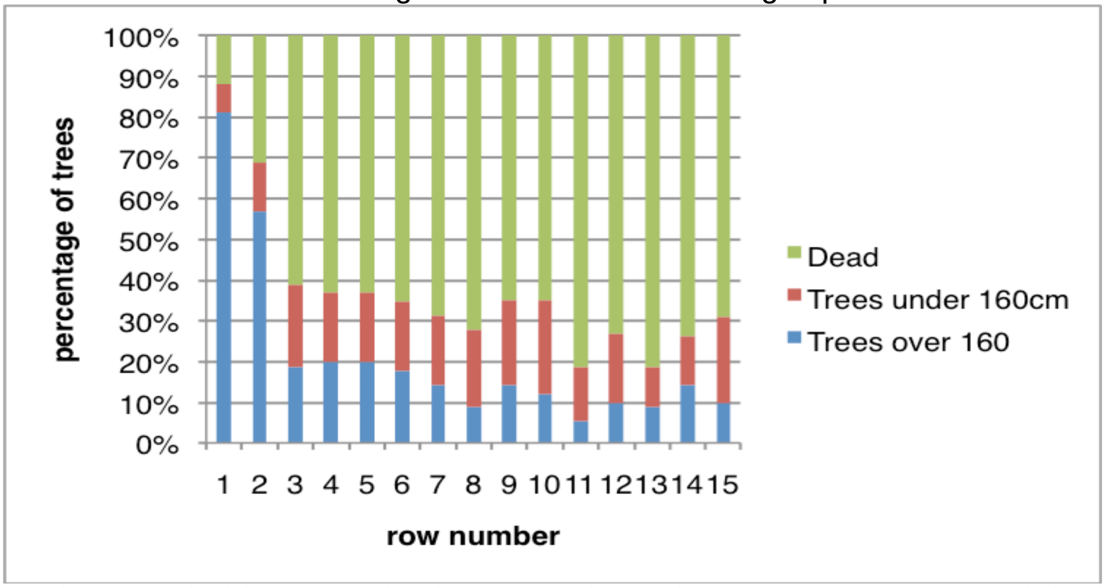
	Degrees of Freedom	Sum^2	$Mean^2$	F value	Pr(>F)
Site	3	16.6	5.5	54.3	$2.2*10^{-16***}$
Provenance	41	5.1	0.13	1.3	0.1565
Site*Provenance	97	11.4	0.12	1.2	0.1444

Table 10: Results of anova test on site, provenance and survival for British sites

Interaction	**Difference**	**Lower**	**Upper**	**P Adj**
Dornoch- Alice Holt	-0.07	-0.13	-0.01	0.007
Llandovery- Alice Holt	-0.01	-0.08	0.05	0.928
North York Moor-Alice Holt	0.17	0.12	0.22	0
Llandovery- Dornoch	0.06	-0.003	0.12	0.069
North York Moor-Dornoch	0.24	0.189	0.28	0
North York Moor-Llandovery	0.18	0.13	0.24	0

Table 11: Results of Tukey HSD test at 95% significance for interaction of site on survival for British sites

A survival study at NYM was done, which involved recording whether trees were over 160 cm tall, under 160 cm tall, missing or too small to be considered trees. Every tree per plot (9), provenance, and column and row were recorded. The survival and height of trees at North York Moor was dependent on provenance, this was not found across all British sites. Positional effect was stronger than the effect of provenance suggesting that here site was more important than provenance (tables 12-15). The trees in lower rows had better survival and were larger than trees at the other end of the site (Graph 10). At the end of the site where the trees were taller (rows 1 and 2) there was also taller and lusher vegetation such as bracken and rosebay willow herb whereas the other end of the site had a dense covering of gorse and bilberries. This extreme effect was only present in the first two rows indicating a very localized site gradient, this is similar to what was found at Innertavle where the site gradient was the overriding important factor.



Graph 10: Stacked bar graph showing row number and large trees, small trees and dead trees at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Provenance	39	43368	1112	1.744	0.0104	*
Residuals	136	86700	637.5			

Table 12: Result of anova test on survival and provenance at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Row number	1	32248	32248	57.36	$2.05*10^{-12}$	***
Residuals	174	97820	562			

Table 13: Result of anova test on survival and row number at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Column	1	10	10.1	0.014	0.908	
Residuals	174	130057	747.5			

Table 14: Result of anova test on survival and column number at North York Moor

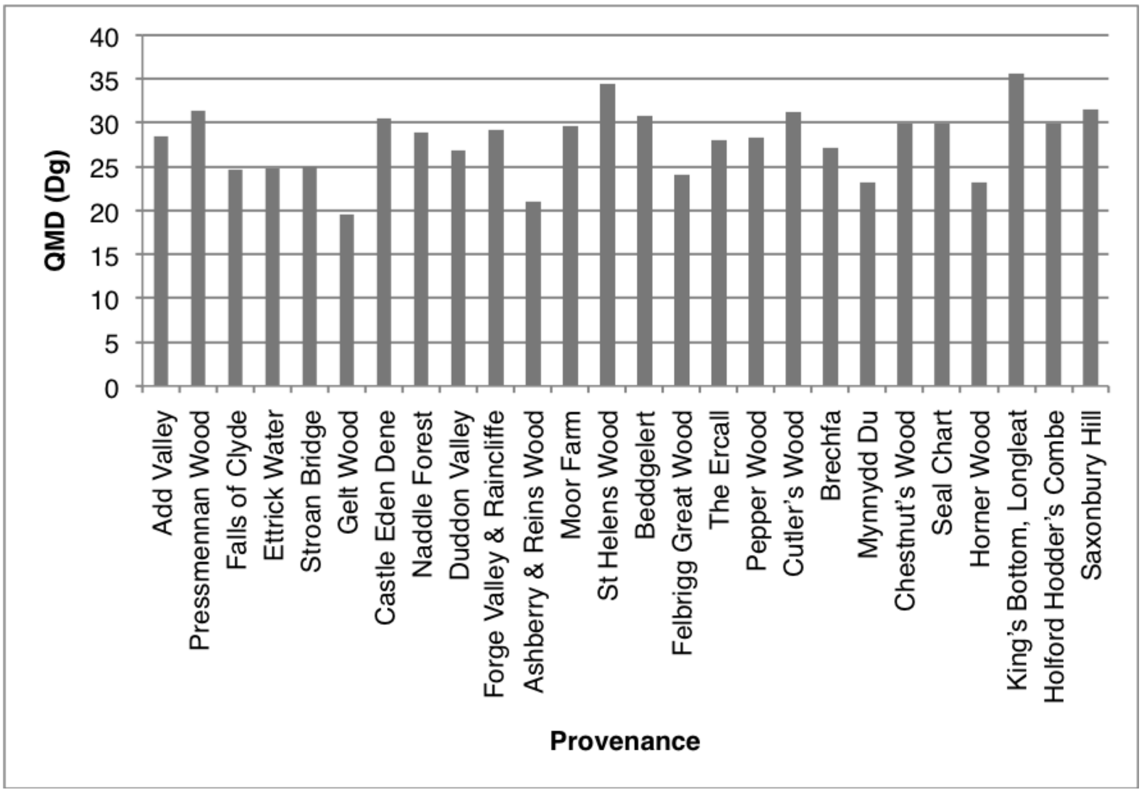
	Degrees of Freedom	Sum^2	$Mean^2$	F value	Pr(>F)
Row	1	261.2	261.21	63.782	$3.04*10^{-12***}$
Provenance	39	253.7	6.51	1.59	0.0355*
Row*Provenance	39	145.4	3.73	0.91	0.6206

Table 15: Results of anova test on row number and survival at North York Moor

4.3. British Sites - Tight Data Set (Alice Holt, Llandovery and Dornoch)

There was a significant difference between sites and provenances on the QMD of trees (Table 16). Trees at Llandovery had the largest QMD of all the British sites 37.05 followed by Alice Holt (27.8) and Dornoch (12.95). 23% of trees had a diameter of zero at Dornoch, and 2% at Llandovery and 1% at Alice Holt (Graph 11). Tukey HSD tests revealed that all three sites had significantly different QMD from one another.

The provenances with the largest QMD over all sites were King's Bottom, St Helen's Wood, Saxonbury Hill, Pressmennan Wood and Cutler's Wood. Provenances with the smallest QMD were Gelt Wood, Ashberry and Reins Woods, Mynydd Du and Horner Wood. There were also a significant difference from the combined effected of provenance and site. The provenance Pressmennan at the site Llandovery had the highest QMD for any provenance at any site (47.73). King's Bottom (37.95) had the largest QMD at Alice Holt, Duddon Valley the highest at Dornoch (26.75). All the QMD for every provenance at every site is shown in table 81. The Ercall had the smallest QMD at Dornoch (8.43), Gelt Wood had the smallest QMD at Llandovery (25.78) Falls of Clyde had the smallest QMD at Alice Holt (8.39).



Graph 11: Bar graph showing QMD by provenance at all British sites, ordered by latitude

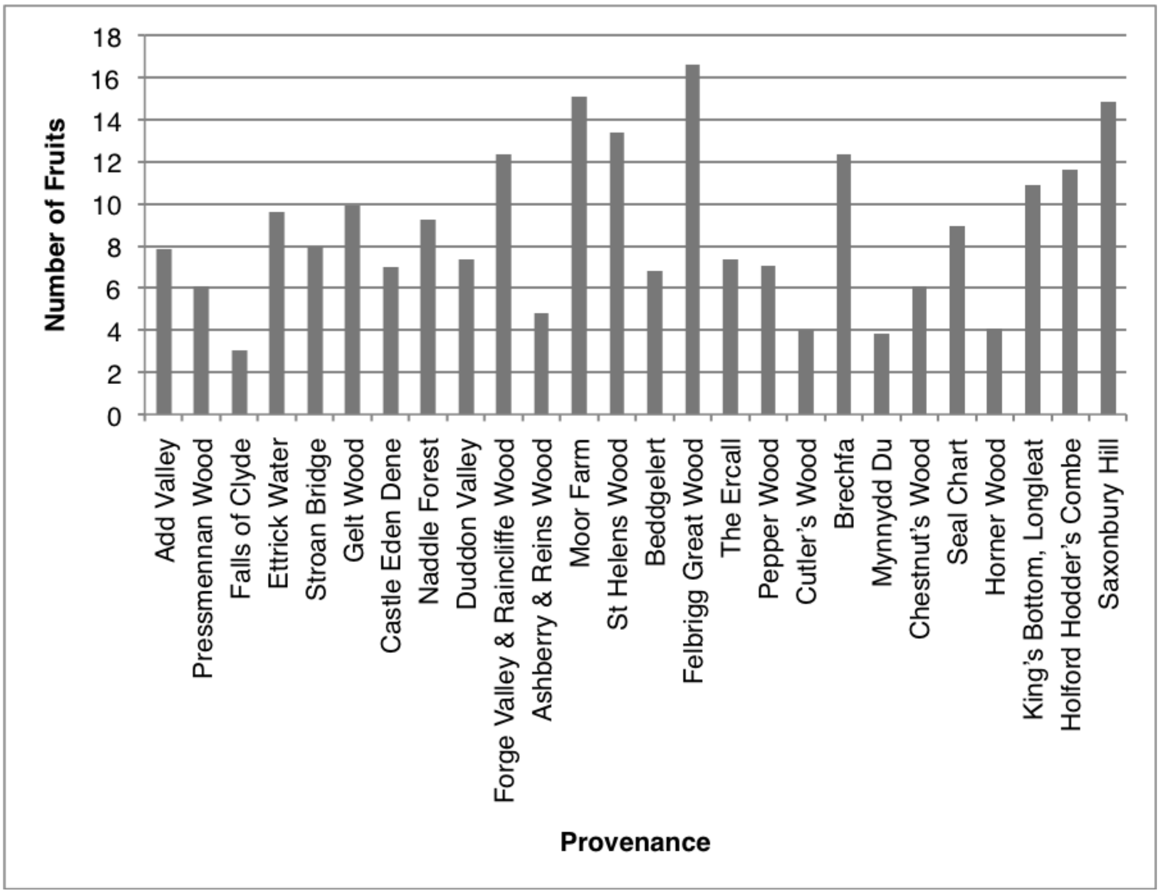
	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	2	76300	38150	387.353	$2.2*10^{-16***}$
Provenance	25	9483	379	3.851	$1.4*10^{-9***}$
Site* Provenance	97	15346	313	3.18	$1.5*10^{-11***}$

Table 16: Results of two-way anova on site, provenance and diameter for the tight data se

4.3.1. Number of Fruits

Two way anova and Tukey HSD revealed that there were significantly more fruits at Alice Holt and Llandovery than at Dornoch (Table 17). The number of fruits at Alice Holt and Llandovery did not differ from one another. 99% of trees at Dornoch, 26% at Llandovery and 19% at Alice Holt had no fruits.

Felbrigg Great Wood (16.6) had the most fruits of all the provenances, Saxonbury Hill, St Helen's Wood, Forge Valley and Raincliffe Woods and Brechfa had the next most. Provenances with the least mean fruits were Falls of Clyde, Cutler's Wood, Ashberry and Reins Woods, Horner Wood and Mynydd Du. St Helen's Wood at Alice Holt (21.3), Duddon Valley at Dornoch (2.6), Moor Farm at Llandovery (27.3) had the most fruits per provenance at each site (Graph 12). Ashberry and Reins Wood had no fruits at Alice Holt, 14 provenances at Dornoch had no fruits, no provenances at Llandovery had no any fruits; Stroan Bridge had the lowest number of mean fruits (2).



Graph 12: Bar graph showing mean number of fruits of provenances at all British sites, ordered by latitude

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	2	26072	13036	96.533	$2.2*10^{-16***}$
Provenance	25	9872	395	2.924	$2.9*10^{-6***}$
Site*Provenance	49	10294	210	1.556	0.0102^{*}

Table 17: Results of two-way anova on site, provenance and number of fruits for tight data set

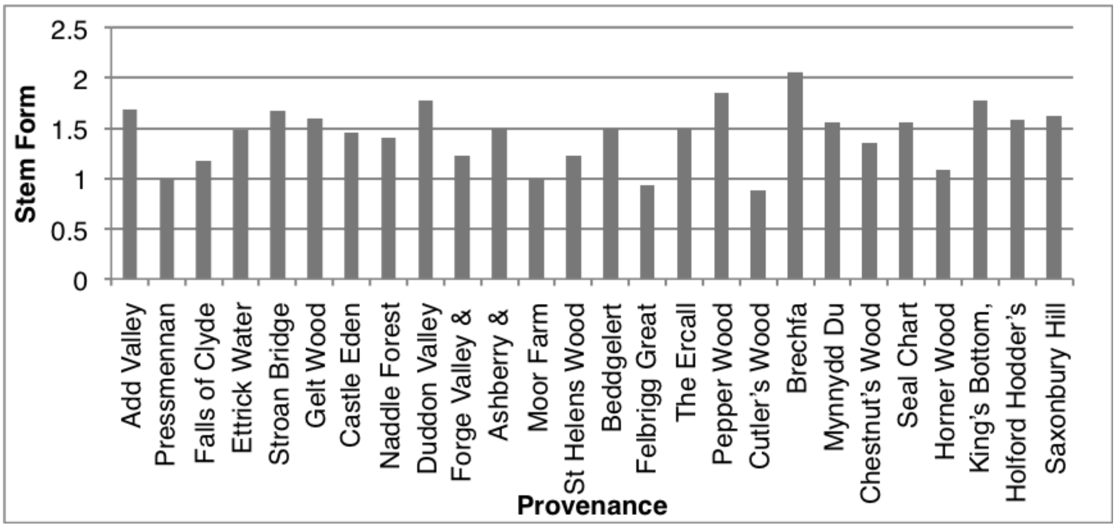
4.3.2. Stem form and number of stems

The highest mean number of stems was at Alice Holt (4.25), the least was at Llandovery (1.76). Anova tests showed that the mean number of stems at Alice Holt was significantly different to all other sites, see fig 5. At the time of data collection the fences had been removed from Alice Holt and Llandovery while Dornoch was still fenced.

Provenances with the fewest mean stems were Duddon Valley, Mynydd Du, Cutlers Wood and Chestnuts Wood. Provenances with the most stems were

The Ercall, Pressmennan Wood, Holford/Hodder's Combe and Stroan Bridge. The Ercall had 6.9 stems on average at Alice Holt; one tree had 18 stems.

The effect of stem form on site was significant at 99.9% level shown by anova tests and Alice Holt was significantly different from Llandovery and Dornoch. Provenance did however have a significant effect on stem form, those with the best stem form were Brechfa, Pepper Wood, King's Bottom and Duddon Valley. Provenances with the worst stem form were Cutler's Wood, Felbrigg Great Wood, Moor Farm and Pressmennan (Graph 13). Duddon Valley at Dornoch and Holford/Hodder’s Combe (2.4) had the highest mean stem form of any provenance at any site.



Graph 13: Graph showing mean stem form of provenances at all British sites, ordered by latitude

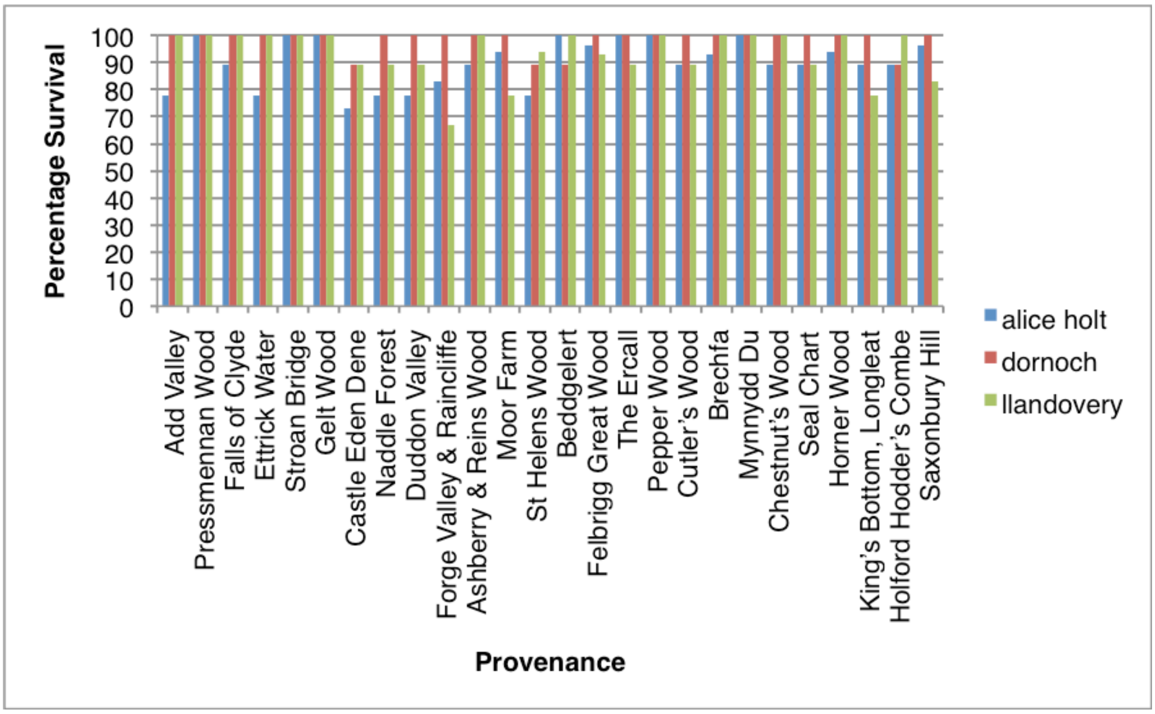
4.3.3. Forking

Trees at Alice Holt had the greatest mean fork height (109cm) followed by Llandovery (105cm); anovas and Tukey HSD tests showed that these results were significantly different to the results at Dornoch which had a mean fork height of 81cm. There was also a statistically significant difference between the fork heights of different provenances, the provenances with the highest forks were King’s Bottom, Brechfa, Duddon Valley, St Helen’s Wood and Pepper Wood. Provenances with the lowest mean fork height were Horner Wood, Cutlers Wood and Forge Valley and Raincliffe Woods.

Dornoch had the highest percentage of trees without forks (6.5), followed by Llandovery (5.5) and Dornoch (3.5). There were differences between provenances, Pepper Wood at Llandovery had the highest percentage of trees without forks (33.3). Two provenances had zero percentage of trees without forks, these were Moor Farm and Ettrick Water.

4.3.4. Survival

Trees at Dornoch had the highest survival 98.5%, Llandovery and Alice Holt both had over 90% survival. One-way anova tests did not show that provenance had a significant effect on survival of rowan (Table 16). Site did however effect survival. There were no provenances (plots) at Dornoch with more than one dead tree. Ettrick Water and Castle Eden Dene both had 73% survival at Alice Holt, Forge Valley and Raincliffe Woods had 67% survival at Llandovery (Graph 14).



