Dendrochronology, a tool to investigate the past of our cities

Paolo Cherubini

WSL Swiss Federal Institute for Forest, Snow and Landscape Research
CH-8903 Birmensdorf
Switzerland

paolo.cherubini@wsl.ch
http://www.wsl.ch/staff/paolo.cherubini/

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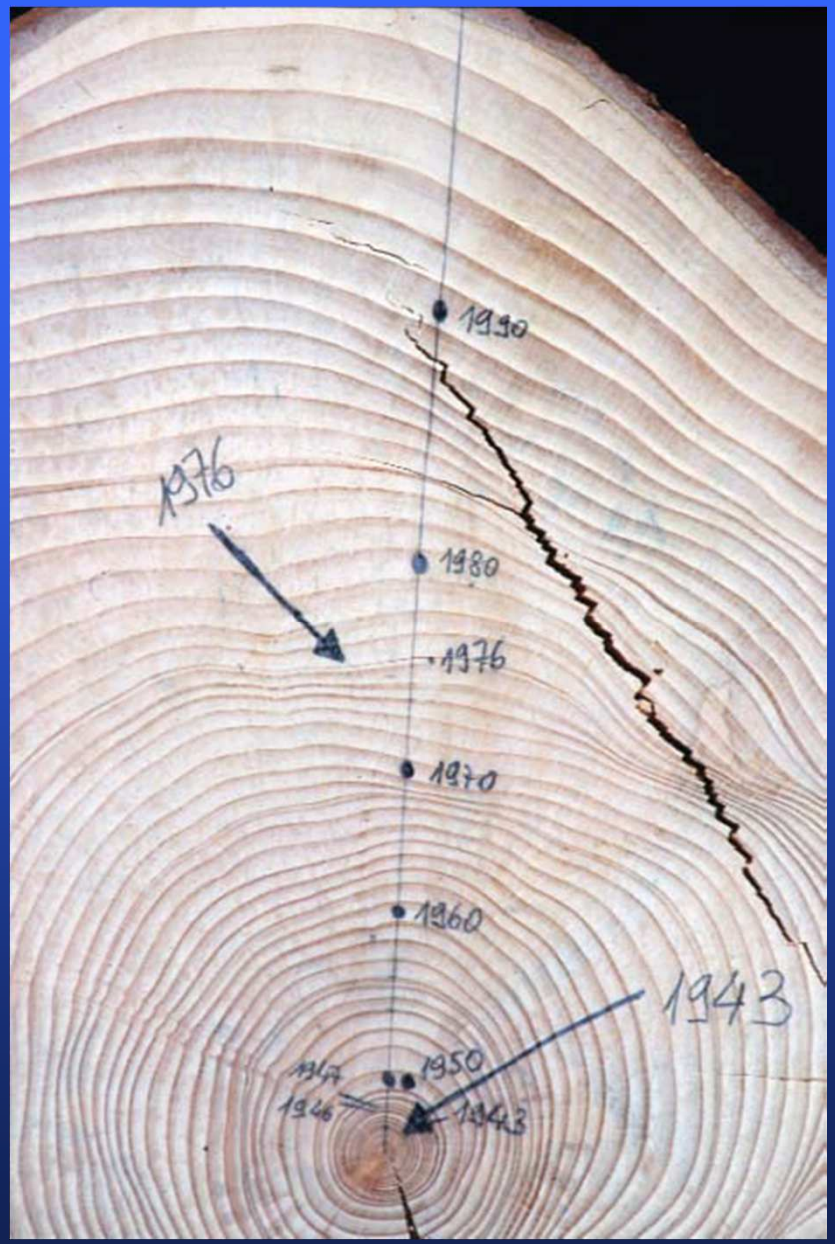
Dendron - kronos - logos


1990
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1980
1976
1970
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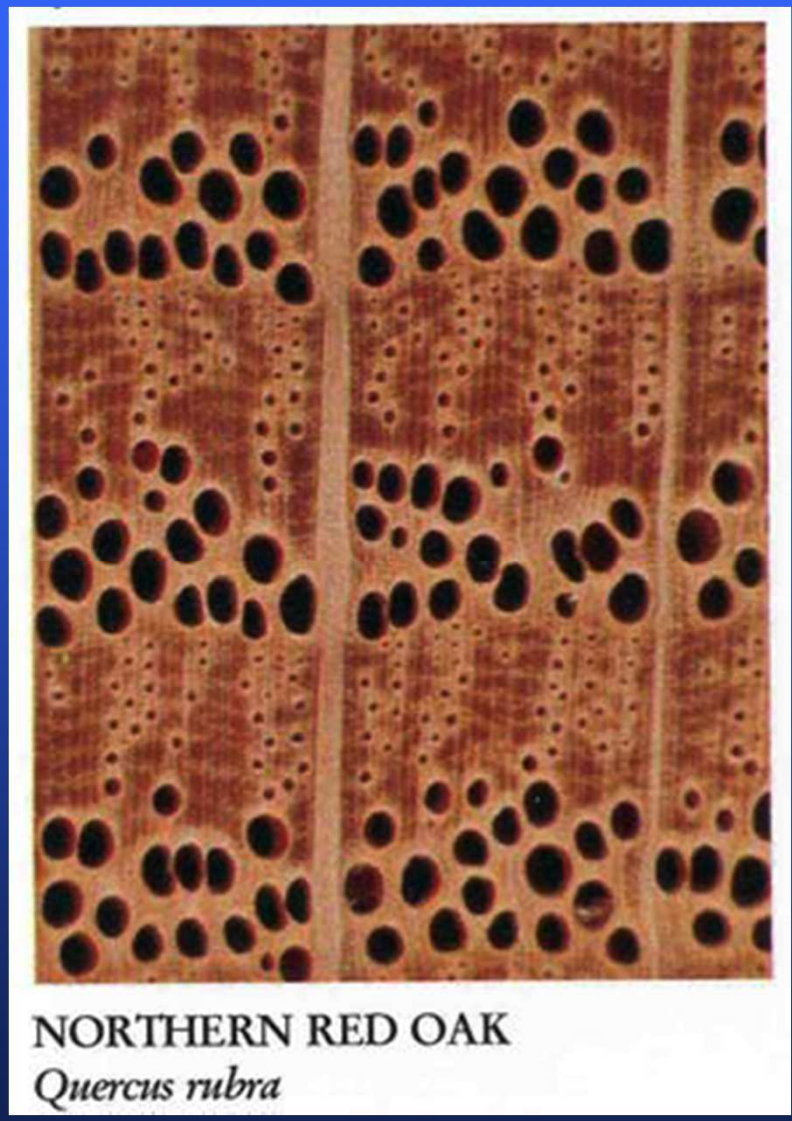
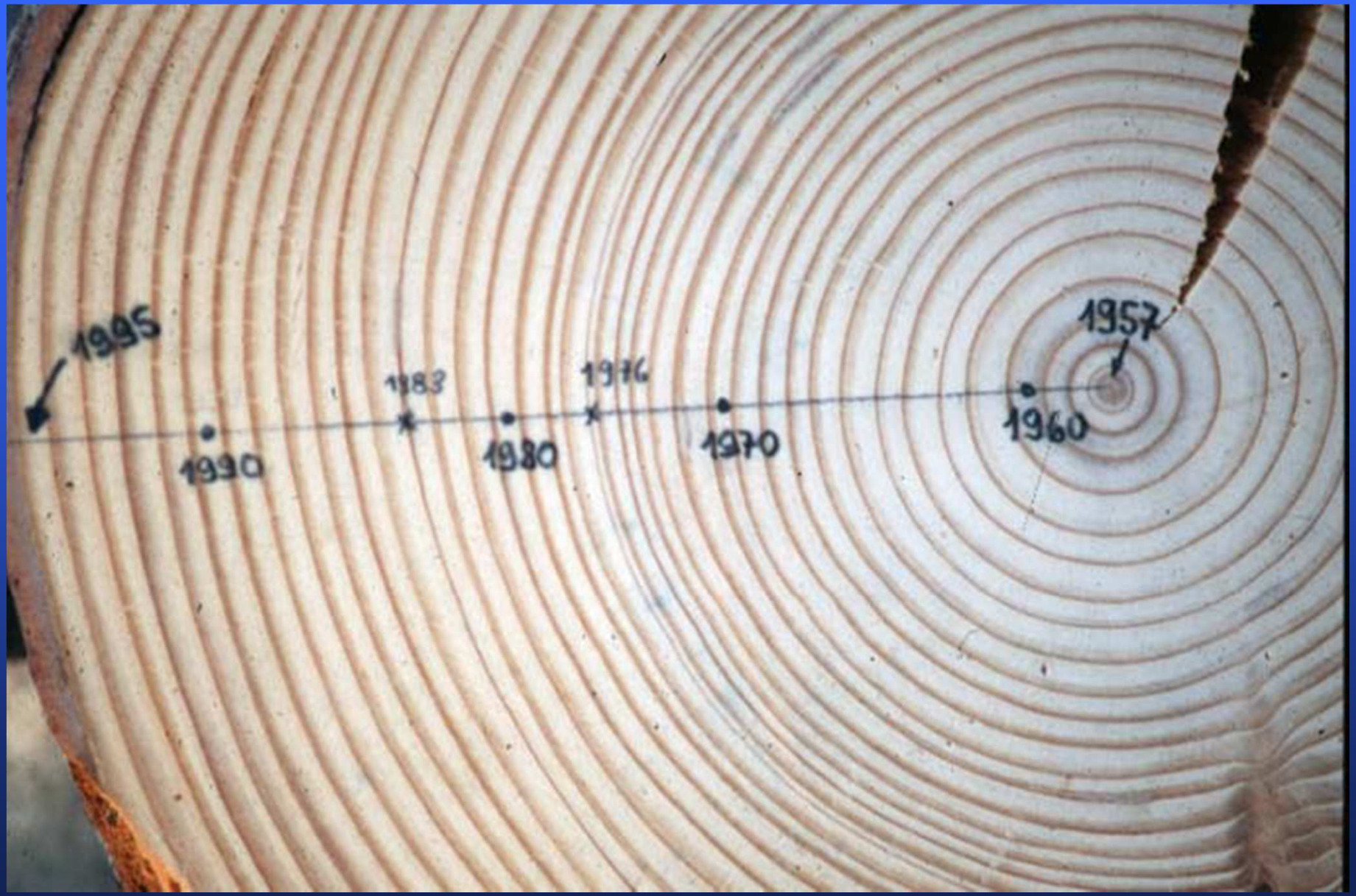
1943
1950
1947
1946
1943

Tree ring

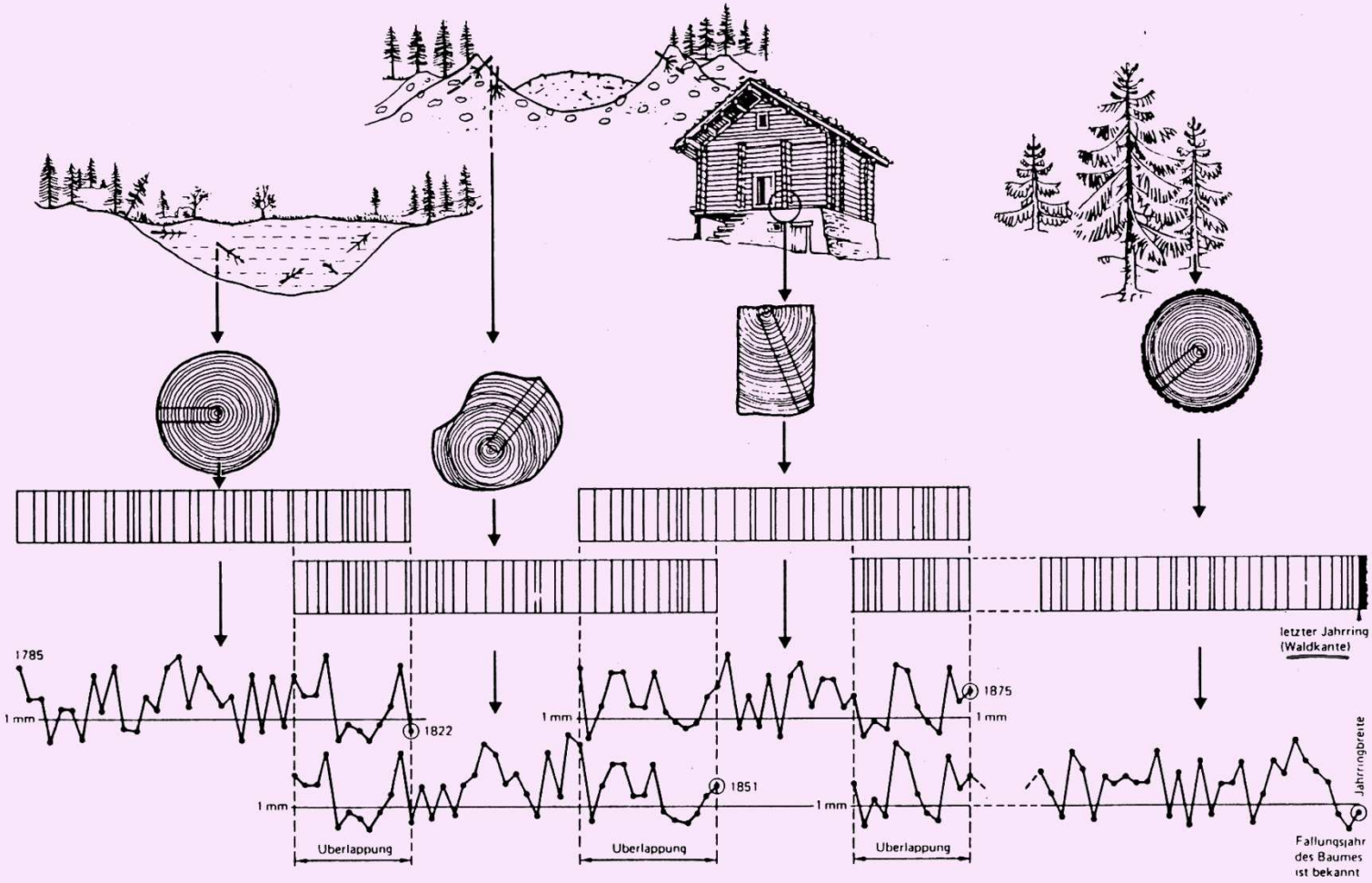
Earlywood

Latewood




1995
1990
1983
1980
1974
1970
1960
1957

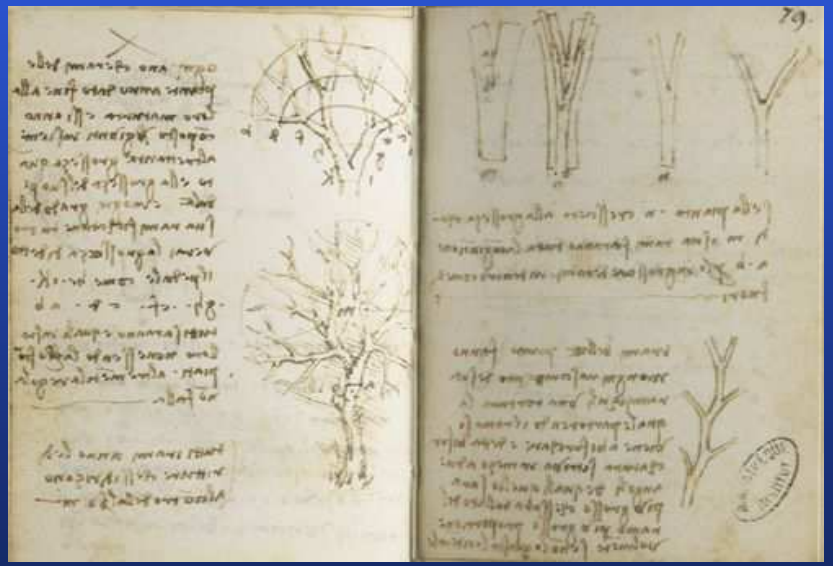
Tree rings


1785
1 mm
1822
1851
1875
Überlappung
Überlappung
Überlappung
letzter Jahrring
(Waldkante)
Jahrringbreite
Fällungsjahr
des Baumes
ist bekannt

