ALTERFOR

ALTERNATIVE MODELS AND ROBUST DECISION-MAKING
FOR FUTURE FOREST MANAGEMENT

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# EXCURSION GUIDE TO THE LONG-TERM NORWAY SPRUCE THINNING AND SPACING TRIAL ZUSMARSHAUSEN 603

## An ALTERFOR Demonstration Site for the Forest Management Models „Production Forest“ and „Set Aside“

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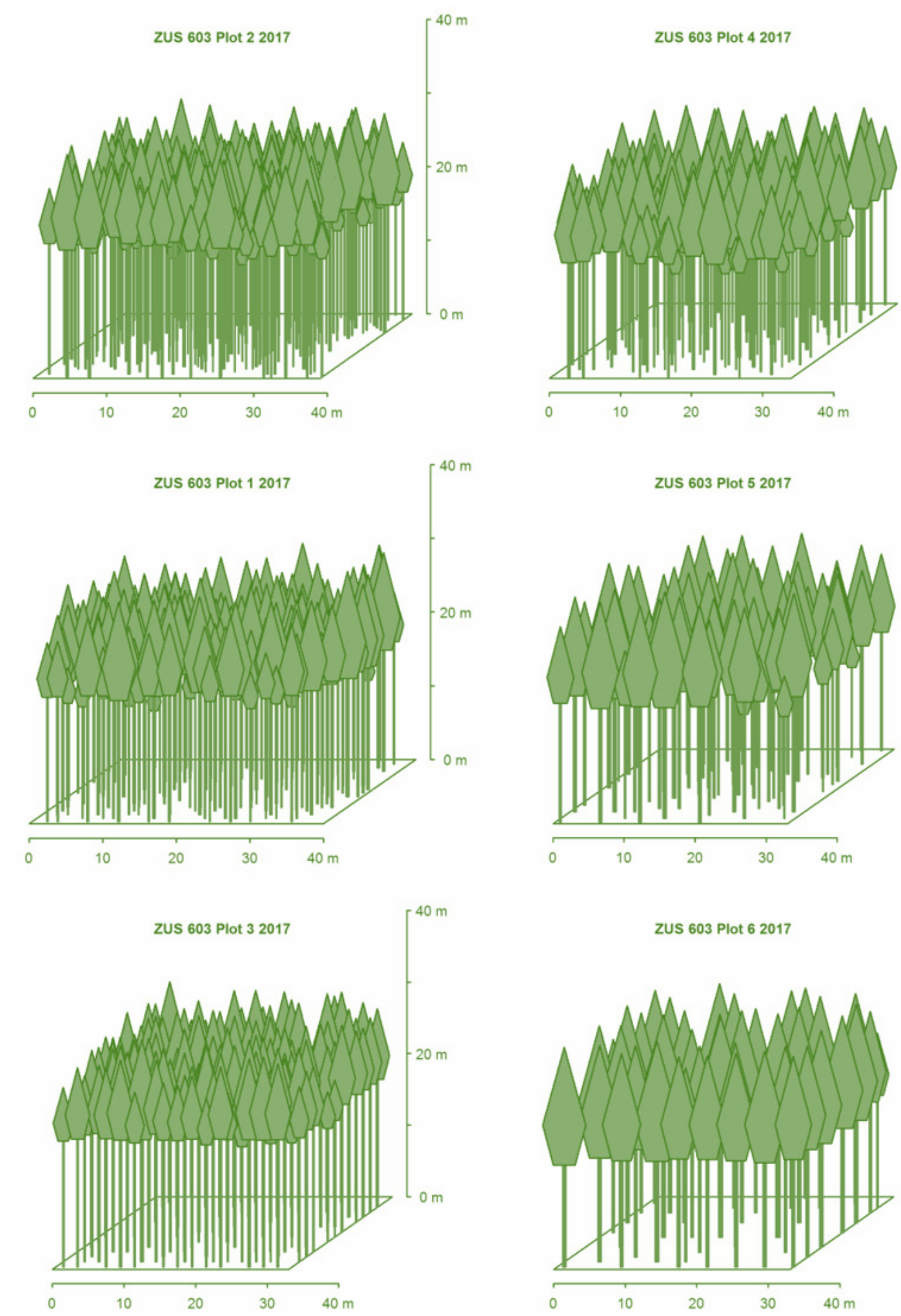


## 1 INTRODUCTION

In the project ALTERFOR we simulated three alternative forest management scenarios the German case study areas, namely “the production forest”, the “multifunctional forest” and “set aside”. The Norway spruce trial Zusmarshausen 603 (ZUS 603) is one of our ALTERFOR demonstration sites mainly for the production forest, but also for the set aside scenario. As the trial includes unthinned plots, these represent the development of artificially established monospecific forest stands after management has been halted.

The experiment ZUS 603 which is introduced in this guide (and the neighboring experiment ZUS 604 which is also an ALTERFOR demonstration site) are part of a federal state wide station network of long term growth and yield experiments that has been initiated in the 1870ies, at a time when such efforts were taken throughout Central Europe.
This network has been gaplessly supervised by the Chair of Forest Growth and Yield Science at the Technical University of Munich on behalf of the Bavarian State Forest Service. Currently, the network comprises 141 trials with about 900 plots in total. It covers a broad range of forest types (from monospecific to uneven-aged mixed stands) and scientific questions, and continues to provide invaluable time series data that document, not least, the influence of climate change on forest dynamics in and without interaction with management.

Norway spruce (Picea abies (L.) H.KARST.) is still one of the most relevant tree species in German forestry. In Bavaria, it covers about 50% of the forest area, however with reducing shares of monospecific stands. Appropriate tending and thinning of Norway spruce stands is an ongoing topic, especially in the context of changing environmental conditions. Our knowledge about optimizing spruce treatment has been derived to a relevant proportion from long term growth and yield experiments. In 2009, the Bavarian state forest enterprise (BaySF) have issued a new internal guideline for managing Norway spruce stands on that scientific basis. While their concept, as it strives for transforming monospecific into mixed stands, is closely related to our “multifunctional forest” scenario in ALTERFOR, other forest owners might want to continue managing monospecific Norway spruce stands which is a main point of the “production forest” scenario. Illustrating important aspects for this concept is the idea of the demonstration site Zusmarshausen 603.

Photo Credit: L. Steinacker

## 2 CLIMATE AND SITE

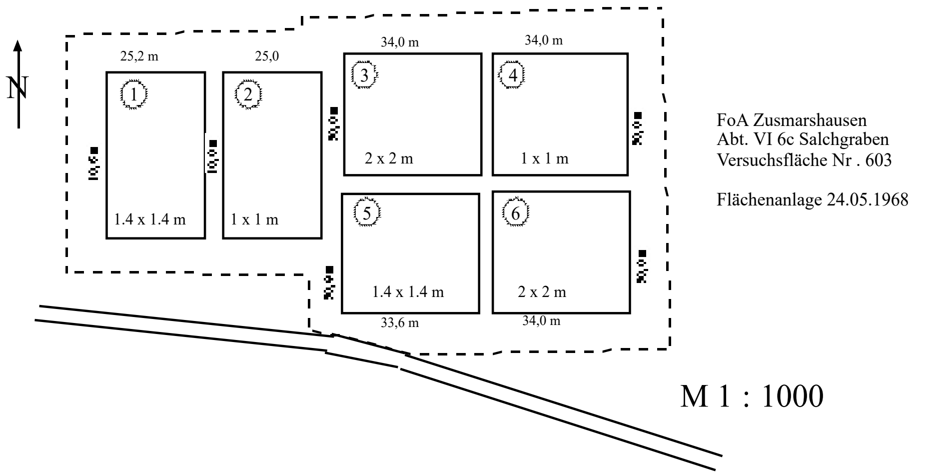
The experiment ZUS 603 is situated about 30 km west of the city of Augsburg at about 510 m a.s.l. Annual precipitation is at 800 mm. Of that, 450 mm fall within the vegetation period which amounts to 150 days per year. The average annual temperature is at 7.5°C, 15°C during the vegetation period. The geologic parent material comprises sands of the upper freshwater molasse and quaternary gravel cover, to some part with a top layer of loess-loam. From that source substrate, deep and well aerated brown earth and luvisols of mesotrophic nutrient supply have developed.

