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growing in the neighborhood of black cherry (*Prunus serotina*)

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Summary

Atmospheric nitrogen deposition and former land use have led to widespread acidification of forest soils and disturbed nutrient balances, which has been linked to reduced forest vitality and tree growth. The admixture of rich-litter tree species in forests dominated by poor-litter species that further accelerate soil acidification may alleviate the impact of soil acidification on poor sandy soils. Admixture of litter with high base cation content has a positive impact on topsoil pH, as well as base saturation and may potentially affect growth and vitality of trees. To date, the effect of introducing rich-litter species on the long-term growth of co-occurring tree species has not been systematically studied.

In this study, we aimed to evaluate the effect of the rich-litter species *Prunus serotina* on the growth of the poor-litter tree species *Quercus robur* by means of dendrochronology. We hypothesized that the presence of *Prunus* will – through soil amelioration - positively affect both the growth and the drought susceptibility of *Quercus*. We investigated the growth of co-occurring *Quercus* and *Prunus* trees in six forest sites with sandy, poor soils in the Netherlands and Germany. We compared tree-ring patterns of oaks growing next to cherry trees (influenced), oaks growing next to other oaks (uninfluenced) and the cherry trees. Tree-ring widths were analyzed on (a) average annual growth variation and basal area increment; (b) the climate sensitivity of the annual growth; (c) the growth response to selected drought years; and (d) the tree-individual growth variation.

For most analyses, influenced and uninfluenced oaks showed little differences. Individual growth variation between oaks did show a division between influenced and uninfluenced trees in some sites. However, this division seemed to be linked to spatial separation rather than rich-litter effects.

Overall, this study indicated that there is no clear evidence for a facilitating effect of *Prunus* on the growth of oak. It is likely that the studied sites were too poor to capture an effect of the improved soil conditions on the growth of oak, or that competition for water may have overruled any direct soil effect by *Prunus*. We conclude that this study did not provide evidence the rich litter species *Prunus serotina* does positively affect the growth of *Quercus robur* on the studied acidic poor sandy soils.

Samenvatting

Atmosferische stikstofdepositie en voormalig landgebruik hebben geleid tot een sterke verzuring van bosbodems en verstoorde nutriëntenbalansen, wat in verband wordt gebracht met een verminderde vitaliteit en groei van bomen. Bovendien worden de bossen gedomineerd door boomsoorten met slecht verteerbaar strooisel, waardoor de verzuring van de bodem verder versnelt. Om de impact van bodemverzuring op arme zandgronden te verzachten wordt nu gewerkt aan het (her)introduceren van boomsoorten met goed verteerbaar strooisel in bossen. Bijmenging van strooisel met een hoog gehalte aan basische kationen (met name calcium, kalium, magnesium) heeft een positieve invloed op de pH van de bovengrond, evenals op de base-verzadiging en kan mogelijk de groei en vitaliteit van bomen positief beïnvloeden. Tot op heden is het effect van het introduceren van rijk-strooiselsoorten op de groei van bomen nauwelijks bestudeerd.

In deze studie is het effect bestudeerd van de aanwezigheid van de rijk-strooiselsoort Amerikaanse vogelkers (*Prunus serotina*) op de groei van de zomereik (*Quercus robur*) met behulp van jaarringanalyse. Onze hypothese was dat de aanwezigheid van *Prunus* - door bodemverbetering - zowel de groei als de droogtegevoeligheid van *Quercus* positief zal beïnvloeden. We onderzochten de groei van naast elkaar voorkomende *Quercus* en *Prunus* bomen in zes bosgebieden op arme droge zandgronden in Nederland en Duitsland. We vergeleken de jaarringpatronen van eiken die naast vogelkersen groeiden ('beïnvloed') met die van eiken die te midden van andere eiken groeiden ('niet beïnvloed') en met die van de vogelkersen. Jaarringbreedtes werden geanalyseerd op (a) de gemiddelde jaarlijkse groeivariatie en grondvlakbijgroei; (b) de klimaatgevoeligheid van de jaarlijkse groei; (c) de groeirespons op geselecteerde droogtejaren; en (d) de patronen in groeivariatie in individuele bomen.

De meeste analyses toonden aan dat er weinig verschillen zijn in groei tussen beïnvloede en niet-beïnvloede eiken. Op sommige locaties werd wel een verschil gevonden in de jaarlijkse fluctuaties in jaarringbreedtes tussen individuele beïnvloede en niet-beïnvloede eiken, maar dit leek eerder verband te houden met de ruimtelijke scheiding tussen de twee groepen op de betreffende locaties dan met rijk-strooisel effecten.

Over het algemeen geeft deze studie aan dat er geen duidelijk bewijs is voor een faciliterend effect van vogelkers op de groei van eiken. Mogelijk waren de bestudeerde locaties te arm om een effect van de verbeterde bodemgesteldheid op de groei van eiken te veroorzaken en was vogelkers te kort aanwezig om een duidelijke invloed te hebben op de standplaatskwaliteit. Het is ook mogelijk dat mogelijk positieve effecten van bijmenging met vogelkers werden gemaskeerd door negatieve effecten als gevolg van concurrentie om water. We concluderen dat deze studie geen bewijs leverde dat de rijk-strooiselsoort *Prunus serotina* een positieve invloed heeft op de groei van *Quercus robur* op de bestudeerde zure arme zandgronden.

Preface and acknowledgements

This report is the result of the work of many. The basis of this report was prepared by the lead author, Josephine Haas, and was presented as her MSc thesis at Wageningen University. The data were further collected and processed by an additional number of students as part of their BSc theses: Lars Feldmann, Bart Visser, Johanneke Methorst and Lennart Bakker.

The field and lab work, and the data analysis, were done under the supervision of Jan den Ouden, Ute Sass-Kaassen and Linar Akhmetzyanov. Their contribution to this project covered the period 2017-2020 and was part of their regular work activities.

The authors would also like to thank Ellen Wilderink for her assistance in the lab, and Alan Buras for his statistical advice and preparation of the necessary R-codes. Finally, we thank *Bosgroep Zuid Nederland* for their support and the coordination of the umbrella project 'Correlatief onderzoek Rijk-strooiselsoorten in Natuurgericht Bosbeheer', and the province of Noord Brabant for financing.

Table of contents

1 INTRODUCTION	1
1.1 Nitrogen deposition and soil acidification.....	1
1.2 Rich litter as soil restoration measure.....	2
1.3 Study objective and hypotheses.....	3
2 METHODS	4
2.1 Study species and sample locations	4
2.2 Field sampling.....	5
2.3 Dendrochronological analyses	6
2.4 Computing growth response	7
2.5 Climate growth-response	8
2.5.1 Correlations with climatic variables	8
2.5.2 Growth response to drought years.....	9
2.6 Individual tree approach.....	10
3 RESULTS.....	11
3.1 Neighbourhood indices	11
3.2 Average annual growth variation and basal area increment	12
3.2 Climate-growth correlations.....	14
3.3 Resilience, resistance and recovery	15
3.4 Principle component gradients and correlations with neighborhood indices	15
3.5 Individual tree correlations with climate variables.....	17
4 DISCUSSION AND CONCLUSION	20
4.1 Prunus effect on absolute growth	20
4.2 Climate-growth response of oak.....	21
4.3 Disentangling competition and facilitation.....	21
4.4 The individual approach	22
4.5 Does prunus positively effect soil conditions?	23
4.6 Conclusion	23
5 REFERENCES	25
APPENDICES	29

1 | INTRODUCTION

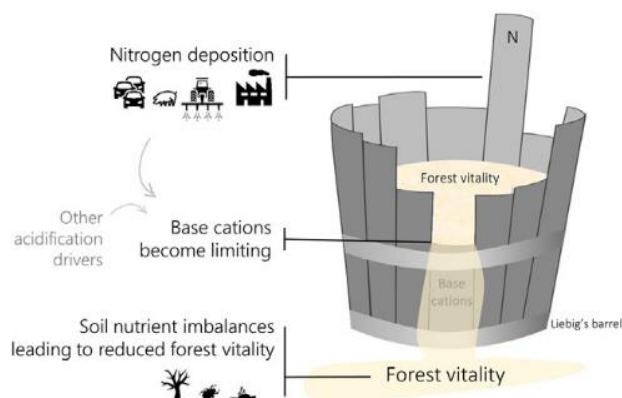
1.1 | Nitrogen deposition and soil acidification

Decades of excessive nitrogen (N) deposition have had a large and complex impact on northwest European ecosystems (Bobbink & Lamers, 1999). Effects range from eutrophication, direct toxicity to plant species and changed chemical composition of plants which, in turn, effects the fauna in higher trophic levels (Bobbink et al., 2019; Nyssen et al., 2014). Additionally, excessive N deposition has led to the acidification of forest soils and accumulation of large N-loads in the ecosystem (Bobbink et al., 2019).

Soil acidification can have a severe impact on forest ecosystems, especially in poorly buffered sandy soils that are characterized by a low base cation exchange capacity. Continued input of excessive N and the subsequent release of H^+ will deplete the base cations from the soil buffer complex, further lowering the pH until Al^{3+} is released inducing soil toxicity (Bowman et al., 2008). Reduced base saturation (De Vries et al. 2017) , along with an overload of N causes nutrient imbalances in plants, leads to a change in stoichiometry in plants and reduction of food quality for herbivores (Bobbink & Lamers, 1999; Bowman et al., 2008; Tian & Niu, 2015; Lucassen et al., 2014; Tomlinson, 2003), reduced tree growth (Högberg et al., 2006) and even tree death (Magill et al., 2004). See figure 1 for a graphical overview.

Measures to increase soil buffering capacity may alleviate the impact of soil acidification (Lucassen et al., 2014). To date, strategies to restore soil pH and nutrient balance mainly focused on the application of lime, wood ash or rock dust, measures which increase the availability of carbonates and cations (Bobbink et al., 2018; De Vries et al., 2019; Lundström et al., 2003). However, these are mitigating measures with merely temporary effects.

Forests on acidified, poorly buffered sandy soil



Rich litter as restoration measure

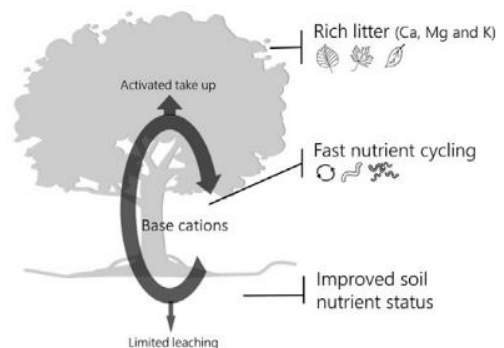


Figure 1. Graphical summary of the problem of nitrogen deposition and rich litter as restoration measure. The left image summarizes the effect of nitrogen deposition on forest vitality by Liebig's barrel. In nutrient poor sandy soils, acidification will rapidly cause base cations to become limiting, inducing a disbalance of soil nutrients leading to reduced forest vitality. The right image summarizes the effect of rich litter input as soil restoration measure, limiting leaching of base cations. Images are derived from Desie et al. (2020a).

1.2 | Rich litter as soil restoration measure

A more sustained soil restoration measure that is recently being explored is the admixture of tree species with nutrient rich, easily degradable litter (further referred to as rich-litter species) (i.e. by Hommel et al., 2007; Carnol & Bazgir, 2018). The chemistry of the litter returned to the soil alters soil properties (Finzi et al., 1998; Kooch et al., 2017; Reich et al., 2005; Sayer, 2006) and more specifically has the potential to increase base cation concentrations in the soil (Desie et al. 2020a). Planting rich-litter species appears to be a promising restoration strategy to improve soil quality in forests with poor, acidic soils (see figure 1) and is currently implemented in the Netherlands, amongst other in the project Correlatief onderzoek Rijk-strooiselsoorten in Natuurgericht Bosbeheer.

Multiple studies have hypothesized that the admixture of rich-litter species will help to reduce soil acidification, increase base saturation and (partially) restoring the nutrient balance (Carnol & Bazgir, 2013; Desie et al., 2020; Hommel et al., 2007; Nyssen et al., 2013). Sandy soils seem especially suitable for this restoration measure: not only do these soils acidify relatively rapidly, they also more easily de-acidify as they have a relatively small cation exchange complex (Desie et al., 2019).

Through enrichment of the soil, rich-litter species may subsequently have a positive, facilitating feedback on the growth of the surrounding vegetation. The first few studies on this effect do suggest a facilitating effect of rich-litter input on tree growth (Pretzsch et al., 2010; Sapijanskas et al., 2013). Pretzsch et al. (2010) showed that Norway spruce benefits from the facilitative effects of European beech on nutrient-poor soils, resulting in stand growth acceleration. The suggested mechanism behind this facilitative effect was improved nutrient supply by beech since beech litter contains higher nutrient levels and a lower C/N ratio than Norway spruce litter (Pretzsch et al., 2010).

The study of Sapijanskas et al. (2013) disentangled the effect of competition for light with residual neighborhood effects on individual tree growth. They found that light competition was not the only mechanism driving growth, and that litter production by neighbors explained residual neighborhood effects on growth better than crowding indices based on the summed basal area of neighbor trees (Sapijanskas et al., 2013). Even though these studies did not specifically show a positive impact of rich litter on tree growth, they did suggest that trees share resources through litter and therefore decrease interspecific competition (Pretzsch et al., 2010; Sapijanskas et al., 2013).

Besides the proposed positive effect on topsoil pH and base saturation, litter rich in base cations has been shown to promote earthworm abundance, leading to an increase in organic soil matter (Desie et al., 2020; Reich et al., 2005). In turn, this might lead to an improved water holding capacity of the topsoil, possibly increasing tree resilience to drought. This indicates that the facilitating effect of rich litter input might mitigate growth responses to weather fluctuations and drought events. However, this is based on assumptions and has not been studied yet. Multiple studies focused on the general effect of interspecific facilitation on climate-growth responses, indicating improved resilience to weather fluctuations (Mölder & Leuschner, 2014) and extreme climatic events, such as droughts (Chhin & Wang, 2016; Pretzsch et al., 2013) in mixed forests. However, these studies did not directly link this facilitating effect to rich litter input.

Overall, the admixture with rich litter species seems to be a potentially effective soil restoration measure; rich litter showed to have a positive impact on topsoil pH and base saturation (i.e. Desie et al., 2020) and studies suggest a positive facilitating effect of rich litter on tree growth (i.e. Pretzsch et al., 2010). Thereby, rich litter may improve water holding capacity and therefore decrease drought susceptibility in trees. However, these are merely suggestions, knowledge on the effect of rich litter input on actual tree growth is lacking let alone the effect under various site conditions and interaction of different species.

1.3 | Study objective and hypotheses

The main objective of this study was to investigate whether there is an effect of the rich-litter species *Prunus serotina* (Black cherry) on the radial growth and climate-growth response of the poor-litter species *Quercus robur* (Common oak) growing in the same site. The main hypothesis was that the presence of *Prunus* would have a positive effect on the growth of *Quercus* by improving the soil nutrient status. The conceptual model underlying the theory of the main hypothesis is depicted in figure 2.

As a second hypothesis it was expected that the presence of *Prunus* will mitigate the response of *Quercus* to weather fluctuations, specifically drought events, through the facilitating effect of rich-litter input on soil properties increasing water holding capacity.

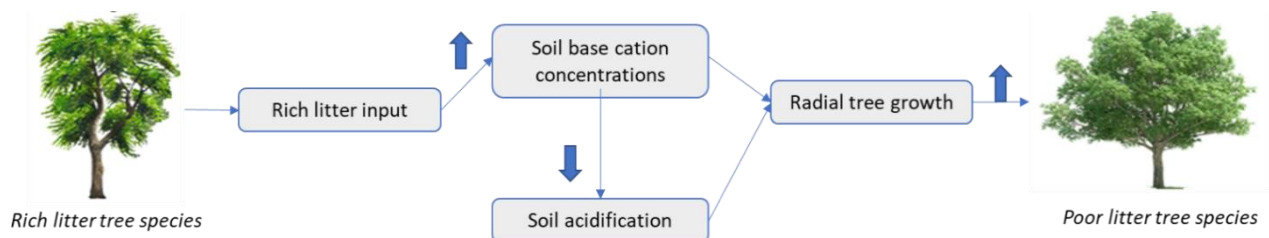


Figure 2. Conceptual model of the main hypothesis. The presence of tree species with litter rich in base cations is hypothesized to improve radial growth of poor litter tree species growing in vicinity to these rich litter species, through the mechanism of rich litter enriching the soil and reducing soil acidification.

2 | METHODS

2.1 | Study species and sample locations

To date, studies on tree litter quality have frequently summarized the litter quality by the amount of recalcitrant carbon (C) compounds, such as lignin, relative to the N content of the litter; the C/N ratio (Cuchietti et al., 2014; Kooch et al., 2017). However, in forest ecosystems with a high N deposition, the C/N ratio may not be a suitable indicator for litter quality, since N is not the limiting resource in such a system. Instead, the most prominent driver of litter quality in such ecosystems is found to be the base-cation concentration (Desie et al., 2020). Desie et al. (2020) defined 'rich litter' as litter with base-cation concentrations higher than 20g/kg dry weight and ranked tree species from rich-litter species (e.g. *Prunus*, *Alnus*, *Acer*, *Tilia* and *Betula*) to species with poorer litter (e.g. *Quercus* and *Fagus*).

Table 1. Site characteristics. Sites sorted by increasing sand content (Data derived from Desie et al. 2020b).

Site	Clay (%)	Silt (%)	Sand (%)	Soiltype	Subsoil CEC (meq/100g DW)	Forest since (earliest map)
Veldhoven	3.57	29.03	67.42	Anthrosol	1.47 ±0.32	1850
Walbeck	6.68	24.5	68.78	Arenosol	2.87 ±0.64	1850
Loon op Zand	2.01	19.84	80.39	Podzol	1.96 ±0.48	1988
Someren	1.99	13.17	86.55	Arenosol	2.19 ±1.17	1933
Grashoek	1.67	9.09	89.23	Podzol	3.85 ±1.25	1926
't Zand	1.27	3.94	94.77	Arenosol	1.36 ±0.144	1899

In this study we made use of these ranks and selected the poor litter pedunculate oak (*Quercus robur*) (from here on referred to as 'oak') and the rich litter species Black cherry (*Prunus serotina*) (from here on referred to as 'prunus') as study species. Oak has poor litter with a low litter base-cation concentration of 15.4 g/kg dry weight and prunus has rich litter with a high base-cation concentration of 23.8 g/kg dry weight (Desie et al., 2020).

Furthermore, prunus and oak were selected as study species because they frequently occur together in Dutch forests, which made it possible to select sufficient suitable study locations within the study region.

The study region stretched from the southern part of the Netherlands to the border with Germany and is located on Pleistocene deposits of the West-European sand belt (figure 3). This region is characterized by a temperate climate with a mean annual precipitation (MAP) of circa 800 mm and a mean annual temperature (MAT) of 10.5 °C (data from the Royal Netherlands Meteorological Institute). Six forest sites were selected using several criteria: relatively poor, sandy and slightly acid soil; the presence of old prunus trees (>25yr); the

presence of oak in vicinity (<10m) to prunus; and the presence of oak not (or only slightly) influenced by prunus (figure 4). The soil types of the six sites varied between Arenosols, Podzols and Anthrosols with soil texture ranging from sandy loam to almost pure sand (67% - 95% sand) (table 1). The cation exchange capacity of the soils was low at all studied sites (ranging between 1.36 and 3.85 meq/100g DW).

