Norway spruce and its reaction to drought events:
A site comparison in the Sihlwald, Switzerland

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Abstract

Droughts are predicted to occur more often in the near future. This study looks at the impact of drought events on *Picea abies* (Norway spruce) in Sihlwald, Switzerland. Cores of eight trees along a slope were sampled to answer the following research question: Are trees located in a small depression reacting better to drought events than trees on top of a hill or on a slope? Based on past drought years and the measured mean tree ring width (mm), the three locations were compared within each other. A t-test and ANOVA were applied to estimate the significance of the result. Although drought years were clearly visible in the data, the hypothesis that trees that are growing in a depression will have a higher mean tree ring width during a drought period than trees on a slope or on top was not confirmed.

Introduction

Climate change is happening at a fast pace and with it more extreme weather conditions are occurring. Currently, an increase in frequency and duration of droughts events in Central Europe has been observed (Lévesque et al., 2013). This change in weather pattern is having a significant effect on the biosphere for instance on a forest composition. Around 30% of Switzerland's area is covered by forest and with a changing climate some tree species will be able to adapt better to the new conditions than others (BAFU et al., 2020).

Norway spruce (*Picea abies*) is a native species in Switzerland and can mainly be found in the central plateau, where it is planted for economic purposes (Liesebach et al., 2018, BAFU et al., 2020). However, it is also one of the species that is being threatened by climate change as it prefers a colder and rather moist environment (Pretzsch et al., 2020). With increasing water scarcity during the summer months and higher temperatures, its climate niche starts to vanish, and the species becomes highly sensitive to summer droughts (Ditmarová et al., 2010). This has already been visible in the years 2003 and 2018, in which the mortality of Norway spruce increased not only due to the dry summers but also due to secondary effects. The species has a higher susceptibility to biotic disturbances such as bark beetle attacks after drought years, which can result in the observed higher mortality rates (Cherubini et al., 2021).

How severe a drought is going to be depends on the amount of precipitation, the air temperature as well as the soil characteristics. In addition, these three factors influence the vitality of a tree and its ability to grow (Lévesque et al., 2013, Rehschuh et al., 2017). Thus, a growth reaction during the drought periods should be visible in the tree-ring structure (Liesebach et al., 2018). Furthermore, using stable isotopes to analyse the tree ring composition can improve the assessment of the individual water use strategy of a tree. Additionally, it can also be used to increase the general knowledge about the climatic conditions of the studied period (Cherubini et al., 2021).

This study has its emphasis on Norway spruce and its reaction to the drought periods in the last 30 years. Based on tree-ring width data for the time period of 1990-2020 the following hypothesis is reviewed: Trees that are located in a local depression should have better growth conditions (and thus, wider tree rings) than trees growing on top of the hill or trees located in-between as water flows downwards and should therefore be longer available for the trees in the depression.

Materials and Methods

Study site

This study was conducted in the Wildnispark Zürich, Sihlwald. The samples were taken in one of the Wildnispark's transition zones, namely "IVS2 Waldschutzzone S2: Sicherheitszone" and "IVA Naturerlebniszone". Here, the forest is managed in a way that there will be no hazard for the visitors of the forest but most of the time nature can evolve undisturbed (Spuler, 2021). Sixteen core samples of eight different Norway spruces were taken (see Figure 1A and 2A in the appendix) as well as three cookies of supposedly the first, third and fourth tree. The coring occurred at a height of 1.3 meters with the two samples being around 120° to 180° apart from each other. The hill down facing part of the tree was avoided due to the possibility of reaction wood (Cherubini et al., 2020). Some trees have been attacked by bark beetles. The location of each tree can be seen in Figure 1 (see appendix). T1 and T2 were in a local depression and closest to a river, whilst T7 and T8 were on top of the hill and farthest away from the river. Thus, T1 and T2 are assumed to have the best growing conditions during the drought events.