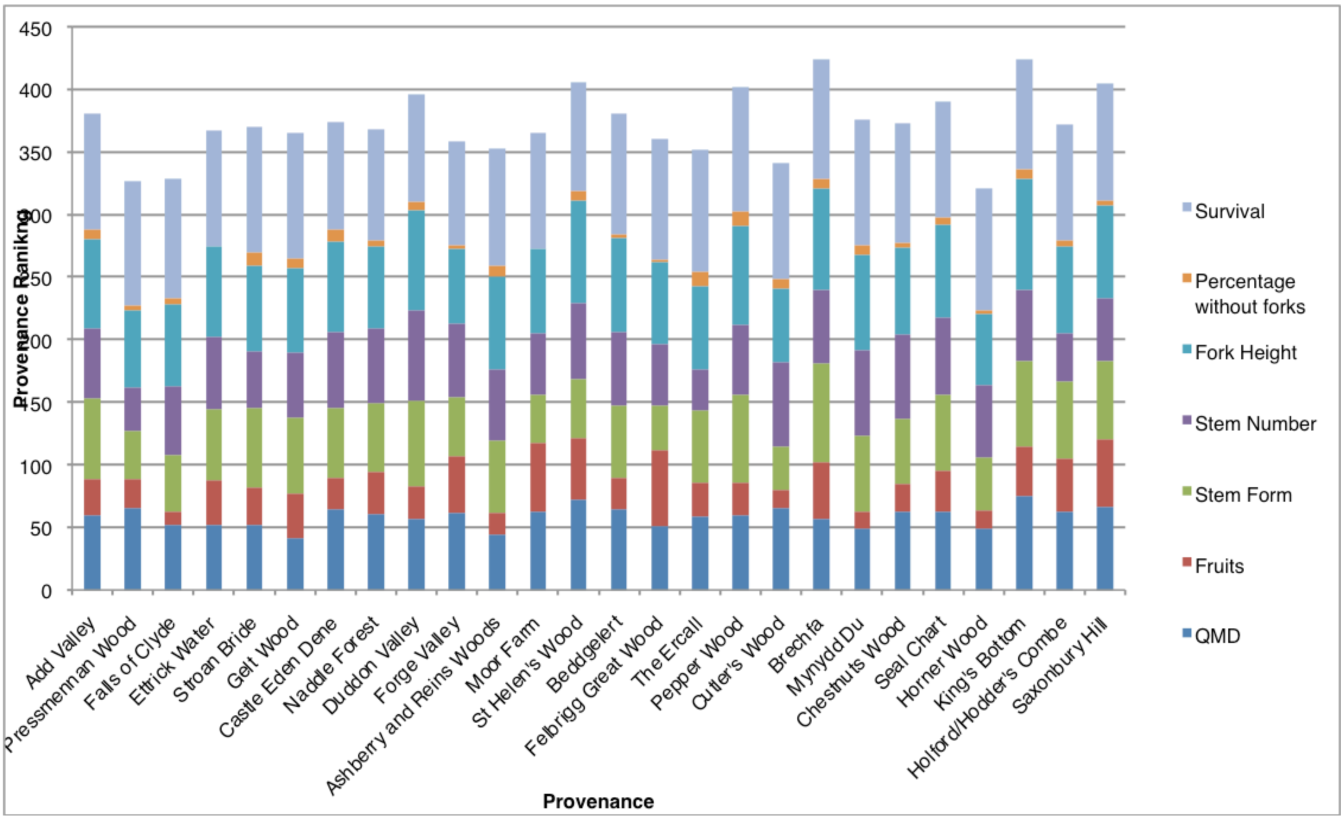
Graph 14: Bar graph showing percentage survival or provenances at each British site, ordered by location

	Degrees of Freedom	Sum^2	$Mean^2$	F value	Pr(>F)
Site	2	0.81	0.4068	6.709	0.00129**
Provenance	25	2.10	0.0808	1.332	0.12464
Site*Provenance	49	2.74	0.0548	0.903	0.66513

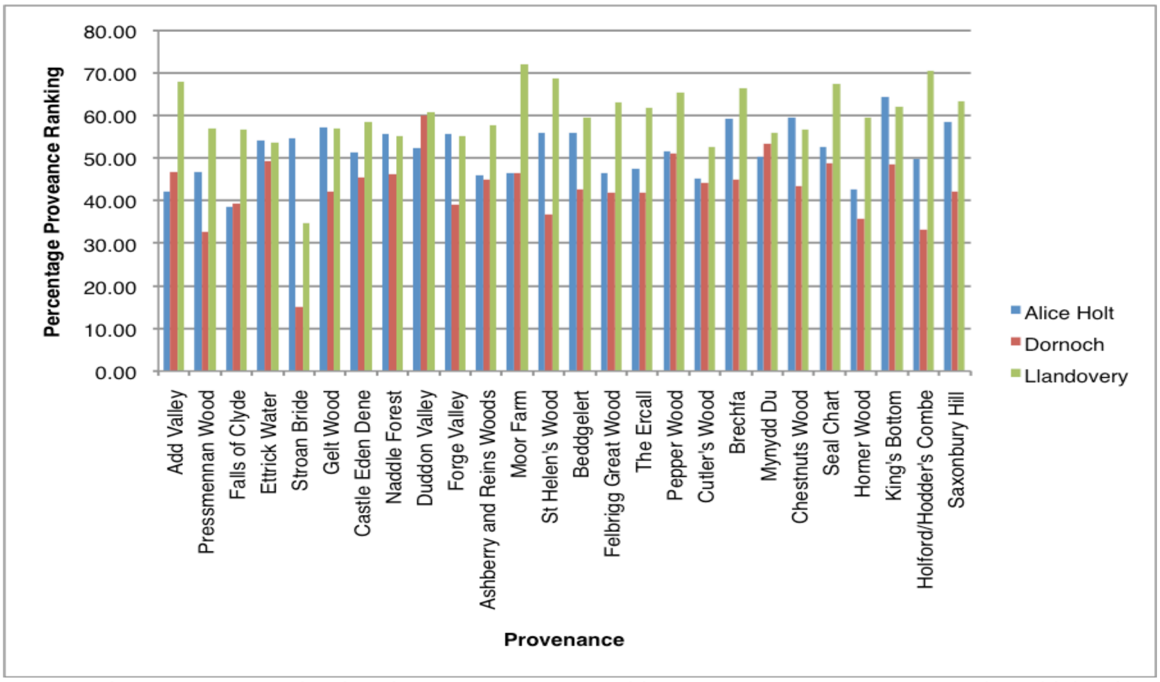
Table 18: Results of two-way anova for site, provenance and survival for tight data set

4.3.5. Provenance Ranking

When combining all the seven variables (QMD, number of fruits, number of stems, stem form, fork height, percentage of forks and survival) an overall provenance ranking was obtained. Across all sites the highest ranked provenances were Brechfa (61%), King's Bottom (61%), St Helen's Wood (58%), Saxonbury Hill (58%) and Duddon Valley (57%). The provenances with the lowest score were Horner Wood (46%), Pressmennan Wood (47%), Falls of Clyde (47%) and Cutler's Wood (49%). Pressmennan Wood had a low ranking despite having the largest trees at Llandovery, the low ranking was caused by many stems and poor stem form.



Graph 15: Stacked bar graph showing provenance ranking of all variables at all British sites, ordered by latitude



Graph 16: Bar graph showing percentage ranking for provenances at each British site, ordered by latitude

4.3.6. Provenances at sites

4.3.6.1. Alice Holt

King's Bottom and Saxonbury Hill are the two most local provenances to Alice Holt. King's Bottom is west of the site and Saxonbury Hill is to the east. King's Bottom had better QMD, number of fruits, stem form, fork height and survival than the site mean and was the best performing provenance at the site. Saxonbury Hill had the second best percentage score at Alice Holt and Brechfa had the third highest percentage score at Alice Holt. Falls of Clyde (West Scotland), Add Valley (West Scotland) and Horner Wood (Southwest England) had the lowest percentage score.

4.3.6.2. Dornoch

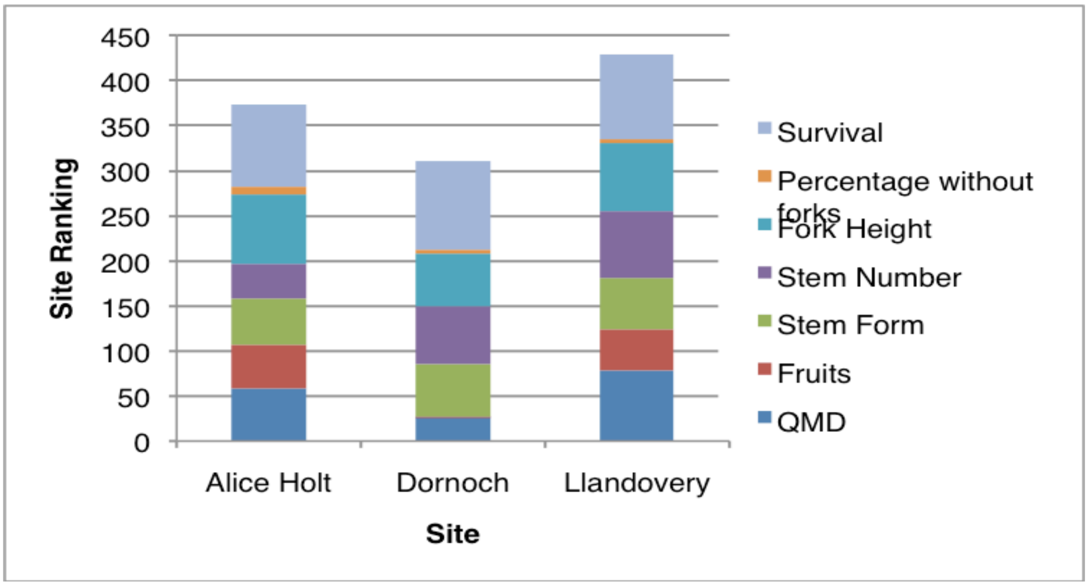
The closest provenances to Dornoch were Assynt and Inverpolly both provenances scored better than the site average on all variables. The only other replication of these provenances was Assynt at Llandovery therefore they are not included in the tight data set. Duddon Valley (North England), Mynydd Du (South Wales) and Pepper Wood were the best performing provenances at Dornoch. Allt Volagir (Northwest Scottish islands), Pressmennan (East Scotland) and Holford/Hodders Combe (Southwest England) had the lowest percentage score at Dornoch.

4.3.6.3. Llandovery

Brechfa and Mynnydd Du were the most local provenances to Llandovery, which is located in a mountainous area of SW Wales. Brechfa was the 6th best provenance at Llandovery however Mynnydd Du was 25th out of 33. Mynnydd Du had the worst QMD, number of fruits, stem form and fork height than the site mean. Moor Farm (East England), Holford/Hodders Combe (Southwest England) and St Helen's Wood (East England) had the highest percentage score at Llandovery. Pepper Wood (West England), Strathlachlan (West Scotland) and Castle Eden Dene (Northeast England) had the lowest percentage score at the site.

4.3.7. Site Summary

Llandovery was ranked as the overall best site followed by Alice Holt and Dornoch (Graph 17). Llandovery had the largest QMD, joint best stem form (with Dornoch) and the lowest mean number of stems. The most fruits were found at Alice Holt which also had the highest fork heights but the most stems. Dornoch had the highest survival and the joint best stem form but the fewest number of fruits. The ordering of the provenance ranking at each site showed that there were little correlations between the performance of provenances at each site. There was a weak positive correlation between Alice Holt and Dornoch but Llandovery had no correlation with either of the other sites.

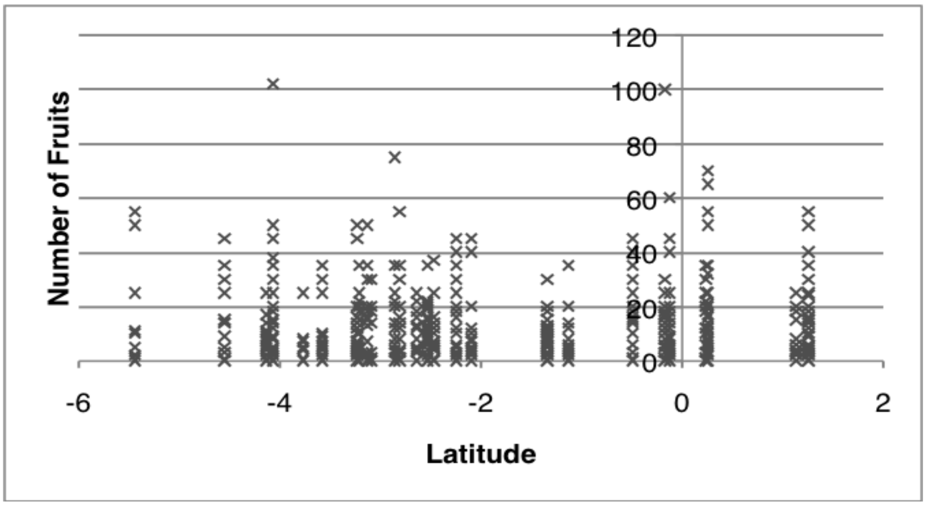


Graph 17: Stacked bar graph showing ranking of all variables for British sites

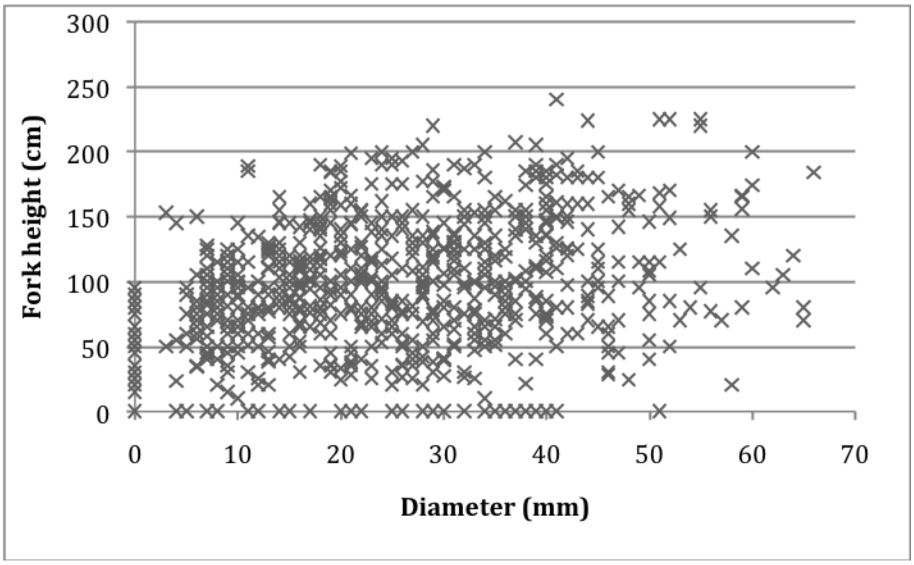
4.4. Correlations Between Variables

There were correlations between latitude, longitude and provenances at all site shown by all three correlation coefficients used (Pearson, Spearman and Kendall). Longitude and annual rainfall were also strongly correlated, with western Britain receiving more rainfall than the east. This is a reminder that all these factors are linked and should not be viewed in isolation. In Britain there are two main climatic variables with the south being warmer and the east being drier. Due to the shape of Britain there is an overrepresentation of provenances from the southeast and northwest.

Across all sites there were significant correlations between longitude and fruits, diameter and fork height, diameter and fruits, rainfall and stem form and diameter and stem form as shown by all three correlation coefficients. Kendall and Spearman's also showed correlations between stem form and stem number, fork height and fruits and temperature and fruits (Tables 19-21). At Alice Holt there were correlations between diameter and fork height, diameter and fruits and diameter and stem form, these were all shown by all three correlation coefficients. Significant correlations were shown between longitude and fruits, longitude and stem form, fruits and stem form, diameter and fork height, diameter and stem form and diameter and fruits were shown by Kendall and Spearman tests. The significant correlations at Dornoch shown by all correlation tests were diameter and fork height, diameter and stem form, fruits and stem form. Additional correlations shown by Kendall and Spearman were fork height and stem form and diameter and stem form. At Llandovery the significant correlations shown by all correlation coefficients were diameter and fork height, diameter and fruits, diameter and stem form and fork height and stem form. Kendall and Spearman tests also showed correlations between stem form and stem number.



Graph 18: Scatterplot showing correlation between number of fruits and latitude



Graph 19: Scatterplot showing fork height and diameter

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.31***							
Temperature	-0.73***	0.41***						
Diameter	-0.08	0.06	0.06					
Fork Height	-0.07	-0.03	0.00	0.23***				
No of Fruits	-0.07	0.15***	0.09.	0.48***	0.13**			
Stem Form	-0.04	-0.14***	-0.04	0.21***	0.18**	0.21**		
No of Stems	0.03	-0.00	0.02	-0.07.	0.01	0.11*	-0.20***	
Rainfall	0.06.	-0.64***	-0.08.	0.05	0.09*	-0.01	0.11**	-0.03

Table 19: Result of Pearson's correlation coefficient for all sites

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.24***							
Temperature	-0.58***	0.34***						
Diameter	-0.05.	0.05.	0.05					
Fork Height	-0.04	-0.01	-0.00	0.21***				
No of Fruits	-0.04	0.11***	0.08**	0.47***	0.17***			
Stem Form	-0.04	-0.09**	-0.05	0.16***	0.18***	0.06.		
No of Stems	0.02	0.02	0.01	-0.06.	0.03	0.12***	-0.18***	
Rainfall	-0.00	-0.55***	-0.08*	0.01	0.06*	-0.01	0.11***	-0.03

Table 20: Result of Kendall correlation coefficient across all sites

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.30***							
Temperature	-0.76***	0.44***						
Diameter	-0.07.	0.07.	0.06					
Fork Height	-0.06	-0.02	-0.00	0.30***				
No of Fruits	-0.05	0.16***	0.11**	0.62***	0.23***			
Stem Form	-0.05	-0.11*	-0.06	0.22***	0.23***	0.08.		
No of Stems	0.02	0.03	0.01	-0.08.	0.04	0.15***	-0.22***	
Rainfall	0.01	-0.71***	-0.12**	0.01	0.08.	-0.01	0.15***	-0.04

Table 21: Result of Spearman’s correlation coefficient for all sites

For additional graphs and tables, see appendix I.

5. Discussion

5.1. Site at Innertavle

There was a site gradient at Innertavle, which was shown by the smaller size and higher number of dead trees at one end, this was similar to what was seen at North York Moor. There were a lower percentage of dead trees at Innertavle than at North York Moor but more than at any other of the British sites. Another difference was that at Innertavle most of the trees appeared healthy and only a few had a diameter of 0mm whereas the surviving trees appeared unhealthy at North York Moor. A possible reason is that the trees at Innertavle were more mature and all unhealthy trees had died. Survival may be lower at Innertavle than at most British sites as the northern part of Sweden is a less suitable and harsher climates. The site gradient was in two directions, one faint and one extreme. This was not found at North York Moor where the site gradient was only one directional but more extreme. This result shows that sites can have unpredictable gradients that can be problematic for the establishment and growth of rowan stands.

5.1.1. Swedish Provenances

There were two provenances with high rankings these were 62 ad 19, 19 was slightly higher. The other two northern coastal provenances had higher ranks than the other two inland southern provenances. 62 did have a high score due to lots of corymbs and high mean forking height but otherwise the southern provenances had lower rankings, with worse stem form and lower survival. As Umea is a northerly location the long cold winters and snow covering may have been detrimental to the trees' health which provenances from the south were not adapted to. Despite provenance 62 being from the most southerly location (Vaxjo) this has a harsh cold climate and maybe provenances will have adapted to this. It was not expected that provenances from the south would have more corymbs than those from the north (at least not in fairly early spring). There may be additional physiological responses caused by boreal climates such as the requirement for chilling before bud burst and flowering (Linkosalo et al, 2008), which explain why all northern provenances (except 62) had fewer corymbs.

5.2. British sites

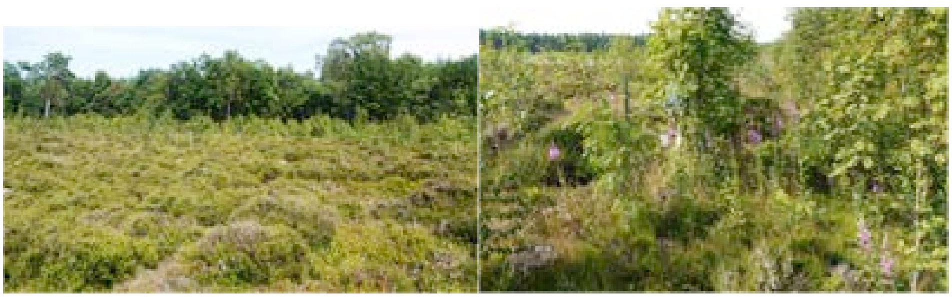
Provenance and site were both shown to be important variables in the growth, fruiting and stem form of rowan. In this study site was found to have a slightly larger effect than provenance however provenance should not be considered to be an unimportant variable. The large variability caused by site was in part due to the unsuitable site at North York Moor, this is why the second data set was created in order to eliminate this erroneous result. There were certain provenances such as King's Bottom that performed better than other provenances such as Allt Volagir. Southern sites tended to have higher productivity in general. In order to fully assess the site gradient and the effect this had on the variables a regression analysis could have been done. Whereby, for example, diameter was calculated as a function of position at the site and provenance. This could have been done for all variables in order to attempt to create a comprehensive analysis of how the variable was affected by position at the site and also conditions at the provenance origin such as latitude.

5.2.1. North York Moor

The high percentage of trees with a diameter of zero at North York Moor indicates that they were not at the same level of maturity as at the other sites. This is still true when the effect of warmer sites is taken into account, as trees at Dornoch were larger on average. This further skews the provenance evaluation if the data from North York Moor is included, especially due to the uneven site conditions. The row number was shown to have a bigger impact on survival than provenance, column or row number or edge effects from one-way anova tests. Two-way anovas also showed that the combined effect of provenance and row number had no effect. Therefore the variation at the site was caused not by provenance but by another factor, which is why the analysis has been split to leave three comparable sites Alice Holt, Llandovery and Dornoch. However as provenance was shown to be significant at North York Moor, some provenances may have had lower survival than others in the same location.

North York Moor was by far the worst site for the species and it was unexpected that rowan would perform so badly here. The forestry commission database lists this site as suitable for the species due to the soil conditions. The soil was listed as being moist with very poor nutrients on a sandstone parent material with a silty loam to sandy loam texture, which are all suitable for rowan and not drastically different to the other British sites. There was nothing to indicate that the site had poor growth potential. There are three major possibilities for the poor performance of rowan at North York Moor; one is that the result is a total anomaly (caused by external factors such as poor planting or seeds), or that the site was inherently unsuitable for rowan implying specific site requirements.

The final possibility is that there was a localized microclimate or extreme site gradient to back this up, one end of the site did seem suitable for rowan. At one end of the site the trees were much larger than at the other end, it is unlikely that the poor performance was caused by an anomalous external factor such as poor seeds. It was also observed that the ground floor flora was different at each ends of the site suggesting there was a strong site gradient. This can be seen in the photographs above, there were also other large trees surrounding the site such as spruce and fir. This result implies that there was some local variation at the site, furthermore it was similar to what was observed at the site at Innertavle which also had a less extreme site gradient where the trees performed significantly worse at one end.



Pictures 22 and 23: both ends of the site at North York Moor

Most of the end of the site where rowan had poor performance at North York Moor was dominated by a dense covering of heather, gorse and blueberry. Therefore the floristic community is likely to be either *Calluna vulgaris- Ulex gallii* (H8) or *Calluna vulagaris- Erica cinerea* (H10) (Elkington et al, 2001). This was deduced from looking at the ground flora at the site. Rowan can normally grow on heather moorland (Raspe et al, 2001), however the H8 and H10 do not normally become wooded. Burning and browsing in moorland areas is common and inhibits woodland sucession, although neither was present at North York Moor. The presence of these communities may have inhibited both the survival and maturation of rowan. Rowan cannot germinate where there is continuous weed cover (Mauer and Palatova, 2002); this probably reduces the growth of rowan. The other end of the site had a completely different vegetation community, which was more varied and included species such as bracken, which was not dense on the ground. The poor response from rowan at Innertavle and North York Moor were both unexpected results. There were differences at the sites as rowan had very low survival at North York Moor and such small trees so the problem was probably with the establishment of trees, caused in part by the floristic community.

Although there was no evidence of waterlogging, the site was visited in a dry, hot period. It is possible that the site had previously been waterlogged having a negative effect on tree growth and this was not visible when the site was visited. A hardpan, which would have decreased the site drainage is another possible reason why the growth was so poor.