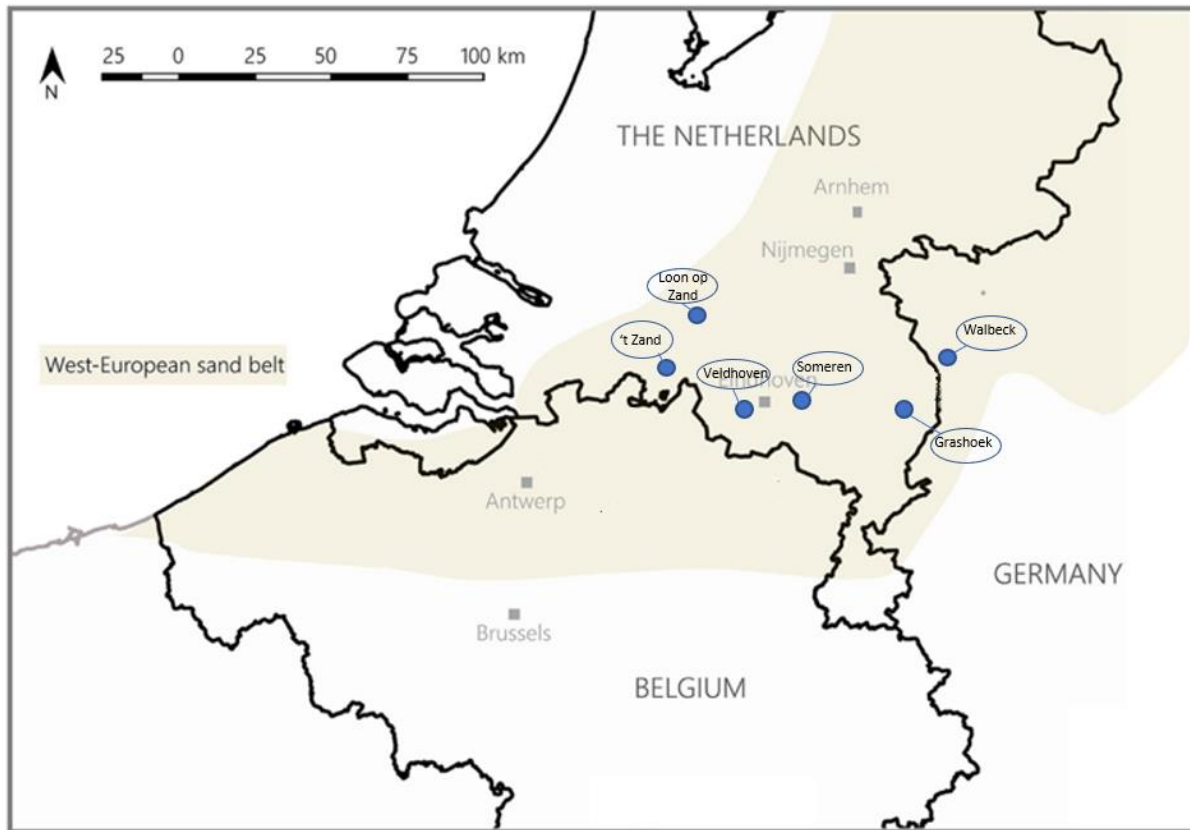


Figure 3. Locations of the study sites. The study region stretches from the Southern part of the Netherlands to the boarder of Germany and is located on Pleistocene deposits of the West-European sand belt, indicated by shading (based on (Beerten et al., 2014) and (Desie et al., 2020b)).

2.2 | Field sampling

Data for this study were collected in the sites Grashoek and Walbeck (winter 2017), Someren (autumn 2018), and Veldhoven, Loon op Zand and 't Zand (winter 2019). At each site prunus trees ($n_{\text{total}}=34$), oaks influenced by prunus ($n_{\text{total}}=54$) and oaks uninfluenced by prunus ($n_{\text{total}}=81$) were selected. The selected trees were (co-)dominant and were in the highest diameter breast height (dbh) classes present at the site to avoid large age differences. For each tree, two increment cores were extracted perpendicular to each other at 50 cm stem height in order to include a maximum number of tree rings. Samples were stored in straws in order to prevent them from drying out and transported to the dendrochronology lab of Wageningen University & Research. Additionally to the core extraction, the diameter breast height and the height of the trees were measured and vitality and social position were recorded

(appendix S14). Neighborhood basal area around each tree was measured twice at opposite sides of the stem, at approximately one meter distance, using an angle gauge with basal area factor 2 (De Vries & Stoffels, 1967). Tree counts included the focal tree, and were averaged over the two measurements.

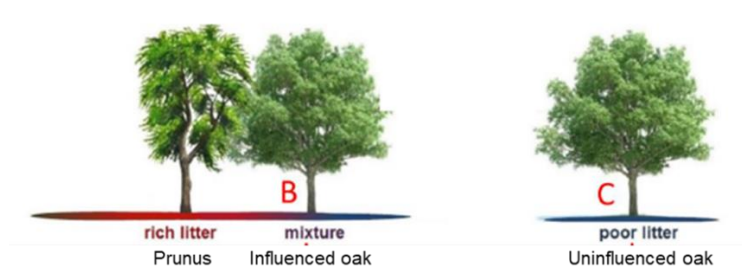


Figure 4. Study design setup. Oak growing in vicinity of prunus trees and therefore influenced by rich litter was labelled as ‘B oak’ and oak uninfluenced by rich prunus litter was labelled as ‘C oaks’.

2.3 | Dendrochronological analyses

In the laboratory, the samples were glued on wooden holders with the wood fibers oriented vertically. When dried, the samples were cut with a microtome and polished with a series of successively finer grades of sandpaper in order to make the xylem cell structure clearly visible. Samples with large rotten segments were excluded, since these samples could not be analyzed properly. The samples were inspected under a stereo-microscope and tree rings were determined. The number of missed tree rings from the pit was estimated by drawing the orientation of the oldest sampled tree rings, extending the rays and estimating missed years based on the average width of oldest sampled rings. In the case of missing bark, missing youngest tree rings were estimated by comparing the concerned core chronology to the second core of that same tree. The estimation of missed tree rings allowed for a more accurate determination of the tree age.

Ring width was measured with a 1/100 mm accuracy using a LINTAB measuring table in combination with the Time Series Analysis Program (TSAPWin) (both Rinntech, Heidelberg, Germany). The ring-width series were visually cross-dated per tree to correct for potential double or absent rings and measurement errors. Subsequently, the quality of these cross-dated series was assessed by means of the COFECHA software (Grissino-mayer, 2000; Holmes, 1983).

The mean of the two ring-width series from the same tree was calculated to obtain a ring-width chronology for each tree. Tree age was estimated by taking the number of measured tree rings and add the estimated missed tree rings and the estimated growth years before reaching the core-extraction height of 50 cm (appendix S14). Ring-width series statistics were calculated for all prunus and oak trees, including the mean ring width, first order auto-correlation, standard deviation, first and last measured year and skewness (appendix S12).

Before further processing, a ‘smoothing spline’ was used to detrend the individual time series. Detrending removes low-frequency variation related to age and forest dynamics and maximizes the high-frequency climatic information (Helama et al., 2004). Per site and tree species, the individual detrended time series were averaged into a master chronology. The statistical quality of the master chronology at the site level was assessed in the common

overlap period of all trees per site by calculating the mean correlation between trees (r_{bar}), signal-to-noise ratio (snr), and expressed populations signal (eps) (appendix S11). The r_{bar} gives the average correlation among trees within a site for the common overlap period, whereas the eps takes into account the number of samples contributing to r_{bar} (Buras et al., 2016). The snr index informs about the ratio between short-term and long-term variation in the chronologies. High values of r_{bar} ($>\pm 0.3$) and eps ($>\pm 0.85$) suggest that trees react strongly to a common signal and therefore give an indication of the strength of the master chronology representing the site.

2.4 | Computing growth response

The dendrochronological analysis of the 169 trees focused on the effect of rich litter input on (1) average annual growth variation and basal area increment, (2) the climate sensitivity of the annual growth, (3) the resilience, resistance and recovery related to selected drought years and (4) the individual growth variation. In most analyses, we used the whole growth period of the trees. For the analysis of the effect of rich litter input on the basal area increment, the 6-year period 2012-2017 was selected. This period was chosen for two reasons: it is the common growth period for all tree-ring chronologies and in this period we could be sure that the effects of rich-litter input are proportional to the basal areas of the tree species surrounding the focal trees. This is because from 2012 onwards, prunus trees had been influencing the neighborhood of the influenced oaks for at least 20 years. On average the prunus trees which were growing at the study sites at the moment of sampling were 20 years younger than the oak trees. However, many prunus trees had two stems which indicates earlier cutting of the prunus trees and hence indicates previous presence of prunus at all study sites.

To compare similarities between oak type chronologies, the average Gleichläufigkeit (glk , (Buras & Wilmking, 2015) was computed between influenced (B oaks) and uninfluenced (C oaks) per site and over sites. Gleichläufigkeit is frequently used in dendrochronology, and calculates the percentage of common signs of the annual growth between two time series (Buras & Wilmking, 2015). From the radial increments, and calculated diameters based on the measured tree-ring widths, we computed the average annual basal area increment (BAI; $cm^2/year$) of each sampled tree. We calculated cumulative basal area in the whole growth period to compare the growth of prunus, and B and C oaks. Additionally, the BAI of the specific 6-year growth period of 2012-2017 was used to test whether absolute growth differed between the influenced and uninfluenced oaks in this period.

The effect of rich litter on oak trees was investigated at a neighborhood scale, which can be defined as the area at which neighbor trees influence a tree through inter- and intraspecific interactions. To be able to disentangle neighborhood interactions, the positive facilitative effects of rich litter and the negative competitive effects of neighbor trees were taken into account by using three indicators of neighborhood interaction: a neighborhood competition index, the percentage of prunus in the local basal area around the focal oak tree, and a neighborhood litter quality index. The neighborhood competition index (NCI) was calculated for focal tree i as the total basal area (BA; cm^2) of neighbor trees j ($NCI_i = \sum BA_j$) (for a related approach see (Fichtner et al., 2017)). It was assumed that this competition index mainly concerned competition for water and nutrients, since sampled trees were (co-)dominant canopy trees and were thus not directly competing for light.

The facilitating effect of prunus was calculated as the percentage of prunus of the total basal area of the focal tree's neighborhood. This variable was used to get an indication of the amount of facilitating influence of prunus litter on the focal oak tree. However, prunus was not the only

rich litter species growing in the neighborhood of oak (see appendix S16 for average basal area of all tree species in the oak neighborhoods). Therefore, a litter quality index was calculated per focal tree indicating the quality of the litter input from its neighbor trees. This index was based on the species' leaf litter base cation concentrations obtained by the study from Desie et al (2020). For the species which were not studied by Desie and colleagues, base cation concentrations were estimated based on the concentrations of species with similar leaf traits. The index was finally calculated as the average base concentration of the surrounding tree species, weighted by their basal area (see appendix S15 for leaf base cation concentrations per species and S17 for average neighborhood indices per site).

Since the subdivision of B and C oaks depended on observations in the field, the accuracy of this subdivision was tested by comparing the difference in litter quality indices and percentages of prunus between the B and C oaks with a two-sample t-test or, in case of a non-parametric distribution, a Mann-Whitney U test. It was thus tested whether there was a clear difference in the presence of prunus or assumed input of high quality litter between B and C oaks.

Next, linear mixed models were used to test the difference in litter quality and NCI, including *site* as a random factor. Since the data of the percentage of prunus was not normally distributed, a generalized linear mixed model with a Poisson distribution including a 'log link' was calculated:

$$\begin{aligned} \text{Percentage of prunus} &\sim \text{Tree type} + (1 \mid \text{Site}) & (1) \\ \text{Litter quality index} &\sim \text{Tree type} + (1 \mid \text{Site}) & (2) \\ \text{NCI} &\sim \text{Tree type} + (1 \mid \text{Site}) & (3) \end{aligned}$$

Linear mixed models were calculated to examine the influence of the litter quality index and percentage of prunus on the average basal area increment (BAI) in 2012-2017 of the focal tree. In these mixed models, *site* was again used as a random factor. The average BAI was logarithmically transformed in order to normalize the data. In order to disentangle the facilitating and competitive neighborhood effect, the NCI was included as a fixed factor:

$$\begin{aligned} \log(\text{Average BAI}_{2012-2017}) &\sim \text{Litter quality index} + \text{NCI} + (1 \mid \text{Site}) & (4) \\ \log(\text{Average BAI}_{2012-2017}) &\sim \text{Percentage of prunus} + \text{NCI} + (1 \mid \text{Site}) & (5) \end{aligned}$$

2.5 | Climate growth-response

2.5.1 | Correlations with climatic variables

The climate data used in this study were monthly gridded time series for total precipitation (Prec) and mean temperature (T_{mean}) from the weather station at Eindhoven, obtained from the Climate Explorer of the Royal Netherlands Meteorological Institute (<http://climexp.knmi.nl/>). Missing data were supplemented with data from the weather station De Bilt. In order to better assess the effects of drought, the Standardized Precipitation Evaporation Index (SPEI) was calculated using the SPEI package in R (Beguería & Vicente-Serrano, 2017). SPEI uses the monthly difference between precipitation and potential evaporation to represent a climatic water balance and can be used to identify the intensity and duration of drought episodes (Vicente-Serrano et al., 2010). Potential evaporation was calculated using the Penman-Monteith equation, which includes precipitation, temperature, cloud coverage (or hours of sun) and site latitude. In this study, the timescale of a 3-month SPEI was used, which indicates the cumulative water deficit of a specific month and the two preceding months. The 3-month SPEI therefore gives a better seasonal indication for drought compared to the 1- and 2-month SPEI.

We calculated SPEI₃ for every month of the year (January to December). Negative SPEI values indicate dry conditions: moderate drought (SPEI < -1), severe drought (SPEI -1 ≤ -1.5), or extreme drought (SPEI -1.5 ≤ -2) (Potop et al., 2014). Correlations between the climatic variables (SPEI₃, Prec, T_{mean}) and the master chronologies of the B and C oaks and prunus from the six different sites were calculated. Since high SPEI values indicate humid conditions, significant positive correlations with this index indicate a positive growth reaction to humid conditions.

2.5.2 | Growth response to drought years

Five drought years characterized by extreme spring and/or summer drought events were identified using the calculated SPEI₃ values and climatic information on the website of the Royal Netherlands Meteorological Institute (<https://www.knmi.nl/>): 1959 (spring and summer drought), 1976 (spring and summer drought), 2003 (spring drought), 2011 (spring drought) and 2018 (summer drought) (figure 5). To explore the different responses of oaks to drought we analyzed the growth response to these five drought episodes. Growth in a drought year (Dr), before drought (PreDr) and after drought (PostDr) are used to calculate indices for resistance (Rt = Dr/PreDr), resilience (Rs = PostDr/PreDr) and recovery (Rc = PostDr/Dr) (Lloret et al., 2011) (figure 5). A period of 3 years pre and post drought was used, therefore values for resilience and recovery could not be calculated for 2018.

Additionally, linear mixed models were used to examine the effects of percentage of prunus and litter quality on the responses to these episodes in terms of resilience, resistance and recovery, including *site* as an random factor and litter quality index or NCI as a fixed factor. The values for resilience, resistance and recovery were logarithmically transformed in order to normalize the data:

$$\log(\text{resilience/resistance/recovery}) \sim \text{Litter quality index} + \text{drought year} + (1|\text{Site}) \quad (6)$$

$$\log(\text{resilience/resistance/recovery}) \sim \text{Percentage of prunus in BA} + \text{drought year} + (1|\text{Site}) \quad (7)$$

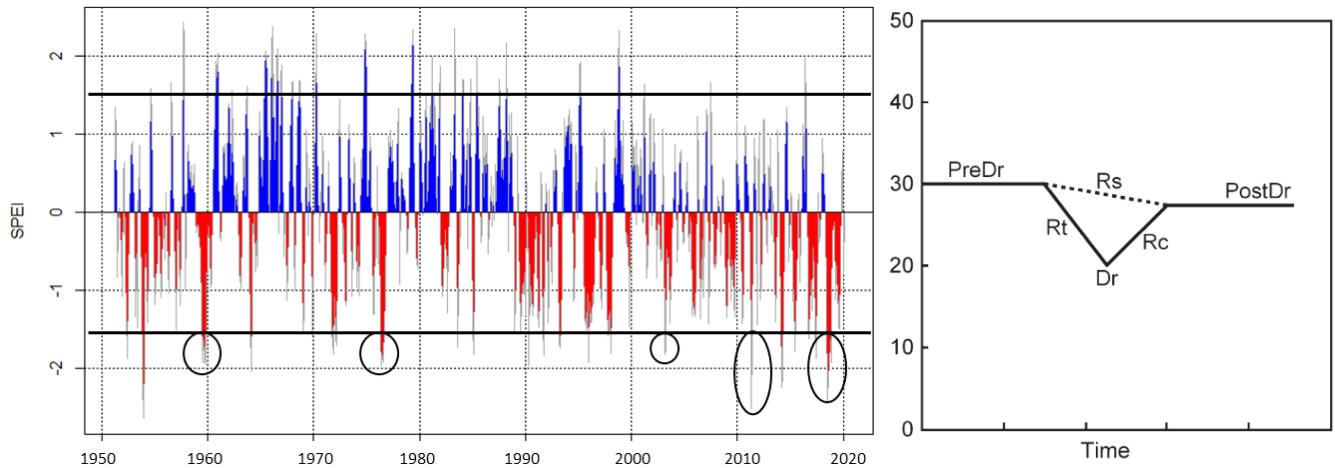


Figure 5. SPEI₃ graph and schematic graph for drought response. Left graph shows SPEI₃ values for 1950-2020. Lower thick black line is set at SPEI₃ = -1.5. Values below -1.5 are characterized as extremely dry (Potop et al., 2014). Circled drought peaks indicate analyzed drought years: 1959, 1976, 2003, 2011 and 2018. Right graph shows a schematic overview of the growth response to a drought year (modified after Lloret et al., 2011)). Growth in the drought year (Dr), before drought (PreDr) and after drought (PostDr) are used to calculate indices for resistance (Rt = Dr/PreDr), resilience (Rs = PostDr/PreDr) and recovery (Rc = PostDr/Dr).

2.6 | Individual tree approach

The use of master individual chronologies even out individual growth variation (Carrer, 2011). Therefore, next to the analyses of average chronologies per site, we used an individualistic treatment of time series. Tree-ring data were explored for possible differences in individual growth responses by performing a Principal Component Gradient Analyses (PCGA, Buras et al., 2016). PCGA is based on the first two principle components obtained from a normal PCA, defining a gradient among the individual time series based on the angle of these loadings. With this gradient, responder groups can be defined which represent different variance patterns (Buras et al., 2016). The obtained PCGA gradients can be explored for possible mechanisms driving it. In this study, PCGA was used to explore whether rich litter input may explain the identified gradient, therefore the PCGA gradient was correlated with the percentage of prunus and the litter quality index of the individual trees using Spearman's rank correlations. Additionally, the PCGA gradient was correlated with the NCI to explore to what extent neighborhood competition explained the ecological gradient. Wilcoxon rank sum tests were used to test whether the polar angles representative of the loadings for B oaks differed significantly from the loading of the C oaks.

For the sites which correlated with the rich litter indices, gradients derived from the PCGAs were further explored since these could give more information on the differences between oaks influenced and uninfluenced by rich litter. Individual tree-ring series were correlated with the climate parameters temperature, precipitation and SPEI₃ using Pearson pairwise complete correlations. In this individual approach, the climate correlations were referring to the climate of the current growth year. Significance of these individual climate correlations were visualized by means of correlograms.

Spearman correlation tests were used to test whether the shift of correlation coefficients along the gradient was significant, which would indicate a shift in the individual responses to climate variation along the PCGA gradient. Correlations with the climatic variables were again sorted over the gradient to investigate whether there was a trend in the number of correlations in that test. Significant correlations were visualized in correlograms. These significant correlations indicated an increasing or decreasing response to the climate variable over the obtained principal component gradient.

All calculations were done in R 3.6.2 (R Development Core Team, 2017) with the additional packages 'Dendrochronology Program Library in R' (dplR) (Bunn, 2010), 'Numerical Calibration of Proxy-Climate Relationships' (treeclim) (Zang & Biondi, 2015) and 'dendRoIAB' (Buras, 2019).