After the sampling, the cores were air dried and glued on a wood support. The cores were smoothed by hand and had occasionally been cut in smaller pieces to ensure that the wood fibres are facing into a vertical direction. The sanding was done with five different sandpapers, ranging from low grain to high grain (coarse to fine). Afterwards, the rings were counted and every 10, 50 and 100 years a certain dot pattern was drawn on the core. This dotting is later used in case of missing rings during the crossdating (see Figure 3A in the appendix). The cookies were cut into smaller pieces to have an easier handling for the sanding with the machine.

Tree-ring width analysis

The cores were analysed remotely with Coo Recorder. Photos of the cores were taken (see Figure 4A in the appendix) and then stacked together. Afterwards, the border of each tree ring was marked in the CooRecorder. Figure 2 in the appendix shows an example of tree number 4, core 4a. After the dating of the sample the ring width curve of different samples was compared and used to crossdate the trees. First within the samples of the same tree to see the similarities and where possible faults could be and secondly, also within different trees for the same reasoning. Lastly, a reference sample from Gut, 2018 was applied to see how the crossdating compares to an established chronology. To establish mean curves of each tree CDendro was used. The cookies were analysed the same way, but this time the used image was of high resolution, as it has been photographed with "Skippy" at WSL (see Figure 3 in the appendix). Again, the two transects were crossdated within each other and compared with the mean curves of the cores. After the crossdating was acceptable, the ring width of each of the eight mean sample curves as well as the reference curves were exported into a .txt file for further analysis with Excel. Based on their respective location in the field (e.g., in the depression, on the hill or in-between) a mean ring width (mm) for each class has been calculated like this:

$$\frac{mean\ curve\ (e.g. T1) + mean\ curve\ (e.g. T2)}{2}$$

To quantify the mean ring width of each class a t-test and ANOVA were performed.

Climate data

As this study has its emphasis on drought years, Table 1 (see appendix) was established with combined data of BAFU, 2020 to have an overview of the drought years from 1990 - 2020. The years, which are perceived as especially dry are selected with data from the yearly rainfall – or the lack thereof – and with the help of the SPEI, a mass to detect dryness in the soil (see Figures 4 and 5 in the appendix). The focus for the selected years was the soil dryness, as this is one of the basis for the nourishment of a tree. A year was chosen to be especially dry if the SPEI deviates – 1.0 or more from the average and/or the year has both below average rainfall and below average SPEI.

Results

Crossdating the cores:

Table 2 (in the appendix) shows the age of our tree samples based on the crossdating. It is visible that the age span is quite broad with 171 year (tree 2) to 94 years (tree 1). Generally, most trees are around 100 - 130 years old. Tree number 5 is the only one with very narrow rings (from 1990-1999) and very broad ones closer to today, see Figure 6 in the appendix. Due to this it was excluded for further analysis, as it did not crossdate well with the other trees. Tree number 3 has also been excluded for the ring-width measurements, again due to not fitting well within the two cores taken from this tree and then also with the other cores.

Crossdating the cookies:

Of the three cookies the one from tree number 4 did yield a high correlation within its two parts and with the mean curve of tree number 4. Furthermore, it also correlated well with all other mean curves (expect no. 3 & 5) as well as the used reference established by Gut, 2018. The cookie of the first tree did not crossdate well within the two parts nor with the cores from the first tree. This is probably due to it being taken a little bit too close to the roots. The last cookie of supposably tree 3 did crossdate well within the two parts of the tree but not well with the core of the third tree or any of the rest. Due to the uncertainty of a wrong classification (e.g., as tree 3) and thus, wrong assumption where the tree was located, the decision was made to not use the data of the first and third cookie for further analysis.

Ring width:

Figure 7 in the appendix shows the mean ring width (mm) distribution of our six trees for the three defined locations as well as the reference by Gut, 2018 (in black) for the years 1990 - 2020. The green line represent the mean ring width for the trees located in the depression, whilst the red one indicates the mean ring width for the trees on top of the hill, close to the road. The orange line shows the data of the trees in between.

There are quite a few dominant decreases of the ring width visible especially in the following years: 1992, 1995, 2002, 2003, 2006, 2013 and 2018.

