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**„Genetic analysis of inherited resistance of *Fraxinus excelsior* L. to ash dieback "**


verfasst von / submitted by

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# 1. Abstract

Common ash (*Fraxinus excelsior*) has recently become seriously endangered throughout Europe by a fungal disease (ash dieback) that is caused by the ascomycete *Hymenoscyphus fraxineus*. This disease developed into a threat for forest management as it leads to high mortality of ash trees and it raised concerns for the future of common ash. Previous studies have revealed differences in susceptibility among ash individuals providing evidence of genetically based resistance or tolerance against the pathogen.

The aim of the study was to identify if a correlation between damage intensity of mature trees and their offspring exists that indicates inherited resistance. Crown damage from natural infection on trees and shoot damage from saplings were assessed in two isolated ash stands in Austria. A range between nearly healthy to severely damaged individuals were found on both sites, with many moderately damaged and no dead trees. Parentage analysis, carried out with molecular markers, resulted in 26 offspring that could assigned to both parents, and 58 that could assigned to one parent. A total of 45% of the offspring were left unassigned.

No significant correlation of damage intensity between parent and offspring could be verified using Spearman's rank correlation analysis (offspring with both parents: $r_s$ = 0.098, P = 0.318; offspring with one parent: $r_s$ = -0.082, P = 0.272), suggesting a lack of evidence of truly resistant or tolerant trees at the study sites. Supported by results of other studies, it is considered that resistant or tolerant individuals within European ash populations occur in low frequency and are probably better detectable when populations are severely damaged. As most of the previous studies about estimations of inheritance of possible resistance were carried out in controlled environments like progeny trails or seed orchards, results from the current investigation suggests a more complex mechanism of susceptibility differences under natural heterogeneous conditions.

The robustness of the observed resistance in previous studies should to be evaluated. Further analyses are needed to obtain a better understanding of gene-

environment interactions and individual infection pressure against ash dieback in natural environments. Large-scale dieback of *Fraxinus excelsior* trees is becoming a realistic scenario for the near future, and therefore identifying and propagating non-susceptible ash trees is an important challenge.

## 2. Zusammenfassung

Die Gemeine Esche (*Fraxinus excelsior*) ist in ganz Europa durch eine invasive Pilzkrankheit (Eschentriebsterben) ernsthaft gefährdet. Verursacht wird die Krankheit durch den Schlauchpilz *Hymenoscyphus fraxineus*. Beachtliche Schäden und die hohe Mortalität von Eschen führen zu großen Problemen für die Forstwirtschaft und machen die Zukunft dieser Baumart ungewiss. Studien haben hohe Unterschiede in der Befallsintensität zwischen Individuen gezeigt. Vermutet wird heute, dass diese Unterschiede genetische Resistenz oder Toleranz einzelner Bäume gegen die Krankheit darstellen und möglicherweise weitervererbt werden.

Das Ziel der Studie war es, einen Zusammenhang zwischen der Befallsintensität von Bäumen und deren Nachkommen herzustellen, um eine mögliche, vererbte Resistenz aufzudecken. In zwei relativ isolierten Eschenbeständen in Österreich wurden der Grad der Kronenschädigung an Bäumen und der Grad der Schädigung an Jungtrieben gemessen. Beide Standorte zeigten eine Bandbreite zwischen nahezu gesunden und stark geschädigten Individuen, die meisten waren mäßig geschädigt. Tote Bäume wurden nicht gefunden. Elternschaftsanalysen wurden mittels molekularen Markern durchgeführt. 26 Jungbäumen konnten beide Eltern und 58 einem Elternteil zugeordnet werden. Für 45% der Jungbäume wurden keine Eltern gefunden.

Spearmans Rangkorrelation zeigte keinen signifikanten Zusammenhang der Befallsintensität zwischen Eltern und Nachkommen (Jungbäume mit beiden Eltern: $r_s$ = 0.098, P = 0.318; Jungbäume mit einem Elternteil: $r_s$ = -0.082, P = 0.272). Das könnte auf ein Fehlen resistenter oder toleranter Bäume in beiden Standorten hinweisen. Bekräftigt von den Ergebnissen anderer Studien, ist davon auszugehen, dass resistente oder tolerante Individuen innerhalb europäischer

Eschenpopulationen in eher geringer Häufigkeit auftreten und wahrscheinlich besser erkennbar sind, wenn die Population sonst stark geschädigt ist.

Da die meisten Studien, in mehr oder weniger kontrollierter Umgebung von Samenplantagen durchgeführt wurden, könnte diese Studie die Komplexität der Ursachen für unterschiedliche Befallsintensitäten unter natürlichen, heterogenen Bedingungen aufzeigen. Die Robustheit beobachteter Resistenzen in diesen Studien müsste weiter evaluiert werden. Weitere Analysen sind erforderlich um ein besseres Verständnis über Gen-Umwelt Interaktionen und individuellen Befallsdruck gegen das Eschentriebsterben in natürlicher Umgebung zu bekommen. Massive Dezimierung von *Fraxinus excelsior* Populationen in Europa wird als Szenario immer wahrscheinlicher. Es ist daher zu empfehlen, nahezu gesunde Bäume europaweit zu identifizieren und ein geeignetes Management Programm zu entwickeln.

**3. Keywords:** ash dieback, common ash, disease tolerance, *Hymenoscyphus fraxineus*, parentage analysis, resistance

# 4. Introduction

Common ash (*Fraxinus excelsior*) is a widely distributed tree species throughout temperate Europe and of substantial ecologic and economic importance. The species tolerates a wide range of environmental conditions from riparian to mountain habitats (Pautasso et al. 2013). Compared to beech, common ash is adapted to sites that are moister or drier and it prefers nutrient rich soils (Marigo et al. 2000, Thomas 2016). Although the seedlings are shade tolerant, good light conditions are needed to compete with other broad-leaved tree species (Marigo et al. 2000). Common ash has a special mating system with male, female and hermaphrodite individuals and its pollen and seeds (samaras) are wind-dispersed (Wallander 2008, Morand-Prieur et al. 2003).

Recently, common ash has become highly threatened by a fungal disease (ash dieback) caused by the ascomycete *Hymenoscyphus fraxineus* (Gross et al. 2014), previously known as *H. pseudoalbidus*, with its anamorph stage *Chalara fraxinea* (Kowalski 2006, Queloz et al. 2011). The pathogen was most likely introduced from East Asia (Zhao et al. 2012, Gross et al. 2014) and was first observed in Poland in the early 1990s (Przybyl 2002, Pautasso et al. 2013). Since then, the pathogen spread all over Europe. First ash dieback symptoms were observed in Austria in 2005 at a few sites in Lower Austria, Upper Austria and Styria and subsequently spread to all federal provinces of Austria by 2009 (Cech 2006a, b; Cech et al. 2012).

The symptoms of ash dieback range from necrotic lesions and wilting on ash leaves and petioles to necrotic lesions on branches, shoots and stem, leading to wood discoloration and crown dieback and in most severe cases to death of the tree (Cech 2006b, Bakys et al. 2009). Through wind dispersal, the fungus infects ash leaves during summer, growing into shoots and twigs and overwinters on infected leaf stalks in the litter after leaf fall (Kräutler & Kirisits 2012, Landolt et al. 2016). Ash dieback attacks all tree age classes, although symptoms progress more severely and more rapidly in younger individuals, causing immense problems for rejuvenation (Heinze et al. submitted, Keßler et al. 2012). As the pathogen causes

high mortality of ash trees, ash dieback has become a serious problem raising concerns about the future of the species.

In many European countries, studies in seed orchards, progeny trials and also in natural stands during the last years aimed for a better knowledge of the pathogen and its impact on Common ash. Although there is an overall progression of the disease, several studies have revealed differences in symptom intensity among individuals providing the evidence of genetically based variation in susceptibility suggesting resistance or tolerance (Pliura et al. 2011, McKinney et al. 2011, Stener 2012, Kjaer et al. 2012). Results from inoculation studies show that the pathogen was less penetrative in less susceptible individuals suggesting a better response mechanism of the host (Mc.Kinney et al. 2012, Cleary et al. 2014). Possible resistance against ash dieback was previously estimated based on covariance and estimated heritability among half-sibs and full-sibs in progeny trails suggesting that parents that are less susceptible transmit the resistance to their offspring (Kjaer et al. 2012; Lobo et al. 2014; Lobo et al. 2015).

The aim of this study was to investigate how closely symptom intensity of saplings and their parents are correlated, investigated in natural ash stands by direct parent offspring comparisons. Positive correlations should therefore imply a likely inheritance of resistance to ash dieback.

# 5. Materials and Methods

## *5.1. Study sites and sampling*

Preceding requirements were defined for selecting suitable sampling sites. The optimal site must represent a fairly isolated ash stand with enough rejuvenation and healthy to severely damaged mature trees. Two study sites were finally chosen (figure 1).

The first sampling site is a small ash stand within the Johannser Kogel, which is a natural forest reserve of about 45 ha and is located in the northwestern part of the Lainzer Tiergarten with the geographical coordinates N 48° 11' and E 16° 12' (Türk & Pfleger 2008). The Lainzer Tiergarten is conservation reserve and a NATURA 2000 site of 2.460 ha with a high biodiversity, old trees and a high amount of deadwood located in the western part of Vienna and the eastern part of the biosphere reserve Wienerwald (https://www.wien.gv.at/umwelt/wald/erholung/lainzertiergarten/lebensraum/lage.html, 05-20-2016). The natural forest reserve Johannser Kogel has an altitudinal range of 290 to 377 m and an average annual precipitation of about 650 mm (Türk & Pfleger 2008). It is dominated by an oak-hornbeam forest with characteristic old oak trees which are up to 400 years old (Türk & Pfleger 2008). The ash stand has an area of about 2 ha and is found on the top of the hill in the middle of the reserve and is further described as a so called "hilltop ash forest" ("Gipfeleschenwald") (Willner 1996). Hilltop ash forests ash-dominated forests that often form pure stands on hilltops and on northern slopes (Willner 1996). The hilltops may represent atypical sites where ash find better conditions and outcompete other forest trees (Willner 1996). The ash forest at Johannser Kogel is mixed with field maple (*Acer campestre*).

The second sampling site, Siegenfeld, is a small ash stand of about 1 ha area located in a forest between Siegenfeld and Heiligenkreutz (N 48° 03' and E 16° 9'). It is surrounded by a spruce forest in the north, west and south and confined by a forest street in the east. Other tree species found in the ash stand are beech, maple

and larch. The altitude is about 400 m and mean annual precipitation is about 688 mm (http://de.climate-data.org/location/142025/, 02-19--2016). In 2007, the Federal Research Centre for Forests (BFW) started a monitoring program on 50 plots in Lower Austria where crown dieback intensity was estimated on 20 trees per plot. Two years later, the Austrian Forest Inventory included 1200 more plots for ash dieback monitoring. Siegenfeld is one of those plots in Lower Austria (Cech et al. 2012). Most of the 20 trees from Siegenfeld showed less symptom intensity from 2007 till 2009 (Cech et al. 2012), which made Siegenfeld as one of the healthiest monitoring plots by now (personal information by Katharina Schwanda).

Leaf or cambium samples were collected at both sites in June, July and August 2015 from 160 saplings and all mature trees observed (a total of 134 trees). Ash dieback was recorded as the degree of crown dieback. Mature trees were classified into one of six damage classes (figure 1B). Class 1: trees with no or few symptoms and <10% loss of crown foliage; class 2: trees between 10% and 25% crown foliage; class 3: trees with more than 25% but less than 50% crown foliage; class 4: between 50% and 75 %; class 5: between 75% and < 100% crown foliage and trees that had died from infection were scored as Class 6 (100% crown defoliation). Saplings were categorized in same damage classes, but instead crown damage, shoot damage was recorded (figure 2B). Additionally the diameter of breast height (DBH) of each tree and the height of each sapling were measured. Saplings were only sampled when they exceeded the height of about 60 cm, so that symptom identification and damage class categorization were confident enough.

One leaf per sapling and either a leaf (catched by a slingshot) or a bark plug per mature tree was collected. The bark plug from which cambium tissue can be sliced, was cut out of the trunk with a 1 cm diameter leather punch. After sampling the material was immediately dried in silica gel and kept at room temperature prior to DNA extraction.

### *5.2. DNA extraction*

On average, 25 – 45 mg dried leaf or cambium tissue per individual was put in 2 mL tubes together with two 3 cm diameter and one 4 cm diameter glass balls (for cambium tissue steal balls were used), one spatula tip of glass powder, activated charcoal, polyvinyl pyrrolidon (PVP 40,000) and sodium metabisulfite. For homogenization, the material was frozen in liquid nitrogen for two minutes and grounded with a TissueLyser (QIAGEN) at 25 Hz for two minutes. The process was repeated a second time. The DNA was extracted using the Invisorb® Spin Plant Mini Kit from STRATEC Molecular, applying the protocol recommended for the kit. But instead of Lysis Buffer P, provided by the kit, a mixture of 800 µL 2x CTAB Buffer (100 mM Tris-HCL pH 8.0, 1.4 M NaCL, 25 mM EDTA pH 8.0) plus 1.6 µL β-Mercaptoethanol and 1 µL proteinase K was used for lysis. Additionally 40 µL RNAse A (10 mg/mL) were added to each sample before the binding process. To determine DNA concentrations a NanoDrop 1000 Spectrophotometer (Thermo Fischer Scientific) was used.

### *5.3. DNA amplification and fragment analysis*

DNA concentrations for all samples were below 20 ng per µL. Therefore, DNA extractions were maintained undiluted for polymerase chain reaction. Nine nuclear microsatellite loci were used for amplification (Femsatl-4, Femsatl-10, Femsatl-11, Femsatl-12, Femsatl-16, Femsatl-19, M230, FR639485 and FR646655) (Lefort et al. 1999; Brachet et al. 1999; Beatty et al. 2015). Each forward primer was labelled with a fluorescent dye. PCRs were carried out using the QIAGEN Type It Microsatellite Kit. The amplification reactions were performed on a PTC-100® Thermal Cycler (BIO RAD) under the following conditions: An initial denaturation step of 5 min at 95°C, 28 cycles of denaturation at 95°C for 30s, annealing with corresponding temperatures according to table 1 for 90s and extension at 72°C for 30s and a final extension step at 60°C for 30 min.

A CEQ 8000 Beckman Coulter Sequencer was used to visualize the PCR products based on fragment length polymorphism, as compared to CEQ DNA Size

Standard Kit-400. Allele assessment, binning and calling were carried out using the fragment analysis tool of GenomeLab GeXP Beckman Coulter software, with additional visual inspection of peaks.

### *5.4. Parentage Analysis*

CERVUS 3.0.7 software (Kalinowski et al. 2007; Marshall et al. 1998) was used for parentage analysis and for calculating other parameters, such as expected (*He*) and observed (*Ho*) heterozygosity, polymorphic information content (PIC), average non-exclusion probability for one candidate parent (NE-P1), average non-exclusion probability for a candidate parent pair (NE-PP), Hardy Weinberg equilibrium (HW) and estimated null allele frequency (NULL). All of these parameters give information about the loci and their suitability for parentage analysis.

For parentage assignment, the program uses likelihood, a well-established statistical method (Marshall et al. 1998). Parentage is assigned to a candidate parent if the likelihood ratio is large relative to the likelihood ratio of alternative candidate parents. The likelihood ratio is expressed as LOD scores (logarithm of the likelihood ratio) (Marshall et al. 1998). Candidate parents with negative LOD scores are less likely to be the true parent. If two or more parents have positive LOD scores, Marshall et al. (1998) defined the logarithm of the ratio of likelihood to be delta (difference in LOD scores). In a simulation of parentage appropriate LOD and delta scores for valid parentage assignment are generated. The advantage in the use of CERVUS lies in the allowance for mistyping and missing data for individuals at a specified number of loci.

Parentage analysis for one parent (implemented by the maternity analysis function of CERVUS) and parent-pair analysis were carried out for both sites separately. Prior to parentage analysis, a simulation of parentage was performed with 10,000 offspring, an error rate of 0.01 at strict (95%) and relaxed (80%) confidence levels. As additional parameters candidate parents were set to 100 for Johannser Kogel with a 0.75 proportion of candidate parents sampled and 60 candidate parents with a 0.90 proportion of candidate parents sampled for Siegenfeld. The proportion of sampled candidate parents were estimated by field observation,

as the occurrence of unsampled trees in the proximity of the stands cannot be excluded with certainty. Unsampled candidate parents were estimated to be at low frequency in Siegenfeld and at moderate frequency in Johannser Kogel.

### *5.5. Statistical analysis*

To estimate the significance of correlation between damage class of parent and offspring, a one-tailed Spearman's rank correlation analysis was calculated using SPSS Statistics 23 software. The calculation was applied separately for those offspring were both parents were assigned (Spearman's rank correlation coefficient between the damage class of the offspring and the averaged mean damage class of both parents) and for those were only one parent was assigned (Spearman's rank correlation coefficient between the damage classes of the offspring and the one parent). The boxplot (DBH for damage class) was done in SPSS, whereas the tables and the bar diagram was done in Microsoft Excel 2013. Figure 1 was created with ArcMap 10.2 software from ESRI.