Rowan is able to grow multi-stemmed trees with shoots of different ages. This can often explain its persistence in the landscape and ability to live under tree canopies as when one shoot dies another can take over. This can act as a survival mechanism when there are high numbers of browsers as trees can survive after the leading shoot has gone. The surviving trees at North York Moor were very small and did not appear to be 7 years old, as can be seen in picture 4. This may explain the incredibly small sizes that were actually different shoots from the original seedling planted. Despite the fence there was also some evidence of browsing at North York Moor, however it is unlikely that would explain the extent of lack of growth and furthermore it would not be localized to one end of the site. Multi-stemmed trees has been explained as a survival strategy by Tanentzap et al (2012) who found the more stems a tree has the higher the survival. This could therefore be a response to the poor conditions and competition from other vegetation. There were the lowest percentage of forked trees at North York Moor; this was due to their small size. Using the definition of an acute angle branch at least 1/3 of the stem thickness would be irrelevant for these small trees.

Three of the five highest ranked provenances at North York Moor were from western Scotland; the remaining two were from South East England. These are probably the areas with the worst and best conditions for growth in Britain. Provenances from western Scotland may be adapted to the harsher conditions resulting in better growth. In addition these three provenances – Mugdock Country Park, Falls of Clyde and Add Valley all had high survival at

North York Moor. Whereas provenances from the southwest may have benefited from the warmer climate of their origin these provenances had larger diameters than average at North York Moor. The other high ranked provenances were Moor Farm and Seal Chart.

There was an extreme site gradient at North York Moor, which allowed plant communities that are incompatible with rowan to take over, making growth harder and harder. Consequently the survival was low and trees were small with poor form. Provenances that had high rankings either had high survival and were from harsh locations or from mild locations and were relatively large trees for the site.

5.2.2. Alice Holt, Dornoch and Llandovery

Survival does not appear to be linked to growth, stem form and fruiting in rowan as trees at Dornoch had the best survival but the lowest scores for most other categories. Dornoch is in the Scottish Highlands, the coldest and windiest location of the four British sites. This is however an environment that rowan is known to be well adapted to and is one of the few trees that can be seen growing wild in the landscape, in contrast to the South of Britain, which is home to diverse temperature broadleaved woodlands. Trees at Dornoch had the best stem form although the trees were generally smaller, again this points to the fact that fast growth is not necessarily linked to survival and health.

There was little competition at Dornoch whereas at southern sites there was more competing vegetation and this may have inhibited growth when it was dense. At Llandovery and particularly at Alice Holt there was high competing vegetation such as bracken and brambles, some of which was as high as the rowan trees. Growth rates may have increased in response to the competition in order to outgrow other vegetation and receive more light. This may have resulted in the poor stem form at Alice Holt. In this environment small trees could become shaded out and suppressed, and may not survive, as rowan is shade intolerant in later years. Considering that rowan has a very northerly distribution, Scotland is not considered to be an extreme environment, in terms of climate and survival is unlikely to be reduced. This is unlike at Innertavle where unhealthy trees may have suffered from long cold winters. In addition the young age of trees in Britain means that unhealthy trees may still be present, yet likely to die soon, younger trees also explains the higher percentage of trees with 0cm diameter.

Pictures 24 and 25: Dense Vegetation at Alice Holt

Llandovery had a higher site ranking than Alice Holt for rowan this may be in part because the vegetation was not quite as vigorous and aggressive as at Alice Holt. The competition for rowan was therefore lower, this may have resulted in fewer stems and better stem form. Llandovery is at a higher altitude and has a cooler climate than Alice Holt this may account for the poorer growth of other vegetation while not hampering the growth of rowan. The moist soil conditions at Alice Holt are not as suitable as the fresh soils at Llandovery consequently the site was listed as very suitable in the forestry commission database. The high number of stems at Alice Holt may be another indication of the high levels of competition as new stems grow to find light and nutrients. Alternatively it could suggest a high presence of browsers at the site, there are higher numbers of deer (such as Fallow Deer, Red Deer and Roe Deer) surrounding Alice Holt than Llandovery (Great British Deer Survey, 2011). The site was fenced when the trees were planted so this would not have been a problem with establishment and early growth however, as shown by the removal of stems at Innertavle, this can produce more secondary stems even when done in later years. The fact that Llandovery had a higher QMD compared to Alice Holt may have been due to the tendency towards single stems, at Alice Holt there were often trees with two fairly ‘main’ stems of similar size. Therefore the biomass may have been similar to that at Llandovery due to increased number of stems as opposed to large diameter.

From looking at the ground vegetation, if left to natural succession processes the floristic community at Llandovery would likely become ‘W16 *Quercus spp - Betula spp - Deschampsia flexuosa’* which is often an oak coppice woodland or wood pasture. Rowan is more often a componant of this community than the one that would be likely to dominate at Alice Holt (W10a). The W10a *Quercus robur- Pteridium aquilinum- Rubus fruticosus* is more species rich than W16 and has a hazel understorey (Rodwell, 2003). The number of stems is found to increase in rowan when the trees are growing in the understorey. If other vegetation was higher than the rowan trees at Alice Holt this may have increased the number of stems, which generally results in increased net productivity. In addition stems of understorey hazel and hawthorn have been found to increase with higher numbers of herbivores (Tanentzap et al, 2012). The combined effect of herbivory, competition and productivity resulted in the large number of stems at Alice Holt. The growth rates at Alice Holt and Llandovery were both high, however the competition from the dense vegetation at Alice Holt resulted in lower quality trees.

Alice Holt was the only site visited in mid July, which is the start of the fruiting period, however there were abundant fruits on many trees, although some were not ripe. Summer 2013 was very hot for Britain and may have resulted in early fruiting and therefore many trees may have completed fruiting. If data was collected later then some provenances may have had even more fruits, this is a problem with collection dates being weeks apart and with only one collection period. The fact that many fruits were not ripe at Alice Holt may be an indication that fruiting was not complete. As all other sites were visited in August it is likely that the fruiting was complete at these sites due to the hot weather. Trees from high altitudes have been shown to have higher quality but fewer seeds (Kollas et al, 2012). This may explain the fewer number of fruits at Llandovery than at Alice Holt. In southern climates, there would be different vegetation such as mixed broadleaved woodland. There will be more competition and therefore more seeds to increase chances of germination or, in areas where there is high competition, trees will not receive as many nutrients to be passed onto seeds. On the other hand there is less competition at northern sites such as Dornoch, but plants will need more nutrients to cope with harsh conditions hence the higher quality seeds. Higher quality seeds will be more likely to survive which may have resulted in the higher percentage survival at Dornoch. When trees grow in boreal zones such as northern Sweden chilling is required to break dormancy, this could be a problem for provenance transference (Linkosalo et al, 2008).

As predicted, productivity is higher in the south with trees growing larger and having more fruits. Metabolic rates in the south will also be higher allowing plants to grow faster. Heat is only limiting when combined with drought, this is clearly not the case in southern England where sites should mostly be suitable and productive. The signals that break dormancy and initiate growth in rowan are all in response to temperature and not day length, which is a more common factor in plants (Heide, 2011). Therefore southern Britain will give rowan growth signals before northern Britain thus meaning trees in the south will have a longer growth period, resulting in larger trees and more fruits. Rowan is insensitive to day length and bud burst has been shown to be influenced by a rise in temperature and not an increase in day length. This has worrying implications for climate change; as trees' responses will be out of sync with the seasons. Extreme weather events such as storms and late frosts are likely to increase which could be problematic when trees begin growing early. This temperature control may also explain why some provenances from the very south (such as Horner Wood and Holford/Hodders Combe) were not so healthy in the north. The temperature did not reach the normal high which is required for good growth whereas if trees were responding to changes in day length the levels required would occur.

As shown by North York Moor and Innertavle, there can be a strong site gradient with rowan. This can affect the survival or growth of the species, when collecting data only one plot per provenance was selected in most cases. If site gradients were present, it may be hard to detect due to the uneven plot selection processes, this may give a skewed result. Therefore it is possible that some data from provenances at certain sites may be as much a reflection of site as it is of provenance. It may have been useful to do a site wide survival study like at North York at all sites. Although North York Moor had a clear site gradient, easy to see by eye, which was not the case for any other sites. Collecting from a range of locations over the site does however ensure that the variation within the species is captured.

5.2.3. Effects of Provenance

Provenance did not have an effect on survival, this indicates the hardy nature of the species and that none of the provenances were representative of extreme environments. There were clear differences between provenances but these did not fit into a neat geographical pattern or appear be in response to temperature or rainfall, nor did there appear to be any effect of coastal provenance origin like at Innertavle. This may be expected as rowan is a bird dispersed species and seeds are able to travel large distances. There were however slight trends. At Alice Holt northern provenances had the worst survival. Northern provenances had better stem form at Dornoch, similar to what was seen as Innertavle. There were however no correlations between dbh or fruits and temperature or latitude of the provenance origin.

It was expected that southern provenances would have more fruits, this result may be swayed by the fact that data was only collected once therefore the maximum number of fruits was not recorded. However it was thought northern provenances would fruit earlier. There was a slight trend with southern provenances having more fruits, however the east-west gradient seemed to be more important with eastern provenances having more fruits. Only large fruit clusters were counted and the size of individual fruits was not taken into account. Northern provenances may have had few clusters of large fruits as this had previously been reported (Kollas et al, 2012). The aesthetical and biodiversity benefits of larger number of fruits and flowers is important where growing rowan for recreational or conservation purposes. If this is the objective then southeastern British proveances should be used.

Root morphology of Rowan has shown to be influenced by soil conditions and this may also affect other variables. In waterlogged gleysols the roots of rowan are shallow (about 10cm) and far spreading (around 6m), this is an environment that rowan does not grow well in. The depth and lateral projections of roots have an inverse relationship in rowan. In more suitable soils such as arenic cambisols, cambisols rendzina and pseudogleys the roots reach further down but spread less far than in gleysols. This could be an explanation as to why rowan does not grow well in waterlogged soils (Mauer and Palatova, 2002). Other morphological changes can be seen in response to different soils; for instance pine needle morphology changes at different sites in Japan (Ishii et al, 2007). This may be an explanation for provenances differences and the differences in performance of provenances at different sites.

Picture 26: Tress from the provenance Allt Volagir at the site Dornoch

Provenances did not always appear to be healthier when grown close to their location. Britain is in the middle of Rowan's geographical range therefore none of the provenances are representative of 'extreme' locations for rowan (maybe with exception of the North West Islands of Scotland, these provenances did have poor growth). The provenance – Allt Volagir, had the lowest ranking at Dornoch, it is from the Outer Hebrides (Northwest Scottish islands). The trees in this provenance had a shrub like morphology with small diameters (0 cm diameter), low forks and lots of stems. The trees were unhealthy and many had fruits this morphology may be an indication of their location where there are few large trees due to high winds. The provenance was also at Llandovery where it was likewise the lowest ranked provenance, trees were also small here with low forks and small diameters, the provenance did not have good survival here. In addition few of the provenances from the very north of Scotland were grown at southern sites and this may have given different results.

It is perhaps naïve to think of provenance as simply a result of the climatic factors from their origin as there are a whole host of biotic and abiotic factors that could affect growth, stem form and fruiting of the species. These include soil nutrients and parent material that can be vastly different over small distances in Britain. Other factors that could affect growth and morphology are management practices, presence of browsers and the genetic contamination from ornamental and garden varieties of Sorbus aucuparia. In addition, as rowan is a bird dispersed species, seeds can travel large distances therefore there is unlikely to be a geographical gradient. This is merely scratching the surface of all the factors that could alter a provenance which is a mixture of genetic information and life history traits from a variety of sources. The fact that there is so much to consider with provenance highlights how important it is know as much about a provenance as possible.

The overall highest ranked provenance – Brechfa is from an ancient royal Welsh hunting forest. This provenance did not have exceptionally high values in any variables except stem form and survival, it was the third highest ranked provenances at Alice Holt. The second highest provenance – King's Bottom – is from Longleat in South West England, which has been a stately home with an attached forest since the 16th century. This provenance had large trees with large diameter and high forks, it was the best provenance at Alice Holt. The third highest ranked provenance – St Helen's Wood – is a historical forest in South East England. Trees had large diameters and lots of fruits, it was the third highest ranked provenance at Llandovery but one of the lowest at Dornoch.

The lowest ranked provenance – Horner Wood – is from an an ancient coastal forest in South West England. These trees were small and had poor stem form, it was the 4th and 3rd worst ranked provenance at Alice Holt and Dornoch respectively. The second lowest provenance – Pressmennan – is from an ancient woodland on the east cost of Scotland, this provenance had poor stem form, lots of stems and low survival. It was the lowest ranked provenance at Dornoch but had larg stems at Llandovery. The third lowest ranked – Falls of Clyde – is also in Scotland and is the home of a hydro-electric power station, this was one provenance that ranked highly at North York Moor. This provenance had few fruits and poor stem form, it was the worst ranked provenance at Alice Holt. Pressmennan Wood and Falls of Clyde are the second and third most northern of all the British provenances respectively. There was also a large amount of variation between which provenances did well at which site. Provenances rarely had rankings at both Llandovery and Dornoch.

At Alice Holt (the most southerly of the sites) the highest ranked provenances were all southern in origin. However some low ranked provenances such as Horner Wood were also from the south. Northern and mountainous provenances had the highest ranking at Dornoch and low ranked provenances were from all over Britain. The provenance Mynydd Du had a high ranking at Dornoch, the origin of which is close to Llandovery where it did not have a high ranking. There were discrepancies between the provenances that did have a high ranking at Dornoch and Llandovery, such as Holford/Hodders Combe which is from coastal south-west Britain, and had a high ranking at Llandovery and a low ranking at Dornoch. Most high ranked provenances at Llandovery were from the south, there were however exceptions such as Add Valley- ranked 4th. Poor provenances at Llandovery were generally from Scotland.

There do not seem to be any trends between soil conditions, pH or parent material and high or poorly performing provenances. However the conditions listed in table 3 are from data relating to the general area and not the exact provenance location. Soil conditions at the origin could be something that effects the performance of the provenance. Taking soil samples at each site may have helped to analyze this better.

The fact that rowan seeds are largely dispersed by birds mean that seeds can travel large geographical distances which is an explanation for the high genetic variation and also for large shifts in provenance traits over small geographical distances such as the differences seen in Welsh provenances. CpDNA has shown that long distance seed dispersal is often linked to high genetic diversity (Raspe and Jacquemart, 1998). Hotspots of diversity in the

Sorbus genus are thought to be a response to niche conditions. This indicates sensitivity and adaptability in the species which are attricutes that will be important in response to future climate. Britain is a diverse island and has many intricacies and niche environments.

5.3. Silvicultural recommendations

There is a large influence of provenance and this should be considered when choosing the species. Trees from the north may not be so good in southern climates; this discrepancy is likely to increase with climate change. Forking is a major problem for the species and at best provenances had 38% of trees without forks. This would be a major problem if growing trees for high quality timber, there can also be significant variation in stem form. Provenance selection would have to be accompanied by pruning to significantly reduce forks. Rowan is currently able to survive in a large range of climates and if, as predicted, the envelop shifts north then the species may be able to grow not only further north but also at higher altitudes. It may be a good species to use in areas that are threatened by erosion.

Some southern populations, particularly where there is also landscape fragmentation, may be threatened and this genetic material may become lost. Therefore human intervention would be needed to help the species migrate and ensure the large amount of genetic variation within the species is maintained. However, care should be taken if one wants to move the species northwards or upwards especially considering that rowan responds to temperature signals. One provenance from a mountainous location in Wales – Mynnydd Du – was one of the best performing provenances at Dornoch indicating that provenances from high altitudes and northern locations share traits and could be grown in each others' location. Also it is known that seeds from high altitudes tend to be high quality (Kollas et al, 2012). Mountainous provenances should therefore be considered for northern locations and while northern provenances perform well in the north the same is not true for mountainous locations. Using Scottish provenances in Scotland would also be advisable. In general southern provenances performed better at southern sites however some from more exposed locations such as Horner Wood from the very South West of Britain had lower rankings. Central and Eastern Southern England are therefore probably the best choices. As western Scottish provenances often had high survival at North York they should be considered for use on unfavorable sites such as for reclamation.

The fast growing, pioneer nature of the species may mean that it is one of the first trees to adapt to changes in future climate. Tree migration and evolution will however happen at a rate slower than anthropogenic caused climate change and human intervention is key in order to rebalance equilibrium and ensure diversity at all levels. The consequences of climate change are unknown and the exact future climate is hard to predict. Therefore it may be useful to create forest transition zones that will not further fragment forest landscapes (one of the biggest threats to genetic conservation). Furthermore this type of forest management would not commit landowners to use a species that will be unsuitable for the future climate of the forest or yield lower quality timber than expected. As a fast growing highly tolerant species rowan would be a good option to use in these areas.

As shown by the different growth at different sites, rowan is a responsive and adaptive tree. For instance the morphology at Alice Holt, where trees had many stems and many fruits was different to that at Dornoch where trees were smaller and more shrub-like – this is why the species is so hardy and can grow in a wide range of locations. In addition there are likely to be increases in extreme weather that may cause windthrow and pests such as bark beetle. Rowan grows well under spruce and therefore could be used to colonise forests after these disasters. It also has potential to be used as a reclamation species after storms or bark beetle outbreak, which are both predicted to increase in the future. Rowan's ability to grow under partial canopies and in the presence of lots of dead wood mean it could be used following one of these activities. While survival was low at North York Moor, the number of very small trees did show an ability to survive in difficult conditions. As a fast growing multi stemmed species there is a potential to use rowan for bioenergy. There is a possibility to create additional stems, either through removal of stems or dense vegetation and increase biomass by removal of secondary stems that may have applications for producing bioenergy.

6. Conclusion

Provenance was shown to have a large effect on survival, stem form, fruiting and growth of rowan. This effect was shown to be significant at sites in Britain and Sweden, showing the large amount of genetic variation in the species.

- There was a great deal of responsiveness and adaptability from different site resulting in morphological differences. Numbers of stems are likely to increase where there is lots of competition or mechanical stem removal.
- In general provenances from northern Britain had poorer growth, stem form, and less fruits than at southern sites at southern provenances. There were some exceptions to this particularly when southern sites are in higher altitudes. Growing northern provenances in southern locations is therefore inadvisable as this problem will increase if climates become warmer.
- There was not shown to be any positive relationship of growing provenances close to their origin. Genetic differences can be larger over small distances in rowan due to the bird dispersal.
- Northern provenances generally had less fruits than southern ones in contrast to the predicted outcome. The main gradient of fruit production was west east in Britain, which is linked to rainfall. Northern provenances may require chilling in order to produce fruits, resulting in lower numbers of fruits.
- Southern sites were shown to be more productive than northern ones, however rowan may benefit from higher altitudes where there is less competition from other plants. Survival was highest in northern Britain again this was linked to reduced competition.
- Contrary to what was expected there were some sites with low survival and poor growth. Site gradients and unfavourable floristic communities

can be problematic for the establishment of rowan.

- Southeastern provenaces tend to have more fruits and would be recommended for recreation and conservation. Wood production is less important for thus purpose.

There is unexplored silvicultural potential for rowan such as for bioenergy (due to the multi-stemmed nature) and in response to disasters such as bark beetle outbreak. The large amount of variation in the species does mean that provenance selection is important and should be considered. In the future some changes to forestry will be necessary due to factors such as climate change and increases in diseases. The adaptable nature of rowan may result in additional uses for the species and should be considered in areas that are likely to undergo a change or the landuse is threatened such as at forest edges.

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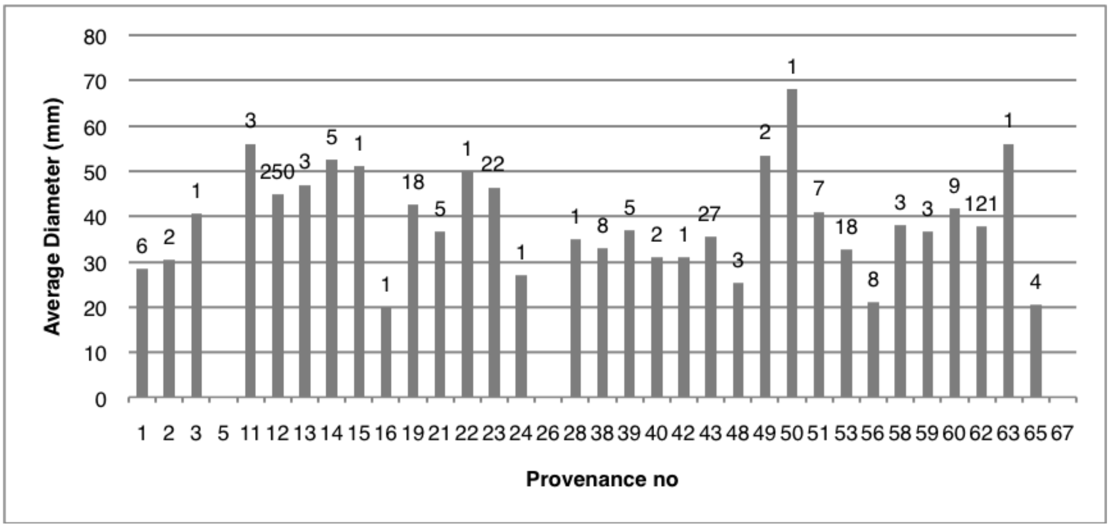
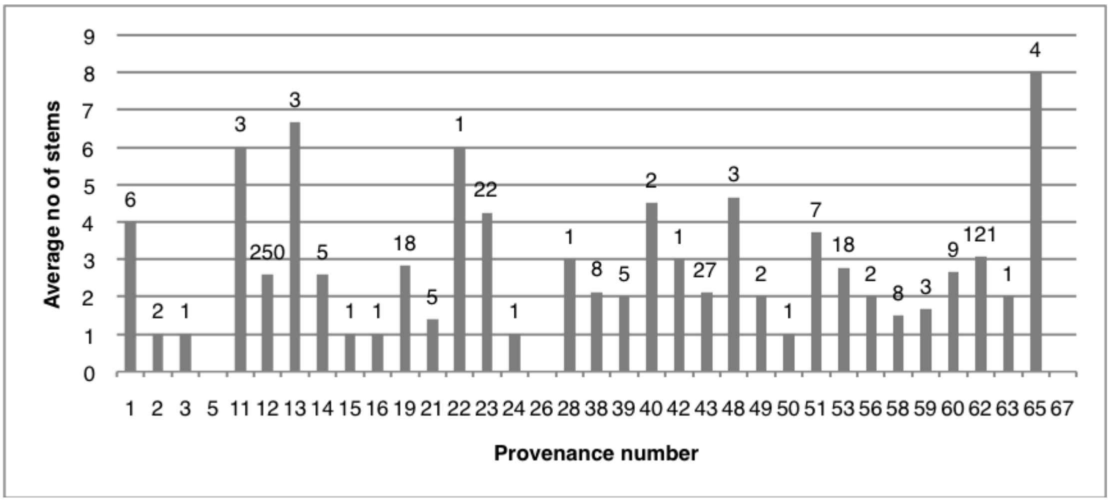
8. Appendices