Statistical analysis:

The results of the mean ring width have been tested with a t-test as well as an ANOVA. The results of the test can be seen in the appendix in Tables 3 - 6.

Discussion

Generally, the two most dominant declines for all four classes in Figure 7 (see appendix) can be assigned to the years 1992 and 2003. They do correspond well with the drought years in Switzerland (see Table 1 in the appendix). In 2006 another huge decrease can be observed. Yet, this time the trees located on top of the small hill and close to the road are the only ones that have a small increase in growth. Furthermore, this year has not officially been classified as a drought year. Yet, it was ranked in 2007 as the fifth warmest year since 1864 (RAOnline EDU).

The hypothesis for this study is that tree no. 1 and 2 (green curve) had better growth conditions during the drought periods, as they are located in a small depression and also close to a river. Thus, the soil moisture should be higher compared to the slope or the top of the hill. However, when looking at the decline of ring width in 1992, this is only partly the case. The strongest growth decrease is visible for the trees on top of the hill, yet the ones in-between had a wider mean ring width than the ones at the bottom. In 1995, the biggest ring width decrease can be seen in the green curve, thus the trees that should have had the best growing conditions. Interestingly, the trees on top had a very small growth increase, whilst the ones in-between show a decrease. For 1998, it looks as if the trees in the depression show a growth increase, whilst the ones on top as well as the reference curve indicate a decrease. In 1999, Lothar occurred, and it seems as if it might have a very strong negative influence on the trees located somewhere on the slope as they show a declining growth trend until 2001. Here all the tree rings show a decline. The next two decreases can be attributed to the drought in 2003 and the extremely warm year 2006. In 2003, the trees in the depression had wider rings than the others. However, in 2006 these trees are showing the most negative growth response. 2011 and 2013 also show a growth decrease especially in the trees located on top of the hill. For the last few years there are some years where the trees responded similarly and some where they did not. 2015 has again been a really warm year. Here, it is interesting that only the trees located on the slope show a strong decline, the others seem not to be affected as strongly. Lastly, again a decrease for 2018 is visible, which is higher for the trees on the slope as well as the ones in the depression. The ones located on top still seem to be in recovery of the drought period in 2015.

The results of the statistical tests with a p-value of 0.05 show that the difference of the tree ring width is not statistically significant enough to illustrate a clear difference between the locations. With the used methods, it is therefore not possible to clearly state that some trees were better equipped for a drought situation based on their location than others.

The hypothesis must thus be rejected as the trees close to the local depression are only sometimes better equipped for the drought conditions but not all the time.

Limitations

There are different areas, where uncertainties or limitations influence the result of this study. Some concern the sampling as the cores were really unstable and tended to fall apart. Furthermore, the cores had to be cut into many different parts as the wood fibres seemed to be distorted (resembling a helix shape) and thus, there could be some parts that were glued facing the wrong direction (older rings outwards instead of inwards looking). In addition, the cores were photographed with a normal camera and some self-build construction, which sometimes resulted in an image deformation. However, as the deformation was constant over the whole image it was possible to still count the rings. Yet, these two points influenced the crossdating result. Another uncertainty factor is that the age determination is likely to be underestimated, as the core of the tree was often missed. But as the emphasis lies on the last 30 years this should not have influenced the result. Lastly, there are many other factors that determine if a location is drought prone or not. Soil properties, stand dynamics as well as forest management methods were not considered, which is why this approach can be assumed to be really simplistic. A way to improve the results would be to integrate these aspects and combine the ring width data with stable isotope measurements to assess the physiological responses to biotic and abiotic disturbances (Cherubini et al., 2021).

Conclusion

The drought periods are clearly visible in the data. However, there does not seem to be a consistent pattern in the data with the trees located in a depression being better prepared for drought periods than others. With further statistical tests one could also conclude that the differences, while visible, are not statistically relevant. The sampling area as well as the sample amount might be too small to make a general assumption. Therefore, if one would conduct the same study within a larger area, more samples as well as more trees per class, a different result might occur. Furthermore, with more samples, outliers in the data should be better detectable. In addition, applying stable isotope measurements such as $\delta^{13}C$ and $\delta^{18}O$ can lead to better understanding of the physiological processes within the tree. Lastly, taking other factors into account such as soil parameters, management methods, tree competition as well as the timing and duration of the drought periods may lead to a completely different result.

