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Dendrochronological monitoring of air pollution in the Ghent canal area (Belgium)

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Introduction

The uptake of heavy metals is assumed to be a possible limiting factor for tree growth. In addition, it may also induce toxic effects. In the past, several studies have been conducted on the effect of industrial emissions on the growth of trees and the fixation of heavy metals in their wood (e.g. Baes & McLaughlin 1984, Stoeckhardt 1871 & Bakke 1913 in Cook & Kairiukstis 1990). Unfortunately, the results of this research are often contradictory. Furthermore, the past studies were mainly based on American tree species (USA) while this project focuses on three European, indigenous trees. In this study, we investigate the link between aerial pollution by heavy metals and the growth response of trees located in the heavily industrialized Ghent canal area (Belgium).

An important Belgian steel producing company is situated in the heart of the Ghent canal area and owns a forested area of approximately 250 ha within its operating limits. The tree-ring patterns and the content of heavy metals in the wood of three indigenous species, abundant in the industrial area (high emission values) and two nearby reference forests (lower emission values), were used to test the following hypotheses:

- Aerial emissions of heavy metals influence the tree-ring pattern of trees in and around the Ghent canal area.
- The content of heavy metals in the wood of trees in the Ghent canal area differs from the content in trees at the reference sites.
- Trees can be used to monitor aerial pollution by heavy metals over time.

Material and methods

Three indigenous tree species were sampled with an increment corer: 50 pedunculate oaks (*Quercus robur* L.), 30 beeches (*Fagus sylvatica* L.) and 30 pines (*Pinus sylvestris* L.). This sums up to a total of 110 trees on 11 sampling sites. Each sampling site contains 10 trees. One sampling site per forest and per tree species was chosen, with exception of the pedunculate oaks in the forest area of the steel producing company Sidmar NV (Ghent canal area). There, oaks from three sites were analyzed. The mean tree age per sampling site is given in table 1.

Table 1: Overview of the mean age of sampled trees per sampling site (unit: years).

	Pedunculate oak			Beech	Pine
Ghent canal area	71	76	76	91	64
Reference forest Kloosterbos	79	-	-	60	75
Reference forest Heidebos	77	-	-	96	57

The two reference forests, Kloosterbos and Heidebos, are situated 1 and 4.5 km eastward of Sidmar NV, respectively, and both of the reference forests have similar stand and soil properties. The selected species have a comparable age in all the sampling sites, except for the beeches of the Kloosterbos. They were all planted on dry sandy soils. Figure 1 visualizes the study area.

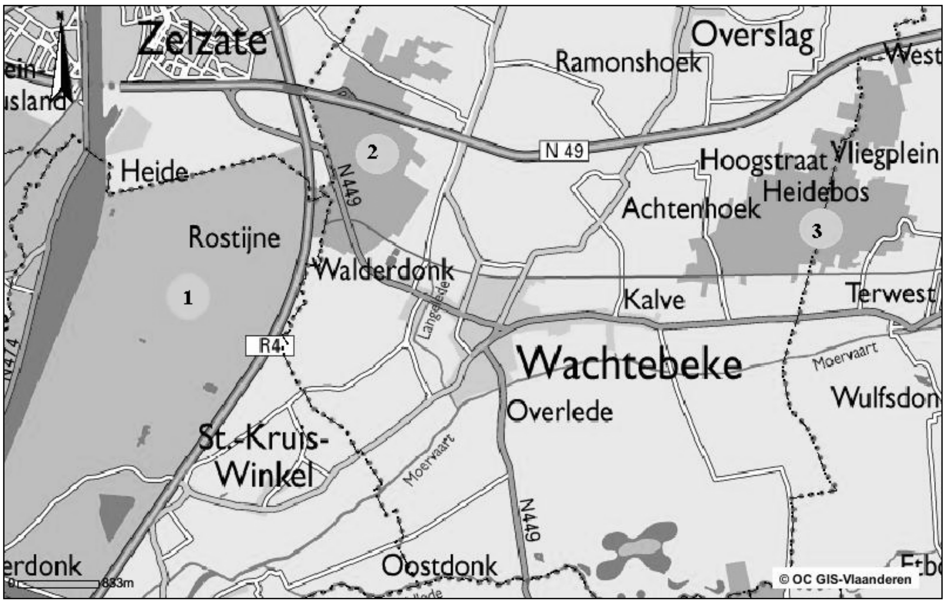

Figure 1: Study area (1: industrial site of Sidmar NV, 2: Kloosterbos, 3: Heidebos)

Per tree, two cores were taken to account for inter-tree variability (Watmough, 1999). The wood cores were dried and glued to avoid warping. After sanding, the tree rings became visible and ring-width series were measured using a digital positioning table (LINTAB, accuracy: 0.01 mm) and the corresponding software TSAP-Win (Rinn 2003). An average tree-ring series was calculated from the two cores of every tree.

