SILVE

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APPLIED PERIOD (Research Activities)

The effect of climate and hydrology on tree-ring width of Oak (Quercus robur) from different sites at Slangenburg forest in the Netherlands

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ABSTRACT

Global temperature is currently increasing and this is expected to continue in the near future. The change of certain aspects of climate, i.e. temperature and precipitation, can be examined by studying variation in tree-ring width. Tree rings are an important data source to gather information on (past) forest management. Tree-ring chronologies of oak have been used to reconstruct aspects of climate in different regions in Europe. The aim of the study was to determine the effect of climate and hydrology on tree-ring width of oak (*Quercus robur*), on 12 forest inventory plots in the Slangenburg forest. These plots can be classified into four groups that differ in altitude and therefore in hydrological circumstances. A total of 60 cores samples were collected. The cores were prepared, measured the tree rings and analyzed the data in the laboratory of University of Wageningen, Department of Forest Ecology and Management. The results show that, the oak trees in the different plots and sites have minor differences in growth trend and level. Furthermore, the climate-growth relationship of the oak trees growing at the four sub-sites is very similar which means that local hydrology has hardly any influence on the climate effects on the growth of the oaks. Therefore we can conclude that the oaks are well adapted to the local water availability. In addition, the amount of precipitation during the growing season has no influence on tree growth, whereas precipitation during the previous winter and (early) spring are positively (and significantly) related to the growth of oak. Dry winters can have a dramatically bad influence on the physiology of oak.

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Chapter one

Introduction

The surface of the Earth is in constant change. One of the main driving forces behind this change is climate. Climate is not static; instead, it changes over longer periods of time. The climate of one region today can be completely different from the climate of the past (and of the future)

The life cycles of most plants are strongly influenced by climate. Global temperature is currently increasing and this is expected to continue in the near future (Askeyev *et al.*, 2004). The change of certain aspects of climate, i.e. temperature and precipitation, can be examined by studying variation in tree-ring width of different tree species. Tree-ring width series can be taken as a record to study and reconstruct those external, i.e. climate (related) factors that mainly influence the growth of a tree species growing under certain site conditions. This means that tree species growing under poor soil conditions and under dry climate conditions are very likely to show a positive response to the amount of precipitation as precipitation acts as limiting factor for tree growth.

In addition, tree rings are an important data source to gather information on (past) forest management. The general growth trend, reflected by changes in growth level from the juvenile to the adult phase, provides information on the way how the tree reached the canopy and indicates whether it experienced favourable or unfavourable light conditions during its life cycle. Tree rings width sometimes increases rapidly in the first years of a tree's life and then decreases more or less rapidly over subsequent decades, the main change occurring in early wood rather than latewood. Abrupt changes in growth level may point to management activities such as cutting events (Spiecker, 2002).

Oak is an important species in forest ecosystems and plays a basic role in the functioning of ecosystems by providing food and habitat for a wide range of animals. Pedunculate oak (*Quercus robur*) has an important symbolic, cultural, historic, commercial and biodiversity role in many European countries.

The objective of this study was to determine the relationship between the growth of oak, as reflected by tree-ring width, and varying weather/climate conditions. Monthly mean temperature and the monthly sum of precipitation are used to study the influence of both factors on the growth of oak during the last 55 years. The climatic factors affecting tree growth were identified (1) by distinguishing “pointer years”, which correspond to abrupt changes in growth pattern and most likely reveal the tree growth response to extreme climate events (2) by establishing the mean relationships between tree-ring width and climate by using DendroClim 2002 programme (Biondi and Waikul, 2004).

Chapter two

Literature Review

Oak description

European oak (*Quercus robur and Q. petraea*) are deciduous tree species. These are broad-leaved trees that shed all their leaves during one season. The term oak can be used as part of the common name of any of several hundred species of tree and shrubs in the genus *Quercus*. The genus is native to the northern hemisphere, and includes deciduous and evergreen species extending from cold latitudes to tropical Asia and the Americans.

The tree bear a nut -fruit called an acorn (figure 1), borne in a cup-like structure known as a cupule's. Each acorn contains one seed (rarely two or three) and takes 6-18 months to mature, depending on species.

Figure 1, Foliage and acorns of *Quercus robur* in Slangenburg Forest

The acorns dormancy is not deep; many begin to germinate by putting out a root very soon after falling, though a shoot is not produced until the spring. The seedlings develop a substantial tap root. Under sheltered conditions and deep soil, oaks can grow into magnificent trees 40 m (130 ft) or more in height. The tallest trees are not, however, particularly old – probably no more than about 300 years. As oak is a non-shadow tolerant species the typical development of the tree includes a period of quite rapid growth for around 80-120 years, followed by a gradual slowing down.

Uses of oak

Oak became the main wood for making the charcoal needed for the furnaces which separated iron from its ore. It later became the main construction material for houses, churches and ships as it was strong and durable and its twisted branches provided the right shapes needed (Glennie, 1998). The Oak tree also, has medicinal value especial their leaves and barks. A decoction of the bark can be used for reducing fevers, diarrhea, dysentery, tonsillitis, pharyngitis and laryngitis (Glennie, 1998).

Dendrochronology and oak

Oak is one of the main species used for Dendrochronology in Europe. Tree-ring chronologies of oak have been used to reconstruct aspects of climate in different regions in Europe. Tree rings are formed by the physiological growth of a tree. As ring-porous species tree rings of oak consist of two distinct zones, the early wood, and the late wood (figure 2). The early wood is formed during (early) spring before bud break and is characterized by big, up to 200 µm wide vessels. The late wood is formed during the rest of the growing season and contains small vessels which are imbedded in fibre tissue (Fritts, 1976).

The early growth in a tree, which produces early wood, is called periclinal growth, and lasts in early summer (Fritts, 1976). At this time of the year, the growth activity is reduced and the type of growth is termed aestival growth. By the middle of the summer nearly all of the growth has already taken place. The tree will grow only slightly until the end of the growing season. The period of aestival growth is also called late-wood. The latewood in a tree ring marks the end of one year and the beginning of the next year.

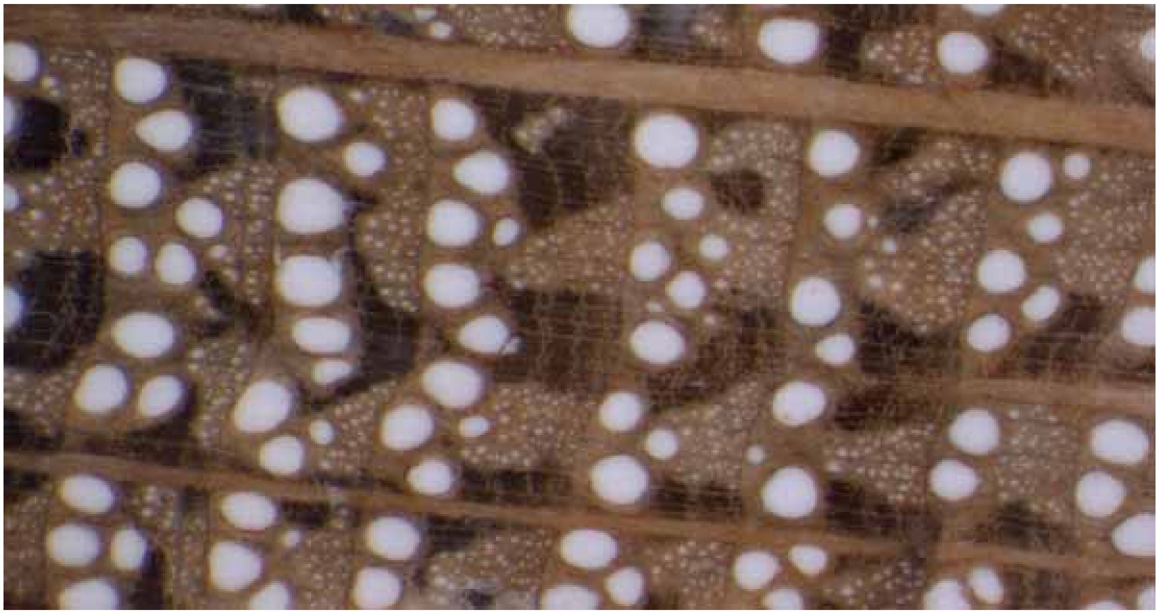

Figure 2, Microscopic view of oak early wood (white spot bands) and late wood (brown bands).

A tree's growth potential usually decreases from top (crown) to bottom (stem base). Tree ring, early wood and late wood widths decrease after an initial juvenile phase, and then continuously decline. The tree-ring width of a certain year reflects the growth activity of a tree in this specific year which can be affected by numerous factors. Thus, tree-ring width can be regarded as a highly integrating variable (Stokes and Smile, 1996). Moreover, the growth activity of the tree in one year will affect its performance of growth in the following years (Schweingruber, 1988).

Effect of weather/climate on tree rings

In early summer the early wood grows rapidly and life of the cells is short, only 5-20 days. In the late summer the rate of growth is greatly reduced and the formation of the latewood takes about 2-3 months. Climate can influence the radial increment of a stem at any time. As trees in the forest grow up in a stand, changing in light conditions have a strong influence on tree growth, less light, due to competition with neighbouring trees may lead to the formation of narrow tree rings.

Temperature

Temperature is a major limiting factor for tree growth. Generally, tree rings are very narrow in stands along cold area and potentially wider in warm, moist regions. Most influential and damaging are extreme temperature changes such as late frosts and strong winter frosts. Important for growth are the processes which take place in the water-conducting sapwood area and in the cambium. Direct effects of temperature on radial growth are often observed at the beginning of the season when the unusually cold weather causes a delay in growth activation after dormancy. (Fritts, 1976). In cold areas warm conditions during the end of the growing season are most favourable and result in wider tree rings while at hot and dry sites tree-ring width is affected negatively due to increasing drought stress.

Precipitation

Precipitation falls on and is absorbed by plants in the form of rain, snow, cloud, dew, sleet and hail. The intensity of the precipitation in each form determines the growth. The amount of precipitation is closely related to the geographical location. The availability of water is also determined by soil's physical properties.

Chapter Three

Methodology

Study site

This study was conducted in the Slangenburg forest. This forest is located 5 km east of the town of Doetinchem in the province of Gelderland (51°57'40, 6°22'02). Soils are mainly podzolic soils in loamy, fine sands. On the higher sites the sands have little loam. Most sites are under the influence of soil water, according to the soil map. However, the hydrological conditions have changed in this part of the country and the ground water table is nowadays generally lower than it used to be. The forest of Slangenburg has an area of 282 ha, and is located on altitudes ranging from14 to 18 m above sea level.

The Slangenburg forest belongs to the Dutch Forest Service. The forest is dominated by oak (*Quercus robur*) and beech (*Fagus sylvatica).* Birch (*Betula spp.*), Douglas fir (*Pseudotsuga menziesii), Norway spruce* (*Picea abies)* and Japanese larch (*Larix kaempferi)* also have their share. The management objectives of this forest are ecological and timber harvesting. The mean annual temperature and total annual precipitation is 9.4°C and 782 mm, respectively during the period from 1904 to 2004. The growing season in the study area is approximately April–October.

Climate condition

The climate of the study area is Maritime, with cool summers and mild winters (figure 3).

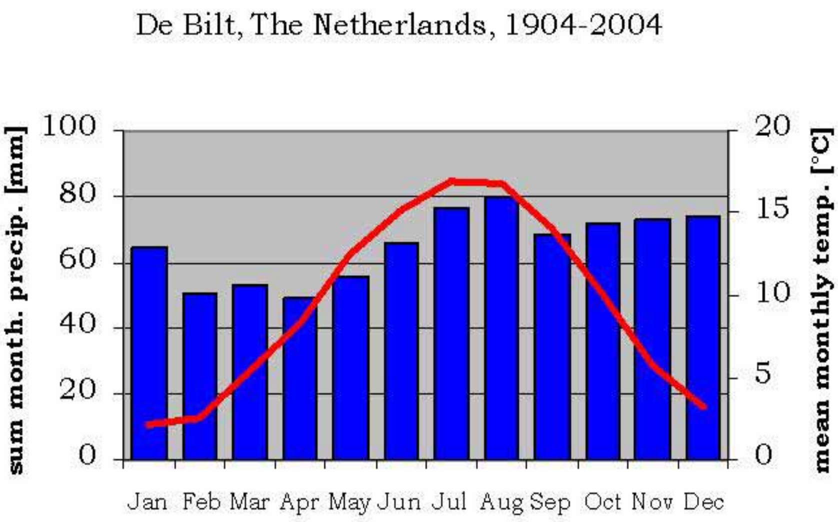

Figure 3, Climatic data from De Bilt, bar indicating sum monthly Precipitation (mm) and line for mean monthly temperature (°c)

Site description

Field work

A total of 60 dominant oaks (> 40 cm of diameter) from 4 site classes were selected and cored to the pith (one core per tree) and measured (diameter at breast height over bark). Trees which are damaged by strong winter frosts and drought were excluded. Classification of site classes depends on altitude and hydrological condition as:

- site 1 ≤ 16 meter above sea level (wettest site),
- site 2 ≥16-16.5m a.s.l.
- site 3 ≥ 16.5-17 m a.s.l. and
- site 4 ≥ 17m a.s.l. (dryest site).