## 6. Results

### *6.1. Damage assessment*

Both sites show a range of slightly to severely damaged individuals, but most mature trees had a crown damage intensity between 10 to 50% and were assessed to damage classes 2 and 3 (54% of the trees from Siegenfeld and 67% from Johannser Kogel). Percentages of assessment to damage class 1 were higher in Siegenfeld than in Johannser Kogel (figure 3). No tree was observed to have lost the whole crown foliage (damage class 6).

Six saplings in Siegenfeld had only wilted leaves or no leaves and severely damaged shoots, so they were classified as dead (figure 2B). In Siegenfeld, 23 saplings were classified into damage class 1, and in Johannser Kogel, 14 saplings. More saplings from Johannser Kogel were assessed to damage class 2 (22) than from Siegenfeld (12). In general, both sites were similar regarding to damage in-

tensity. Around 45 % of the individuals had less than 25% crown or shoot damage (damage class 1 and 2) and more than the half of the individuals showed severe damage intensity (damage class 3, 4, 5).

In Siegenfeld, the mean height of the saplings was 99.3 cm ranging from 70 to 170 cm, and in Johannser Kogel mean height was 96.5 cm with a range from 65 to 190 cm. The mean diameter of the mature trees at breast height (DBH) was 35 cm in Siegenfeld and 39.7 cm in Johannser Kogel. Johannser Kogel had some older trees with DBH diameters of around 60 cm.

### *6.2. Allele frequency*

A total of 285 individuals from 294 sampled were genotyped for nine microsatellite loci. DNA from one ash tree and eight saplings (including all of the six dead saplings from Siegenfeld) couldn't be amplified, likely due to insufficient DNA quality. These individuals were not considered for further analysis.

The loci showed high allele numbers (N) and revealed that most of the loci are highly polymorphic (table 1). The highest allele variation was shown by locus Femsatl-10 with 48 alleles, whereas the lowest variation with seven alleles exhibited Femsatl-16. 183 alleles were detected in 161 individuals from Johannser Kogel with an average number of 20.3 alleles per locus and 166 alleles were detected for 124 individuals from Siegenfeld with an average number of 18.4 alleles per locus. The mean proportion of loci typed exceeded 0.99 for both sites. Mean expected heterozygosity (*He*) was 0.75 for Johannser Kogel and 0.80 for Siegenfeld. Observed heterozygosity (*Ho*) ranged from 0.38 to 0.85 for Johannser Kogel, and from 0.29 to 0.87 for Siegenfeld. Expected heterozygosity was higher than observed in most of the loci and in both sites. Mean polymorphic information content was 0.71 for Johannser Kogel and 0.77 for Siegenfeld. Combined non-exclusion probability for the first parent and for the parent pair were 5.70E-03 and 6.00E-07 for Johannser Kogel and 8.92E-04 and 8.73E-09 for Siegenfeld. Deviations from Hardy-Weinberg equilibrium were detected at five loci in Johannser Kogel and at one locus in Siegenfeld. The estimated frequency of null alleles ranged from -0.003

(FR639485, Johannser Kogel) to 0.5 (Femsatl-12, Siegenfeld) with a mean value of 0.072.

### *6.3. Parentage assignment*

The assignment rate for the parent-pair analysis in Johannser Kogel was 7.5 % implying that five saplings from Johannser Kogel were assigned both parents at relaxed confidence level and one at strict confidence level. In Siegenfeld, the assignment rate for the parent-pair analysis was higher with 27.7%. Both parents were determined for 20 saplings from Siegenfeld at a relaxed confidence level and 10 at strict confidence level.

Maternity analysis resulted in a 48.7% assignment rate for Johannser Kogel (42 saplings, 20 at strict confidence level) and the assignment rate for maternity analysis for Siegenfeld exceeded 30% (all of the assignments are with strict confidence). For 41.6 percent of the saplings from Siegenfeld and 43.8 percent from Johannser Kogel, no parent was assigned.

### *6.4. Statistical analysis*

Spearman's rank correlation coefficients showed no significant association between damage classes of offspring and parents, neither for parent-pair, nor for maternity analysis (table 2). In addition, a Wilcoxon–Mann–Whitney test was calculated between damage classes of parents and high/low damage of offspring (damage class one and two were put together and categorized as low damage whereas class three, four, five were set as high damage). The results showed no significant difference (results not shown).

The boxplot (figure 4) shows that thin, young trees tend to be more affected by ash dieback than thick, old ones.

# 7. Discussion

## *7.1. Genetic parameters and parentage assignment*

The majority of the loci used in this study were highly polymorphic with an average of 19 alleles per locus. Expected heterozygosity was high with an average of 0.79. Similar observations were made for the same microsatellite loci in previous population genetic studies on *F. excelsior,* suggesting high genetic diversity within populations (Heuertz et al. 2001, Hebel et al. 2006, Beatty et al. 2015). Allelic diversity did not differ much between Johannser Kogel and Siegenfeld (Mean number per loci: 20.3 and 18.4 respectively). Both sites had nearly the same set of alleles with few private alleles at each site. Therefore, genetic differentiation between both sites is assumed to be low (Heuertz et al. 2001, Hebel et al. 2006, Ballian et al. 2008).

Surprisingly, positive assignments of at least one parent were made only for c. half of the saplings, and for only 17% of the saplings both parents could be assigned. Although it was tried to sample all putative parents in both fairly enclosed stands, likely trees that grow outside the sampled stands are these missing parents. Another possible explanation for the low assignment rate could be genotyping or binning errors which would probably lead to undetected parentage, although CERVUS uses likelihood equations that take into account of such errors.

High combined exclusion probability (99%) across all loci for unrelated parents suggests low error rate in parentage assignment and shows that the microsatellite set used was rather adequate. However, a few loci showed problematic values that would lead to issues in parentage analysis and therefore need some discussion. The estimated frequency of null alleles displayed high values at some loci (0.33 and 0.5 at Femsatl-12, 0.09 at Femsatl-10) (table 1). Null alleles consistently do not amplify during PCR and can thus be not detected, leading to false assessments of heterozygotes as homozygotes (Kalinowski 2006). They are problematic in parentage analysis and appear sometimes simultaneously with deviations from the Hardy-Weinberg equilibrium (Pemperton et al. 1995), which was

also the case for five loci in Johannser Kogel and at one locus in Siegenfeld. Estimation of null allele frequencies does not necessarily imply that a null allele is present. If no parent-offspring relationship is definitely known, it is difficult to identify a null allele with certainty (Dakin 2004). Although Femsatl-12 was problematic, because of high estimated null allele frequency values and deviation from the Hardy-Weinberg equilibrium, it was included in parentage analysis, because CERVUS tolerates null alleles at low or moderate frequency. A general observation is that this locus amplifies well in Western Europe, less well in Central Europe, and very poorly in Eastern Europe (Heinze and Fussi submitted, their Table 4), which points at a geographical clustering of null alleles.

Another more likely explanation for the low assignment rate is that most of the saplings had been sired by trees that grow outside of the study stands suggesting high seed and pollen inflow from the surroundings. Similar results have been reported by Lobo et al. (2015), were paternity analysis in two Danish seed orchards resulted in an assignment rate of less than 40%. They suggested the small size of the seed orchard as one possible explanation (12 putative parents in the orchard). Analysis of seed dispersal in isolated, semi-continuous ash populations in Ireland carried out by Beatty et al. (2015) indicates the potential for seed dispersal over hundreds of meters. Bacles et al. (2005) and Bacles and Ennos (2008) estimated pollen dispersal in fragmented ash populations in Scotland, suggesting effective pollination within 300 m, but detected also pollination events over distances of up to 3 km. While these studies on pollination were carried out in isolated populations, where pollen can be transported easier with less barriers being present, a study by Heuertz et al. (2003) in a Romanian continuous ash woodland estimates pollination events within a distance of 14 m from female trees and pollen flow below 140 m distance. The low assignment rate for parent-pair analysis and moderate assignment rate for maternity analysis infer possible underestimation of seed and pollen dispersal within mixed continuous woodland and imply further analysis. However, it allows calculating ‘population differences’ in susceptibility between locally sired and incoming seedlings (with a good standardization of environmental effects). If technical errors and null alleles are a main reason for low assignment rates, then our conditions are conservative (in the sense that

more relaxed assignment conditions would lead to higher errors in parent-offspring assignments, so that correlations of disease tolerance would further be blurred).

### *7.2. Variation in ash dieback susceptibility*

No significant relationship was found based on Spearman's rank correlation between damage intensity of parents and their offspring, whether for parent-offspring duos (offspring with one parent), nor for parent-offspring trios (offspring with both parents) (table 2).

Previous studies suggested genetically based variation as explanation for observed differences in susceptibility to dieback symptoms and assumed that these differences might be transferred across ash generations (Bakys et al. 2009, McKinney et al. 2011, Lobo et al. 2014). However, most of these studies were performed in clonal seed orchards or established progeny trails. Often the seedlings were raised in a nursery prior to planting (Kjaer et al. 2012) or the mother clones were grafted onto rootstocks (McKinney et al. 2011, Stener 2013). Therefore, progeny trails and seed orchards represent controlled environments and they often lack natural woodland conditions. In contrast, this study was conducted in natural ash stands. Lobo et al. (2014) estimated the heritability of damage intensity in two progeny trails in Denmark. Both trails included progenies from the same mother trees, but one trail was left unfenced and progenies were put under strong competition from vegetation and exposed to browsing animals, whereas the other was protected by fencing. Lower estimated heritability values of the unfenced (0.2) compared to the fenced site (0.42-0.53) indicated that expression of estimated heritability under heterogeneous natural conditions may be lower (Lobo et al. 2014). Johannser Kogel is also fenced, but the fence may be penetrable at some points, as boars were observed inside the fence during sampling. Pliura et al. (2014) tested clones from seven different sites from Lithuania exposed to different ash-dieback infection pressure. They calculated the genotype-environment interaction on phenotypic variation and found significant contributions of genetic variation in plasticity and reaction norms of clones across a range of infection

pressure environments (Pliura et al. 2014). This indicates the presence of variation of individual response to the disease across sites depending on site conditions (Pliura et al. 2011, 2014) or different levels of disease pressure. Results from previous studies, together with the current one suggest an overestimation of heritability in more controlled environments. Therefore, environmental conditions could be more relevant and need to be considered for inferences on susceptibility.

It seems from all cited studies that up to now, only a small fraction of ash individuals maintain potential resistance to the disease, as practically all trees are infected at some point. Kjaer et al. (2012) found high susceptibility and mortality among trees in two progeny trails in Denmark. They further estimated that only 1% of trees have the potential to pass lower susceptibility to their offspring. In three Lithuanian progeny trails almost 90% of the trees died during the observation period of 8 years (Pliura et al. 2011). In Austria, such high mortality rates have not yet been reported from observation sites (Heinze et al. submitted). In 50 ash dieback monitoring plots in Lower Austria, mean crown dieback intensity reached 18.1% in 2009 and 17.6% in 2010 (Kirisits and Freinschlag 2012). Three seed orchards in Austria showed moderate mean crown dieback intensity in 2011 (14.2%, 13.5% and 31%) and no clone was totally unaffected (Heinze et al. submitted). Crown and shoot dieback intensity was also relatively moderate in Siegenfeld and Johannser Kogel (66% and 72% of the individuals respectively had lower than 50% damage intensity). It is likely that the mature trees that were identified as parents did not express assessable resistance due to low infection pressure (especially for the higher crowns of thicker trees, supplementary figure 2), while infection pressure was higher for saplings close to the forest floor, where the presence of petioles and more humid conditions would favour high spore concentrations. This could be one reason for the low correlation found (although it may only impact the severity, but not so much the direction of susceptibility; healthier mature trees should then still produce healthier offspring, though the average damage class rating would be shifted between old trees and young saplings, which was the case in this study). Probably, the small sample size of parent-offspring trios (N = 28) and half-sib families (only nine mature trees produced more than two offspring) may have led to underestimation of present, but weak

correlations of damage intensity between parent and offspring for possible resistance.

Younger ash trees are assumed to be more affected by ash dieback, because disease is progressing more severely and rapidly than in older individuals (Heinze et al. submitted). Figure 4 indicates a possible relationship between diameter at breast height (DBH) and damage intensity, especially in Johannser Kogel, where older trees (higher DBH) tend to be less affected than younger ones (lower DBH).

Breeding values, which represent the average effect of the parent genotype, estimated from the performance of its offspring (McKinney et al. 2014), were calculated by Kjaer et al. (2012) in a Danish progeny trail. Only one of 101 tested mother trees had breeding values below 10% and was estimated to produce healthy offspring and four trees with breeding values below 20% were estimated to produce fairly healthy offspring. Another study carried out by McKinney et al. (2011) supported these findings, with only one of 39 tested clones exhibited breeding values below 10%. Distribution of breeding values for susceptibility in Kjaer et al. (2012) were normally distributed suggesting that possible resistance is based on expression of several genes rather than on one alone (McKinney et al. 2014).

Unfortunately, the genetic background of low susceptibility thus remains unclear and the robustness of the observed potential resistance in previous studies needs to be evaluated. It is uncertain whether resistance in single individuals could hinder massive decline of ash in Europe and if that resistance would sustain massive infection pressure at natural forest sites. However, by selection and breeding of non-susceptible trees throughout Europe might reduce the impact of ash dieback in the future.

# 8. Conclusion

In this study, no significant correlation could be found between ash dieback damage intensity of parent and offspring. I conclude that genetic resistance in parent trees is missing at both sites and that the weak statistical power of detecting

possible correlations is due to the low assignment rate of parent offspring trios or half-sib families. I further suggest that variation in susceptibility on a genetic basis might be more complex under natural heterogeneous conditions than in controlled environments. The robustness of the observed potential resistance in previous studies should therefore be critically evaluated. A scenario of large-scale decline of *Fraxinus excelsior* trees is becoming more and more likely. It will be important to identify and propagate healthy ash individuals throughout Europe, find out about the genetic mechanism of any resistance in more detail and implement a management program that accounts for these facets.

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### *9.2. Web Page*

https://www.wien.gv.at/umwelt/wald/erholung/lainzertiergarten/lebensraum/lage.html, 05-20-2016

# 10. Figures and tables

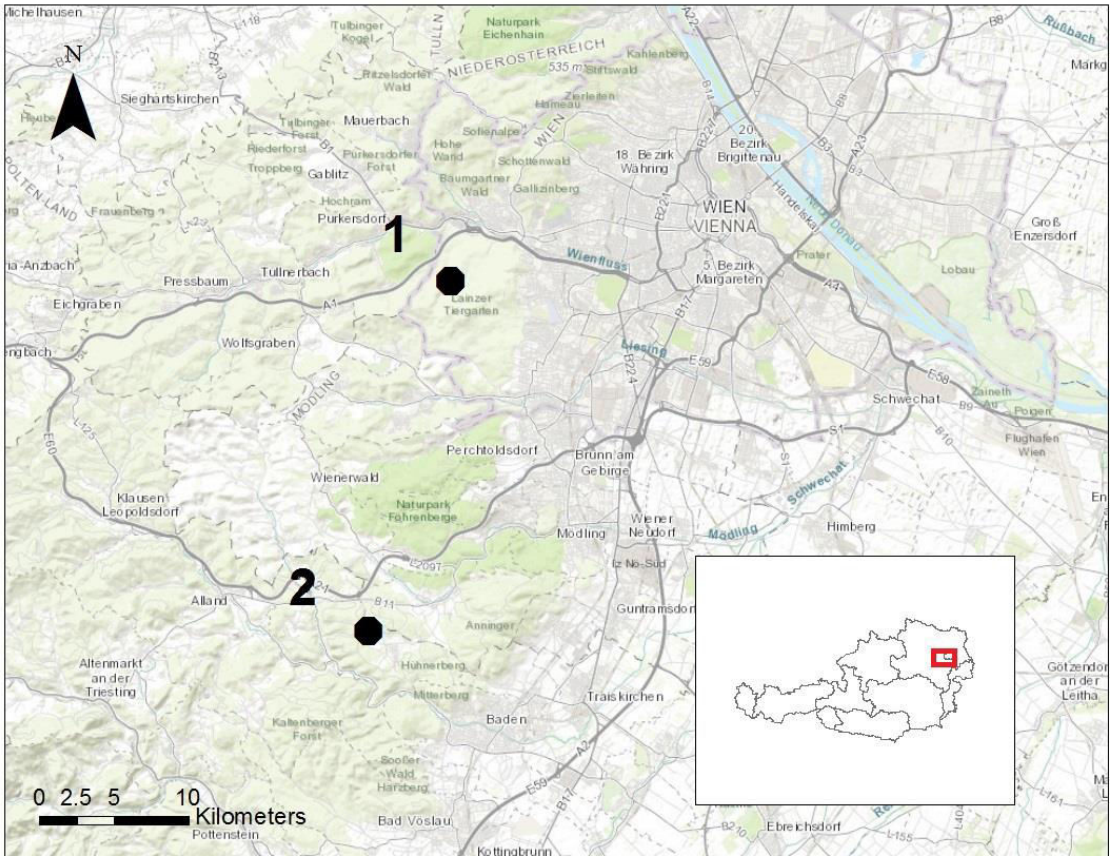



Figure 1: Location of the study sites in eastern Austria; 1: Johannser Kogel (Lainzer Tiergarten, southwest Vienna); 2: Siegenfeld (Heiligenkreuz, Wienerwald)