8.1. Appendix I – Supplementary Graphs and Tables

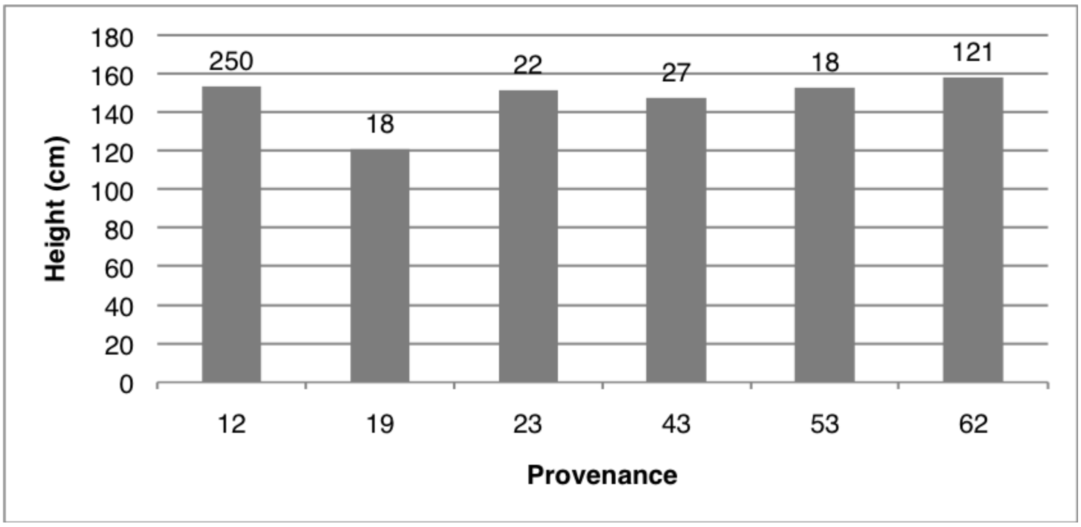
8.1.1. Innertavle



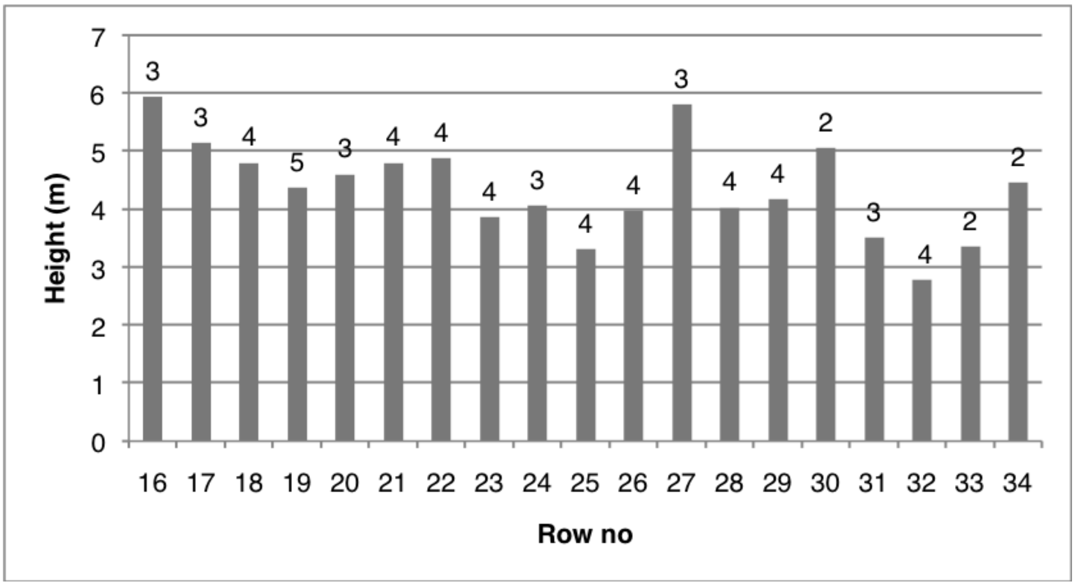
Graph 1: Bar graph showing all Swedish provenances and diameter, number of replications shown above bar



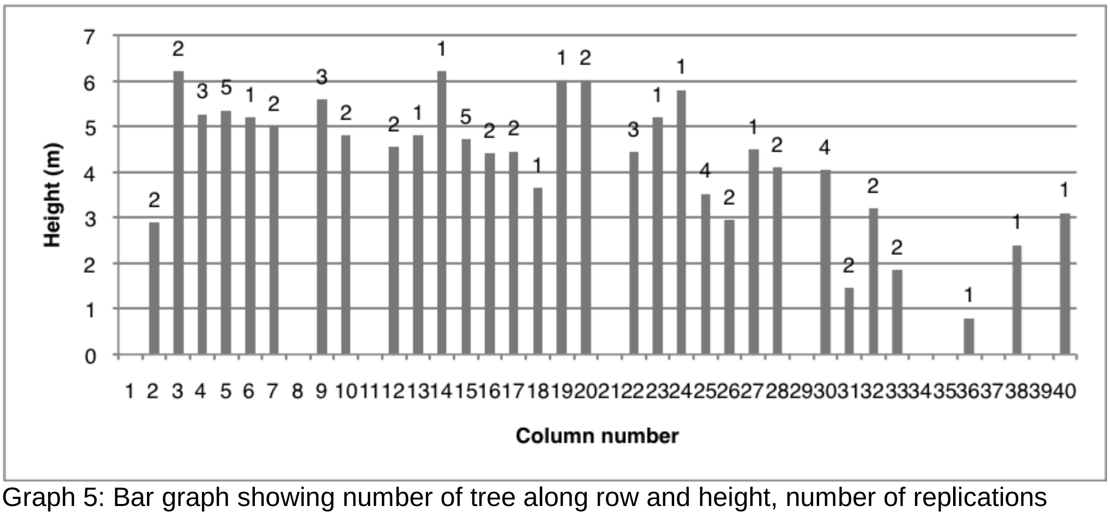
Graph 2: Bar graph showing mean number of stems for all Swedish provenances, number or replications shown above bar



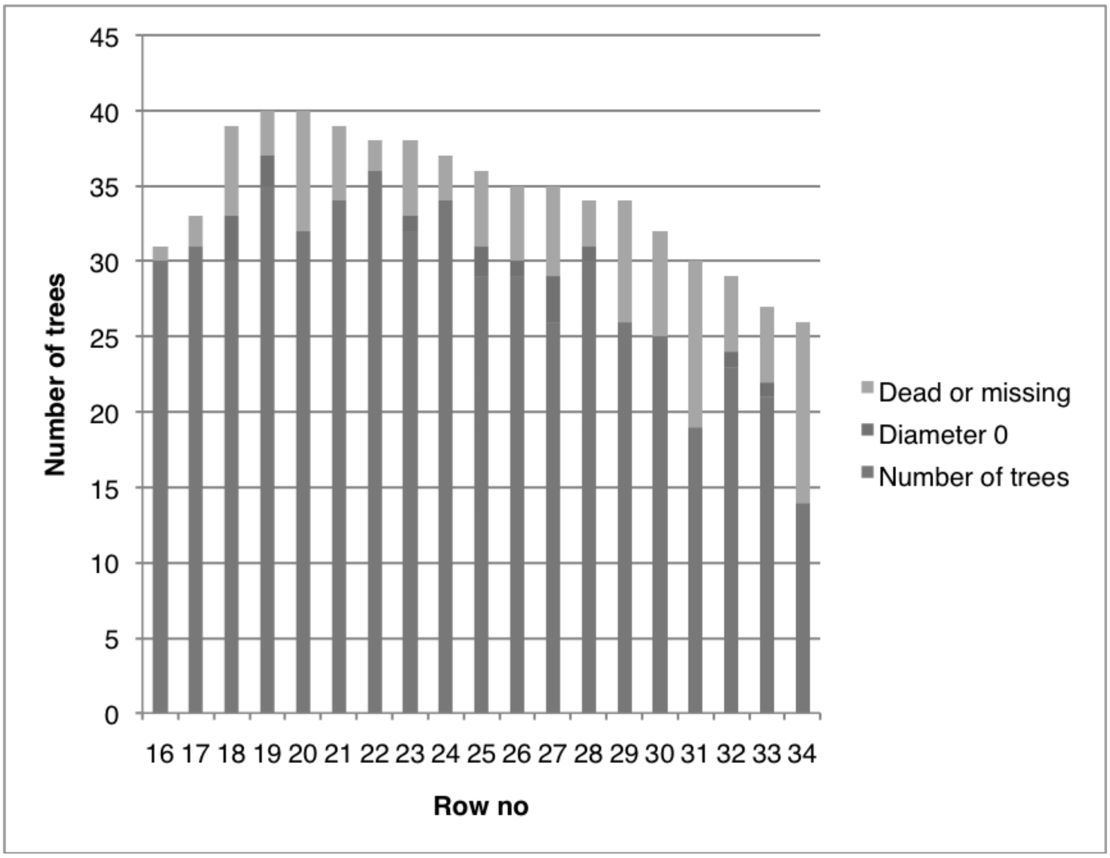
Graph 3: Bar graph showing mean fork height (cm) for Swedish provenances, number of replications shown above bar



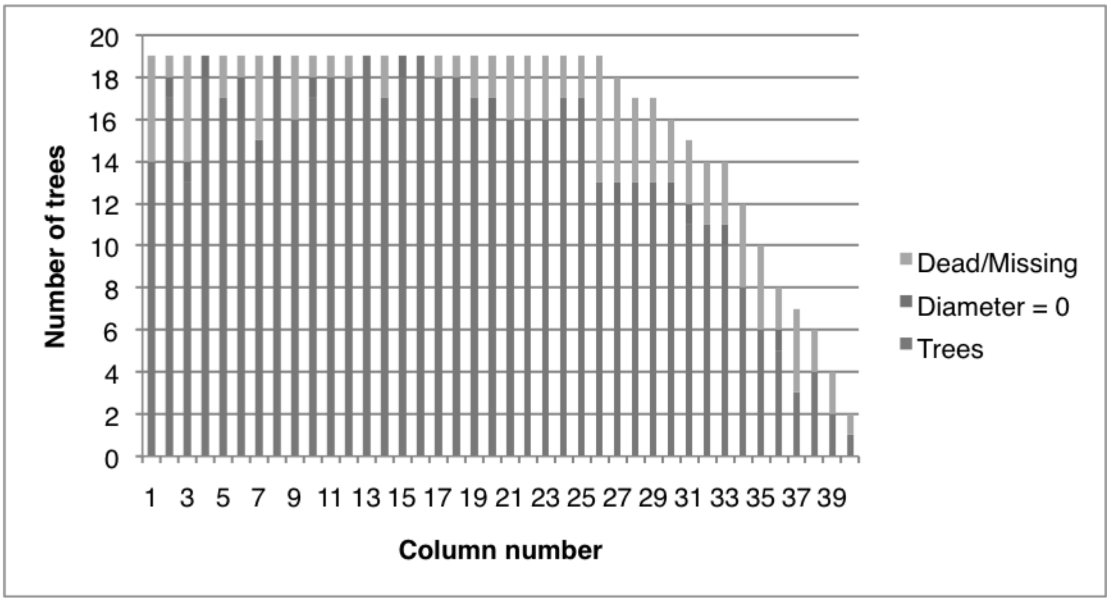
Graph 4: Bar graph showing row number and tree height, number of replications shown above bar



Graph 5: Bar graph showing number of tree along row and height, number of replications shown above bar



Graph 6: Stacked bar graph showing row number of large trees, small and dead and missing trees



Graph 7: Stacked bar graph showing number of tree in row and number of large trees, small trees and dead and missing trees

	Degrees of Freedom	Sum Square	Mean Square	F Value	P>F
Provenance	1	12	12.382	1.773	0.184
Residuals	541	3778	6.983		

Table 1: Results of anova test on number of stems and provenance at Innertavle

	Degrees of Freedom	Sum Square	Mean Square	F Value	P>F
Provenance	1	0.1	0.0599	0.076	0.783
Residuals	541	426.8	0.789		

Table 2: Results of anova test on stem form and provenenace at Innertavle

	Degrees of Freedom	Sum Square	Mean Square	F Value	P>F
Provenance	1	24181	24181	5.008	0.0256*
Residuals	540	2607368	4828		

Table 3: Results of anova test on fork height and provenance at Innertavle

t	3.609
Degree of Freedom	543
P-Value	0.0003
95% Confidence	0.070. 0.234
Correlation	0.153

Table 4: Results of Pearson's Correlation test on diameter and number of stems at Innertavle

t	1.705
Degree of Freedom	543
P-Value	0.089
95% Confidence	-0.011. 0.156
Correlation	0.073

Table 5: Results of Pearson's Correlation test on diameter and number of corymbs at Innertavle

t	2.647
Degree of Freedom	543
P-Value	0.008
95% Confidence	0.029. 0.195
Correlation	0.113

Table 6: Results of Pearson's Correlation test on diameter and fork height at Innertavle

t	1.95
Degree of Freedom	543
P-Value	0.051
95% Confidence	-0.0004. 0.166
Correlation	0.08

Table 7: Results of Pearson's Correlation test on number of corymbs and number of stems at Innertavle

t	0.084
Degree of Freedom	543
P-Value	0.049
95% Confidence	0.0004. 0.17
Correlation	0.08

Table 8: Results of Pearson's Correlation test on stem form and number of stems at Innertavle

t	2.75
Degree of Freedom	542
P-Value	0.0017
95% Confidence	0.051 0.216
Correlation	0.134

Table 9: Results of Pearson's Correlation test on fork height and number of stems at Innertavle

t	-1.43
Degree of Freedom	543
P-Value	0.151
95% Confidence	-0.145. 0.022
Correlation	-0.062

Table 10: Results of Pearson's Correlation test on stem form and number of corymbs at Innertavle

t	0.834
Degree of Freedom	542
P-Value	0.405
95% Confidence	-0.048. 0.120
Correlation	0.036

Table 11: Results of Pearson's Correlation test on fork height and number of corymbs at Innertavle

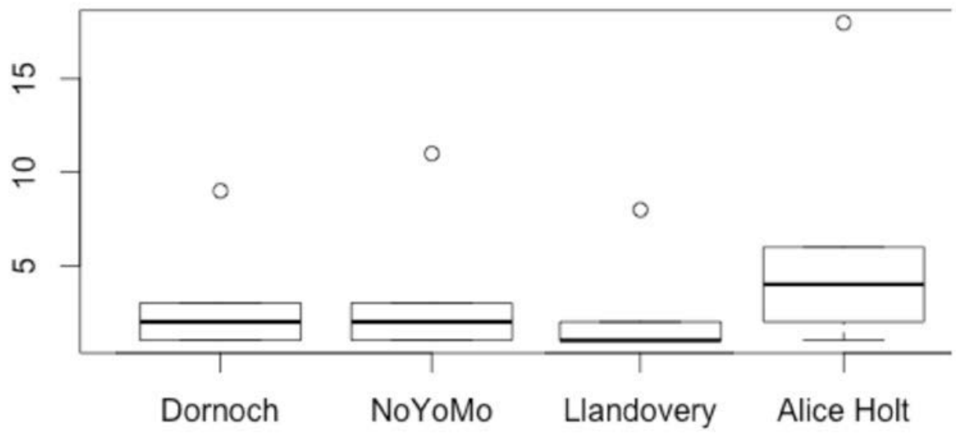
t	3.652
Degree of Freedom	542
P-Value	0.0003
95% Confidence	0.072 0.234
Correlation	0.155

Table 12: Results of Pearson's Correlation test on stem form and fork height at Innertavle

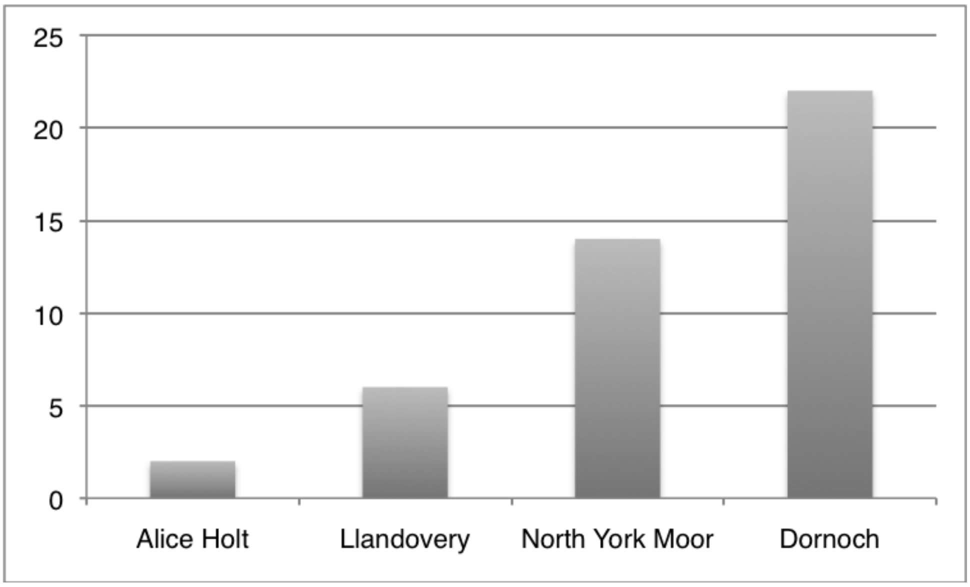
Code	Significance
***	0
**	0.001
**	0.01
*	0.05
.	0.1
	1

Table 13: Significance codes for all anova tests

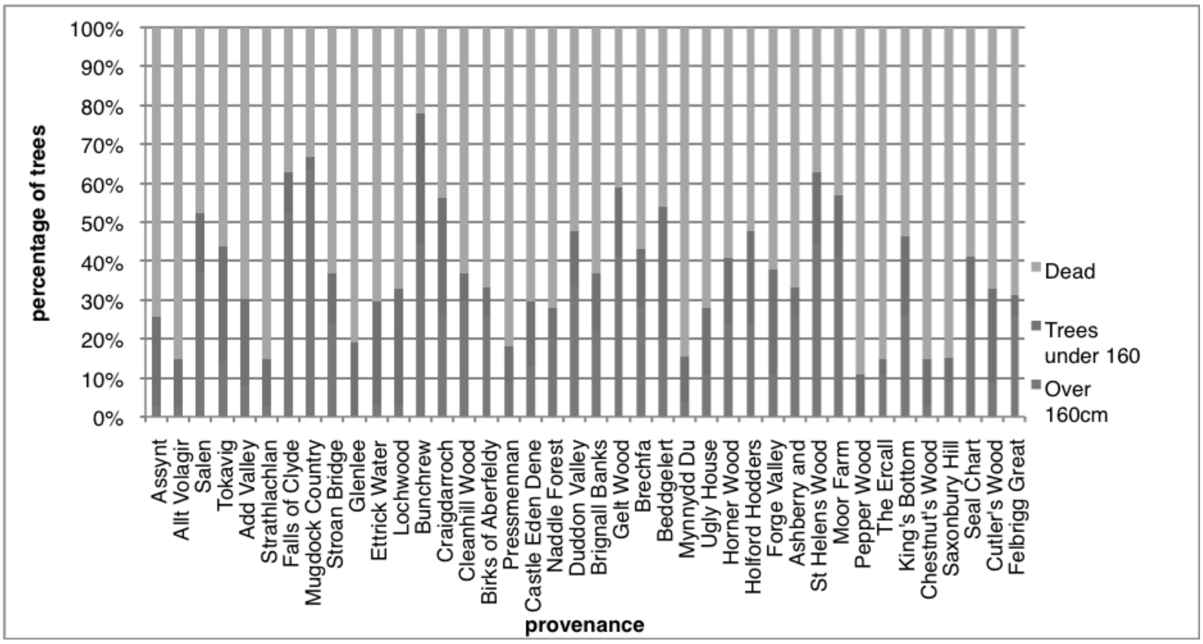
8.1.2. All British Site



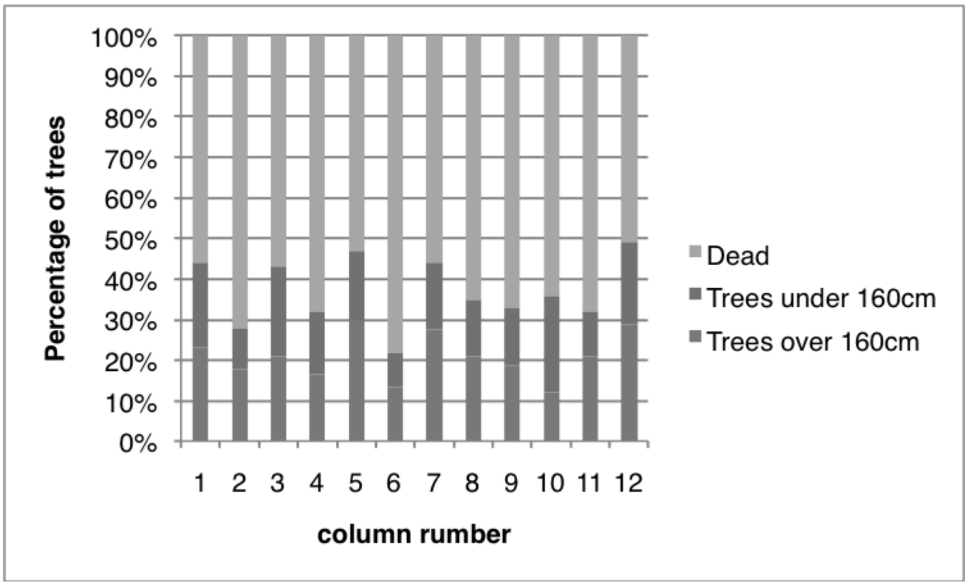
Graph 8: Boxplot showing minimum, lower quartile, mean, upper quartile and maximum number of stems for each British site



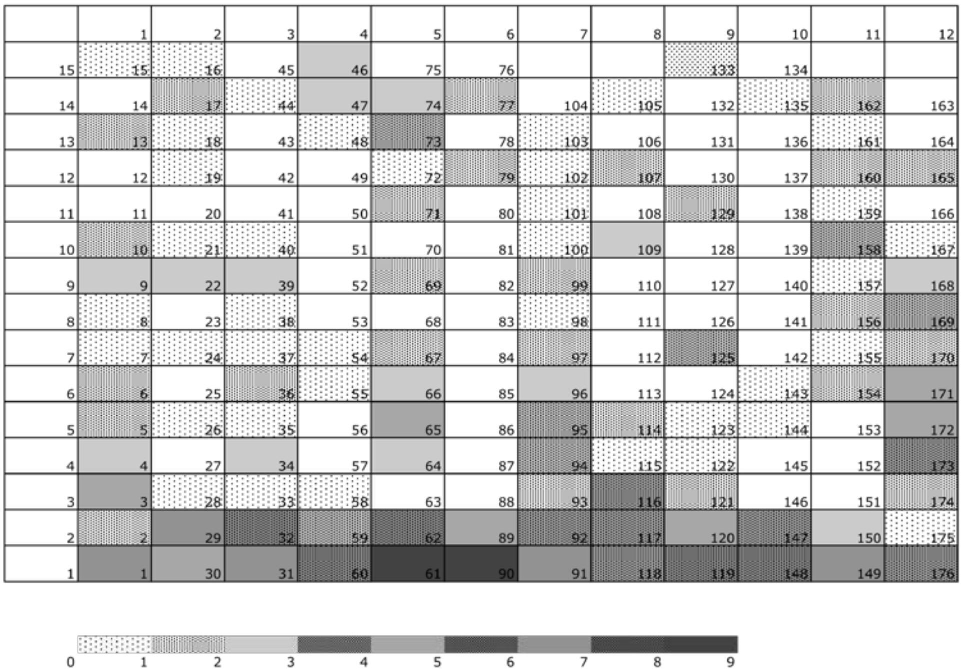
Graph 9: Barchart showing percentage of trees that were recorded as having poor health