Tree cores were taken by using an increment borer (figure 4). The tree core sample was then placed into the increment core holder and labeled.

Figure 4, Extraction of core by using Increment Borer in Oak Tree

Laboratory work

In the laboratory the tree cores were mounted with water–soluble glue in wooden holder’s band labeled. The cores (annual ring surfaces) were glued vertically into the groove, and fixed until they have fully dried out (figure 5).

Figure 5, core mounting

Surface preparation the cross section of the wood was cut with a Stanley knife, until all rings are clearly visible. The number of sapwood rings was counted for each sample. After that, chalk was rubbed on the surface to enhance the contrast between cell lumina and cell walls and enable a better detection of the tree-ring boundaries.

Tree-ring measurement

Tree-ring widths were measured starting from the bark to the pith with a precision of 0.01 mm, using a LINTAB measuring table (RinnTec) associated with the program TSAP (Rinn, 1996). The time series were visually and statistically cross-dated (Cook & Kairiukstis, 1990; Stokes and Smiley, 1996). Visual cross-dating was checked by using the COFECHA software (Holmes, 1983; Grissino-Mayer, 2001).

Statistical description of tree-ring series

A standard arithmetic mean function was used to produce a standardized growth curve for each site. TSAP also provides a statistical description of the cross-dated time series comprising information on mean tree-ring width, standard deviation (SD), mean sensitivity (MS) and autocorrelation (AC) (Fritts, 1976).

The *Mean Sensitivity* of a tree-ring series describes its year-to year variability and is calculated as

$$\overline{S} = \frac{\sum_{i=1}^{n-1} \left| s_i + 1 \right|}{n-1} \qquad \text{Where } s_i = \frac{\left(x_i - x_{i-1}\right)}{\left(x_i + x_{i-1}\right)} * 2$$

$\overline{S}$ = mean sensitivity

N= total number of rings in the series

S_i= sensitivity in interval i

x_i = observed value of the tree ring series x at moment i

The *Autocorrelation* describes the relation of the ring width in a particular year to that of the proceeding year(s) and is expressed by the autocorrelation coefficient. The value of Pearson’s correlation coefficient is used as Autocorrelation coefficient and is calculated as

Pearson's correlation coefficients = r

$$r=\pm \sum (xi-\bar{x})(y_i-\bar{y})/\text{sqrt} \sum (x_i-\bar{x})^2 \sum (y-\bar{y})^2$$

Standardized tree ring series are used for calculation of correlation coefficient. Plots are made for all measured tree ring series per plot (5trees) and per site (15 trees) in order to discuss the similarity in tree ring partner.

Standardisation and calculation of tree-ring chronologies

Growth trend due to physiological ageing processes can be predicted from statistically derived equations, by dividing the actual tree ring measurements by their predicted value. A 30-year spline was fitted to the single tree-ring records to remove any age-related trend in the series. Tree-ring indices were then calculated by dividing each of the original tree-ring widths by the value of the fitted spline (Cook, 1985). Tree-ring chronologies were calculated on plot level (5 trees) and site level (15 trees). In addition a site chronology was constructed whereby all 60 trees were included after standardisation.

Response-Function Analysis

Climate-growth analyses were carried out (program DendroClim 2002, Biondi and Waikul, 2004) to assess the impact of changes in monthly mean temperature and the monthly sum of precipitation on the annual variation of tree-ring width during the period from 1951 to 2004. Climate data records from De Bilt were used to study the impact of precipitation and temperature from October of the previous year till September of the observed year. Response function analyses were carried out by using the site chronology calculated from all 60 trees as well as the chronologies of site 1 (wettest site) and site 4 (dry site).

Chapter Four

Results

Standardisation and calculation of tree-ring chronologies

The results show that (table 1) growth rate is highest (2.21mm/yr) at the wettest site 1 (<16m) and lowest (1.87mm/yr) at the drier site 4 (>17m), comparable growth rates were found at the two other sites (2.08 and 2.06 mm/yr). The variation of the individual tree-ring widths around this mean (presented by the standard deviation) was relatively low and comparable for the four sites, indicating the ecological homogeneity of the sites (Schweingruber, 1988).

Mean sensitivity is slightly higher for site 1 than for the other sites, indicating that the growth of individual trees on this site is affected most by environmental factors or other factors which influence physiological process of tree growth. Autocorrelation coefficients are considerably higher at site 4 compared to the other three sites (0.68 compared to 0.56, 0.60 and 0.64).On this site, growth in the proceeding year has influenced the year under investigation and a significant growth trend is present in the samples.

Table1. Descriptive statistics of the tree-ring series of oak for the four sites at Slangenburg Forest.

Descriptive statistics	**Site 1**	**Site2**	**Site 3**	**Site 4**
Number of trees	15	15	15	15
Mean ring width (mm)	2.21	2.08	2.06	1.87
Standard deviation (mm)	0.8	0.8	0.85	0.85
Mean sensitivity	0.27	0.26	0.26	0.25
Autocorrelation r	0.56	0.60	0.64	0.68

Tree-ring chronology curves per plot level (5 trees) (appendix 1) shows similar growth pattern; however there is big depression of tree–ring width (less than 2mm) during 1900- 1930 for plots Z25, AB26, AG28 and W13. Also, the depression growth was observed on the site level (15 trees) (appendix 2). This may be due to unusual cold weather which causes delay in breaking dormancy and decreasing the length of the growing seasons and consequently narrow ring formed. Peaks coincide almost everywhere for the all 4 sites (appendix 3) during the investigated period which means that there is no real difference in the way the sample trees react to environmental factors.

Response-Function Analysis

The correlation coefficients between the sites chronology comprising of all 60 trees is illustrated in figure 6. The response functions for the wettest and the driest site are given in appendix 4. The bars represented the influence of the sum of precipitation in a certain month and the lines reflect the influence of monthly mean temperature; asterix indicate months of significant coefficients at the 0.05 level. Coefficients of precipitation for the (early) summer month, from May to September are generally negative whereas above-average precipitation during the previous winter and spring are positively related to the growth of oak at the Slangenburg site (fig.6).

Significant correlation occurs between the tree-ring chronologies and the sum of precipitation in the previous November as well as in early spring, in March and April of the observed year (r= 0.36, 0.22, 0.35) respectively. Thus, the amount of precipitation during previous autumn and winter and in (early) spring, the period just before the start of the growing season is crucial for the growth of oak. In addition there is significant correlation in temperature during January and September; warm weather at the end of the growing season is favorable for respiration and photosynthesis process and results in the formation of wide tree rings due to prolonged growing seasons.

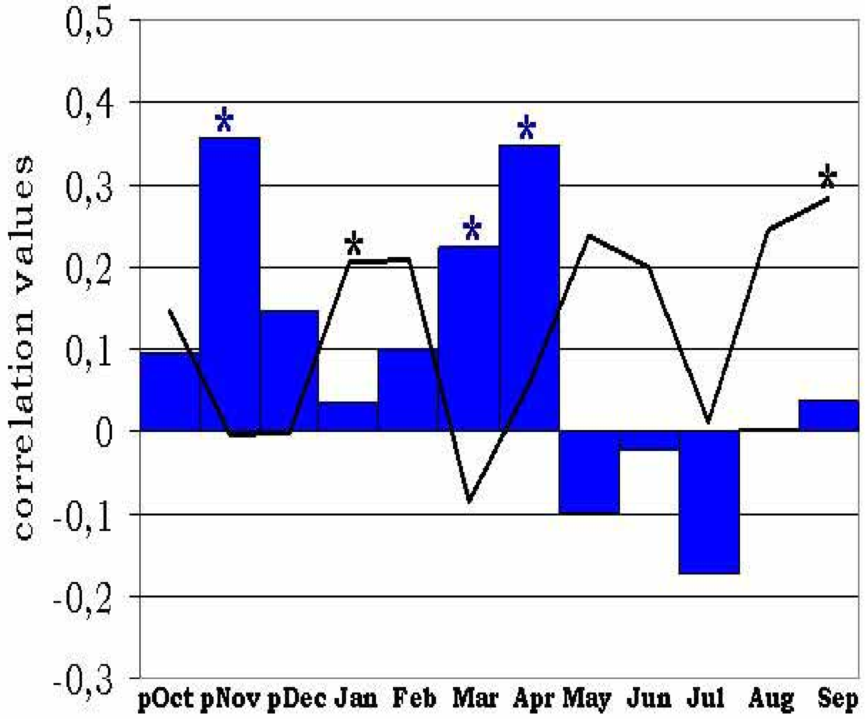

Figure 6: Response function for all oaks line indicate mean monthly temperature (°c), bars for sum monthly precipitation and asterix indicate significant values (0, 05).

This same climate-growth relationship was found in the wettest site 1 and dry(er) site 4. The response-functions (appendix 4) of both sites show hardly any difference. However, there is a slight tendency that in the dry site above average rainfall in spring is most important for tree growth whereas the oaks in the dry site prefer above-average rainfall in the winter months (nov/dec).

To verify the strong relationship between the site chronology and the sum of precipitation in winter and early spring, both records are plotted together throughout the period from 1940-2004 (Fig.7). Both records show are very well correlated (0.38) and show a synchronous behaviour across the whole period with only some exceptions (e.g. around 1965).

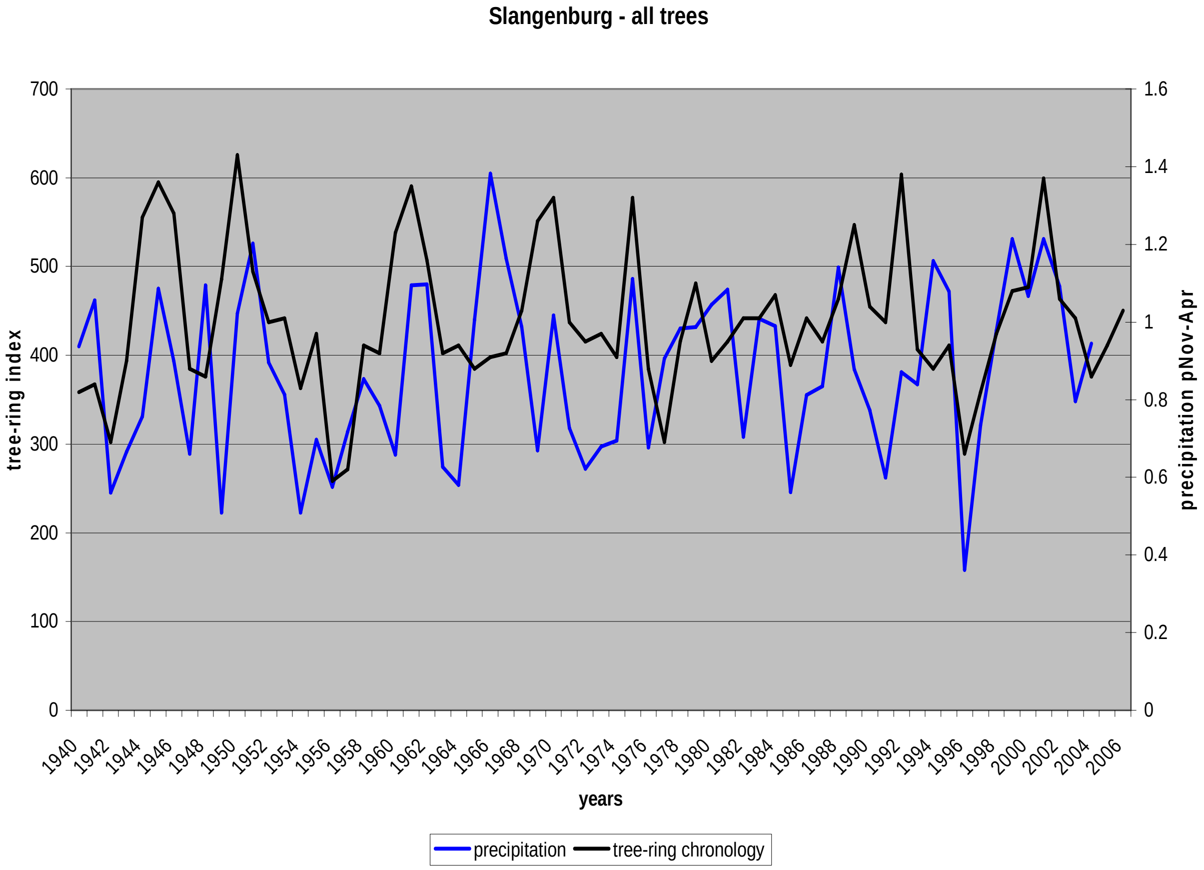

Figure 7. Site chronology and the sum of precipitation (mm) in winter and early spring.