A


B

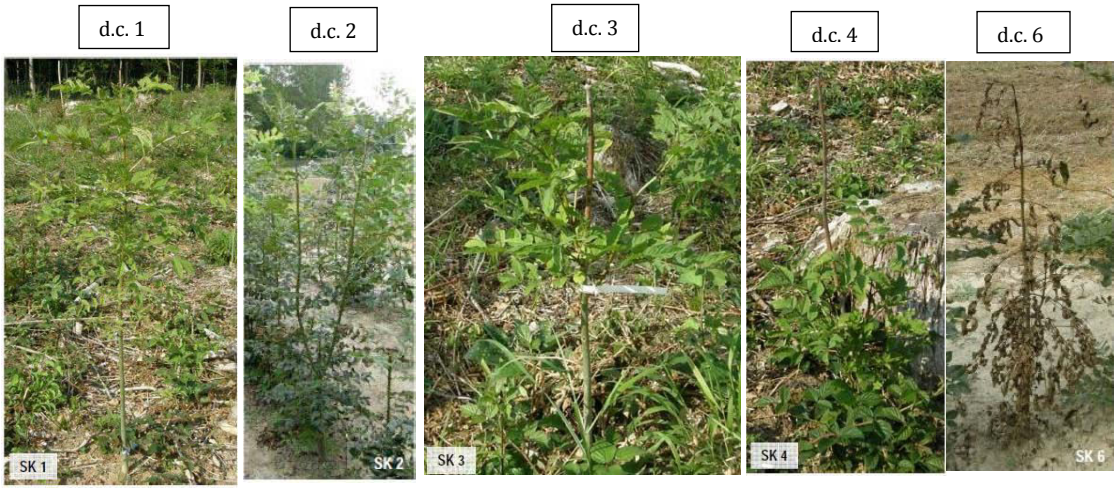



Figure 2: Illustration of the visually assessed damage classes (d.c.) (A) for mature trees, no tree was assessed for damage class 6 (photos from Siegenfeld, by Alexandra Wohlmuth); (B) for saplings (d.c. 5 is not shown) (Photos by T. Kirisits, IFFF-BOKU Wien)

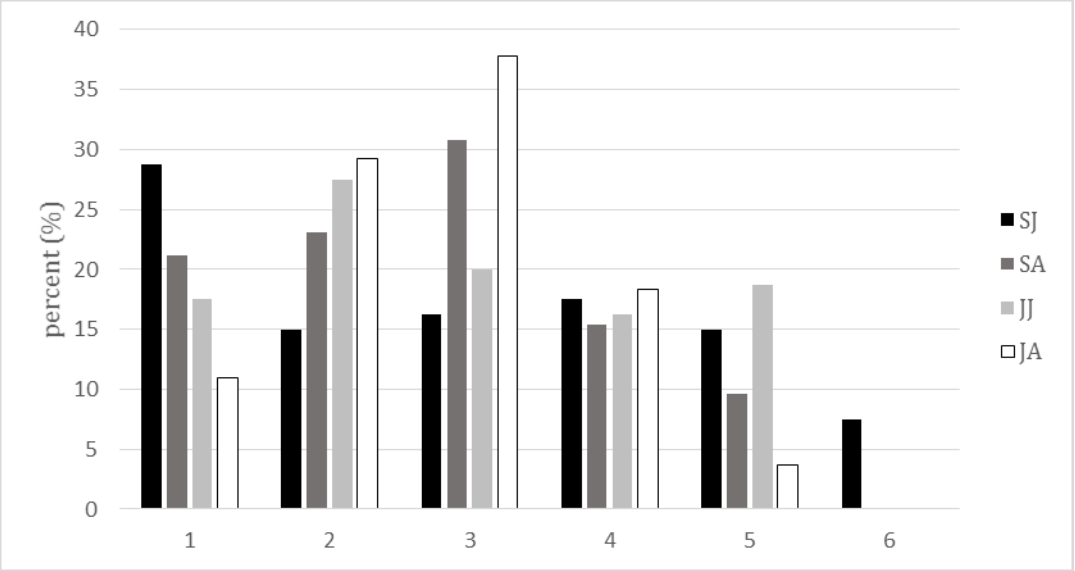



Figure 3. The percentage of ash individuals that belong to damage classes 1 – 6 shown separately for mature trees and saplings from each study site; SJ: saplings from Siegenfeld; SA: mature trees from Siegenfeld; JJ: saplings from Johannser Kogel; JA: mature trees from Johannser Kogel

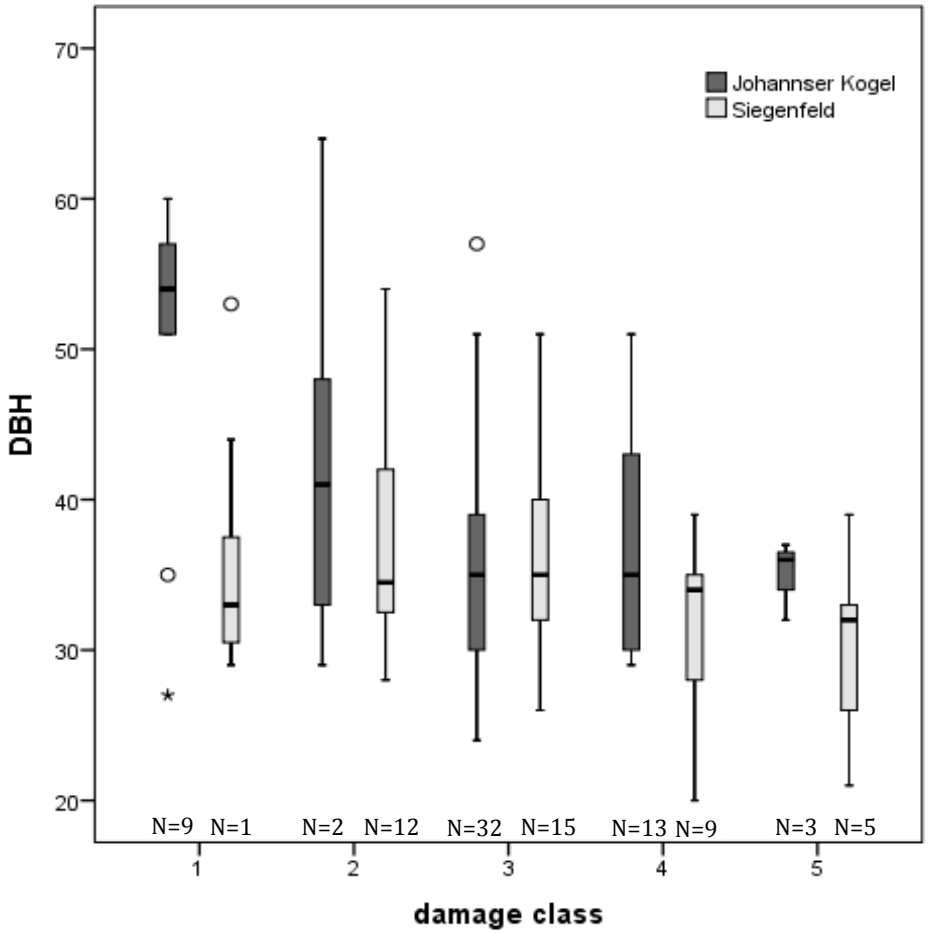



Figure 4. Boxplot of the assignment of mature ash trees of different size (measured by their diameter at breast height) to different damage classes at the study sites

Table 1: Information about the microsatellite loci used and the analyzed parameters. Legend: *number of alleles; Ho: observed heterozygosity; He: expected heterozygosity; PIC: polymorphic information content; NE-1P: average non-exclusion for one candidate parent; NE-PP: average non-exclusion probability for one candidate parent; NE-PP: average non-exclusion probability for a candidate parent-pair; HW: Significance of deviation from Hardy-Weinberg equilibrium - NS = not significant, * = significant at 5% level, ** = significant at 1% level, *** = significant at 0.1% level; Null: Estimated null allele frequency*

| Locus | Annealing temp. (C°) | analyzed parameters Johannser Kogel | | | | | | | | analyzed parameters Siegenfeld | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *N* | *Ho* | *He* | PIC | NE-1P | NE-PP | HW | Null | *N* | *Ho* | *He* | PIC | NE-1P | NE-PP | HW | Null |
| Femsatl-4 | 60 | 26 | 0.665 | 0.734 | 0.695 | 0.65 | 0.275 | NS | 0.052 | 21 | 0.734 | 0.808 | 0.787 | 0.53 | 0.162 | NS | 0.0437 |
| Femsatl-10 | 50 | 41 | 0.745 | 0.895 | 0.884 | 0.347 | 0.067 | * | 0.0924 | 37 | 0.772 | 0.935 | 0.927 | 0.24 | 0.031 | ND | 0.0913 |
| Femsatl-11 | 55 | 22 | 0.776 | 0.873 | 0.858 | 0.406 | 0.096 | *** | 0.0589 | 19 | 0.789 | 0.883 | 0.869 | 0.384 | 0.085 | NS | 0.0561 |
| Femsatl-12 | 55 | 17 | 0.376 | 0.737 | 0.701 | 0.646 | 0.268 | *** | 0.3333 | 15 | 0.286 | 0.855 | 0.837 | 0.446 | 0.114 | *** | 0.5006 |
| Femsatl-16 | 62 | 7 | 0.547 | 0.526 | 0.454 | 0.858 | 0.588 | NS | -0.0227 | 6 | 0.459 | 0.524 | 0.489 | 0.85 | 0.507 | NS | 0.0853 |
| Femsatl-19 | 58 | 16 | 0.85 | 0.802 | 0.776 | 0.549 | 0.186 | ** | -0.0328 | 17 | 0.79 | 0.877 | 0.861 | 0.403 | 0.096 | NS | 0.0515 |
| M230 | 57 | 37 | 0.844 | 0.891 | 0.881 | 0.349 | 0.066 | * | 0.0234 | 36 | 0.871 | 0.94 | 0.933 | 0.225 | 0.027 | ND | 0.0366 |
| FR639485 | 55 | 9 | 0.638 | 0.583 | 0.524 | 0.816 | 0.496 | NS | -0.051 | 8 | 0.677 | 0.654 | 0.601 | 0.757 | 0.405 | NS | -0.0258 |
| FR646655 | 60 | 8 | 0.696 | 0.695 | 0.647 | 0.719 | 0.36 | NS | -0.0029 | 7 | 0.697 | 0.71 | 0.66 | 0.701 | 0.342 | NS | 0.008 |

Table 2. Spearman's rank-correlation analysis for offsprings for which both both parents were assigned (n = 26) (A), and for offspring for which one parent was assigned (n = 58) (B)

A

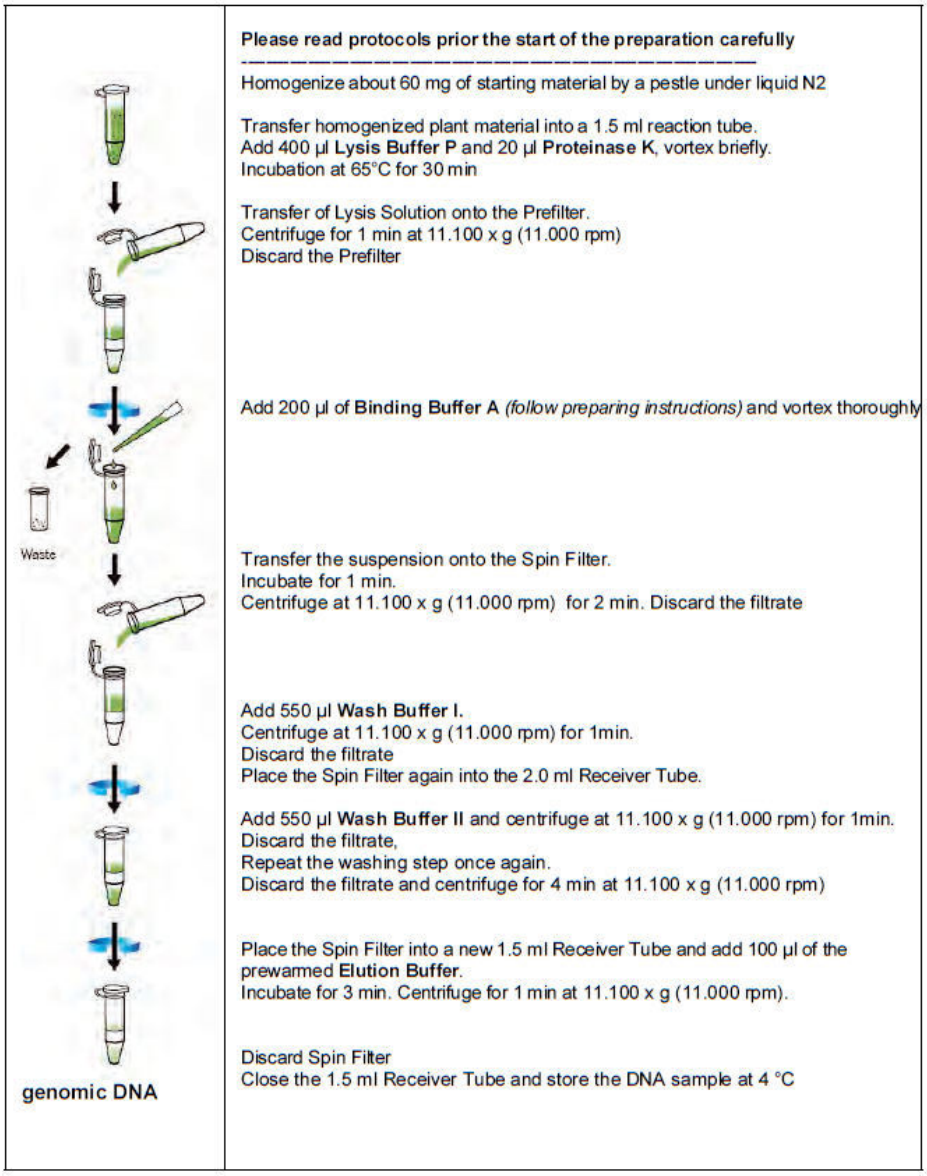
| both parents assigned | | mean damage parent-pair |
|---|---|---|
| Damage class offspring | Correlation Coefficient ($r_s$) | 0.098 |
| | **P** | **0.318** |

B

| one parent assigned | | damage class one parent |
|---|---|---|
| Damage class offspring | Correlation Coefficient ($r_s$) | -0.082 |
| | **P** | **0.272** |

# Appendix A:

Supplementary figure 1: DNA extraction scheme using Invisorb® Spin Plant Mini Kit.



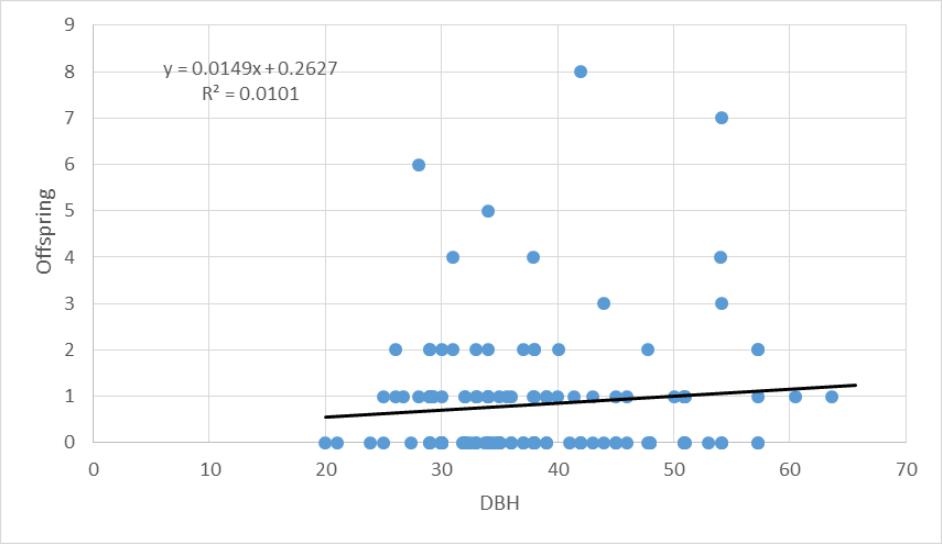
# Appendix B:

Supplementary table 1: Number of offspring per mature ash tree separately shown for each damage class

| offspring d.c. / d.c. parent | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 6 | 4 | 3 | 2 | 0 |
| 2 | 10 | 8 | 4 | 5 | 7 | 0 |
| 3 | 7 | 7 | 5 | 11 | 9 | 0 |
| 4 | 3 | 9 | 0 | 1 | 4 | 0 |
| 5 | 1 | 1 | 0 | 1 | 1 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 |

# Appendix C:

Supplementary figure 2: Diameter at breast height (DBH) of mature ash trees and the number of assigned offspring



## Appendix D:

Supplementary table 2: Genotype data for each individual at each allele. Missing genotypes are encoded by 0.