Leonardo da Vinci (1452 – 1519)

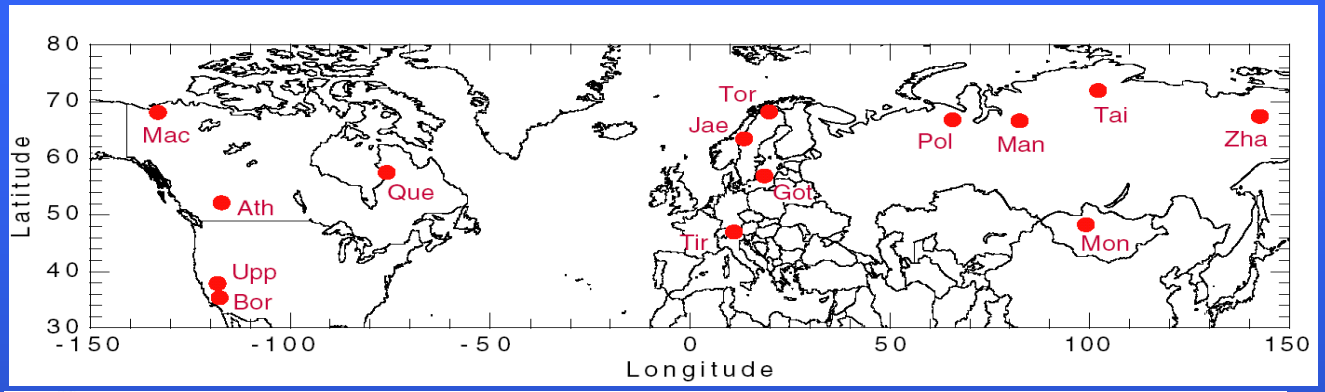
Possible self-portrait, around 1512

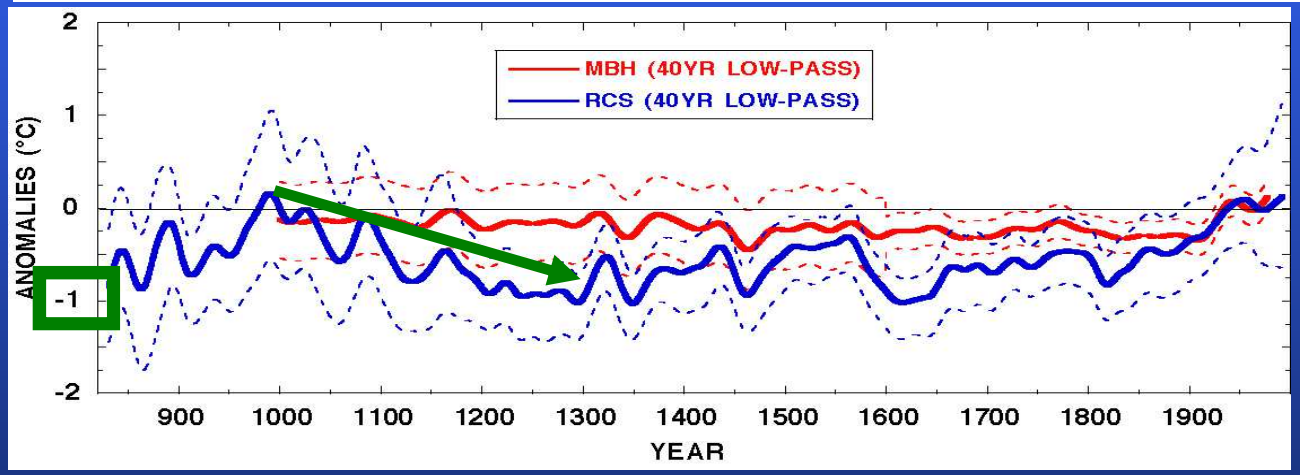
Leaves and acorns of oak



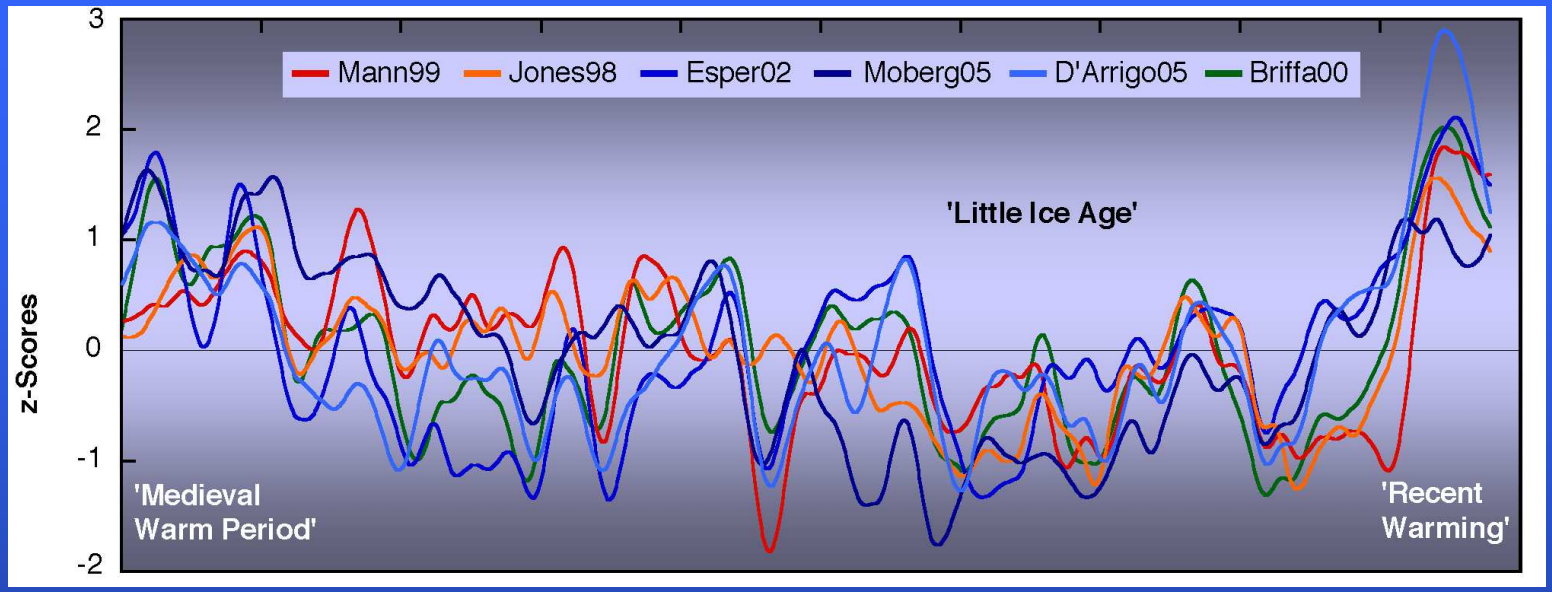
Paris manuscript M: Growth of a tree

Dendroecology





Esper et al. (2002) *Science*


Mann99
Jones98
Esper02
Moberg05
D'Arrigo05
Briffa00
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3
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-2
'Little Ice Age'
'Medieval
Warm Period'
'Recent
Warming'

Leaves and Roots as Interfaces to the Environment

Traffic

Air pollution:
tropospheric ozone too!

Tropospheric Ozone

Fagus sylvatica

Tree Physiology 27, 941–949

Ozone air pollution effects on tree-ring growth, $\delta^{13}C$, visible foliar injury and leaf gas exchange in three ozone-sensitive woody plant species

KRISTOPHER NOVAK,[1,2] PAOLO CHERUBINI,[1] MATTHIAS SAURER,[3] JÜRG FUHRER,[2,4] JOHN M. SKELLY,[5] NORBERT KRÄUCHI[1] and MARCUS SCHAUB[1]

[1] *Swiss Federal Institute for Forest, Snow, and Landscape Research WSL, Zuercherstrasse 111, CH-8903 Birmensdorf, Switzerland*

[2] *Agroscope FAL Reckenholz, Swiss Federal Research Station for Agroecology and Agriculture, Reckenholzstrasse 191, CH-8046 Zürich, Switzerland*

[3] *Paul Scherrer Institute PSI, CH-5232 Villigen, Switzerland*

[4] *Corresponding author (juerg.fuhrer@art.admin.ch)*

[5] *Department of Plant Pathology, The Pennsylvania State University, University Park, PA 16802, USA*

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Summary We assessed the effects of ambient tropospheric ozone on annual tree-ring growth, $\delta^{13}C$ in the rings, leaf gas exchange and visible injury in three ozone-sensitive woody plant species in southern Switzerland. Seedlings of *Populus nigra* L., *Viburnum lantana* L. and *Fraxinus excelsior* L. were exposed to charcoal-filtered air (CF) and non-filtered air (NF) in open-top chambers, and to ambient air (AA) in open plots during the 2001 and 2002 growing seasons. Ambient ozone exposures in the region were sufficient to cause visible foliar injury, early leaf senescence and premature leaf loss in all species. Ozone had significant negative effects on net photosynthesis and stomatal conductance in all species in 2002 and in *V. lantana* and *F. excelsior* in 2001. Water-use efficiency decreased and intercellular CO_2 concentrations increased in all species in response to ozone in 2002 only. The width and $\delta^{13}C$ of the 2001 and 2002 growth rings were measured for all species at the end of the 2002 growing season. Compared with CF seedlings, mean ring width in the AA and NF *P. nigra* seedlings was reduced by 52 and 46%, respectively, in 2002, whereas in *V. lantana* and *F. excelsior*, ring width showed no significant reductions in either year. Although $\delta^{13}C$ was usually more negative in CF seedlings than in AA and NF seedlings, with the exception of *F. excelsior* in 2001, ozone effects on $\delta^{13}C$ were significant only for *V. lantana* and *P. nigra* in 2001. Among species, *P. nigra* exhibited the greatest response to ozone for the measured parameters as well as the most severe foliar injury and was the only species to show a significant reduction in ring width in response to ozone exposure, despite significant negative ozone effects on leaf gas exchange and the development of visible foliar injury in *V. lantana* and *F. excelsior*. Thus, significant ozone-induced effects at the leaf level did not correspond to reduced tree-ring growth or increased $\delta^{13}C$ in all species, indicating that the timing of ozone exposure and severity of leaf-level responses may be important in determining the sensitivity of tree productivity to ozone exposure.

Keywords: Fraxinus excelsior, open-top chambers, Populus nigra, southern Switzerland, stable carbon isotopes, Viburnum lantana.

Introduction

Plant responses to tropospheric ozone pollution are often species specific and depend on several morphological, biochemical and physiological characteristics as well as environmental factors. A variety of negative forest tree responses to ozone have been documented in open-top chambers (OTCs), growth chamber fumigations and field studies (see review by Matyssek and Sandermann 2003). Of the various tree responses, annual increment growth is one of the most important because it is an integration of many underlying processes (Innes 1993, Ferretti et al. 2002, McLaughlin et al. 2002). Tree growth responses to ozone have frequently been assessed by measurements of height, relative growth rate (RGR), leaf production and biomass partitioning between root and shoot, but fewer studies have examined tree ring growth and stable carbon isotope composition ($\delta^{13}C$) to assess ozone effects on tree growth.

Early reports on the negative impacts of ozone on trees included foliar damage in coniferous species (Miller et al. 1963), reductions in radial growth in *Pinus ponderosa* Laws. (McBride et al. 1975) and reductions in mean annual growth increment of eastern white pine (*Pinus strobus* L.) (Benoit et al. 1982) and two broadleaf species (Somers et al. 1998). More recently, changes in whole-canopy ozone uptake have been related to changes in radial growth in mature *Fagus sylvatica* L. trees as a possible basis for deriving critical threshhold values for ozone effects on forests (Dittmar et al. 2005). Although these studies generally attribute a reduction in radial growth to ozone exposure, some uncertainty remains because

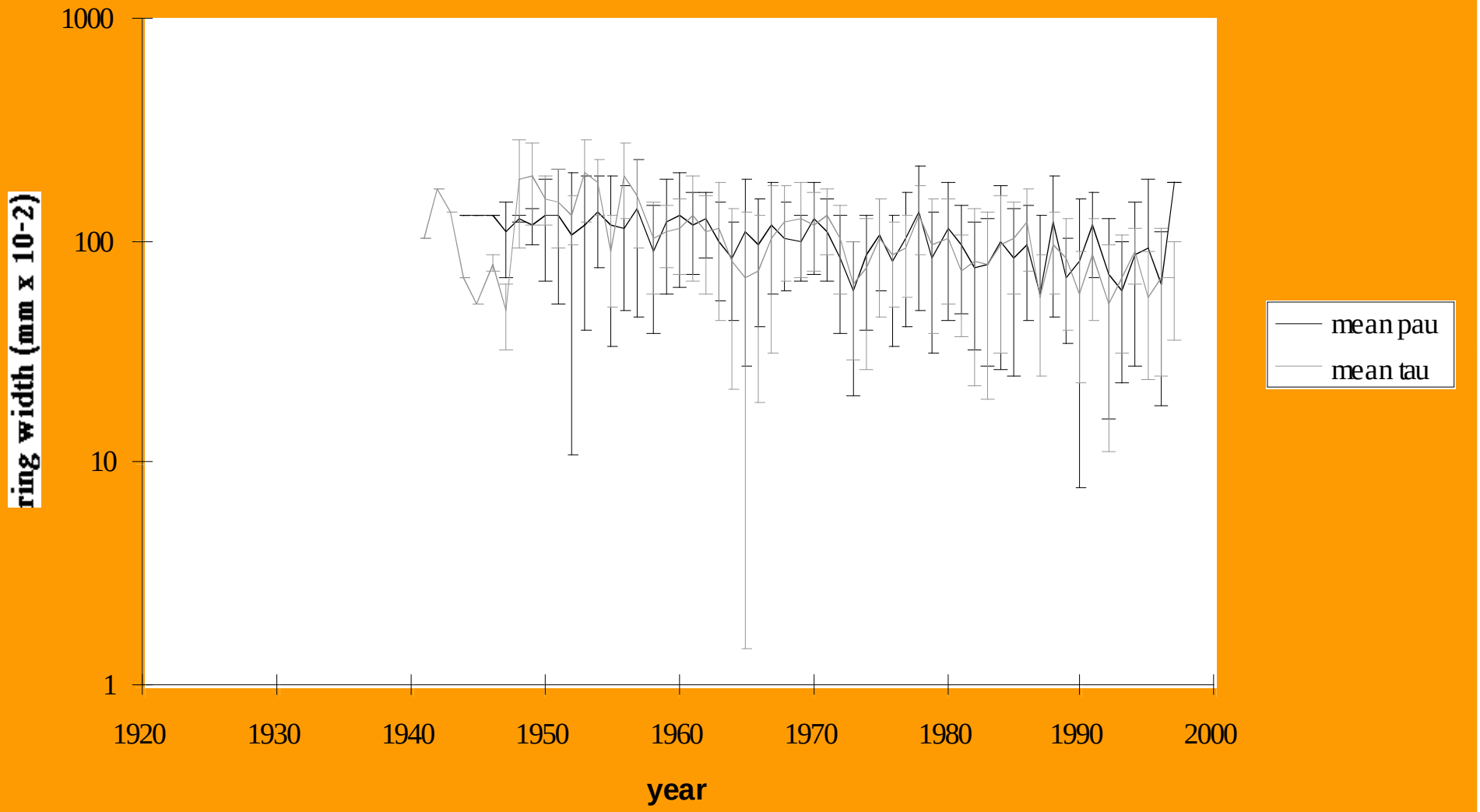
Natural CO_2 springs in Tuscany as research facilities

Studies at Italian natural CO_2 springs have shown:

- lower stomatal density and stomatal index;
- reduced stomatal conductance; and
- smaller foliage area for a corresponding sapwood cross-sectional area.