Graph 10: Stacked bar graph showing provenance and large trees, small trees and dead and missing trees



Graph 11: Stacke bar graph showing column number and large trees, small trees and dead and missing trees



Graph 12: Plan showing number of large trees (over 160cm) at North York Moor for every plot

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	3	47335	15778	184.9	$2.2*10^{-16***}$
Provenance	41	9927	242	2.8	$1.1*10^{-8***}$
Site*Provenance	97	14886	153	1.8	$7.1*10^{-6***}$

Table 14: Results of anova on site, provenance and diameter for British sites

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	3	171	57	83.2	$2.2*10^{-16***}$
Provenance	41	98	2.4	3.5	$2.5*10^{-12***}$
Site*Provenance	97	155	1.6	2.3	$5.3*10^{-11***}$

Table 15: Results of anova test on site, provenane and number of fruits at British sites

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	3	213634	71211	920.7	$2.2*10^{-16***}$
Provenance	41	14468	353	4.6	$2.2*10^{-16***}$
Site*Provenance	97	28688	296	3.8	$2.2*10^{-16***}$

Table 16: Results of anova test on site, provenance and stem form for British sites

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	3	1166	389	120.8	$2.2*10^{-16***}$
Provenance	41	404	10	3.1	$6.1*10^{-10***}$
Site*Provenance	97	630	6.5	2.0	$6.8*10^{-8***}$

Table 17: Results of anova test on site, provenance and number of stems for British sites

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	3	1050016	350005	167.9	$2.2*10^{-16***}$
Provenance	41	172063	4197	2.0	0.0002***
Site*Provenance	97	368090	3795	1.8	$4.6*10^{-6***}$

Table 18: Results of anova test on site, provenance and fork height for British sites

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Edge	1	15981	15981	24.37	$1.85*10^{-6}$	***
Residuals	174	114087	656			

Table 19: Result of anova test on survival and edge at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Provenance	39	277.4	7.113	1.53	0.0393	*
Residuals	136	632.3	4.65			

Table 20: Result of anova test on percentage of large trees and provenance at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Row	1	275.03	275.03	75.4	$2.71*10^{-15}$	***
Residuals	174	634.7	3.65			

Table 21: Result of anova test on percentage of large trees and row number at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Column	1	0.1	0.149	0.028	0.866	
Residuals	174	909.6	5.227			

Table 22: Result of anova test on percentage of large trees and column number at North York Moor

	Degrees of Freedom	Sum sq	Mean sq	F Value	Pr(>F)	Significance
Edge	1	110.3	110.33	24.02	$2.18*10^{-6}$	***
Residuals	174	799.4	4.59			

Table 23: Result of anova test on percentage of large trees and edge at North York Moor

Interaction	**Difference**	**Lower**	**Upper**	**P Adj**
Dornoch-Alice Holt	-12.65	-14.48	-10.82	0
Llandovery-Alice Holt	-1.84	-3.77	0.08	0.07
North York Moor-Alice Holt	-11.56	-13.32	-9.80	0
Llandovery-Dornoch	10.80	8.88	12.72	0
North York Moor-Dornoch	-1.09	-0.69	-2.84	0.38
North York Moor-Llandovery	-9.72	-11.60	-7.86	0

Table 24: Result of Tukey HSD test at 95% significance for interactions of site on number of fruits for British sites

Interaction	Difference	Lower	Upper	P Adj
Dornoch-Alice Holt	0.23	0.64	0.40	0.002
Llandovery-Alice Holt	0.18	0.01	0.36	0.04
North York Moor-Alice Holt	-0.58	-0.74	-0.42	0
Llandovery-Dornoch	-0.05	-0.22	0.13	0.90
North York Moor-Dornoch	-0.81	-0.98	-0.65	0
North York Moor-Llandovery	-0.77	-0.94	-0.60	0

Table 25: Result of Tukey HSD test at 95% significance for interaction of site on stem form for British sites

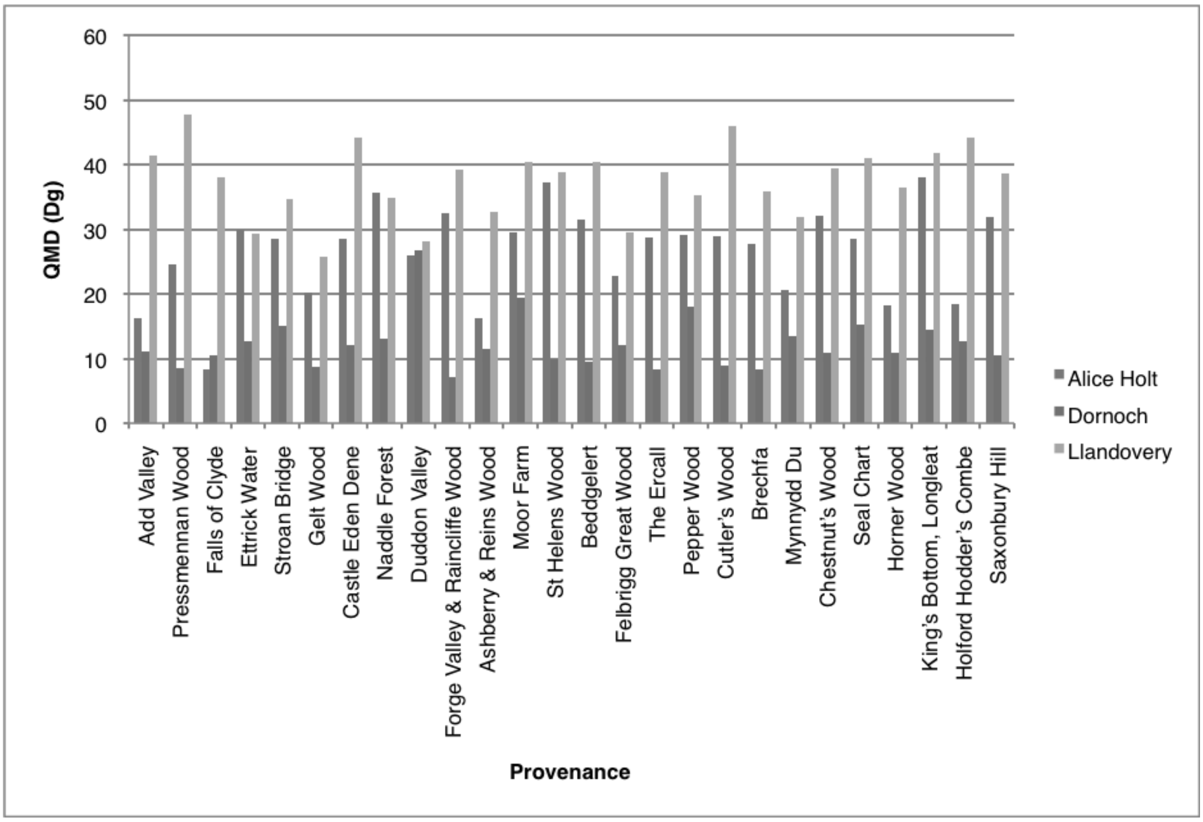
Interaction	Difference	Lower	Upper	P Adj
Dornoch-Alice Holt	-1.75	-2.11	-1.40	0
Llandovery-Alice Holt	-2.49	-2.87	-2.11	0
North York Moor-Alice Holt	-1.68	-2.03	-1.34	0
Llandovery-Dornoch	-0.74	-1.12	-0.36	0.000003
North York Moor-Dornoch	0.07	-0.28	0.41	0.957
North York Moor-Llandovery	0.81	0.44	1.17	0.0000001

Table 26: Result of Tukey HSD test at 95% significance for interaction on number of stems for British sites

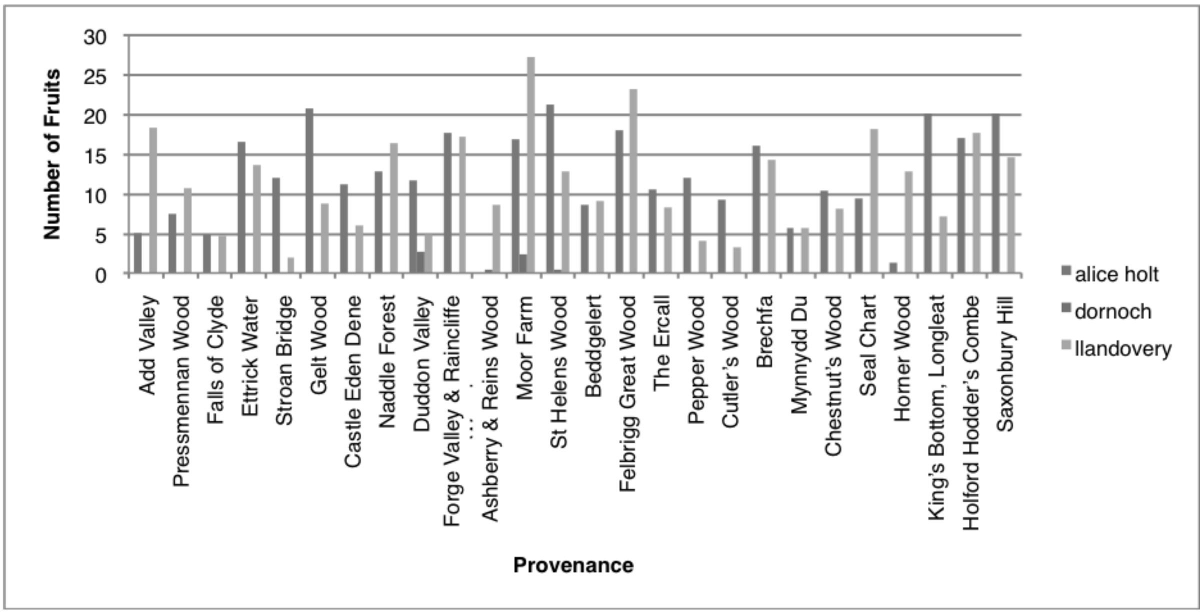
Interaction	Difference	Lower	Upper	P Adj
Dornoch-Alice Holt	-28.7	-36.9	-20.6	0
Llandovery-Alice Holt	-4.37	-12.9	4.3	0.56
North York Moor-Alice Holt	-31.9	-41.3	-22.6	0
Llandovery-Dornoch	24.4	15.8	32.9	0
North York Moor-Dornoch	-3.17	-12.5	6.12	0.82
North York Moor-Llandovery	-27.5	-37.3	-17.8	0

Table 27: Result of Tukey HSD test at 95% significance for interaction of site on fork height for British sites

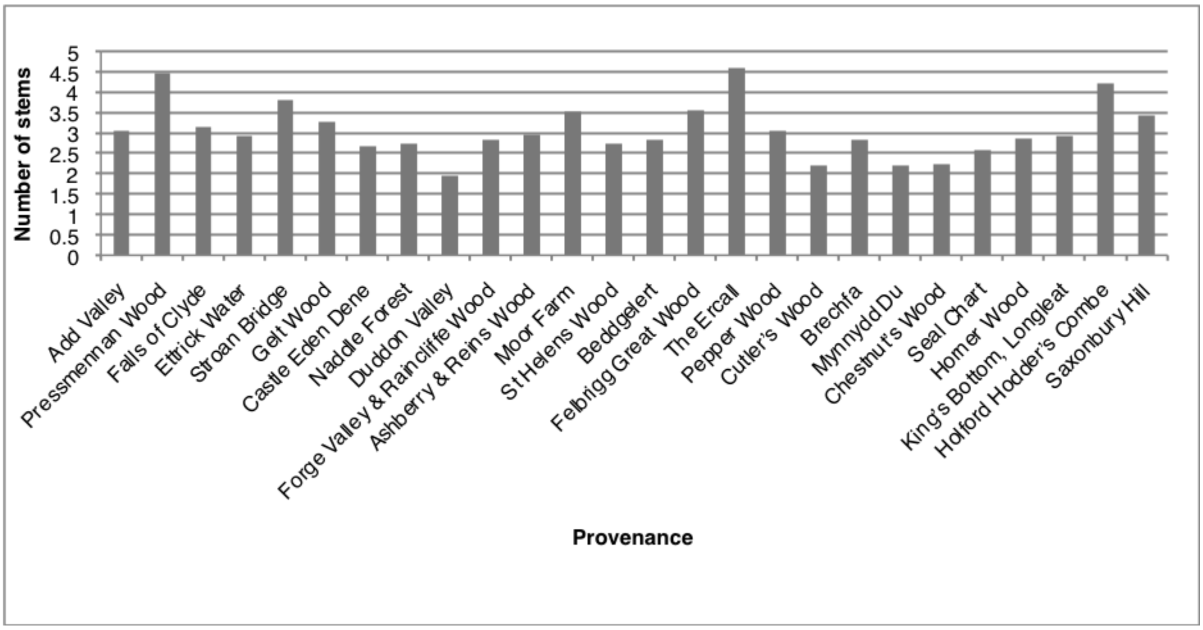
8.1.3. British Sites – Tight Data Set



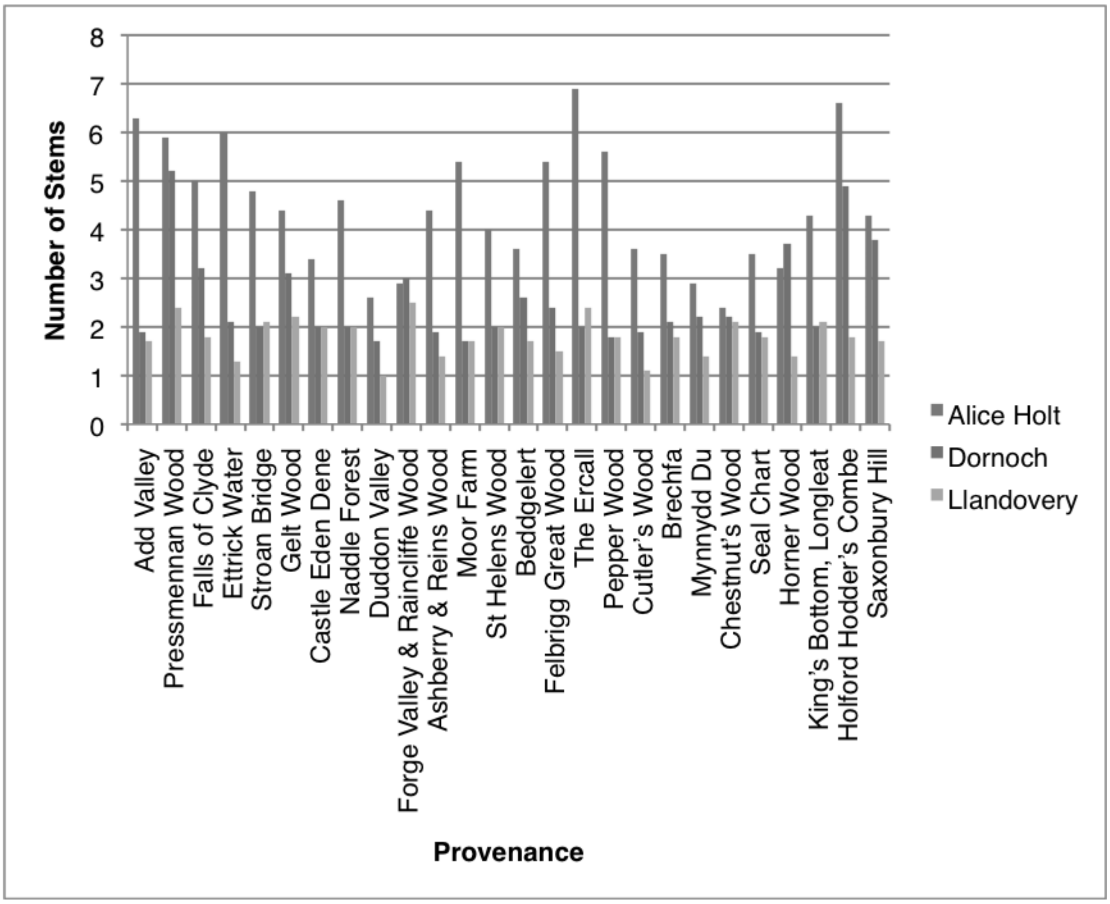
Graph 13: Bar graph showing QMD of provenances at each British site, ordered by latitude



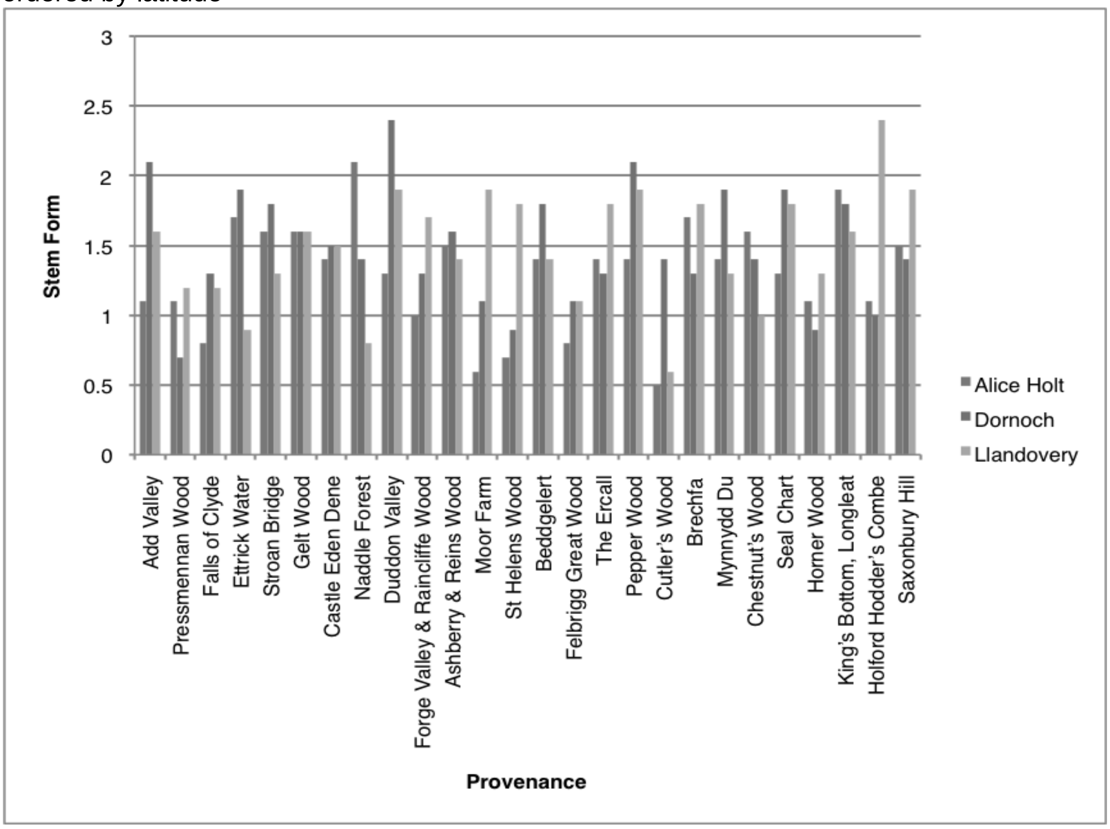
Graph 14: Bar showing mean number of fruits for provenances at each British site, ordered by latitude



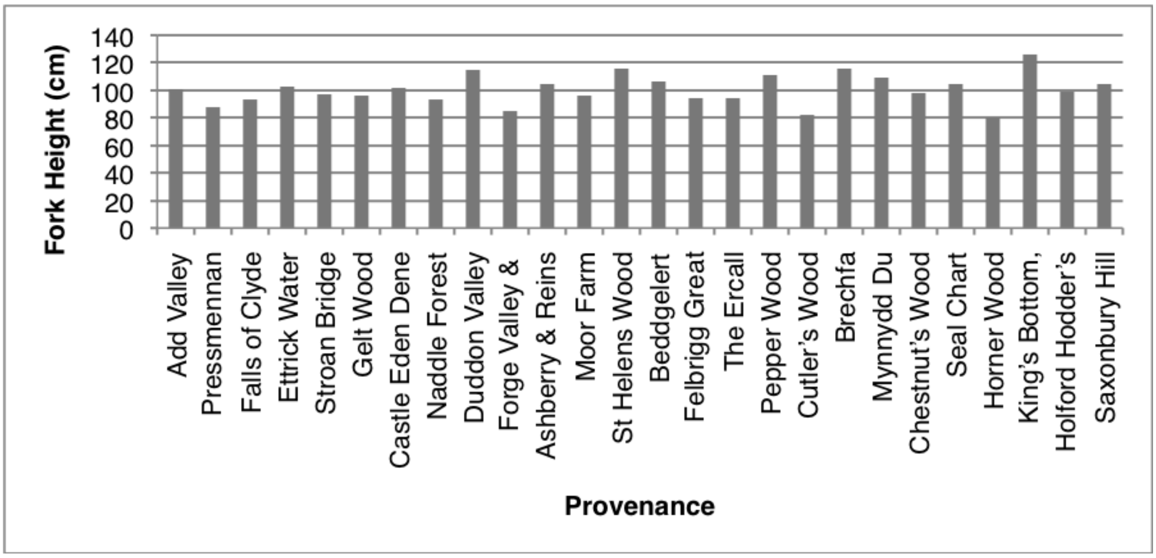
Graph 15: Bar graph showing mean number of stems of provenances for all British sites. Ordered by latitude