Acknowledgments

We would like to thank Ronald Schmidt for the permission to take our sample in Sihlwald and Christoph Spuler for helping us during the sampling as well as for taking the cookies. A huge thank you to Daniel Nievergelt, not only for the stitching of our panorama image of the cores but also for all the crossdating zoom sessions and to Anne Verstegen and Walter Godli for the preparation of our cookies. Lastly, we would like to thank Paolo Cherubini for his feedback on our first draft and the support throughout the whole process.

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RAOnline EDU (2021): Klima - Klima in der Schweiz - Witterungsjahr 2006 <https://www.raonline.ch/pages/edu/cli2/clich_2006.html#:~:text=Das%20Jahr%202006%20war%20in,Die%20Besonnung%20erreichte%20%C3%BCbernormale%20Werte> (Access: 10.04.2021)

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Appendix

Figures:

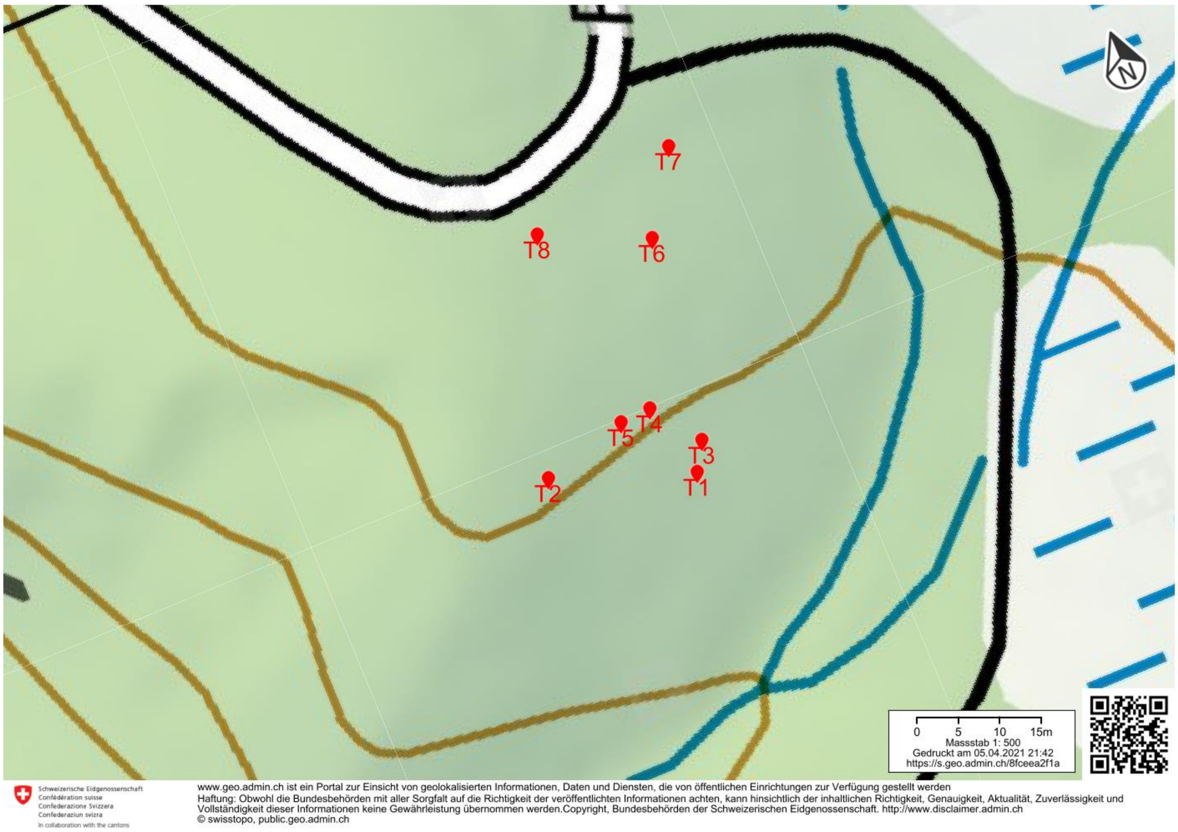

Figure 1: Location of the tree samples in the Sihlwald, Switzerland

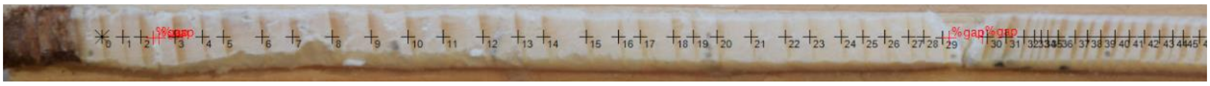

Figure 2: Drillcore of tree 4a.

Figure 3: Tree disc "Cookie" from tree 4, side b.

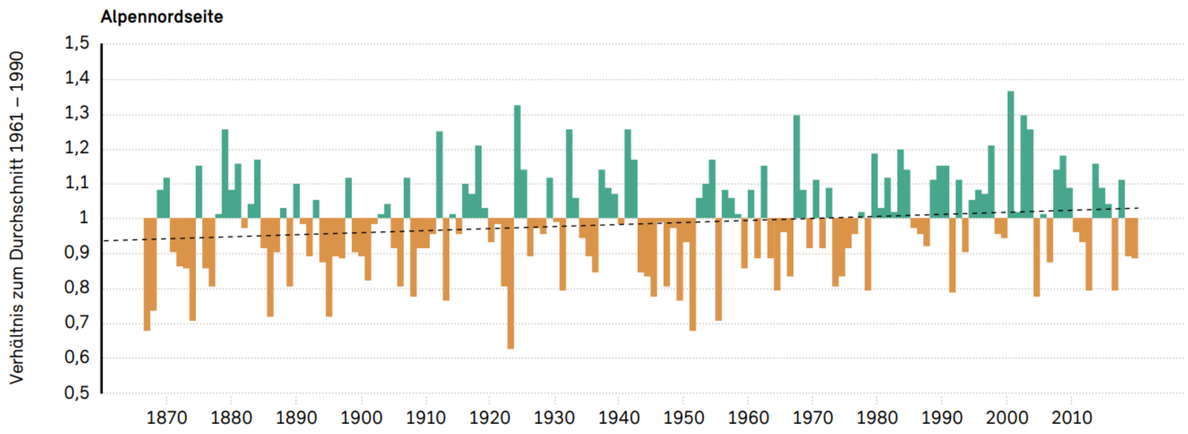

Figure 4: Annual deviation of rain from the norm 1961 to 1990. Average rain amount on the north side of the alps 1864 – 2019 (BAFU, 2020, p. 36).