CONCLUSIONS AND DISCUSSION

In this study four sub-sites were chosen where oaks are growing under different hydrological regimes. A comparison of the tree-ring series of the sample trees from the four different sites show no striking differences in the year-to year variability. The annual variation in the chronologies of the four sub-sites is very similar (appendix 3); the trees in the different plots and sites only show small differences in growth trend and growth level. Almost identical climate-growth relationships (response-functions) are found for the four sub-sites. The results show that the total amount of precipitation in winter and (early) spring, i.e. the months just before the growing season, is most important for the growth of oak in the Slangenburg forest. The precipitation during the growing season has no significant influence on tree growth; there is even a slightly negative correlation.

Wet conditions in winter and early spring lead to a refilling of the groundwater reservoir and complete water-saturation of the top-soil layer. Both processes seem to provide good starting conditions for tree growth. These starting conditions are favourable for the growth of oak throughout the whole growing season with the consequence that a wide tree ring is formed. A lack of a positive response to summer precipitation in the response-functions points to the fact that the oaks in general do not suffer from summer drought.

This climate-growth relationship has been found for all investigated oaks; no clear differences are found between the oak trees growing at the four sub-sites which mean that local hydrology has almost no influence on the climate-growth relationship of the oaks. The main reason for this might be that the oaks are well adapted to the local water availability. On wet sites the oaks create their own favourable (dryer) circumstances by the uptake of water, starting from the top roots. As the soil becomes dryer more (deeper) roots are involved in water uptake which enables even more roots to become active. On dryer sites the trees generally take advantage of the fact that the water content is at “field capacity”. The oaks are used to and capable of transporting large amounts of water at great speed. This transport mainly takes place in the large early-wood vessels, that are formed just before the leafs are put out (current year vessels) as well as part of the (late-wood) vessels that are formed during the previous year. Early-wood vessels from previous years do not take part in water transportation since they underwent embolism during winter and have partly been put out of business by the formation of tyloses.

A dry condition in the top soil at the beginning of the growing season has negative impact on root growth as well as fine-root- and mycorrhizza formation. This can have a negative effect on cambial activity throughout the whole growing season. The lack of water availability restricts water transport in the newly developed early-wood vessels. This is due to the fact that their size is partly determined by water availability during early spring: a shortage of water leads to smaller vessels with a reduced water-conducting capacity. Moreover can the capacity of water transport in those large vessels be decreased by the formation of air bubbles with the consequence of embolism under the influence of very strong tensions that built up between the water demanding leafs and the more or less failing water supplying roots.

Loosing its high speed capacity water transportation system causes the water demands from the crown not to be met. Other vessels are capable of transporting water upwards but the amount of water that they can supply to the crown is much less. Early leaf shedding and even the dying of complete branches is the result. Consequently, the tree ring which is formed in such a year is very small. And next year's ring width can also be affected since the water-transport capacity in the following year is also affected.

Dry winters and springs thus present the oaks with severe problems. The analyses presented in this report show that compared to these problems the effect of dry summers on tree growth are minor. That is, we have not been able to find a statistically significant proof that dry summers generally cause tree ring widths to be small. Based on the ring width analyses we may conclude that in general water availability during the growing season, even under temporary warm and dry weather conditions in summer, seems not to be a problem for the growth of oak on the study sites.

There is no indication that a gap between water supply and demand occurs during the growing season. On the contrary, the results of the response-function analysis suggest a negative impact of above-average precipitation in summer on the growth of the oak trees. One possible explanation is that total growth is limited by cloudy and cool summer conditions, which go together with a high summer precipitation. Another explanation might be that wood formation in oak generally stops quite early and therefore the 'signal' of a warm and dry summer is not captured in tree-ring width.

Investigations of the cambial activity of oaks from a relatively dry site in the Netherlands during the year 2003 with a dry summer have shown that these oaks already stopped growing in July. No effect of the dry summer conditions could be detected from tree-ring width, instead a slight decrease in tree-ring width occurred during the following year 2004 (van der Werf *et al.*, 2006). Another example is the dry and hot summer

1976: all oak trees show a reduction in ring widths in 1976 and an extreme narrow ring in 1977. 1976 is a well-known drought year which was characterized by a lack of precipitation during the whole rainy season and in late winter and spring. The latter might explain the clear growth reaction already in 1976 in all oaks.

Hence, the lack of a clear precipitation ‘signal’ in summer does not necessarily mean that there is no effect of extremely hot and dry summers. The fact that we do not find statistical evidence from the tree ring analysis for this phenomenon is partly due to the statistical analysis itself. Additional variables, such as early-wood and late-latewood width or vessel area and other statistical tools may result in other results.

KNMI predictions of the climate changes for the Netherlands show more precipitation in winter months and hotter and dryer summers (www.knmi.nl). Based on the results in this study it can be concluded that the decreasing chance of dry winters is a positive development for the well being of oak in the Netherlands. Water management should be aimed at the conservation of the extra amount of water through summers to try to reduce the potentially negative effects of prolonged summer droughts.

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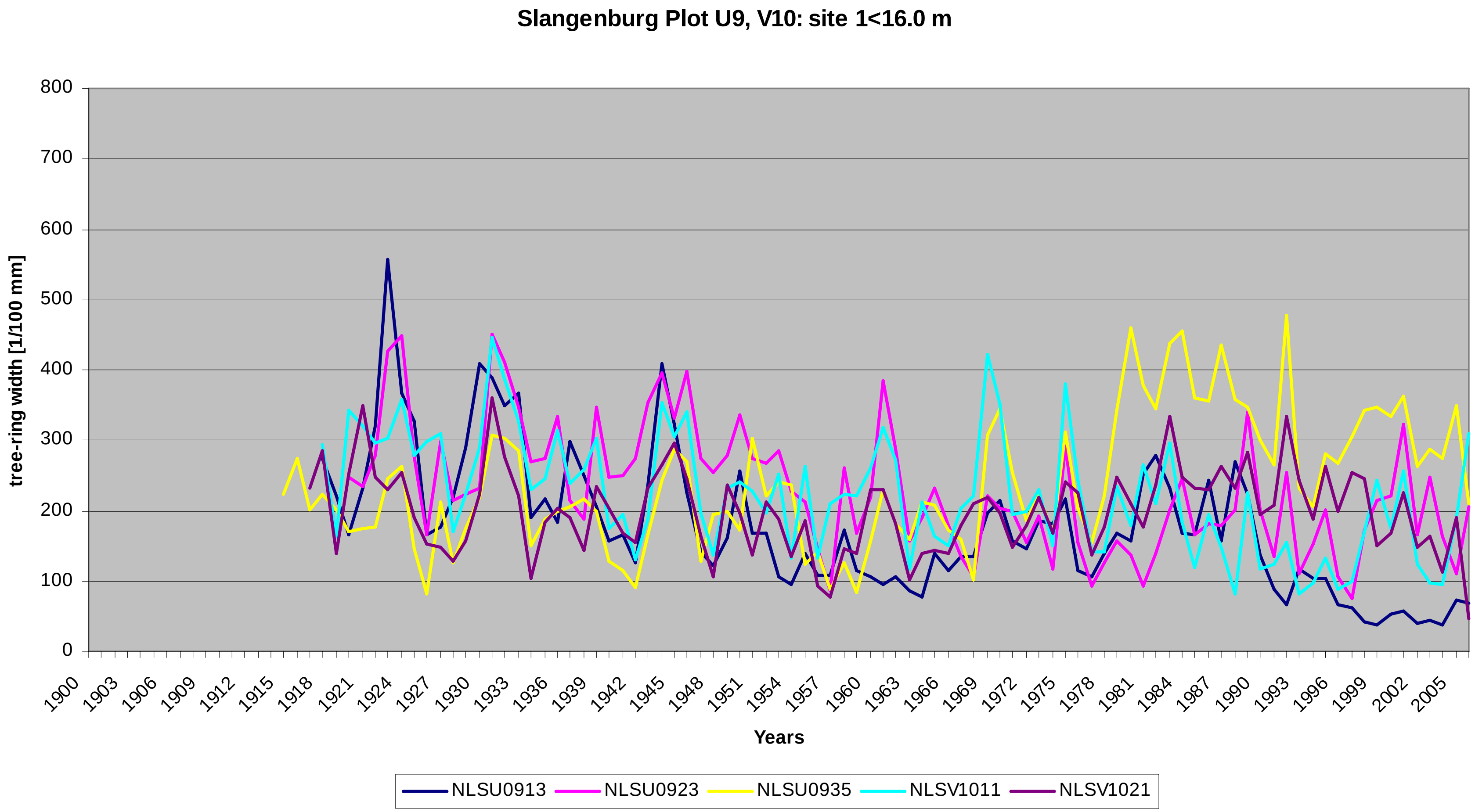
Appendix 1



Slangenburg Plot U9, V10: site 1<16.0 m
tree-ring width [1/100 mm]
0
100
200
300
400
500
600
700
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1903
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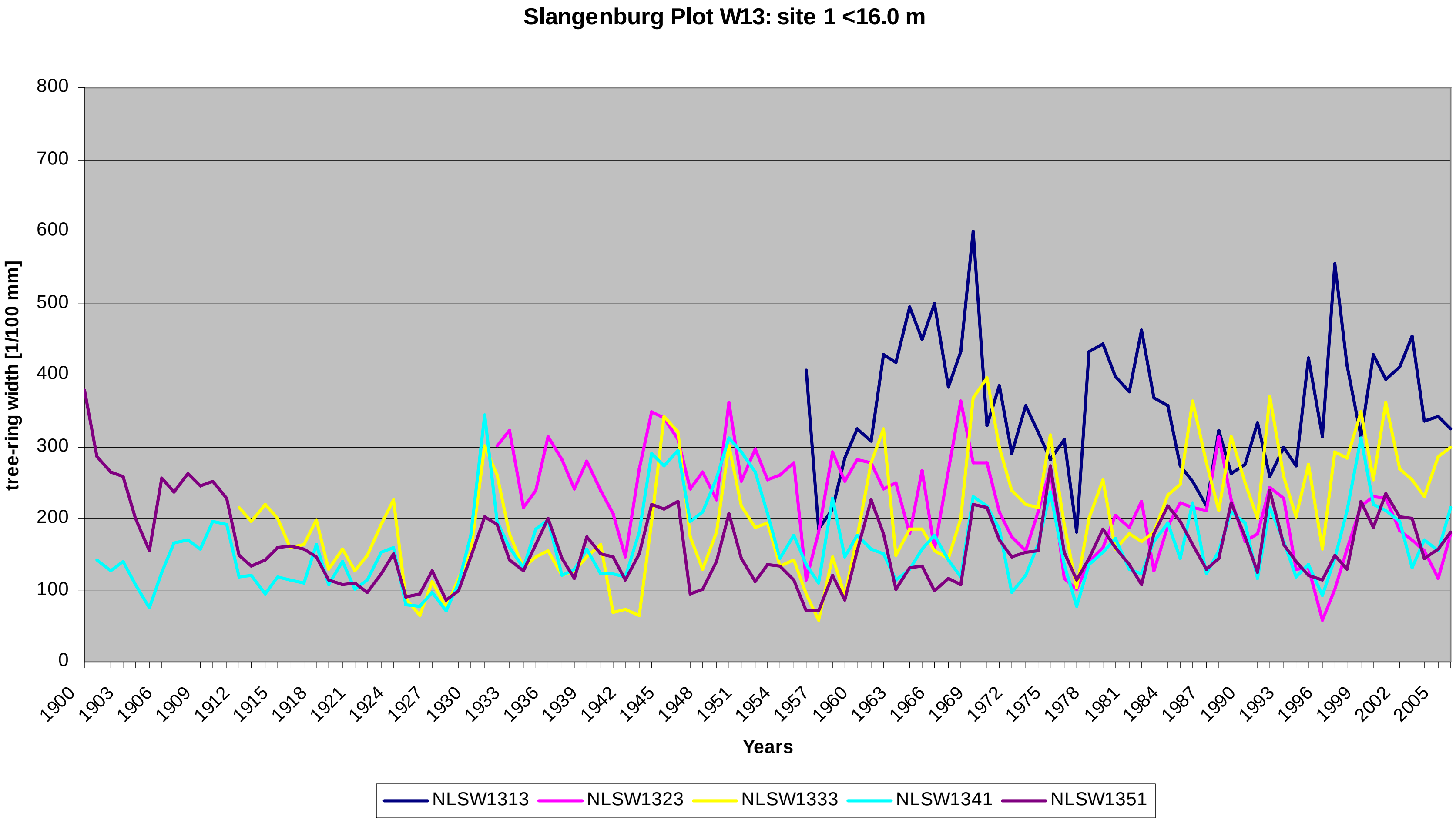