Arbutus unedo

Arbutus unedo L.: mean chronologies



Why?

Low soil N availability?

Photosynthetic acclimation response? (frequent under N-limited conditions)

Greater root growth responses than above-ground responses?

(high root to shoot ratios are associated with environments where water and nutrients are limiting)

Secondary metabolites? (which may be more convenient than the investment in stemwood in semi-arid environments like the Mediterranean)

Higher photorespiration rates? (high leaf temperature are induced by stomata closure) (Loreto pers. comm.)

RESEARCH *New Phytol.* (2000), 146, 59–74

Comparative stem-growth rates of Mediterranean trees under background and naturally enhanced ambient CO_2 concentrations

ROBERTO TOGNETTI[1,2], PAOLO CHERUBINI[3]* AND JOHN L. INNES[4]

[1]*Istituto per l'Agrometeorologia e l'Analisi Ambientale applicata all'Agricoltura, Consiglio Nazionale delle Ricerche (IATA–CNR), Piazzale delle Cascine 18, I-50144 Firenze, Italy*
[2]*Department of Botany, University of Dublin, Trinity College, Dublin 2, Ireland*
[3]*Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland*
[4]*Forest Resources Management, University of British Columbia, Forest Sciences Centre 2045, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada*

Received 28 June 1999; accepted 14 December 1999

SUMMARY

Ring widths of five Mediterranean forest tree species (*Arbutus unedo*, *Fraxinus ornus*, *Quercus cerris*, *Quercus ilex* and *Quercus pubescens*) growing close to a natural source of CO_2 in Tuscany, Italy and at a nearby control site were compared. At the CO_2-enriched site, trees have been growing for decades under elevated CO_2 concentrations. They originated from parent trees that also grew under elevated CO_2 in natural conditions, and they have been continuously exposed to elevated CO_2 throughout their growth. Tree-ring series from each of the species were prepared. Assigning calendar dates to rings was difficult but possible, and ring-width series were built for all species. The ring-width data were analysed using a two-sided *t*-test to assess if there was a difference between the radial growth at the CO_2-enriched site and the control site. The cumulative basal area at the same cambial age at both sites was also compared using a Wilcoxon test. Radial growth of trees at the CO_2-enriched site was not significantly different from growth at the control site. For each species, year by year, radial growth at the CO_2-enriched site was tested against the control site and significant differences were found in only a few years; these differences were not synchronous with extreme climatic events. The expected increase in above-ground productivity, as one of the ecosystem responses to increasing CO_2 during drought stress, was not observed in this Mediterranean woody plant community, despite being water-limited. Other resource limitations, such as low nutrient availability (common in the Mediterranean region), may have counteracted the positive effect of elevated CO_2 under drought stress, or trees may have acclimated to the high CO_2.

Key words: *Arbutus unedo* (strawberry tree), carbon sequestration, dendroecology, Mediterranean trees, natural CO_2 springs, *Quercus ilex* (holm oak), tree rings, water stress.

INTRODUCTION

Atmospheric CO_2 mole fractions are rising at a rate of 1–2 μmol mol^{-1} yr^{-1}, largely as a result of the burning of fossil fuels (Keeling *et al.*, 1995), and are expected to reach more than 700 μmol mol^{-1} by the year 2100 (Houghton *et al.*, 1995). Climate change associated with increases in CO_2, as well as other greenhouse-active gases, may result in higher temperatures and decreasing soil moisture (Mitchell *et al.*, 1990) if precipitation does not increase (Rind *et al.*, 1990). Plant communities in ecosystems that experience a combination of high temperatures, sub-optimal levels of soil moisture and the presence of airborne pollutants are expected to be particularly sensitive to elevated CO_2 (Moreno & Oechel, 1995). Many ecosystems in the Mediterranean Basin experience these conditions. Moreover, the whole

*Author for correspondence (fax +41 1 739 22 15; e-mail paolo.cherubini@wsl.ch).

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Tree Physiology 23, 997–1004

Tracing carbon uptake from a natural CO_2 spring into tree rings: an isotope approach

MATTHIAS SAURER,[1,2] PAOLO CHERUBINI,[3] GEORGES BONANI[4] and ROLF SIEGWOLF[1]

[1] *Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland*

[2] *Author to whom correspondence should be addressed (matthias.saurer@psi.ch)*

[3] *Swiss Federal Research Institute WSL, CH-8903 Birmensdorf, Switzerland*

[4] *Institute of Particle Physics, ETH Hönggerberg, CH-8093 Zürich, Switzerland*

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Summary We analyzed ^{14}C, ^{13}C and ^{18}O isotope variations over a 50-year period in tree rings of *Quercus ilex* L. trees growing at a natural CO_2 spring in a Mediterranean ecosystem. We compared trees from two sites, one with high and one with low exposure to CO_2 from the spring. The spring CO_2 is free of ^{14}C. Thus, this carbon can be traced in the wood, and the amount originating from the spring calculated. The amount decreased over time, from about 40% in 1950 to 15% at present for the site near the spring, indicating a potential difficulty in the use of natural CO_2 springs for elevated CO_2 research. The reason for the decrease may be decreasing emission from the spring or changes in stand structure, e.g., growth of the canopy into regions with lower concentrations. We used the ^{14}C-calculated CO_2 concentration in the canopy to determine the ^{13}C discrimination of the plants growing under elevated CO_2 by calculating the effective canopy air $^{13}C/^{12}C$ isotopic composition. The trees near the spring showed a 2.5‰ larger ^{13}C discrimination than the more distant trees at the beginning of the investigated period, i.e., for the young trees, but this difference gradually disappeared. Higher discrimination under elevated CO_2 indicated reduced photosynthetic capacity or increased stomatal conductance. The latter assumption is unlikely as inferred from the ^{18}O data, which were insensitive to CO_2 concentration. In conclusion, we found evidence for a downward adjustment of photosynthesis under elevated CO_2 in *Q. ilex* in this dry, nutrient-poor environment.

Keywords: carbon isotope ratio, dendrochronology, elevated carbon dioxide, oxygen isotope ratio, Quercus ilex, radiocarbon analysis.

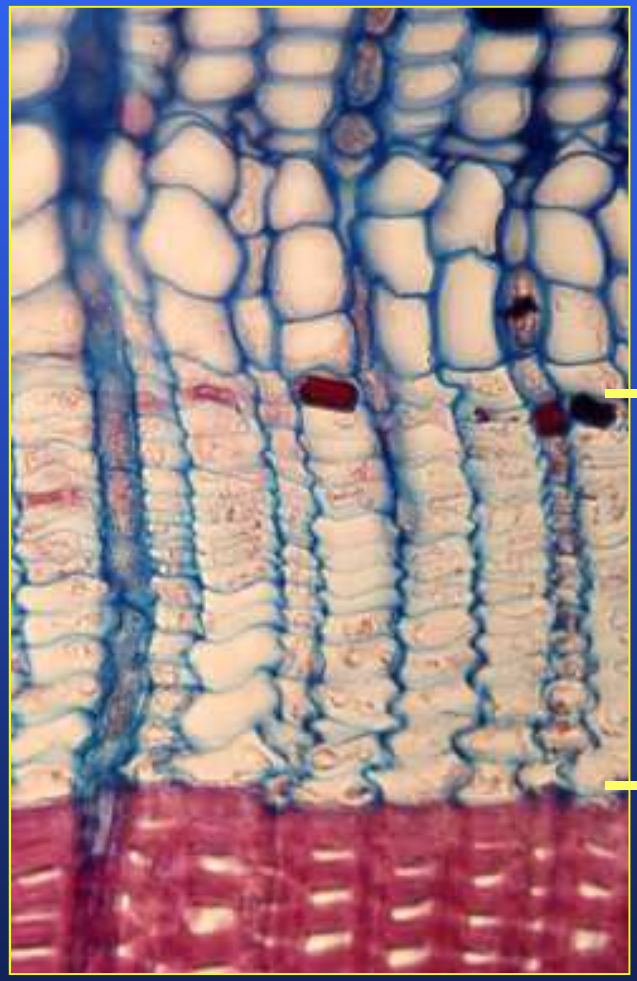
Introduction

The potential growth response of trees to increased atmospheric CO_2 concentrations is an important factor in the global carbon cycle (Amthor 1995). Forests constitute large reservoirs of carbon, and a change in their carbon storage capacity induced by the fertilizing effect of CO_2 may have an impact on future atmospheric CO_2 concentrations (Dixon et al. 1994). Whereas many studies of the CO_2 concentration effect have been carried out on seedlings, the growth response of mature trees is difficult to assess experimentally because of the long life cycle of trees (Mooney et al. 1991, Körner et al. 1996). One approach has been to study the effects of natural CO_2 springs on intact ecosystems (Miglietta et al. 1993, Grace and van Gardingen 1997). Mineral CO_2 springs are found mainly in active volcanic regions and emit CO_2 at concentrations as high as 100%, thereby raising the atmospheric CO_2 concentration in the immediate vicinity.

A limitation to the value of CO_2 springs for the study of ecosystems under conditions that may prevail in the future is that gases other than CO_2, for example H_2S, may be emitted by the spring with a toxic effect on plants. Further, it may be difficult to find a control site with growth conditions comparable to those at the spring site (Scarascia-Mugnozza et al. 2001). Another important consideration is whether the plants have been exposed to a constant CO_2 concentration throughout their lifetime. In some cases, it is known from historic records that a spring has been active for decades or even centuries. However, the stability over time in the amount of the gas emitted is usually unknown (Etiope and Lombardi 1997). Because CO_2 from the spring is distributed by diffusion and convection to the surrounding area, changes in vegetative cover and canopy height may also influence the concentration of CO_2 reaching the leaves. In particular, stand history and past management have to be considered.

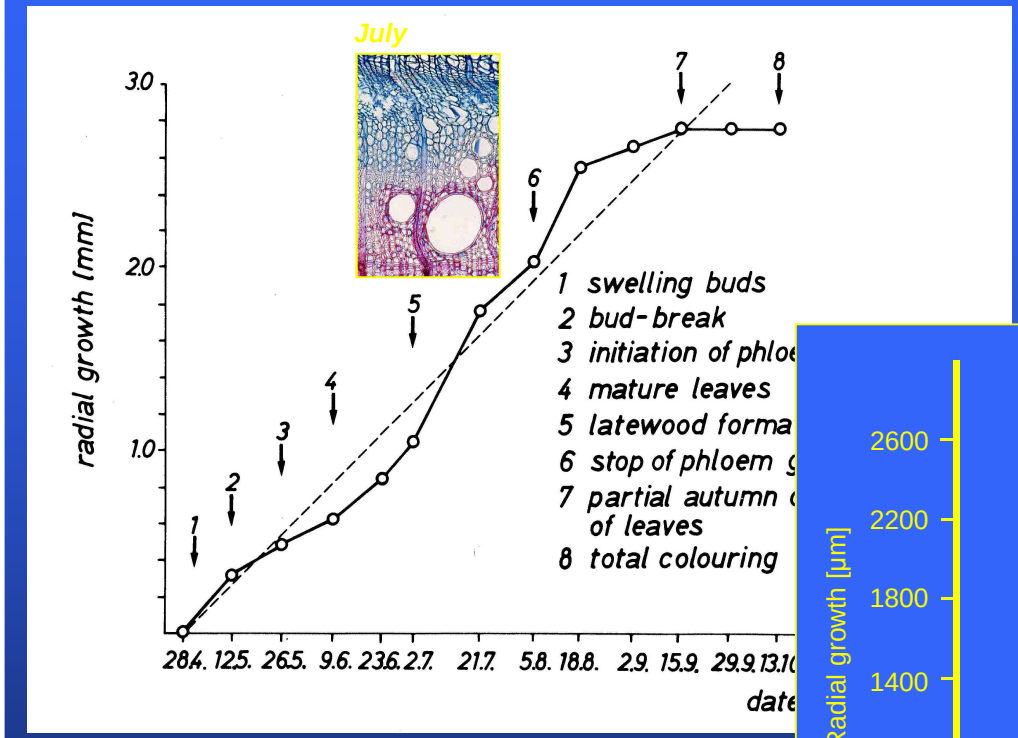
We studied carbon uptake from a CO_2 spring in Toscana, Italy. Previous studies comparing the growth response of *Quercus ilex* L. trees at this site with trees growing under normal CO_2 concentrations have yielded conflicting results. In one study, increased growth of trees during the juvenile period was observed (Hättenschwiler et al. 1997), whereas a second more recent study failed to confirm those findings (Tognetti et al. 2000). We evaluated the use of ^{14}C, ^{13}C and ^{18}O isotopes to determine the effect of the CO_2 spring on these trees. Carbon dioxide is ideally suited as a tracer because CO_2 from the spring is free of ^{14}C and thus has a distinct signal from background atmospheric CO_2. Isotope discrimination in photo-