Standardisation was performed with ARSTAN in order to remove the age trend and endogenous trends (Cook & Holmes 1999). Trees that didn’t show any visual or statistical correlation (t-value Baillie-Pilcher < 4) (Baillie-Pilcher 1973) were not used to compose a site chronology. The remaining standardised ring-width series were used to build one site chronology per sample site. These site chronologies were compared with air pollution data, available for lead and zinc emissions, for a short period of 9 years. As an alternative approach to study the influence of climate and industrial pollution on the ring-width patterns, *pointer years* were identified using the method cited by Schweingruber et al. (1990). The *pointer years* that can not be explained by climate, might be related to exogenous factors like air pollution, which also has strong year to year variations in the Ghent canal area (VMM 2002). Due to this strong variations, it will be difficult to detect chronic effects of pollution.

To analyze and quantify the content of heavy metals in wood, the cores were chipped and incinerated in a muffle furnace. The period under study for the chemical analyses spans from 1960 (six years before the onset of steel production) to 2004. After a chemical treatment with nitric acid (10% HNO_3), the metal content of the wood cores was measured with an atomic absorption spectrometer (AAS, type Perkin Elmer 3110). This device has a detection limit of 0.01 ppm and is used to determine the content of lead (Pb), zinc (Zn), copper (Cu) and cadmium (Cd). When it was difficult to obtain the minimum weight of 1 g for the analysis with AAS, several cores of different trees of one sample site were combined. This should be taken into account when interpreting the outcome of the analysis. Statistical analysis (One Way ANOVA) was used to examine significant differences between sample sites and sampled tree species.

Results and discussion

Pointer years and climate

Between the different sampling sites, there are few consistent *pointer years* identified for each species. Those consistent pointer years are marked in bold in table 2.

Table 2: Overview of the negative and positive pointer years (PY) per sample plot (the pine sample plot in Heidebos didn't produce any pointer years and is not included here). Years with an asterix (*) could not be explained by climate analysis.

Sample plot	Negative PY	Positive PY
Pedunculate oak Sidmar 1	1990	
Pedunculate oak Sidmar 2	**1996**	1975* **1982***
Pedunculate oak Sidmar 3		1971 **1982**
Pedunculate oak Kloosterbos		**1982** 1997
Pedunculate oak Heidebos	1962 1975 1988 1995	
Beech Sidmar	1977 1983* **1996**	1993*
Beech Kloosterbos	1976 1983* 1990* **1996**	1980 1987 1988
Beech Heidebos	1936 1971 1984 **1996**	1932 1994 1999*
Pine Sidmar	1988* 1995	1975 2002*
Pine Kloosterbos	1944 1981 1991 **1996**	

Only the negative *pointer year* 1996 is on the list of pan-European *pointer years* by Kelly et al. (2002). It should be taken into account that several definitions exist for the term *pointer year*. In the Kelly et al. (2002) study, a *pointer year* is determined when an extreme wide or narrow ring width is found in 75% of the samples. In our study, the definition by Schweingruber et al. (1990), with a threshold of 80%, was followed.

The site chronologies were compared to monthly rainfall and temperature data from June of the previous year until November of the present growing season. Correlation values of temperature with ring width are lower, compared to correlation with precipitation. This was already stated by Vitas (2004) and Lebourgeois et al. (2004). Generally, the influence of rainfall on growth of pedunculate oaks is most significant during the previous autumn and early winter (October to December). In the case of beech, the rainfall of the previous summer (June to August) determines tree growth, while for pine, the rainfall of the previous summer and early autumn (July to October) has the most significant influence. Precipitation accounts for a maximum of 25 % of the variance. An additional analysis was performed on the *pointer years*. Their relative growth changes (in %) were compared to the months with significantly related temperature and rainfall values. This way, the *pointer years* induced by climate, were separated and excluded from further research.

The link with industrial events and emission data series

Sidmar NV provided information on the emissions of heavy metals and a detailed history of the development of the steel company. First, the unexplained *pointer years* were compared with the start-up dates of some of the most important units with a risk of higher emissions. Since this kind of comparison is difficult to be proven statistically, it is not possible to draw clear conclusions. In addition, current influences of traffic and other companies in the area can not be excluded.