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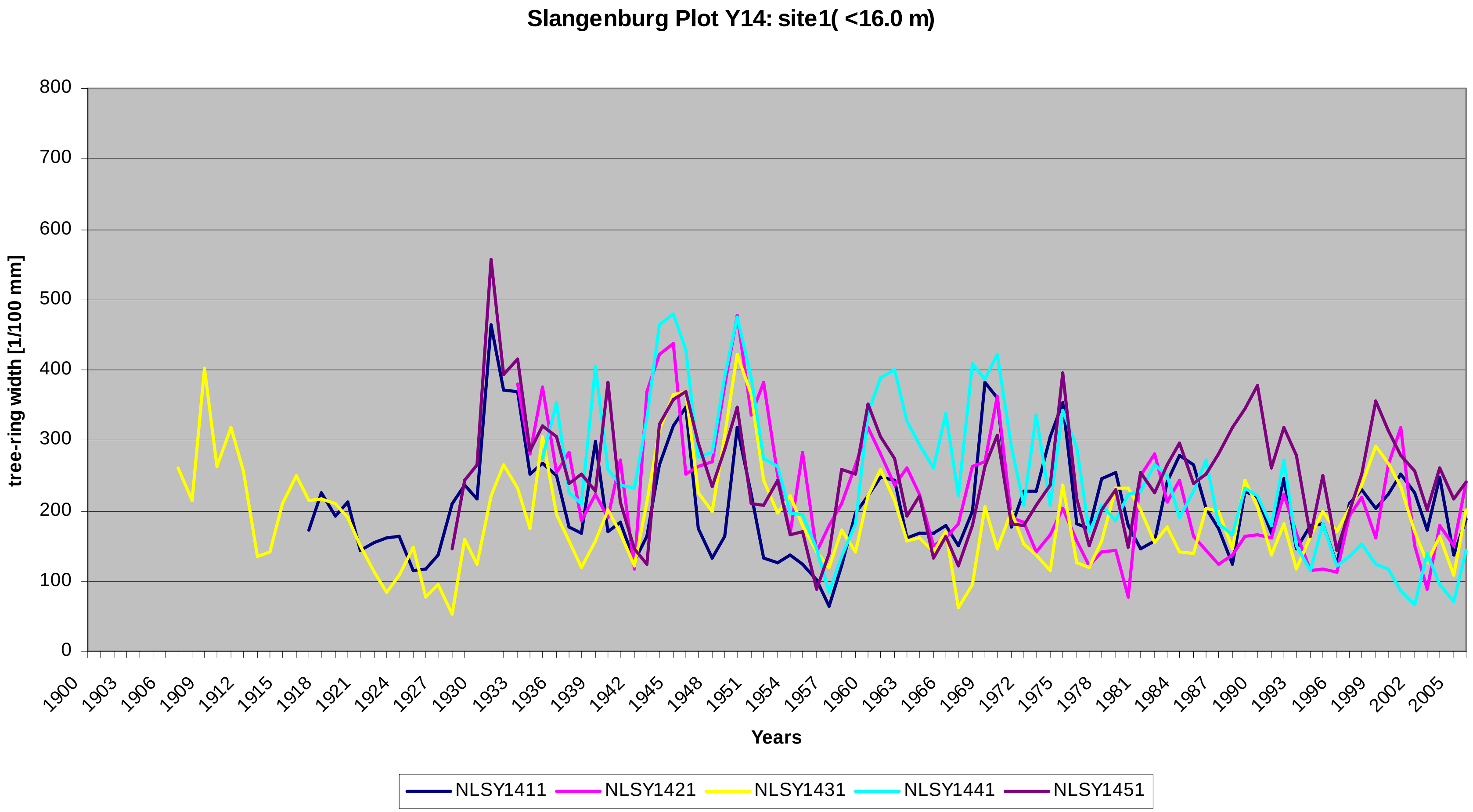

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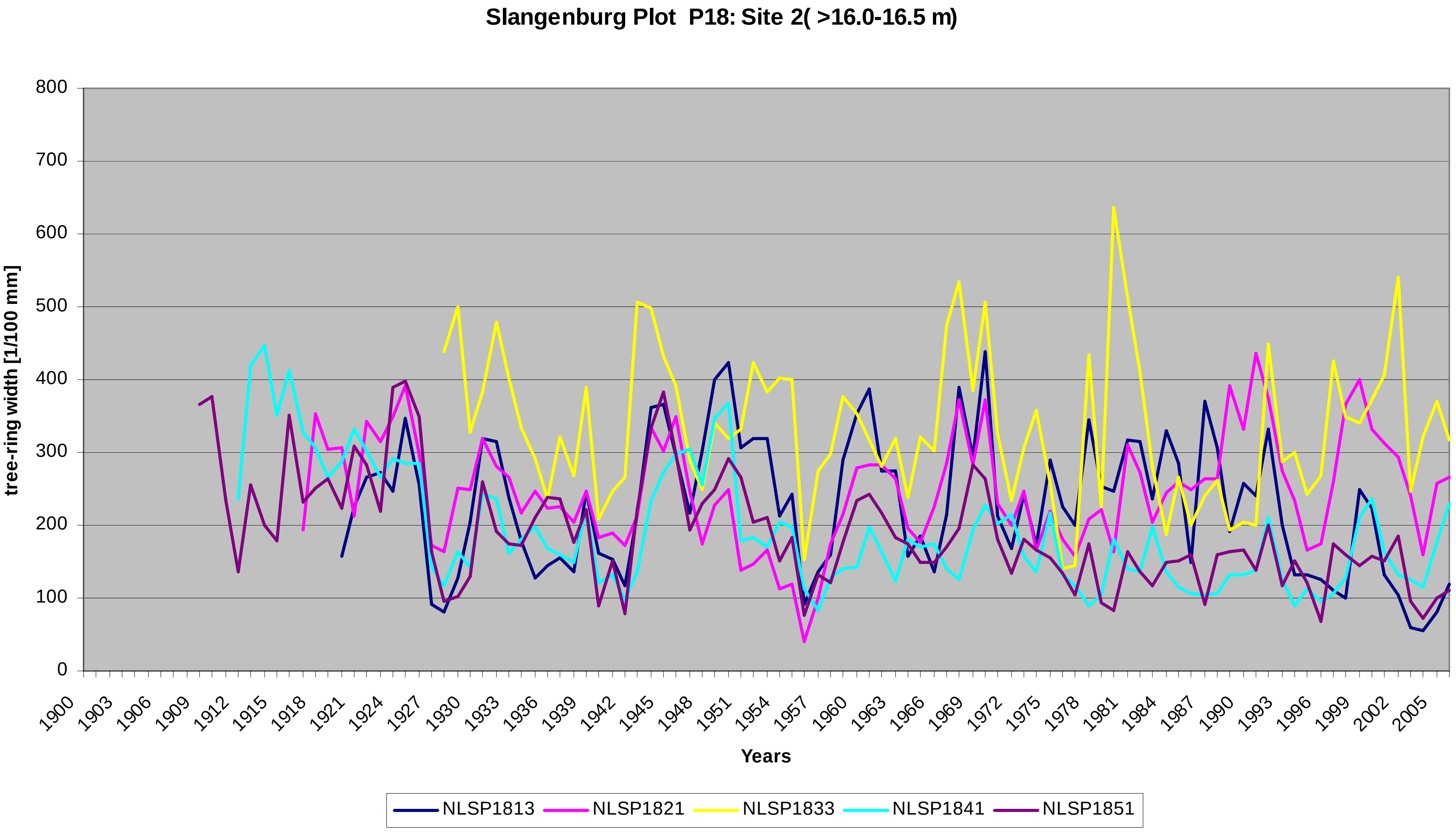

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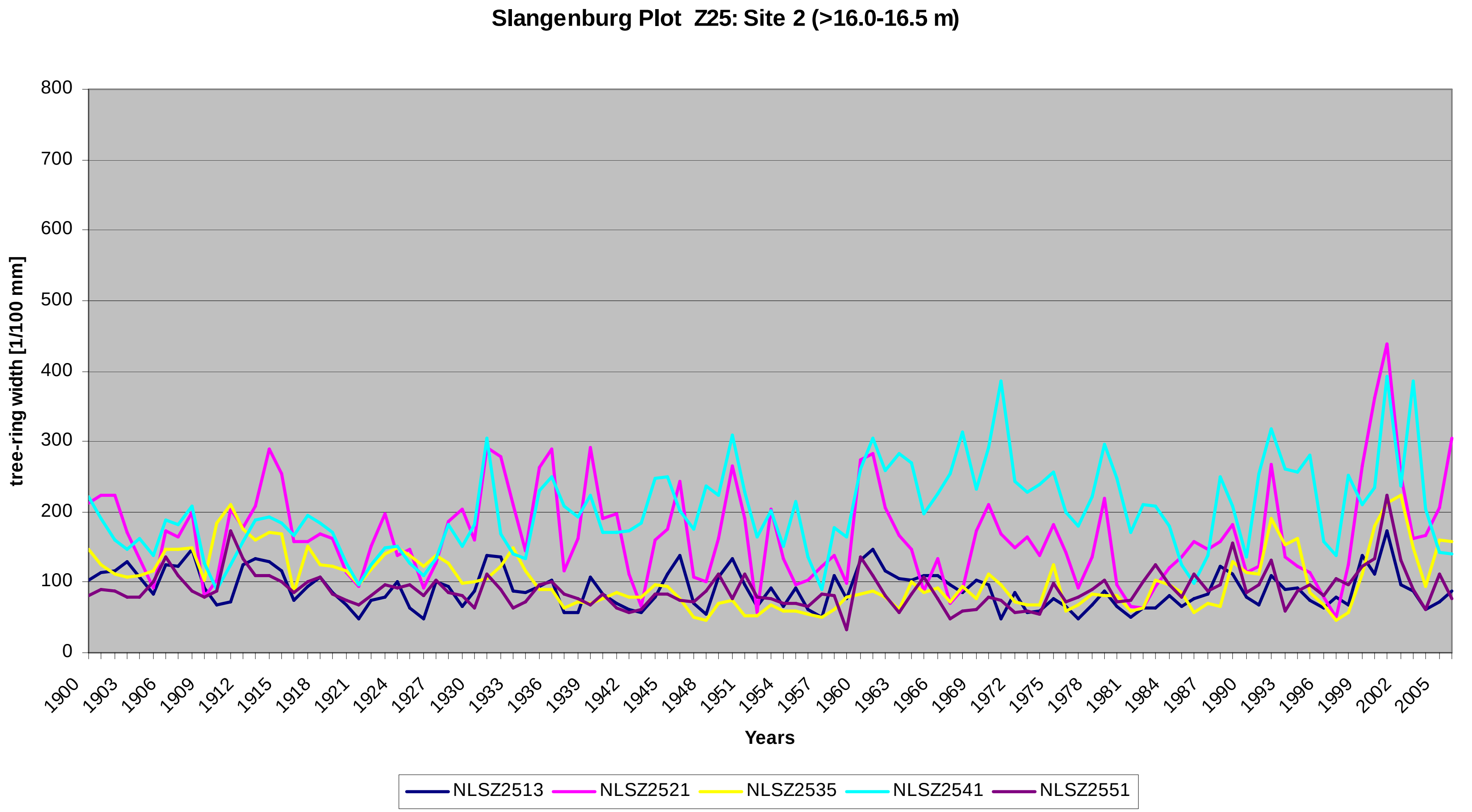