Cambium of Spruce *(Picea abies)*

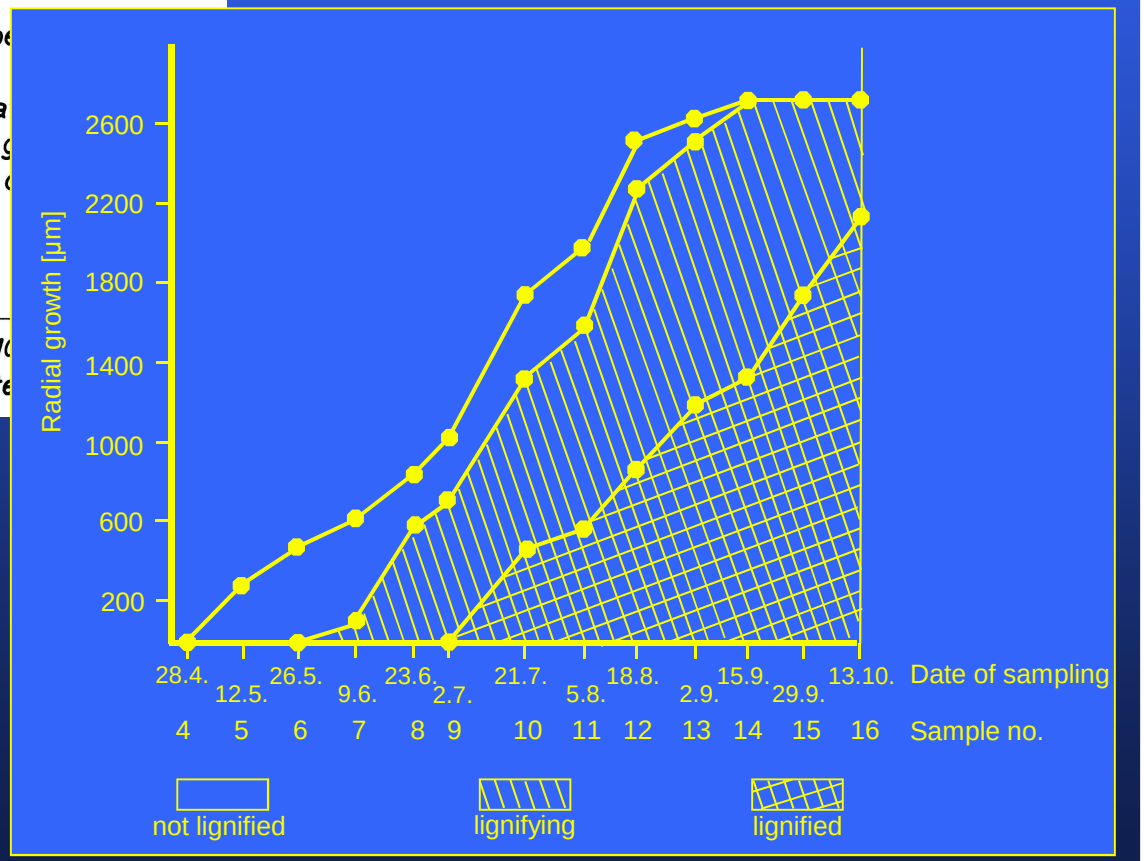


Wood formation of oak during one growing season

Radial increment

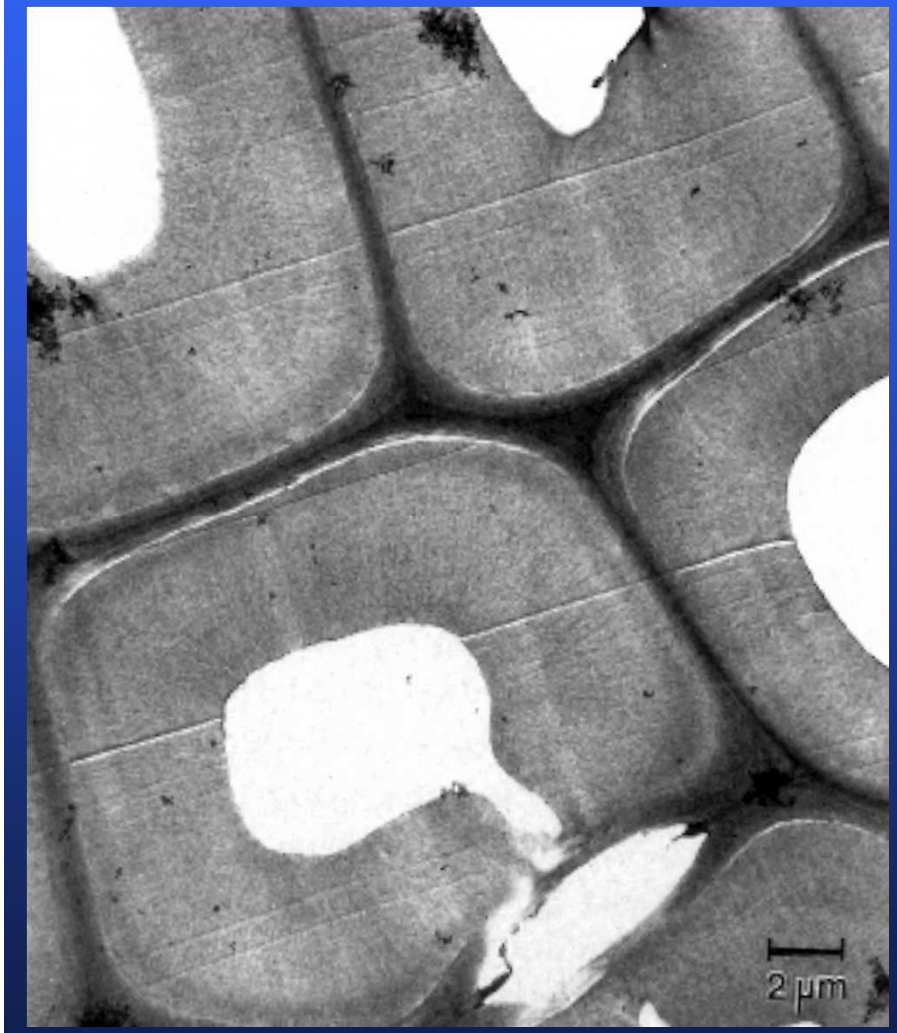


Lignification

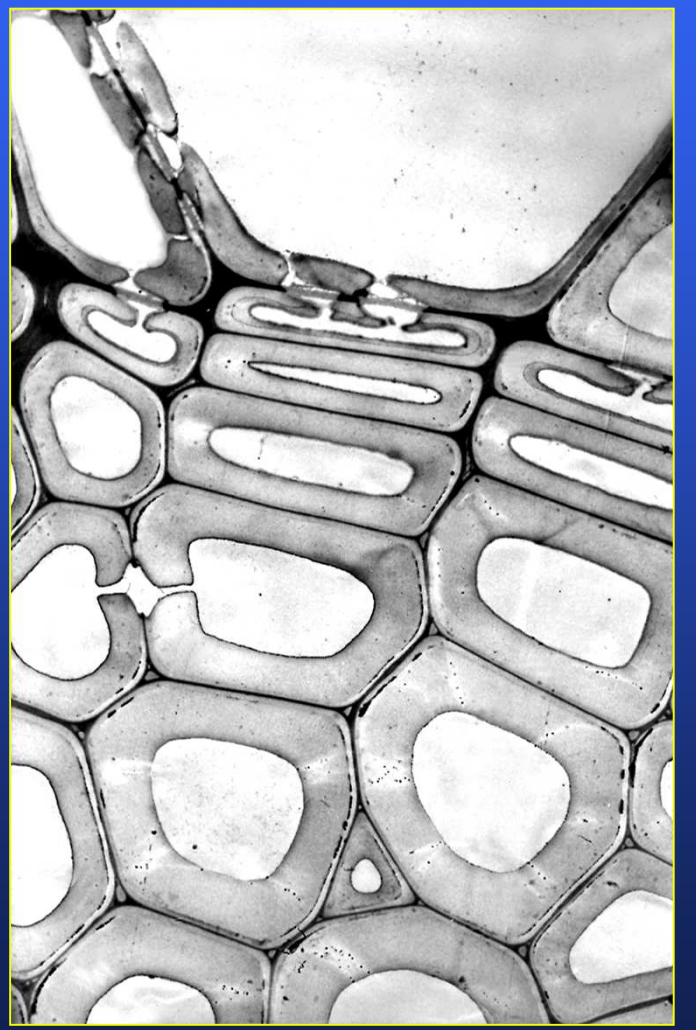


Fine Structure of Wood

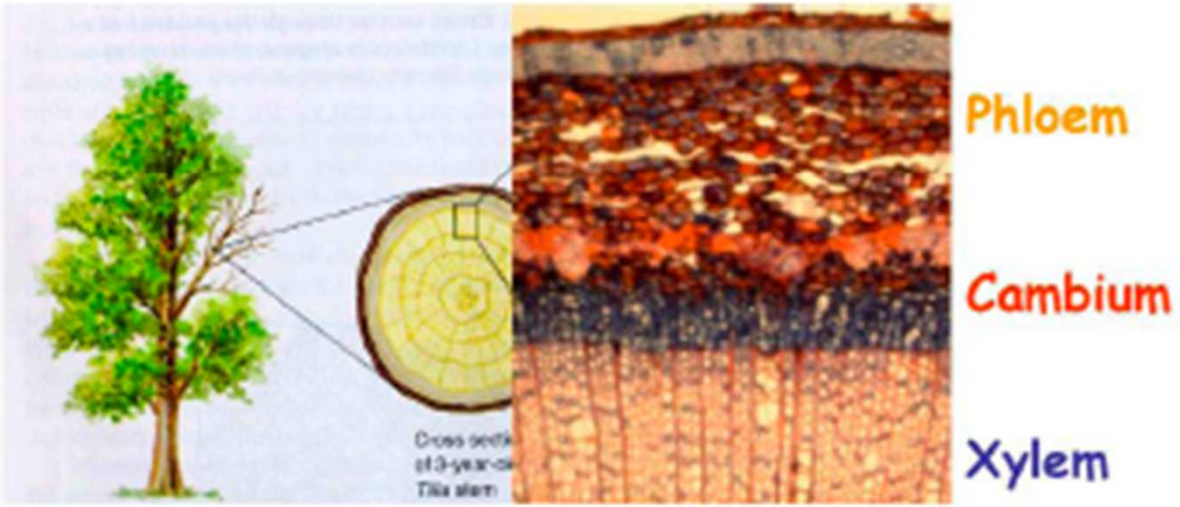
Spruce (*Picea sp.*)
Latewood tracheids

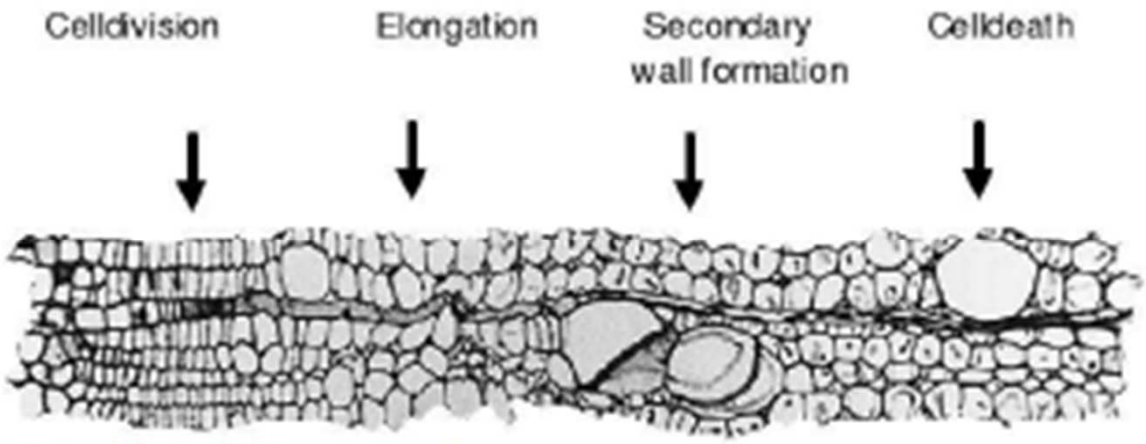


Birch (*Betula sp.*)
Tree-ring border

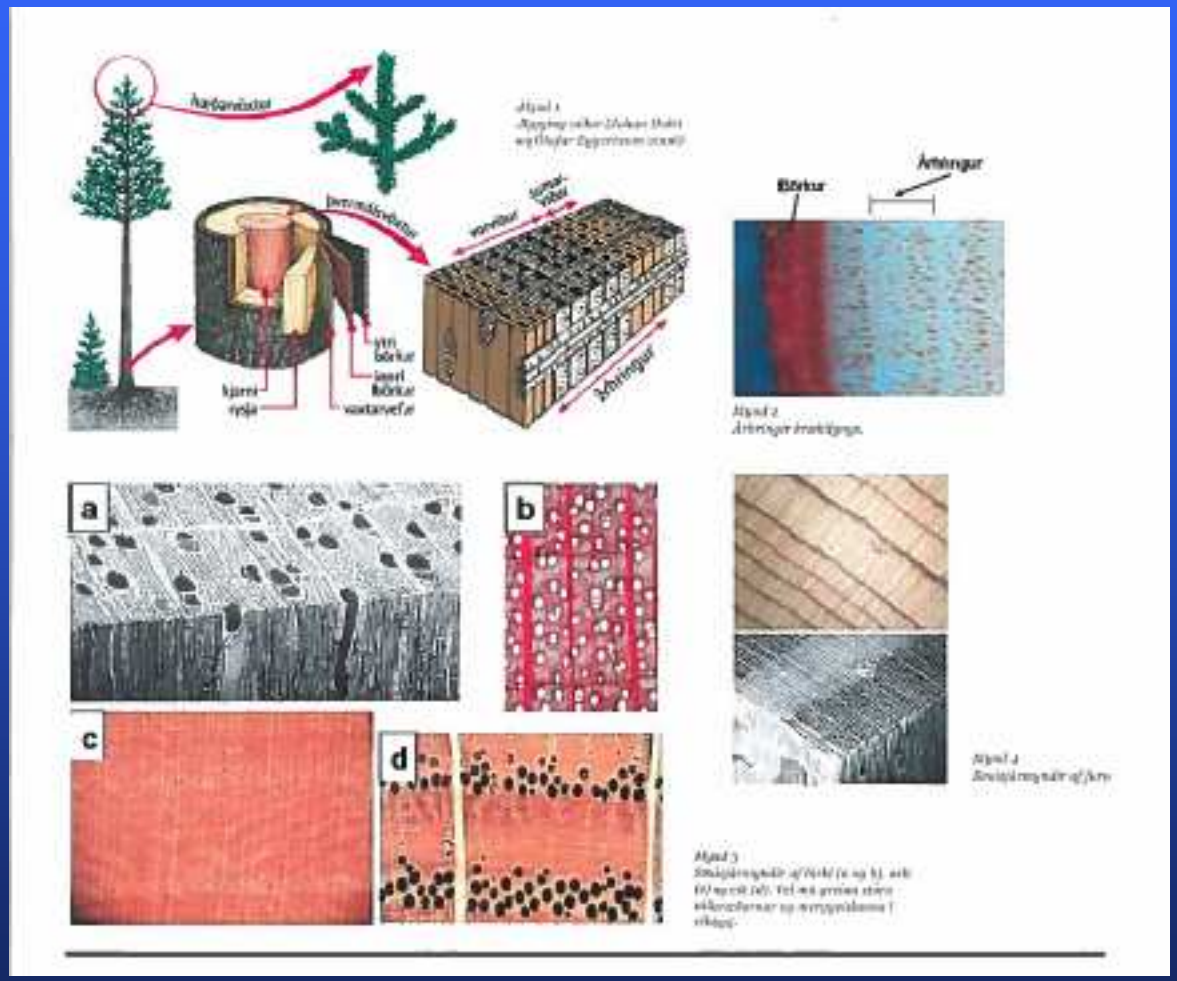


Wood Formation





Phloem Cambium Xylem


Árhringir
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a
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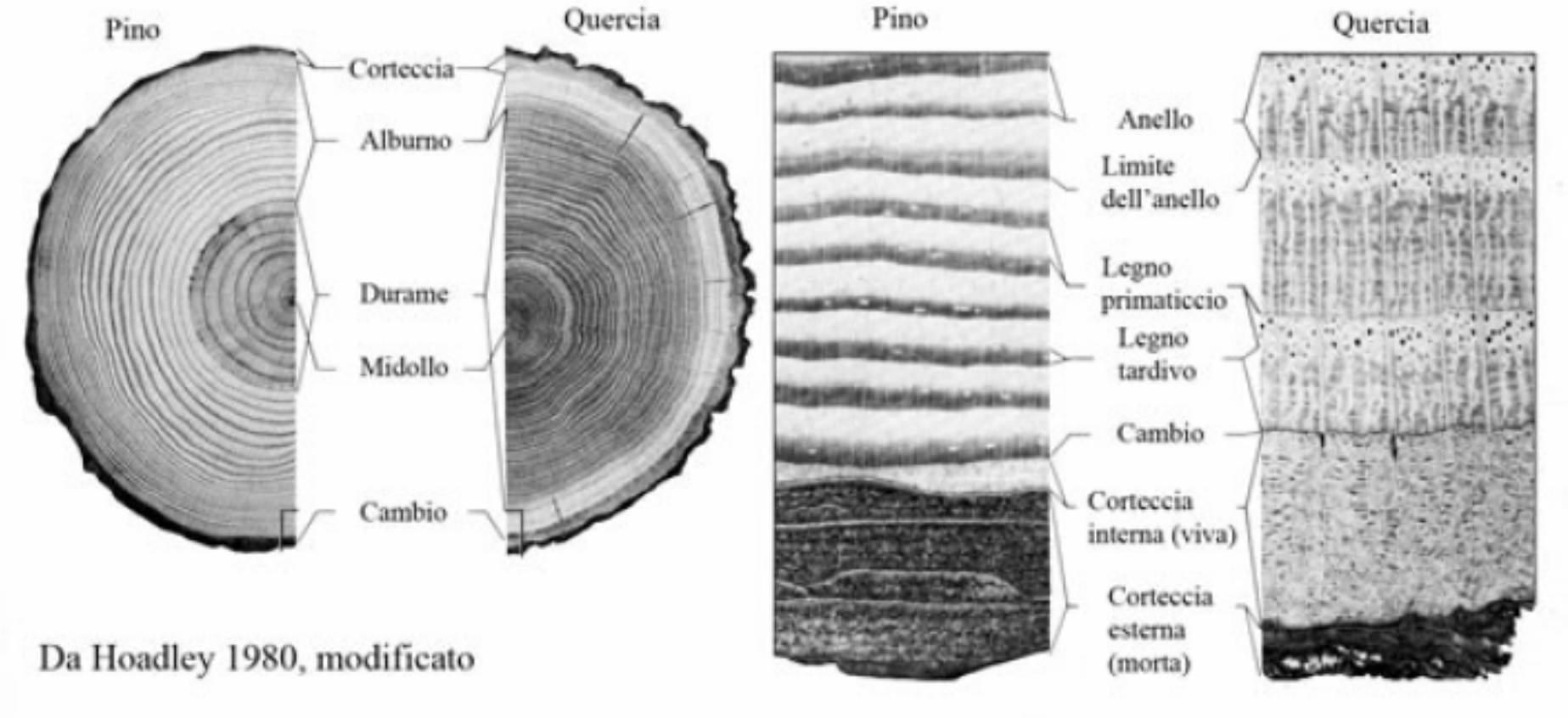
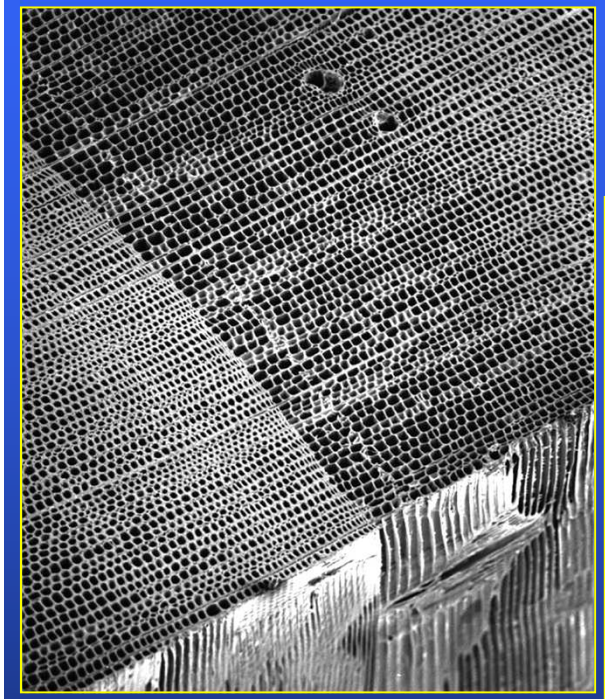


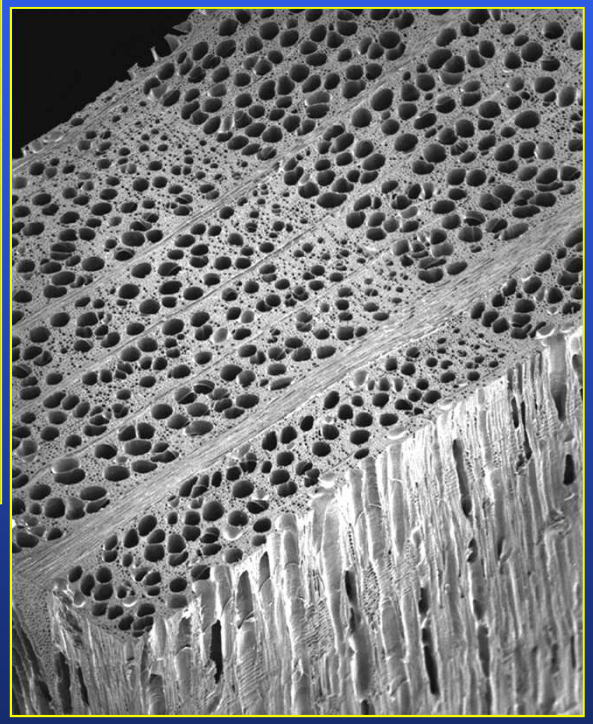
Da Hoadley 1980, modificato

Structure of Wood

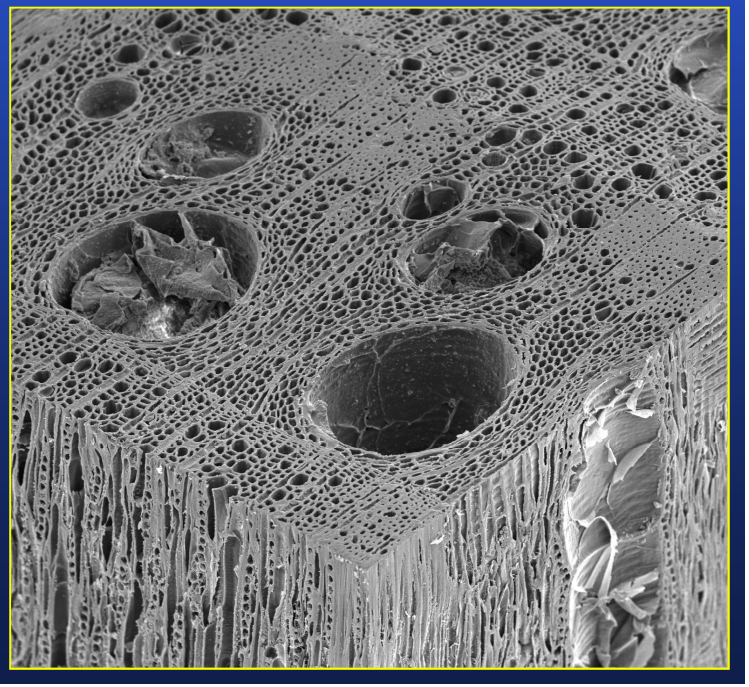
Pine *(Pinus sp.)*



Beech *(Fagus sp.)*



Oak *(Quercus sp.)*



Abstract

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Anatomical, Chemical, and Ecological Factors Affecting Tree Species Choice in Dendrochemistry Studies

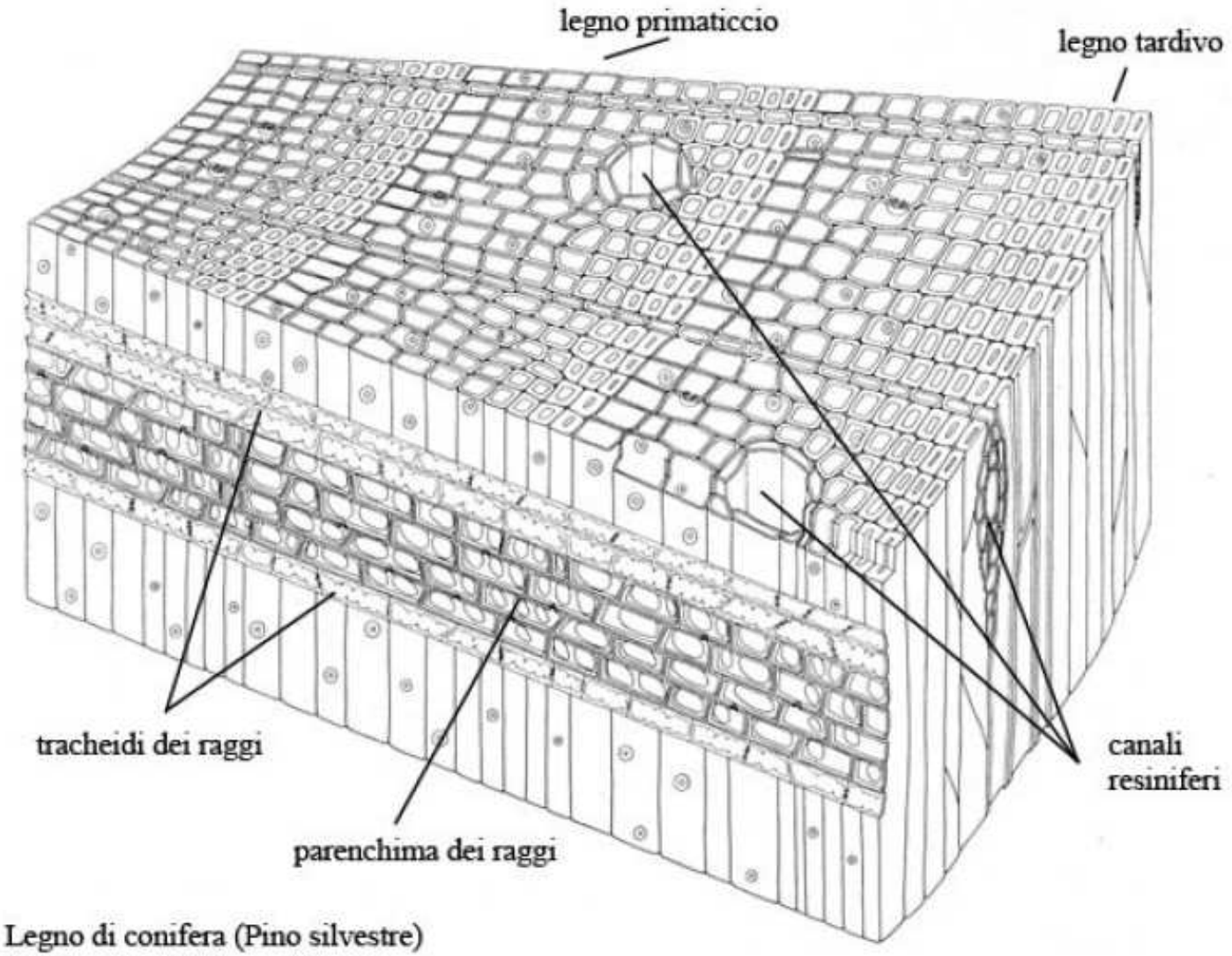
Bruce E. Cutter * and Richard P. Guyette

Author Affiliations

Abstract

Recently, element concentrations in tree rings have been used to monitor metal contamination, fertilization, and the effects of acid precipitation on soils. This has stimulated interest in which tree species may be suitable for use in studies of long-term trends in environmental chemistry. Potential radial translocation of elements across ring boundaries can be a confounding factor in assessing environmental change. Thus, the