## 3 EXPERIMENTAL SETUP AND SURVEYS

The experiment ZUS 603 was planted in spring 1968 with spruce 2+2 from a private nursery (provenance „Graf v. Stauffenberg'sche Forstverwaltung Jettingen"). The previous stand on the site had been destroyed by storms in 1967. The experiment aims at investigating the influence of stem density, planting pattern, and thinning strength on the structure and growth of spruce stands.

The experiment Zus 603 comprises six rectangular plots with an area of 0.1000 ha to 0.1035 ha each (Figure 1). These plots form three plot pairs, each with a distinct equidistant quadratic planting pattern and thus a distinct initial planting density. One plot per pair was thinned and the other was left as an untreated control plot.

*Figure 1. Layout of the experiment ZUS 603, located in the forest section "Salchgraben" of the Bavarian State Forest Estate Zusmarshausen. Detailed location available on request at the Chair for Forest Growth and Yield, Technische Universität München.*




The plot pair 2 and 4 were planted with the densest spacing of 1 x 1 m (10,000 trees/ha), plot pair 1 and 5 have been established with a spacing of 1.4 x 1.4 m (5100 trees/ha), and the plot pair 3 and 6 had a spacing of 2 x 2 m (2,500 trees/ha). Plots 1, 2, and 3 were left untreated ("A-grade"). At a stand age of 16 years, every second plant row was removed on the treated plots (4, 5, 6); five years later, 300 elite trees were selected and subsequently promoted during the following decades by removing competitors. Hereby, the number of remaining trees was kept on different levels, highest on the plot with the narrowest initial spacing (plot 4) and lowest on the plot with the widest initial spacing (plot 6). The first survey of the trial was conducted in 1974 at a stand age of eleven years. So far, nine surveys have been conducted, the last one in 2017 at a stand age of 54 years. The tables at the end of this document (section 7) show the development and treatment of all plots in detail.

# 4 EVALUATION RESULTS

## 4.1 CURRENT STATUS

Figure 2 shows schematic stand representations from the last survey in 2017. The plots are arranged in a matrix, where the left column represents the unthinned and the right column represents the thinned plots. The rows of the matrix refer to the initial planting densities "high" (1 x 1 m), "medium" (1.4 x 1.4 m), "low" (2 x 2 m) from top to bottom. Thus, each row represents one of the above-mentioned plot pairs. With the same arrangement in columns and rows, we show the stem diameter distributions of 2017 in Figure 3.

*Figure 2. Schematic stand view of the status quo at the 2017 survey. Each row represents a plot pair (left: unthinned, right: thinned), with decreasing initial plant density (and increasing thinning strength) from top to bottom.*

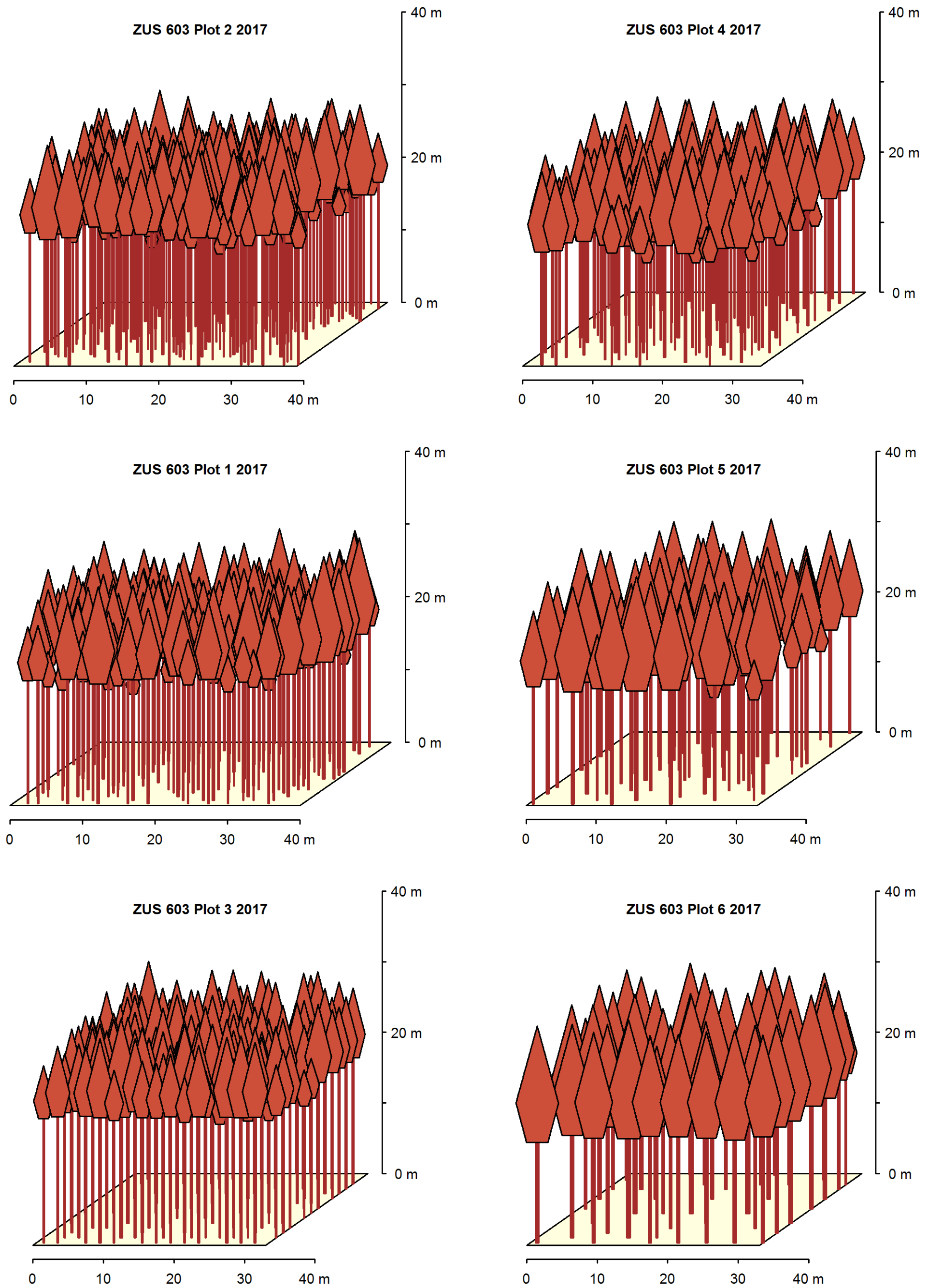
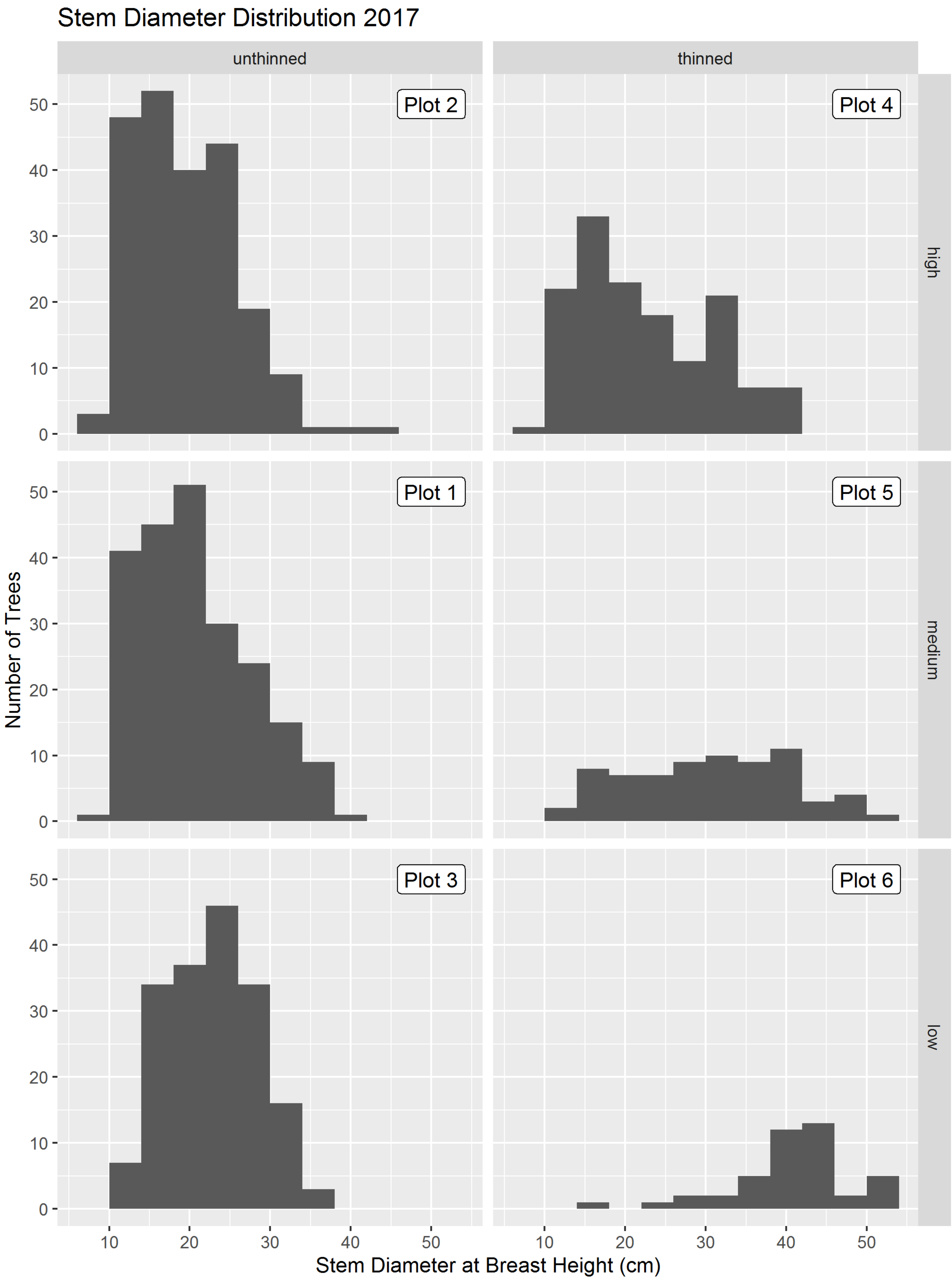