Johannser Kogel

| sapling | FEM 4a | FEM 4b | FEM 10a | FEM 10b | FEM 11a | FEM 11b | FEM 12a | FEM 12b | FEM 16a | FEM 16b | FEM 19a | FEM 19b | M230 a | M230 b | FR 63a | FR 63b | FR 64a | FR 64b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JJ1 | 116 | 118 | 184 | 256 | 175 | 185 | 186 | 186 | 194 | 194 | 141 | 148 | 207 | 233 | 300 | 306 | 180 | 186 |
| JJ2 | 116 | 122 | 230 | 234 | 181 | 185 | 188 | 188 | 178 | 194 | 133 | 148 | 225 | 233 | 300 | 300 | 186 | 186 |
| JJ3 | 112 | 122 | 164 | 302 | 185 | 185 | 188 | 208 | 178 | 180 | 138 | 155 | 241 | 255 | 304 | 304 | 180 | 180 |
| JJ4 | 116 | 116 | 220 | 234 | 173 | 173 | 188 | 188 | 178 | 178 | 141 | 148 | 225 | 233 | 300 | 302 | 180 | 180 |
| JJ5 | 116 | 142 | 186 | 186 | 185 | 193 | 188 | 188 | 178 | 194 | 141 | 141 | 233 | 253 | 304 | 314 | 180 | 186 |
| JJ6 | 122 | 148 | 233 | 233 | 179 | 205 | 264 | 264 | 178 | 178 | 148 | 155 | 272 | 272 | 298 | 308 | 186 | 189 |
| JJ7 | 118 | 152 | 186 | 186 | 189 | 220 | 200 | 214 | 178 | 194 | 130 | 141 | 209 | 223 | 300 | 306 | 189 | 189 |
| JJ8 | 116 | 116 | 226 | 235 | 175 | 175 | 208 | 208 | 178 | 178 | 150 | 155 | 235 | 257 | 300 | 304 | 189 | 195 |
| JJ9 | 118 | 126 | 186 | 220 | 175 | 195 | 186 | 202 | 178 | 178 | 150 | 155 | 233 | 233 | 300 | 308 | 186 | 189 |
| JJ10 | 118 | 134 | 186 | 238 | 175 | 220 | 186 | 186 | 178 | 194 | 148 | 153 | 209 | 275 | 300 | 304 | 180 | 189 |
| JJ11 | 118 | 118 | 186 | 334 | 175 | 175 | 0 | 0 | 194 | 194 | 141 | 148 | 209 | 233 | 306 | 306 | 183 | 189 |
| JJ12 | 118 | 130 | 186 | 186 | 175 | 175 | 186 | 186 | 178 | 194 | 150 | 155 | 209 | 233 | 304 | 306 | 189 | 189 |
| JJ13 | 116 | 118 | 186 | 189 | 207 | 213 | 190 | 190 | 178 | 194 | 141 | 141 | 209 | 275 | 296 | 300 | 189 | 189 |
| JJ14 | 118 | 118 | 164 | 186 | 175 | 189 | 200 | 212 | 178 | 194 | 141 | 150 | 249 | 249 | 304 | 304 | 180 | 189 |
| JJ15 | 116 | 116 | 186 | 252 | 185 | 220 | 186 | 186 | 178 | 194 | 155 | 158 | 207 | 223 | 304 | 304 | 189 | 189 |
| JJ16 | 118 | 134 | 186 | 186 | 173 | 173 | 186 | 186 | 178 | 194 | 141 | 148 | 233 | 275 | 298 | 306 | 186 | 189 |
| JJ17 | 118 | 120 | 183 | 186 | 173 | 173 | 186 | 186 | 180 | 180 | 141 | 148 | 223 | 243 | 304 | 304 | 189 | 195 |
| JJ18 | 116 | 126 | 164 | 186 | 191 | 195 | 186 | 204 | 194 | 194 | 169 | 179 | 229 | 241 | 300 | 304 | 189 | 189 |
| JJ19 | 118 | 136 | 234 | 234 | 173 | 181 | 188 | 188 | 176 | 178 | 150 | 153 | 223 | 275 | 300 | 304 | 180 | 189 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JJ20 | 118 | 118 | 186 | 186 | 173 | 177 | 188 | 188 | 170 | 194 | 141 | 153 | 223 | 223 | 300 | 304 | 180 | 189 |
| JJ21 | 148 | 154 | 254 | 370 | 179 | 181 | 188 | 204 | 178 | 178 | 141 | 153 | 209 | 243 | 304 | 304 | 189 | 195 |
| JJ22 | 118 | 154 | 186 | 186 | 175 | 187 | 200 | 200 | 178 | 178 | 141 | 160 | 215 | 275 | 304 | 304 | 180 | 189 |
| JJ23 | 118 | 142 | 164 | 224 | 173 | 193 | 186 | 186 | 178 | 178 | 141 | 148 | 217 | 263 | 304 | 304 | 180 | 189 |
| JJ24 | 118 | 118 | 235 | 241 | 173 | 215 | 186 | 186 | 178 | 194 | 155 | 155 | 233 | 241 | 304 | 304 | 189 | 189 |
| JJ25 | 116 | 116 | 234 | 330 | 173 | 195 | 188 | 188 | 178 | 178 | 130 | 141 | 221 | 233 | 304 | 304 | 180 | 189 |
| JJ26 | 120 | 124 | 186 | 254 | 181 | 181 | 190 | 190 | 178 | 178 | 150 | 155 | 231 | 267 | 304 | 304 | 180 | 189 |
| JJ27 | 116 | 116 | 186 | 243 | 173 | 195 | 196 | 196 | 178 | 178 | 141 | 155 | 257 | 275 | 304 | 304 | 180 | 189 |
| JJ28 | 118 | 118 | 186 | 220 | 173 | 185 | 186 | 188 | 178 | 194 | 153 | 155 | 249 | 275 | 300 | 300 | 186 | 186 |
| JJ29 | 116 | 118 | 234 | 235 | 175 | 197 | 188 | 188 | 178 | 194 | 146 | 155 | 267 | 275 | 304 | 304 | 186 | 189 |
| JJ30 | 116 | 116 | 186 | 247 | 173 | 181 | 186 | 188 | 178 | 194 | 130 | 146 | 233 | 233 | 304 | 304 | 180 | 195 |
| JJ31 | 116 | 116 | 235 | 260 | 175 | 195 | 188 | 188 | 178 | 178 | 141 | 148 | 209 | 261 | 300 | 304 | 189 | 192 |
| JJ32 | 118 | 118 | 220 | 278 | 173 | 195 | 198 | 200 | 180 | 194 | 146 | 160 | 231 | 249 | 300 | 306 | 189 | 189 |
| JJ33 | 116 | 116 | 185 | 247 | 173 | 195 | 186 | 208 | 178 | 178 | 143 | 148 | 217 | 217 | 300 | 300 | 189 | 189 |
| JJ34 | 116 | 118 | 220 | 234 | 173 | 197 | 214 | 214 | 178 | 178 | 141 | 155 | 275 | 275 | 300 | 304 | 189 | 207 |
| JJ35 | 118 | 118 | 164 | 328 | 175 | 191 | 214 | 214 | 178 | 194 | 141 | 146 | 237 | 249 | 300 | 306 | 189 | 189 |
| JJ36 | 158 | 158 | 186 | 226 | 173 | 173 | 0 | 0 | 178 | 178 | 141 | 150 | 231 | 231 | 304 | 304 | 186 | 186 |
| JJ37 | 116 | 148 | 230 | 230 | 173 | 181 | 186 | 186 | 178 | 180 | 0 | 0 | 251 | 275 | 300 | 304 | 186 | 189 |
| JJ38 | 116 | 118 | 186 | 186 | 183 | 183 | 186 | 186 | 178 | 194 | 150 | 153 | 231 | 231 | 304 | 304 | 189 | 195 |
| JJ39 | 118 | 118 | 185 | 370 | 183 | 209 | 200 | 200 | 180 | 180 | 148 | 155 | 225 | 225 | 298 | 300 | 180 | 189 |
| JJ40 | 152 | 166 | 234 | 234 | 173 | 195 | 184 | 188 | 178 | 194 | 146 | 155 | 275 | 275 | 304 | 304 | 186 | 186 |
| JJ41 | 116 | 116 | 220 | 234 | 173 | 181 | 188 | 190 | 178 | 194 | 141 | 141 | 251 | 275 | 300 | 300 | 189 | 189 |
| JJ42 | 116 | 116 | 164 | 256 | 173 | 195 | 188 | 188 | 178 | 178 | 141 | 155 | 233 | 245 | 300 | 300 | 180 | 186 |
| JJ43 | 118 | 120 | 184 | 241 | 175 | 175 | 188 | 188 | 178 | 194 | 130 | 141 | 233 | 233 | 300 | 304 | 189 | 189 |
| JJ44 | 116 | 118 | 183 | 183 | 183 | 203 | 188 | 214 | 194 | 194 | 141 | 155 | 233 | 233 | 300 | 304 | 189 | 189 |
| JJ45 | 118 | 122 | 234 | 234 | 175 | 175 | 186 | 186 | 178 | 194 | 141 | 146 | 209 | 233 | 300 | 304 | 180 | 189 |
| JJ46 | 118 | 122 | 185 | 185 | 173 | 185 | 186 | 212 | 178 | 194 | 155 | 155 | 217 | 233 | 300 | 304 | 183 | 189 |

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| JJ47 | 116 | 118 | 186 | 238 | 179 | 185 | 186 | 186 | 178 | 194 | 141 | 155 | 217 | 267 | 300 | 304 | 180 | 189 |
| JJ48 | 118 | 118 | 164 | 238 | 185 | 193 | 188 | 200 | 194 | 194 | 141 | 141 | 217 | 272 | 304 | 306 | 180 | 189 |
| JJ49 | 116 | 118 | 164 | 247 | 183 | 183 | 208 | 212 | 178 | 180 | 141 | 155 | 215 | 223 | 298 | 304 | 195 | 195 |
| JJ50 | 116 | 134 | 185 | 185 | 175 | 189 | 186 | 186 | 178 | 194 | 148 | 155 | 209 | 241 | 304 | 304 | 180 | 189 |
| JJ51 | 116 | 116 | 183 | 234 | 185 | 211 | 188 | 188 | 178 | 178 | 141 | 150 | 233 | 257 | 298 | 300 | 186 | 189 |
| JJ52 | 116 | 142 | 264 | 278 | 173 | 183 | 198 | 198 | 178 | 194 | 146 | 150 | 225 | 255 | 300 | 306 | 189 | 189 |
| JJ53 | 116 | 124 | 164 | 235 | 175 | 175 | 198 | 198 | 178 | 178 | 146 | 146 | 233 | 255 | 308 | 316 | 189 | 195 |
| JJ54 | 116 | 130 | 164 | 252 | 175 | 207 | 186 | 186 | 178 | 194 | 141 | 150 | 255 | 283 | 304 | 306 | 183 | 183 |
| JJ55 | 116 | 122 | 250 | 256 | 181 | 185 | 186 | 198 | 178 | 194 | 141 | 155 | 207 | 275 | 304 | 306 | 186 | 186 |
| JJ56 | 118 | 124 | 220 | 326 | 173 | 195 | 190 | 198 | 178 | 178 | 150 | 155 | 263 | 275 | 300 | 304 | 186 | 195 |
| JJ57 | 122 | 146 | 250 | 338 | 175 | 175 | 188 | 202 | 178 | 194 | 133 | 155 | 253 | 275 | 304 | 304 | 189 | 189 |
| JJ58 | 116 | 120 | 164 | 247 | 189 | 193 | 264 | 264 | 178 | 194 | 155 | 171 | 209 | 257 | 300 | 304 | 180 | 186 |
| JJ59 | 116 | 136 | 164 | 254 | 175 | 175 | 198 | 198 | 178 | 194 | 146 | 146 | 219 | 249 | 306 | 306 | 186 | 189 |
| JJ60 | 116 | 122 | 185 | 254 | 185 | 185 | 186 | 188 | 178 | 178 | 141 | 160 | 209 | 233 | 298 | 304 | 180 | 195 |
| JJ61 | 136 | 152 | 185 | 185 | 173 | 197 | 186 | 202 | 178 | 194 | 141 | 155 | 233 | 233 | 300 | 304 | 189 | 195 |
| JJ62 | 116 | 136 | 183 | 280 | 197 | 213 | 186 | 186 | 178 | 178 | 150 | 155 | 231 | 257 | 300 | 304 | 180 | 186 |
| JJ63 | 116 | 116 | 234 | 234 | 185 | 185 | 186 | 188 | 178 | 178 | 138 | 155 | 233 | 247 | 304 | 304 | 180 | 195 |
| JJ64 | 118 | 118 | 185 | 234 | 185 | 185 | 198 | 198 | 178 | 178 | 155 | 155 | 233 | 275 | 304 | 304 | 180 | 195 |
| JJ65 | 118 | 118 | 235 | 235 | 185 | 185 | 188 | 188 | 178 | 178 | 148 | 155 | 219 | 233 | 304 | 306 | 189 | 189 |
| JJ66 | 116 | 116 | 183 | 235 | 173 | 185 | 188 | 188 | 178 | 178 | 130 | 155 | 211 | 275 | 300 | 304 | 195 | 195 |
| JJ67 | 118 | 144 | 186 | 235 | 175 | 185 | 200 | 200 | 178 | 178 | 155 | 155 | 275 | 275 | 300 | 304 | 186 | 195 |
| JJ68 | 138 | 148 | 185 | 185 | 175 | 193 | 188 | 188 | 178 | 194 | 135 | 158 | 231 | 272 | 304 | 304 | 186 | 195 |
| JJ69 | 116 | 118 | 186 | 186 | 185 | 195 | 186 | 204 | 178 | 178 | 141 | 155 | 213 | 275 | 300 | 300 | 186 | 186 |
| JJ70 | 116 | 118 | 185 | 185 | 173 | 173 | 186 | 186 | 178 | 194 | 141 | 141 | 194 | 223 | 300 | 306 | 186 | 189 |
| JJ71 | 116 | 118 | 186 | 186 | 191 | 220 | 186 | 190 | 178 | 180 | 130 | 155 | 233 | 255 | 304 | 304 | 189 | 189 |
| JJ72 | 116 | 116 | 186 | 256 | 183 | 220 | 182 | 182 | 178 | 180 | 150 | 155 | 211 | 223 | 304 | 304 | 180 | 195 |
| JJ73 | 116 | 116 | 185 | 185 | 173 | 181 | 186 | 186 | 178 | 194 | 141 | 148 | 223 | 253 | 304 | 306 | 180 | 189 |

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| JJ74 | 118 | 158 | 186 | 250 | 175 | 220 | 188 | 206 | 178 | 194 | 130 | 155 | 225 | 233 | 304 | 306 | 186 | 189 |
| JJ75 | 116 | 142 | 185 | 218 | 173 | 220 | 186 | 200 | 178 | 180 | 141 | 155 | 233 | 233 | 304 | 306 | 189 | 189 |
| JJ76 | 116 | 118 | 186 | 324 | 177 | 220 | 186 | 186 | 194 | 194 | 141 | 148 | 233 | 233 | 300 | 304 | 186 | 189 |
| JJ77 | 116 | 118 | 164 | 186 | 175 | 220 | 186 | 186 | 180 | 180 | 141 | 141 | 223 | 267 | 300 | 304 | 189 | 195 |
| JJ78 | 132 | 132 | 235 | 235 | 181 | 193 | 190 | 190 | 178 | 178 | 141 | 141 | 229 | 257 | 304 | 308 | 189 | 189 |
| JJ79 | 116 | 118 | 185 | 258 | 173 | 181 | 0 | 0 | 178 | 180 | 153 | 155 | 233 | 253 | 298 | 304 | 189 | 195 |
| JJ80 | 116 | 116 | 220 | 220 | 173 | 183 | 188 | 188 | 178 | 178 | 155 | 155 | 233 | 249 | 300 | 304 | 180 | 186 |
| | | | | | | | | | | | | | | | | | | |
| tree | FEM 4a | FEM 4b | FEM 10a | FEM 10b | FEM 11a | FEM 11b | FEM 12a | FEM 12b | FEM 16a | FEM 16b | FEM 19a | FEM 19b | M230 a | M230 b | FR 63a | FR 63b | FR 64a | FR 64b |
| JA1 | 116 | 118 | 185 | 233 | 185 | 193 | 186 | 188 | 180 | 194 | 146 | 155 | 233 | 275 | 300 | 304 | 189 | 189 |
| JA2 | 116 | 116 | 185 | 220 | 185 | 215 | 186 | 212 | 178 | 192 | 153 | 155 | 257 | 275 | 304 | 304 | 180 | 189 |
| JA3 | 116 | 118 | 189 | 234 | 177 | 185 | 188 | 202 | 178 | 194 | 143 | 155 | 233 | 261 | 300 | 304 | 180 | 189 |
| JA4 | 116 | 118 | 185 | 233 | 185 | 193 | 186 | 186 | 178 | 178 | 138 | 141 | 247 | 275 | 304 | 304 | 183 | 189 |
| JA5 | 116 | 160 | 185 | 234 | 175 | 183 | 186 | 186 | 178 | 194 | 141 | 146 | 231 | 275 | 304 | 304 | 186 | 189 |
| JA6 | 116 | 146 | 234 | 334 | 173 | 193 | 186 | 186 | 178 | 194 | 141 | 150 | 219 | 275 | 300 | 304 | 186 | 189 |
| JA7 | 116 | 118 | 234 | 326 | 175 | 185 | 188 | 204 | 194 | 194 | 141 | 141 | 233 | 233 | 298 | 304 | 189 | 189 |
| JA8 | 118 | 122 | 234 | 250 | 173 | 195 | 186 | 196 | 178 | 178 | 148 | 155 | 233 | 251 | 300 | 304 | 180 | 186 |
| JA9 | 116 | 118 | 185 | 234 | 173 | 189 | 182 | 188 | 178 | 178 | 141 | 150 | 247 | 275 | 300 | 304 | 180 | 189 |
| JA10 | 116 | 116 | 183 | 234 | 175 | 175 | 188 | 188 | 178 | 194 | 155 | 158 | 233 | 245 | 304 | 304 | 189 | 195 |
| JA11 | 118 | 140 | 185 | 245 | 181 | 185 | 186 | 186 | 178 | 194 | 141 | 153 | 223 | 233 | 300 | 304 | 189 | 189 |
| JA12 | 116 | 116 | 164 | 234 | 185 | 195 | 186 | 202 | 178 | 194 | 141 | 141 | 249 | 275 | 300 | 304 | 180 | 189 |
| JA13 | 116 | 118 | 185 | 234 | 173 | 181 | 186 | 186 | 178 | 194 | 141 | 155 | 223 | 275 | 300 | 304 | 189 | 189 |
| JA14 | 118 | 158 | 234 | 338 | 173 | 191 | 186 | 214 | 178 | 178 | 155 | 158 | 227 | 275 | 300 | 304 | 180 | 189 |
| JA15 | 116 | 136 | 226 | 234 | 185 | 195 | 186 | 186 | 178 | 178 | 141 | 155 | 253 | 275 | 300 | 304 | 186 | 189 |
| JA16 | 116 | 122 | 164 | 185 | 185 | 191 | 188 | 208 | 178 | 178 | 146 | 155 | 243 | 275 | 304 | 304 | 189 | 189 |
| JA17 | 118 | 122 | 164 | 234 | 173 | 181 | 188 | 188 | 178 | 178 | 141 | 155 | 235 | 235 | 300 | 304 | 180 | 189 |