selection of species which minimizes radial translocation of elements can be critical to the success of dendrochemical research. Criteria for the selection of species with characteristics favorable for dendrochemical analysis are categorized into (i) habitat-based factors, (ii) xylem-based factors, and (Hi) element-based factors. Species with a wide geographic range and ecological amplitude provide an advantage in calibration and better controls on the effects of soil chemistry on element concentrations. The most important xylem-based criteria are heartwood moisture content, permeability, and the nature of the sapwood-heartwood transition. The element of experimental interest is important in determining which tree species will be suitable because all elements are not equally mobile or detectable in the xylem. Ideally, the tree species selected for dendrochemical study will be long-lived, grow on a wide range of sites over a large geographic distribution, have a distinct heartwood with a low number of rings in the sapwood, a low heartwood moisture content, and have low radial permeability. Recommended temperate zone North American species include white oak (*Quercus alba* L.), post oak (*Q. stellata* Wangenh.), eastern redcedar (*Juniperus virginiana* L.), old-growth Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and big sagebrush (*Artemisia tridentata* Nutt.). In addition, species such as bristlecone pine (*Pinus aristata* Engelm. syn. *longaeva*), old-growth redwood [*Sequoia sempervirens* (D. Don) Endl.], and giant sequoia [*S. gigantea* (Lindl.) Deene] may be suitable for local purposes.