Another option is the study of year-to-year variability in radial growth and emissions of heavy metals in the air. Emission data for nine years (1995-2003) were available for lead and zinc. Unlike lead, zinc emissions proved to have a significant influence on the radial increment over this period (Fig. 2). The tree-ring series of every site of pedunculate oak (both Sidmar and reference sites) showed a consistent, significant, negative correlation with the trend in zinc emissions ($p < 0.05$). This means that high zinc emissions corresponded with low radial increments and vice versa. It was not expected that the correlation would also be significant at the reference sites. This might be the consequence of the considerable height of the emitting chimneys (50 to 72 m), causing a larger sphere of influence. Eklund (1995) and Watmough & Hutchinson (2003) carried out successful research on emission sources with a maximum height of 18 and 30 m, respectively. The modelling of the plume of smoke from different chimneys at Sidmar NV could determine if reference sites at a greater distance would be more useful.

Zinc is known to be an essential element for tree growth, what might clarify the link between zinc emissions and tree growth. Zinc takes part in the biosynthesis of enzymes, auxins and some of the proteins but is only needed in small amounts (Dmuchowski & Bytnerowicz 1995). An excessive amount of zinc may adversely affect the formation of growth hormones like auxins, and therefore, may express itself as an influence on tree-ring widths. However, this hypothesis hasn't been proven yet.

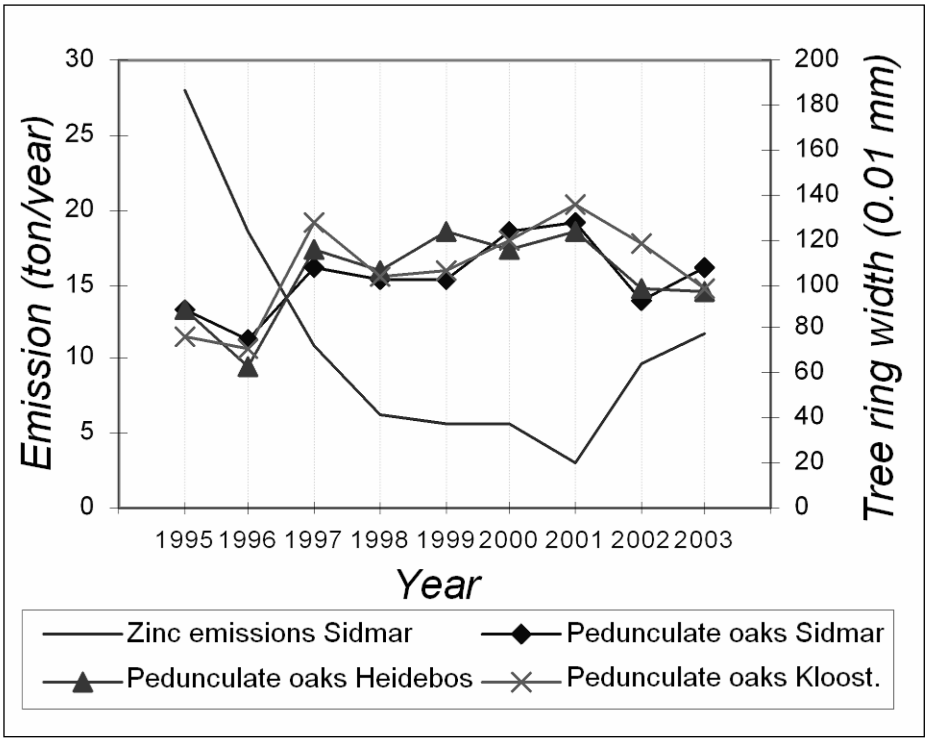

Figure 2: Air emission series of zinc versus the site chronologies of pedunculate oak (1995-2003)

Despite the significant results it is not advisable to draw a final conclusion on the influence of zinc on the tree rings of pedunculate oak. The emission data only covered a short period and was the result of different emission sources. A longer data set, based on the emissions of one source, can provide further evidence.

Chemical analysis

The content of lead, zinc and copper in the wood was measured. Since cadmium values are very close to the detection limit, they have not been included.

The content of lead in the wood of all the species, especially in oak, is extremely high. Latimer et al. (1996) found a lead content of 14 ppm on a site close to a refinery. This is low compared to the values in figure 3. One peak value in pine can be ascribed to lead shot but it is quite implausible to say that hunting is the main cause of the higher lead content in pedunculate oaks in and around the canal area. The explanation for the higher lead content and the within-site variation hasn't been investigated yet.

The average lead content shows the expected decrease with increasing distance from the emission source. However, the average lead content in pine shows the opposite pattern; more lead is found in Heidebos, the most distant reference forest. However, the content of zinc in pine decreases from Sidmar to Heidebos. The relationship between distance to the emission source and heavy metal content seems to depend on the species and on the element that is analyzed.