3 | RESULTS

3.1 | Neighbourhood indices

The average age of the influenced and uninfluenced oaks was similar within the sites Loon op Zand, 't Zand, Veldhoven and Walbeck (table 2). However, the absolute age difference at Grashoek and Walbeck was high since a few older C oaks were sampled (see appendix S14 for the age of sampled trees). Nevertheless, we decided to include these trees in the analyses since this only concerned a few trees. At Someren, there was a large difference in average age of 21 years, since most sampled uninfluenced oaks (9 out of 12) were from a ± 30 years older stand than the influenced oaks. Since this represented such a large proportion of the sampled C oaks, we decided to exclude these older trees from further analyses, which left us with only 3 C oaks at Someren.

Statistical tests (see figure 6) confirmed that the percentage of prunus in stand basal area around influenced B oaks ($\bar{x}=30.6$, $\sigma=9.9$) was substantially higher than around the uninfluenced C oaks ($\bar{x}=8.1$, $\sigma=7.7$). Additionally, the B oaks had a higher average litter quality index ($\bar{x}=17.8$, $\sigma=1.1$), compared to C oaks ($\bar{x}=15.9$, $\sigma=1.2$) (figure 6). This holds for all sites except for Grashoek, which did not show a significant difference in litter quality index between B and C oaks. This was due to the high abundance of *Betula pendula* at this site (see appendix S16 for basal area of tree species around focal trees). Mixed models, with *site* as random factor, confirmed the overall significant difference in the percentage of prunus in basal area ($z = -25.45$, $p < 0.001$) and litter quality ($\chi^2 = 97.56$, $p < 0.001$) (see appendix S2 for model parameters). These results confirmed the appropriateness of using the subdivision of B and C oaks in further analyses of the effect of rich litter input on the growth of oak (we refer to the appendix S1 for all test results and to S17 for the average neighborhood indices per site). The average NCI of B and C oaks did not differ significantly for the sites Someren, 't Zand and Walbeck. For Grashoek, Veldhoven and Loon op Zand there was a stronger competition around B oaks (appendix S1 and S17). Taking the six sites together, the mixed model for NCI indicated similar competition in B and C oak neighborhoods (figure 6).

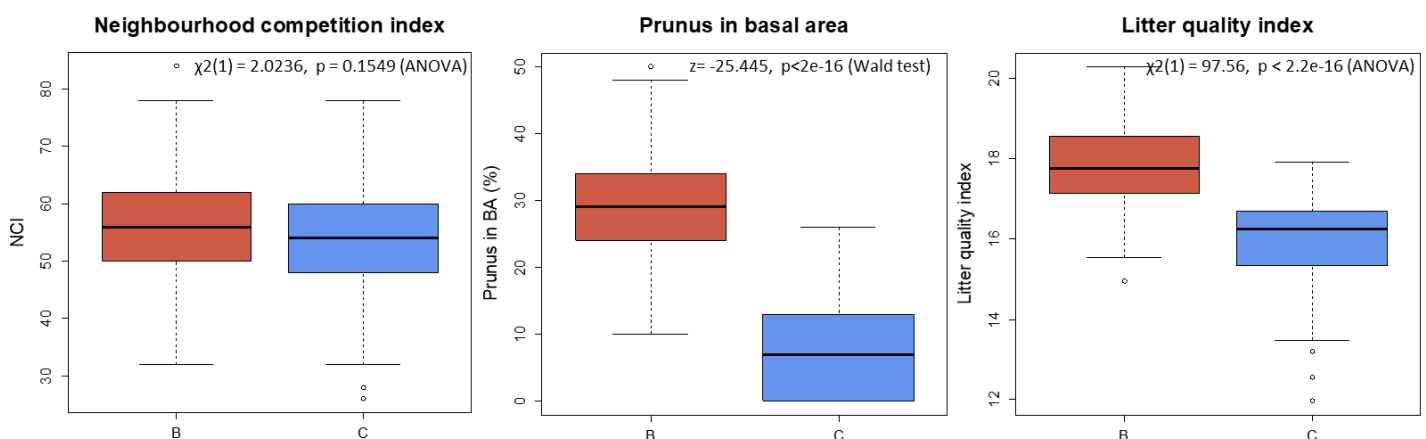


Figure 6. Comparison of neighborhood indicators between tree types. The left graph compares the neighborhood competition index (NCI) between influenced B oaks (red) and uninfluenced C oaks (blue). The middle graph compares the average basal area share (%) of prunus next to B and C oaks. The right graph compares the litter quality index. Graphs include the results of the statistical tests comparing the three neighborhood indices for B and C oaks.

Table 2. Sampled trees per site. An overview of the number of sampled trees and the average and standard deviation of the age of the trees per site.

Site	Influenced B oaks <i># sampled trees</i>	Uninfluenced C oaks <i># sampled trees</i>	Prunus <i># sampled trees</i>	Average age B oaks <i>years</i>	Average age C oaks <i>years</i>	Average age prunus <i>years</i>
Grashoek	12	13	1	46±2.7	54±4.2	39
Loon op Zand	9	11	5	58±3.2	65±4.8	45±6.2
Someren	11	12	8	40±13.1	61±1.1	33±1.8
Veldhoven	12	13	7	68±4.1	68±4.9	32±3.0
Walbeck	11	19	8	86±6.9	90±14.4	66±22.8
't Zand	4	14	5	74±5.7	78±38	55±6.1
total	54	81	34	62±17.1	71±15.4	46±17.9

3.2 | Average annual growth variation and basal area increment

The Gleichläufigkeit (glk) between the chronologies of C oaks of all sites was between 54-77% and for the B oaks between 61-77%, indicating high similarities of the growth variation of these two tree types over the sites (see appendix S3 for glk tables and chronologies). The glk between B and C oaks at a same site showed values ranging from 69-87% (figure 7).

Cumulative basal area (cm²) of B and C oaks was highly comparable within Veldhoven, Loon op Zand and 't Zand. At Grashoek, the cumulative basal area graph showed higher values for the C oaks than the B oaks. However, this had to do with the average age difference between the two types of oaks. Taking age into account, both oak types had very similar values for cumulative basal area as well. Someren did show a slightly higher cumulative basal area in B oaks than C oaks. At Walbeck, the B oaks grew faster at a young age than the C oaks (figure 7). Comparing prunus and the influenced oaks (appendix S13) clearly showed that prunus had a higher cumulative BA than the neighboring oaks in Grashoek and Someren. At Walbeck, absolute growth was very similar. Prunus at Loon op Zand, 't Zand and Veldhoven initially showed a lower cumulative BA. However, when trees aged the absolute cumulative BA of prunus exceeded that of B oaks (see appendix S13).

Influenced and uninfluenced oaks showed very similar values for basal area increment (BAI) in the 6-year period of 2012-2017 (figure 8) (for figures per site we refer appendix S4). Mixed models did not show a significant effect of percentage prunus on the BAI in this period (ANOVA, comparing model with and without percentage of prunus as fixed factor: $\chi^2=1.63$, $p=0.20$), neither for the litter quality indices (ANOVA, comparing model with an without litter quality index as fixed factor: $\chi^2=0.03$, $p=0.85$). In both mixed models, the NCI showed a neglectable influence on BAI, lowering BAI with $\pm 1.3\%$ per unit increase of competition (see appendix S6 for model parameters).

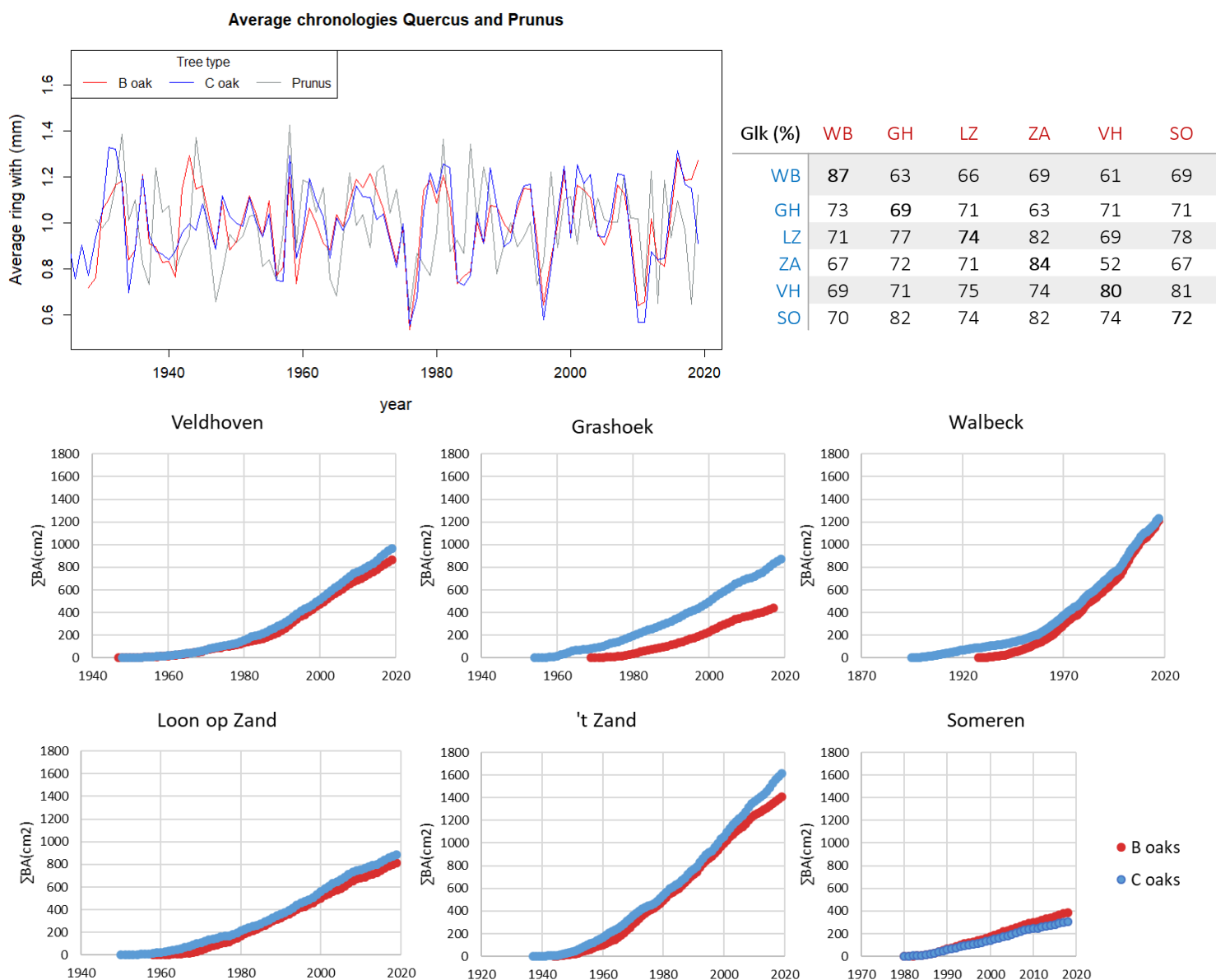


Figure 7. Evaluation of chronologies and growth. Upper left panel: the average detrended chronologies for the B oaks, C oaks and prunus from the 6 study sites with the average ring width (mm) on the y-axis and the growth year on the x-axis. Upper right panel: table of the Gleichläufigkeit, comparing average chronologies of the B and C oaks per site (WB = Walbeck, GH = Grashoek, LZ = Loon op Zand, ZA = 't Zand, VH = Veldhoven, SO = Someren). Glk represents the percentage of common signs of the annual growth between two time series. Lower panel: cumulative BA (cm²) of influenced oaks (B oaks, in red) and uninfluenced oaks (C oaks, in blue) over the years.

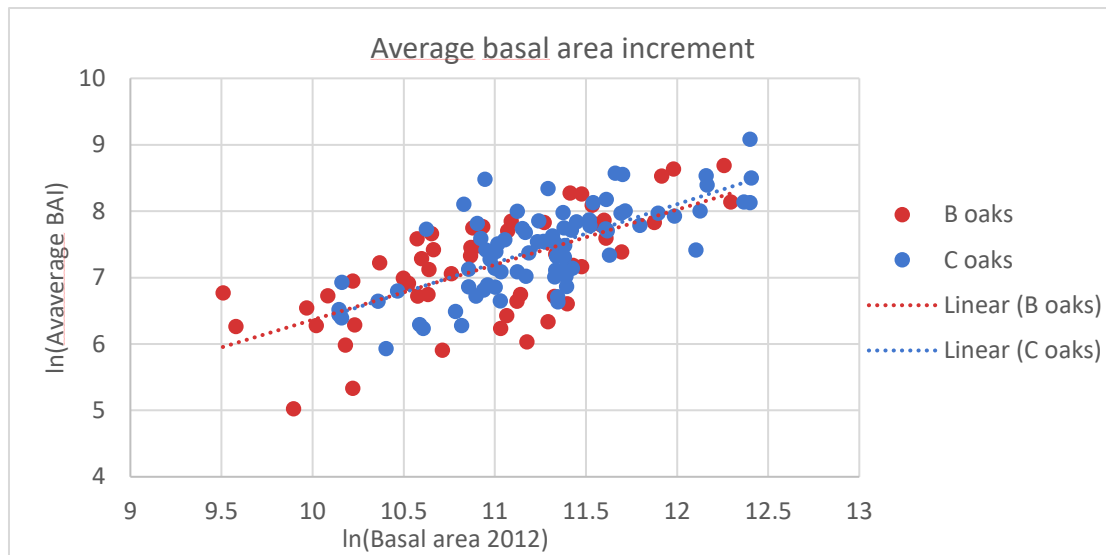


Figure 8. Average basal area increment. Absolute growth averaged for all sites. Average basal area increment on the y-axis, and the corresponding basal area in 2012 on the x-axis. Both axes are transformed with a natural logarithm. Oaks influenced by prunus are indicated in red (B oaks) and oaks uninfluenced in blue (C). Linear line indicates the trendline per oak type.

3.2 | Climate-growth correlations

Correlations of detrended chronologies of B and C oaks with temperature and precipitation showed very similar reactions to these climatic variables. Significant differences between these correlations were tested for each site and correlations were plotted against each other to visualize the similarities (we refer to appendix S6 and S7 for all graphs and correlations). For both B and C oaks, growth was positively affected by previous summer and current spring precipitation, and by high temperatures in the current spring. Ring widths were negatively correlated with high temperatures in previous summer. The only exception to these patterns was Grashoek, where B oaks reacted more strongly to temperature as compared to the C oaks, especially temperatures in previous summer. Ring widths in prunus showed little significant correlations with temperature and precipitation (see appendix S9 for correlation analyses of prunus).

Correlations of ring widths with SPEI₃ indicated more variation in response to humid conditions between the types of oaks and between sites. The values of SPEI₃ were similar for Walbeck, 't Zand and Loon op Zand, at these sites humid conditions both in the previous summer as in the current spring had a significant positive impact on the growth of both oak types. At the other sites this response varied from more positive correlations of C oaks with high SPEI₃ values in previous summer at Someren and Veldhoven, to more positive correlations of current spring in B oaks at Grashoek (see appendix S8 for graphs and correlations). For prunus, correlations with SPEI₃ indicated a significant effect of humid conditions in current summer at most sites (appendix S9).

3.3 | Resilience, resistance and recovery

Resilience, recovery and resistance to drought episodes showed similar values for B and C oaks (figure 9). Linear mixed models did not result in a significant effect of litter quality to resilience ($\chi^2= 2.20$, $p=0.14$), resistance ($\chi^2= 0.15$, $p=0.70$) and recovery ($\chi^2= 0.93$, $p=0.34$). Also, the percentage of prunus did not have a significant effect on resilience ($\chi^2=4e-0.4$, $p=0.98$), resistance ($\chi^2= 0.07$, $p=0.80$), and recovery ($\chi^2= 0.59$, $p=0.44$). The variation explained by the random factor *site* was only very small and specific drought events did not have a large effect on either resilience, resistance or recovery (see appendix S10 for model parameters).

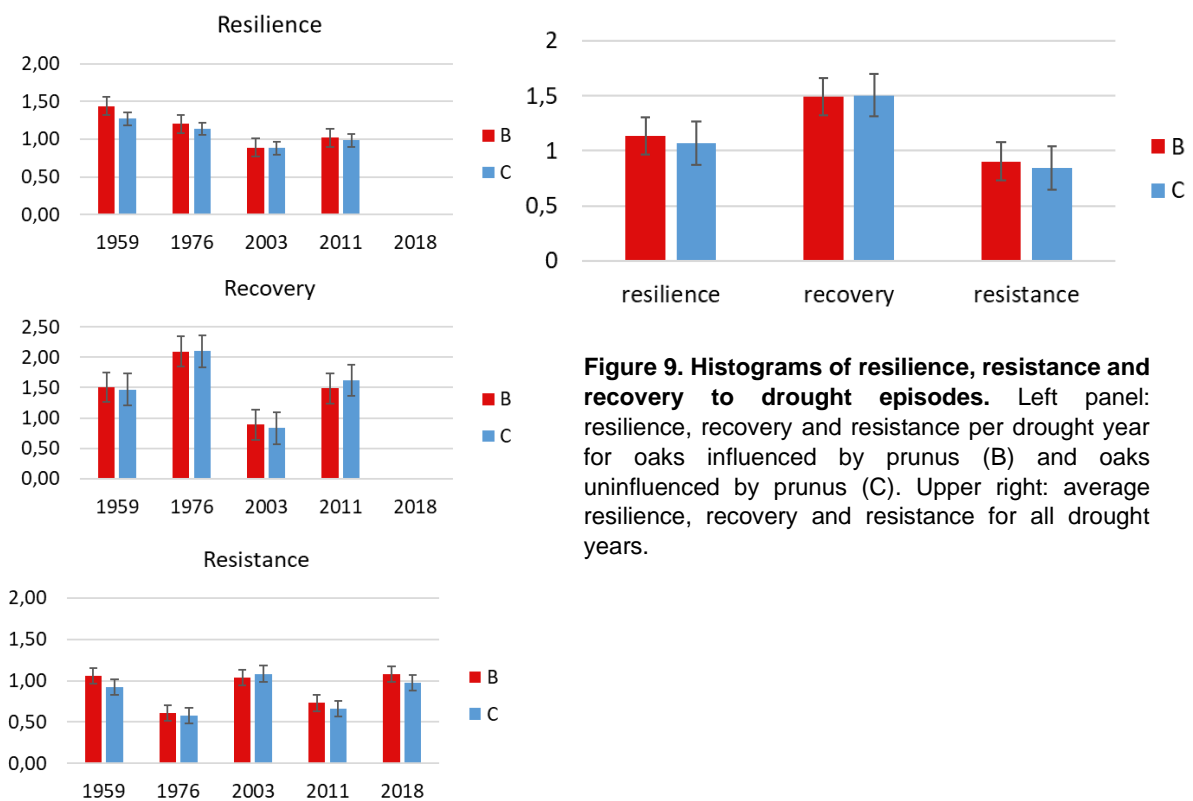


Figure 9. Histograms of resilience, resistance and recovery to drought episodes. Left panel: resilience, recovery and resistance per drought year for oaks influenced by prunus (B) and oaks uninfluenced by prunus (C). Upper right: average resilience, recovery and resistance for all drought years.