This contribution is no. 11910 in the Journal Series from the University of Missouri Agric. Experiment Station.



Legno di conifera (Pino silvestre)
da Giordano 1971, modificato

Figura 8. Schema del legno di una conifera.

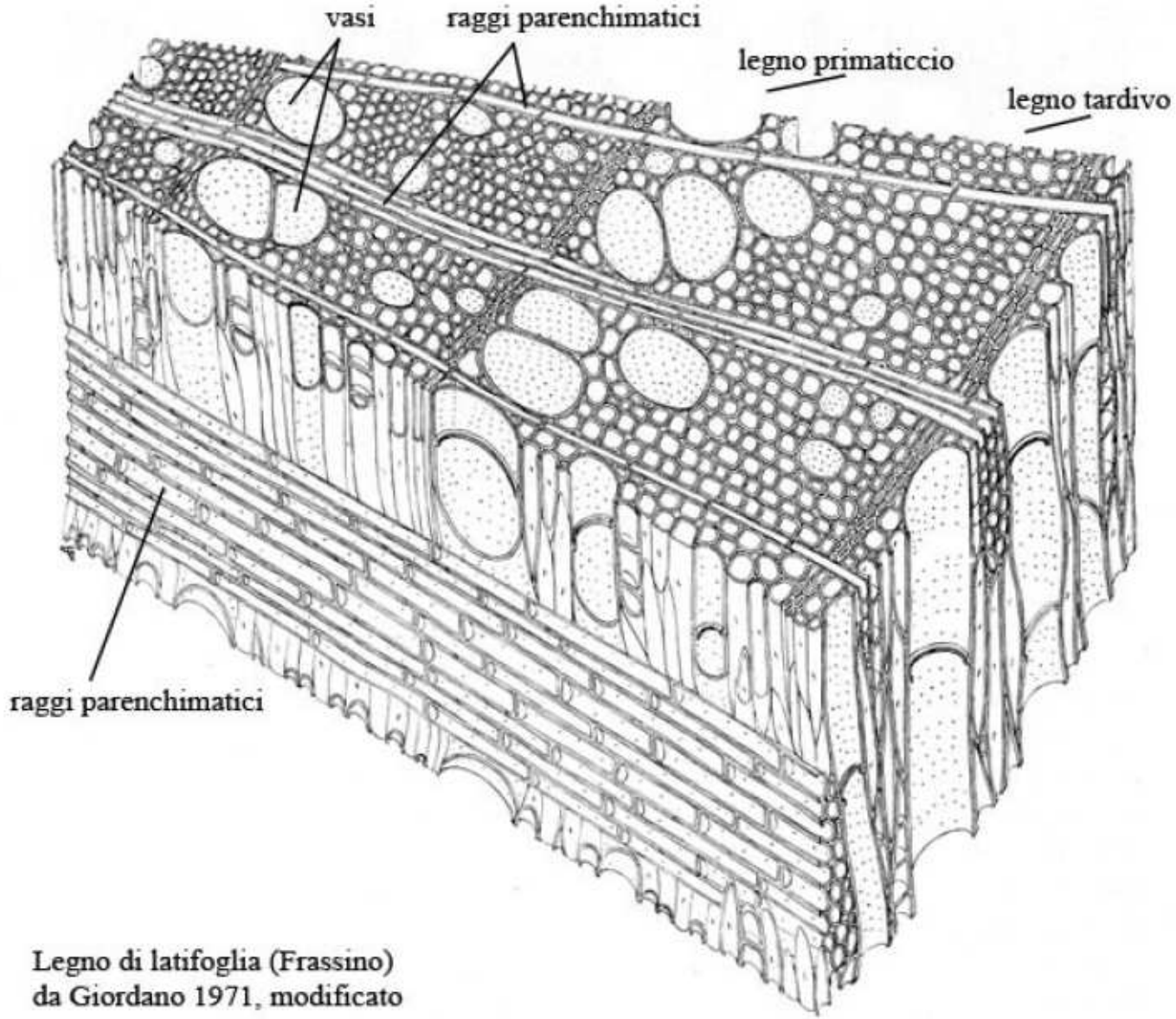


Figura 7. Schema del legno di una latifoglia.

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The Science of the Total Environment 166 (1995) 77–87

the Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Man

Seasonal variations in concentrations and radial distribution patterns of Cd, Pb and Zn in stem wood of beech trees (*Fagus sylvatica* L.)

Jürgen Hagemeyer*, Hartmut Schäfer

Bielefeld University, Faculty of Biology, Department of Ecology, D-33615 Bielefeld, Germany

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Environmental Pollution 104 (1999) 79–88

ENVIRONMENTAL POLLUTION

Change in the dendrochemistry of sacred fir close to Mexico City over the past 100 years

S.A. Watmough*, T.C. Hutchinson

ERS Program, Trent University, Peterborough, Ontario K9J 7B8, Canada

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Abstract

The chemistry of the tree-rings of sacred fir (*Abies religiosa*) growing in the high elevation forest park, Desierto de los Leones, close to Mexico City was measured in 5 year increments dating back to 1897. Surface soil beneath sampled trees had elevated concentrations of trace metals, especially Pb, Cd and Zn, compared with a reference site at San Pablo 45 km upwind of Mexico City. High metal concentrations were associated with low soil pH. Lead and Cd increased in tree-rings formed since the 1960s, reflecting the increase in urbanization and vehicle numbers in Mexico City. Small increases in Cu and Ni during this period appear to be a natural occurrence, as similar changes were found at San Pablo. Peaks in Cd and most obviously Pb, were found in rings formed in the period 1920–1940 corresponding to the heartwood–sapwood boundary, but were most apparent in trees growing in contaminated soils with low pH. It is suggested that Pb and Cd taken up by roots of sacred fir accumulate in the heartwood, whereas Pb and Cd entering through bark are transported radially to a much lesser extent and more accurately record changes in trace metal deposition.

Keywords: Dendrochemistry; Forest decline; Trace metals; Sacred fir; Mexico City

1. Introduction

Recent reports on the status of sacred fir (*Abies religiosa* [H.B.K.] et Cham) in the high elevation forest park, Desierto de los Leones, southwest of Mexico City have suggested that air pollution is a major factor contributing to the current tree decline, which was first recognized in 1982 (Vazquez, 1987; Alvarado et al., 1993). Sacred fir is not the only tree species to be affected. Several pines including *Pinus hartwegi* (Lindl.), *Pinus leiophylla* and *Pinus montezumae* (Lamb. var. *Lindleyi*) as well as deciduous species such as black cherry (*Prunus serotina* var. *Capuli*) have all shown decline symptoms (Hernandez and de Bauer, 1984; de Bauer et al., 1985; Skelly et al., 1997). These symptoms typically include chlorosis, necrosis and early leaf senescence (Skelly et al., 1997), while Zn, K and Mn deficiencies have also been associated with declining sacred fir (Alvarado et al., 1993; López et al., 1998).

Mexico City has over 20 million inhabitants and is recognized as one of the most polluted geographic areas in the world (de Bauer and Krupa, 1990; Miller et al., 1994). Its location, at the southwest corner of a flat basin (2250 m above sea level (MSL)) surrounded by mountains elevated 600–800 m above the valley floor, results in poor air circulation and a tendency to form photochemical smogs (Nickerson et al., 1992; Ruiz-Suarez et al., 1993). Rapid and large scale urbanization in and around Mexico City in recent decades has also led to large increases in emissions of sulphur dioxide, nitrogen oxides and trace metals (de Bauer and Krupa, 1990). The negative impacts of photochemical smogs on human health, and the occurrence of high human blood lead levels are well documented (Namihira et al., 1993) and field studies have demonstrated that crop plants are sensitive to the poor air quality in Mexico City (de Bauer, 1972; Laguette et al., 1986).

A definite link between air pollution and forest decline at Desierto de los Leones has not been demonstrated (Alvarado et al., 1993). Current data show that ozone levels at Desierto de los Leones are high, although there is no historical evidence documenting the timing and magnitude of increases in gaseous pollutants or trace metal deposition on the park (Skelly et al., 1997). Dendrochemical techniques have been used

* Corresponding author. Tel.: +1-705-748-1071; fax: +1-705-748-1569; e-mail: swatmough@trentu.ca.

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DENDROCHRONOLOGIA

Air pollution and environmental chemistry – what role for tree-ring studies?*

Marco Ferretti[1], John L. Innes[2], Risto Jalkanen[3], Matthias Saurer[4], Juergen Schäffer[5], Heinrich Spiecker[6], Klaus von Wilpert[5]

[1] LINNÆA ambiente Srl, Firenze, Italy
[2] Dept. of Forest Resources Management, University of British Columbia, Forest Sciences Centre 2045, Vancouver, BC, Canada
[3] METLA, Rovaniemi Research Station, Rovaniemi, Finland
[4] Paul Scherrer Institute, Villigen PSI, Switzerland
[5] Forest Research Station Baden-Württenberg, Dept. Soil Science and Forest Nutrition, Freiburg, Germany
[6] Institut für Waldwachstum, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Summary
Tree-rings are a unique source of long-term data and have often been used in studies aimed at understanding and quantifying the impact of air pollution on forests. A variety of approaches have been used, ranging from traditional dendrochronology to studies focussing on the chemical and physical properties of tree-rings. However, there are some issues to be considered when attempting to use tree-rings as a response indicator in air pollution studies and when inferences over large geographical scales are being made. These issues include the inherent ambiguity of tree-ring width as indicator of air pollution effects, the absence of reference data, the problems associated with integrating traditional dendrochronology with more complex ecosystem studies and the relatively poor attention paid to sound statistical design in some air pollution impact studies. Together with progress in specific disciplines like climatology, biochemistry, genetics, tree physiology, tree nutrition and soil science, the interdisciplinary and international collaboration in the analysis of environmental effects on tree growth will increase the research potential of tree-rings.

Keywords: Tree-rings, air pollution, dendrochemistry, stable isotopes, needle trace method.

* Paper prepared after the panel discussion "Tree rings, air pollution and environmental chemistry" at the Conference "Tree Rings and People", held in Davos, Switzerland, September 22nd–26th, 2001.

Address for correspondence:
Marco Feretti, LINNÆA ambiente Srl,
Via G. Sirtori 37, I-50137 Firenze, Italy
Tel.: ++39 055 60 8073; Fax: ++39 055 60 8311
m.ferretti@linnaea.org

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Impact of different nitrogen emission sources on tree physiology as assessed by a triple stable isotope approach

M.R. Guerrieri [a,b,*], R.T.W. Siegwolf [b], M. Saurer [b], M. Jäggi [b], P. Cherubini [c], F. Ripullone [a], M. Borghetti [a]

[a] Department of Crop Systems, Forestry and Environmental Sciences, University of Basilicata, Viale dell'Ateneo Lucano 10, I-85100 Potenza, Italy
[b] Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[c] Swiss Federal Institute for Forest, Snow and Landscape Research, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland

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ABSTRACT

The importance that nitrogen (N) deposition has in driving the carbon (C) sequestration of forests has recently been investigated using both experimental and modeling approaches. Whether increased N deposition has positive or negative effects on such ecosystems depends on the status of the N and the duration of the deposition. By combining $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$ and dendrochronological approaches, we analyzed the impact of two different sources of NO_x emissions on two tree species, namely: a broad-leaved species (*Quercus cerris*) that was located close to an oil refinery in Southern Italy, and a coniferous species (*Picea abies*) located close to a freeway in Switzerland. Variations in the c_i/c_a ratio and the distinction between stomatal and photosynthetic responses to NO_x emissions in trees were assessed using a conceptual model, which combines $\delta^{13}C$ and $\delta^{18}O$. $\delta^{15}N$ in leaves, needles and tree rings was found to be a bioindicator of N input from anthropogenic emissions, especially at the oil refinery site. We observed that N fertilization had a stimulatory effect on tree growth near the oil refinery, while the opposite effect was found for trees at the freeway site. Changes in the c_i/c_a ratio were mostly related to variations in $\delta^{13}C$ at the freeway site and, thus, were driven by photosynthesis. At the oil refinery site they were mainly related to stomatal conductance, as assessed using $\delta^{18}O$. This study demonstrates that a single method approach does not always provide a complete picture of which physiological traits are more affected by N emissions. The triple isotope approach combined with dendrochronological analyses proved to be a very promising tool for monitoring the ecophysiological responses of trees to long-term N deposition.

Forest@

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(a cura di: E. Lingua, R. Marzano, G. Minotta, R. Motta, A. Nosenzo, G. Bovio)

Impatto del traffico veicolare su $\delta^{15}N$, $\delta^{13}C$ e $\delta^{18}O$ di aghi ed anelli annuali di abete rosso (*Picea abies* L.) presso un'autostrada in Svizzera

Guerrieri MR [(1)]*, Saurer M [(2)] , Siegwolf RTW [(2)], Waldner P [(3)], Cherubini P [(3)]

*(1) Dipartimento di Scienze dei Sistemi Colturali, Forestali e dell'Ambiente, Università della Basilicata, Italia; (2) PSI - Paul Scherrer Institut, 5232 Villigen PSI, Switzerland; (3) WSL - Swiss Federal Institute for Forest, Snow and Landscape Research, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland. - *Corresponding author: Maria Rosa Guerrieri - mguerrieri@unibas.it*

Abstract: *Impact of traffic on $\delta^{15}N$, $\delta^{13}C$ and $\delta^{18}O$ of needles and annual wood cores of Norway spruce (Picea abies L.) near a motorway in Switzerland*. Increase of nitrogen depositions, as oxidized (NO_x) and reduced (NH_x) compounds, has important implications on ecosystem nitrogen cycle. NO_x comes predominantly from fossil fuel combustion in car engines and industrial processes, while agricultural activities (cattle farming, fertilizations) are the main sources for NH_x emissions. Such fertilisations could stimulate growth and, therefore, productivity of forests, especially in temperate forests, where nitrogen is a limiting factor. On the other hand an excess of nitrogen can lead to an acidification of the soil and have a negative impact on the microbial fauna and structure of plants. NO_x and NH_x depositions can be separated with the help of stable isotopes with different ^{15}N-values reported for NO_x originating from combustion sources. Consequently it was observed that the nitrogen isotopic composition of the vegetation reflects the isotopic signature of nitrogen sources. Our preliminary results on needles of Norway spruce trees exposed to NO_x emissions along a transect perpendicular to a highway close to Faido and Brittnau show a clear isotopic enrichment in ^{15}N in trees growing closer to traffic pollution, indicating an uptake of atmospheric nitrogen by stomatal pathway. Carbon and oxygen isotopic composition measured in tree rings reveals the physiological response in plants. Trees more exposed to air pollution from traffic show an increase in $\delta^{13}C$ and $\delta^{18}O$ in tree rings, since mid sixties next to Erstfeld. This could mean a higher photosynthetic activity, enhanced by NO_x traffic emissions, under low or not changed stomatal conductance. Our results confirm that stable isotopes of carbon, oxygen and nitrogen measured in needles and tree rings represent an important tool to monitor the impact of NO_x load on tree physiology.