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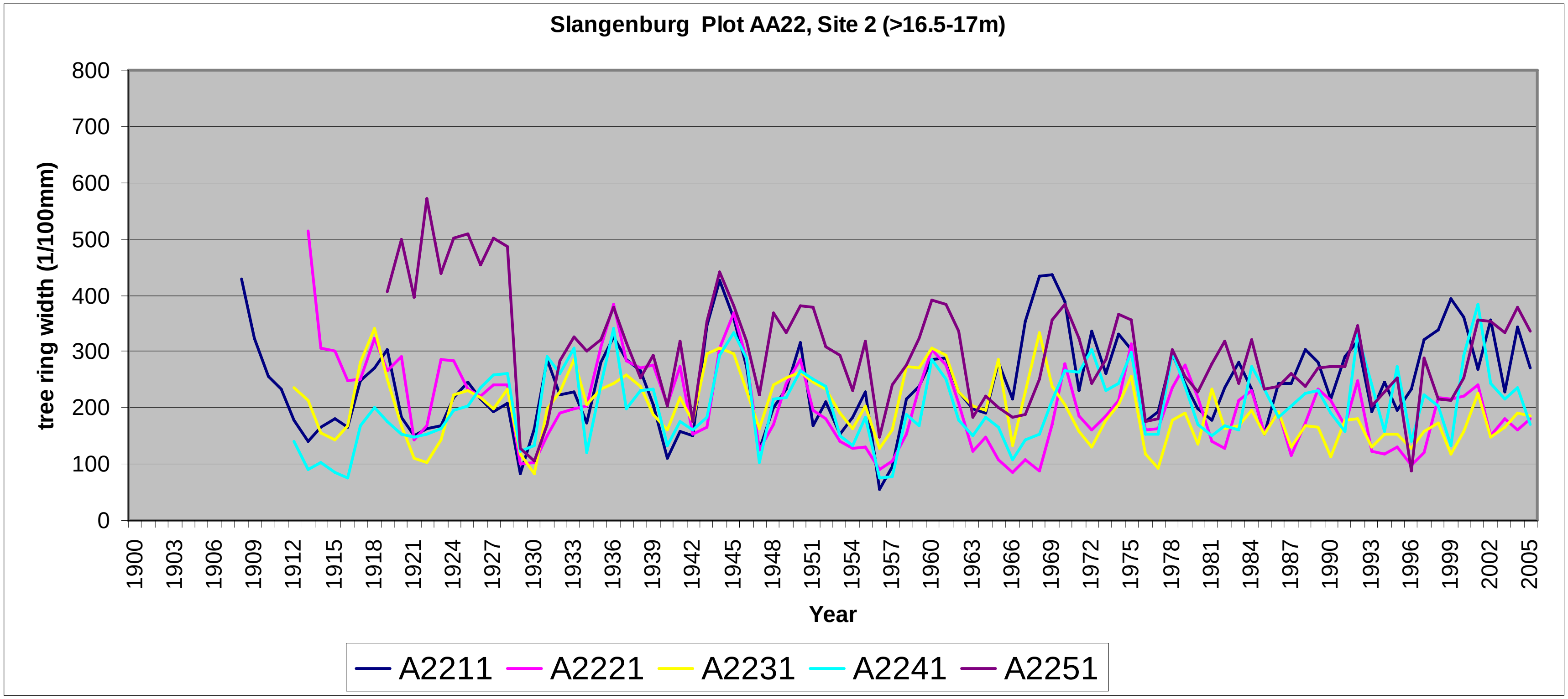

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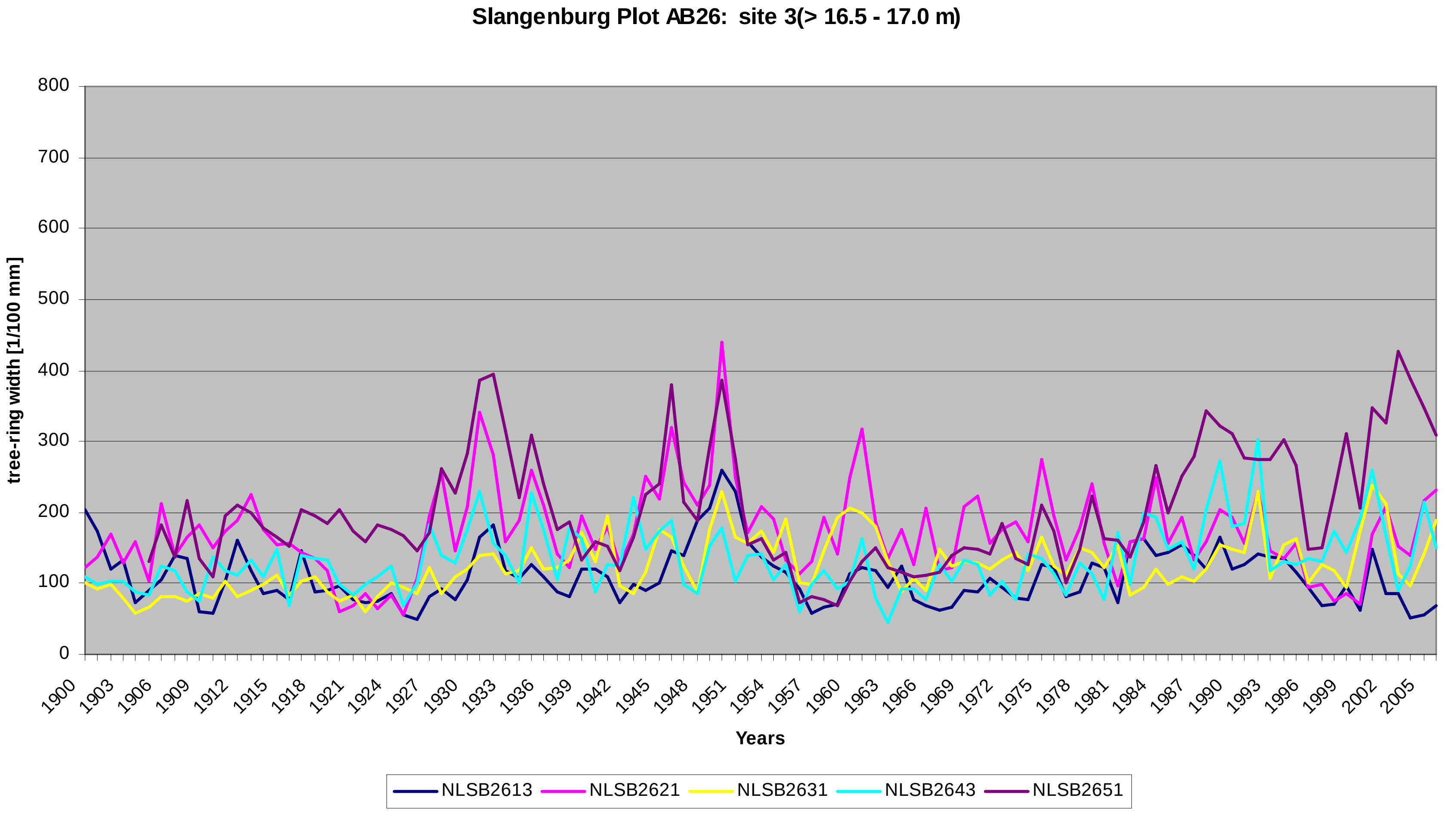
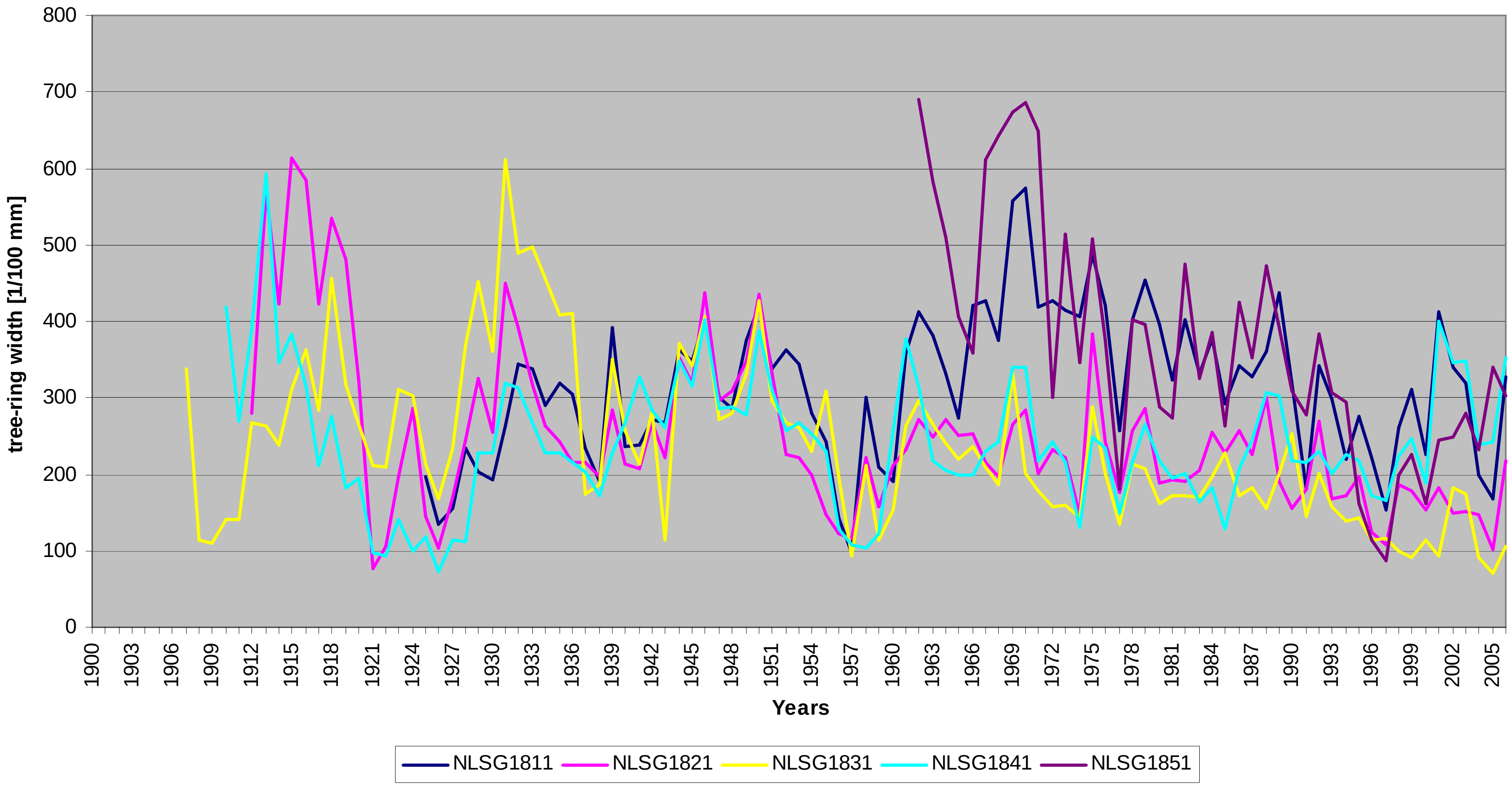
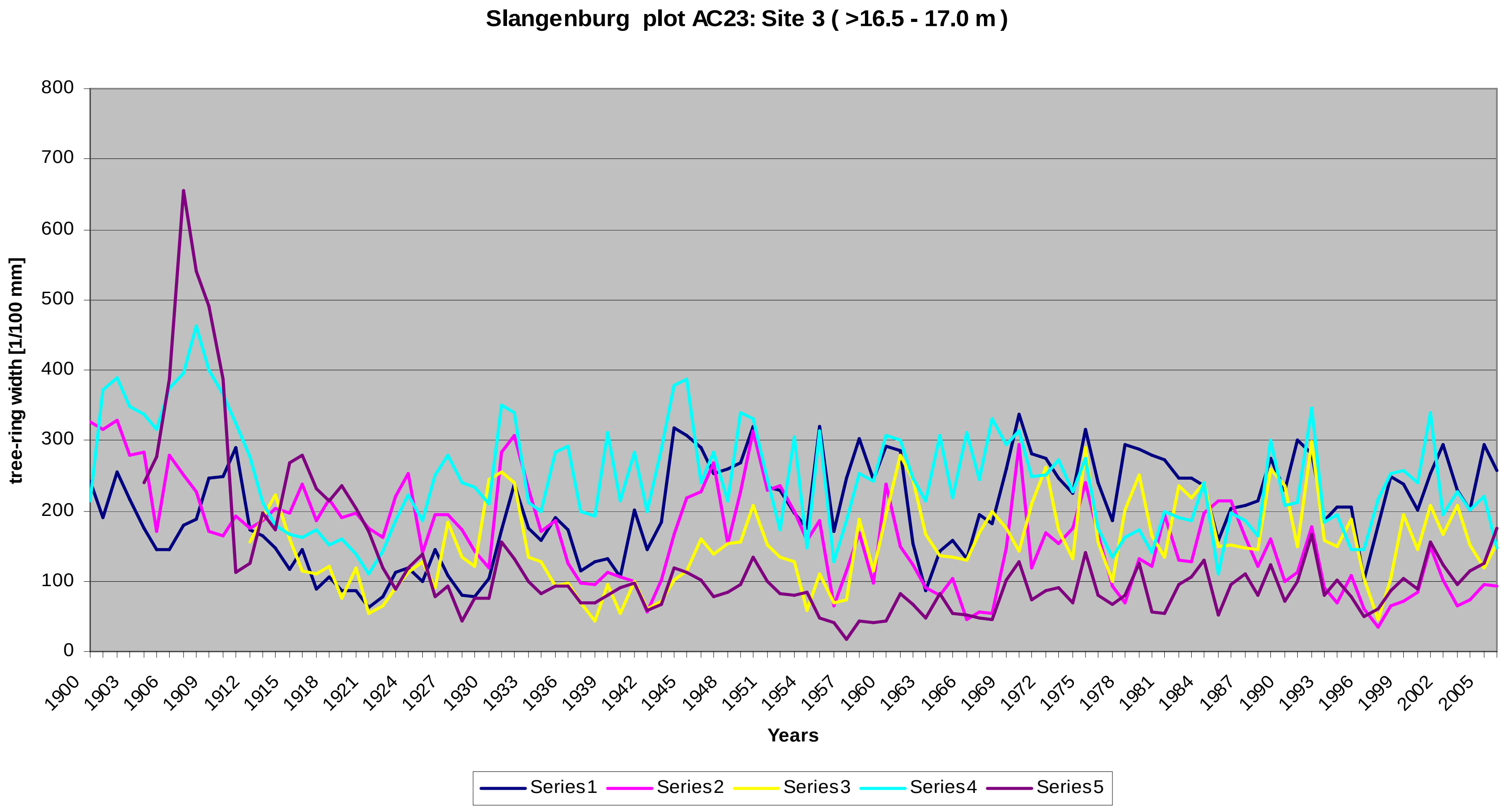