3.4 | Principle component gradients and correlations with neighborhood indices

Separate PCGAs were conducted with the detrended ring-width data for each site, since performing a PCGA for all sites together resulted in responder groups which mainly reflected the sites themselves. The first two principal components of PCGA explained overall variance ('t Zand: $r^2 = 0.70$, Veldhoven: $r^2 = 0.48$, Grashoek: $r^2 = 0.63$, Loon op Zand: $r^2 = 0.67$, Someren: $r^2 = 0.68$, Walbeck: $r^2 = 0.67$). The PCGAs demonstrated that there was a separation between the loadings of B and C oaks for some sites (figure 10). This separation, tested with a Wilcoxon rank sum test, was significant for the sites Veldhoven ($W=137$, $p<0.001$), Loon op Zand ($W=8$, $p<0.001$) and Walbeck ($W=167$, $p= 0.006$). Correlation analysis between the

derived principle component gradients and the rich-litter indicators showed strong correlations for Veldhoven ($p < 0.01$ for litter quality and $p < 0.001$ for prunus in BA) and Loon op Zand ($p < 0.01$) and a weaker but significant correlation for Walbeck ($p < 0.05$). The principle component gradient of Grashoek showed a significant correlation with NCI ($p < 0.05$). The gradients of 't Zand and Someren did not show any significant correlations (figure 11).

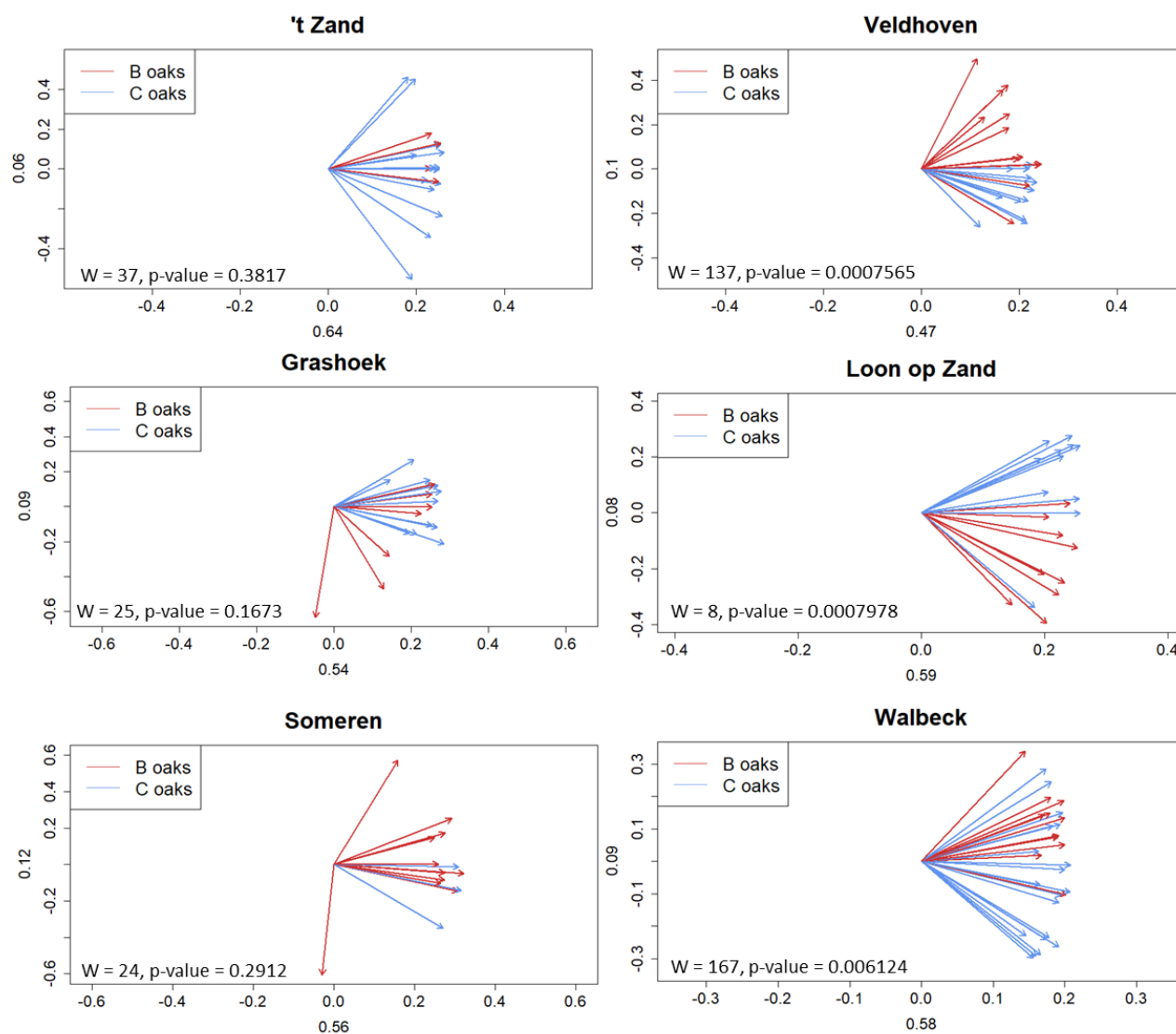


Figure 10. Loadings plot for the principal component gradient analyses. Loadings are based on detrended ring-width chronologies. Each arrow represents the loadings on the first two principal components from an individual tree at one site. Labels on the x- and y-axes represent the amount of explained variance by the respective principal component. Wilcoxon rank sum test to test the difference between loadings of influenced (B, red arrows) and uninfluenced oaks (C, blue arrows), are significant for Loon op Zand, Walbeck and Veldhoven.

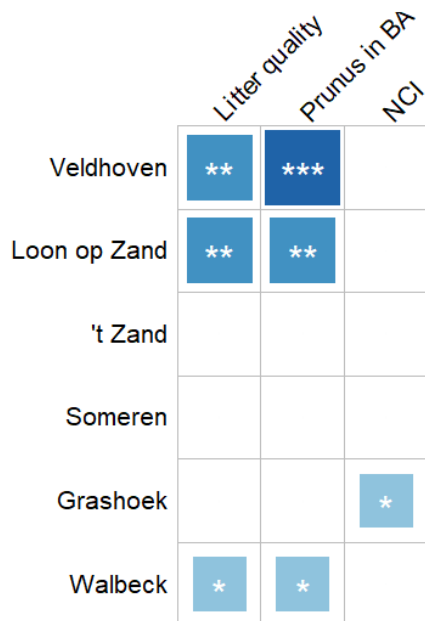


Figure 11. Correlogram PCGA gradients. Correlations of the ranks of the individual trees within the PCGA gradient with tree specific litter quality index, percentage of prunus in basal area and NCI. Significance indicated with (***) $p < 0.001$, (**) $p < 0.01$ and (*) $p < 0.05$ and visually supported by strength of blue colors.

3.5 | Individual tree correlations with climate variables

For the sites Loon op Zand, Veldhoven and Walbeck, gradients derived from the PCGAs were further explored. Multiple correlations shifted significantly among the principle component gradient (figure 13). These shifts suggest a significant difference of correlations between B and C oaks with the concerned climate variable. In case of significant shifts, the correlograms of the correlations of individual trees with climate variables were checked for significant strength of correlations (figure 14).

Figure 12 provides two visualized examples of individual correlations, the shifts among the gradient and significance of these correlations. In both these examples there is a significant shift among the gradient, however only for the upper graph there are significant correlations with the climate variable. Climate correlations were calculated for the current growth year.

There was no clear difference in reaction to temperature in B and C oaks of Walbeck and Veldhoven. For Loon op Zand, there was a slight difference in significant positive response to May temperatures (8 B oaks and 5 C oaks) (figure 14).

At Loon op Zand, C oaks reacted negatively to precipitation in November (8 C oaks, 1 B oak). The C oaks in Veldhoven reacted more positive to precipitation in March (8 C oaks and no B oaks). At Walbeck, there was only a clear difference for the month April, in which more C oaks correlated significantly positive to precipitation (7 C oaks and 1 B oaks).

The correlations with the $SPEI_3$ did not indicate any notable differences for Loon op Zand. At Veldhoven, a few B oaks reacted negatively to high summer $SPEI_3$ values. The opposite is the case at Walbeck, where B oaks reacted slightly more positive to high summer $SPEI_3$ values (10 B and 8 C oaks for July, 5 B and 3 C oaks for August).

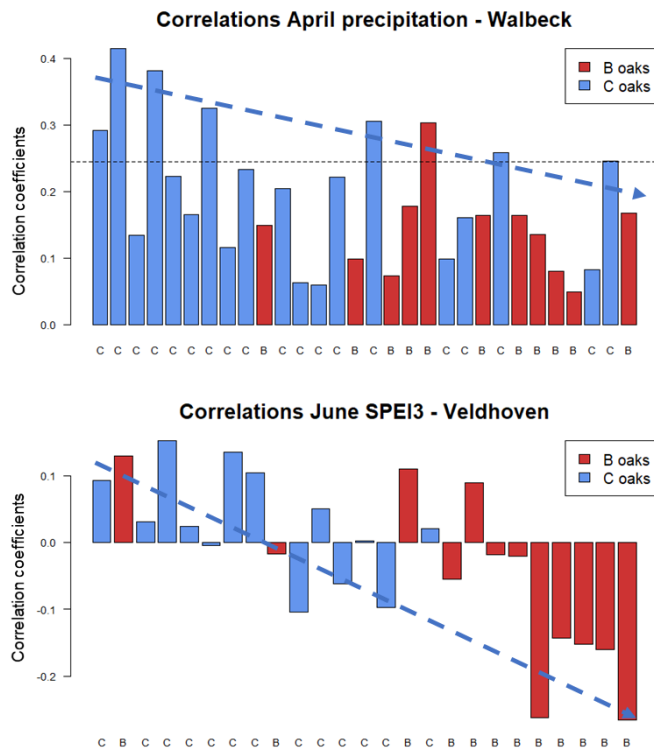


Figure 12. Examples of individual correlations with climate variables. The graphs show the individual correlation coefficients of the oaks influenced (B oaks, in red) and uninfluenced (C oaks, in blue) by prunus, sorted by the principle component gradient. Arrow indicates shift of correlations among this gradient. The dotted black line in the upper graph indicates significance level of correlation coefficients. The lower graph does not contain any significant correlations.

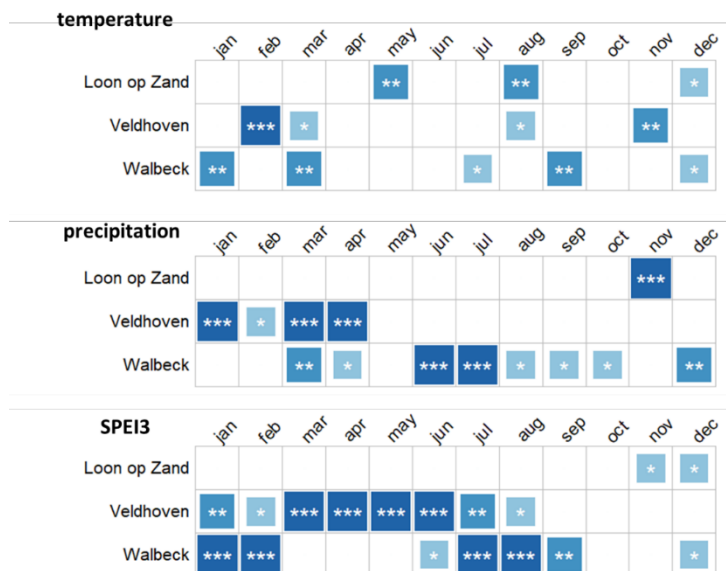


Figure 13. Correlogram PCGA gradients and climate variables. Correlogram showing test results of whether the shift of correlations from influenced (B) to uninfluenced (C) oaks along the principle component gradient is significant. Significance indicated with (***) $p < 0.001$, (**) $p < 0.01$ and (*) $p < 0.05$ is visually supported by the blue colors. Months represent those of the current growth year.

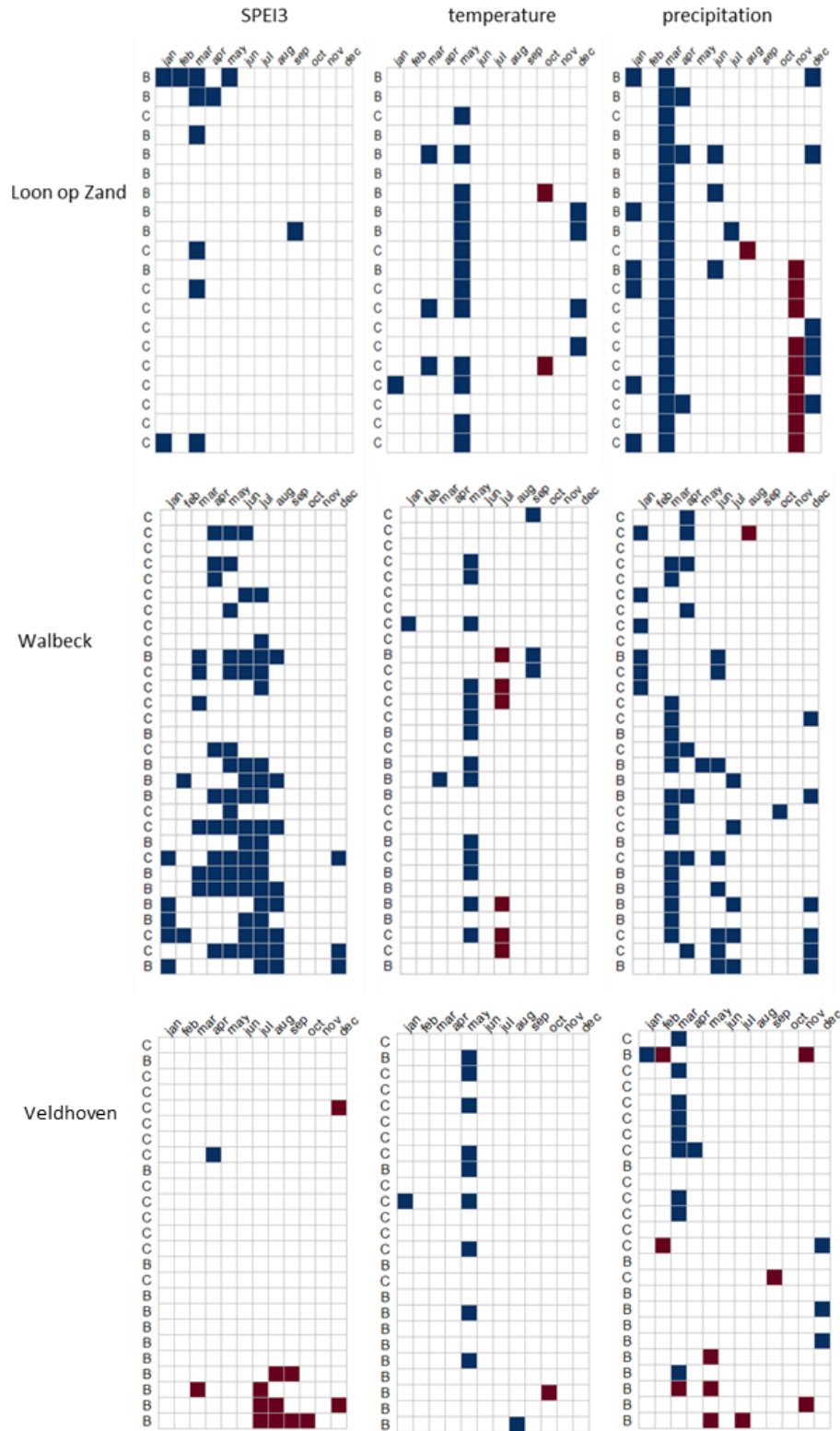


Figure 14. Correlograms of significant correlations of individual tree-ring series with climatic variables. For each location, correlations of all influenced (B) and uninfluenced (C) oaks with the climate variables SPEI₃, temperature and precipitation are visualized in correlograms. Blue boxes indicate a significant positive correlation for that month ($p < 0.05$), red boxes indicate negative significant correlations ($p \geq 0.05$). Individual trees are labelled by their tree type (B or C) and ordered by their ranks in the principle component gradient. Months concern the months of the current growth year.

4 | DISCUSSION AND CONCLUSION

The objective of this study was to investigate whether there was an effect of the rich-litter species *Prunus serotina* on the radial growth and climate-growth response of *Quercus robur* growing in the same neighborhood. We hypothesized that the presence of prunus would have a positive effect on the growth of oak and would mitigate the response of oak to weather fluctuations and drought events.

Our results did not show any difference in absolute growth between the oaks influenced and uninfluenced by rich-litter input by prunus. This was the case for both the entire growth period enclosed in the samples (figure 7), as for the 6-year period 2012-2017 (figure 8). With respect to the relative growth of oak, results indicated that there was no systematic effect of the presence of rich-litter species mitigating the response to weather fluctuations and drought (figure 9). However, when considering the ring-width patterns of the individual trees there were indications that there were some differences in growth variation between the two oak types (figure 10).

In this section we will first discuss the results of the analysis of absolute growth and climate growth responses on the master chronologies. Secondly, we will discuss the results of the PCGA and the approach considering the variation in individual trees. Finally, the effect of prunus litter on soil conditions will be considered.

4.1 | Prunus effect on absolute growth

The absolute growth of oaks influenced by prunus showed highly similar values with oaks uninfluenced by prunus for all analyses. One effect was noticed with respect to the calculations of the cumulative basal area for Walbeck: the influenced oaks grew faster at a young age than the uninfluenced oaks (figure 7). These influenced oaks were established around the same year as the prunus trees (appendix S13). Based on our hypothesis this could be the result of changes in soil properties due to the relatively highest presence of prunus and the highest values for the litter quality index on this site compared to the others (appendix S17), especially since this site contained the highest percentage of clay in the soil, strengthening the rich-litter effect on soil properties (Desie et al. 2020). However, since this concerns the early growth of the oaks, for any effect on soil properties by prunus to occur this would imply that prunus had also been present before the current oaks established. We have no information on this, but given the high age of the oaks this seems unlikely.

A more likely explanation for the high initial growth rate in influenced oaks at Walbeck might be connected to reduced competition, either by a lower stand density that both favored the growth of the young oaks and allowed prunus to establish and grow up in the young stand. It is noteworthy that this effect was not observed for the other sites, which could imply differences in management history. Nonetheless, other analyses did not indicate a better growth performance of influenced oaks at Walbeck, nor on the other sites.

It is not clear how long prunus could have had an effect on the soil properties. In most stands, prunus showed clear signs of previous cuttings, indicated by multiple stems growing from single root systems. In all sites, prunus was clearly younger than the influenced oaks (table 2). In Grashoek and Someren, prunus was on average 7 years younger than the oaks, suggesting that they have grown up together with the oaks, possibly after being cut in a tending operation a few years after the oak was planted. It is not clear whether prunus was already present on the site before planting. This also holds for Loon op Zand, 't Zand and Walbeck, where the age

difference between prunus and oak was higher (13-20 years). In Veldhoven, the large age difference of 36 years, combined with the configuration of the trees in the stand, indicates that prunus may only have entered the stand after a major disturbance opened the neighboring stand. In any case, the current presence of prunus is high enough to exert an effect on topsoil conditions (Desie et al., 2020b) but the presence of prunus may have not been long enough to exert an effect on overall soil quality to alter the growth of oak.

4.2 | Climate-growth response of oak

Although litter rich in base cations has shown to increase earthworm abundance and forest floor turnover rates (Desie et al., 2020; Reich et al., 2005), which may in turn increase water holding capacity, oaks growing in the vicinity of prunus did not show a mitigated response to drought compared to the uninfluenced oaks (figure 9 and appendix S6-8). For both the influenced and uninfluenced oaks, growth was similarly positively affected by current spring precipitation and previous summer precipitation on most sites. Current summer precipitation only correlated significantly with ring width for two sites. This is in line with previous studies that have shown that spring water availability is more important for oak growth than water availability in summer (Van der Werf et al., 2007; Vanhellemont et al., 2019) which is related to the fact that spring precipitation plays a key role in early-wood vessel formation (González & Eckstein, 2003). The significant positive correlations of oak ring widths with previous summer precipitation indicate the importance of available reserves stored at the end of the previous growth season that provide for good starting conditions in spring (Barbaroux & Breda, 2002; Van der Werf et al., 2007)..