*Figure 3. Stem diameter distributions at the 2017 survey. Each row represents a plot pair (left: unthinned, right: thinned), with decreasing initial plant density (high, medium, low) along with increasing thinning strength from top to bottom.*



Clear effects of initial spacing and thinning strength are become visible in the diameter distributions at the last survey (Figure 3). Among the untreated plots (1, 2, 3) plot 3, which had the widest initial spacing, shows a considerably higher modal value compare to plots 1 and 2. The diameter ranges of all three unthinned plots, however, are remarkably similar. On the three thinned plots, the diameter distributions are significantly flatter due to the lower numbers of trees, and they are shifted towards the stronger tail of the distribution. Expectedly, this effect is the stronger the stronger the thinning is. On plot 5 and 6 the biggest trees have diameters more than 10 cm greater than the biggest trees on their unthinned counterpart plots. This impression is confirmed in a more intuitive way by the stand plots in Figure 2.

## 4.2 DEVELOPMENT OF KEY STAND VARIABLES

The observed development of four important stand level variables is shown in Figure 4. For the number trees the gradual decline of the tree numbers in the unthinned plots (dark red) stands in clear contrast to the initially steep reductions caused by active thinning. For both, the basal area and the standing wood volume, the unthinned and the thinned plots form two different strands of development with increasing age. At an age of 54 years, the unthinned plots have basal areas about 70 $m^2$/ha and volumes about 900 $m^3$/ha; for the thinned plots the values are considerably smaller (50 $m^2$/ha, 700 $m^3$/ha), but in all cases, there is a strong increasing tendency. Reineke's stand density index SDI (calculated as SDI = N*(25/dq)^-1.605 with N being the number of threes per ha and dq the stand's quadratic mean diameter) that since about a stand age of 30 years the plots are more or less at a constant density. With an SDI of about 1500, the unthinned plots represent the maximum density of Norway spruce stands under the given site conditions; the higher the planting density, the earlier they arrived there. The stronger thinned stands (plots 5 and 6) are kept at an SDI of about 750, while the less heavily thinned plot 4 oscillates around an SDI of 1000.

While these characteristics of the stands as they are in the field show such distinct differences, there is much less clear distinction in the total volume production (which includes the standing volume and the volume sum of all previously harvested or died trees), see Figure 5. All plots have reached a total volume production of about 1100 $m^3$/ha at an age of 54 years, the thinned plots being only slightly lower than the unthinned plots 1 and 2. The unthinned plot 3 with the lowest initital spacing is even at level with the lowest thinned (plot 4). This close similarity as also visible for the periodic annual increments which reached a maximum of almost 40 $m^3$/ha/year at an age of 30 years and are now slowly receding with values between 25 and 30 $m^3$/ha/year at age 54 (Figure 5). The same narrow bundle of developments is evident for the mean annual increment which is currently at about 20 $m^3$/ha/year and has not reached its maximum yet, indicating that the increment-optimal rotation age for spruce under the local site conditions is beyond 54 years.

Even more pronounced than stem number, basal area, standing volume, and stand density index, the mean and dominant diameters (Figure 6) show that more or less the same volume production (as just described) can be achieved with different stand level variables. Generally, these differences are more pronounced for the mean diameters compared to the dominant diameters, and expectedly much less for the heights compared to the diameters. On the unthinned plots, the wider spacing accelerates diameter growth but this effect almost vanished unto the age of 54 years. But while the weakest thinned plot has a similar mean diameter as the unthinned plots, the heavier thinned plots have reached a mean diameter that is 10 cm (plot 5) and even 20 cm higher (plot 6).

*Figure 4. Development of the number of trees, the basal area, the standing volume, and the stand density index. Dark red: Unthinned (A-grade); bright red: thinned plots. Different colors with the same line type represent a plot pair with the same initial plant density.*