Appendix 1 cont…

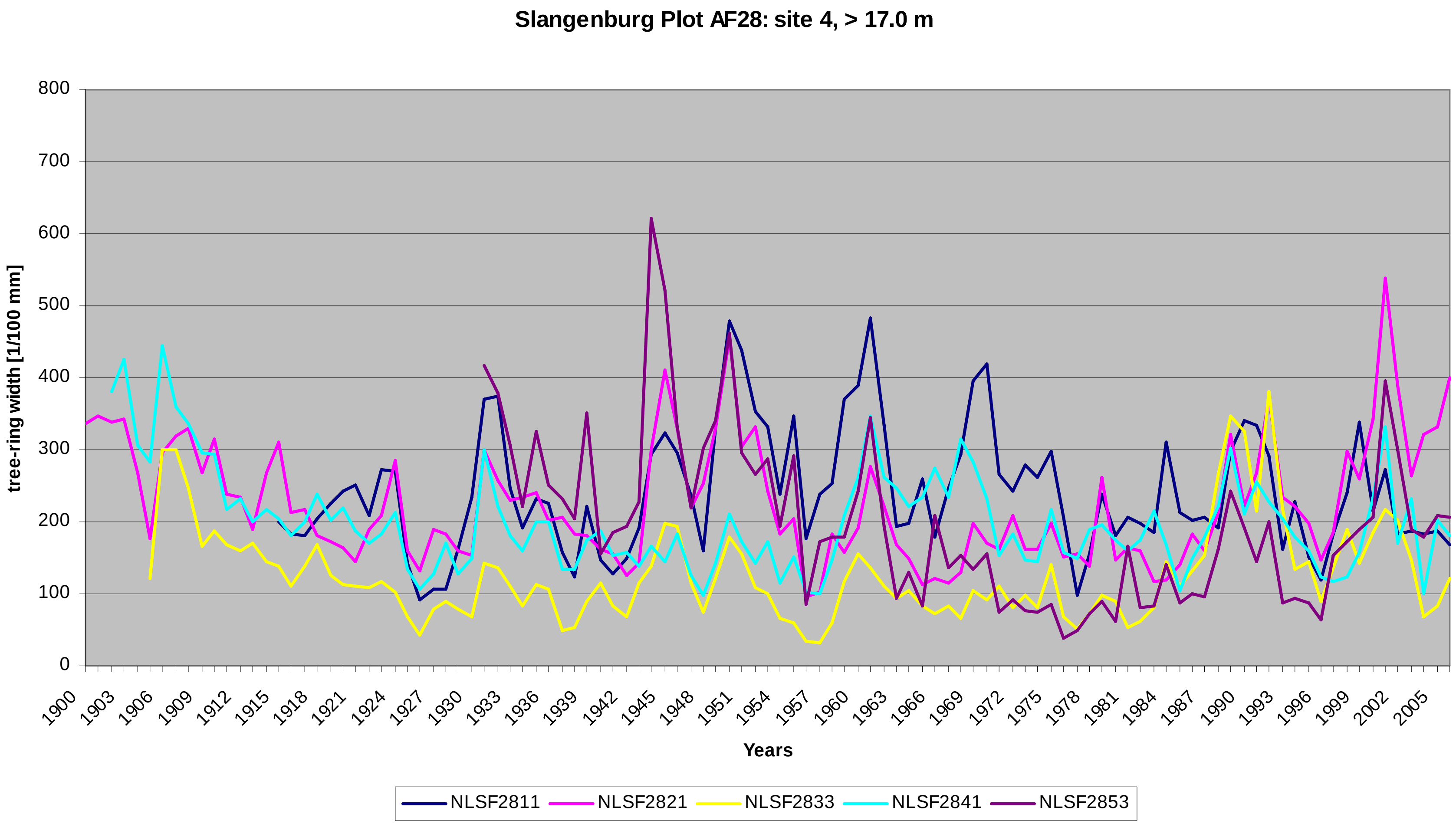
Slangenburg plot AG18: Site 3 (16.5 - 17.0 m)