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| JA18 | 118 | 124 | 185 | 185 | 175 | 183 | 186 | 188 | 178 | 194 | 141 | 141 | 192 | 233 | 304 | 306 | 186 | 189 |
| JA19 | 114 | 116 | 164 | 185 | 185 | 189 | 186 | 188 | 178 | 178 | 148 | 155 | 251 | 275 | 300 | 304 | 180 | 195 |
| JA20 | 116 | 148 | 185 | 324 | 175 | 200 | 188 | 188 | 178 | 194 | 135 | 141 | 275 | 275 | 300 | 304 | 180 | 195 |
| JA21 | 116 | 118 | 189 | 234 | 181 | 185 | 186 | 186 | 178 | 194 | 155 | 155 | 229 | 233 | 300 | 304 | 180 | 189 |
| JA22 | 116 | 118 | 185 | 230 | 181 | 185 | 182 | 186 | 178 | 194 | 141 | 141 | 257 | 275 | 300 | 304 | 189 | 189 |
| JA23 | 116 | 116 | 234 | 256 | 181 | 185 | 188 | 264 | 178 | 194 | 141 | 146 | 229 | 233 | 300 | 304 | 189 | 189 |
| JA24 | 116 | 140 | 183 | 234 | 185 | 191 | 186 | 186 | 178 | 194 | 138 | 155 | 194 | 233 | 300 | 304 | 180 | 189 |
| JA25 | 116 | 126 | 164 | 234 | 173 | 177 | 186 | 212 | 178 | 178 | 141 | 150 | 235 | 275 | 304 | 304 | 180 | 201 |
| JA27 | 116 | 164 | 183 | 185 | 175 | 175 | 186 | 186 | 178 | 194 | 138 | 155 | 231 | 275 | 300 | 304 | 186 | 189 |
| JA28 | 116 | 116 | 185 | 235 | 177 | 177 | 186 | 186 | 178 | 178 | 153 | 155 | 253 | 275 | 300 | 304 | 186 | 189 |
| JA29 | 118 | 122 | 186 | 189 | 175 | 179 | 188 | 188 | 178 | 194 | 141 | 148 | 275 | 294 | 298 | 304 | 189 | 207 |
| JA30 | 116 | 166 | 185 | 250 | 181 | 185 | 186 | 186 | 178 | 194 | 141 | 150 | 233 | 275 | 300 | 304 | 180 | 186 |
| JA31 | 116 | 122 | 185 | 185 | 173 | 181 | 188 | 200 | 178 | 194 | 155 | 160 | 263 | 305 | 304 | 304 | 180 | 195 |
| JA32 | 118 | 118 | 185 | 324 | 175 | 175 | 188 | 200 | 178 | 178 | 146 | 155 | 275 | 275 | 300 | 304 | 189 | 189 |
| JA33 | 116 | 116 | 185 | 247 | 173 | 179 | 188 | 202 | 178 | 178 | 141 | 155 | 231 | 275 | 300 | 304 | 189 | 189 |
| JA34 | 118 | 138 | 234 | 234 | 181 | 185 | 188 | 188 | 178 | 178 | 153 | 155 | 251 | 275 | 300 | 304 | 180 | 189 |
| JA35 | 116 | 118 | 234 | 256 | 175 | 183 | 186 | 216 | 176 | 194 | 138 | 155 | 215 | 233 | 304 | 304 | 180 | 189 |
| JA36 | 118 | 150 | 185 | 250 | 175 | 191 | 188 | 190 | 178 | 194 | 141 | 148 | 215 | 275 | 300 | 304 | 180 | 189 |
| JA37 | 116 | 122 | 185 | 247 | 185 | 193 | 186 | 204 | 176 | 194 | 148 | 155 | 275 | 287 | 300 | 304 | 189 | 189 |
| JA38 | 118 | 118 | 234 | 256 | 173 | 193 | 186 | 192 | 178 | 178 | 133 | 141 | 237 | 237 | 304 | 306 | 180 | 186 |
| JA39 | 118 | 118 | 234 | 250 | 185 | 185 | 186 | 198 | 178 | 194 | 141 | 155 | 219 | 275 | 300 | 304 | 186 | 189 |
| JA40 | 118 | 118 | 185 | 185 | 173 | 200 | 186 | 186 | 178 | 178 | 141 | 155 | 209 | 209 | 304 | 304 | 189 | 207 |
| JA41 | 118 | 134 | 185 | 234 | 185 | 193 | 186 | 186 | 176 | 194 | 141 | 155 | 253 | 275 | 300 | 304 | 180 | 189 |
| JA42 | 116 | 116 | 234 | 234 | 173 | 179 | 186 | 186 | 178 | 178 | 155 | 155 | 217 | 275 | 302 | 304 | 180 | 207 |
| JA43 | 118 | 126 | 185 | 241 | 175 | 185 | 188 | 188 | 178 | 194 | 141 | 150 | 233 | 275 | 304 | 304 | 189 | 189 |
| JA44 | 116 | 116 | 234 | 234 | 175 | 175 | 186 | 186 | 178 | 178 | 141 | 158 | 233 | 243 | 300 | 304 | 180 | 207 |
| JA45 | 116 | 116 | 234 | 234 | 175 | 185 | 188 | 188 | 178 | 178 | 141 | 148 | 223 | 275 | 304 | 306 | 186 | 189 |

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| JA46 | 116 | 118 | 234 | 252 | 185 | 197 | 188 | 188 | 178 | 194 | 155 | 155 | 209 | 275 | 304 | 304 | 189 | 189 |
| JA47 | 118 | 132 | 185 | 185 | 173 | 185 | 188 | 188 | 178 | 178 | 141 | 155 | 209 | 233 | 304 | 306 | 180 | 189 |
| JA48 | 114 | 116 | 185 | 330 | 177 | 185 | 188 | 206 | 178 | 178 | 141 | 141 | 209 | 233 | 300 | 304 | 186 | 189 |
| JA49 | 116 | 116 | 234 | 234 | 185 | 215 | 186 | 200 | 178 | 194 | 141 | 146 | 225 | 233 | 304 | 304 | 180 | 186 |
| JA50 | 116 | 116 | 185 | 260 | 185 | 195 | 188 | 188 | 178 | 178 | 141 | 155 | 261 | 275 | 300 | 304 | 189 | 189 |
| JA51 | 118 | 118 | 164 | 185 | 175 | 175 | 186 | 186 | 178 | 194 | 141 | 141 | 215 | 233 | 304 | 304 | 180 | 189 |
| JA52 | 116 | 122 | 234 | 234 | 175 | 179 | 186 | 186 | 178 | 178 | 141 | 148 | 225 | 275 | 304 | 304 | 180 | 186 |
| JA53 | 116 | 152 | 234 | 266 | 175 | 185 | 186 | 186 | 178 | 194 | 155 | 179 | 225 | 233 | 304 | 304 | 180 | 180 |
| JA54 | 116 | 154 | 185 | 254 | 181 | 185 | 188 | 200 | 178 | 194 | 141 | 160 | 209 | 275 | 304 | 304 | 180 | 195 |
| JA55 | 114 | 116 | 234 | 274 | 173 | 185 | 186 | 186 | 178 | 194 | 141 | 148 | 233 | 249 | 304 | 304 | 180 | 183 |
| JA56 | 118 | 122 | 234 | 247 | 175 | 175 | 186 | 186 | 178 | 194 | 148 | 155 | 225 | 275 | 304 | 304 | 180 | 186 |
| JA57 | 118 | 118 | 183 | 234 | 173 | 193 | 188 | 188 | 178 | 194 | 130 | 141 | 209 | 233 | 304 | 304 | 180 | 189 |
| JA58 | 116 | 118 | 234 | 271 | 181 | 185 | 188 | 188 | 178 | 194 | 141 | 143 | 233 | 233 | 300 | 304 | 180 | 180 |
| JA59 | 116 | 148 | 278 | 278 | 195 | 213 | 186 | 186 | 178 | 178 | 148 | 155 | 231 | 255 | 300 | 300 | 186 | 186 |
| JA60 | 118 | 136 | 185 | 185 | 185 | 197 | 186 | 186 | 178 | 194 | 141 | 150 | 233 | 257 | 304 | 304 | 180 | 195 |
| JA61 | 118 | 128 | 234 | 234 | 185 | 185 | 188 | 188 | 178 | 178 | 150 | 155 | 217 | 275 | 304 | 304 | 189 | 189 |
| JA62 | 118 | 118 | 183 | 185 | 185 | 203 | 188 | 188 | 194 | 194 | 141 | 158 | 235 | 275 | 300 | 304 | 189 | 189 |
| JA63 | 116 | 116 | 164 | 185 | 173 | 173 | 186 | 212 | 178 | 194 | 141 | 148 | 245 | 275 | 300 | 304 | 180 | 186 |
| JA64 | 118 | 152 | 220 | 234 | 185 | 195 | 186 | 188 | 178 | 194 | 146 | 155 | 245 | 275 | 300 | 304 | 186 | 189 |
| JA65 | 118 | 124 | 185 | 247 | 173 | 200 | 186 | 186 | 178 | 188 | 141 | 148 | 225 | 233 | 300 | 304 | 180 | 189 |
| JA66 | 118 | 118 | 185 | 247 | 175 | 175 | 182 | 188 | 178 | 178 | 141 | 150 | 217 | 233 | 304 | 304 | 180 | 189 |
| JA67 | 116 | 116 | 234 | 250 | 185 | 185 | 188 | 188 | 178 | 178 | 141 | 148 | 233 | 280 | 296 | 304 | 189 | 195 |
| JA68 | 116 | 158 | 185 | 238 | 175 | 177 | 188 | 188 | 178 | 194 | 148 | 155 | 233 | 275 | 304 | 304 | 180 | 186 |
| JA69 | 116 | 116 | 185 | 316 | 175 | 185 | 188 | 188 | 194 | 194 | 135 | 141 | 261 | 275 | 298 | 304 | 180 | 189 |
| JA70 | 116 | 116 | 183 | 235 | 173 | 183 | 200 | 200 | 178 | 178 | 141 | 141 | 0 | 0 | 296 | 302 | 180 | 189 |
| JA71 | 116 | 124 | 234 | 254 | 173 | 181 | 186 | 190 | 178 | 194 | 141 | 155 | 231 | 275 | 300 | 304 | 186 | 189 |
| JA72 | 116 | 118 | 234 | 328 | 173 | 185 | 188 | 196 | 178 | 178 | 146 | 155 | 215 | 233 | 304 | 304 | 180 | 195 |

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| JA73 | 118 | 158 | 164 | 234 | 173 | 173 | 0 | 0 | 178 | 178 | 143 | 155 | 221 | 231 | 0 | 0 | 180 | 189 |
| JA74 | 116 | 118 | 164 | 234 | 173 | 195 | 186 | 186 | 178 | 178 | 150 | 155 | 275 | 275 | 300 | 304 | 189 | 189 |
| JA75 | 116 | 118 | 220 | 234 | 175 | 175 | 186 | 186 | 178 | 178 | 141 | 158 | 231 | 275 | 300 | 304 | 180 | 189 |
| JA76 | 118 | 122 | 234 | 278 | 187 | 187 | 186 | 186 | 178 | 178 | 155 | 158 | 233 | 253 | 300 | 304 | 180 | 186 |
| JA77 | 116 | 118 | 164 | 185 | 185 | 215 | 186 | 214 | 170 | 194 | 141 | 153 | 217 | 233 | 304 | 304 | 180 | 186 |
| JA78 | 116 | 116 | 164 | 185 | 181 | 185 | 186 | 216 | 180 | 194 | 141 | 153 | 233 | 253 | 300 | 304 | 186 | 189 |
| JA79 | 116 | 118 | 185 | 214 | 173 | 185 | 186 | 202 | 178 | 178 | 148 | 155 | 257 | 275 | 304 | 304 | 189 | 189 |
| JA80 | 116 | 118 | 185 | 185 | 173 | 220 | 186 | 186 | 180 | 194 | 141 | 155 | 223 | 233 | 304 | 306 | 180 | 189 |
| JA81 | 136 | 136 | 164 | 164 | 173 | 177 | 186 | 186 | 170 | 176 | 148 | 153 | 223 | 229 | 300 | 304 | 180 | 189 |
| JA82 | 118 | 126 | 186 | 186 | 173 | 195 | 186 | 186 | 178 | 194 | 155 | 179 | 229 | 233 | 300 | 304 | 180 | 189 |

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| sapling | FEM 4a | FEM 4b | FEM 10a | FEM 10b | FEM 11a | FEM 11b | FEM 12a | FEM 12b | FEM 16a | FEM 16b | FEM 19a | FEM 19b | M230 a | M230 b | FR 63a | FR 63b | FR 64a | FR 64b |
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| SJ1 | 114 | 114 | 164 | 330 | 173 | 195 | 188 | 188 | 178 | 178 | 148 | 153 | 231 | 247 | 304 | 304 | 186 | 195 |
| SJ2 | 118 | 118 | 185 | 266 | 177 | 193 | 200 | 200 | 178 | 178 | 150 | 150 | 219 | 265 | 300 | 300 | 189 | 192 |
| SJ3 | 116 | 118 | 183 | 186 | 183 | 193 | 184 | 200 | 178 | 178 | 150 | 158 | 235 | 235 | 300 | 304 | 189 | 189 |
| SJ4 | 116 | 122 | 220 | 234 | 173 | 173 | 186 | 186 | 180 | 194 | 150 | 158 | 213 | 249 | 304 | 304 | 186 | 189 |
| SJ6 | 116 | 126 | 220 | 233 | 181 | 195 | 200 | 202 | 178 | 194 | 146 | 153 | 233 | 237 | 304 | 306 | 180 | 186 |
| SJ7 | 116 | 124 | 233 | 245 | 179 | 195 | 196 | 196 | 178 | 178 | 130 | 153 | 237 | 251 | 300 | 304 | 186 | 189 |
| SJ8 | 122 | 144 | 226 | 238 | 173 | 173 | 214 | 214 | 178 | 178 | 148 | 153 | 233 | 233 | 300 | 306 | 186 | 195 |
| SJ9 | 116 | 116 | 164 | 164 | 173 | 183 | 188 | 212 | 178 | 178 | 150 | 150 | 209 | 235 | 304 | 310 | 186 | 189 |
| SJ10 | 116 | 116 | 164 | 183 | 175 | 185 | 200 | 200 | 178 | 178 | 141 | 153 | 247 | 253 | 300 | 304 | 189 | 189 |
| SJ11 | 126 | 148 | 183 | 342 | 173 | 173 | 186 | 186 | 178 | 188 | 143 | 153 | 225 | 233 | 300 | 304 | 189 | 189 |
| SJ12 | 116 | 122 | 235 | 247 | 183 | 189 | 188 | 188 | 188 | 194 | 146 | 153 | 229 | 247 | 300 | 300 | 186 | 189 |
| SJ13 | 118 | 118 | 194 | 230 | 173 | 185 | 204 | 204 | 178 | 180 | 148 | 148 | 213 | 272 | 306 | 306 | 180 | 189 |