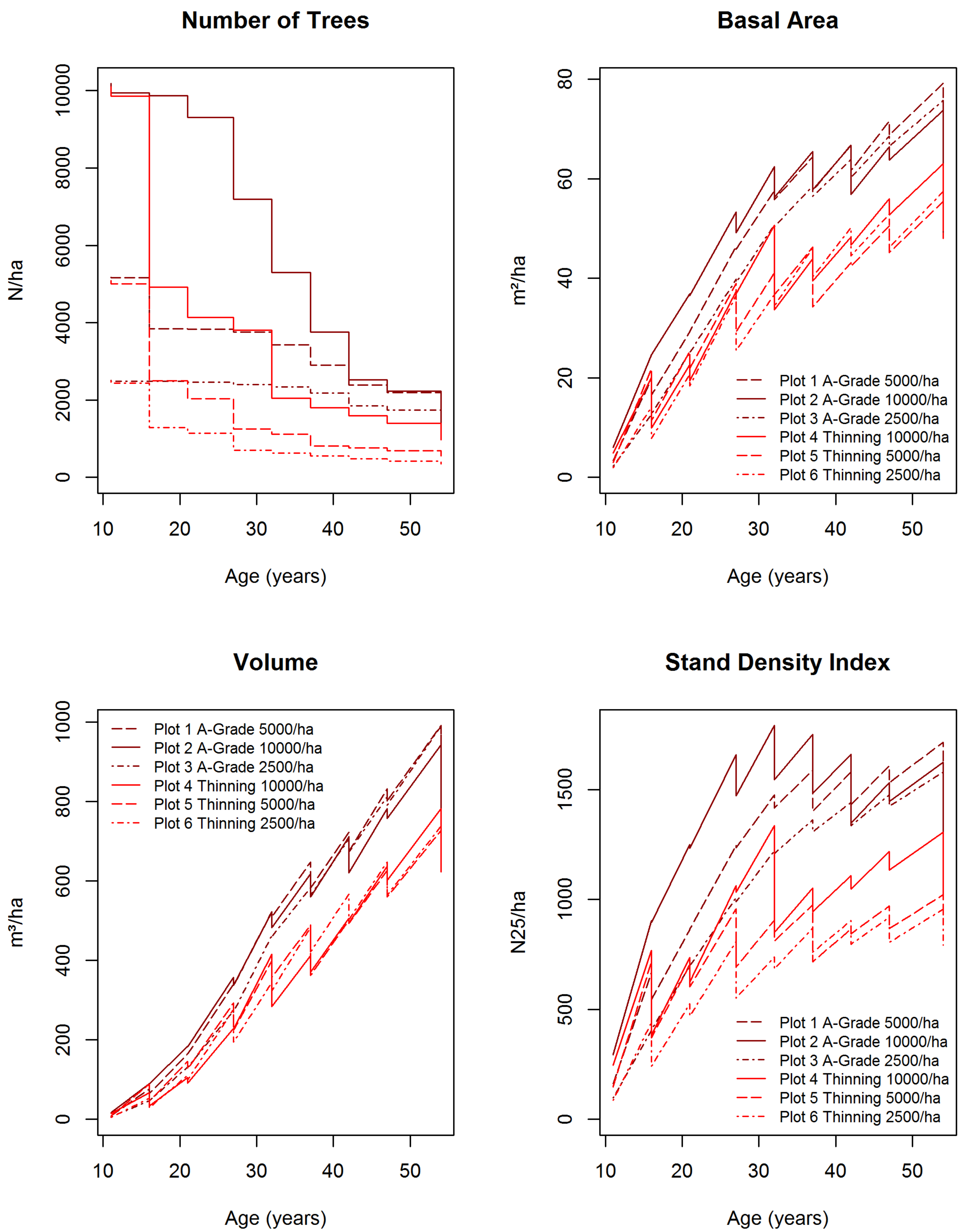


*Figure 5. Development of the total volume production, the periodic annual increment, and the mean annual increment.*
*Dark red: Unthinned (A-grade); Bright red: Thinned plots.*
*Different colors with the same line type represent a plot pair with the same initial plant density.*

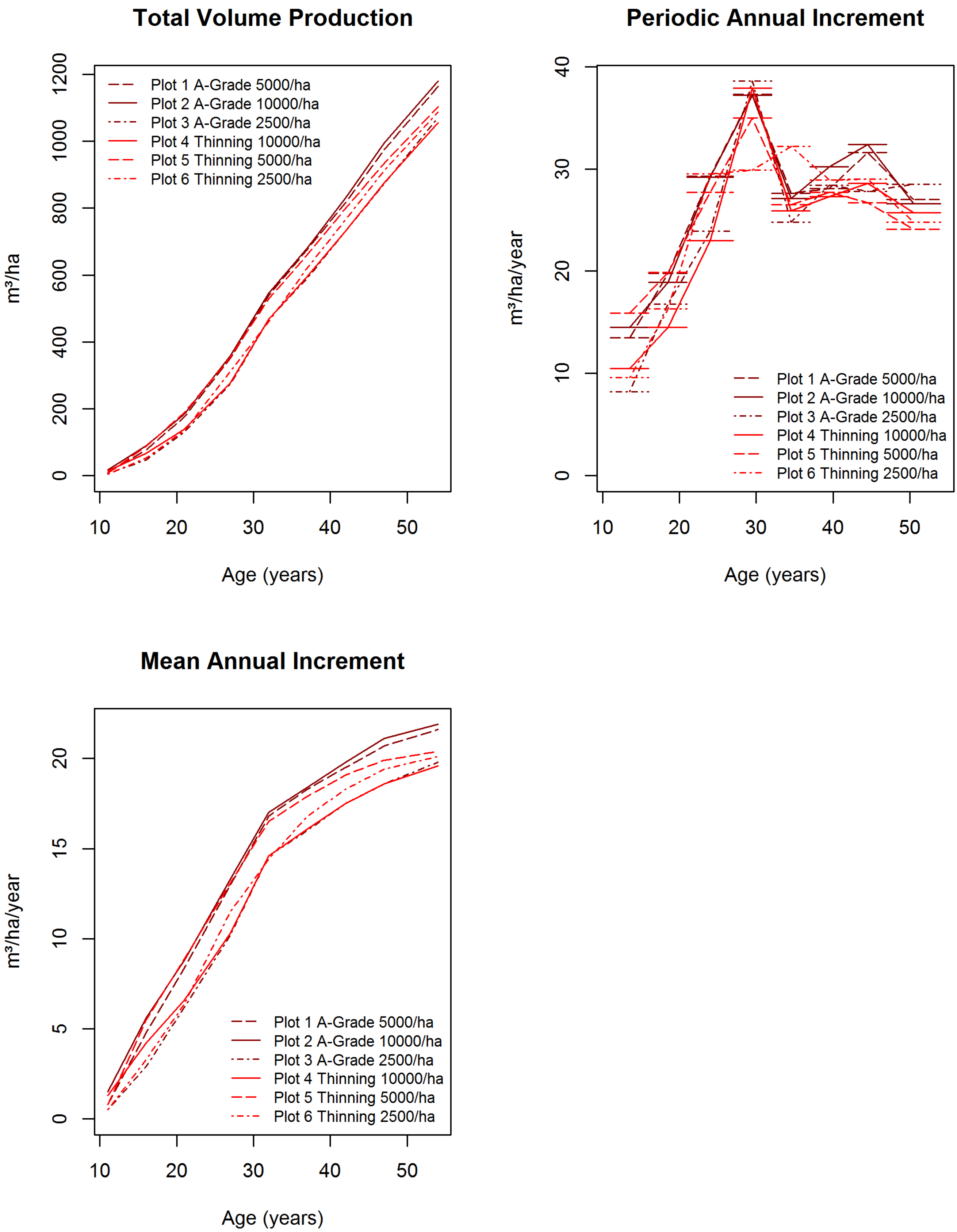


*Figure 6. Development of the quadratic mean diameter, the quadratic mean height, the dominant diameter, and the dominant height (dominant: 100 tallest trees/ha).*
*Dark red: Unthinned (A-grade); Bright red: Thinned plots.*
*Different colors with the same line type represent a plot pair with the same initial plant density.*