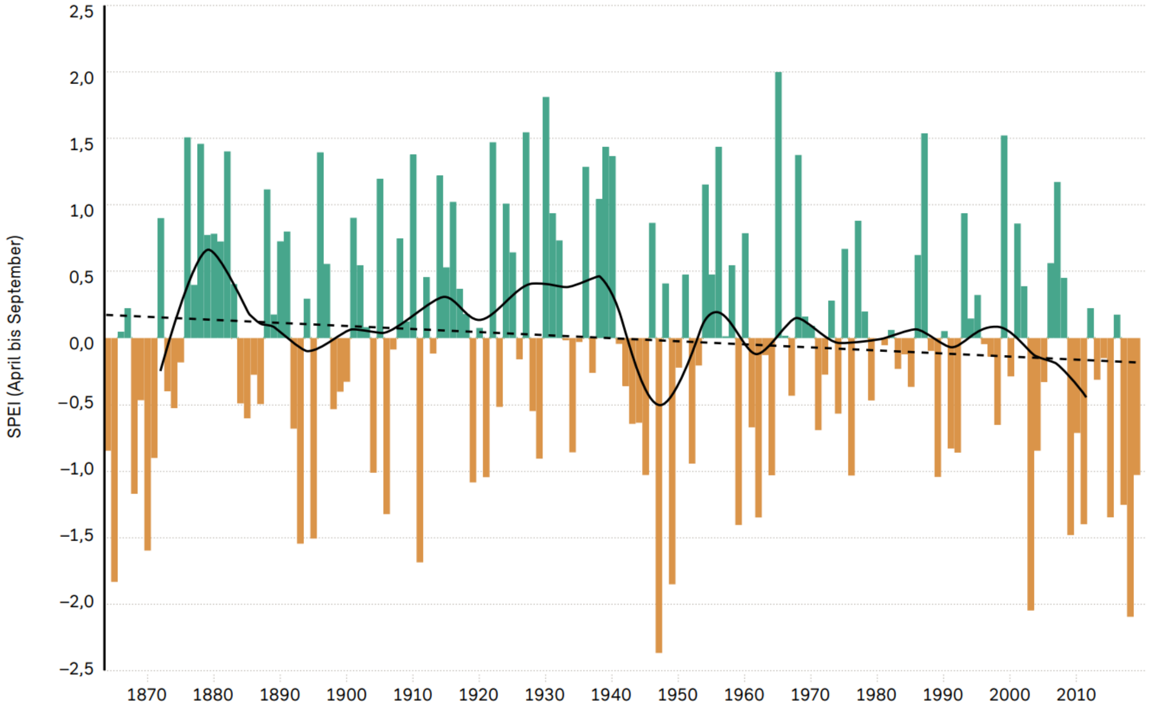

Figure 5: Annual deviation of SPEI from the norm 1961 to 1990. SPEI (mass for drought) for the summer half year, April until September, 1864 – 2019 (BAFU 2020, p. 38).

Figure 6: Drillcore from tree 5.