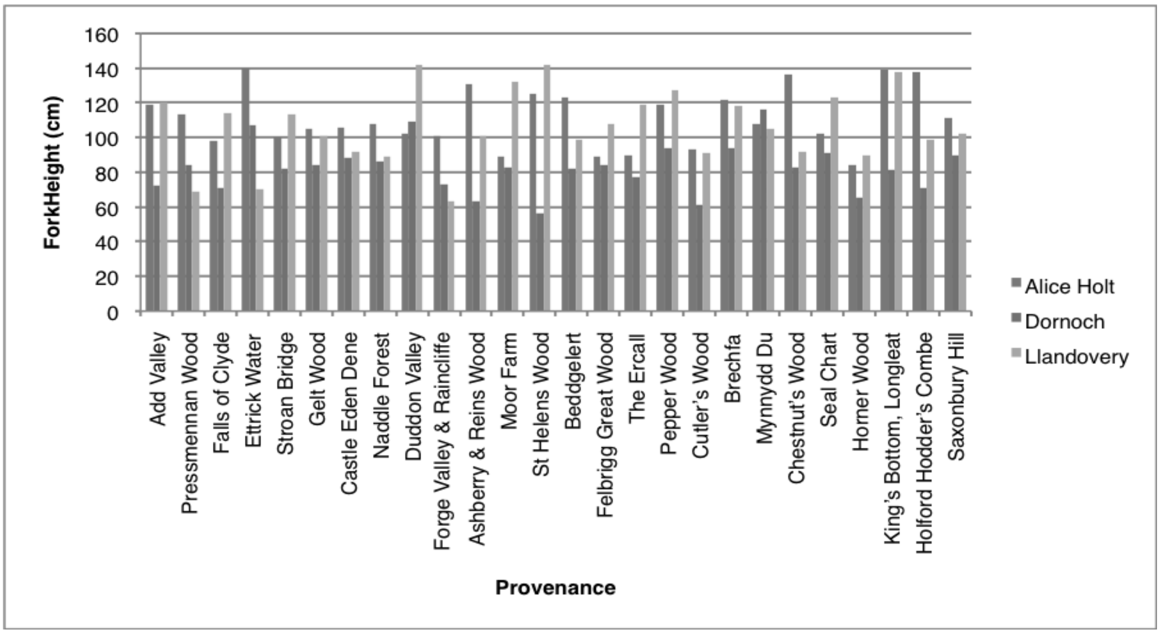
Graph 16: Bar graph showing mean number of stems of provenances for each British site, ordered by latitude



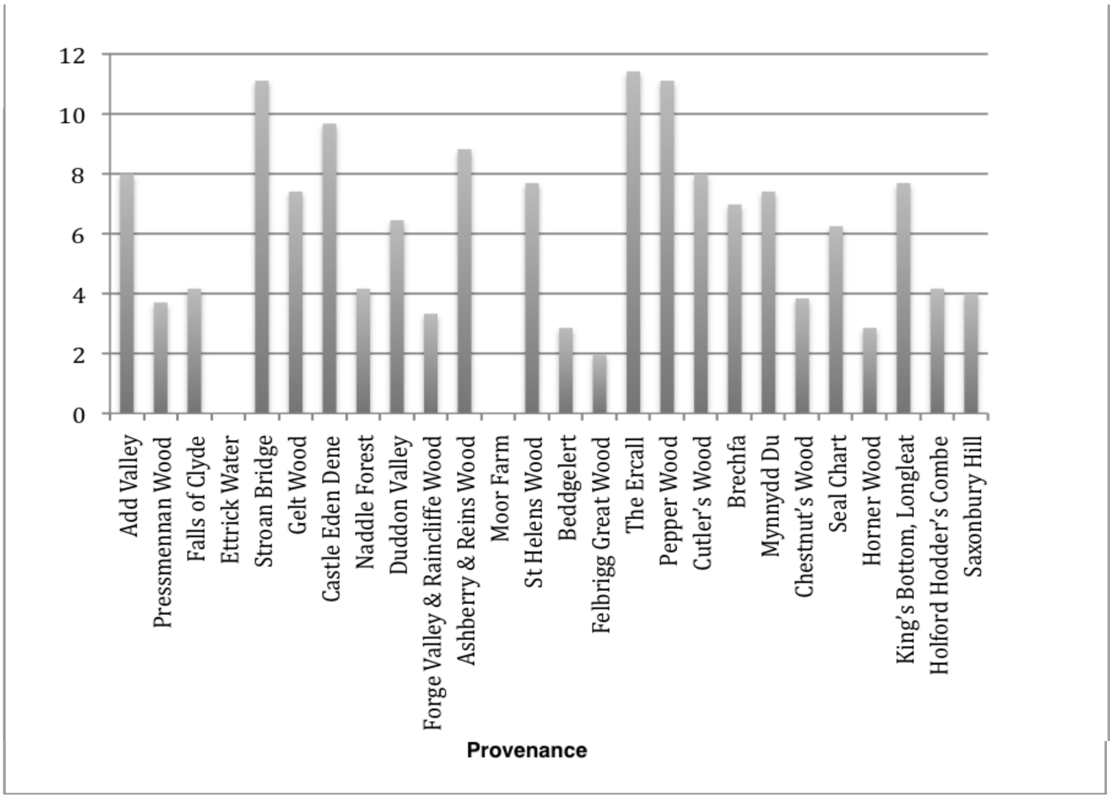
Graph 17: Bar graph showing mean stem form of provenances at each British sites, ordered by latitude



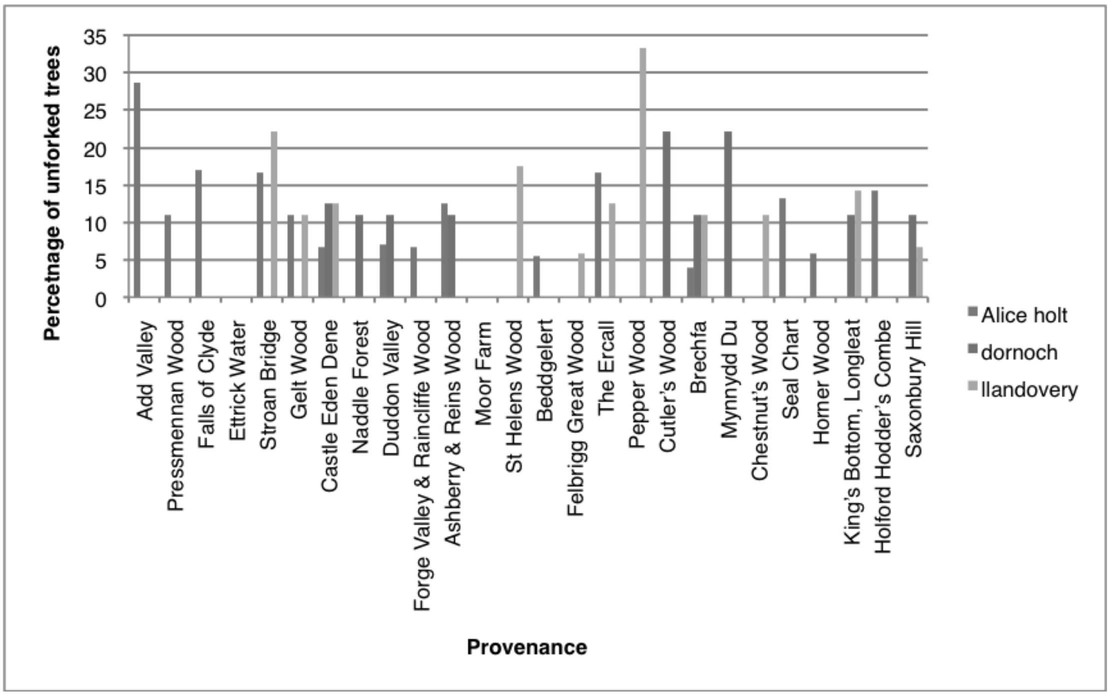
Graph 18: Bar graph showing mean fork height of provenances at all British sites, ordered by latitude



Graph 19: Bar graph showing mean fork height of provenances at each British site, ordered by latitude



Graph 20: Bar graph showing percentage of trees with forks at all British sites, ordered by latitude



Graph 21: Bar graph showing percentage of trees with forks of all provenances at each British site

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	2	109024	54512	30.852	$1.4*10^{-13***}$
Provenance	25	88119	3525	1.995	0.00286^{**}
Site*Provenance	49	144065	2881	1.631	0.0475^{**}

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	2	1037.1	518.6	135.642	$2.2*10^{-16***}$
Provenance	25	335.9	13.4	3.514	$2.4*10^{-8***}$
Site*Provenance	49	377.9	7.7	2.018	$7.5*10^{-5***}$

	Degrees of Freedom	Sum^2	Mean^2	F value	Pr(>F)
Site	2	4.7	2.343	2.335	0.09748.
Provenance	25	77.7	3.109	3.099	$7.19*10^{-7***}$
Site*Provenance	49	78.3	1.597	1.592	0.00722^{**}

Table 28: Results of two-way anova on stem form for the tight data set

Table 30: Results of two-way anova on number of stems for tight data set
Table 29: Results of two-way anova on fork height for the tigh data set

Pair	Diff	Lower	Upper	P
Dornoch- Alice Holt	0.156	-0.053	0.364	0.188
Llandovery- Alice Holt	0.149	-0.057	0.355	0.206
Llandovery- Dornoch	-0.01	-0.234	0.221	0.997

Table 31: Results of Tukey-HSD test for the two-way anova on stem form

Pair	Diff	Lower	Upper	P
Dornoch- Alice Holt	-1.823	-2.238	-1.409	0
Llandovery- Alice Holt	-2.552	-2.961	-2.143	0
Llandovery- Dornoch	-0.728	-1.180	-0.277	0.0005

Table 32: Results of Tukey-HSD test for two-way anova on number of stems

Pair	Diff	Lower	Upper	P
Dornoch- Alice Holt	-27.28	-36.21	-18.34	0
Llandovery-Alice Holt	-2.52	-11.29	6.26	0.779
Llandovery-Dornoch	24.76	15.14	34.38	0

Table 33: Results of Tukey-HSD test for two-way anova on fork height

Pair	Diff	Lower	Upper	P
Dornoch- Alice Holt	-0.074	-0.122	-0.026	0.001
Llandovery-Alice Holt	-0.019	-0.065	0.026	0.570
Llandovery-Dornoch	0.054	0.003	0.106	0.035

Table 34: Results of Tukey-HSD test for two-way anova on survival

Pair	Diff	Lower	Upper	P
Dornoch- Alice Holt	-12.942	-15.356	-10.528	0
Llandovery-Alice Holt	-1.104	-3.485	1.277	0.521
Llandovery-Dornoch	11.838	9.21	14.467	0

Table 35: Results of Tukey-HSD test for two-way anova on number of fruits

Pair	Diff	Lower	Upper	P
Dornoch- Alice Holt	-14.904	-17.080	-12.727	0
Llandovery-Alice Holt	10.431	8.285	12.578	0
Llandovery-Dornoch	25.335	22.966	27.704	0

Table 36: Results of Tukey-HSD test for two-way anova on diameter

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.26***							
Temperature	-0.73***	0.41***						
Diameter	-0.12.	0.11.	0.04					
Fork Height	-0.09	-0.01	-0.03	0.23***				
No of Fruits	-0.08	0.17*	0.08.	0.48***	0.07			
Stem Form	-0.02	-0.19*	-0.15*	0.31***	0.17*	0.16*		
No of Stems	0.08	-0.01	-0.03	-0.08	-0.05	0.07	-0.14*	
Rainfall	0.02	-0.67***	-0.09.	0.05	0.07	-0.06	0.14*	-0.08.

Table 37: Results of Pearson's Correlation test for Alice Holt

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.31***							
Temperature	-0.73***	0.39***						
Diameter	-0.01	-0.07	-0.03					
Fork Height	-0.05	-0.09	-0.12	0.40***				
No of Fruits	-0.08	0.03	0.02	0.22**	0.11			
Stem Form	0.06	-0.14.	-0.12	0.40***	0.40***	0.06		
No of Stems	-0.00	-0.05	0.07	-0.12	-0.02	0.07	-0.31***	
Rainfall	0.21**	-0.63***	-0.14.	-0.01	0.04	-0.02	0.16.	-0.06

Table 38: Result of Pearson's Correlation test for Dornoch

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.31***							
Temperature	-0.73***	0.39***						
Diameter	-0.03	-0.03	0.07					
Fork Height	-0.05	0.00	0.09	0.25***				
No of Fruits	-0.02	0.14.	0.06	0.24***	0.15.			
Stem Form	-0.14.	-0.02	0.17**	0.29***	0.26***	0.14.		
No of Stems	0.04	-0.03	-0.02	0.14.	0.05	-0.02	-0.16.	
Rainfall	-0.02	-0.61***	-0.02	0.06	0.06	-0.02	0.03	-0.03

Table 39: Result of Pearson's Correlation test for Llandovery

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.24***							
Temperature	-0.58***	0.36***						
Diameter	-0.06	0.08.	0.05					
Fork Height	-0.02	-0.00	-0.01	0.15***				
No of Fruits	-0.04	0.15***	0.08.	0.40***	0.07.			
Stem Form	-0.05	-0.13*	-0.10.	0.22***	0.13**	0.12*		
No of Stems	0.04	0.04	-0.01	-0.05	-0.01	0.11*	-0.11*	
Rainfall	-0.03	-0.54***	-0.06	0.01	0.04	-0.01	0.14*	-0.07.

Table 40: Result of Kendall Correlation test for Alice Holt

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.23***							
Temperature	-0.58***	0.34***						
Diameter	-0.03	-0.02	0.05					
Fork Height	-0.03	0.02	0.04	0.17***				
No of Fruits	-0.04	0.10.	0.11.	0.22***	0.12*			
Stem Form	-0.12.	-0.02	0.08	0.22***	0.23***	0.14*		
No of Stems	0.03	-0.01	-0.04	0.10	0.03	0.03	-0.12.	
Rainfall	-0.05	-0.52***	-0.06	0.05	-0.05	-0.04	0.05	-0.03

Table 41: Result of Kendall Correlation test for Llandovery

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.27***							
Temperature	-0.60***	0.31***						
Diameter	-0.02	-0.05	-0.01					
Fork Height	0.02	-0.07	-0.08	0.31***				
No of Fruits	0.06	0.02	0.02	0.17*	0.07			
Stem Form	0.05	-0.09	-0.11.	0.31***	0.32***	0.08		
No of Stems	-0.01	-0.04	0.03	-0.08	-0.04	0.03	-0.27***	
Rainfall	0.10.	-0.59***	-0.13*	0.11.	0.08	0.01	0.14*	0.01

Table 42: Result of Kendall Correlation test for Dornoch

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.28***							
Temperature	-0.75***	0.45***						
Diameter	-0.09	0.12.	0.07					
Fork Height	-0.09	-0.00	-0.01	0.22***				
No of Fruits	-0.03	0.21***	0.10	0.55***	0.10.			
Stem Form	-0.05	-0.17**	-0.13.	0.28***	0.17**	0.15**		
No of Stems	0.07	-0.06	-0.01	-0.07	-0.02	0.14**	-0.15**	
Rainfall	-0.05	-0.70***	-0.09	0.01	0.05	-0.02	0.18**	-0.09

Table 43: Result of Spearman’s Correlation test for Alice Holt

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.28***							
Temperature	-0.76***	0.44***						
Diameter	-0.04	-0.02	0.06					
Fork Height	-0.05	-0.02	0.05	0.26***				
No of Fruits	-0.05	0.13.	0.15	0.32***	0.17**			
Stem Form	-0.15.	-0.02	0.10	0.29***	0.29***	0.19**		
No of Stems	0.04	-0.01	-0.05	0.12	0.04	0.04	-0.13.	
Rainfall	-0.07	-0.70***	-0.01	-0.07	0.07	-0.06	0.06	-0.04

Table 44: Result of Spearman’s Correlation test for Llandovery

	Latitude	Longitude	Temp	Diameter	Fork Height	No of Fruits	Stem Form	No of Stems
Latitude								
Longitude	-0.34***							
Temperature	-0.78***	0.41***						
Diameter	-0.04	-0.07	-0.01					
Fork Height	-0.03	-0.09	-0.11	0.42***				
No of Fruits	0.08	0.03	0.03	0.20**	0.09			
Stem Form	0.06	-0.12	-0.13.	0.38***	0.40***	0.08		
No of Stems	-0.02	-0.05	0.04	-0.10	-0.06	0.03	-0.32***	
Rainfall	0.18**	-0.76***	-0.21**	0.16*	0.12.	0.01	0.19**	0.01

Tabe 45: Result of Spearman’s Correlation test for Dornoch

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	2.9	2.9	0.05	0.8
Longitude	1	95.6	95.6	1.6	0.2
Temperature	1	31.4	31.4	0.5	0.5
Latitude*Longitude	1	85.1	85.1	1.5	0.2
Latitude*Temp	1	52	51.9	0.9	0.3
Longitude*Temp	1	145.9	145.9	2.5	0.1
Latitude*Longitude* Temp	1	72.1	72.1	1.2	0.3

Table 46: Result of anova test on Diameter at Dornoch

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	625	625	0.5	0.47
Longitude	1	1767	1767	1.4	0.22
Temperature	1	3883	3883	3.2	0.07
Latitude*Longitude	1	77	77	0.1	0.80
Latitude*Temp	1	342	342	0.3	0.59
Longitude*Temp	1	139	139	0.1	0.73
Latitude*Longitude* Temp	1	102	102	0.1	0.77

Table 47: Result of anova test on Fork Height at Dornoch

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	1.4	1.4	0.6	0.46
Longitude	1	1.6	1.6	0.7	0.42
Temperature	1	2.7	2.7	1.1	0.30
Latitude*Longitude	1	1.7	1.7	0.7	0.41
Latitude*Temp	1	2.1	2.1	0.8	0.36
Longitude*Temp	1	0	0.0	0.01	0.91
Latitude*Longitude* Temp	1	2.8	2.8	1.1	0.30

Table 48: Result of anova test of number of fruits at Dornoch

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	725	724.6	5.3	0.02*
Longitude	1	342	341.6	2.5	0.11
Temperature	1	551	551.5	4.1	0.04*
Latitude*Longitude	1	6	5.8	0.04	0.83
Latitude*Temp	1	176	176.5	1.3	0.25
Longitude*Temp	1	3	3.1	0.02	0.88
Latitude*Longitude* Temp	1	219	219.5	1.6	0.20

Table 49: Result of anova test of stem form at Dornoch

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	0.5	0.5	0.8	0.37
Longitude	1	2.7	2.7	4.2	0.04*
Temperature	1	1.4	1.4	2.2	0.14
Latitude*Longitude	1	6.3	6.3	9.8	0.001**
Latitude*Temp	1	7.1	7.1	11.1	0.001**
Longitude*Temp	1	1.7	1.7	2.6	0.11
Latitude*Longitude* Temp	1	0.1	0.1	0.2	0.68

Table 50: Result of anova test on number of stems at Dornoch

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	0	0	0.002	0.96
Longitude	1	2.4	2.4	0.9	0.33
Temperature	1	7.5	7.5	2.9	0.09
Latitude*Longitude	1	4.4	4.4	1.7	0.19
Latitude*Temp	1	61.9	61.9	24.2	$1.68*10^{-6***}$
Longitude*Temp	1	0.8	0.8	0.3	0.57
Latitude*Longitude* Temp	1	20.9	20.9	8.2	0.004**

Table 51: Result of anova test on diameter at Alice Holt

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	8545	8545	3.2	0.07
Longitude	1	1547	1547	0.6	0.44
Temperature	1	19973	19963	7.4	0.006**
Latitude*Longitude	1	383	383	0.1	0.71
Latitude*Temp	1	1325	1325	0.5	0.48
Longitude*Temp	1	0	0	0	0.99
Latitude*Longitude* Temp	1	2488	2488	0.9	0.33

Table 52: Result of anova test on fork height at Alice Holt

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	475	475.2	2.3	0.13
Longitude	1	1721	1720.9	8.3	0.004**
Temperature	1	12	11.6	0.1	0.81
Latitude*Longitude	1	24	24.2	0.1	0.73
Latitude*Temp	1	192	191.7	0.9	0.33
Longitude*Temp	1	497	496.9	2.4	0.12
Latitude*Longitude* Temp	1	247	246.7	1.2	0.28

Table 53: Results of anova on number of fruits at Alice Holt

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	0.11	0.11	0.14	0.71
Longitude	1	14.2	14.2	17.1	$4.3*10^{-5}$***
Temperature	1	10.4	10.4	12.7	0.0004***
Latitude*Longitude	1	0.8	0.8	0.9	0.33
Latitude*Temp	1	0.0	0	0	0.99
Longitude*Temp	1	2.4	2.4	2.9	0.09.
Latitude*Longitude* Temp	1	3.2	3.2	3.9	0.04*

Table 54: Results of anova on stem form at Alice Holt

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	16.3	16.3	2.2	0.13
Longitude	1	3.5	3.5	0.5	0.49
Temperature	1	1.6	1.6	0.2	0.64
Latitude*Longitude	1	23	22.9	3.1	0.08.
Latitude*Temp	1	17.4	17.4	2.4	0.12
Longitude*Temp	1	15.7	15.7	2.1	0.14
Latitude*Longitude* Temp	1	30.7	30.7	4.2	0.04*

Table 55: Results of anova test on number of stems at Alice Holt

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	28	27.6	0.8	0.37
Longitude	1	57	56.9	0.9	0.75
Temperature	1	341	340.5	1.6	0.21
Latitude*Longitude	1	289	289.4	1.8	0.18
Latitude*Temp	1	476	476.4	3.2	0.02*
Longitude*Temp	1	598	597.9	4.0	0.91
Latitude*Longitude* Temp	1	11	10.7	0.1	0.11

Table 56: Result of anova test on diameter at Llandovery

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	2297	2297	0.8	0.37
Longitude	1	273	273	0.1	0.75
Temperature	1	4515	4515	1.6	0.21
Latitude*Longitude	1	5116	5116	1.8	0.18
Latitude*Temp	1	14600	14600	5.1	0.02*
Longitude*Temp	1	34	34	0.01	0.91
Latitude*Longitude* Temp	1	7081	7081	2.5	0.11

Table 57: Result of anova on fork height at Llandovery

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	16	16	0.1	0.76
Longitude	1	904	904.3	4.9	0.03*
Temperature	1	46	46	0.3	0.61
Latitude*Longitude	1	73	73	0.4	0.53
Latitude*Temp	1	289	289	1.6	0.21
Longitude*Temp	1	613	613	3.3	0.07.
Latitude*Longitude*Temp	1	1175	1175	6.4	0.01*

Table 58: Result of anova on number of fruits at Llandovery

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	4.3	4.3	5.0	0.50
Longitude	1	1.1	1.1	1.3	0.78
Temperature	1	4	4.	4.7	0.63
Latitude*Longitude	1	0.01	0.0	0.0	0.23
Latitude*Temp	1	1.0	1.2	1.2	0.81
Longitude*Temp	1	7.2	8.4	8.4	0.004**
Latitude*Longitude*Temp	1	0.3	0.3	0.3	0.56

Table 59: Result of anova on stem form at Llandovery

	Degrees of Freedom	Sum Sq	Mean Sq	F Value	Pr>F
Latitude	1	0.5	0.5	0.5	0.50
Longitude	1	0.1	0.1	0.1	0.78
Temperature	1	0.3	0.3	0.2	0.63
Latitude*Longitude	1	1.6	1.6	1.5	0.23
Latitude*Temp	1	0.1	0.1	0.6	0.81
Longitude*Temp	1	3.1	3.1	2.8	0.09.
Latitude*Longitude*Temp	1	0.1	0.1	0.1	0.77