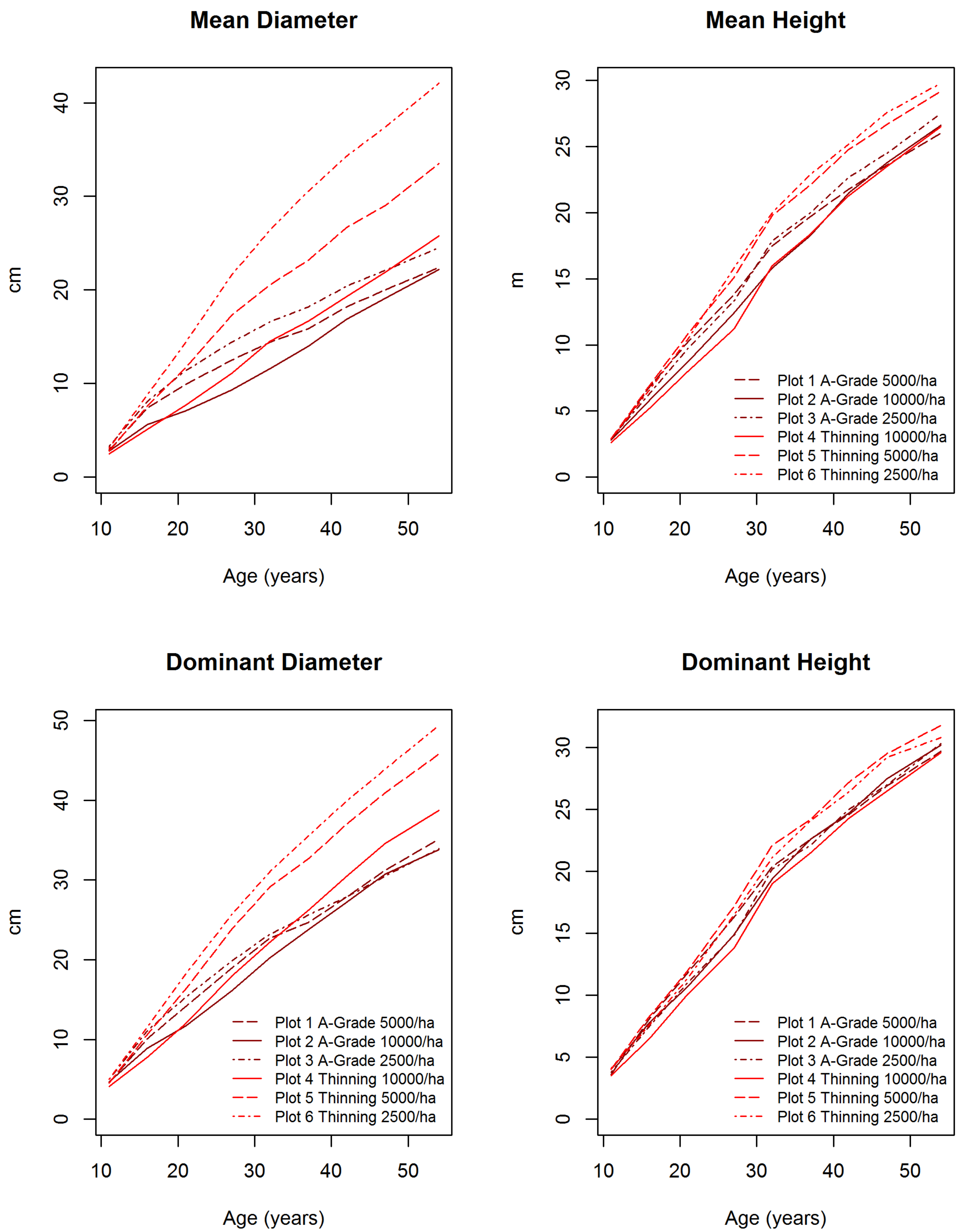
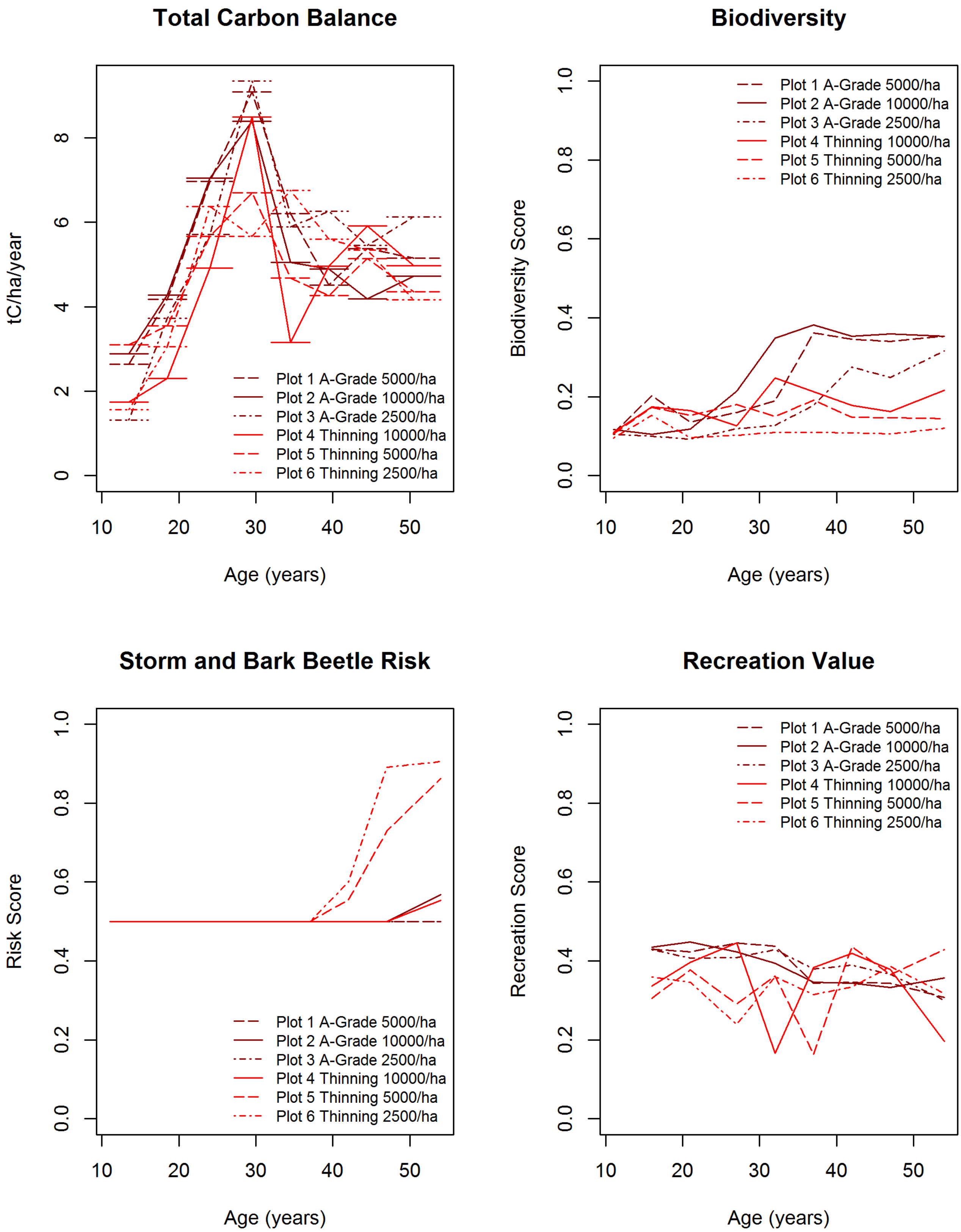


*Figure 7. Total carbon balance (forest stocks, product stocks, emission savings), the bio-diversity score, storm and bark beetle risk, and the recreation value (scale for the latter three variables: 0: very low, 1: very high).*
*Dark red: Unthinned (A-grade); Bright red: Thinned plots.*
*Different colors with the same line type represent a plot pair with the same initial plant density.*



Periodic annual carbon balances, a biodiversity score, a storm and bark beetle risk score and a score for the recreation value was calculated with an evaluation system we developed in the ALTERFOR framework (Biber et al. 2018). These variables are shown in Figure 7. The total carbon balance as shown comprises the carbon stocks in the forest itself, the related stocks of wood products and carbon emission savings due to the usage of wood instead of other raw materials like steel or concrete. A positive carbon balance indicates a net carbon uptake, a negative balance indicates a net carbon release. Its development is similar to the periodic annual volume increment as shown in Figure 5. The highest carbon balances with more than 8 tC/ha/year are observed at stand ages around 30 years, when the volume increment is at its maximum. These high values are, however, only achieved by the unthinned plots and the plot with the weakest thinning. While being similarly productive, the heavier-thinned plots 5 and 6 store less carbon in the forest, and more in wood products which are a less effective storage, which leads to a considerable lower peak carbon balance (about 6 tC/ha/year). At age 54 years the balances are between 4 and 6 tC/ha/year with a less clear disctinction of differently treated plots.

The biodiversity score shown in Figure 7 results from a fuzzy logic evaluation which takes into account tree species and stand structure diversity, the occurrence of big trees, and the amount of coarse deadwood. The biodiversity score can cover a range between 0 and 1, where 0 means "very low", 1 indicates "very high", and ½ represents "medium". Due to no tree species diversity and only low stand structure diversity, and no occurcence if big trees, all plots start with a very low to low biodiversity score. For the thinned plots, the score remains on that level or increases only slighty, with the heavier thinnings being lowest, as they create the most homogenous stand structures. For the unthinned plots the biodiversity score up to almost medium values between stand ages of 30 and 40 years, due the deadwood accumulating in the stands, which occurs slowest on the plots with the widest initial spacing (plot 3).

The score for the combined risk of storm damages and bark beetle infestations (Figure 7) also comes from a fuzzy logic evaluation system and follows the same scaling as with biodiversity (0: "very low", 1: "very high". It takes into account the volume share of the high-risk species Norway spruce, the volume share of trees with a stem diameter at breast height of 40 cm and more, and the species and stand structure diversity. While the latter is a risk mitigating factor, the other two tend to increase the risk. Bigger trees are insofar more risk-prone, as they are most attractive to the most aggressive spruce bark beetle, Ips typographus, and as only taller trees reach heights where wind speeds become regularly critical. This size effect is mainly the reason for how the risk score behaves in Figure 7. Up to stand ages between 30 and 40 years, the overall risk is constantly medium, but when trees reach critical sizes on the more heavily thinned plots, their risk score rises quickly to a level of "high to very high". Between age 40 and 50 most other plots set off with increasing risk scores.

The receation value score as also shown in Figure 7 follows the same principle (fuzzy logic evaluation, scaling from 0 to 1) as both previous variables. The assessment follows the insight, that the general public prefers forests which are managed, but with as few as possible visible management. This means that extremes are often perceived as negative, e.g. big trees are desired, but not too many of them at one spot, very high and very low stand densities are undesired; also undesired are higher amounts of deadwood and harvest residuals in general. Mixed and rich structured stands are positive, but not if visibility is too much constrained. As evident from Figure 7, the recreation value scores of all plots decline from "medium" to "low to medium values". When stronger thinnings occur, the score drops down temporarily due to the harvest operations and their visible remnants.