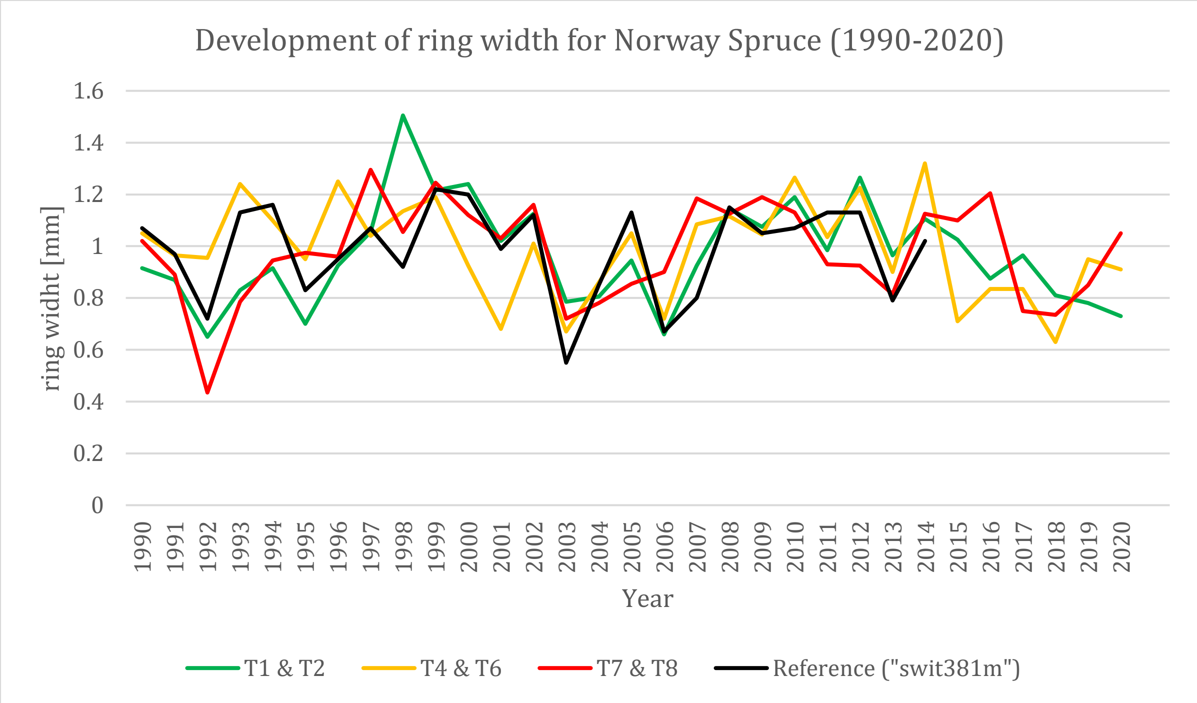

Figure 7: Development of mean ring width [mm] of Norway Spruce located in Sihlwald for the time period 1990 – 2020. The colours indicate the three locations along the slope. The reference swit381m was established by Gut, 2018.

Tables:

Table 1: Drought years marked in bold. Based on figures 4 and 5.

1990	**1991**	**1992**	1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	**2003**	2004	2005	2006	2007	2008	**2009**
2010	**2011**	2012	2013	2014	**2015**	2016	**2017**	**2018**	**2019**
2020									

Table 2: Ages of the tree samples.

Tree 1: 1926 = 94 a	Tree 2: 1849 = 171 a	Tree 3: 1890 = 130 a
Tree 4: 1907 = 113 a	Tree 5: 1916 = 104 a	Tree 6: 1913 = 107 a
Tree 7: 1890 = 130 a	Tree 8: 1893 = 127 a	
Cookie 1: 1890 = 130 a	Cookie 3: 1888 = 132 a	Cookie 4: 1907 = 113 a

Table 3: ANOVA: Single Factor. Data based on mean ring width of the samples.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	31	30	0,967742	0,038428
Column 2	31	30,65	0,98871	0,035028
Column 3	31	30,285	0,976935	0,036283

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0,006849	2	0,003424	0,093616	0,910721	3,097698
Within Groups	3,292174	90	0,03658			
Total	3,299023	92				

Table 4: t-Test: Two-Sample Assuming Equal Variances – Tree 1,2 with Tree 4,6. Data based on mean ring width of the samples.

	Variable 1	*Variable 2*
Mean	0,967742	0,98871
Variance	0,038428	0,035028
Observations	31	31
Pooled Variance	0,036728	
Hypothesized Mean Difference	0	
Df	60	
t Stat	-0,43074	
P(T<=t) one-tail	0,334099	
t Critical one-tail	1,670649	
P(T<=t) two-tail	0,668199	
t Critical two-tail	2,000298	

Table 5: t-Test: Two-Sample Assuming Equal Variances - Tree 1,2 with Tree 7,8. Data based on mean ring width of the samples.

	Variable 1	*Variable 2*
Mean	0,967742	0,976935
Variance	0,038428	0,036283
Observations	31	31
Pooled Variance	0,037355	
Hypothesized Mean Difference	0	
df	60	
t Stat	-0,18727	
P(T<=t) one-tail	0,42604	
t Critical one-tail	1,670649	
P(T<=t) two-tail	0,852079	
t Critical two-tail	2,000298	

Table 6: t-Test: Two-Sample Assuming Equal Variances – Tree 7,8 with Tree 4,6. Data based on mean ring width of the samples.

	Variable 1	*Variable 2*
Mean	0,976935	0,967742
Variance	0,036283	0,038428
Observations	31	31
Pooled Variance	0,037355	
Hypothesized Mean Difference	0	
df	60	
t Stat	0,187272	
P(T<=t) one-tail	0,42604	
t Critical one-tail	1,670649	
P(T<=t) two-tail	0,852079	
t Critical two-tail	2,000298	

Appendix II


Tree 1: BHD = 80


Tree 2: BHD = 39


Tree 3: BHD = 62


Tree 4: BHD = 72


Tree 5: BHD = 40


Tree 6: BHD = 78


Tree 7: BHD = 75


Tree 8: BHD = 48

Sampling and Tree ring analysis images

Figure 1A: Core drilling

Figure 2A: Cores

Figure 3A: Counting of tree rings

Figure 4A: Taking a picture of a core to crossdate it