Oak ring widths were also negatively correlated with high temperatures in previous summer months, and , at most sites, positively correlated with current spring and previous summer SPEI₃ values. High summer temperatures increase evaporation of water, especially in years with little precipitation, and may subsequently reduced the storage of carbohydrate reserves (Van der Werf et al., 2007). The observed response to drought of both oak types suggests that the lack of a growth response to potential soil amelioration by prunus is due to the overriding influence of water availability on growth limitation in oak, relative to potentially altered soil nutrient status, humus form, etc. by prunus.

4.3 | Disentangling competition and facilitation

In order to disentangle neighborhood interaction effects on oak growth, we used NCI as a fixed factor in our models to test for effects of competition on average BAI; model outcomes showed that, overall, competition only explained a small, insignificant amount of variation in growth (appendix S5). However, some results of other analyses could indicate a competition effect. One example is the result of climate correlations of the oaks at Grashoek, which deviate from the other sites. Contrary to our expectations, influenced oaks are more susceptible to high temperatures and more dependent on a wet previous summer than the uninfluenced oaks (appendix S6-8). Additionally, the NCI is significantly higher for the influenced oaks than for the uninfluenced oaks at Grashoek (appendix S17). It could be argued that the prunus trees and the influenced oaks compete for water, which possibly has a larger impact on oak growth than the facilitative effects of soil amelioration. Previous studies have pointed to the fact that prunus can be an important competitor for both water and nutrients (Muys & Maddelein, 1992; Nyssen et al., 2013), and there may be an interaction of competition and climate response

(Buechling et al., 2017; Rollinson et al., 2016). The importance of competition in the growth response of the oaks at Grashoek is confirmed by the correlation of the NCI values with the ecological gradient obtained by the PCGA (figure 11). The fast growth of prunus and little response to drought compared to influenced oaks does indicate competition for water availability (appendix S9 and S13).

On the other hand, Grashoek did also deviate to other sites with regard to the litter quality index; it is the only site for which the litter quality index did not differ significantly between the oak types, which could also explain why we did not observe the expected facilitative effect of rich litter input (appendix S1).

Overall, based on this example for the site Grashoek, we argue that facilitation and competition are difficult to disentangle with certainty. Facilitative effects can be counteracted by competition for water, there could be an interaction effect between competition and climate response or both mechanisms could occur simultaneously.

4.4 | The individual approach

While the calculation of master chronologies is useful to increase a common signal, this does neglect individual growth variation. Therefore, additional to using master chronologies, we analyzed the growth variation of the individual trees. The use of an individual approach has already proved useful in studying tree growth (Aussenac et al., 2019; Rozas, 2015). In the study of Rozas (2015) competition did not show a relationship with climate-growth responses when individuals were averaged into a mean stand master chronology. Yet, these responses did become visible in individual tree-ring series, emphasizing the usefulness of such an individual-approach (Rozas, 2015).

In our study, the approach using master chronologies did not reveal significant differences in variation of oak growth which could be related to rich-litter influences of neighboring prunus trees. However, the PCGAs using individual tree ring series did indicate the existence of an ecological gradient which separated influenced and uninfluenced oaks in responder groups for half of the sites (figure 10). We cannot exclude the effect of spatial separation for at least two sites as in Walbeck and Veldhoven the uninfluenced were spatially separated from the influenced oaks.. The responder groups in the PCGA might therefore reflect a difference in non-vegetation dependent soil conditions, such as local clay content, between the oaks rather than the influence of prunus.

In the three sites which had been further explored in the individual approach, overall correlations of the individual trees with climatic variables were similar to results of the chronology approach, with no systematic differences between the oak types (figure 14). The most notable difference in climate response in the individual approach was found in the highly negative response to November precipitation in uninfluenced oaks compared to influenced oaks. As trees don't grow anymore in November, we cannot explain this and this result may be a demonstration of the well-known fact that correlations do not indicate causality.

4.5 | Does prunus positively effect soil conditions?

Desie et al. (2020a) demonstrated a positive effect of prunus litter on soil pH and base saturation. This study focused on the effects of rich litter species in monocultures. In a study including all our sites, Desie et al. (2020b) found significantly enriched topsoil conditions when prunus litter was mixed with oak litter, but this effect became apparent only at relatively large (30%) basal area shares of prunus in the stand. Van Nevel et al. (2014) found that prunus litter did not have an effect on topsoil chemistry in Scots pine and oak stands on poor sandy podzolic soils. However, this was studied in the context of prunus growing in the shrub layer and therefore producing a relative low amount of litter compared to canopy trees; contributing only up to 17% of the total litterfall. The area around the influenced oak trees in our study had average basal area shares of prunus close to 30% (Walbeck >40%; see table S17), so some soil amelioration effect should have occurred near our sampled oaks. When looking at the variation in ring widths in individual oaks, patterns of variation were correlated with prunus shares, and also litter quality index for half of the sites sampled. Nevertheless, we conclude that there was no clear positive effects of the presence of prunus on oak growth. Therefore, the question remains: does prunus effect soil conditions strong enough to improve the growing conditions of oak?

A previous study by Lucassen et al. (2014) indicated that oak performs better on sandy soils with a more balanced nutrient status. At our study sites an increase in soil base cation concentration was observed in the presence of prunus, yet the influenced oaks did not perform better. Comparing the actual values of the soil status of our sites (Desie et al., 2020b) and Lucassen et al. (2014) reveals a possible explanation: the soil of our study sites is considerably poorer (with a base saturation of $\pm 20\%$ for uninfluenced oaks, $\pm 22\%$ for influenced oaks (Desie et al. 2020b) against $\pm 27\%$ for unhealthy oaks and $\pm 40\%$ for vital oaks in the study by Lucassen et al. (2014) (figure 16). Hence, it could be argued that the soil at our sites was too poor to begin with in order for prunus to enrich soil conditions to an extent in which we would expect improved oak growth.

4.6 | Conclusion

Our study of the effect of prunus rich litter on the growth of oaks on acidic sandy soils did not show a systematic difference in growth level and annual growth variation between influenced and uninfluenced oaks. It remains to be seen if a longer influence of rich prunus litter could at some point further increase base saturation, creating better soil conditions and ultimately improve tree growth. In order to get more insight into the effect of rich-litter input, we recommend to study the nutrient availability in the leaves of influenced and uninfluenced trees. This would clarify if trees influenced by rich litter actually take up more nutrients. For our study, it can be argued that either our sites were too poor to begin with and that prunus litter did not provide enough base cation input to enrich the soil, or that a potential beneficial effect of prunus was masked by increased competition for water causing growth limitation in oak in the presence of prunus. Our study failed to find evidence for the facilitation of growth in *Quercus robur* in the presence of *Prunus serotina* on poor acidic sandy soils.

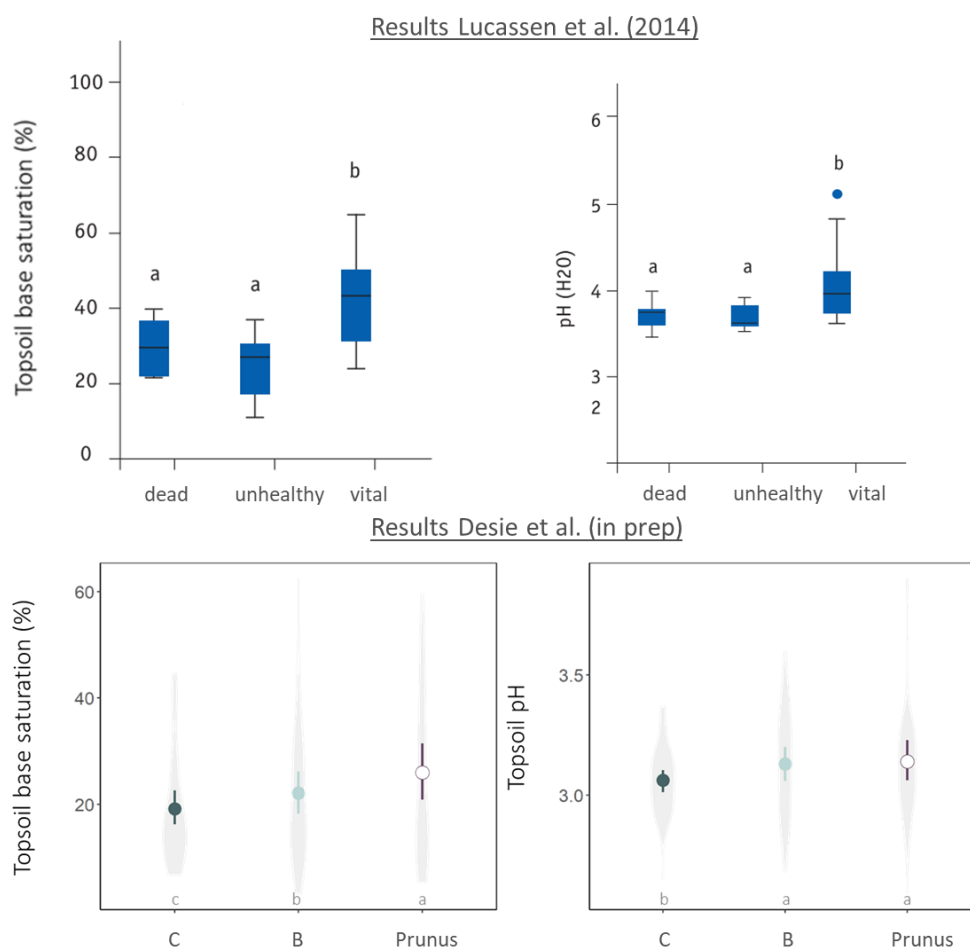


Figure 16. Boxplots of the results of soil conditions of Lucassen et al. (2014) and Desie et al. 2020b). The results of study of Lucassen et al. (2014) are depicted in the upper graphs. The horizontal line in the boxplots represent the median. Topsoil base concentration (%) and $\text{pH}_{\text{H}_2\text{O}}$ was compared for the soil under dead, unhealthy and vital trees. The results of Desie et al. (in preparation) are depicted in the lower graphs. Topsoil base concentrations (%) and topsoil pH_{NaCl} was compared for oaks uninfluenced by prunus (C), oaks influenced by prunus (B) and prunus are compared. Keep in mind that soil tested in sodium chloride solution gives pH values about 0.5–0.8 lower than the same soil tested in water. For all graphs, means with a same letter do not significantly differ. Graphs are modified from Lucassen et al. (2014) and Desie et al. (in preparation).

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APPENDICES

S1. Test results of comparison of influenced (B) and uninfluenced (C) oaks in difference in percentage of prunus in basal area, litter quality index and neighbourhood competition index (NCI) per site and for all sites together.

Site	Test results – comparison B and C		
	Litter quality index	Prunus in basal area (%)	NCI
Grashoek	T-test $t = 1.7714$, $df = 7.0$, $p = 0.119$	Mann-Whitney U test $W = 79$, $p < 0.001$	T-test $t = 2.5082$, $df = 10.4$, $p = 0.030$
Loon op Zand	T-test $t = 5.9036$, $df = 14.7$, $p < 0.001$	Mann-Whitney U test $W = 88$, $p < 0.001$	T-test $t = 2.1673$, $df = 15.5$, $p\text{-value} = 0.046$
Someren	Mann-Whiney U test $W = 127$, $p < 0.001$	Mann-Whiney U test $W = 13$, $p < 0.001$	T-test $t = 1.0685$, $df = 5.5$, $p\text{-value} = 0.330$
Veldhoven	Mann-Whitney U test $W = 156$, $p < 0.001$	Mann-Whitney U test $W = 156$, $p < 0.001$	T-test $t = 2.4844$, $df = 22.7$, $p\text{-value} = 0.021$
Walbeck	Mann-Whiney U test $W = 19$, $p < 0.001$	Mann-Whitney U test $W = 205.5$, $p < 0.001$	T-test $t = -1.5289$, $df = 23.4$, $p\text{-value} = 0.130$
't Zand	T-test $t = 6.7549$, $df = 8.36$, $p < 0.001$	Mann-Whitney U test $W = 56$, $p = 0.003$	Mann-Whitney U test $W = 24.5$, $p\text{-value} = 0.239$
Total	LMM: $\chi^2(1) = 97.56$, $p < 2.2e-16$ (ANOVA)	GLMM: $z = -25.445$, $p < 2e-16$ (Wald test)	LMM: $\chi^2(1) = 2.0236$, $p = 0.1549$ (ANOVA)

S2. Model parameters for mixed model equations (1), (2) and (3) displaying the effect of the parameter *tree type* on litter quality index, percentage of prunus in the basal area and the neighbourhood competition index including: parameter estimate for fixed effect with standard error (Std. Error) and test values (t) or p value (p) and the standard deviation (Std. Dev.) of random effects.

(1) Litter quality index

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Intercept	17.6195	0.3874	45.48
	C oaks	-1.755	0.146	-12.04
Random effect		<i>Std. dev</i>		
	Site	0.907		

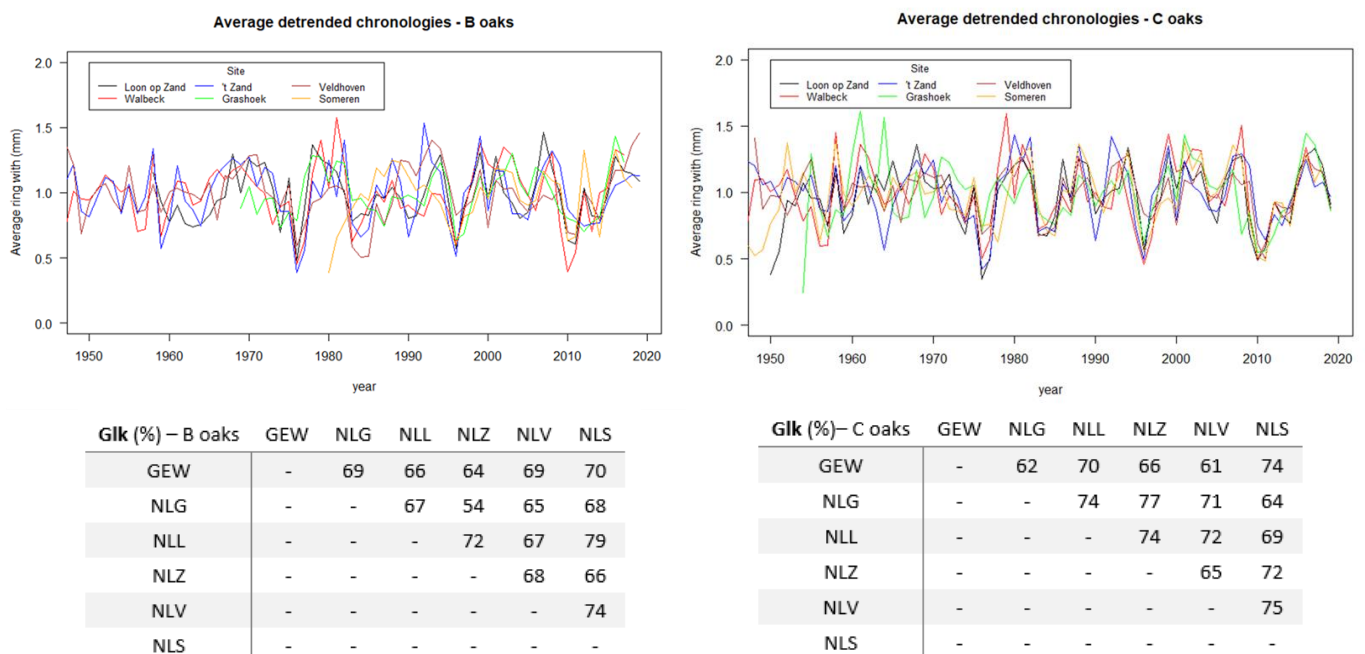
(2) Percentage of prunus

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>p</i>
	B oaks	-0.249	0.037	<2.66e-11
	C oaks	-1.238	0.049	<2e-16
Random effect		<i>Std. dev</i>		
	Site	0.156		

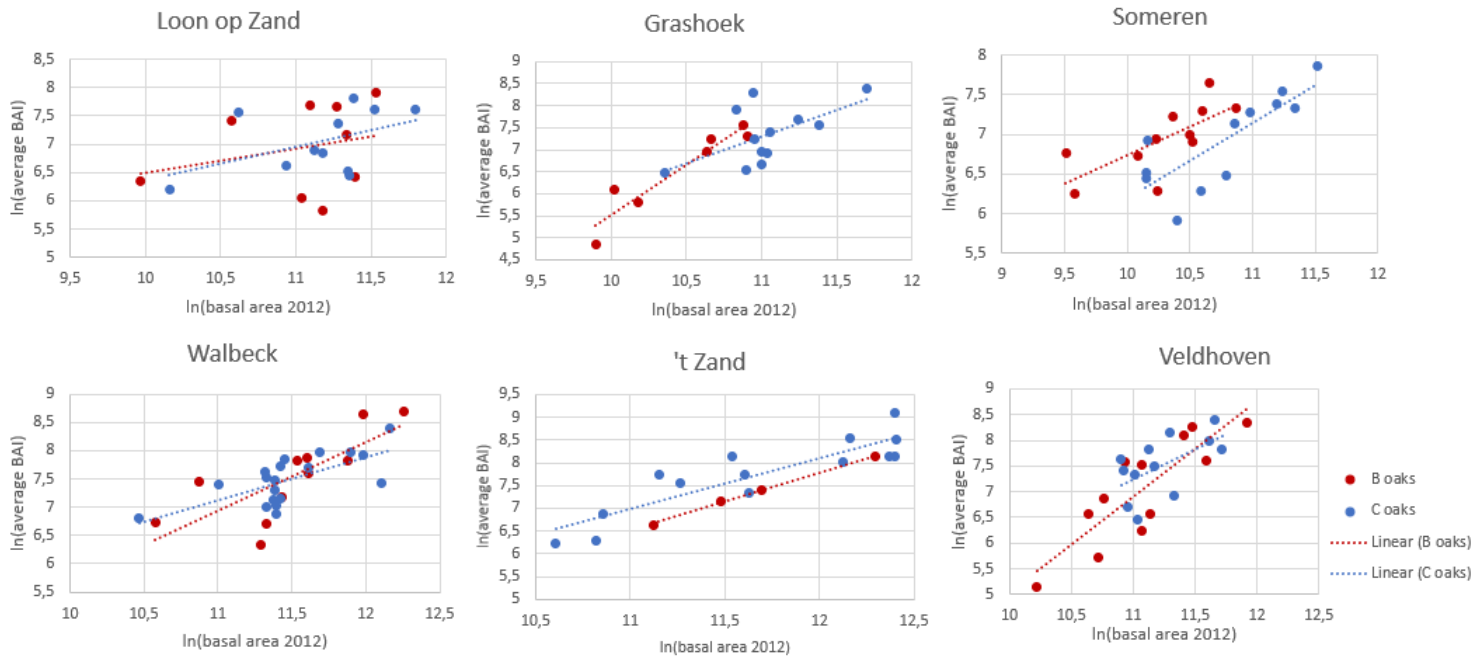
(3) Neighbourhood competition index

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Intercept	56.156	1.833	30.634
	C oaks	-2.562	1.793	-1.429
Random effect		<i>Std. dev</i>		
	Site	2.898		

S3. Graphs and Gleichläufigkeit (glk) calculations for master chronologies for influenced (B) and uninfluenced (C) oaks separately per site (GEW = Walbeck, NLG = Grashoek, NLL = Loon op Zand, NLZ = 't Zand, NLL = Loon op Zand, NLV = Veldhoven, NLS = Someren). Glk represents the percentage of common signs of the annual growth between two time series.



S4. Graphs of average basal area increment (BAI) with corresponding basal area at 2012, in the 6-year period of 2012-2017 for each site. Oaks uninfluenced by prunus (C oaks) are indicated in blue, oaks influenced by prunus (B oaks) in red.