## 5 ALTERFOR SUMMARY

From the “production forest” point of view, the experiment Zusmarshausen 603 shows that there is a wide corridor of different thinning strength which achieve the same high total wood production in $m^3$. This indicates a broad variety of options for steering wood quality and log sizes and also the individual stability of the trees. However, as soon as the trees reach critical sizes, the overall risk will become typically high in such monospecific spruce stands. A risk mitigation strategy in such a production setting could be to perform heavy thinning like on plot 6 in order to produce high diameters quickly and harvest at an age not much beyond the current age of the ZUS 603 plots. Biodiversity is low and decreasing with age under such conditions, and will be the more so, the heavier the thinnings are. Recreation values are not exceedingly bad, but not impressive. The carbon balances are very good, with the accumulating risk as a caveat.

Seen from the “set aside” perspective, the development we observe on the unthinned plots would be the scenario to be seen on the large areas, where the existing Norway spruce monocultures were not managed anymore. The accumulating deadwood amounts add to the biodiversity, which, however, is limited due to the general monospecific and poorly-structured context. This might change if the accumulated risk leads to events that increase the forest’s structuredness and heterogeneity on different spatial scales. Clearly, such risk-induced structuring stands in trade-off with carbon sequestration, which is – potentially - very high in such stands.

## 6 REFERENCES

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Biber, P., Nieuwenhuis, M., Nordström, E.-M., Black, K., Borga, M., Borges, J.G., Eriksson, L.O., Felton, A., Hengeveld, G., Hoogstra-Klein, M., Lindbladh, M., Zoccatelli, D., 2019. Synthesis report: New forest management models in a landscape perspective: Innovation needs and gains in ecosystem service provisioning. ALTERFOR Deliverable 3.4.

# 7 STAND DEVELOPMENT TABLES

## ZUS 603 Plot 1, initial spacing 1.4 x 1.4 m, untreated

| | | | Verbleibender Bestand Remaining Stand | | | | | | | | | Ausscheidender Bestand Removal Stand | | | | | | Gesamtbestand Total Stand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHR YEAR | A T | BA SP | NV N | HO hdom | DO ddom | HO/DO h/ddom | HGV hg | DGV dg | HG/DG h/dg | GV G | VV V | NA N | HGA hg | DGA dg | h/d h/dg | GA G | VA V | GWLV GWL | MGH MGH | IG IG | IV IV | DGZ dGZ | PER PER | VG V | GG G |
| | a | | | m | cm | | m | cm | | m² | m³ | | m | cm | | m² | m³ | m² | m² | m² | m³ | m³ | a | m³ | m³ |
| 1974 | 11 | N. spruce | 5163 | 3.6 | 4.6 | 78 | 2.8 | 2.9 | 96 | 3.38 | 9 | 10 | 1.9 | 1.1 | 172 | 0.00 | 0 | 9 | | | | 0.8 | | 9 | 3.4 |
| 1979 | 16 | N. spruce | 3841 | 8.1 | 10.1 | 80 | 6.8 | 7.4 | 91 | 16.53 | 65 | 1322 | 5.7 | 5.6 | 101 | 3.22 | 11 | 77 | 11.6 | 3.3 | 13.5 | 4.8 | 5 | 77 | 19.8 |
| 1984 | 21 | N. spruce | 3830 | 11.8 | 14.1 | 83 | 10.2 | 9.9 | 103 | 29.31 | 164 | 11 | 5.6 | 4.3 | 130 | 0.02 | 0 | 176 | 22.9 | 2.6 | 19.8 | 8.4 | 5 | 164 | 29.3 |
| 1990 | 27 | N. spruce | 3757 | 16.3 | 18.9 | 86 | 13.8 | 12.5 | 110 | 45.85 | 336 | 73 | 12.1 | 9.8 | 123 | 0.55 | 4 | 352 | 37.9 | 2.8 | 29.3 | 13.0 | 6 | 340 | 46.4 |
| 1995 | 32 | N. spruce | 3431 | 20.4 | 22.7 | 89 | 17.5 | 14.4 | 121 | 55.82 | 510 | 326 | 13.8 | 8.3 | 166 | 1.76 | 14 | 538 | 51.7 | 2.3 | 37.3 | 16.8 | 5 | 523 | 57.6 |
| 2000 | 37 | N. spruce | 2896 | 22.6 | 24.7 | 91 | 19.7 | 15.9 | 123 | 57.63 | 583 | 535 | 18.0 | 12.7 | 141 | 6.82 | 65 | 677 | 60.1 | 1.7 | 27.6 | 18.3 | 5 | 648 | 64.5 |
| 2005 | 42 | N. spruce | 2382 | 24.6 | 27.9 | 88 | 21.8 | 18.2 | 119 | 61.71 | 674 | 514 | 17.7 | 11.3 | 156 | 5.13 | 49 | 817 | 62.2 | 1.8 | 28.1 | 19.5 | 5 | 723 | 66.8 |
| 2010 | 47 | N. spruce | 2193 | 26.9 | 31.2 | 86 | 23.6 | 20.0 | 118 | 68.86 | 803 | 189 | 20.1 | 13.6 | 147 | 2.72 | 29 | 975 | 66.6 | 2.0 | 31.6 | 20.7 | 5 | 832 | 71.6 |
| 2017 | 54 | N. spruce | 1794 | 29.7 | 35.1 | 84 | 26.0 | 22.4 | 116 | 70.48 | 890 | 399 | 22.9 | 16.7 | 137 | 8.71 | 102 | 1164 | 74.0 | 1.5 | 27.0 | 21.6 | 7 | 992 | 79.2 |

## ZUS 603 Plot 2, initial spacing 1 x 1 m, untreated

| | | | Verbleibender Bestand Remaining Stand | | | | | | | | | Ausscheidender Bestand Removal Stand | | | | | | Gesamtbestand Total Stand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHR YEAR | A T | BA SP | NV N | HO hdom | DO ddom | HO/DO h/ddom | HGV hg | DGV dg | HG/DG h/dg | GV G | VV V | NA N | HGA hg | DGA dg | h/d h/dg | GA G | VA V | GWLV GWL | MGH MGH | IG IG | IV IV | DGZ dGZ | PER PER | VG V | GG G |
| | a | | | m | cm | | m | cm | | m² | m³ | | m | cm | | m² | m³ | m² | m² | m² | m³ | m³ | a | m³ | m³ |
| 1974 | 11 | N. spruce | 9941 | 4.0 | 4.7 | 85 | 2.8 | 2.8 | 100 | 5.96 | 17 | 248 | 1.5 | 1.0 | 150 | 0.02 | 0 | 17 | | | | 1.5 | | 17 | 6.0 |
| 1979 | 16 | N. spruce | 9870 | 7.8 | 8.9 | 87 | 5.8 | 5.6 | 103 | 24.62 | 89 | 71 | 3.0 | 1.8 | 166 | 0.02 | 0 | 89 | 15.3 | 3.7 | 14.5 | 5.6 | 5 | 89 | 24.6 |
| 1984 | 21 | N. spruce | 9304 | 10.7 | 11.7 | 91 | 8.7 | 7.1 | 122 | 36.50 | 182 | 566 | 4.5 | 3.0 | 150 | 0.39 | 1 | 184 | 30.8 | 2.5 | 18.9 | 8.8 | 5 | 184 | 36.9 |
| 1990 | 27 | N. spruce | 7193 | 14.9 | 16.1 | 92 | 12.4 | 9.3 | 133 | 49.11 | 337 | 2111 | 8.9 | 5.0 | 178 | 4.19 | 21 | 359 | 44.9 | 2.8 | 29.2 | 13.3 | 6 | 358 | 53.3 |
| 1995 | 32 | N. spruce | 5295 | 19.4 | 20.2 | 96 | 15.8 | 11.6 | 136 | 56.32 | 482 | 1898 | 11.6 | 6.5 | 178 | 6.23 | 40 | 545 | 55.8 | 2.7 | 37.2 | 17.0 | 5 | 522 | 62.5 |
| 2000 | 37 | N. spruce | 3762 | 22.6 | 23.8 | 94 | 18.3 | 14.0 | 130 | 57.81 | 560 | 1533 | 13.5 | 8.0 | 168 | 7.71 | 58 | 681 | 60.9 | 1.8 | 27.1 | 18.4 | 5 | 618 | 65.5 |
| 2005 | 42 | N. spruce | 2524 | 24.7 | 27.2 | 90 | 21.5 | 16.9 | 127 | 56.90 | 621 | 1238 | 16.8 | 10.0 | 168 | 9.75 | 89 | 832 | 62.2 | 1.8 | 30.2 | 19.8 | 5 | 711 | 66.7 |
| 2010 | 47 | N. spruce | 2229 | 27.5 | 30.7 | 89 | 23.8 | 19.1 | 124 | 63.79 | 757 | 295 | 17.9 | 10.8 | 165 | 2.72 | 26 | 994 | 61.7 | 1.9 | 32.4 | 21.1 | 5 | 783 | 66.5 |
| 2017 | 54 | N. spruce | 1274 | 30.2 | 33.8 | 89 | 26.6 | 22.2 | 119 | 49.08 | 636 | 955 | 24.6 | 18.2 | 135 | 24.73 | 307 | 1180 | 68.8 | 1.4 | 26.6 | 21.9 | 7 | 943 | 73.8 |