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| SJ14 | 116 | 116 | 164 | 332 | 175 | 189 | 186 | 186 | 188 | 194 | 141 | 153 | 233 | 247 | 304 | 308 | 189 | 189 |
| SJ16 | 128 | 128 | 186 | 266 | 209 | 215 | 202 | 202 | 178 | 178 | 130 | 179 | 237 | 251 | 300 | 304 | 186 | 189 |
| SJ17 | 116 | 116 | 164 | 233 | 185 | 195 | 200 | 200 | 188 | 194 | 148 | 153 | 225 | 245 | 300 | 304 | 186 | 186 |
| SJ18 | 116 | 118 | 233 | 247 | 181 | 193 | 190 | 202 | 194 | 194 | 141 | 148 | 215 | 275 | 304 | 306 | 186 | 195 |
| SJ19 | 116 | 118 | 186 | 235 | 181 | 226 | 186 | 186 | 178 | 180 | 148 | 148 | 233 | 272 | 300 | 304 | 189 | 192 |
| SJ21 | 116 | 120 | 164 | 260 | 173 | 183 | 200 | 202 | 178 | 178 | 130 | 130 | 207 | 280 | 300 | 306 | 186 | 186 |
| SJ22 | 116 | 132 | 186 | 247 | 173 | 195 | 200 | 200 | 178 | 194 | 150 | 155 | 237 | 283 | 300 | 304 | 186 | 189 |
| SJ23 | 116 | 122 | 260 | 310 | 173 | 195 | 186 | 186 | 178 | 188 | 150 | 158 | 227 | 251 | 300 | 300 | 189 | 189 |
| SJ24 | 142 | 142 | 186 | 234 | 173 | 173 | 204 | 212 | 180 | 180 | 150 | 150 | 255 | 272 | 300 | 306 | 186 | 189 |
| SJ25 | 116 | 116 | 183 | 258 | 195 | 195 | 198 | 198 | 178 | 194 | 148 | 155 | 227 | 280 | 300 | 310 | 186 | 192 |
| SJ26 | 116 | 122 | 258 | 258 | 183 | 183 | 188 | 188 | 178 | 178 | 148 | 150 | 207 | 213 | 300 | 304 | 186 | 186 |
| SJ27 | 118 | 126 | 184 | 220 | 175 | 215 | 198 | 198 | 178 | 178 | 148 | 150 | 209 | 219 | 300 | 300 | 186 | 189 |
| SJ28 | 118 | 122 | 0 | 0 | 195 | 195 | 0 | 0 | 178 | 178 | 146 | 148 | 194 | 194 | 304 | 306 | 186 | 195 |
| SJ29 | 116 | 116 | 226 | 235 | 175 | 175 | 202 | 202 | 194 | 194 | 148 | 148 | 209 | 223 | 304 | 304 | 189 | 195 |
| SJ30 | 116 | 152 | 184 | 184 | 183 | 183 | 200 | 200 | 178 | 178 | 148 | 150 | 272 | 283 | 298 | 310 | 186 | 189 |
| SJ31 | 116 | 148 | 185 | 185 | 195 | 195 | 0 | 0 | 178 | 188 | 130 | 150 | 233 | 283 | 300 | 310 | 186 | 186 |
| SJ34 | 122 | 144 | 164 | 183 | 173 | 195 | 184 | 184 | 178 | 178 | 153 | 158 | 209 | 263 | 300 | 306 | 189 | 189 |
| SJ35 | 118 | 122 | 184 | 184 | 179 | 226 | 186 | 186 | 178 | 180 | 148 | 148 | 280 | 289 | 300 | 300 | 186 | 189 |
| SJ36 | 116 | 116 | 183 | 332 | 175 | 195 | 200 | 200 | 178 | 188 | 146 | 158 | 225 | 225 | 300 | 300 | 186 | 189 |
| SJ37 | 134 | 148 | 183 | 330 | 175 | 193 | 182 | 200 | 178 | 188 | 138 | 150 | 231 | 247 | 300 | 304 | 180 | 207 |
| SJ38 | 120 | 128 | 180 | 185 | 175 | 195 | 186 | 186 | 178 | 178 | 141 | 150 | 245 | 251 | 300 | 304 | 180 | 189 |
| SJ39 | 142 | 152 | 180 | 180 | 0 | 0 | 0 | 0 | 178 | 180 | 150 | 155 | 229 | 233 | 304 | 310 | 186 | 186 |
| SJ40 | 118 | 138 | 164 | 185 | 181 | 209 | 198 | 198 | 178 | 178 | 130 | 155 | 209 | 229 | 300 | 304 | 189 | 189 |
| SJ41 | 118 | 124 | 164 | 185 | 173 | 191 | 204 | 204 | 178 | 178 | 135 | 138 | 207 | 207 | 300 | 308 | 183 | 186 |
| SJ42 | 116 | 118 | 212 | 235 | 187 | 226 | 186 | 186 | 178 | 180 | 143 | 148 | 209 | 272 | 300 | 304 | 186 | 192 |
| SJ43 | 116 | 128 | 183 | 214 | 173 | 173 | 200 | 200 | 178 | 180 | 141 | 185 | 245 | 249 | 304 | 304 | 189 | 195 |
| SJ44 | 116 | 124 | 164 | 183 | 183 | 187 | 200 | 204 | 178 | 180 | 153 | 179 | 227 | 247 | 300 | 300 | 186 | 195 |

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| SJ45 | 116 | 142 | 185 | 330 | 175 | 175 | 190 | 190 | 178 | 180 | 158 | 158 | 213 | 225 | 300 | 306 | 186 | 189 |
| SJ46 | 114 | 116 | 164 | 234 | 181 | 181 | 202 | 202 | 180 | 194 | 148 | 153 | 237 | 245 | 300 | 306 | 180 | 186 |
| SJ47 | 118 | 142 | 186 | 235 | 183 | 226 | 190 | 190 | 180 | 180 | 158 | 158 | 272 | 280 | 300 | 306 | 180 | 192 |
| SJ48 | 118 | 122 | 183 | 185 | 181 | 226 | 186 | 186 | 178 | 178 | 141 | 148 | 251 | 280 | 300 | 300 | 189 | 192 |
| SJ49 | 116 | 148 | 330 | 330 | 175 | 195 | 200 | 200 | 178 | 178 | 130 | 150 | 225 | 247 | 300 | 304 | 189 | 195 |
| SJ50 | 116 | 148 | 310 | 310 | 195 | 195 | 186 | 186 | 178 | 178 | 130 | 141 | 225 | 233 | 300 | 308 | 189 | 195 |
| SJ51 | 128 | 148 | 230 | 330 | 173 | 189 | 186 | 214 | 178 | 178 | 130 | 153 | 245 | 255 | 300 | 308 | 189 | 189 |
| SJ53 | 134 | 148 | 271 | 271 | 195 | 195 | 200 | 200 | 178 | 188 | 146 | 153 | 225 | 243 | 300 | 304 | 186 | 186 |
| SJ54 | 116 | 122 | 238 | 238 | 183 | 209 | 188 | 204 | 178 | 178 | 146 | 150 | 229 | 233 | 304 | 306 | 186 | 189 |
| SJ56 | 118 | 134 | 185 | 230 | 173 | 193 | 182 | 190 | 178 | 178 | 148 | 153 | 213 | 225 | 304 | 306 | 189 | 207 |
| SJ57 | 114 | 122 | 186 | 238 | 173 | 209 | 186 | 202 | 178 | 178 | 148 | 148 | 237 | 251 | 300 | 304 | 189 | 195 |
| SJ59 | 116 | 116 | 185 | 243 | 179 | 183 | 204 | 204 | 178 | 178 | 148 | 158 | 225 | 283 | 304 | 304 | 189 | 189 |
| SJ60 | 144 | 144 | 164 | 220 | 195 | 195 | 0 | 0 | 178 | 180 | 150 | 158 | 233 | 263 | 300 | 300 | 189 | 195 |
| SJ61 | 114 | 116 | 238 | 264 | 175 | 175 | 186 | 204 | 178 | 178 | 138 | 150 | 233 | 233 | 304 | 308 | 186 | 186 |
| SJ62 | 116 | 122 | 233 | 238 | 173 | 183 | 202 | 202 | 178 | 178 | 130 | 158 | 241 | 255 | 304 | 304 | 180 | 189 |
| SJ63 | 114 | 116 | 180 | 183 | 175 | 183 | 212 | 214 | 178 | 178 | 138 | 141 | 217 | 243 | 300 | 306 | 186 | 186 |
| SJ64 | 116 | 116 | 164 | 238 | 181 | 195 | 186 | 186 | 178 | 180 | 141 | 148 | 209 | 247 | 300 | 304 | 189 | 195 |
| SJ65 | 126 | 148 | 180 | 185 | 181 | 193 | 200 | 200 | 178 | 178 | 150 | 185 | 233 | 265 | 300 | 304 | 180 | 192 |
| SJ66 | 118 | 118 | 186 | 220 | 181 | 195 | 188 | 188 | 178 | 180 | 148 | 148 | 209 | 265 | 300 | 304 | 189 | 189 |
| SJ67 | 116 | 160 | 235 | 247 | 185 | 197 | 182 | 182 | 178 | 178 | 148 | 171 | 233 | 233 | 296 | 300 | 192 | 195 |
| SJ68 | 114 | 118 | 186 | 254 | 181 | 207 | 200 | 200 | 178 | 178 | 141 | 148 | 209 | 233 | 300 | 300 | 186 | 192 |
| SJ69 | 118 | 122 | 183 | 186 | 183 | 193 | 200 | 204 | 178 | 194 | 148 | 148 | 233 | 287 | 300 | 304 | 186 | 189 |
| SJ70 | 122 | 148 | 278 | 285 | 177 | 183 | 186 | 186 | 178 | 178 | 153 | 153 | 233 | 255 | 300 | 306 | 180 | 186 |
| SJ71 | 116 | 122 | 235 | 235 | 175 | 185 | 182 | 196 | 178 | 178 | 146 | 150 | 231 | 267 | 296 | 304 | 186 | 192 |
| SJ72 | 116 | 118 | 186 | 220 | 193 | 230 | 204 | 204 | 178 | 178 | 148 | 158 | 251 | 265 | 300 | 300 | 189 | 189 |
| SJ73 | 114 | 134 | 183 | 186 | 173 | 195 | 200 | 200 | 178 | 188 | 135 | 153 | 217 | 225 | 300 | 300 | 186 | 195 |
| SJ74 | 118 | 118 | 226 | 226 | 183 | 197 | 204 | 204 | 178 | 178 | 150 | 158 | 233 | 233 | 300 | 304 | 195 | 195 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SJ75 | 134 | 142 | 164 | 180 | 177 | 177 | 186 | 186 | 178 | 178 | 130 | 148 | 217 | 229 | 300 | 308 | 186 | 189 |
| SJ76 | 148 | 170 | 226 | 226 | 173 | 195 | 200 | 200 | 178 | 188 | 150 | 153 | 225 | 233 | 300 | 304 | 195 | 195 |
| SJ77 | 148 | 148 | 212 | 212 | 195 | 195 | 182 | 182 | 178 | 178 | 130 | 141 | 233 | 237 | 300 | 300 | 180 | 195 |
| SJ78 | 116 | 128 | 184 | 186 | 195 | 209 | 200 | 200 | 178 | 178 | 148 | 150 | 209 | 255 | 300 | 300 | 180 | 189 |
| SJ79 | 116 | 148 | 164 | 164 | 183 | 195 | 184 | 200 | 188 | 192 | 153 | 153 | 225 | 243 | 300 | 300 | 186 | 189 |
| SJ80 | 118 | 118 | 184 | 184 | 179 | 195 | 200 | 200 | 180 | 188 | 141 | 158 | 225 | 247 | 298 | 300 | 189 | 189 |
| | | | | | | | | | | | | | | | | | | |
| tree | FEM 4a | FEM 4b | FEM 10a | FEM 10b | FEM 11a | FEM 11b | FEM 12a | FEM 12b | FEM 16a | FEM 16b | FEM 19a | FEM 19b | M230 a | M230 b | FR 63a | FR 63b | FR 64a | FR 64b |
| SA1 | 122 | 148 | 184 | 186 | 175 | 195 | 200 | 202 | 178 | 178 | 141 | 169 | 225 | 257 | 300 | 300 | 189 | 189 |
| SA2 | 116 | 116 | 183 | 233 | 175 | 183 | 202 | 202 | 178 | 188 | 141 | 155 | 225 | 249 | 300 | 304 | 180 | 189 |
| SA3 | 122 | 148 | 186 | 330 | 175 | 181 | 200 | 214 | 0 | 0 | 143 | 160 | 231 | 247 | 300 | 304 | 0 | 0 |
| SA4 | 118 | 122 | 226 | 235 | 175 | 175 | 0 | 0 | 0 | 0 | 150 | 155 | 233 | 251 | 300 | 300 | 0 | 0 |
| SA5 | 116 | 116 | 330 | 330 | 181 | 195 | 186 | 186 | 188 | 192 | 148 | 153 | 225 | 231 | 300 | 304 | 186 | 189 |
| SA6 | 116 | 148 | 334 | 334 | 185 | 195 | 190 | 190 | 178 | 188 | 141 | 153 | 247 | 267 | 300 | 306 | 189 | 189 |
| SA7 | 124 | 148 | 183 | 183 | 175 | 207 | 186 | 186 | 188 | 194 | 141 | 141 | 247 | 267 | 300 | 304 | 186 | 207 |
| SA8 | 116 | 148 | 233 | 330 | 181 | 191 | 200 | 200 | 178 | 188 | 141 | 153 | 225 | 237 | 300 | 306 | 180 | 189 |
| SA9 | 116 | 148 | 164 | 183 | 175 | 195 | 200 | 200 | 188 | 188 | 153 | 179 | 209 | 247 | 300 | 306 | 186 | 186 |
| SA10 | 116 | 116 | 164 | 183 | 173 | 193 | 200 | 200 | 178 | 188 | 141 | 163 | 243 | 247 | 300 | 304 | 186 | 186 |
| SA11 | 116 | 118 | 164 | 224 | 181 | 189 | 214 | 214 | 178 | 178 | 148 | 148 | 217 | 223 | 300 | 306 | 180 | 186 |
| SA12 | 118 | 148 | 183 | 280 | 191 | 195 | 200 | 206 | 178 | 188 | 141 | 141 | 219 | 247 | 298 | 300 | 186 | 207 |
| SA13 | 116 | 118 | 164 | 185 | 183 | 195 | 212 | 212 | 178 | 178 | 150 | 155 | 209 | 257 | 300 | 310 | 186 | 189 |
| SA14 | 148 | 148 | 164 | 183 | 175 | 195 | 212 | 212 | 178 | 188 | 153 | 169 | 225 | 225 | 300 | 300 | 189 | 189 |
| SA15 | 116 | 118 | 183 | 183 | 177 | 177 | 186 | 200 | 180 | 188 | 153 | 160 | 215 | 247 | 300 | 304 | 186 | 186 |
| SA16 | 116 | 118 | 183 | 234 | 177 | 177 | 202 | 212 | 178 | 178 | 148 | 148 | 209 | 233 | 300 | 306 | 186 | 189 |
| SA17 | 116 | 116 | 183 | 185 | 181 | 195 | 200 | 200 | 178 | 194 | 148 | 150 | 283 | 283 | 304 | 310 | 186 | 189 |
| SA18 | 116 | 116 | 183 | 226 | 175 | 195 | 204 | 212 | 178 | 178 | 150 | 160 | 209 | 219 | 300 | 300 | 186 | 189 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SA19 | 116 | 126 | 185 | 185 | 175 | 175 | 198 | 212 | 178 | 178 | 148 | 150 | 209 | 243 | 300 | 300 | 186 | 189 |
| SA21 | 116 | 154 | 185 | 238 | 173 | 195 | 200 | 212 | 178 | 178 | 148 | 158 | 237 | 280 | 308 | 310 | 186 | 195 |
| SA22 | 116 | 124 | 183 | 214 | 179 | 195 | 200 | 202 | 178 | 178 | 153 | 185 | 225 | 283 | 300 | 304 | 180 | 189 |
| SA23 | 116 | 132 | 183 | 330 | 175 | 179 | 200 | 200 | 178 | 178 | 141 | 160 | 211 | 247 | 300 | 304 | 189 | 195 |
| SA24 | 130 | 140 | 164 | 189 | 181 | 183 | 182 | 188 | 178 | 178 | 158 | 158 | 194 | 227 | 304 | 304 | 186 | 189 |
| SA25 | 116 | 122 | 238 | 334 | 175 | 195 | 214 | 214 | 180 | 188 | 153 | 153 | 225 | 225 | 300 | 306 | 189 | 189 |
| SA26 | 128 | 128 | 185 | 238 | 175 | 209 | 186 | 186 | 178 | 178 | 130 | 148 | 251 | 255 | 300 | 300 | 180 | 189 |
| SA27 | 116 | 118 | 185 | 185 | 173 | 195 | 200 | 200 | 178 | 178 | 148 | 148 | 209 | 213 | 300 | 304 | 186 | 189 |
| SA28 | 116 | 116 | 183 | 226 | 175 | 195 | 200 | 200 | 178 | 178 | 130 | 150 | 209 | 237 | 300 | 310 | 186 | 189 |
| SA29 | 116 | 122 | 238 | 334 | 175 | 195 | 214 | 214 | 180 | 188 | 153 | 153 | 225 | 225 | 300 | 306 | 189 | 189 |
| SA30 | 116 | 116 | 310 | 330 | 175 | 195 | 186 | 186 | 178 | 178 | 141 | 158 | 225 | 251 | 300 | 308 | 186 | 189 |
| SA31 | 116 | 148 | 330 | 338 | 195 | 195 | 186 | 264 | 188 | 188 | 141 | 153 | 225 | 259 | 300 | 304 | 186 | 189 |
| SA32 | 116 | 148 | 247 | 330 | 175 | 189 | 214 | 214 | 178 | 188 | 150 | 153 | 247 | 247 | 300 | 308 | 186 | 189 |
| SA33 | 116 | 118 | 164 | 233 | 181 | 185 | 202 | 202 | 178 | 194 | 148 | 158 | 245 | 272 | 304 | 306 | 180 | 186 |
| SA34 | 114 | 148 | 330 | 330 | 195 | 195 | 200 | 200 | 178 | 188 | 130 | 153 | 225 | 233 | 300 | 300 | 186 | 195 |
| SA35 | 116 | 116 | 164 | 338 | 183 | 205 | 184 | 184 | 178 | 192 | 148 | 153 | 225 | 243 | 300 | 306 | 189 | 189 |
| SA36 | 114 | 134 | 183 | 185 | 175 | 193 | 182 | 188 | 178 | 178 | 138 | 153 | 209 | 225 | 304 | 304 | 186 | 207 |
| SA37 | 114 | 148 | 220 | 328 | 175 | 181 | 200 | 200 | 176 | 188 | 141 | 150 | 237 | 247 | 300 | 300 | 180 | 189 |
| SA38 | 116 | 148 | 183 | 183 | 175 | 179 | 182 | 182 | 178 | 178 | 150 | 160 | 247 | 255 | 300 | 304 | 186 | 189 |
| SA39 | 116 | 128 | 230 | 230 | 173 | 187 | 186 | 186 | 178 | 178 | 130 | 148 | 255 | 267 | 300 | 304 | 189 | 189 |
| SA40 | 116 | 122 | 235 | 278 | 183 | 209 | 188 | 188 | 178 | 194 | 146 | 158 | 229 | 237 | 300 | 300 | 189 | 195 |
| SA41 | 116 | 116 | 164 | 185 | 183 | 191 | 202 | 202 | 178 | 194 | 141 | 153 | 209 | 249 | 300 | 304 | 186 | 186 |
| SA42 | 122 | 148 | 183 | 245 | 183 | 195 | 200 | 200 | 178 | 188 | 143 | 143 | 225 | 233 | 300 | 300 | 180 | 189 |
| SA43 | 116 | 116 | 226 | 238 | 173 | 183 | 204 | 204 | 178 | 178 | 150 | 150 | 233 | 233 | 306 | 306 | 186 | 195 |
| SA44 | 116 | 118 | 183 | 234 | 179 | 195 | 190 | 200 | 180 | 188 | 141 | 158 | 225 | 233 | 298 | 300 | 186 | 189 |
| SA45 | 118 | 118 | 186 | 186 | 181 | 193 | 200 | 200 | 178 | 178 | 148 | 150 | 233 | 265 | 300 | 300 | 189 | 192 |
| SA46 | 116 | 148 | 185 | 234 | 183 | 187 | 182 | 182 | 178 | 178 | 148 | 150 | 231 | 231 | 296 | 304 | 189 | 192 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SA47 | 126 | 128 | 183 | 183 | 179 | 193 | 190 | 202 | 178 | 178 | 143 | 143 | 209 | 227 | 304 | 304 | 189 | 189 |
| SA48 | 116 | 118 | 183 | 264 | 175 | 195 | 186 | 186 | 178 | 188 | 135 | 141 | 251 | 251 | 300 | 300 | 189 | 207 |
| SA49 | 116 | 118 | 183 | 235 | 175 | 226 | 200 | 200 | 178 | 180 | 148 | 158 | 272 | 280 | 300 | 300 | 186 | 192 |
| SA50 | 122 | 122 | 238 | 238 | 173 | 209 | 188 | 188 | 178 | 188 | 130 | 158 | 237 | 255 | 300 | 304 | 180 | 180 |
| SA51 | 112 | 116 | 183 | 266 | 175 | 175 | 206 | 258 | 178 | 178 | 141 | 150 | 237 | 280 | 300 | 316 | 186 | 186 |
| SA52 | 116 | 122 | 183 | 185 | 183 | 195 | 200 | 202 | 178 | 188 | 141 | 146 | 225 | 261 | 300 | 300 | 189 | 189 |
| SA53 | 118 | 142 | 185 | 226 | 173 | 197 | 188 | 214 | 178 | 194 | 153 | 185 | 217 | 225 | 304 | 306 | 186 | 189 |