Appendix 1 cont…

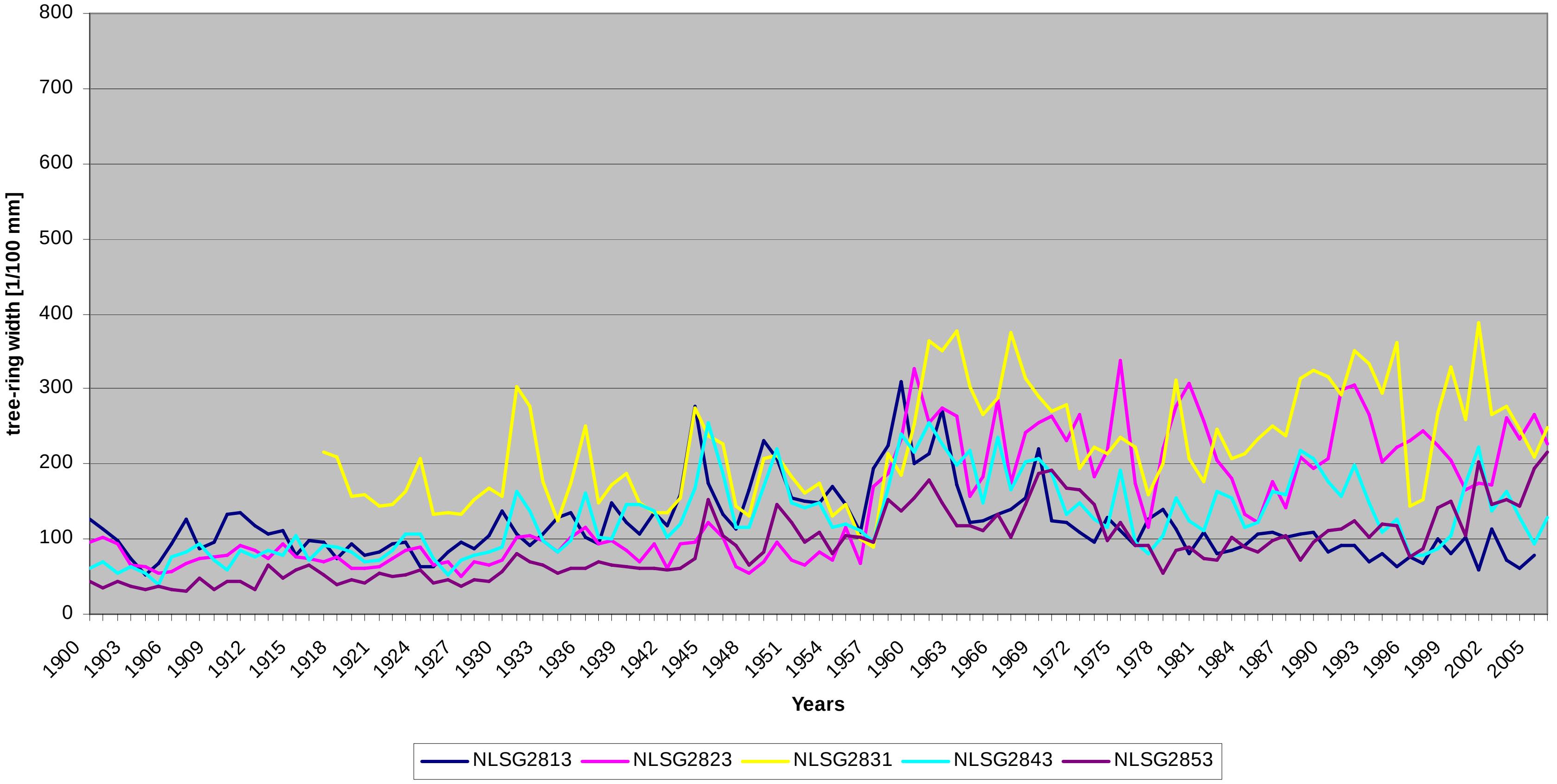


Appendix 1 cont…

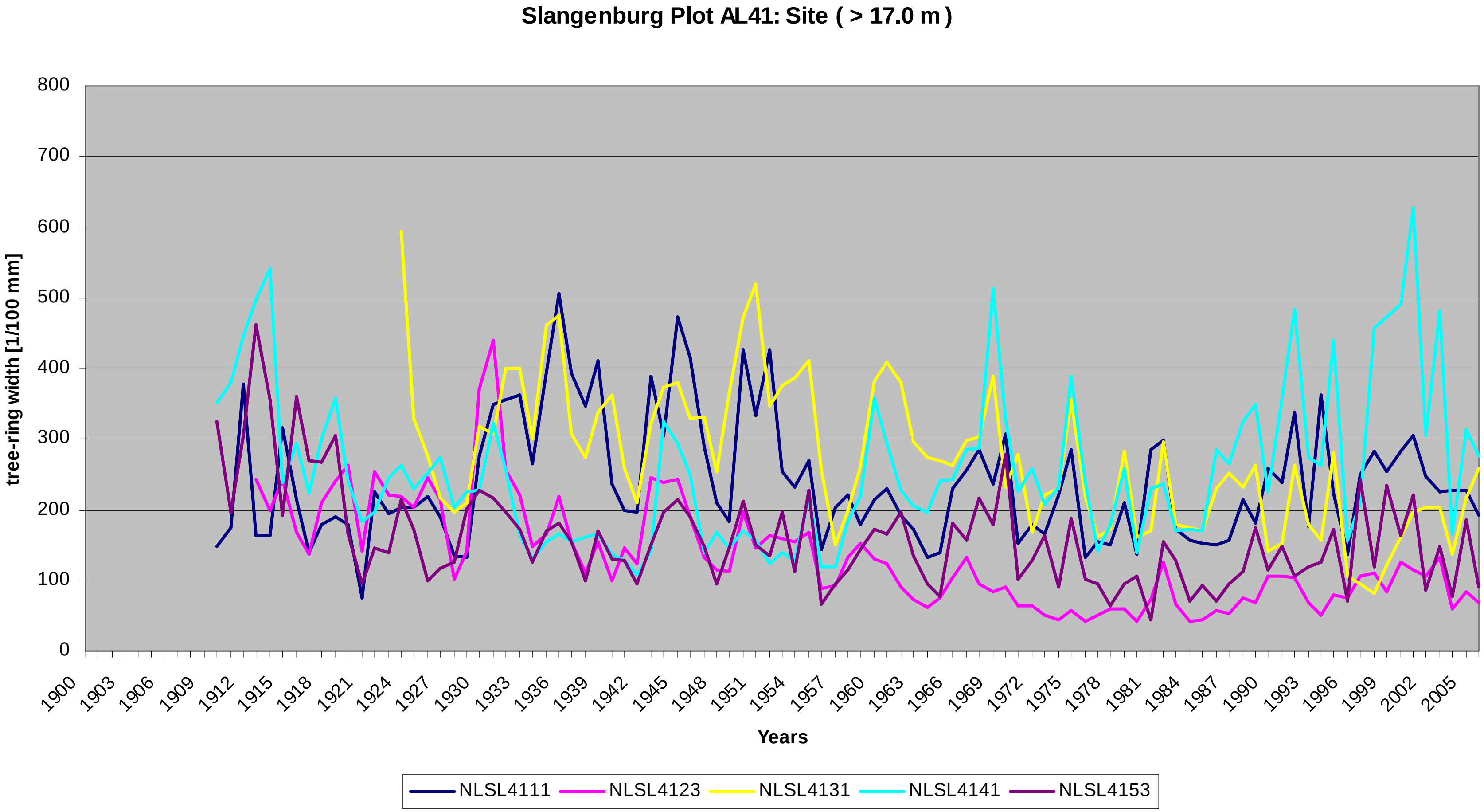


Appendix 1 cont…

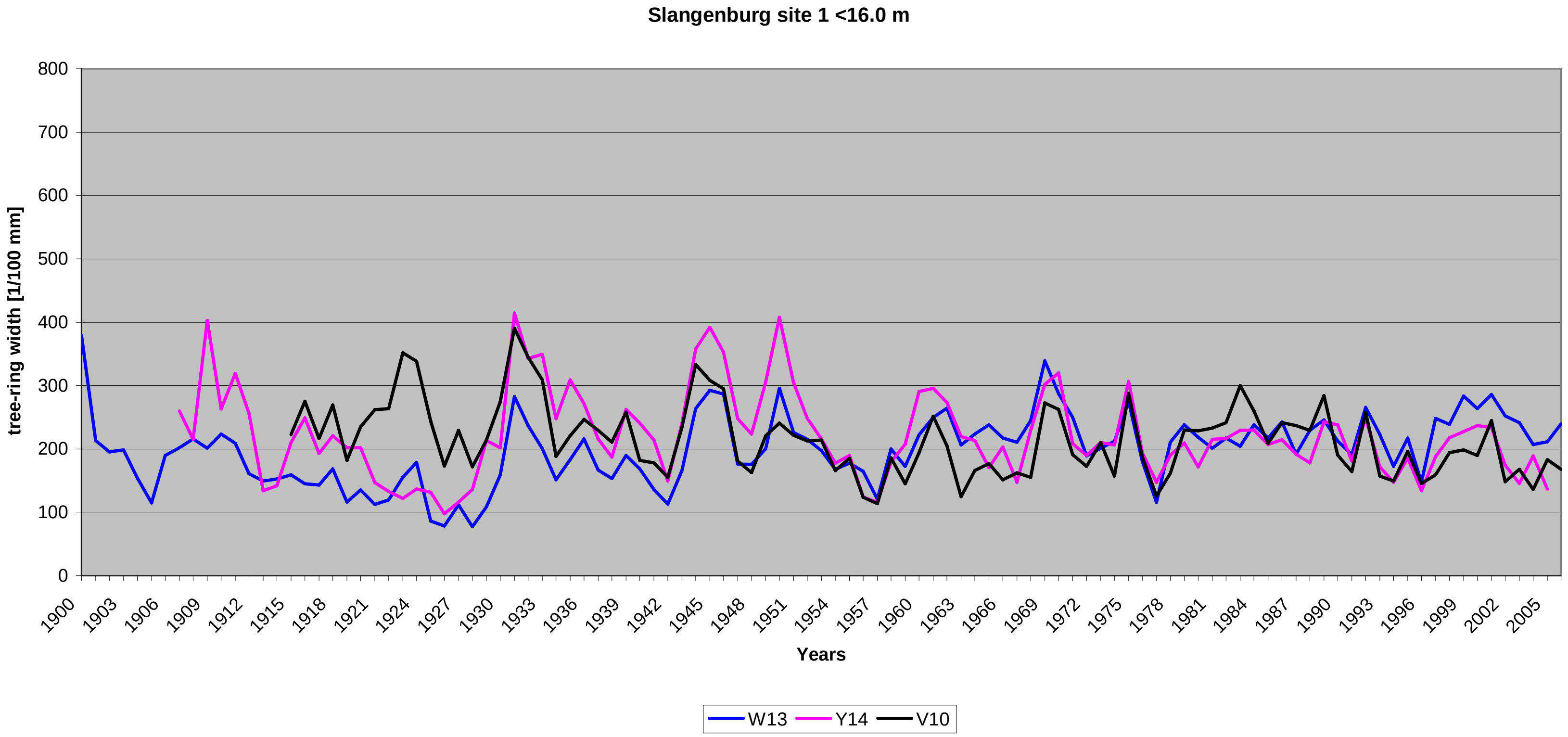
Slangenburg plot AG28: Site 4 , > 17.0 m (roadside plantation)



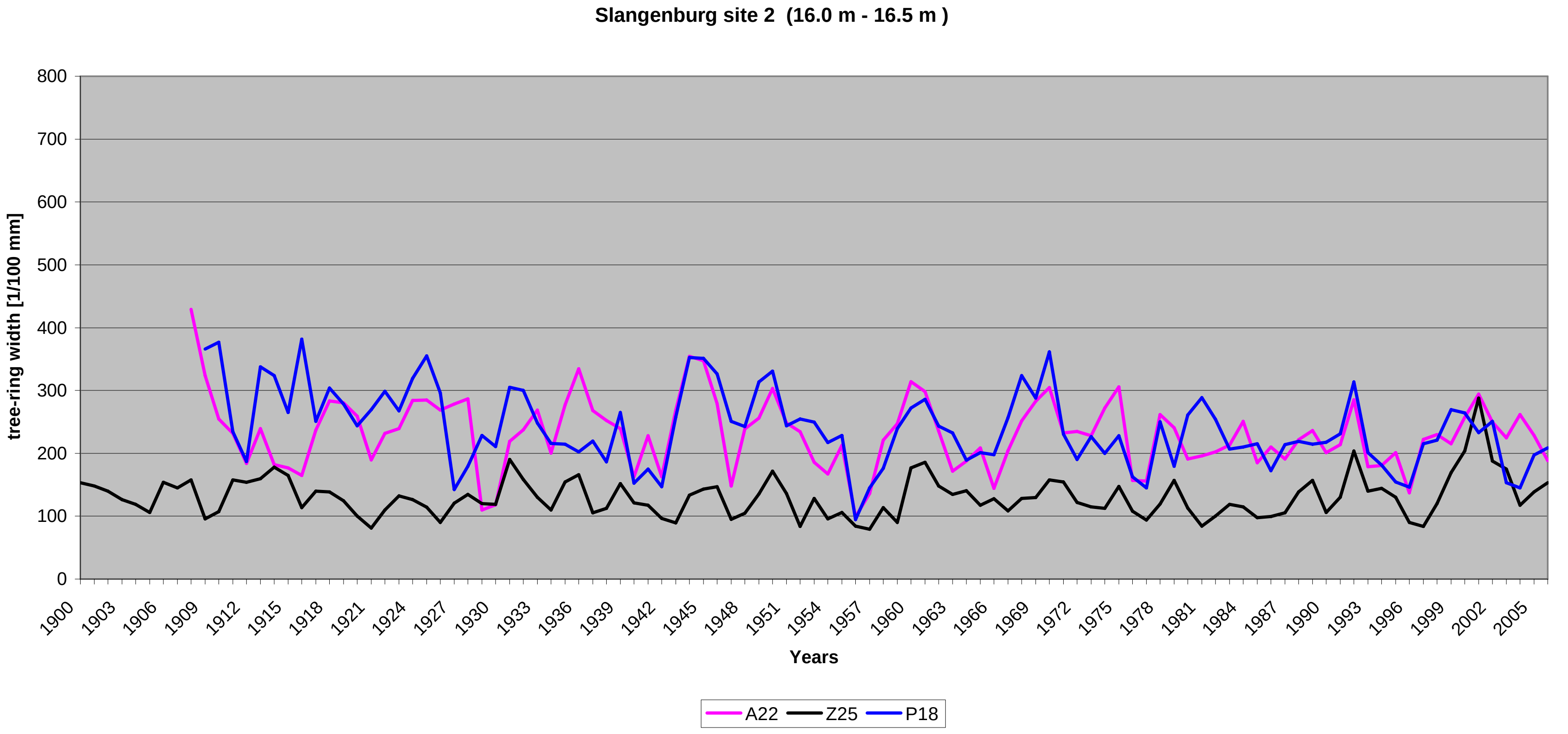
Appendix 1 cont…



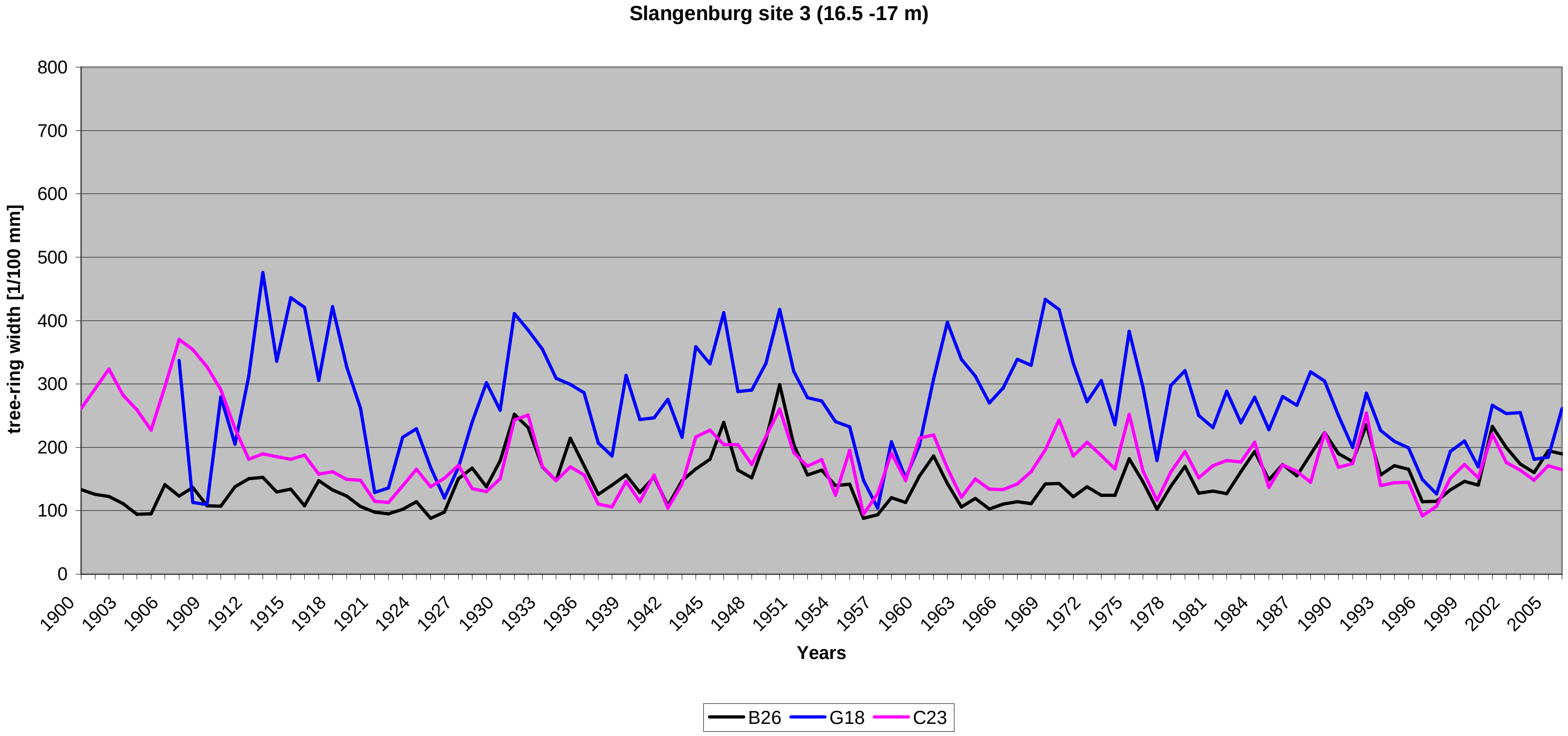
Appendix 2


Slangenburg site 1 <16.0 m
tree-ring width [1/100 mm]
800
700
600
500
400
300
200
100
0
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
Years
W13
Y14
V10