## ZUS 603 Plot 3, initial spacing 2 x 2 m, untreated

| | | | Verbleibender Bestand Remaining Stand | | | | | | | | | Ausscheidender Bestand Removal Stand | | | | | | Gesamtbestand Total Stand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHR YEAR | A T | BA SP | NV N | HO hdom | DO ddom | HO/DO h/ddom | HGV hg | DGV dg | HG/DG h/dg | GV G | VV V | NA N | HGA hg | DGA dg | h/d h/dg | GA G | VA V | GWLV GWL | MGH MGH | IG IG | IV IV | DGZ dGZ | PER PER | VG V | GG G |
| | a | | | m | cm | | m | cm | | m² | m³ | | m | cm | | m² | m³ | m² | m² | m² | m³ | m³ | a | m³ | m³ |
| 1974 | 11 | N. spruce | 2480 | 3.8 | 5.0 | 76 | 2.9 | 3.3 | 87 | 2.18 | 6 | 30 | 1.7 | 1.1 | 154 | 0.00 | 0 | 6 | | | | 0.5 | | 6 | 2.2 |
| 1979 | 16 | N. spruce | 2480 | 7.5 | 11.1 | 67 | 6.3 | 8.1 | 77 | 12.68 | 47 | 0 | 0.0 | 0.0 | 166 | 0.00 | 0 | 47 | 7.4 | 2.1 | 8.2 | 2.9 | 5 | 47 | 12.7 |
| 1984 | 21 | N. spruce | 2461 | 11.0 | 15.3 | 71 | 9.7 | 11.4 | 85 | 25.04 | 130 | 19 | 6.8 | 6.6 | 103 | 0.07 | 0 | 131 | 18.9 | 2.5 | 16.8 | 6.2 | 5 | 131 | 25.1 |
| 1990 | 27 | N. spruce | 2402 | 14.8 | 19.8 | 74 | 13.3 | 14.4 | 92 | 39.15 | 269 | 59 | 12.2 | 12.0 | 101 | 0.66 | 5 | 274 | 32.4 | 2.5 | 23.9 | 10.2 | 6 | 274 | 39.8 |
| 1995 | 32 | N. spruce | 2333 | 20.2 | 23.2 | 87 | 17.9 | 16.6 | 107 | 50.42 | 460 | 69 | 11.5 | 7.9 | 145 | 0.34 | 2 | 467 | 45.0 | 2.3 | 38.6 | 14.6 | 5 | 463 | 50.8 |
| 2000 | 37 | N. spruce | 2176 | 22.1 | 25.6 | 86 | 20.0 | 18.2 | 109 | 56.43 | 564 | 157 | 17.6 | 13.2 | 133 | 2.16 | 20 | 591 | 54.5 | 1.6 | 24.8 | 16.0 | 5 | 584 | 58.6 |
| 2005 | 42 | N. spruce | 1853 | 25.0 | 27.9 | 89 | 22.7 | 20.4 | 111 | 60.31 | 673 | 323 | 17.6 | 11.8 | 149 | 3.54 | 33 | 733 | 60.1 | 1.5 | 28.4 | 17.5 | 5 | 706 | 63.9 |
| 2010 | 47 | N. spruce | 1735 | 27.0 | 30.5 | 88 | 24.5 | 22.1 | 110 | 66.55 | 791 | 118 | 20.3 | 14.5 | 140 | 1.93 | 20 | 872 | 64.4 | 1.6 | 27.8 | 18.6 | 5 | 812 | 68.5 |
| 2017 | 54 | N. spruce | 1451 | 30.3 | 33.9 | 89 | 27.5 | 24.5 | 112 | 68.33 | 898 | 284 | 24.5 | 18.3 | 133 | 7.52 | 93 | 1071 | 71.2 | 1.3 | 28.5 | 19.8 | 7 | 991 | 75.8 |

## ZUS 603 Plot 4, initial spacing 1 x 1 m, thinned

| | | | Verbleibender Bestand Remaining Stand | | | | | | | | | Ausscheidender Bestand Removal Stand | | | | | | Gesamtbestand Total Stand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHR YEAR | A T | BA SP | NV N | HO hdom | DO ddom | HO/DO h/ddom | HGV hg | DGV dg | HG/DG h/dg | GV G | VV V | NA N | HGA hg | DGA dg | h/d h/dg | GA G | VA V | GWLV GWL | MGH MGH | IG IG | IV IV | DGZ dGZ | PER PER | VG V | GG G |
| | a | | | m | cm | | m | cm | | m² | m³ | | m | cm | | m² | m³ | m² | m² | m² | m³ | m³ | a | m³ | m³ |
| 1974 | 11 | N. spruce | 9863 | 3.5 | 4.1 | 85 | 2.6 | 2.5 | 104 | 4.85 | 14 | 245 | 1.5 | 1.0 | 150 | 0.02 | 0 | 14 | | | | 1.3 | | 14 | 4.9 |
| 1979 | 16 | N. spruce | 4922 | 6.5 | 7.8 | 83 | 5.2 | 5.1 | 101 | 9.88 | 33 | 4941 | 5.2 | 5.1 | 101 | 10.26 | 34 | 67 | 12.5 | 3.1 | 10.5 | 4.2 | 5 | 67 | 20.1 |
| 1984 | 21 | N. spruce | 4137 | 10.1 | 12.0 | 84 | 8.0 | 7.7 | 103 | 19.45 | 91 | 785 | 7.6 | 7.2 | 105 | 3.15 | 14 | 139 | 16.2 | 2.5 | 14.5 | 6.6 | 5 | 105 | 22.6 |
| 1990 | 27 | N. spruce | 3804 | 13.8 | 17.9 | 77 | 11.2 | 11.1 | 100 | 36.91 | 227 | 333 | 7.6 | 4.4 | 172 | 0.50 | 2 | 278 | 28.4 | 3.0 | 23.0 | 10.3 | 6 | 229 | 37.4 |
| 1995 | 32 | N. spruce | 2039 | 19.0 | 22.2 | 85 | 16.0 | 14.5 | 110 | 33.64 | 283 | 1765 | 14.0 | 11.1 | 126 | 17.10 | 134 | 467 | 43.8 | 2.8 | 37.9 | 14.6 | 5 | 416 | 50.7 |
| 2000 | 37 | N. spruce | 1804 | 21.5 | 26.2 | 82 | 18.4 | 16.7 | 110 | 39.42 | 370 | 235 | 17.8 | 15.6 | 114 | 4.51 | 42 | 597 | 38.8 | 2.1 | 25.9 | 16.1 | 5 | 412 | 43.9 |
| 2005 | 42 | N. spruce | 1588 | 24.3 | 30.5 | 79 | 21.3 | 19.3 | 110 | 46.70 | 494 | 216 | 14.9 | 9.6 | 155 | 1.56 | 13 | 733 | 43.8 | 1.8 | 27.3 | 17.5 | 5 | 506 | 48.3 |
| 2010 | 47 | N. spruce | 1402 | 26.5 | 34.6 | 76 | 23.5 | 21.9 | 107 | 52.73 | 602 | 186 | 20.3 | 14.9 | 136 | 3.26 | 35 | 876 | 51.3 | 1.9 | 28.6 | 18.6 | 5 | 637 | 56.0 |
| 2017 | 54 | N. spruce | 971 | 29.6 | 38.7 | 76 | 26.5 | 25.8 | 102 | 50.86 | 638 | 431 | 23.6 | 18.9 | 124 | 12.16 | 144 | 1056 | 57.9 | 1.5 | 25.7 | 19.6 | 7 | 782 | 63.0 |