## Appendix E:

Supplementary table 3: Results of maternity analysis for Johannser Kogel (A), Siegenfeld (B) and parent-pair analysis for Johannser Kogel (C), Siegenfeld (D)

A

| sapling | NE-P1 | p1 | loci-mm | Pair LOD | Pair Delta | Pair conf. |
|---|---|---|---|---|---|---|
| JJ1 | 1.08E-03 | JA18 | 1 | -1.02 | 0.00 | |
| JJ2 | 8.91E-04 | JA45 | 2 | -3.56 | 0.00 | |
| JJ3 | 3.29E-05 | JA16 | 2 | -1.45 | 0.00 | |
| JJ4 | 2.49E-03 | JA58 | 1 | -0.62 | 0.00 | |
| JJ5 | 4.18E-03 | JA58 | 1 | -1.61 | 0.00 | |
| JJ6 | 5.05E-09 | JA29 | 3 | -5.63 | 0.00 | |
| JJ7 | 9.03E-05 | JA80 | 2 | -3.54 | 0.00 | |
| JJ8 | 2.74E-05 | JA16 | 3 | -7.97 | 0.00 | |
| JJ9 | 3.98E-03 | JA82 | 0 | 5.61 | 5.61 | * |
| JJ10 | 3.92E-03 | JA56 | 1 | -1.13 | 0.00 | |
| JJ11 | 7.31E-04 | JA18 | 1 | -0.12 | 0.00 | |
| JJ12 | 4.69E-03 | JA82 | 1 | -1.70 | 0.00 | |
| JJ13 | 4.34E-05 | JA36 | 2 | -4.65 | 0.00 | |
| JJ14 | 2.63E-04 | JA51 | 2 | -2.95 | 0.00 | |

B

| sapling | NE-P1 | p1 | loci-mm | Pair LOD | Pair Delta | Pair conf. |
|---|---|---|---|---|---|---|
| SJ1 | 7.67E-05 | SA34 | 3 | -5.17 | 0.00 | |
| SJ2 | 4.67E-05 | SA45 | 1 | 7.10 | 7.10 | * |
| SJ3 | 2.95E-04 | SA45 | 1 | 2.37 | 2.37 | * |
| SJ4 | 2.85E-05 | SA41 | 4 | -10.50 | 0.00 | |
| SJ6 | 1.07E-03 | SA8 | 0 | 6.09 | 5.89 | * |
| SJ7 | 3.58E-05 | SA28 | 2 | -4.66 | 0.00 | |
| SJ8 | 8.13E-05 | SA53 | 2 | -1.95 | 0.00 | |
| SJ9 | 2.59E-04 | SA13 | 0 | 9.83 | 9.83 | * |
| SJ10 | 2.13E-03 | SA23 | 0 | 5.10 | 5.10 | * |
| SJ11 | 5.54E-04 | SA42 | 2 | -1.55 | 0.00 | |
| SJ12 | 6.38E-05 | SA40 | 0 | 11.81 | 8.11 | * |
| SJ13 | 3.49E-06 | SA33 | 2 | -0.05 | 0.00 | |
| SJ14 | 3.49E-04 | SA32 | 2 | -0.09 | 0.00 | |
| SJ16 | 4.36E-06 | SA26 | 2 | 0.20 | 0.20 | * |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JJ15 | 1.47E-03 | JA80 | 1 | 0.53 | 0.53 | + | SJ17 | 1.26E-03 | SA33 | 1 | 4.80 | 4.17 | * |
| JJ16 | 2.29E-03 | JA80 | 1 | -2.02 | 0.00 | | SJ18 | 4.16E-06 | SA33 | 1 | 4.54 | 4.54 | * |
| JJ17 | 2.01E-04 | JA80 | 1 | 0.51 | 0.51 | + | SJ19 | 7.49E-04 | SA49 | 1 | 6.42 | 3.20 | * |
| JJ18 | 1.35E-05 | JA82 | 0 | 12.48 | 12.48 | * | SJ21 | 1.82E-04 | SA41 | 2 | -4.16 | 0.00 | |
| JJ19 | 3.75E-03 | JA34 | 0 | 6.11 | 2.77 | * | SJ22 | 1.39E-03 | SA17 | 1 | 2.47 | 2.47 | * |
| JJ20 | 6.61E-04 | JA81 | 3 | -1.43 | 0.00 | | SJ23 | 1.87E-04 | SA30 | 0 | 7.28 | 7.28 | * |
| JJ21 | 1.19E-05 | JA54 | 0 | 9.45 | 9.45 | * | SJ24 | 3.01E-06 | SA43 | 4 | -9.42 | 0.00 | |
| JJ22 | 6.95E-04 | JA54 | 2 | 0.95 | 0.95 | + | SJ25 | 8.43E-05 | SA17 | 2 | -2.52 | 0.00 | |
| JJ23 | 8.09E-04 | JA51 | 2 | -4.18 | 0.00 | | SJ26 | 1.14E-05 | SA27 | 3 | -7.80 | 0.00 | |
| JJ24 | 1.42E-03 | JA82 | 1 | -1.48 | 0.00 | | SJ27 | 5.18E-05 | SA19 | 1 | 5.83 | 5.83 | * |
| JJ25 | 7.72E-03 | JA57 | 1 | 1.02 | 0.23 | + | SJ28 | 6.78E-04 | SA27 | 1 | -1.74 | 0.00 | |
| JJ26 | 7.06E-06 | JA71 | 0 | 10.26 | 10.26 | * | SJ29 | 1.91E-05 | SA41 | 4 | -8.83 | 0.00 | |
| JJ27 | 3.94E-04 | JA72 | 2 | -2.76 | 0.00 | | SJ30 | 2.80E-05 | SA17 | 2 | -0.52 | 0.00 | |
| JJ28 | 3.17E-03 | JA64 | 0 | 4.80 | 4.80 | * | SJ31 | 2.64E-03 | SA17 | 0 | 7.36 | 5.97 | * |
| JJ29 | 1.13E-02 | JA46 | 0 | 5.92 | 5.71 | * | SJ34 | 1.07E-04 | SA35 | 3 | -5.19 | 0.00 | |
| JJ30 | 2.20E-03 | JA72 | 1 | 0.29 | 0.29 | + | SJ35 | 2.19E-05 | SA49 | 2 | -0.66 | 0.00 | |
| JJ31 | 6.57E-04 | JA50 | 0 | 10.78 | 10.78 | * | SJ36 | 2.48E-03 | SA52 | 0 | 6.16 | 1.75 | * |
| JJ32 | 2.11E-05 | JA64 | 2 | -2.84 | 0.00 | | SJ37 | 3.03E-04 | SA36 | 1 | 7.35 | 5.20 | * |
| JJ33 | 2.87E-04 | JA65 | 2 | -3.73 | 0.00 | | SJ38 | 1.88E-04 | SA26 | 1 | 4.89 | 4.89 | * |
| JJ34 | 1.42E-03 | JA14 | 0 | 4.09 | 2.79 | * | SJ39 | 8.81E-05 | SA13 | 3 | -7.38 | 0.00 | |
| JJ35 | 3.05E-05 | JA14 | 3 | -6.16 | 0.00 | | SJ40 | 2.70E-05 | SA13 | 2 | -2.60 | 0.00 | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JJ36 | 4.05E-05 | JA73 | 3 | -4.03 | 0.00 | | SJ41 | 3.59E-06 | SA27 | 3 | -9.55 | 0.00 | |
| JJ37 | 1.54E-03 | JA22 | 0 | 4.19 | 4.19 | * | SJ42 | 1.10E-04 | SA49 | 1 | 5.88 | 5.88 | * |
| JJ38 | 1.44E-04 | JA5 | 2 | -2.40 | 0.00 | | SJ43 | 1.60E-04 | SA22 | 2 | -1.67 | 0.00 | |
| JJ39 | 3.53E-06 | JA65 | 3 | -7.16 | 0.00 | | SJ44 | 1.25E-03 | SA15 | 1 | -0.43 | 0.00 | |
| JJ40 | 1.88E-04 | JA64 | 0 | 8.52 | 8.52 | * | SJ45 | 1.93E-04 | SA30 | 1 | 0.37 | 0.37 | * |
| JJ41 | 5.09E-03 | JA71 | 0 | 5.35 | 3.78 | * | SJ46 | 7.53E-05 | SA33 | 0 | 10.30 | 10.30 | * |
| JJ42 | 2.57E-03 | JA63 | 1 | 3.05 | 3.05 | * | SJ47 | 1.40E-06 | SA49 | 1 | 8.07 | 8.07 | * |
| JJ43 | 4.44E-04 | JA43 | 0 | 6.63 | 6.63 | * | SJ48 | 5.32E-04 | SA49 | 1 | 3.44 | 1.81 | * |
| JJ44 | 3.81E-04 | JA62 | 1 | 5.31 | 4.67 | * | SJ49 | 2.95E-03 | SA34 | 0 | 7.98 | 5.68 | * |
| JJ45 | 1.23E-02 | JA52 | 1 | 0.53 | 0.31 | + | SJ50 | 2.59E-04 | SA30 | 0 | 9.40 | 9.40 | * |
| JJ46 | 1.37E-02 | JA1 | 0 | 1.30 | 0.34 | + | SJ51 | 1.16E-04 | SA39 | 0 | 10.47 | 5.32 | * |
| JJ47 | 3.90E-03 | JA42 | 1 | 1.26 | 1.26 | + | SJ53 | 4.37E-05 | SA34 | 1 | 1.70 | 1.70 | * |
| JJ48 | 4.39E-04 | JA77 | 1 | 0.75 | 0.75 | + | SJ54 | 3.00E-04 | SA43 | 0 | 9.19 | 8.20 | * |
| JJ49 | 1.57E-05 | JA72 | 3 | -7.56 | 0.00 | | SJ56 | 2.83E-04 | SA36 | 0 | 10.71 | 8.85 | * |
| JJ50 | 3.30E-03 | JA19 | 1 | 0.21 | 0.21 | + | SJ57 | 4.14E-04 | SA26 | 1 | 2.99 | 2.99 | * |
| JJ51 | 5.40E-03 | JA23 | 0 | 1.48 | 0.86 | + | SJ59 | 2.01E-04 | SA17 | 2 | -2.37 | 0.00 | |
| JJ52 | 7.75E-06 | JA59 | 4 | -9.74 | 0.00 | | SJ60 | 1.91E-04 | SA44 | 2 | -4.95 | 0.00 | |
| JJ53 | 3.87E-06 | JA16 | 4 | -12.35 | 0.00 | | SJ61 | 2.20E-04 | SA43 | 2 | -0.22 | 0.00 | |
| JJ54 | 2.19E-05 | JA55 | 3 | -8.22 | 0.00 | | SJ62 | 7.18E-05 | SA50 | 1 | 6.28 | 6.28 | * |
| JJ55 | 1.96E-03 | JA30 | 0 | 3.87 | 1.54 | + | SJ63 | 1.98E-04 | SA19 | 2 | -2.33 | 0.00 | |
| JJ56 | 2.56E-04 | JA71 | 1 | 1.36 | 1.36 | + | SJ64 | 3.47E-03 | SA30 | 2 | -5.78 | 0.00 | |