S5. Model parameters for linear mixed model equations (4) and (5) displaying the effect of parameters on average basal area increment including: parameter estimates for fixed effects with standard errors (Std. Error) and test values (t) and the standard deviation (Std. Dev.) of random effects. Since the dependent variables was logarithmically transformed, the exponent of the parameter estimates, Std. error and Std. dev was taken and percent change calculated.

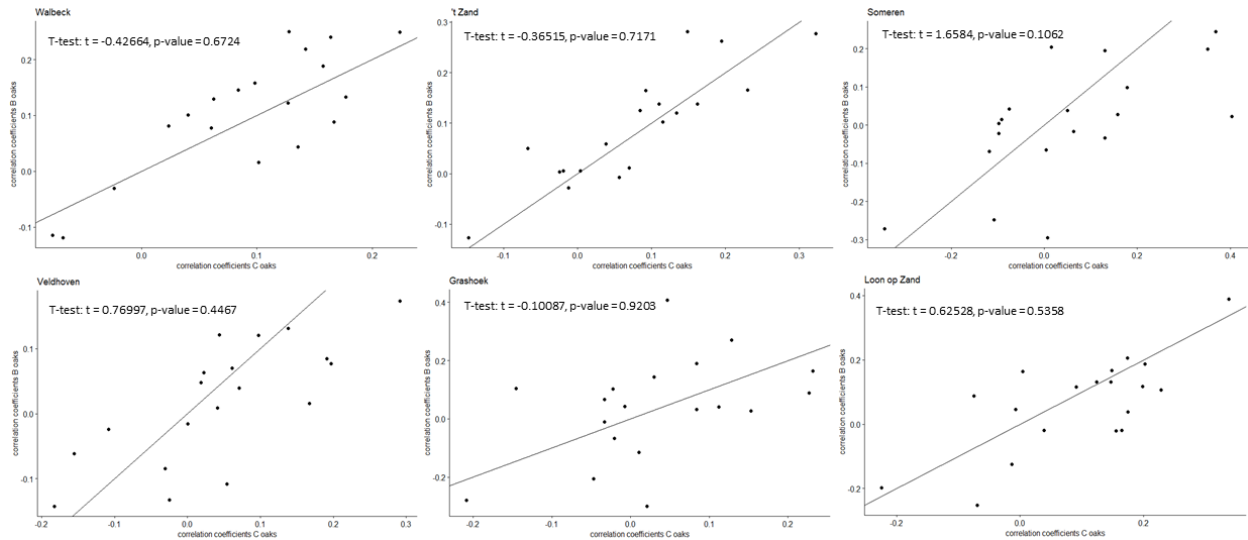
(4) Litter quality index

Fixed effects		Parameters	Estimate	Std. error	t
		Litter quality index	0.945 (-5.5%)	1.044	-1.312
		NCI	0.987 (-1.3%)	1.006	-2.464
Random effect			Std. dev		
		Site	1.21		

(5) Percentage of prunus

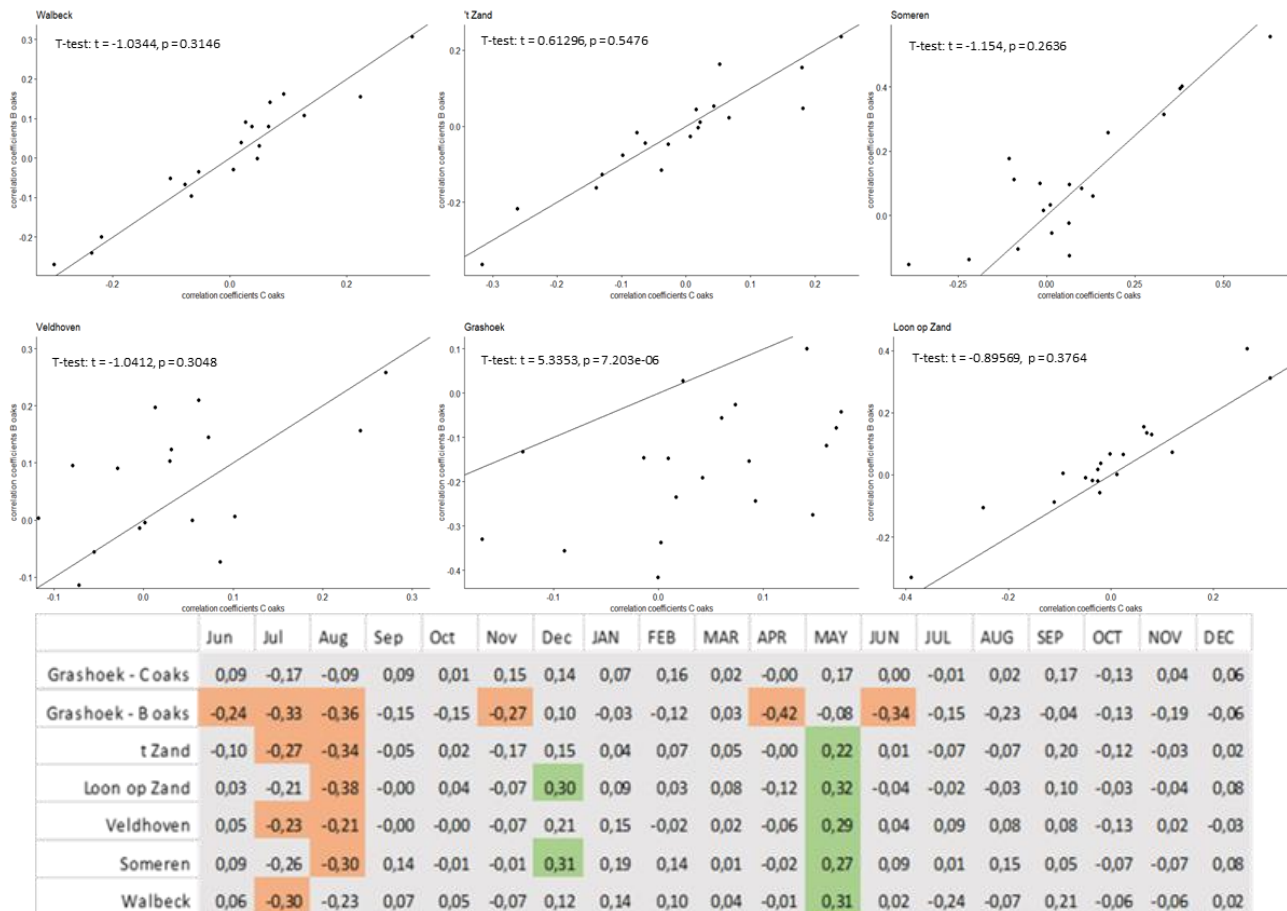
Fixed effects		Parameters	Estimate	Std. error	t
		Percentage of prunus	0.995 (-0.5%)	1.004	-1.254
		NCI	0.987 (-1.3%)	1.006	-2.433
Random effect			Std. dev		
		Site	1.2166		

S6. Comparison of precipitation correlations. Top panel: graphs of correlations of detrended growth of influenced (B) and uninfluenced (C) oaks per site. Top left of each graph, t-test results indicate significant differences between precipitation correlations of B (x-axis) and C (y-axis) oaks. Bottom panel: table of correlation coefficients per site for previous June to current December. Green fillings indicate significant positive correlations, no significant negative correlations were found.

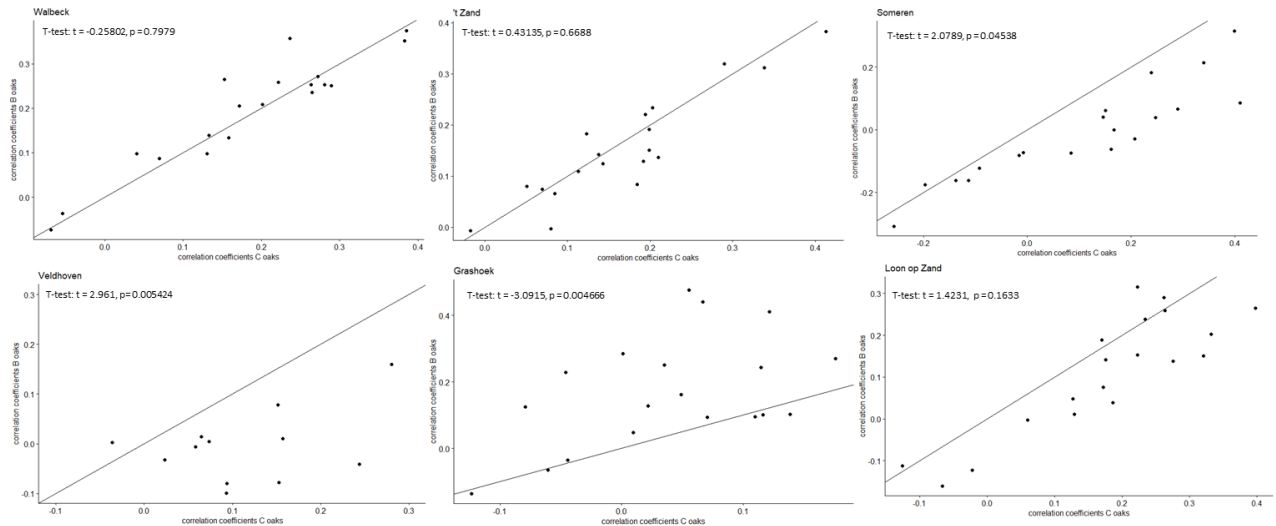


	Jun	Jul	Aug	Sep	Oct	Nov	Dec	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Grashoek	-0,01	0,08	0,04	-0,02	0,23	0,22	-0,14	0,13	0,02	0,05	0,15	-0,03	0,11	-0,06	-0,21	-0,06	0,14	-0,03	0,05
t Zand	0,17	0,28	0,17	-0,04	0,16	0,25	0,06	0,07	0,01	0,34	0,13	-0,00	0,09	0,24	-0,03	0,02	0,08	-0,13	0,14
Loon op Zand	0,17	0,19	0,15	0,06	0,11	0,12	0,16	0,21	-0,01	0,40	0,22	0,10	0,22	0,12	-0,13	-0,00	-0,10	-0,18	0,10
Veldhoven	0,13	0,30	0,08	0,03	0,11	0,00	0,08	0,08	-0,05	0,16	0,17	0,00	-0,02	-0,07	-0,09	-0,10	0,03	-0,13	0,11
Someren	0,14	0,39	0,12	0,06	0,10	-0,06	0,25	0,26	0,05	0,33	0,21	-0,02	0,13	0,16	-0,21	0,01	0,01	-0,06	0,11
Walbeck	0,17	0,28	0,20	0,11	0,12	0,08	0,10	0,22	0,08	0,30	0,24	0,12	0,18	0,22	-0,14	-0,07	0,08	-0,11	0,21

S7. Comparison of temperature correlations. Top panel: graphs of correlations of detrended growth of influenced (B) and uninfluenced (C) oaks per site. Top left of each graph, t-test results indicate significant differences between temperature correlations of B (x-axis) and C (y-axis) oaks. Bottom panel: table of correlation coefficients per site for previous June to current December. Red fillings indicate significant negative correlation, green fillings significant positive correlations.



S8. Comparison of SPEI3 correlations. Top panel: graphs of correlations of detrended growth of influenced (B) and uninfluenced (C) oaks per site. Top left of each graph, t-test results indicate significant differences between SPEI3 correlations of B (x-axis) and C (y-axis) oaks. Bottom panel: table of correlation coefficients per site for previous June to current December. Red fillings indicate significant negative correlation, green fillings significant positive correlations.



	Jun	Jul	Aug	Sep	Oct	Nov	Dec	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Walbeck	0,07	0,28	0,40	0,40	0,30	0,16	0,15	0,21	0,19	0,26	0,28	0,26	0,24	0,28	0,19	0,06	-0,01	-0,08	0,11
't Zand	0,13	0,37	0,43	0,33	0,23	0,16	0,23	0,20	0,07	0,16	0,22	0,16	0,10	0,16	0,18	0,13	0,07	-0,01	0,07
Loon op Zand	0,10	0,27	0,35	0,30	0,24	0,11	0,14	0,22	0,18	0,27	0,30	0,29	0,27	0,21	0,15	0,04	-0,06	-0,11	-0,09
Grashoek - B oaks	0,23	0,16	0,10	0,10	0,10	0,27	0,24	0,25	0,13	0,28	0,44	0,48	0,41	0,13	-0,03	-0,14	-0,07	0,05	0,09
Grashoek - C oaks	-0,05	0,05	0,11	0,12	0,14	0,18	0,11	0,03	-0,08	0,00	0,07	0,06	0,12	0,02	-0,04	-0,12	-0,06	0,01	0,07
Veldhoven - B oaks	-0,17	-0,04	0,17	0,16	0,08	-0,01	0,01	0,00	-0,03	-0,08	0,01	-0,08	-0,10	-0,26	-0,23	-0,25	-0,18	-0,12	0,00
Veldhoven - C oaks	0,01	0,24	0,36	0,28	0,15	0,06	0,06	0,07	0,02	0,09	0,15	0,15	0,09	-0,04	-0,04	-0,13	-0,10	-0,15	-0,04
Someren - B oaks	-0,07	0,18	0,31	0,21	0,06	-0,12	-0,08	-0,06	0,04	0,09	0,07	-0,03	0,04	0,00	-0,08	-0,16	-0,31	-0,16	-0,17
Someren - C oaks	-0,01	0,24	0,40	0,34	0,15	-0,09	-0,02	0,16	0,25	0,41	0,29	0,21	0,15	0,17	0,08	-0,11	-0,26	-0,14	-0,20

S9. Climate correlations with prunus. Tables of correlation coefficients of the growth of prunus with temperature, precipitation and SPEI3 per site for previous June to current December. Red fillings indicate significant negative correlation, green fillings significant positive correlations.

Temperature	Jun	Jul	Aug	Sep	Oct	Nov	Dec	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Grashoek	0,03	-0,08	-0,03	0,17	0,11	-0,07	-0,19	-0,03	-0,19	0,20	-0,01	0,06	0,05	-0,17	-0,08	0,01	0,04	-0,10	0,07
't Zand	0,04	-0,04	-0,13	-0,10	0,11	0,06	0,11	-0,02	0,14	0,12	0,07	-0,16	-0,18	-0,08	0,14	0,08	-0,14	0,09	0,01
Loon op Zand	0,02	-0,18	-0,17	0,02	-0,05	0,01	0,10	-0,10	0,07	0,18	-0,04	0,08	-0,09	0,05	-0,01	0,09	-0,19	0,18	0,04
Veldhoven	-0,15	-0,20	-0,14	0,04	-0,09	-0,02	0,02	0,06	-0,08	0,09	0,02	0,01	-0,11	-0,09	-0,18	0,25	-0,19	0,14	-0,04
Someren	-0,23	-0,43	-0,02	0,04	0,05	0,08	0,19	-0,01	0,05	0,27	-0,16	0,25	0,07	-0,04	-0,23	0,20	-0,17	-0,17	0,20
Walbeck	0,13	-0,14	-0,04	0,00	0,14	-0,14	0,03	-0,07	0,19	0,19	0,13	0,02	-0,15	-0,22	-0,08	-0,02	-0,14	-0,12	-0,09

Precipitation	Jun	Jul	Aug	Sep	Oct	Nov	Dec	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Grashoek	0,20	-0,35	0,20	-0,01	0,11	0,12	-0,24	0,07	-0,10	-0,14	0,19	0,39	0,14	0,08	0,09	-0,11	-0,02	-0,29	0,36
't Zand	-0,02	0,05	0,09	0,19	0,15	-0,04	-0,17	0,17	0,13	-0,07	-0,14	0,03	0,04	0,18	-0,05	-0,10	-0,07	0,05	-0,17
Loon op Zand	-0,02	0,12	0,11	0,05	0,17	0,03	-0,09	-0,02	0,03	0,15	0,07	0,20	0,19	0,22	-0,04	-0,19	0,08	0,04	-0,16
Veldhoven	0,01	0,01	0,07	0,07	0,13	0,41	-0,25	0,09	0,17	-0,03	-0,05	0,22	0,03	0,47	0,24	-0,29	-0,15	0,16	0,04
Someren	-0,03	0,32	0,02	-0,14	0,08	0,05	-0,15	-0,27	-0,05	-0,01	0,40	-0,04	0,18	0,22	0,24	-0,27	0,02	0,02	0,03
Walbeck	0,12	0,06	-0,05	0,03	0,02	0,04	0,06	-0,08	0,09	0,03	-0,09	0,29	0,14	0,21	0,14	-0,10	0,11	0,07	-0,06

SPEI3	Jun	Jul	Aug	Sep	Oct	Nov	Dec	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Grashoek	-0,00	-0,10	0,03	-0,04	0,17	0,07	0,01	-0,03	-0,15	-0,13	-0,04	0,18	0,34	0,33	0,22	0,09	-0,02	-0,22	0,06
't Zand	-0,13	0,01	0,07	0,19	0,24	0,17	-0,07	-0,06	0,01	0,09	-0,07	0,00	0,11	0,25	0,14	0,04	-0,09	-0,03	-0,06
Loon op Zand	0,03	0,09	0,07	0,06	-0,01	0,00	0,03	-0,01	0,02	-0,03	-0,03	0,15	0,27	0,42	0,35	0,21	0,13	0,05	0,08
Veldhoven	-0,18	0,01	0,12	0,10	0,12	0,24	0,17	0,16	0,03	0,17	0,13	0,18	0,18	0,47	0,51	0,28	0,02	-0,07	0,13
Someren	-0,23	0,21	0,27	0,20	-0,02	-0,04	-0,02	-0,28	-0,35	-0,28	0,15	0,11	0,19	0,17	0,36	0,10	0,01	-0,12	0,12
Walbeck	0,03	0,09	0,07	0,06	-0,01	0,00	0,03	-0,01	0,02	-0,03	-0,03	0,15	0,27	0,42	0,35	0,21	0,13	0,05	0,08

S10. Model parameters for linear mixed model equations (6) and (7) displaying the effect of parameters on resistance, resilience and recovery to drought episodes: parameter estimates for fixed effects with standard errors (Std. Error) and test values (t) and the standard deviation (Std. Dev.) of random effects. Since the dependent variables was logarithmically transformed, the exponent of the parameter estimates, Std. error and Std. dev was taken and percent change calculated.

Resistance – litter quality index

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Litter quality index	0.995 (-0.5%)	1.137	-0.411
	NCI	1.001 (0.1%)	1.002	0.596
	Year	1.003 (0.3%)	1.001	3.195
Random effect		<i>Std. dev</i>		
	Site	1.07		

Resistance – percentage of prunus

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Percentage of prunus	0.999 (-0.3%)	1.001	-0.257
	NCI	1.001 (0.1%)	1.002	0.601
	Year	1.003 (0.3%)	1.001	3.199
Random effect		<i>Std. dev</i>		
	Site	1.07		

Resilience – litter quality index

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Litter quality index	1.002 (0.2%)	1.009	1.936
	NCI	0.999 (-0.1%)	1.001	-0.992
	Year	0.996 (-0.6%)	1.001	-9.278
Random effect		<i>Std. dev</i>		
	Site	1.03		

Resilience – percentage of prunus

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Percentage of prunus	1.018 (1.8%)	1.009	1.936
	NCI	0.999 (-0.1%)	1.001	-0.992
	Year	0.994 (-0.6%)	1.001	-9.278
Random effect		<i>Std. dev</i>		
	Site	1.03		

Recovery – litter quality index

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Litter quality index	1.014 (1.4%)	1.014	0.977
	NCI	0.998 (-0.2%)	1.002	-1.076
	Year	0.993 (-0.7%)	1.001	-6.861
Random effect		<i>Std. dev</i>		
	Site	1.07		

Recovery – percentage of prunus

Fixed effects	<i>Parameters</i>	<i>Estimate</i>	<i>Std. error</i>	<i>t</i>
	Percentage of prunus	1.001 (0.1%)	1.001	0.773
	NCI	0.998 (-0.2%)	1.002	-1.159
	Year	0.993 (-0.7%)	1.001	-6.851
Random effect		<i>Std. dev</i>		
	Site	1.044		

S11. Overview of statistic overview for the tree chronologies at site level, separate for oak and prunus. Common interval is different depending on the shortest time series per site. Table includes: the number of trees, the mean between trees correlation (rbar.bt), the expressed population signal (eps), the signal to noise ratio (snr) and the common interval of the time series. Data is not available for the prunus tree at Grashoek since only one tree was included in this analysis.