## ZUS 603 Plot 5, initial spacing 1.4 x 1.4 m, thinned

| | | | Verbleibender Bestand Remaining Stand | | | | | | | | | Ausscheidender Bestand Removal Stand | | | | | | Gesamtbestand Total Stand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHR YEAR | A T | BA SP | NV N | HO hdom | DO ddom | HO/DO h/ddom | HGV hg | DGV dg | HG/DG h/dg | GV G | VV V | NA N | HGA hg | DGA dg | h/d h/dg | GA G | VA V | GWLV GWL | MGH MGH | IG IG | IV IV | DGZ dGZ | PER PER | VG V | GG G |
| | a | | | m | cm | | m | cm | | $m^2$ | $m^3$ | | m | cm | | $m^2$ | $m^3$ | $m^2$ | $m^2$ | $m^2$ | $m^3$ | $m^3$ | a | $m^3$ | $m^3$ |
| 1974 | 11 | N. spruce | 5010 | 4.0 | 4.5 | 88 | 2.9 | 2.8 | 103 | 2.98 | 8 | 77 | 1.9 | 1.2 | 158 | 0.01 | 0 | 8 | | | | 0.8 | | 8 | 3.0 |
| 1979 | 16 | N. spruce | 2500 | 8.3 | 10.6 | 78 | 6.9 | 7.6 | 90 | 11.41 | 46 | 2510 | 6.7 | 7.3 | 91 | 10.43 | 42 | 88 | 12.4 | 3.8 | 15.9 | 5.5 | 5 | 88 | 21.8 |
| 1984 | 21 | N. spruce | 2038 | 12.0 | 16.3 | 73 | 10.8 | 11.7 | 92 | 21.89 | 127 | 462 | 10.1 | 9.7 | 104 | 3.40 | 19 | 188 | 18.3 | 2.8 | 19.9 | 8.9 | 5 | 146 | 25.3 |
| 1990 | 27 | N. spruce | 1250 | 17.2 | 23.8 | 72 | 15.1 | 17.3 | 87 | 29.29 | 224 | 788 | 13.3 | 12.5 | 106 | 9.69 | 69 | 354 | 30.4 | 2.8 | 27.7 | 13.1 | 6 | 293 | 39.0 |
| 1995 | 32 | N. spruce | 1115 | 22.1 | 29.1 | 75 | 19.8 | 20.5 | 96 | 36.71 | 357 | 135 | 19.8 | 20.3 | 97 | 4.35 | 42 | 529 | 35.2 | 2.4 | 35.0 | 16.5 | 5 | 399 | 41.1 |
| 2000 | 37 | N. spruce | 808 | 24.2 | 32.7 | 74 | 22.1 | 23.2 | 95 | 34.23 | 362 | 307 | 21.8 | 22.4 | 97 | 12.12 | 128 | 662 | 41.5 | 1.9 | 26.5 | 17.9 | 5 | 490 | 46.3 |
| 2005 | 42 | N. spruce | 760 | 27.2 | 37.0 | 73 | 24.8 | 26.7 | 92 | 42.44 | 493 | 48 | 18.4 | 14.1 | 130 | 0.75 | 7 | 800 | 38.7 | 1.8 | 27.7 | 19.1 | 5 | 501 | 43.2 |
| 2010 | 47 | N. spruce | 683 | 29.5 | 40.9 | 72 | 26.7 | 29.0 | 92 | 45.20 | 560 | 77 | 27.0 | 29.9 | 90 | 5.42 | 67 | 934 | 46.5 | 1.6 | 26.7 | 19.9 | 5 | 627 | 50.6 |
| 2017 | 54 | N. spruce | 558 | 31.8 | 45.8 | 69 | 29.2 | 33.5 | 87 | 49.08 | 649 | 125 | 26.5 | 25.3 | 104 | 6.30 | 80 | 1103 | 50.3 | 1.5 | 24.1 | 20.4 | 7 | 728 | 55.4 |

## ZUS 603 Plot 6, initial spacing 2 x 2 m, thinned

| | | | Verbleibender Bestand Remaining Stand | | | | | | | | | Ausscheidender Bestand Removal Stand | | | | | | Gesamtbestand Total Stand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAHR YEAR | A T | BA SP | NV N | HO hdom | DO ddom | HO/DO h/ddom | HGV hg | DGV dg | HG/DG h/dg | GV G | VV V | NA N | HGA hg | DGA dg | h/d h/dg | GA G | VA V | GWLV GWL | MGH MGH | IG IG | IV IV | DGZ dGZ | PER PER | VG V | GG G |
| | a | | | m | cm | | m | cm | | $m^2$ | $m^3$ | | m | cm | | $m^2$ | $m^3$ | $m^2$ | $m^2$ | $m^2$ | $m^3$ | $m^3$ | a | $m^3$ | $m^3$ |
| 1974 | 11 | N. spruce | 2441 | 4.1 | 5.0 | 82 | 2.9 | 3.1 | 93 | 1.88 | 5 | 59 | 1.7 | 1.3 | 130 | 0.01 | 0 | 5 | | | | 0.5 | | 5 | 1.9 |
| 1979 | 16 | N. spruce | 1284 | 7.6 | 11.6 | 65 | 6.6 | 8.8 | 75 | 7.77 | 29 | 1157 | 6.4 | 8.4 | 76 | 6.43 | 24 | 53 | 8.0 | 2.5 | 9.6 | 3.3 | 5 | 53 | 14.2 |
| 1984 | 21 | N. spruce | 1137 | 11.4 | 18.2 | 62 | 10.4 | 14.4 | 72 | 18.40 | 99 | 147 | 10.3 | 14.0 | 73 | 2.26 | 12 | 135 | 14.2 | 2.6 | 16.3 | 6.4 | 5 | 111 | 20.7 |
| 1990 | 27 | N. spruce | 696 | 16.5 | 25.6 | 64 | 15.8 | 21.6 | 73 | 25.53 | 194 | 441 | 14.9 | 17.8 | 83 | 10.94 | 81 | 312 | 27.4 | 3.0 | 29.5 | 11.5 | 6 | 276 | 36.5 |
| 1995 | 32 | N. spruce | 627 | 21.1 | 31.0 | 68 | 20.0 | 26.4 | 75 | 34.43 | 323 | 69 | 18.2 | 21.0 | 86 | 2.38 | 21 | 461 | 31.2 | 2.3 | 29.9 | 14.4 | 5 | 344 | 36.8 |
| 2000 | 37 | N. spruce | 549 | 24.1 | 35.5 | 67 | 22.9 | 30.6 | 74 | 40.31 | 422 | 78 | 23.0 | 31.0 | 74 | 5.92 | 62 | 622 | 40.3 | 2.4 | 32.2 | 16.8 | 5 | 484 | 46.2 |
| 2005 | 42 | N. spruce | 480 | 26.4 | 39.9 | 66 | 25.2 | 34.3 | 73 | 44.51 | 503 | 69 | 24.7 | 32.4 | 76 | 5.66 | 64 | 767 | 45.2 | 2.0 | 28.9 | 18.3 | 5 | 567 | 50.2 |
| 2010 | 47 | N. spruce | 422 | 29.2 | 43.9 | 66 | 27.6 | 37.4 | 73 | 46.22 | 565 | 58 | 27.8 | 38.2 | 72 | 6.75 | 83 | 912 | 48.7 | 1.7 | 29.0 | 19.4 | 5 | 648 | 53.0 |
| 2017 | 54 | N. spruce | 343 | 30.8 | 49.4 | 62 | 29.8 | 42.1 | 70 | 47.72 | 615 | 79 | 29.4 | 39.6 | 74 | 9.64 | 124 | 1086 | 51.8 | 1.6 | 24.8 | 20.1 | 7 | 739 | 57.4 |

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