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|---|---|---|---|---|---|---|
| JJ57 | 1.51E-04 | JA36 | 2 | -4.41 | 0.00 | |
| JJ58 | 2.49E-05 | JA19 | 2 | -4.59 | 0.00 | |
| JJ59 | 3.59E-06 | JA45 | 4 | -12.10 | 0.00 | |
| JJ60 | 9.61E-03 | JA54 | 0 | 8.19 | 8.19 | * |
| JJ61 | 1.82E-03 | JA60 | 0 | 8.36 | 8.36 | * |
| JJ62 | 9.03E-05 | JA60 | 1 | 4.80 | 1.36 | + |
| JJ63 | 6.12E-03 | JA24 | 0 | 4.63 | 0.41 | + |
| JJ64 | 1.18E-03 | JA39 | 1 | 1.94 | 1.25 | + |
| JJ65 | 1.06E-03 | JA47 | 1 | 0.49 | 0.49 | + |
| JJ66 | 8.63E-04 | JA19 | 1 | -0.45 | 0.00 | |
| JJ67 | 7.42E-04 | JA32 | 2 | -1.34 | 0.00 | |
| JJ68 | 9.91E-06 | JA20 | 1 | 5.48 | 5.48 | * |
| JJ69 | 2.76E-03 | JA15 | 1 | 0.27 | 0.27 | + |
| JJ70 | 2.16E-03 | JA80 | 0 | 6.24 | 0.93 | + |
| JJ71 | 1.72E-03 | JA80 | 1 | 0.18 | 0.18 | + |
| JJ72 | 1.91E-05 | JA80 | 2 | -2.62 | 0.00 | |
| JJ73 | 5.46E-03 | JA80 | 0 | 5.92 | 1.56 | + |
| JJ74 | 5.24E-03 | JA68 | 1 | -0.04 | 0.00 | |
| JJ75 | 1.22E-02 | JA80 | 0 | 7.13 | 7.13 | * |
| JJ76 | 1.91E-03 | JA80 | 1 | -0.96 | 0.00 | |
| JJ77 | 4.40E-04 | JA80 | 1 | 2.23 | 2.23 | + |

| | | | | | | |
|---|---|---|---|---|---|---|
| SJ65 | 1.38E-04 | SA45 | 2 | 0.47 | 0.47 | * |
| SJ66 | 1.57E-04 | SA45 | 1 | 4.28 | 4.28 | * |
| SJ67 | 1.10E-05 | SA46 | 3 | -4.12 | 0.00 | |
| SJ68 | 3.62E-04 | SA45 | 0 | 8.91 | 8.91 | * |
| SJ69 | 2.38E-03 | SA45 | 0 | 6.05 | 6.05 | * |
| SJ70 | 3.60E-05 | SA42 | 3 | -8.02 | 0.00 | |
| SJ71 | 2.36E-05 | SA46 | 2 | 2.24 | 2.24 | * |
| SJ72 | 6.42E-05 | SA45 | 1 | 4.77 | 4.77 | * |
| SJ73 | 6.73E-04 | SA34 | 1 | 3.43 | 3.43 | * |
| SJ74 | 1.45E-05 | SA43 | 2 | 3.09 | 1.68 | * |
| SJ75 | 1.40E-05 | SA11 | 3 | -8.08 | 0.00 | |
| SJ76 | 2.38E-04 | SA34 | 1 | 2.94 | 2.94 | * |
| SJ77 | 5.74E-06 | SA34 | 2 | -1.64 | 0.00 | |
| SJ78 | 1.92E-03 | SA26 | 2 | 1.11 | 1.11 | * |
| SJ79 | 7.87E-04 | SA35 | 0 | 12.37 | 9.39 | * |
| SJ80 | 1.52E-04 | SA44 | 1 | 6.34 | 6.34 | * |

| | | | | | | |
|---|---|---|---|---|---|---|
| JJ78 | 5.92E-07 | JA22 | 3 | -7.66 | 0.00 | |
| JJ79 | 2.18E-02 | JA78 | 0 | 5.76 | 4.09 | * |
| JJ80 | 1.11E-03 | JA72 | 1 | -1.86 | 0.00 | |

C

| sapling | NE-PP | p1 | p2 | trio LOD | trio Delta | trio conf. |
|---|---|---|---|---|---|---|
| JJ1 | 1.78E-09 | JA30 | JA56 | -4.65 | 0.00 | |
| JJ2 | 3.89E-10 | JA17 | JA22 | -7.77 | 0.00 | |
| JJ3 | 1.72E-14 | JA1 | JA16 | -11.61 | 0.00 | |
| JJ4 | 1.66E-08 | JA65 | JA70 | -0.99 | 0.00 | |
| JJ5 | 6.11E-10 | JA15 | JA57 | -7.70 | 0.00 | |
| JJ6 | 2.52E-19 | JA29 | JA59 | -10.59 | 0.00 | |
| JJ7 | 4.78E-12 | JA9 | JA80 | -11.78 | 0.00 | |
| JJ8 | 1.09E-11 | JA17 | JA60 | -8.54 | 0.00 | |
| JJ9 | 7.17E-10 | JA8 | JA43 | -2.24 | 0.00 | |
| JJ10 | 3.93E-09 | JA40 | JA41 | -4.06 | 0.00 | |
| JJ11 | 8.65E-10 | JA18 | JA29 | -7.88 | 0.00 | |
| JJ12 | 3.18E-08 | JA18 | JA40 | -9.02 | 0.00 | |
| JJ13 | 2.43E-12 | JA36 | JA70 | -4.40 | 0.00 | |
| JJ14 | 4.97E-10 | JA9 | JA51 | -2.70 | 0.00 | |
| JJ15 | 2.83E-09 | JA75 | JA80 | -4.59 | 0.00 | |
| JJ16 | 2.35E-08 | JA8 | JA41 | -4.99 | 0.00 | |
| JJ17 | 7.35E-11 | JA80 | JA81 | -12.29 | 0.00 | |
| JJ18 | 4.26E-14 | JA16 | JA82 | 1.30 | 1.30 | - |
| JJ19 | 6.18E-09 | JA34 | JA81 | 4.35 | 0.13 | - |
| JJ20 | 9.31E-10 | JA13 | JA81 | 2.03 | 0.68 | - |
| JJ21 | 2.86E-14 | JA16 | JA54 | -5.79 | 0.00 | |

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| sapling | NE-PP | p1 | p2 | trio LOD | trio Delta | trio conf. |
|---|---|---|---|---|---|---|
| SJ1 | 1.77E-10 | SA3 | SA10 | -9.18 | 0.00 | |
| SJ2 | 3.04E-11 | SA4 | SA45 | 0.41 | 0.41 | + |
| SJ3 | 6.94E-10 | SA2 | SA45 | -2.47 | 0.00 | |
| SJ4 | 1.88E-11 | SA4 | SA44 | -15.39 | 0.00 | |
| SJ6 | 1.72E-10 | SA17 | SA33 | -5.99 | 0.00 | |
| SJ7 | 1.81E-12 | SA22 | SA28 | -2.88 | 0.00 | |
| SJ8 | 9.70E-11 | SA4 | SA43 | -3.86 | 0.00 | |
| SJ9 | 8.20E-10 | SA10 | SA13 | 1.16 | 1.16 | + |
| SJ10 | 2.53E-08 | SA6 | SA23 | -2.67 | 0.00 | |
| SJ11 | 2.73E-10 | SA14 | SA47 | -2.73 | 0.00 | |
| SJ12 | 9.97E-12 | SA32 | SA40 | 18.91 | 14.37 | * |
| SJ13 | 7.27E-14 | SA27 | SA33 | -1.41 | 0.00 | |
| SJ14 | 1.40E-10 | SA2 | SA32 | -5.38 | 0.00 | |
| SJ16 | 1.20E-13 | SA26 | SA47 | -11.54 | 0.00 | |
| SJ17 | 8.28E-09 | SA9 | SA33 | 7.56 | 1.45 | + |
| SJ18 | 5.95E-14 | SA33 | SA41 | -7.80 | 0.00 | |
| SJ19 | 1.33E-09 | SA45 | SA49 | 10.06 | 9.56 | * |
| SJ21 | 1.19E-11 | SA21 | SA41 | -12.22 | 0.00 | |
| SJ22 | 3.98E-10 | SA17 | SA28 | -5.02 | 0.00 | |
| SJ23 | 4.15E-10 | SA4 | SA30 | -1.69 | 0.00 | |
| SJ24 | 2.96E-13 | SA13 | SA43 | -12.14 | 0.00 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JJ22 | 3.83E-11 | JA51 | JA54 | 2.28 | 2.28 | + | SJ25 | 1.76E-12 | SA13 | SA17 | -7.19 | 0.00 | |
| JJ23 | 1.49E-10 | JA4 | JA63 | -5.21 | 0.00 | | SJ26 | 1.16E-11 | SA4 | SA27 | -10.74 | 0.00 | |
| JJ24 | 6.73E-09 | JA2 | JA82 | -5.75 | 0.00 | | SJ27 | 4.43E-12 | SA4 | SA19 | -0.81 | 0.00 | |
| JJ25 | 1.04E-08 | JA48 | JA73 | -0.32 | 0.00 | | SJ28 | 1.64E-08 | SA27 | SA40 | -5.01 | 0.00 | |
| JJ26 | 5.36E-13 | JA30 | JA71 | -3.66 | 0.00 | | SJ29 | 1.37E-11 | SA33 | SA41 | -9.60 | 0.00 | |
| JJ27 | 3.72E-10 | JA12 | JA79 | -0.32 | 0.00 | | SJ30 | 3.96E-12 | SA17 | SA49 | -6.53 | 0.00 | |
| JJ28 | 8.22E-08 | JA64 | JA82 | -2.52 | 0.00 | | SJ31 | 4.12E-08 | SA17 | SA34 | 11.48 | 7.76 | * |
| JJ29 | 9.31E-08 | JA32 | JA46 | -0.33 | 0.00 | | SJ34 | 3.48E-11 | SA18 | SA35 | -11.58 | 0.00 | |
| JJ30 | 7.91E-08 | JA21 | JA72 | -0.26 | 0.00 | | SJ35 | 6.56E-12 | SA1 | SA49 | -9.21 | 0.00 | |
| JJ30 | 7.91E-08 | JA30 | JA72 | -0.26 | 0.00 | | SJ36 | 5.60E-08 | SA30 | SA52 | 3.50 | 0.49 | + |
| JJ31 | 7.40E-11 | JA45 | JA50 | 2.55 | 0.92 | - | SJ37 | 1.77E-11 | SA36 | SA37 | 12.17 | 2.66 | + |
| JJ32 | 8.27E-13 | JA64 | JA80 | -7.49 | 0.00 | | SJ38 | 1.43E-10 | SA26 | SA30 | -8.09 | 0.00 | |
| JJ33 | 1.87E-10 | JA33 | JA50 | -2.87 | 0.00 | | SJ39 | 1.87E-11 | SA13 | SA15 | -10.58 | 0.00 | |
| JJ34 | 3.25E-09 | JA42 | JA75 | 2.00 | 2.00 | - | SJ40 | 1.06E-12 | SA24 | SA26 | -8.09 | 0.00 | |
| JJ35 | 1.01E-12 | JA14 | JA18 | -7.92 | 0.00 | | SJ41 | 8.13E-16 | SA21 | SA41 | -13.23 | 0.00 | |
| JJ36 | 8.47E-11 | JA71 | JA73 | -5.77 | 0.00 | | SJ42 | 8.46E-12 | SA46 | SA49 | -2.81 | 0.00 | |
| JJ37 | 1.47E-09 | JA8 | JA22 | -1.20 | 0.00 | | SJ43 | 8.78E-12 | SA22 | SA23 | -3.89 | 0.00 | |
| JJ38 | 2.02E-09 | JA28 | JA60 | -5.89 | 0.00 | | SJ44 | 6.96E-11 | SA9 | SA22 | -10.01 | 0.00 | |
| JJ39 | 7.62E-15 | JA56 | JA65 | -13.72 | 0.00 | | SJ45 | 9.39E-11 | SA30 | SA53 | -10.07 | 0.00 | |
| JJ40 | 3.82E-11 | JA64 | JA71 | 4.24 | 4.00 | + | SJ46 | 1.07E-11 | SA33 | SA37 | 0.43 | 0.43 | + |
| JJ41 | 8.71E-08 | JA23 | JA71 | 1.69 | 0.02 | - | SJ47 | 9.76E-15 | SA33 | SA49 | -2.75 | 0.00 | |
| JJ42 | 4.50E-08 | JA8 | JA63 | -0.78 | 0.00 | | SJ48 | 2.27E-09 | SA49 | SA52 | -0.34 | 0.00 | |
| JJ43 | 7.01E-10 | JA43 | JA57 | -3.72 | 0.00 | | SJ49 | 1.79E-07 | SA23 | SA34 | 11.23 | 4.36 | * |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JJ44 | 2.13E-09 | JA10 | JA62 | 2.38 | 1.17 | - | SJ50 | 6.49E-10 | SA30 | SA34 | 8.58 | 8.58 | * |
| JJ45 | 1.91E-06 | JA5 | JA44 | 1.21 | 0.05 | - | SJ51 | 9.07E-12 | SA32 | SA39 | 19.14 | 13.46 | * |
| JJ46 | 4.71E-08 | JA37 | JA40 | -3.56 | 0.00 | | SJ53 | 1.84E-11 | SA10 | SA34 | -5.57 | 0.00 | |
| JJ47 | 3.87E-08 | JA39 | JA42 | 0.59 | 0.01 | - | SJ54 | 2.86E-10 | SA40 | SA43 | 12.76 | 5.27 | * |
| JJ48 | 3.81E-10 | JA57 | JA77 | -6.56 | 0.00 | | SJ56 | 1.60E-11 | SA27 | SA36 | 6.73 | 5.57 | * |
| JJ49 | 3.13E-13 | JA72 | JA80 | -12.40 | 0.00 | | SJ57 | 1.18E-09 | SA21 | SA26 | -3.28 | 0.00 | |
| JJ50 | 1.08E-08 | JA19 | JA41 | 1.21 | 0.79 | - | SJ59 | 2.05E-10 | SA2 | SA22 | -3.99 | 0.00 | |
| JJ51 | 3.16E-09 | JA10 | JA45 | -7.87 | 0.00 | | SJ60 | 1.21E-10 | SA13 | SA44 | -10.34 | 0.00 | |
| JJ52 | 2.96E-14 | JA5 | JA74 | -14.30 | 0.00 | | SJ61 | 6.53E-11 | SA32 | SA36 | -1.79 | 0.00 | |
| JJ53 | 1.45E-14 | JA10 | JA18 | -14.95 | 0.00 | | SJ62 | 2.24E-11 | SA2 | SA50 | 4.77 | 4.77 | * |
| JJ54 | 4.95E-15 | JA18 | JA74 | -15.49 | 0.00 | | SJ63 | 3.89E-11 | SA11 | SA19 | -3.07 | 0.00 | |
| JJ55 | 6.47E-10 | JA38 | JA39 | -0.52 | 0.00 | | SJ64 | 8.20E-08 | SA5 | SA30 | -8.32 | 0.00 | |
| JJ56 | 5.64E-12 | JA71 | JA74 | -6.04 | 0.00 | | SJ65 | 1.66E-11 | SA22 | SA45 | -3.21 | 0.00 | |
| JJ57 | 2.81E-12 | JA14 | JA36 | -12.42 | 0.00 | | SJ66 | 3.98E-10 | SA27 | SA45 | 1.83 | 1.83 | + |
| JJ58 | 3.22E-14 | JA19 | JA37 | -10.67 | 0.00 | | SJ67 | 7.63E-16 | SA4 | SA46 | -9.75 | 0.00 | |
| JJ59 | 1.03E-13 | JA5 | JA32 | -14.15 | 0.00 | | SJ68 | 8.16E-11 | SA34 | SA45 | -3.14 | 0.00 | |
| JJ60 | 7.98E-09 | JA54 | JA60 | 6.45 | 1.23 | - | SJ69 | 2.64E-09 | SA17 | SA45 | -5.71 | 0.00 | |
| JJ61 | 4.69E-09 | JA33 | JA60 | 6.59 | 4.05 | + | SJ70 | 7.89E-12 | SA16 | SA26 | -11.34 | 0.00 | |
| JJ62 | 6.29E-12 | JA59 | JA60 | 15.61 | 8.54 | * | SJ71 | 9.34E-14 | SA4 | SA46 | -6.44 | 0.00 | |
| JJ63 | 1.53E-07 | JA24 | JA72 | 6.87 | 1.10 | - | SJ72 | 3.18E-11 | SA30 | SA45 | 0.71 | 0.71 | + |
| JJ64 | 2.49E-07 | JA39 | JA47 | 2.07 | 1.25 | - | SJ73 | 4.25E-10 | SA10 | SA34 | -5.42 | 0.00 | |
| JJ65 | 1.83E-08 | JA39 | JA47 | -2.04 | 0.00 | | SJ74 | 1.48E-11 | SA4 | SA43 | -0.64 | 0.00 | |
| JJ66 | 1.87E-09 | JA19 | JA72 | -4.57 | 0.00 | | SJ75 | 8.98E-13 | SA26 | SA30 | -14.51 | 0.00 | |

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|---|---|---|---|---|---|---|
| JJ67 | 1.12E-09 | JA19 | JA56 | -5.71 | 0.00 | |
| JJ68 | 6.46E-13 | JA20 | JA62 | -3.02 | 0.00 | |
| JJ69 | 4.38E-09 | JA39 | JA59 | -3.09 | 0.00 | |
| JJ70 | 1.16E-07 | JA63 | JA80 | 6.77 | 3.50 | + |
| JJ71 | 1.26E-09 | JA36 | JA80 | -3.21 | 0.00 | |
| JJ72 | 4.06E-13 | JA9 | JA80 | -10.50 | 0.00 | |
| JJ73 | 4.48E-07 | JA78 | JA80 | 5.17 | 1.63 | - |
| JJ74 | 8.11E-11 | JA68 | JA80 | -7.33 | 0.00 | |
| JJ75 | 1.17E-09 | JA70 | JA80 | 0.15 | 0.15 | - |
| JJ76 | 3.47E-08 | JA68 | JA80 | -2.39 | 0.00 | |
| JJ77 | 1.78E-09 | JA78 | JA80 | -5.49 | 0.00 | |
| JJ78 | 4.72E-15 | JA22 | JA23 | -12.37 | 0.00 | |
| JJ79 | 3.88E-09 | JA72 | JA78 | 3.61 | 3.61 | + |
| JJ80 | 3.91E-08 | JA19 | JA68 | -7.93 | 0.00 | |

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|---|---|---|---|---|---|---|
| SJ76 | 2.46E-10 | SA34 | SA43 | -1.42 | 0.00 | |
| SJ77 | 4.32E-12 | SA8 | SA34 | -0.93 | 0.00 | |
| SJ78 | 1.01E-08 | SA26 | SA28 | 6.32 | 0.78 | + |
| SJ79 | 8.64E-10 | SA9 | SA35 | 16.99 | 0.31 | + |
| SJ80 | 8.14E-11 | SA12 | SA44 | 8.62 | 6.40 | * |