Keywords: Spruce, traffic, nitrogen, deposition, growth rings, needles, stable isotopes.

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Traffic pollution affects tree-ring width and isotopic composition of *Pinus pinea*

Giovanna Battipaglia [a,b,*], Fabio Marzaioli [b], Carmine Lubritto [b], Simona Altieri [b], Sandro Strumia [b], Paolo Cherubini [a], M. Francesca Cotrufo [b,c]

[a] WSL Swiss Federal Institute for Forest, Snow and Landscape Research, CH-8903 Birmensdorf, Switzerland
[b] Department of Environmental Sciences, Second University of Naples, Via Vivaldi 43, I-81100 Caserta, Italy
[c] Department of Soil and Crop Sciences, Colorado State University, CO, USA

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ABSTRACT

This study presents new evidence that radiocarbon, combined with dendrochronological and stable isotopes analysis in tree rings and needles, can help to better understand the influence of pollution on trees. *Pinus pinea* individuals, adjacent to main roads in the urban area of Caserta (South Italy) and exposed to large amounts of traffic exhaust since 1980, were sampled and the time-related trend in the growth residuals was estimated. We found a consistent decrease in the ring width starting from 1980, with a slight increase in $\delta^{13}C$ value, which was considered to be a consequence of environmental stress. No clear pattern was identified in $\delta^{15}N$, while an increasing effect of the fossil fuel dilution on the atmospheric bomb-enriched ^{14}C background was detected in tree rings, possibly as a consequence of the increase in traffic exhausts. Our findings suggested that radiocarbon is a very sensitive tool to investigate small-scale (i.e. traffic exhaust at the level crossing) and large-scale (urban area pollution) induced disturbances.

1. Introduction

Urbanization and industrialization are rapidly growing, and as a consequence roads and their associated vehicular traffic exert major and increasing impacts on adjacent ecosystems (Angold 1997). The effects of a road on adjacent ecosystems are complex and include disturbances during road construction and deterioration of air quality caused by the traffic of the established road. Various studies have shown the impact of vehicle exhausts on road side vegetation through their visible and non-visible effects (Farmer and Lyon 1977, Angold 1997, Nuhoglu, 2005) but, presently little known is about the long-term effects of air pollution on vegetation and on trees in particular. Developing proxies for atmospheric pollution that would be used to identify the physiological responses of trees to roadside car exhaust pollution stress are needed.

In this context, tree rings offer a useful tool to decipher historical changes in the atmospheric environment. Trees in temperate and boreal forests form a new wood-growth layer every year (annual ring). The physical and chemical characteristics of the wood cell formed in each particular year reflect the environmental conditions in which the tree grew in that year, and can be used to reconstruct past environmental conditions (including climatic conditions and air quality). In addition, stable isotope signals in the annual rings of trees are useful proxies for reconstructing past climates and tree ecophysiology (McCarroll and Loader, 2004; Switsur and Waterhouse 1998). Stable carbon isotopes in tree rings have often been used as long-term and sensitive indicators of tree carbon uptake limitations (Panek and Waring 1997) and water use efficiency (Leffler and Evans 1999). Some environmental factors, such as atmospheric pollutants (e.g. increase of SO_2 or NO_x) can alter $\delta^{13}C$ signals by influencing carbon discrimination (Niemelä et al., 1997; Rennenberg and Gessler, 1999). Thus, the analysis of ^{13}C has the potential to reveal the effects of pollutants exposure, showing a possible stimulation of photosynthesis (N-fertilization) and/or an inhibition of stomatal conductance (Siegwolf et al., 2001).

The $\delta^{15}N$ ratio can provide a historical record of N deposition, since the nitrogen isotope ratio in compounds produced from anthropogenic activities may be significantly different from the natural background N in the soil (Freyer, 1991).

To date, a limited number of studies attempted to assess the relationships between car exhausts, tree growth and isotopic composition of tree rings in order to reconstruct past atmospheric pollution history (Poulson et al., 1995; Savard et al., 2008; Saurer et al., 2004; Wagner and Wagner, 2006; Guerrieri et al., 2009; Kwar et al., 2009). Those studies rarely considered other substrates (such as soil and foliage) and selectively measured certain isotopes, rather than combining all the potential indicators.

We propose a novel method to determine the effects of car exhaust pollution on tree growth, coupling classical dendrochronological analyses and analyses of ^{15}N and ^{13}C in tree rings, soils and leaves with tree-ring radiocarbon (^{14}C) data. The $^{14}CO_2$ atmospheric content

* Corresponding author. WSL Swiss Federal Institute for Forest, Snow and Landscape Research, Zürcherstrasse, 111 CH-8903 Birmensdorf, Switzerland. Tel.: +41 44 7392392; fax: +41 44 7392215.
E-mail address: giovanna.battipaglia@wsl.ch (G. Battipaglia).

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Climatic isotope signals in tree rings masked by air pollution: A case study conducted along the Mont Blanc Tunnel access road (Western Alps, Italy)

Giovanni Leonelli[a,*], Giovanna Battipaglia[b,e], Rolf T.W. Siegwolf[c], Matthias Saurer[c], Umberto Morra di Cella[d], Paolo Cherubini[e], Manuela Pelfini[a]

[a] *Dipartimento di Scienze della Terra, Università degli Studi di Milano, Milano, Italy*
[b] *Department of Environmental Sciences, Seconda Università di Napoli, Caserta, Italy*
[c] *Paul Scherrer Institut – PSI, Villigen, Switzerland*
[d] *Agenzia Regionale per la Protezione dell'Ambiente – ARPA Valle d'Aosta, St. Christophe, Italy*
[e] *Swiss Federal Institute for Forest, Snow and Landscape – WSL, Birmensdorf, Switzerland*

HIGHLIGHTS

- Influence of air pollution on the climatic signal recorded in the $\delta^{13}C$ chronologies.
- Air pollution loads strongly influence the photosynthetic process.
- Significant long-term changes in $\delta^{18}O$, $\delta^{15}N$ and total N concentration.
- Trees respond to pollution events but less to the lack of pollution for short times.

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ATMOSPHERIC ENVIRONMENT

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First detection of nitrogen from NO_x in tree rings: a $^{15}N/^{14}N$ study near a motorway

M. Saurer[a,*], P. Cherubini[b], M. Ammann[a], B. De Cinti[b,1], R. Siegwolf[a]

[a] *Paul Scherrer Institute, Villigen PSI CH-5232, Switzerland*
[b] *WSL Swiss Federal Research Institute, Birmensdorf CH-8903, Switzerland*

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Abstract

Nitrogen isotope analysis ($\delta^{15}N$) of tree rings is potentially useful for evaluating the temporal development of the nitrogen (N) deposition to forests and for studying the long-term effects of N accumulation in ecosystems. To test this hypothesis, we investigated three sites across a pollution gradient in differing distances (20,150,1000 m) from a motorway in Switzerland, which was built in 1965. We sampled four *Picea abies* trees per site, whereby we extracted the tree ring cores with hot water and solvents before the isotope analysis to remove mobile N storage compounds, and determined the isotope variations in the stem wood for the period 1928–2000. While tree ring growth was not affected by the construction of the motorway, the $\delta^{15}N$ values were increasing by up to 7.9‰ after 1965 at the most polluted site, indicating the uptake of NO_x from car exhausts, although the signal was highly variable. Isotopically heavy NO_x emissions were observed in an earlier study at the same location resulting in a $\delta^{15}N$-gradient of recent needles from +1.3‰ to −4.4‰ with increasing distance from the motorway. This gradient was also reflected in the tree rings, but dampened by a factor of about 2 compared to the needles. For the trees near the motorway, the total nitrogen concentration in the tree rings varied in parallel with the $\delta^{15}N$ values ($r^2 = 0.52$). This enabled us to apply a mass balance equation for reconstructing the isotope signal of N originating from the car exhausts for the period 1965–2000, with the $\delta^{15}N$ of NO_2 in the range +1.3‰–+6.4‰. The more distant sites were much less affected by the traffic and their isotope ratio reflected the influence of varying proportions of isotopically heavy (NO_2) and light (NH_x) deposition. We conclude that the analysis of tree ring ^{15}N variations is a promising tool for the detection of the role played by nitrogen deposition to the forests.

Keywords: *Picea abies*; Air pollution; Dendroecology; Nitrogen deposition; Stable isotopes; Nitrogen dioxide

1. Introduction

Nitrogen deposition to nitrogen-limited forest ecosystems is receiving considerable attention because it affects ecosystem functions and processes, and may have either positive or negative effects on plant growth (Aber et al., 1989). Increased atmospheric levels of nitrogen oxides ($NO_x = NO + NO_2$) and ammonia gases ($NH_x = NH_3 + NH_4$) are related to human activities like agriculture and the combustion of fossil fuels. Particularly, in industrialized areas these compounds contribute a significant N input via dry and wet deposition to plants and soil, and to the gaseous uptake by the plant leaf stomata. Positive effects might include fertilization of N-limited ecosystems fostering increased carbon-sequestration (Norby, 1998). Negative effects relate to nutrient imbalances, resulting, e.g., in changes in the C/N ratio (Tietema et al., 1998) and in reduced root/shoot

*Corresponding author. Tel.: +41-56-310-2749; fax: +41-56-310-4525.
E-mail address: matthias.saurer@psi.ch (M. Saurer).
[1] Present address: Università della Tuscia, I-01100 Viterbo, Italy.

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in Fig. 2. The variability among the sites was relatively high until 1930, which could have been caused by the low number of trees at the beginning of the investigated period. The oldest trees germinated 1890 at S1, 1902 at S2, and 1900 at S3. Stand age is thus roughly 100 years, but younger trees were also present in this managed forest. Relatively low growth rates were observed in the 1940s, and they may be related to the frequent warm and dry summers during this period in Switzerland. After the construction of the motorway in 1965, the site S1 nearest to the motorway, tended to have reduced growth. The lowest ring-width values for S1 during the whole series were recorded in 1966 and 1967. This short period of reduced growth could be related to adverse effects from the motorway construction. Generally, the three sites showed a high degree of common variance in the period 1940–2000, indicating that climate was the major factor determining the tree ring width variations. The traffic emissions do therefore not appear to have negatively affected tree growth.

The nitrogen concentration signal in the tree rings was clearly disturbed after the construction of the motorway in 1965 for the site S1 (Fig. 3a). While the N-concentration was about 0.05% prior to 1965, up to five times higher concentrations (0.27%) were reached afterwards. The four trees at this site, however, did not react in a similar manner, but showed strongly differing signals. Three out of the four trees analysed had a N-concentration higher than background during some time, but the increased values were varying strongly, with tree No. 2, for instance, having higher levels only in the seventies. In comparison, the time course of the N-concentration for the sites S2 and S3 was much more complacent (Fig. 3b,c). The values during most of the time were around 0.05%, similar to the pre-1965 period for S1, and slightly increased to about 0.1% in the last two decades of the record. This increase resembles patterns found in the literature (Meerts, 2002) and may reflect rather a natural, physiological effect (not caused by increased N-deposition), related to higher levels of N in the living cells of the sapwood.

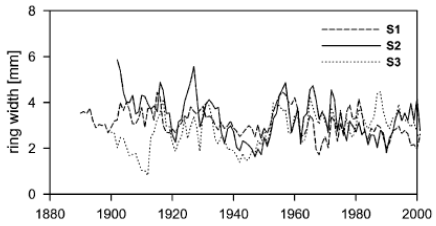


Fig. 2. Average ring width chronologies for *Picea abies* at the three investigated sites in differing distance to the motorway. The distance is 20 m for S1, 150 m for S2 and 1000 m for S3.

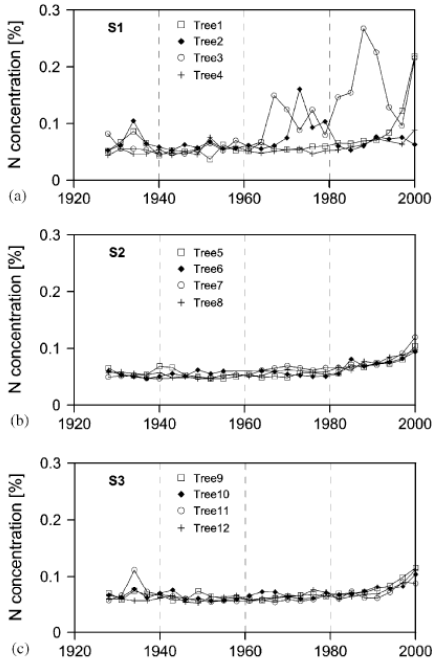


Fig. 3. The N concentration in the tree rings (3-year-intervals) for individual trees for the sites (a) S1; (b) S2; (c) S3.

The $\delta^{15}N$ values of the tree rings for site S1 were in the range from about −4‰ to +1‰ in the pre-1965 period (Fig. 4a). Afterwards, higher values were observed, with the pattern of variation strikingly similar to the N-concentration (Fig. 3a). Trees no. 1, 2 and 3 from S1 had increased ^{15}N after 1965 when comparing to the values found for S2 and S3 (Fig. 4b and c). The highest $\delta^{15}N$-value was found for tree no. 3 in 1988, which is also the sample with the highest N-concentration. We compared the $\delta^{15}N$-values of this tree with the non-responding tree no. 4, which has values in the range of S2 and S3. A difference of 7.9‰ was observed in 1988 reflecting the maximal enrichment by heavy $^{15}NO_x$ during the investigated period. On the other hand, the $\delta^{15}N$-results for the sites S2 and S3 indicated no major disturbances, but also little common variance among individual trees. Overall, there was a slightly decreasing trend at these sites. The average values for the period 1993–1995 at the three sites may be compared to *Picea abies* needle values that were obtained during an earlier study (Ammann et al., 1999). Current-year needles sampled in 1993, 94,

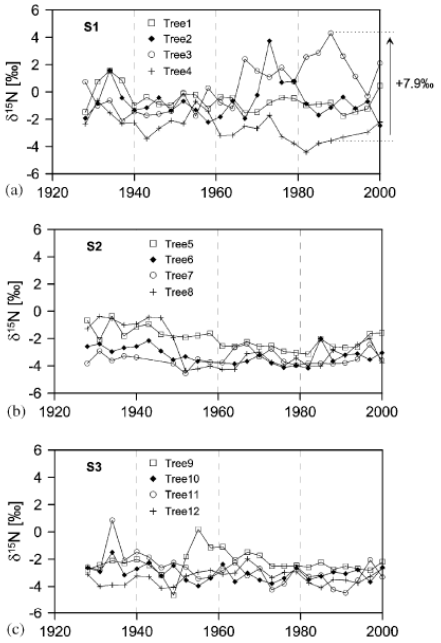


Fig. 4. The δ^{15}N-values of the tree rings (3-year-intervals) for individual trees for the sites (a) S1; (b) S2; (c) S3.