Table 60: Result of anova on number of stems at Llandovery

Provenance	Alice Holt	Llandovery	Domoch	North York Moor	**Provenance Mean**
Add Valley	16.26	41.49	11.16		24.63
Pressmennan Wood	24.51	47.73	8.5	3.63	26.51
Falls of Clyde	8.39	38.04	10.47	9.62	21.47
Ettrick Water	29.84	29.37	12.73	1.6	19.92
Stroan Bridge	28.55	34.63	15.13	3.05	23.75
Gelt Wood	20.16	25.78	8.79	3.21	17.5
Castle Eden Dene	28.57	44.07	12.16	1.94	25.67
Naddle Forest	35.59	34.8	13.1	11.7	24.57
Duddon Valley	26.03	28.13	26.75	11.31	22.92
Forge Valley & Raincliffe Wood	32.54	39.21	7.22	5.06	27.1
Ashberry & Reins Wood	16.29	32.68	11.41	13.2	19.91
Moor Farm	29.54	40.35	19.5	11	27.33
St Helens Wood	37.23	38.88	10.02	2.75	29.13
Beddgelert	31.42	40.47	9.53	6.1	25.52
Felbrigg Great Wood	22.73	29.56	12.01	8.75	22.76
The Ercall	28.73	38.89	8.43	2.27	25.65
Pepper Wood	29.18	35.22	17.94	0	24.56
Cutler’s Wood	29.02	45.94	8.92	3.71	26.45
Brechfa	27.81	35.87	8.41	8.81	24.3
Mynnydd Du	20.56	31.94	13.49	3.64	19.01
Chestnut’s Wood	32.08	39.39	11	1.94	24.46
Seal Chart	28.56	41.04	15.3	16.82	26.17
Horner Wood	18.32	36.53	10.85	16.88	21.55
King’s Bottom, Longleat	37.95	41.73	14.54	13.99	31.58
Holford/Hodder’s Combe	18.42	44.09	12.63	4.69	25.25
Saxonbury Hill	31.89	38.61	10.56	6.01	27.83
Salen		30.27	15.8	6.52	19.73
Assynt			20.14	1.11	12.91
Inverpolly			16.68		16.68
Craigdarroch			12.23	4.96	8
Cleanhill Wood			4.56	10.94	8.95
Bunchrew			11.91	10.22	10.85
Allt Volagir		17.35	0	1.39	8.57
Tokavaig		31.64	13.67	6.92	20.07
Glen Loy			11.55		11.55
Birks of Aberfeldy			21.74	11.28	18.28
Strathlachlan		44.53	5.6	1.58	25.91
Mugdock Country Park		35.24	12.07	21.79	24.43
Lochwood		31.79	6.64	0	16.34
Glenlee			15.62	1.34	9.82
Brignall Banks		36.6	3.33	11.33	22.85
Ugly House	25.69		9.52	3.5	18.89
Site Mean	**27.8**	**37.05**	**12.95**	**8.5**	**23.24**

Table 61: Quadratic Mean Diameter for British provenances and sites, first tight data set arranged by atitude, all other provenances arranged by latitude

Provenance	Alice Holt	Llandovery	Dornoch	North York Moor	**Provenance Mean**
Add Valley	5.1	18.4	0.2	3.5	6.8
Pressmennan Wood	7.6	10.8	0	1.3	4.7
Falls of Clyde	5	4.7	0.1	5.3	3.5
Ettrick Water	16.6	13.6	0.2	0.5	6.3
Stroan Bridge	12	2	0	0.2	4.8
Gelt Wood	20.8	8.8	0.1	0.3	7.9
Castle Eden Dene	11.2	6	0	0	4.9
Naddle Forest	12.9	16.5	0	1.1	6.5
Duddon Valley	11.8	5	2.6	3.5	6.1
Forge Valley & Raincliffe Wood	17.7	17.2	0.1	2.4	10.9
Ashberry & Reins Wood	0	8.7	0.4	3.6	4.6
Moor Farm	16.9	27.3	2.3	2.3	12.5
St Helens Wood	21.3	12.9	0.4	0.3	9.5
Beddgelert	8.7	9.1	0	0.1	4.6
Felbrigg Great Wood	18.1	23.2	0.2	4.5	15.4
The Ercall	10.6	8.4	0	0	6.1
Pepper Wood	12	4.1	0	0	5.3
Cutler's Wood	9.3	3.4	0	0.7	3.1
Brechfa	16.1	14.3	0	0.6	9.8
Mynnydd Du	5.8	5.8	0	0.3	2.6
Chestnut's Wood	10.5	8.2	0	0.1	4.1
Seal Chart	9.4	18.2	0	2.3	6.9
Horner Wood	1.4	12.9	0.3	2.1	3.5
King's Bottom, Longleat	20.2	7.2	0.1	5.1	9.4
Holford/Hodder's Combe	17.1	17.7	0	1.2	8.8
Saxonbury Hill	20.2	14.6	0	1.1	11.7
Salen		6.7	0	0.4	2.4
Assynt			1.3	0	0.1
Inverpolly			1.4		1.4
Craigdarroch			0.9	2.5	1.8
Cleanhill Wood			0	6.2	3.7
Bunchrew			0	1.1	0.7
Allt Volagir		10.6	1.3	0	3
Tokavaig		6.5	0	1.7	2.6
Glen Loy			0.3		0.3
Birks of Aberfeldy			1.4	2.5	1.9
Strathlachlan		8.7	0.1	0.1	3
Mugdock Country Park		19.5	0	4.2	7.5
Lochwood		0.7	0.1	0	0.2
Glenlee			0.2	0	0.1
Brignall Banks		6.2	0	1.3	2.6
Ugly House	7.5		0.4	0.1	3.9
Site Mean	**12.98**	**11.13**	**0.3**	**1.42**	**6.02**

Table 62: Mean number of fruits for British provenances and sites, first tight data set arranged by atitude, all other provenances arranged by latitude

Provenance	Alice Holt	Llandovery	Dornoch	North York Moor	**Provenance Mean**
Add Valley	1.1	1.6	2.1	0.9	1.4
Pressmennan Wood	1.1	1.2	0.7	0.2	0.8
Falls of Clyde	0.8	1.2	1.3	1.1	1.2
Ettrick Water	1.7	0.9	1.9	0.7	1.2
Stroan Bridge	1.6	1.3	1.8	0.5	1.3
Gelt Wood	1.6	1.6	1.6	0.6	1.4
Castle Eden Dene	1.4	1.5	1.5	0.3	1.1
Naddle Forest	2.1	0.8	1.4	0.6	1.1
Duddon Valley	1.3	1.9	2.4	0.5	1.4
Forge Valley & Raincliffe Wood	1	1.7	1.3	1.2	1.2
Ashberry & Reins Wood	1.5	1.4	1.6	1.3	1.5
St Helens Wood	0.7	1.8	0.9	0.5	1
Moor Farm	0.6	1.9	1.1	1.9	1.2
Beddgelert	1.4	1.4	1.8	0.8	1.3
Felbrigg Great Wood	0.8	1.1	1.1	0.3	0.9
The Ercall	1.4	1.8	1.3	0.3	1.3
Pepper Wood	1.4	1.9	2.1	0.1	1.4
Cutler's Wood	0.5	0.6	1.4	0.6	0.8
Brechfa	1.7	1.8	1.3	0.9	1.5
Mynnydd Du	1.4	1.3	1.9	0.4	1.2
Chestnut's Wood	1.6	1	1.4	0.6	1.1
Seal Chart	1.3	1.8	1.9	1.1	1.4
Horner Wood	1.1	1.3	0.9	0.9	1
King's Bottom, Longleat	1.9	1.6	1.8	0.8	1.5
Holford/Hodder's Combe	1.1	2.4	1	0.3	1.2
Saxonbury Hill	1.5	1.9	1.4	0.4	1.3
Salen		1.2	1.6	1.8	1.5
Assynt			2	0.6	1.2
Inverpolly			2.2		2.2
Craigdarroch			1.9	1	1.4
Cleanhill Wood			1.4	0.6	0.9
Bunchrew			1.2	0.6	0.8
Allt Volagir		0.4	0.4	0.3	0.4
Tokavaig		1.8	1.2	0.9	1.3
Glen Loy			1.3		1.3
Birks of Aberfeldy			2.6	1.7	2.2
Strathlachlan		0.9	1.5	0.2	0.8
Mugdock Country Park		1.4	1.3	1.4	1.4
Lochwood		1.7	1.1	0.9	1.2
Glenlee			2	0.5	1.1
Brignall Banks		2.3	1.1	1	1.5
Ugly House	1.2	0	2.1	0.8	1.3
Site Mean	**1.29**	**1.48**	**1.53**	**0.71**	**1.22**

Table 63: Mean stem form for British sites and provenances, first tight data set arranged by atitude, all other provenances arranged by latitude

Provenance	Alice Holt	Llandovery	Dornoch	North York Moor	**Provenance Mean**
Add Valley	6.3	1.7	1.9	2.6	2.9
Pressmennan Wood	5.9	2.4	5.2	2.4	3.9
Falls of Clyde	5	1.8	3.2	2.3	2.9
Ettrick Water	6	1.3	2.1	2.6	2.8
Stroan Bridge	4.8	2.1	2	2.5	3.2
Gelt Wood	4.4	2.2	3.1	3.4	3.3
Castle Eden Dene	3.4	2	2	2.9	2.75
Naddle Forest	4.6	2	2	4.4	3.3
Duddon Valley	2.6	1	1.7	2	2
Forge Valley & Raincliffe Wood	2.9	2.5	3	2.4	2.8
Ashberry & Reins Wood	4.4	1.4	1.9	2.7	2.3
Moor Farm	5.4	1.7	1.7	2.4	3.3
St Helens Wood	4	2	2	1.9	2.5
Beddgelert	3.6	1.7	2.6	2.5	2.7
Felbrigg Great Wood	5.4	1.5	2.4	3.5	3.6
The Ercall	6.9	2.4	2	2.4	4.3
Pepper Wood	5.6	1.8	1.8	2.6	2.9
Cutler’s Wood	3.6	1.1	1.9	2	2.1
Brechfa	3.5	1.8	2.1	2.7	2.8
Mynnydd Du	2.9	1.4	2.2	2.3	2.2
Chestnut’s Wood	2.4	2.1	2.2	2.3	2.3
Seal Chart	3.5	1.8	1.9	2.5	2.6
Horner Wood	3.2	1.4	3.7	3.1	2.9
King’s Bottom, Longleat	4.3	2.1	2	2.2	2.75
Holford/Hodder’s Combe	6.6	1.8	4.9	1.7	3.5
Saxonbury Hill	4.3	1.7	3.8	3.3	3.4
Salen		1.8	1.7	2.3	1.9
Assynt			2.1	2.8	2.5
Inverpolly			2.8		2.8
Craigdarroch			2.7	2.5	2.5
Cleanhill Wood			2.6	3.7	3.25
Bunchrew			2.1	3.2	2.8
Allt Volagir		1.3	4.3	2.5	2.8
Tokavaig		2	3.2	3.2	2.8
Glen Loy			2.4		2.4
Birks of Aberfeldy			1.7	3.2	2.3
Strathlachan		1.9	1.8	3	2.6
Mugdock Country Park		1.8	3.8	1.6	2.4
Lochwood		1.3	1.7	1.7	1.6
Glenlee			2.6	2.4	2.5
Brignall Banks		1.6	2.7	2.1	2.1
Ugly House	2.2	0	2	1.3	1.9
Site Mean	**4.25**	**1.76**	**2.51**	**2.57**	**2.81**

Table 64: Mean number of stems for British sites and provenances, first tight data set arranged by atitude, all other provenances arranged by latitude

Provenance	Alice Holt	Llandovery	Dornoch	North York Moor	**Provenance Mean**
Add Valley	119	120	72	75	98.9
Pressmennan Wood	113	69	84	73	85.6
Falls of Clyde	98	114	71	102	94.7
Ettrick Water	140	70	107	37	88.5
Stroan Bridge	100	113	82	75	95
Gelt Wood	105	101	84	108	97.25
Castle Eden Dene	106	92	88	59	90.1
Naddle Forest	108	89	86	88	92.2
Duddon Valley	102	142	109	93	110.1
Forge Valley & Raincliffe Wood	101	63	73	112	87.3
Ashberry & Reins Wood	131	101	63	104	104.5
Moor Farm	89	132	83	84	94.7
St Helens Wood	125	142	56	68	107.4
Beddgelert	123	99	82	42.5	97.2
Felbrigg Great Wood	89	108	84	64	91.9
The Ercall	90	119	77	85	92.2
Pepper Wood	119	127	94	33	105.5
Cutler's Wood	93	91	61	95	84.5
Brechfa	122	118	94	96	112.25
Mynnydd Du	108	105	116	71	104
Chestnut's Wood	136	92	83	78	100.1
Seal Chart	102	123	91	83	100
Horner Wood	84	90	65	68	78
King's Bottom, Longleat	139	138	81	86	117.9
Holford/Hodder's Combe	138	99	71	75	95
Saxonbury Hill	111	102	90	88	103.6
Salen		109	71	84	88.1
Assynt			88	60	81.25
Inverpolly			97		97.7
Craigdarroch			74	80	77.4
Cleanhill Wood			53	74	62.7
Bunchrew			85	69	74.8
Allt Volagir		86	44	93	66.1
Tokavaig		81	72	83	78.3
Glen Loy			92		91.7
Birks of Aberfeldy			86	70	80
Strathlachan		117	76	56	90
Mugdock Country Park		96	78	124	99.4
Lochwood		92	61	45	69.4
Glenlee			111	75	107.5
Brignall Banks	0	102	80	71	85.4
Ugly House	119	0	91	75	104.2
Site Mean	**109**	**105**	**81**	**78**	**94.6**

Table 65: Mean fork height for British sites and provenances, first tight data set arranged by atitude, all other provenances arranged by latitude

Provenance	Alice Holt	Llandovery	Dornoch	North York Moor	**Provenance**
Add Valley	28.6	0	0	75	24.2
Pressmennan Wood	11.1	0	0	63.6	21.1
Falls of Clyde	17	0	0	57.1	16.1
Ettrick Water	0	0	0	50	17.9
Stroan Bridge	16.7	22.2	0	69.2	28.6
Gelt Wood	11.1	11.1	0	57.1	17.6
Castle Eden Dene	6.7	12.5	12.5	53.8	22.72
Naddle Forest	0	0	11	41.7	16.7
Duddon Valley	7.1	0	11.1	46.7	19.6
Forge Valley & Raincliffe Wood	6.7	0	0	40	8.6
Ashberry & Reins Wood	12.5	0	11.1	14.3	9.8
Moor Farm	0	0	0	25	5
St Helens Wood	0	17.6	0	50	20
Beddgelert	5.6	0	0	64.7	23.1
Felbrigg Great Wood	0	5.9	0	33.3	5.3
The Ercall	16.7	12.5	0	85.7	23.8
Pepper Wood	0	33.3	0	77.8	27.8
Cutler's Wood	0	0	22.2	60	22.9
Brechfa	4	11.1	11.1	33.3	12.7
Mynnydd Du	0	0	22.2	71.4	29.3
Chestnut's Wood	0	11.1	0	84.6	30.8
Seal Chart	13.3	0	0	46.7	19.1
Horner Wood	5.9	0	0	35.7	12.2
King's Bottom, Longleat	0	14.3	11.1	30.8	13.5
Holford/Hodder's Combe	14.3	0	0	44.4	15.2
Saxonbury Hill	0	6.7	11.1	73.3	20
Salen		0	0	0	0
Assynt			0	76.9	45.5
Inverpolly			0		0
Craigdarroch			11.1	15.4	13.6
Cleanhill Wood			0	41.7	25
Bunchrew			0	6.3	4
Allt Volagir		0	0	84.6	37.9
Tokavaig		0	0	33.3	11.5
Glen Loy			0		0
Birks of Aberfeldy			0	16.7	6.7
Strathlachan		0	0	60	22.2
Mugdock Country Park		0	0	0	0
Lochwood		0	11	66.7	0
Glenlee			0	92.9	56.5
Brignall Banks		0	0	0	0
Ugly House	12.5		0	62.5	21.2
Site	**6.5**	**5.5**	**3.5**	**50**	

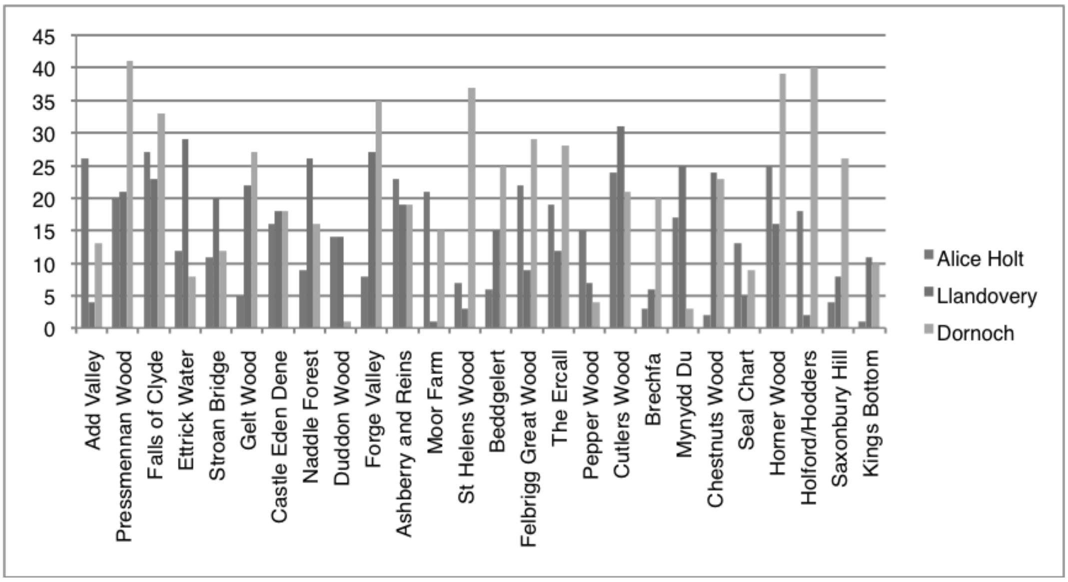
Table 66: Percentage of trees with forks for British sites and provenances, first tight data set arranged by atitude, all other provenances arranged by latitude

Provenance	Alice Holt	Llandovery	Dornoch	North York Moor	**Provenance Mean**
Add Valley	78	100	100	89	92
Pressmennan Wood	100	100	100	56	82
Falls of Clyde	89	100	100	89	92
Ettrick Water	78	100	100	78	87
Stroan Bridge	100	100	100	72	91
Gelt Wood	100	100	100	78	97
Castle Eden Dene	73	89	89	72	81
Naddle Forest	78	89	100	67	80
Duddon Valley	78	89	100	83	85
Forge Valley & Raincliffe Wood	83	67	100	56	78
Ashberry & Reins Wood	89	100	100	78	91
Moor Farm	94	78	100	89	91
St Helens Wood	78	94	89	89	88
Beddgelert	100	100	89	94	96
Felbrigg Great Wood	96	93	100	67	92
The Ercall	100	89	100	39	78
Pepper Wood	100	100	100	50	80
Cutler's Wood	89	89	100	67	78
Brechfa	93	100	100	67	87
Mynnydd Du	100	100	100	78	91
Chestnut's Wood	89	100	100	72	87
Seal Chart	89	89	100	83	89
Horner Wood	94	100	100	78	91
King's Bottom, Longleat	89	78	100	72	83
Holford/Hodder's Combe	89	100	89	100	94
Saxonbury Hill	96	83	100	83	90
Assynt			100	72	81
Salen		100	100	100	100
Inverpolly			100		100
Craigdarroch			100	72	81
Cleanhill Wood			89	67	74
Bunchrew			100	89	93
Allt Volagir		78	100	78	81
Tokavaig		89	100	100	96
Glen Loy			100		100
Birks of Aberfeldy			100	67	83
Strathlachan		100	89	61	75
Mugdock Country Park		89	100	100	96
Glenlee			100	78	85
Brignall Banks		100	100	78	93
Ugly House	94		100	89	94
Site Mean	**81**	**92**	**98.5**	**75**	**87**

Table 67: Percentage survival for British sites and provenances, first tight data set arranged by atitude, all other provenances arranged by latitude

Add Valley	42.04	67.96	46.86	48.89	53.41
Pressmennan Wood	46.67	57.07	32.65	36.61	44.37
Falls of Clyde	38.46	56.75	39.42	52.35	48.05
Ettrick Water	54.05	53.77	49.34	35.50	48.18
Stroan Bridge	54.70	57.32	47.10	40.59	47.35
Gelt Wood	57.32	56.88	42.08	41.83	50.65
Castle Eden Dene	42.02	67.96	45.38	48.89	53.41
Naddle Forest	55.71	55.26	46.27	36.93	47.34
Duddon Valley	52.43	60.69	60.16	45.99	53.94
Forge Valley & Raincliffe Woods	55.75	55.10	39.06	43.66	50.02
Ashberry & Reins Woods	45.97	57.86	44.98	45.32	51.06
Moor Farm	46.47	72.00	46.49	48.99	52.03
St Helens Wood	55.86	68.65	36.65	40.78	54.46
Beddgelert	55.94	59.58	42.61	42.33	52.72
Felbrigg Great Wood	46.44	63.21	41.80	34.43	49.80
The Ercall	47.56	61.71	41.84	38.01	47.18
Pepper Wood	51.65	65.50	51.21	31.03	52.11
Cutler's Wood	45.20	52.70	44.31	42.62	46.76
Brechfa	59.26	66.42	44.93	40.58	54.71
Mynnyd Du	50.31	53.34	53.34	41.45	51.04
Chestnut's Wood	59.60	56.64	43.35	43.67	51.89
Seal Chart	52.53	67.34	48.81	48.27	53.53
Horner Wood	42.64	59.55	35.80	42.05	44.61
King's Bottom, Longleat	64.45	62.06	48.45	44.32	56.79
Holford/Hodder's Combe	49.77	70.45	33.27	42.62	51.02
Saxonbury Hill	58.62	63.48	42.18	43.21	55.02
Salen		54.97	45.71	44.31	48.90
Assynt			50.77	39.42	45.93
Inverpolly			50.35		50.42
Craigdarroch			46.58	37.93	41.51
Cleanhill Wood			36.01	39.41	37.58
Bunchrew			42.93	35.15	37.81
Allt Volagir		44.33	26.97	43.76	38.39
Tokavaig		53.78	39.87	42.96	46.28
Glen Loy			43.61		43.58
Birks of Aberfeldy			55.23	40.68	53.53
Strathlachan		59.23	40.89	32.62	45.56
Mugdock Country Park		61.38	39.31	54.15	52.00
Lochwood		51.21	40.84	39.34	45.64
Glenlee			50.12	44.42	49.20
Brignall Banks		62.36	38.07	37.79	48.20
Ugly House	55.12		48.18	46.28	52.19
Site	51.83	43.28	59.49	40.44	