Oak	trees (#)	rbar.bt	eps	snr	common interval
<i>GEW</i>	30	0.548	0.973	36.334	1953-2017
<i>NLG</i>	19	0.470	0.944	16.878	1985-2017
<i>NLL</i>	20	0.535	0.958	23.051	1976-2019
<i>NLZ</i>	18	0.590	0.963	25.947	1958-2019
<i>NLV</i>	25	0.441	0.952	19.736	1962-2019
<i>NLS</i>	23	0.491	0.957	22.192	1988-2018

Prunus	trees (#)	rbar.bt	eps	snr	common interval
<i>GEW</i>	8	0.443	0.864	6.366	1987-2012
<i>NLL</i>	5	0.358	0.736	2.787	1983-2019
<i>NLZ</i>	5	0.421	0.784	3.633	1972-2019
<i>NLV</i>	7	0.263	0.714	2.501	1994-2019
<i>NLS</i>	8	0.324	0.793	3.841	2003-2018

S12. Ring-width series properties and statistics. First ring, last ring, measured years, mean ring width (mean), standard deviation (stdev), skewness (skew) and first order auto correlation (ar1). Keycodes indicate the site (first three letters), the plots number, the tree type and the tree number in within the plot.

keycode	first year	last year	total years	mean	median	stdev	skew	ar1
GEW1C1	1927	2017	91	1.99	1.90	0.65	0.28	0.64
GEW1C2	1953	2016	64	1.69	1.51	0.79	1.06	0.51
GEW1C3	1933	2017	85	2.63	2.12	1.49	0.70	0.71
GEW2C1	1935	2017	83	2.14	2.02	0.86	0.88	0.43
GEW2C2	1949	2017	69	2.10	1.86	1.08	1.17	0.74
GEW2C3	1930	2017	88	1.88	1.77	0.78	0.77	0.69
GEW2C4	1929	2017	89	1.95	1.94	0.73	0.39	0.51
GEW2C5	1896	2017	122	1.39	1.23	0.63	0.87	0.62
GEW3C1	1932	2017	86	2.00	1.97	0.74	0.49	0.51
GEW3C2	1943	2017	75	2.71	2.74	0.94	0.35	0.47
GEW3C3	1931	2017	87	1.97	1.76	0.93	0.78	0.69
GEW4C1	1928	2017	90	2.87	2.49	1.44	1.01	0.67
GEW4C2	1926	2017	92	1.85	1.87	0.66	0.32	0.41
GEW4C3	1936	2017	82	2.36	2.11	1.01	0.56	0.61
GEW5C1	1912	2017	106	1.59	1.47	0.69	0.86	0.37
GEW5C2	1895	2017	123	1.97	1.74	1.00	0.88	0.57
GEW6C1	1946	2017	72	3.23	2.71	1.71	1.01	0.61
GEW6C2	1928	2017	90	1.89	1.69	0.81	1.27	0.61
GEW6C3	1946	2017	72	2.35	1.91	1.47	1.54	0.64

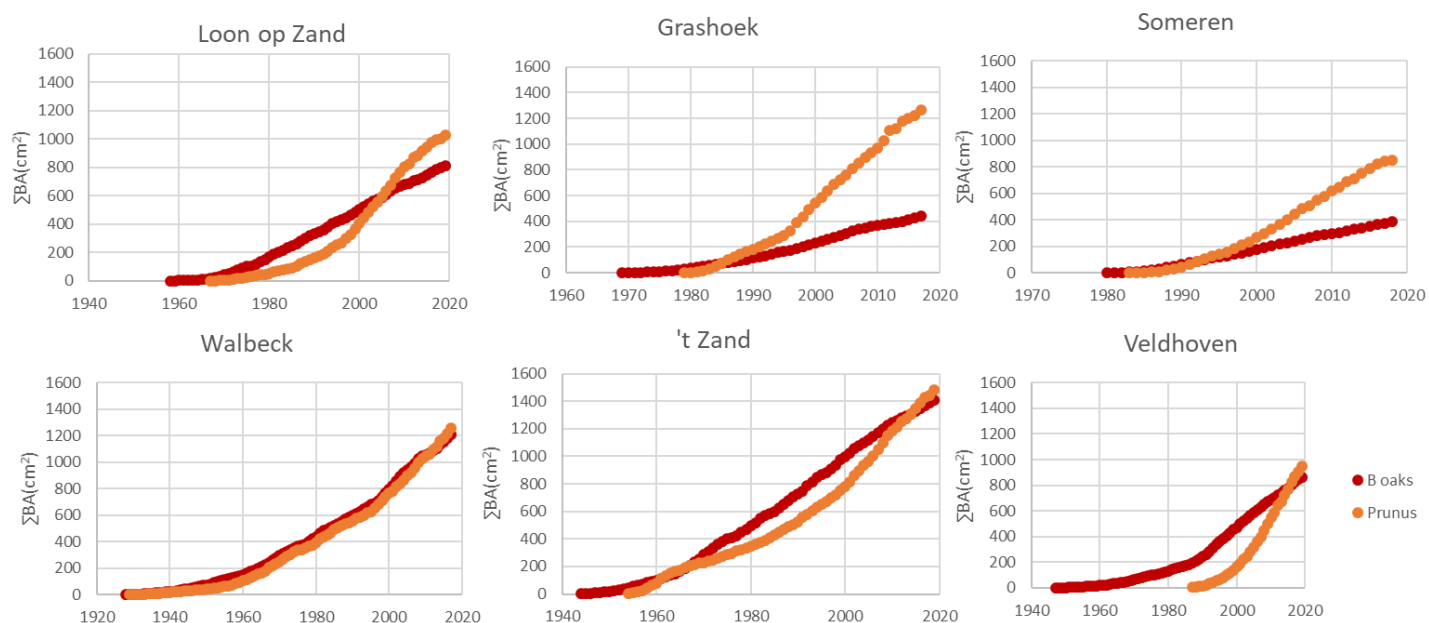
NLS1C1	1961	2018	58	1.78	1.78	0.98	0.54	0.71
NLS1C2	1951	2018	68	2.79	2.73	1.00	0.62	0.46
NLS1C3	1954	2018	65	2.52	2.34	1.01	0.89	0.68
NLS2C1	1957	2018	62	2.56	2.21	1.32	1.42	0.81
NLS2C2	1945	2018	74	1.71	1.26	1.34	1.83	0.71
NLS2C3	1955	2018	64	2.24	2.01	1.04	0.97	0.55
NLS3C1	1956	2018	63	2.14	2.10	0.69	0.19	0.71
NLS3C2	1941	2018	78	1.47	1.33	0.88	1.45	0.81
NLS3C3	1952	2018	67	2.52	2.50	0.87	0.08	0.62
NLS4C1	1980	2018	39	2.41	1.82	1.38	0.65	0.90
NLS4C2	1982	2018	37	2.67	2.66	0.98	0.04	0.65
NLS4C3	1982	2018	37	2.53	2.30	1.49	0.91	0.86
NLL1C1	1952	2019	68	2.03	1.94	0.90	0.52	0.82
NLL1C2	1950	2019	70	2.73	2.65	1.06	0.14	0.66
NLL1C3	1959	2019	61	3.52	3.32	1.54	0.34	0.71
NLL2C1	1962	2019	58	1.63	1.67	0.68	0.04	0.51
NLL3C1	1955	2019	65	2.55	2.12	1.79	0.84	0.85
NLL4C1	1956	2019	64	2.83	2.84	0.98	0.14	0.62
NLL5C1	1961	2019	59	2.83	2.62	1.41	0.49	0.73
NLL5C2	1969	2019	51	2.57	2.66	1.15	0.04	0.61
NLL6C1	1962	2019	58	2.88	2.82	1.64	0.32	0.76
NLL6C2	1957	2019	63	2.46	1.81	1.59	1.11	0.70
NLL6C3	1962	2019	58	2.64	2.71	1.19	0.32	0.68
NLZ1C1	1951	2019	69	4.46	4.35	1.38	0.01	0.39
NLZ2C1	1949	2019	71	2.28	2.16	0.88	1.00	0.48
NLZ2C2	1948	2019	72	1.77	1.35	1.36	2.01	0.76
NLZ2C3	1948	2019	72	1.61	1.52	0.86	1.01	0.71
NLZ3C1	1939	2019	81	3.51	2.87	2.06	0.87	0.84
NLZ3C2	1949	2019	71	2.78	2.49	1.51	0.88	0.78
NLZ3C3	1944	2019	76	2.60	2.65	0.87	0.02	0.53
NLZ4C1	1947	2019	73	2.32	1.95	1.14	0.90	0.80
NLZ4C2	1937	2019	83	3.55	3.16	1.87	1.47	0.80
NLZ4C3	1943	2019	77	3.27	3.14	1.28	0.34	0.62
NLZ5C1	1946	2019	74	2.64	2.46	1.08	0.47	0.57
NLZ5C2	1944	2019	76	1.79	1.40	1.13	1.15	0.82
NLZ6C1	1943	2019	77	3.74	3.33	1.86	0.42	0.75
NLZ6C2	1937	2019	83	3.17	3.22	1.22	0.31	0.50
NLG4C1	1954	2017	64	3.33	3.32	1.04	0.51	0.46
NLG4C2	1966	2017	52	2.71	2.39	1.44	0.47	0.86
NLG4C3	1972	2017	46	2.90	2.63	1.70	0.76	0.82
NLG2C1	1966	2019	54	3.31	3.21	1.55	0.56	0.84
NLG2C2	1978	2019	42	3.93	4.10	1.43	0.14	0.70
NLG3C1	1965	2019	55	2.67	2.29	1.43	0.95	0.78
NLG3C2	1966	2019	54	2.73	2.55	1.16	0.43	0.58
NLG3C3	1967	2019	53	2.01	1.84	0.98	1.15	0.43
NLG5C1	1970	2019	50	2.89	2.32	1.88	0.97	0.86
NLG5C2	1966	2019	54	3.15	3.49	1.14	-0.27	0.63
NLG5C3	1966	2019	54	2.83	2.50	1.58	1.60	0.83

NLG5C4	1965	2019	55	2.64	2.74	0.84	-0.39	0.63
NLV1C1	1950	2019	70	2.41	2.53	0.82	-0.31	0.76
NLV1C2	1955	2019	65	2.49	2.46	0.79	0.11	0.58
NLV1C3	1949	2019	71	2.98	2.79	1.06	0.78	0.45
NLV1C4	1948	2019	72	2.05	1.99	0.87	0.40	0.74
NLV2C1	1959	2019	61	2.46	2.30	0.72	0.35	0.50
NLV2C2	1952	2019	68	3.01	2.89	0.81	0.29	0.44
NLV3C1	1957	2019	63	2.22	1.92	1.05	0.53	0.77
NLV3C2	1960	2019	60	2.44	2.40	0.73	0.62	0.59
NLV3C3	1960	2019	60	3.06	2.98	1.16	0.25	0.65
NLV3C4	1962	2019	58	2.47	2.27	1.29	0.17	0.80
NLV4C1	1949	2019	71	3.07	2.90	1.33	0.32	0.75
NLV4C2	1954	2019	66	2.48	2.47	0.82	0.19	0.55
NLV4C3	1948	2019	72	2.98	2.85	0.87	0.91	0.60
GEW1B1	1930	2017	88	1.82	1.84	0.76	0.02	0.70
GEW1B2	1934	2017	84	1.94	1.81	0.90	0.94	0.70
GEW2B1	1928	2017	90	2.16	2.14	0.70	0.35	0.58
GEW3B1	1930	2017	88	1.98	1.57	1.01	0.89	0.81
GEW3B2	1937	2017	81	1.69	1.54	0.70	0.46	0.68
GEW4B1	1929	2017	89	2.17	2.09	0.80	0.52	0.62
GEW4B2	1930	2017	88	1.31	1.26	0.36	0.46	0.53
GEW4B3	1936	2017	82	2.94	2.59	1.27	1.09	0.61
GEW4B4	1935	2017	83	3.29	3.22	1.22	0.24	0.46
GEW6B1	1950	2017	68	2.77	2.52	1.26	0.74	0.51
GEW6B2	1949	2017	69	3.19	2.83	1.61	0.90	0.71
NLS1B1	1983	2018	36	3.79	3.41	2.11	0.71	0.86
NLS1B2	1982	2018	37	3.08	3.04	1.47	0.22	0.80
NLS2B1	1982	2018	37	3.50	3.39	1.21	0.12	0.55
NLS2B2	1983	2018	36	3.06	2.70	1.25	0.57	0.82
NLS2B3	1985	2018	34	2.20	2.02	0.86	0.98	0.36
NLS3B1	1981	2018	38	2.45	2.10	1.19	1.01	0.84
NLS3B2	1988	2018	31	2.33	2.14	1.05	0.86	0.67
NLS3B3	1980	2018	39	3.11	2.86	1.58	0.84	0.81
NLS4B1	1982	2018	37	2.73	2.56	1.32	0.57	0.80
NLS4B2	1982	2018	37	2.62	2.15	1.64	0.54	0.88
NLS4B3	1983	2018	36	3.16	2.27	1.94	0.88	0.89
NLL1B1	1958	2019	62	2.78	2.65	0.79	0.60	0.49
NLL1B2	1964	2019	56	2.53	2.15	1.62	0.86	0.76
NLL2B1	1966	2019	54	2.36	2.26	0.76	0.37	0.42
NLL2B2	1964	2019	56	3.05	2.83	1.96	0.59	0.89
NLL2B3	1961	2019	59	3.32	3.24	1.15	0.43	0.39
NLL3B1	1963	2019	57	2.66	2.10	2.19	0.74	0.85
NLL4B1	1961	2019	59	2.88	2.34	1.67	1.02	0.75
NLL5B1	1974	2019	46	3.43	3.11	1.23	0.59	0.58
NLL5B2	1976	2019	44	2.01	1.84	0.94	1.40	0.74
NLZ1B1	1948	2019	72	3.83	3.66	1.45	0.77	0.70
NLZ1B2	1947	2019	73	2.06	1.82	1.01	0.64	0.66
NLZ2B1	1958	2019	62	2.89	2.64	1.46	0.40	0.70

NLZ4B1	1944	2019	76	2.67	2.31	1.32	0.39	0.77
NLG1B1	1969	2017	49	2.85	2.80	0.86	-0.04	0.52
NLG1B2	1973	2017	45	1.92	1.87	0.84	0.13	0.54
NLG2B1	1974	2017	44	3.20	3.24	1.16	0.79	0.48
NLG2B2	1971	2017	47	1.97	1.25	1.49	1.09	0.81
NLG3B1	1972	2017	46	2.63	2.65	0.85	-0.12	0.65
NLG3B2	1970	2017	48	1.64	1.08	1.57	1.65	0.89
NLG4B1	1985	2017	33	3.77	3.78	1.60	0.43	0.74
NLV1B1	1947	2019	73	2.72	2.28	1.23	0.45	0.83
NLV1B2	1948	2019	72	2.17	1.80	0.94	1.14	0.77
NLV2B1	1951	2019	69	2.77	2.85	1.22	0.00	0.69
NLV2B2	1950	2019	70	1.72	1.77	0.73	0.09	0.71
NLV2B3	1947	2019	73	2.69	2.53	1.08	0.94	0.81
NLV2B4	1956	2019	64	2.28	2.43	1.28	0.12	0.86
NLV3B1	1958	2019	62	2.45	2.48	1.24	0.82	0.75
NLV3B2	1956	2019	64	3.72	3.63	1.03	-0.15	0.21
NLV3B3	1958	2019	62	2.39	2.58	0.89	0.04	0.71
NLV4B1	1960	2019	60	2.01	1.64	1.24	1.70	0.86
NLV4B2	1957	2019	63	2.11	1.79	1.22	1.15	0.82
NLV4B3	1958	2019	62	1.50	1.15	1.18	1.05	0.84
NLS1A1	2003	2018	16	9.43	9.26	3.42	-0.29	0.26
NLS1A2	1994	2018	25	3.86	3.50	1.76	0.34	0.58
NLS2A1	1989	2018	30	5.60	4.22	4.53	0.83	0.66
NLS2A2	1986	2018	33	5.24	5.54	1.69	-0.84	0.45
NLS3A1	1986	2018	33	4.92	4.82	1.92	0.11	0.50
NLS3A2	1983	2018	36	4.92	4.86	2.33	0.33	0.35
NLS4A1	1987	2018	32	5.05	4.81	2.67	0.55	0.54
NLS4A2	1992	2018	27	4.67	5.20	2.74	0.01	0.67
GEW2A1	1940	2012	73	2.04	1.81	1.10	0.70	0.65
GEW2A2	1937	2017	81	2.90	2.40	1.65	1.13	0.58
GEW2A3	1933	2017	85	2.82	2.29	1.82	1.17	0.71
GEW3A1	1929	2017	89	1.69	1.58	0.66	0.70	0.44
GEW4A1	1937	2017	81	3.22	3.26	1.65	0.64	0.16
GEW4A3	1968	2017	50	2.42	2.17	1.14	0.38	0.23
GEW6A1	1987	2017	31	4.11	4.18	1.62	-0.12	0.11
GEW6A2	1987	2017	31	4.03	4.11	1.64	-0.16	0.36
NLZ1A1	1954	2019	66	3.10	2.60	1.85	1.31	0.68
NLZ1A2	1968	2019	52	3.19	2.95	1.29	0.65	0.33
NLZ2A1	1970	2019	50	4.68	4.52	2.24	0.58	0.76
NLZ2A2	1972	2019	48	3.77	3.73	1.44	0.23	0.61
NLZ4A1	1970	2019	50	4.03	3.86	1.43	0.61	0.35
NLL1A1	1983	2019	37	4.43	4.68	2.18	0.00	0.74
NLL2A1	1967	2019	53	3.24	3.10	1.13	0.50	0.38
NLL3A1	1979	2019	41	4.13	4.03	1.72	0.35	0.59
NLL5A1	1982	2019	38	5.80	6.09	2.28	-0.04	0.57
NLL5A2	1969	2019	51	2.60	2.54	1.27	0.15	0.50
NLG4A1	1979	2017	39	5.15	5.13	2.15	0.67	0.45
NLV1A1	1989	2019	31	6.29	6.34	2.27	0.11	0.53

NLV2A1	1991	2019	29	3.56	2.62	2.17	1.48	0.83
NLV3A1	1994	2019	26	3.97	4.27	1.23	-0.48	0.04
NLV3A2	1988	2019	32	5.56	5.56	2.09	0.39	0.30
NLV3A3	1987	2019	33	6.66	6.27	2.44	0.27	0.59
NLV4A1	1994	2019	26	5.86	6.09	1.35	-0.15	0.35
NLV4A2	1991	2019	29	6.28	6.51	2.09	-0.27	0.72

S13. Cumulative basal area (BA) (cm²) of influenced oaks (B oaks, in red) and prunus (in orange) over the years. For each site the average growth is depicted for the overall growth period.