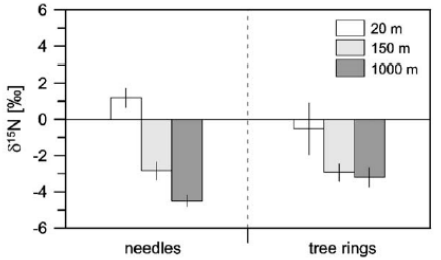


Fig. 5. The average δ^{15}N-values ($\pm$SD) of the tree rings and current-year needles for the period 1993–1995 at the three sites in differing distance to the motorway.

and 95 had an average value of $+1.3‰ \pm 0.4‰$ close to the motorway, decreasing to $-2.6‰ \pm 0.6‰$ at the intermediate site and to $-4.4‰ \pm 0.4‰$ in 1000 m distance (Fig. 5). The tree-ring values corresponding to the same time period showed a similar, but less clear trend, as the difference between S1 and S3 was only about half the value compared to the needles (Fig. 5). This reflects a dilution of the $^{15}NO_x$-signal as recovered in the tree rings, for instance caused by lateral transport and partial mixing of N of previous periods in the stem. The gradient with distance from the motorway was also observed in the soil but shifted to more positive values by about 5‰, reflecting the long-term input signal from the needle litter fall and subsequent fractionations during mineralization (Ammann et al., 1999).

The similar pattern of δ^{15}N and N-concentration for S1 clearly indicate that the increased levels of N are the result of N-deposition with a high δ^{15}N-value. This can be further evaluated by a correlation analysis. As shown in Fig. 6a, there is a relationship between the N-concentration and δ^{15}N. This relation is not linear, which can be understood on the basis of a two-member mixing model (see e.g. (Keeling, 1958). We assume that the N input to the tree rings originates from two sources, $N_{background}$ (from soil) and $N_{emission}$ (from car exhausts) with differing isotope ratios, $\delta^{15}N_{background}$ and $\delta^{15}N_{emission}$, respectively. Thus, the following equation applies:

$$\delta^{15}N_{\text{tree ring}} = \frac{(\delta^{15}N_{background}N_{background} + \delta^{15}N_{emission}N_{emission})}{N_{background} + N_{emission}}. \quad (1)$$

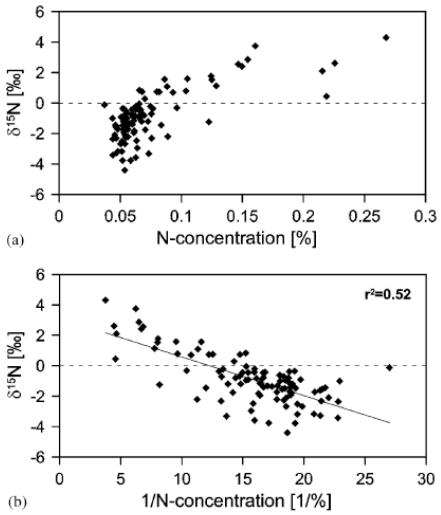


Fig. 6. The relationship between the N-concentration in the tree rings and δ^{15}N (a) and between the inverse of the N-concentration and δ^{15}N (b) for the site S1 close to the motorway.

Take-home message

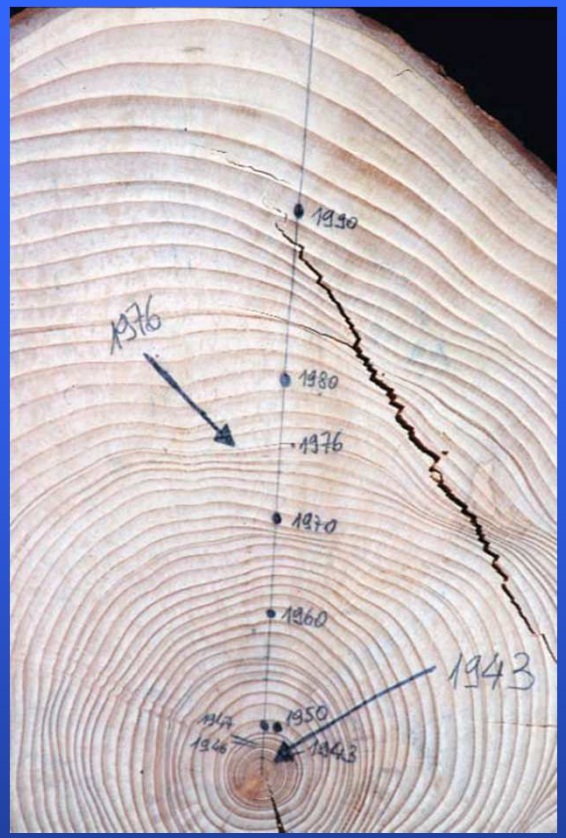
Tree rings contain signals on past environmental conditions to be applied in environmental studies:

^{15}N

^{14}C

Heavy metals

What else? Stable isotopes (^{13}C, ^{18}O)



Tree rings are not just ring widths.
They are beautiful,
partly still unexplored,
archives
for descovering past environmental conditions!!!

European Forest Ecosystems

Faster tree-growth rates since the 1980s

(Spiecker et al. 1996)

Why?

Nitrogen deposition or CO_2

(Spiecker et al. 1996)

Tree rings from a European beech forest chronosequence are useful for detecting growth trends and carbon sequestration

Marco Bascietto, Paolo Cherubini, and Giuseppe Scarascia-Mugnozza

Abstract: Past carbon (C) storage trends were estimated using dendroecological methods in a beech chronosequence in central Germany. Raw-ring-width chronologies, sensitivity curves, and carbon uptake trends were developed for 70-, 110-, and 150-year-old (S70, S110, and S150), even-aged stands. Ecosystem C stock and net ecosystem productivity (NEP_C) were computed as the sum of the C stock and fluxes of the soil, the aboveground compartment, and the estimated belowground compartment. The ecosystem C stock ranged from 216 t C·ha^{-1} in S150, to 265 t C·ha^{-1} in S70, to 272 in S110. NEP_C values followed ecosystem C stocks, ranging from 1.7, to 2.4, to 5.1 t C·ha^{-1}·year^{-1} for S150, S70, and S110, respectively. Stem C-stock uptake rate in S110 showed an increase in growth rate over the first 110 years of S150. We estimate that this increase in stem C stock was 6.2%. Given the constancy of forest management among the stands of the chronosequence, we hypothesize that the increase in C stock shown by S110 is due to indirect human-induced effects. We conclude that managed young forests can take advantage of increased resources and counteract the C losses at harvest that are seen in the old forests.

Résumé : Les tendances passées dans le stockage du carbone (C) ont été estimées à l'aide de méthodes dendrochronologiques dans une chronoséquence de hêtre du centre de l'Allemagne. Des chronologies brutes de largeur de cernes, des courbes de sensibilité et des tendances dans le prélèvement du carbone ont été développées pour des peuplements équiennes de 70, 110 et 150 ans. Le stock de C dans l'écosystème et la productivité nette de l'écosystème (PNE_C) ont été calculés en faisant la somme des stocks et des flux de C dans le sol, dans la biomasse épigée et dans la biomasse hypogée estimée. Le stock de C dans l'écosystème variait de 216 t C·ha^{-1} dans le plus vieux peuplement à 265 t C·ha^{-1} dans le plus jeune peuplement, à 272 t C·ha^{-1} dans celui de 110 ans. Les valeurs de la PNE_C suivaient celles du C accumulé dans l'écosystème, variant de 1,7 à 2,4 et 5,1 t C·ha^{-1}·an^{-1}. Dans le peuplement de 110 ans, le taux de prélèvement du stock de C dans les tiges montre que celui-ci s'est accru au cours des premiers 110 ans dans le peuplement de 150 ans. Nous estimons à 6,2 % cet accroissement du stock de C dans les tiges. Étant donné la constance de l'aménagement forestier dans les peuplements de la chronoséquence, nous faisons l'hypothèse que l'accroissement du stock de C dans le peuplement de 110 ans est dû à des effets indirects d'origine anthropogénique. Nous concluons que les jeunes forêts aménagées peuvent profiter des ressources accrues et peuvent compenser les pertes de C dues à la récolte qui sont constatées dans les vieilles forêts.

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Introduction

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Uncertainty still surrounds the extent to which tree growth can react to environmental changes, such as rising CO_2, N deposition, and increases in temperature and solar radiation. Some studies have indicated that rising CO_2 induces an increase in tree-ring width (e.g., LaMarche et al. 1984; Nicolussi et al. 1995), whereas other data indicate a lack of response (e.g., Kienast and Luxmoore 1988; Briffa et al. 1990). At the stand level, a number of studies have reported an increase in forest biomass over the past 50 years (e.g., Franz et al. 1993; Becker et al. 1995; Spiecker et al. 1996; Bräker 1996; Bert et al. 1997). Recent simulation studies using a two-stage, process-based model have shown that under current climate-change conditions, net annual increments in stem biomass in European forests will further increase, to give an additional 0.9 m^3·ha^{-1}·year^{-1} above that in the current climate scenario, by 2030. By 2050, the increase in increments is reduced to 0.79 m^3·ha^{-1}·year^{-1} (Nabuurs et al. 2002). Tree-ring analysis may be useful for retrospective studies assessing long-term growth changes and C sequestration in forest stands. In the recent past, tree rings have been used more often in ecology as indicators of environmental factors and tree growth. As indicators of tree growth, they provide an estimate of the quantity of biomass produced.

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M. Bascietto[1] **and G. Scarascia-Mugnozza.** Department of Forest Environment and Resources, University of Tuscia, I-01100 Viterbo, Italy.
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[1]Corresponding author (e-mail: bask@unitus.it).

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Fig. 1. Mean tree-ring-width chronologies plotted against calendar date. Standard error bars omitted for clarity. Chronologies end at 2000. S70, 70-year-old stand; S110, 110-year-old stand; S150, 150-year-old stand.

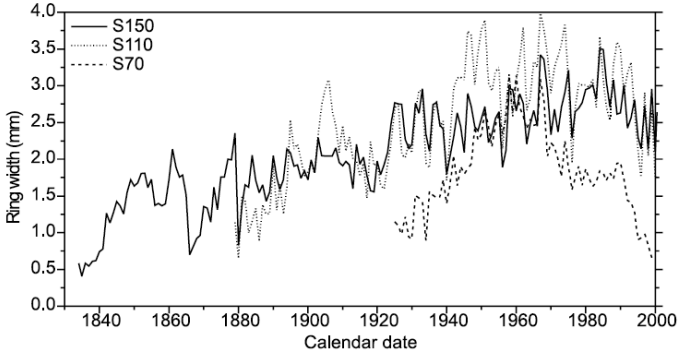
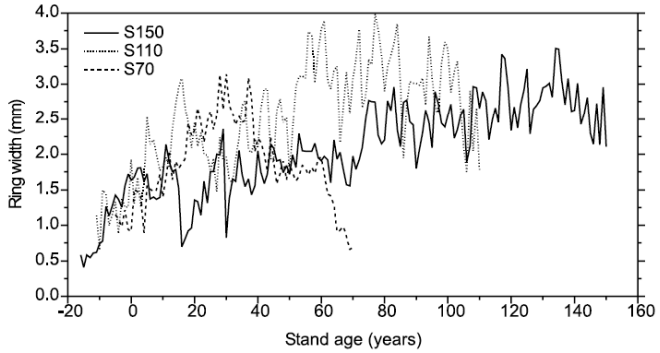


Fig. 2. Mean tree-ring-width chronologies plotted against stand age. Chronologies end at 2000. The establishment year of the stands is spread over the 15-year regeneration period and was thus marked as the mean regeneration year of sample trees. S70, 70-year-old stand; S110, 110-year-old stand; S150, 150-year-old stand.



S70 ring-width series (40%) did not consistently synchronize with stand mean chronology. This result shows higher individual variability in response to environmental conditions in this stand.

Stand mean chronologies from ring-width series of cross sections at stump height were built and plotted with respect to year (Fig. 1) and cambial age (Fig. 2). The S70 chronology starts in 1925 (spanning 75 years); S110, in 1879 (121 years); and S150, in 1834 (166 years). Mean ring width in S70 (±1 SE) is 1.84 ± 0.596 mm; in S110, 2.51 ± 0.758 mm; and in S150, 2.07 ± 0.664 mm.

Mean chronologies for S110 and S150 reveal good synchrony as far as growth trends and Cropper's values are concerned, particularly from 1900 onward, probably as a result of the increase in the S110 sample size.

The mean chronology of S70 differs from those of S110 and S150, not only in diameter growth pattern but also in synchrony. The S70 diameter growth pattern varies between trees and, as a result, the mean stand chronology for S70 does not respond to external factors in the same way as those for S110 and S150 do. Furthermore, S70 shows a peculiar growth trend in which two main growth periods can be detected: enhanced growth between 1940 and 1960 and a decline up to 2000. The declining growth phase has affected the mean stand ring width such that S70, on average, shows the lowest mean increment among the three sampled stands in the Leinefelde forest.

Plotting chronologies versus their cambial age enabled us to make qualitative comparisons between growth rates of the stands. In the first 20 years, the three stands showed similar growth rates and absolute ring-width values. Subsequently, S110 and S150 alternated short slow-growing phases with longer fast-growing ones, with S110 showing, at all times, greater ring-width values. In contrast, S70 extended its active growth period for a further 20–30 years, but its radial increment abruptly declined after cambial age 40–50 years.

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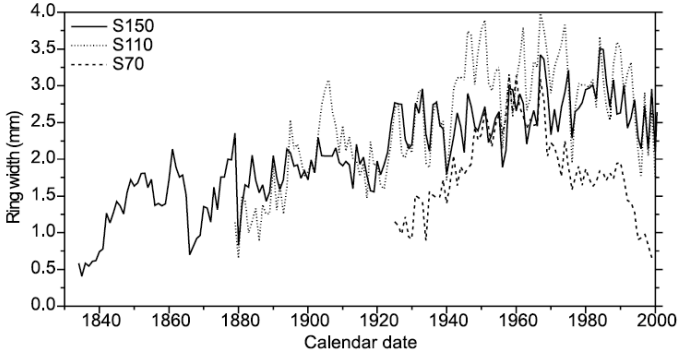

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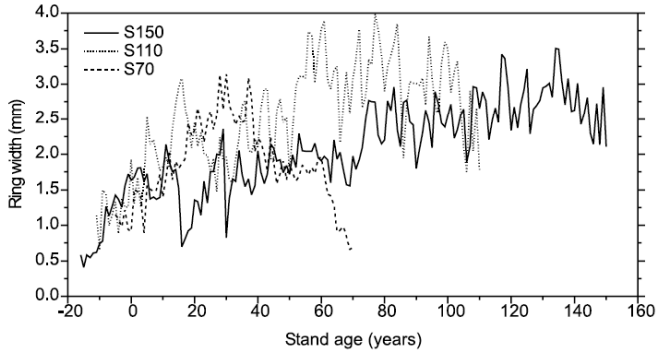

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