Table 68: Provenance ranking score for British sites and provenances, first tight data set arranged by atitude, all other provenances arranged by latitude



Graph 22: Compairsion of ranked order of British provenances, based on provenance ranking, highest ranked provenance given score ‘1’

	Alice Holt	Llandovery	Dornoch
Add Valley	26	4	13
Pressmennan Wood	20	21	41
Falls of Clyde	27	23	33
Ettrick Water	12	29	8
Stroan Bridge	11	20	12
Gelt Wood	5	22	27
Castle Eden Dene	16	18	18
Naddle Forest	9	26	16
Duddon Wood	14	14	1
Forge Valley	8	27	35
Ashberry and Reins	23	19	19
Moor Farm	21	1	15
St Helens Wood	7	3	37
Beddgelert	6	15	25
Felbrigg Great Wood	22	9	29
The Ercall	19	12	28
Pepper Wood	15	7	4
Cutlers Wood	24	31	21
Brechfa	3	6	20
Mynydd Du	17	25	3
Chestnuts Wood	2	24	23
Seal Chart	13	5	9
Horner Wood	25	16	39
Holford/Hodders	18	2	40
Saxonbury Hill	4	8	26
Kings Bottom	1	11	10

Table 69: Ranked score of provenances at British sites, based on provenance ranking, highest ranked provenances given score ‘1’

Pair	Pearsons ranking
Alice Holt – Llandovery	0.001507384
Alice Holt – Dornoch	0.126494158
Llandovery – Dornoch	-0.02241308

Table 70: Pearson's Correlation Coefficient of ranked scores of provenance ranking (table 69)

8.2. Appendix II – British Experimental Data

FOREST RESEARCH

ECOLOGY DIVISION EXPERIMENT PLAN

Experiment Number	FR06002a; FR06002b; FR06002c; FR06002d
Experiment Title	Assessing local adaptation and adaptability in rowan (*Sorbus aucuparia*)
Key Words	Adaptation, provenance, rowan, *Sorbus aucuparia*, native, seed zone, phenology
Local Ref. No.	FR06002a = Dornoch 13 P2006 FR06002b = North York Moors 143 P2006 FR06002c = Llandovery 49 P2006 FR06002d = Alice Holt 473 P2006
Background	Forest planting stock has been increasingly moved over large distances in the past few decades for restocking and new woodland schemes. This long distance movement of plant material can potentially introduce ecologically unsuitable genotypes into a location, which could either cause a planting to fail or allow the introduction of poorly adapted genotypes into the local genepool. This concern led to the development of a policy to create native seed zones (Herbert *et al.* 1999) to guide and encourage growers to plant local native material. Unfortunately there is little scientific work to support the native seed zones and, in addition, it is very difficult to be sure what the assumption – "native is best" – means for common, widely dispersed tree species. Although there is a distance over which it is unwise to move most forest tree species it is currently not possible to define this with any confidence. For this reason, this experiment, and a similar one for ash planned for 2007, aims to test the "local is best" hypothesis by sampling two populations per native seed zone across GB and planting them in a provenance trial on four sites. These four sites provide a north-south, east-west coverage of GB. The aim will be to assess not only the traditional measures of a good provenance, such as height, diameter and form, but also indicators of good ecological adaptation such as phenology and the ability to survive and reproduce successfully at a site.
Objectives	1. To test the hypothesis that "local is best" for rowan using the native seed zones to define localness and reproductive fitness, growth and survival to define best. 2. To test the adaptability of native populations of rowan in different environments.
Location	All the trials are field based in this experiment

	FR06002a = Dornoch 13 P2006 Grid Ref. = NC 57303 08600
	FR06002b = North York Moors 143 P2006 Grid Ref. = SE 954 888
	FR06002c = Llandovery 49 P2006 Grid Ref. = SN 801 311
	FR06002d = Alice Holt 473 P2006 Grid Ref. = SU 8196 4022
Specific Test Conditions	None
Species:	Rowan, *Sorbus aucuparia* L.
Products and Active Ingredients	No proprietary products used in this experiment
Experimental Treatments	Each site will be a treatment testing the provenance genotypes with the local environment and then assessing the resultant phenotype. It is therefore important that the local environment is as uniform as possible at each trial site. The following assessments of the phenotypes are likely to be undertaken: height, survival, bud flushing, diameter, senescence, flowering phenology, flower production, fruit production, seed production, seed viability
Design	At each site there will be three randomised blocks containing 9-tree plots (3x3). Assessments will measure all 9 trees in a plot. Spacing will ideally be 2 m but 1.8 m is acceptable given local circumstances. A record of the spacing used at each site will be contained in the Experiment File. A double guard row, at the same spacing as the plots, will enclose each trial site. Five populations of rowan per Native Seed Zone were identified by Scott Wilson, and the Technical Support Units (TSUs) were allocated populations according to geographic location. Two populations per native seed zone were selected for collection. Site inspections to assess seed availability and collectability were undertaken in June-August 2004. In some cases the TSU recommended populations they were familiar with as more suitable and these were used. The collection aimed to be representative of those trees with seeds and no other selection criteria was used. Each collection was recommended to contain 20 trees per population, approximately 100m apart where possible. These recommendations were relaxed in some cases due to the fact that rowan is not a stand-forming tree and hence trees tend to be more clumped. Where possible the distance between the trees was kept to a maximum. Full details of the provenances are contained in Appendix 1. Collection of seed was undertaken in August-September 2004 just as the berries were ripening. Berries were collected at 43 sites. The only seed zone missing any sites is 101, the Shetlands. All the other seed zones provided two sites except seed zones 103, 203 and 302 were only one site provided berries. The berries were sent to the Newton Field station were they was stored cool prior to the seed being

cleaned out of the berries. This was a very difficult process and was eventually undertaken manually in order to reduce loss of seed. Buds were also sampled from the same trees and sent to East Malling for genetic analysis.

Seed was stratified in cool, damp compost for 16 weeks and was sown when it started to chit in March 2005 at the Bush nursery. The seed was broadcast sown into seed trays and then pricked out into containers (Bowmont 150 trays; 60 cells 150 cm^3 each) in April 2005. The compost used was a single batch of commercially available peat based mix.

The number of provenances at each site is variable due to shortage of plants from some provenances:

FR06002a = Dornoch 13 P2006 = 42 provenances

FR06002b = North York Moors 143 P2006 = 40 provenances

FR06002c = Llandovery 49 P2006 = 34 provenances

FR06002d = Alice Holt 473 P2006 = 32 provenances

In addition some provenance in some experiments are represented by more than one plot per block. See Appendix 2 for details and the design file. Appendix 3 is an experiment plan for each trial.

One demonstration plot, containing 7 trees, will be planted at FR06002a.

Methods

Height

Survival

Bud flushing

This protocol provides a scoring system for young trees (<2m in height) with which to measure the stage of bud burst for a tree and a population and the progress of flushing through the spring. The timing and frequency of assessments will be determined by the Project Leader and may vary from year to year depending on the weather.

- All 9 trees within a plot will be assessed. Missing or dead trees will be noted as “m” or “d” respectively on the assessment.
- The trees within a plot should be identifiable. The data can either be recorded in a map format (i.e. written down on paper on a 3x3 grid to match the plots with an indication of the plot marker or north), or there is a very clear assessment route attached to the experiment plan that will always be used (i.e. the trees within the plots have a number 1-9 which never changes from one assessment to another).

- Only the terminal bud will be assessed. If this is damaged, missing or dead then the next highest bud on the main stem will be assessed. A note of the plot number and tree number should be recorded if this is the case.
- If the tree is forked then the bud on the fork with the largest diameter will be assessed. In the event that the two forks are equal in diameter then the highest bud will be assessed. In the event that the forks are equal in height and diameter then the bud giving the highest score (i.e. more fully open) will be recorded.
- Bud burst will be scored on a 1-6 scale where 1 is for a dormant bud and 6 is for a fully open bud. A written description of the stages and the scores is given below. A pictorial guide is given in Appendix 4:
    1. Bud closed fully dormant winter state.
    2. Bud swollen and the bud scales just started to open, however the bud is still vertical.
    3. Bud scales separated and the tightly furled leaves visible. The bud is bent sideways and can appear “hooded”.
    4. Bud scales completely separated, leaves starting to unfurl and separate but the leaflets (pinnae) on each leaf still furled. The leaves appear brownish in colour since the underside is predominantly visible.
    5. Leaves elongated and leaflets starting to separate as well. The appearance is now much more green since the topside of the leaves is now visible.
    6. All leaflets separated on lowest two leaves and shoot expanding.

Diameter

Leaf senescence

Flowering Count

Flowering phenology

Seed viability

Basal Treatments

Sites will need to be prepared as for the planting of nursery stock. A weed free area 1m in radius around each planting position will be created and maintained for the first three years, 2006 – 2009. Further treatments will depend on site conditions and after discussions with the Project Leader.

The local TSU staff will undertake the treatments and responsibility for managing this work will lie with the local TSU Manager.

The trials will be planted in spring 2006 using container grown stock provided by the Bush Nursery.

Fertiliser should not normally be applied and only after prior consultation with the Project Leader.

All treatments and site preparation will be recorded in the Experiment File.

Requirements

Area

Area required at 2m spacing (excluding guard rows)

FR06002a = Dornoch 13 P2006 = 0.630 ha

FR06002b = North York Moors 143 P2006 = 0.634 ha

FR06002c = Llandovery 49 P2006 = 0.580 ha

FR06002d = Alice Holt 473 P2006 = 0.526 ha

Plants

Containerised one-year old rowan seedlings raised at Bush Nursery. Numbers per trial (excluding guard rows)

FR06002a = Dornoch 13 P2006 = 1582 (including demo plot)

FR06002b = North York Moors 143 P2006 = 1584

FR06002c = Llandovery 49 P2006 = 1422

FR06002d = Alice Holt 473 P2006 = 1341

Other

Stock proof fencing plus gate. The fence should also be rabbit proof and, if necessary, sufficiently high for deer. All plants should have a vole guard.

Records and Assessments

All assessments must be undertaken so that *individual* trees can be identified for different types of assessment and over time.

Height: At planting, and then year 1, 3, 6, 10 and 15

Survival: At year 1, 2, 3, 6, 10 and 15

Bud Flushing: Spring 2006 and then year 3, 5, 7, 9

Diameter: At year 6, 10 and 15

Leaf Senescence: At year 3, 5, 7, 9

Flowering count: Annually from year 6 onwards

Flowering phenology, once all the provenances have flowered, otherwise by year 12 then every year for 3 years

Seed viability: once all the provenances have flowered, otherwise by year 12 then every year for 3 years

Statistical Analysis

(see Tom)

Duration and responsibilities

The experiment should be reviewed 15 years from planting by the project leader. The timing and extent of flowering and fruit production will need to be considered when reviewing the

	experiment.
Relevant approvals	No relevant approvals necessary
Health and Safety	No specific health and safety considerations
SOPs	
Bibliography	Herbert, R., Samuel, S. and Patterson, G. 1999, *Using Local Stock for Planting Native Trees and Shrubs.* Forestry Commission Practice Note 8.
Drafted by	Jason Hubert
Date	
Design Approved	
Date	
Approved	
Date	
Distribution	
Appendices	

8.3. Appendix III – Swedish Experimental Data

8.4.

Institutionen för skogsskötsel
Arbetsrapporter Nr 85

Odlingsförsök på åkermark med rönn, hägg och masurbjörk

Owe Martinsson

Institutionen för skogsskötsel
Sveriges lantbruksuniversitet
Umeå 1994

Institutionen för skogsskötsel

Arbetsrapporter

I serien Arbetsrapporter dokumenteras preliminära forskningsresultat, reseberättelser, försöksplaner, föredrag etc. Författarna är ensamma ansvariga för sina uppsatsers vetenskapliga innehåll, och innehållet får ej citeras utan författarnas medgivande. Slutliga forskningsresultat publiceras i vetenskapliga tidskrifter och institutionens serie Rapporter.

1989

29. **Olofsson, K.** Ett gallringsförsök i ett lärkbestånd i nordvästra Jämtland. - Dokumentation av försöksanläggning samt tillståndsbeskrivning. 48 s.

30. **Valinger, E.** Förändring av tillväxtens fördelning inom trädet efter gallring, gödsling och ändrad vindpåverkan. - Metodbeskrivning. 39 s.

31. **Hallsby, G.** Snöbrottskador hos MoDo, Robertsfors skogsförvaltning, vintern 1987/88. 16 s.

32. **Downie, B.** Initial spacing effects on the technical quality of Pinus contorta var. latifolia Branch characteristics, bole straightness and wood density. (Master of Science in Silviculture Thesis). 168 s.

33. Doktorandresa till Skottland och Irland i april 1988. 111 s.

1990

34. **Elfving, B.** Nya produktionsdata och prognos-funktioner för contortatall. 19 s.

35. **Fries, C., Hagner, M., Hallsby, G. & Sundqvist, H.** Dagboksanteckningar från IUFRO symposiet: "Boreala granarters ekologi och skötsel", New Foundland och Labrador, augusti 1989. 30 s.

36. **Hagner, M.** Applicering av insektsskydd av fibrer kan kombineras med maskinell komplettering av tomma krukor. 6 s.

37. **Hagner, M.** Direct seeding of pine and spruce in Sweden. 25 s.

38. **Hagner, M.** Om skiktade bestånd ger hög produktion måste skogsvårdslagen ändras. 11 s.

39. **Hagner, M.** Högskärmsmetoden - ett naturvänligt alternativ som ger oss svensk kvalitetsfura, men hur blir det med den areella produktionen? 7 s.

40. **Hagner, M.** En grundlig översyn av skogsvårdslagen behövs. 19 s.

41. **Karlman, M., Hansson, P., Rydberg, D.** Skadeläget i praktiska kulturer med Pinus contorta i norra Sverige planterade 1974-81. Resultat från åren 1987-89. 52 s.

42. **Martinsson, O.** Research on Douglas fir in Sweden. 9 s.

43. **Martinsson, O.** The northern forests of Eurasia. Some figures reflecting human activities. 10 s.

44. **Lundqvist, L.** Produktion - Miljö - Natur. Alternativa metoder för skogsskötsel - genomförd, pågående och planerad forskning. 29 s.

45. **Jeansson, E.** Instruktion för inventering av institutionens fasta försöksytor. 24 s.

46. **Hagner, M.** Fältförsök med mekaniska insektsskydd för skogsträdsplantor. 15 s.

47. Aktuella skogsskötselfrågor. Föredrag vid delkonferensen "Skogsskötsel" vid skogskonferensen i Umeå 1988. 98 s.

48. **Lundqvist, L.** Bielite - ett försök med alternativa skogsskötselmetoder i fjällnära granskog. 25 s.

49. **Hagner, M. & de Jong. A.** Rekommendationer för radsådd. 13 s.

50. **Agestam, E.** Nya förbands- och gallringsförsök med contorta i Sverige. 19 s.

51. **Vollbrecht, G.** Varudeklaration av plantor - en enkätundersökning riktad till skogsplantskolor, skogsägarrörelsen och Skogssällskapet. 43 s.

1991

52. **Albrektson, A. & Lundmark, T.** Vegetationens storlek och omsättning inom en barrskog i norra Sverige, samt näring i vegetation och mark och dess omsättning i samband med växandet. 35 s.

53. **Albrektson, A. & Jäghagen. K.** Aktuella skötselkalkyler. Åkerplantering - Föryngringsproblem - Kvalitetsröjning - Höggallring. Skötselkalkyler redovisade vid Nordiska Skogsunionens exkursion hos Södra skogsägarna i Växjö den 12:e juni 1990 under temat; Gårdsskogsbrukets möjligheter - från skog till industri. Exkursionsvärd: Skogsvårdschef Jan-Åke Lundén, Södra skogsägarna. 53 s.

54. **Karlman, M. & Witzell, J.** 1990 års resultat från uppföljning av 110 praktiska planteringar med Pinus contorta i norra Sverige. 25 s.

55. **Egnell, G., Albrektson, A., Örlander, G., Jansson, E., Sjögren, H.** Hesselmans helhackningsförsök på tallhed i Vindeln - tillväxt och näringsförhållanden 67 år efter markberedning. 67 s.

56. **Weetman, G.F. - Faculty of Forestry, University of B.C, Vancouver, B.C.** Environmental Questions About Swedish Forestry. 10 s.

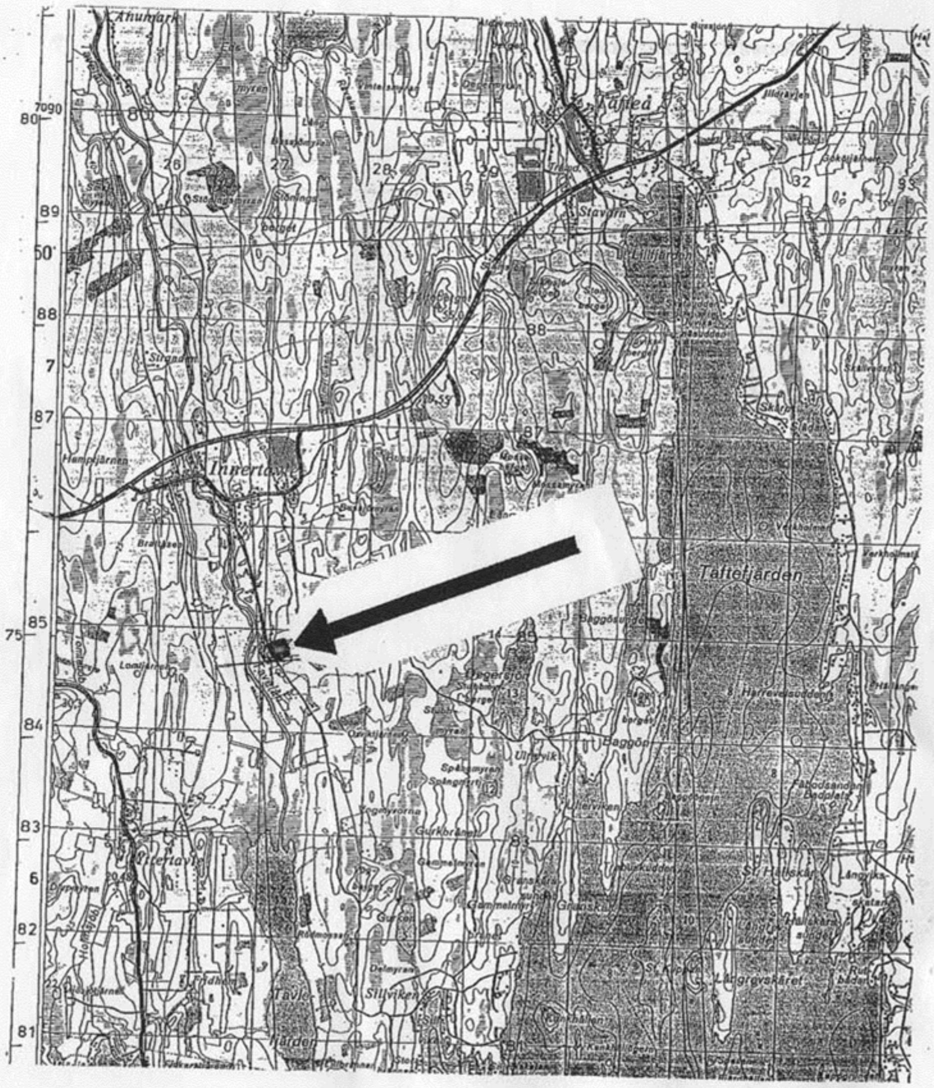
Tabell 1. Ursprungsorter för försöksmaterialet

Hägg Sort nr	Ursprungsort	Rönn Sort nr	Ursprungsort	Masurbjörk Sort nr	Ursprungsort
1	Garphyttan	1	Överkalix	91	Rovaniemi
2	Täfteå	2	Överkalix		
3	Överkalix	3	Råkforsen		
4	Övertorneå	4	Smedsbyn		
5	Alby	5	Smedsbyn		
6	Jämtland (Anders)	6	Byske		
7	Innertavle	7	Lövånger		
8	Sundsvall	8	Lövånger		
9	Boden 3	9	Robertsfors		
10	Boden 5	10	Robertsfors		
11	Löckna	11	Sävar		
12	Heden	12	Umeå, Sillviken		
13	Strömsholm	13	Umeå, Täfteå		
14	Innertavle (Brändström)	14	Umeå, Carlshem		
15	Innertavle (Axel Karlsson)	15	Umeå, Backens kyrka		
		16	Umeå, Lantbruksskolan		
		17	Örnsköldsvik		
		18	Ullånger		
		19	Sandö		
		20	Härnösand		
		21	Härnösand		
		22	Härnösand		
		23	Sundsvall		
		24	Hudiksvall		
		25	Enånger		
		26	Söderhamn		
		27	Gävle		
		28	Edsbyn		
		29	Edsbyn		
		30	Falun		
		31	Uppsala, Grönby		
		32	Uppsala, Grönby		
		33	Uppsala, Vårdsätra		
		34	Uppsala, Vårdsätra		
		35	Uppsala, Vårdsätra		
		36	Uppsala, Ramsta kyrka		
		37	Uppsala, Ramsta kyrka		
		38	Uppsala		
		39	Enköping		
		40	Enköping		
		41	Västerås		
		42	Hjälmaresund		
		43	Kungsör		
		45	Katrineholm		
		46	Katrineholm		
		47	Katrineholm		
		48	Örebro		
		49	Örebro		
		50	Örebro, Fjugesta		
		51	Örebro		
		52	Örebro		
		53	Örebro, Björka		
		54	Örebro, Björka		
		55	Askersund		
		56	S Motala		
		57	S Motala		
		58	Tranås		
		59	Tranås		
		60	Mjölby		
		61	Mjölby		
		62	Växjö		
		63	Växjö		
		64	Höör		
		65	Dalby		
		66	Löwenholm, Danmark		
		67	Archangelsk, Ryssland		

Tabell 2. Utsatta plantor på försöksytan i Innertavle
Planterat: Rönn hösten 1993, hägg och björk våren 1992

Rönn Sort nr	antal	Hägg Sort nr	antal	Masurbjörk Sort nr	antal
1	8	2	147	91	226
2	2				
3	2				
5	1				
11	3				
12	290				
13	5				
14	7				
15	1				
16	2				
19	21				
21	6				
22	1				
23	24				
24	2				
26	1				
28	6				
38	9				
39	5				
40	4				
42	2				
43	34				
48	4				
49	2				
50	1				
51	8				
53	20				
56	3				
58	8				
59	4				
60	12				
62	145				
63	1				
65	6				
67	1				
Summa	651		147		226

9



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