S14. Information per sampled tree. Per sampled tree, the site, keycode, social position (1=dominant, 2=co-dominant, 3=suppressed), vitality (1=vital, 2=less vital, 3=non vital, 4=dead), diameter at breast height in cm (dbh), height in m, the percentage of prunus in the basal area, the estimated age, the calculated litter quality index and neighbourhood competition index (NCI).

site	keycode	species	social position	vitality	dbh	height	Prunus in BA	age	Litter quality index	NCI
			1-3	1-4	cm	m	%	years		
Walbeck	GEW1B1	Oak	2	4	33.7	22.4	48	90	19.4	62
Walbeck	GEW1B2	Oak	2	4	32.0	17.2	48	90	19.4	62
Walbeck	GEW1C1	Oak	1	2	36.5	21.6	10	91	16.4	62
Walbeck	GEW1C2	Oak	1	3	38.4	23.8	20	70	17.1	60
Walbeck	GEW1C3	Oak	1	2.5	41.4	22.6	24	90	17.6	74
Walbeck	GEW2B1	Oak	1	1	42.0	22.0	33	90	16.1	54
Walbeck	GEW2C1	Oak	1	1.5	36.7	21.6	18	85	17.1	56
Walbeck	GEW2C2	Oak	2	2.5	32.5	22.8	21	70	17.1	68
Walbeck	GEW2C3	Oak	1	2	37.2	21.2	8	90	16.4	48
Walbeck	GEW2C4	Oak	1	3	37.1	18.4	26	90	17.4	70
Walbeck	GEW2C5	Oak	1	4	44.6	19.0	8	122	14.0	50
Walbeck	GEW3B1	Oak	1	2	32.8	18.4	39	90	18.8	66
Walbeck	GEW3B2	Oak	1	1.5	31.3	19.5	44	85	19.3	50
Walbeck	GEW3C1	Oak	1	2	36.5	19.8	8	90	16.3	50
Walbeck	GEW3C2	Oak	1	2.5	41.3	25.8	21	80	17.1	58
Walbeck	GEW3C3	Oak	2	2	34.3	16.4	12	90	16.4	50
Walbeck	GEW4B1	Oak	1	2.5	40.4	18.8	43	90	19.1	46
Walbeck	GEW4B2	Oak	1	2	31.0	18.5	30	90	18.4	54
Walbeck	GEW4B3	Oak	1	2	48.0	22.0	45	90	19.2	58
Walbeck	GEW4B4	Oak	1	1.5	61.5	24.3	25	90	17.8	48
Walbeck	GEW4C1	Oak	1	1.5	51.2	22.0	20	90	17.1	60
Walbeck	GEW4C2	Oak	2	2	34.5	20.2	21	92	17.2	48
Walbeck	GEW4C3	Oak	1	2.5	42.0	19.2	25	90	17.5	72
Walbeck	GEW5C1	Oak	2	2	41.2	22.8	9	106	16.2	44
Walbeck	GEW5C2	Oak	1	1	50.6	21.8	26	123	16.1	70
Walbeck	GEW6B1	Oak	1	1	45.5	19.6	50	72	20.3	40
Walbeck	GEW6B2	Oak	1	1	50.0	21.0	50	72	20.0	48
Walbeck	GEW6C1	Oak	1	1	47.5	21.0	11	72	16.4	54
Walbeck	GEW6C2	Oak	2	2	36.0	19.2	26	90	17.9	54
Walbeck	GEW6C3	Oak	1	2	39.0	21.6	17	72	16.4	60
Grashoek	NLG1B1	Oak	2	1	27.0	17.6	29	49	18.2	70
Grashoek	NLG1B2	Oak	3	2.5	18.3	16.4	10	47	14.9	84
Grashoek	NLG2B1	Oak	1.5	1	31.6	20.0	34	47	19.2	64
Grashoek	NLG2B2	Oak	3	2.5	15.8	10.6	27	47	18.5	66
Grashoek	NLG2C1	Oak	2	1	33.2	21.8	0	55	16.5	42
Grashoek	NLG2C2	Oak	2	1	29.8	22.6	8	47	16.0	50
Grashoek	NLG3B1	Oak	2	2	26.7	20.6	28	47	18.0	50
Grashoek	NLG3B2	Oak	2.5	2	24.0	15.8	31	48	18.7	64
Grashoek	NLG3C1	Oak	2	1	31.2	21.6	5	56	17.0	74
Grashoek	NLG3C2	Oak	2	1	32.2	23.6	4	56	17.2	54
Grashoek	NLG3C3	Oak	2	1	30.0	19.0	7	54	17.1	54
Grashoek	NLG4B1	Oak	1.5	1.5	29.0	19.4	34	40	17.0	58
Grashoek	NLG4C1	Oak	1	1	38.0	19.2	14	64	17.4	42
Grashoek	NLG4C2	Oak	2	2.5	28.0	18.0	12	52	17.3	52
Grashoek	NLG4C3	Oak	1.5	2	31.5	19.0	7	47	17.0	56
Grashoek	NLG5C1	Oak	2	1	33.4	18.8	7	53	15.5	54
Grashoek	NLG5C2	Oak	2	1	35.7	20.0	16	56	17.1	50
Grashoek	NLG5C3	Oak	2	1	34.1	20.8	13	55	16.6	60
Grashoek	NLG5C4	Oak	2	1	30.0	20.2	15	55	16.7	54
Loon op Zand	NLL1B1	Oak	1	1	36.6	23.0	25	63	17.8	40
Loon op Zand	NLL1B2	Oak	2	1	27.4	22.5	n.a.	58	n.a.	n.a.
Loon op Zand	NLL1C1	Oak	2	1	32.9	21.0	11	69	16.2	54
Loon op Zand	NLL1C2	Oak	1	1	46.7	22.0	0	74	15.3	32
Loon op Zand	NLL1C3	Oak	1	1	50.3	22.5	13	65	16.4	32
Loon op Zand	NLL2B1	Oak	2	1	27.3	24.8	19	57	18.2	62
Loon op Zand	NLL2B2	Oak	2	1	35.1	21.5	21	60	18.6	58
Loon op Zand	NLL2B3	Oak	1	1	39.5	24.0	30	61	18.5	46
Loon op Zand	NLL2C1	Oak	2	1	23.7	17.0	0	62	16.5	42
Loon op Zand	NLL3B1	Oak	2	2	30.6	17.5	31	59	17.1	58

Loon op Zand	NLL3C1	Oak	2	1	34.2	19.3	0	68	14.5	40
Loon op Zand	NLL4B1	Oak	1	1	36.1	18.5	30	60	16.7	54
Loon op Zand	NLL4C1	Oak	2	1	42.6	22.0	7	67	15.9	28
Loon op Zand	NLL5B1	Oak	2	1	35.5	18.0	34	57	17.0	58
Loon op Zand	NLL5B2	Oak	2	1	28.8	17.0	30	51	16.7	60
Loon op Zand	NLL5C1	Oak	1	1	32.0	13.0	0	67	15.3	26
Loon op Zand	NLL5C2	Oak	2	1	33.2	17.5	0	58	15.4	32
Loon op Zand	NLL6C1	Oak	2	1	34.0	20.0	0	59	15.3	58
Loon op Zand	NLL6C2	Oak	2	1	36.0	19.5	0	66	14.6	70
Loon op Zand	NLL6C3	Oak	2	1	32.0	20.0	0	58	14.5	60
Someren	NLS1B1	Oak	2	2	30.6	19.8	16	40	17.0	50
Someren	NLS1B2	Oak	1	1	24.0	19.2	25	40	17.5	48
Someren	NLS1C1	Oak	1	3	24.4	19.0	0	60	16.1	50
Someren	NLS1C2	Oak	1	1	42.2	22.0	4	70	16.3	48
Someren	NLS1C3	Oak	1	2	33.7	21.4	21	70	17.7	56
Someren	NLS2B1	Oak	1.5	1.5	24.8	17.6	27	40	18.0	44
Someren	NLS2B2	Oak	1	1	24.5	17.8	24	40	17.4	50
Someren	NLS2B3	Oak	1	1	15.5	15.0	25	40	17.9	32
Someren	NLS2C1	Oak	1	1	30.5	19.8	12	65	16.6	68
Someren	NLS2C2	Oak	1.5	1	28.7	17.5	11	74	16.6	54
Someren	NLS2C3	Oak	1	2	30.5	18.2	6	65	16.7	62
Someren	NLS3B1	Oak	1.5	2	20.6	18.0	21	40	17.4	58
Someren	NLS3B2	Oak	2	2	15.9	16.8	29	36	17.8	48
Someren	NLS3B3	Oak	2	2	20.7	17.5	21	40	18.0	56
Someren	NLS3C1	Oak	1	1	29.1	20.8	5	65	16.6	74
Someren	NLS3C2	Oak	1	2.5	27.3	21.3	4	78	16.0	50
Someren	NLS3C3	Oak	1	1	38.6	21.0	13	70	16.5	62
Someren	NLS4B1	Oak	1	1	22.2	19.0	26	40	17.0	46
Someren	NLS4B2	Oak	2	1	23.0	18.0	50	40	19.5	52
Someren	NLS4B3	Oak	2	1	23.3	18.6	50	40	19.5	52
Someren	NLS4C1	Oak	2	1	18.5	15.0	0	40	16.0	42
Someren	NLS4C2	Oak	1	2	21.5	15.6	0	40	15.9	44
Someren	NLS4C3	Oak	2	1	22.0	16.6	0	40	15.6	50
Veldhoven	NLV1B1	Oak	2	2	41.4	24.0	24	74	17.2	50
Veldhoven	NLV1B2	Oak	2	2	34.5	23.2	22	73	17.4	54
Veldhoven	NLV1C1	Oak	2	2	31.6	22.6	7	72	16.1	58
Veldhoven	NLV1C2	Oak	2	2	31.6	23.0	0	68	15.7	54
Veldhoven	NLV1C3	Oak	2	1	43.1	23.2	0	72	15.5	54
Veldhoven	NLV1C4	Oak	1	1	31.3	22.8	3	73	15.6	54
Veldhoven	NLV2B1	Oak	1	1	36.9	23.8	24	69	17.4	68
Veldhoven	NLV2B2	Oak	2	1	25.6	21.0	27	72	17.7	66
Veldhoven	NLV2B3	Oak	1	1	39.3	23.2	21	74	17.1	68
Veldhoven	NLV2B4	Oak	2	1	33.2	22.6	19	64	17.0	52
Veldhoven	NLV2C1	Oak	2	1	31.9	24.2	0	68	15.6	68
Veldhoven	NLV2C2	Oak	1	1	40.1	23.8	0	68	15.7	46
Veldhoven	NLV3B1	Oak	2	1	27.8	21.0	24	63	17.6	58
Veldhoven	NLV3B2	Oak	1	1	46.0	23.0	21	64	17.2	56
Veldhoven	NLV3B3	Oak	2	1	28.1	22.6	25	64	17.5	72
Veldhoven	NLV3C1	Oak	2	1	25.6	20.6	4	64	16.6	56
Veldhoven	NLV3C2	Oak	2	1	29.6	21.6	6	61	16.6	64
Veldhoven	NLV3C3	Oak	1	1	39.3	22.2	8	60	17.0	52
Veldhoven	NLV3C4	Oak	2	3	27.6	21.4	3	61	16.7	60
Veldhoven	NLV4B1	Oak	2	2	25.5	20.0	33	65	17.4	72
Veldhoven	NLV4B2	Oak	3	1	27.0	17.8	38	66	18.1	78
Veldhoven	NLV4B3	Oak	3	3	21.8	18.2	45	65	18.6	62
Veldhoven	NLV4C1	Oak	2	1	43.0	25.4	0	75	15.5	50
Veldhoven	NLV4C2	Oak	2	2	38.3	23.6	7	71	16.7	56
Veldhoven	NLV4C3	Oak	2	1	42.5	22.4	13	73	15.6	32
't Zand	NLZ1B1	Oak	1	1	62.2	20.8	18	75	15.5	56
't Zand	NLZ1B2	Oak	2	1	34.2	20.6	30	74	16.7	54
't Zand	NLZ1C1	Oak	1	1	55.9	22.8	0	76	13.7	52
't Zand	NLZ2B1	Oak	2	1	38.1	19.8	37	65	16.5	38
't Zand	NLZ2C1	Oak	2	1	36.8	22.2	4	72	14.4	56
't Zand	NLZ2C2	Oak	2	1	32.1	21.2	0	76	14.6	60
't Zand	NLZ2C3	Oak	2	1	31.6	20.4	0	77	13.2	46
't Zand	NLZ3C1	Oak	2	1	59.8	23.4	17	81	15.1	58
't Zand	NLZ3C2	Oak	2	1	58.8	21.8	8	71	14.6	78

t Zand	NLZ3C3	Oak	2	1	43.0	21.0	8	77	14.7	72
t Zand	NLZ4B1	Oak	1	1	60.0	20.0	32	81	16.1	62
t Zand	NLZ4C1	Oak	2	1	37.1	23.8	0	75	13.5	46
t Zand	NLZ4C2	Oak	1	1	60.1	23.0	0	83	13.6	50
t Zand	NLZ4C3	Oak	1	1	57.1	22.8	0	83	13.8	48
t Zand	NLZ5C1	Oak	2	1	46.5	21.0	4	78	12.0	50
t Zand	NLZ5C2	Oak	2	1	30.7	19.5	4	79	12.6	56
t Zand	NLZ6C1	Oak	2	1	56.9	20.2	8	79	14.1	50
t Zand	NLZ6C2	Oak	2	1	50.0	19.6	8	84	14.3	48
Walbeck	GEW2A1	Prunus	3	3	32.7	12.0	30	75	16.8	54
Walbeck	GEW2A2	Prunus	2	1	45.6	20.0	33	81	16.0	60
Walbeck	GEW2A3	Prunus	1	2	44.5	20.3	42	86	18.4	52
Walbeck	GEW3A1	Prunus	1	1.5	30.5	17.5	36	89	18.4	50
Walbeck	GEW4A1	Prunus	1	1	44.2	20.0	30	81	18.1	54
Walbeck	GEW4A3	Prunus	2	2	27.5	15.4	28	50	19.4	36
Walbeck	GEW6A1	Prunus	2	2	26.4	14.0	39	31	19.1	46
Walbeck	GEW6A2	Prunus	2	2	28.0	18.4	32	31	18.1	50
Grashoek	NLG4A1	Prunus	1	2	37.0	18.8	25	39	17.6	64
Loon op Zand	NLL1A1	Prunus	1	1	41.9	26.0	23	37	17.6	44
Loon op Zand	NLL2A1	Prunus	2	1	33.7	23.0	23	54	18.3	60
Loon op Zand	NLL3A1	Prunus	1	1	33.6	16.5	28	42	16.9	50
Loon op Zand	NLL5A1	Prunus	1	2	45.9	18.0	54	43	19.2	48
Loon op Zand	NLL5A2	Prunus	2	1	27.4	18.0	33	51	16.8	54
Somereren	NLS1A1	Prunus	1	1	64.5	19.0	29	16	17.1	34
Somereren	NLS1A2	Prunus	2	2	31.4	20.6	22	30	17.2	46
Somereren	NLS2A1	Prunus	1	1	35.0	17.0	38	33	18.6	32
Somereren	NLS2A2	Prunus	1	1	39.3	20.0	67	33	21.2	36
Somereren	NLS3A1	Prunus	1	1	36.6	17.8	14	33	16.6	56
Somereren	NLS3A2	Prunus	1	1	40.5	17.5	25	36	17.9	48
Somereren	NLS4A1	Prunus	1	1	31.2	19.8	35	33	19.5	46
Somereren	NLS4A2	Prunus	1	1	36.5	18.4	30	33	19.7	60
Veldhoven	NLV1A1	Prunus	1	1	40.7	21.8	83	31	22.4	48
Veldhoven	NLV2A1	Prunus	3	2	21.3	20.6	29	31	17.8	56
Veldhoven	NLV3A1	Prunus	2	1	30.1	20.2	50	31	20.1	48
Veldhoven	NLV3A2	Prunus	1	1	34.3	24.2	84	35	22.7	62
Veldhoven	NLV3A3	Prunus	1	1	35.7	25.0	69	38	21.6	52
Veldhoven	NLV4A1	Prunus	1	1	29.7	21.2	68	28	20.6	38
Veldhoven	NLV4A2	Prunus	1	1	45.5	21.4	87	32	22.8	46
t Zand	NLZ1A1	Prunus	1	2	52.2	21.4	26	67	16.2	46
t Zand	NLZ1A2	Prunus	n.a.	n.a.	34.6	22.0	32	53	n.a.	n.a.
t Zand	NLZ2A1	Prunus	2	1	52.7	21.0	45	53	15.0	56
t Zand	NLZ2A2	Prunus	2	1	39.6	21.6	25	50	17.2	44
t Zand	NLZ4A1	Prunus	2	1	53.0	21.8	21	52	15.7	48

S15. Leaf base concentrations. Table gives leaf base concentrations for each tree species found at our sites based on the values obtained by Desie et al. (2020). For the species which were not studied, indicated in bold, base concentrations were based on the values for similar tree species from which base cation concentration data was available.

<i>Leaf base concentrations</i>	
<i>Quercus robur</i>	15.4
<i>Prunus serotina</i>	23.8
<i>Sorbus aucuparia</i>	20 based on <i>Acer</i>
<i>Betula pendula</i>	18.4
<i>Pinus sylvestris</i>	9.1
<i>Acer pseudoplatanus</i>	20.5
<i>Quercus rubra</i>	15 based on <i>Q. robur</i>
<i>Picea abies</i>	10 based on <i>Pinus</i>
<i>Corylus avellana</i>	20 based on <i>Acer</i>
<i>Robinia pseudoacacia</i>	24 based on <i>Prunus</i>

S16. Average basal area of tree species in neighbourhood of focal oak trees. Per site, calculated by means of the two angle gauge measurements for the neighbourhood of influenced oaks (B) and uninfluenced oaks (C).

Neighbourhood B oaks

species	Grashoek	Loon op Zand	Someren	't Zand	Veldhoven	Walbeck
<i>Robinia pseudoacacia</i>	0	0	0	0	0	0
<i>Corylus avellana</i>	0	0	0	0	0	0
<i>Picea abies</i>	0	0	0	0	0	0
<i>Quercus rubra</i>	0	0	0	0	0	0
<i>Acer pseudoplatanus</i>	0	0	1	0	0	0
<i>Betula pendula</i>	13	3	1	1	2	1
<i>Sorbus aucuparia</i>	0	0	0	0	0	0
<i>Pinus sylvestris</i>	6	3	1	7	2	1
<i>Prunus serotina</i>	9	8	7	8	9	11
<i>Quercus robur</i>	5	14	14	11	19	13

Neighbourhood C oaks

species	Grashoek	Loon op Zand	Someren	t Zand	Veldhoven	Walbeck
<i>Robinia pseudoacacia</i>	0	0	0	0	0	0
<i>Corylus avellana</i>	0	0	0	0	0	0
<i>Picea abies</i>	0	0	0	0	0	1
<i>Quercus rubra</i>	1	3	0	0	1	0
<i>Acer pseudoplatanus</i>	0	0	0	0	0	0
<i>Betula pendula</i>	9	1	5	0	4	0
<i>Sorbus aucuparia</i>	0	0	0	0	0	0
<i>Pinus sylvestris</i>	1	1	1	8	1	1
<i>Prunus serotina</i>	2	1	2	1	1	5
<i>Quercus robur</i>	14	16	20	18	20	22

S17. Average neighbourhood indices per site. Litter quality indices, neighbourhood competition indices (NCI) and the percentages of prunus in the basal area (BA) averaged for the influenced (B) and uninfluenced (C) oaks at each site.

Site	Litter quality index		Prunus in BA		NCI	
	B oaks	C oaks	B oaks	C oaks	B oaks	C oaks
Grashoek	17.8	16.8	27.6	9.0	65.1	53.5
Loon op Zand	17.6	15.5	27.5	2.8	54.5	43.1
Someren	17.9	16.4	28.5	6.3	48.7	55
Veldhoven	17.5	16.1	26.9	3.9	63.0	54.1
Walbeck	18.9	16.7	41.4	17.4	53.5	58.3
't Zand	16.2	13.9	29.3	4.4	52.0	55.0