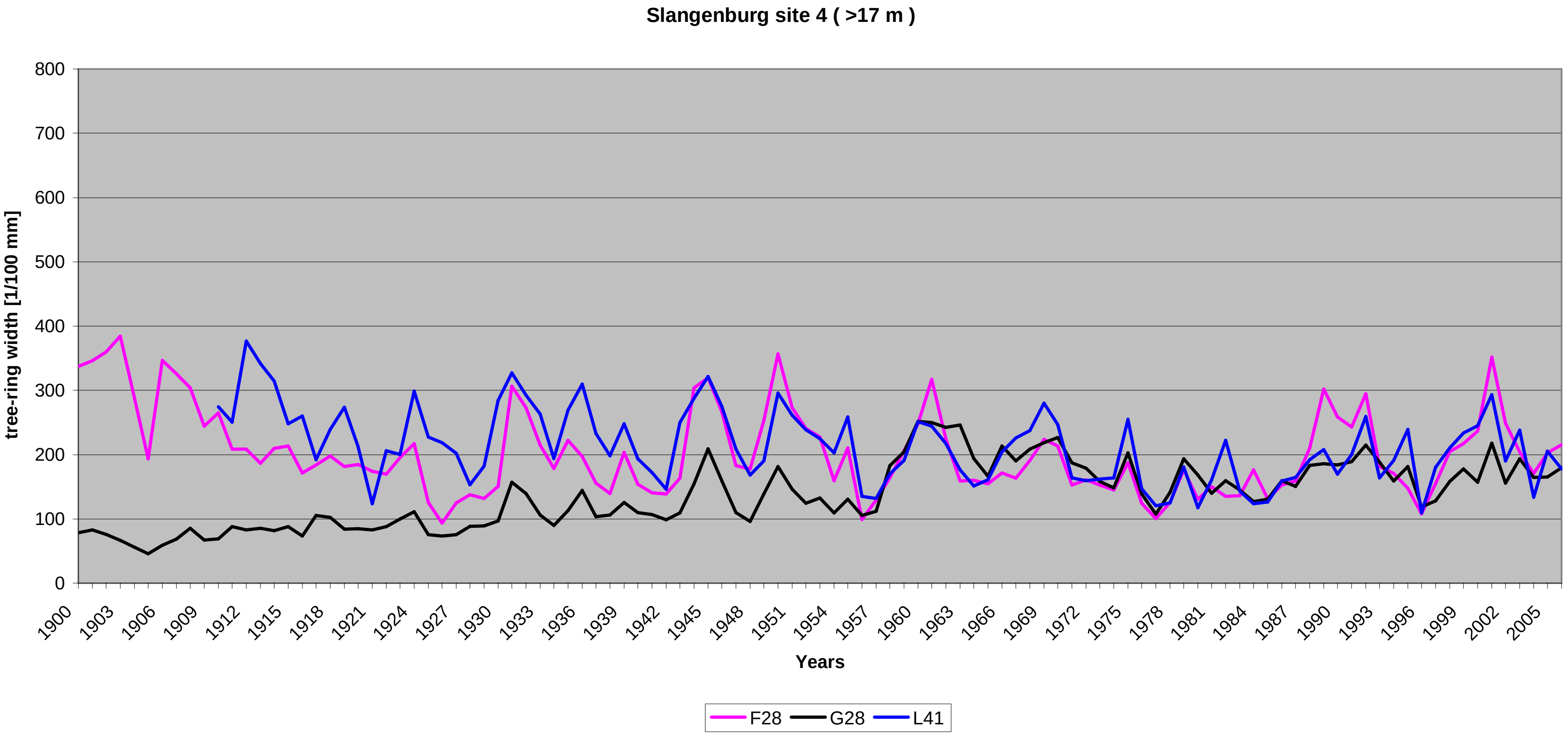
Appendix 2 cont…


Slangenburg site 2 (16.0 m - 16.5 m)
tree-ring width [1/100 mm]
800
700
600
500
400
300
200
100
0
1900
1903
1906
1909
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
Years
A22
Z25
P18

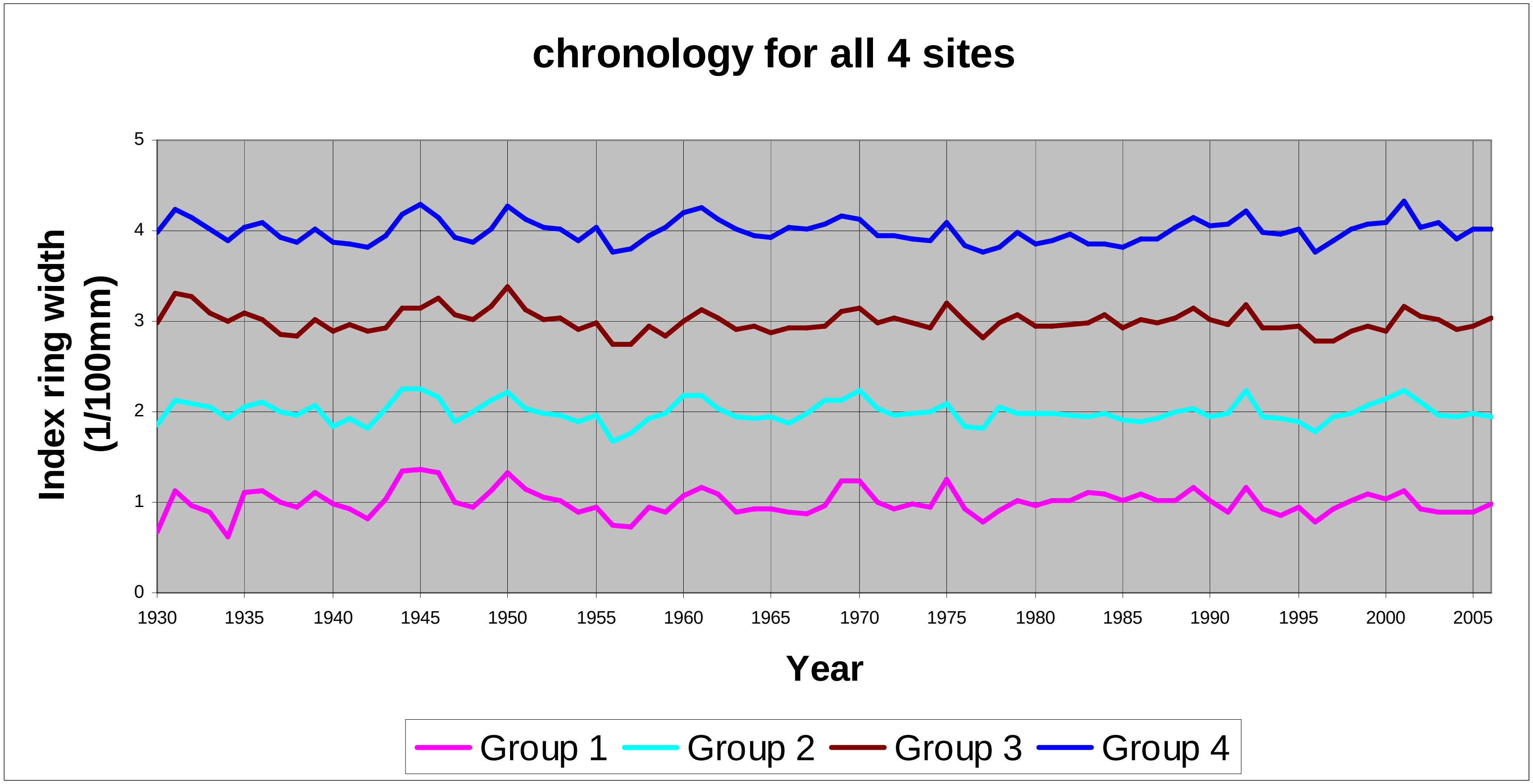
Appendix 2 cont…



Appendix 2 cont…

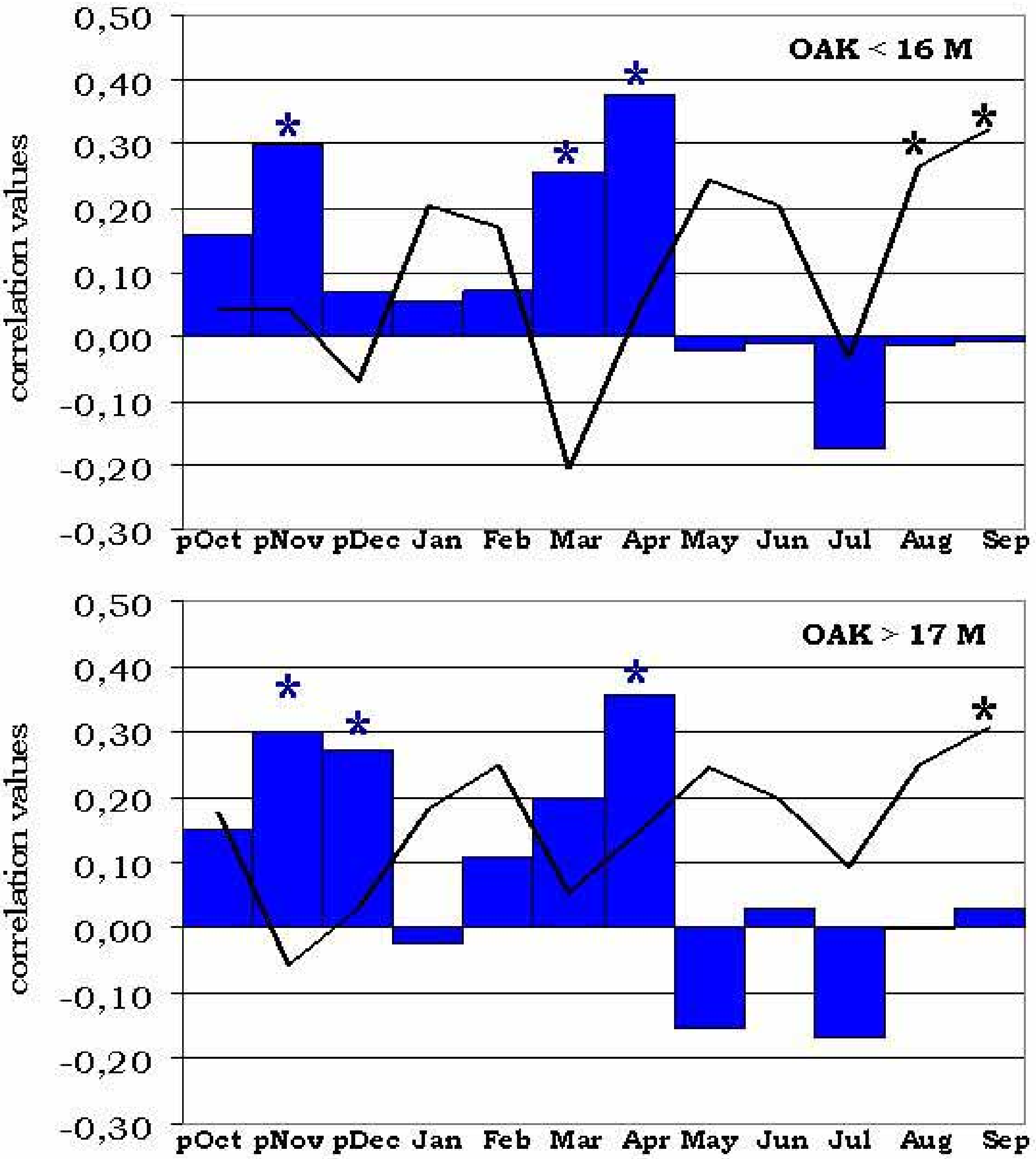


Appendix 3



Note, group = site

Appendix 4



Response function oaks < 16m and > 17m.The bars represented the sum monthly precipitation, the lines for monthly mean temperature and asterix indicate months of significant coefficients at the 0.05 level