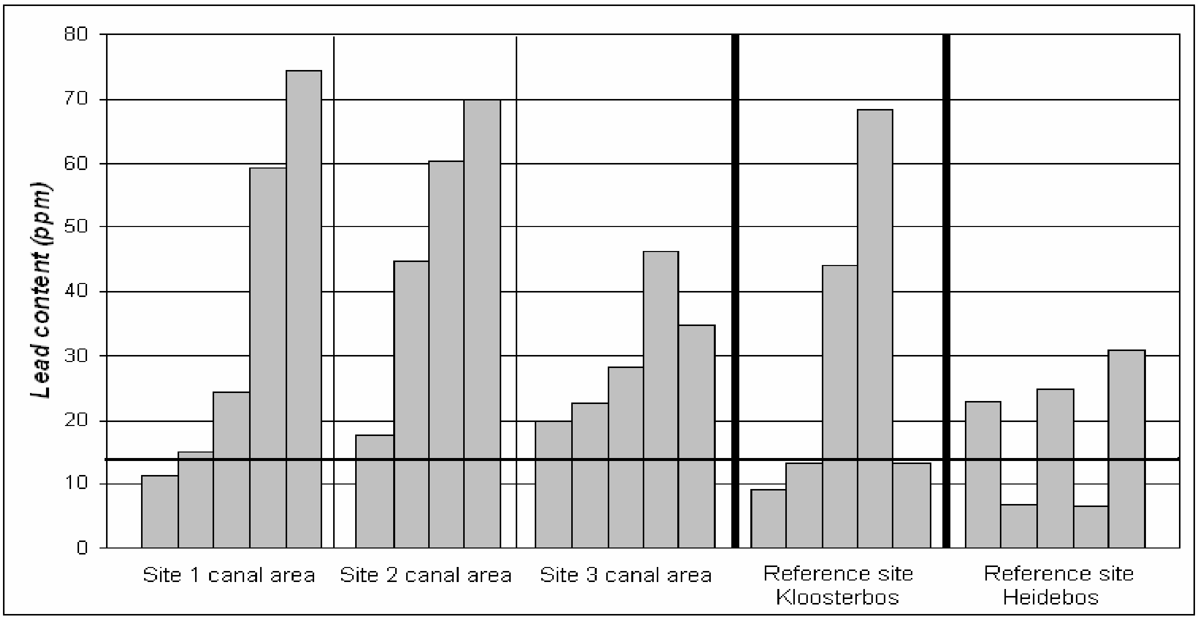

Figure 3: The content of lead in wood of pedunculate oaks (in ppm).
This graph shows the lead content for the period 1960-2004. To reach the detection limit for analysis with AAS, it was necessary lump two or three trees randomly within one site. Each bar represents one sample that passed chemical analysis. The horizontal line indicates the maximum lead content cited in previous research (Latimer et al. 1996). The thick vertical lines separate the three different forests while the thin lines separate the three sampling sites for oak in the Ghent canal area.

Apart from two peaks in the zinc content in pines, all values were situated within the range of previously published research. Latimer et al. (1996) and Schaumloffel et al. (1998) found a minimum of 1.7 and a maximum of 22 ppm zinc. The values in this study range from 2.5 ppm till 27 ppm. The content of copper in the Ghent canal area (1.8-6.1 ppm) is comparable with literature values (Watmough & Hutchinson 2003). Yet, less research has been done on copper because of the higher mobility of this element within the tree. The contents of zinc and copper are strongly correlated, possibly because they are both essential for tree growth. Lead and cadmium are not essential for tree growth and can quickly become toxic (Nabais et al. 1999).

Conclusions

In this study, research was done on the consequences of air pollution from industrial emissions on the growth-ring pattern of three native species and the accumulation of heavy metals in the wood. The following conclusions are drawn with respect to the three hypotheses:

- Emissions of heavy metals in the air influence the tree-ring patterns of trees inside and outside the Ghent canal area. This hypothesis is true for the element zinc, especially when regarding the radial growth of pedunculate oak. Zinc is an essential element for tree growth, taking part in the formation of growth hormones.
- The content of heavy metals in wood in the Ghent canal area differs from the content in trees at the control sites. Here, everything depends on the chemical element and the tree species.

- At present, it was not possible to determine one specific species as a monitor species for air pollution by heavy metals in the Ghent canal area.

The presented results can be considered as preliminary. Further research could include a model to determine the extent of the plume of smoke, longer emission series and more specialised equipment for chemical analysis so that the minimum required sample weight could be reduced and cores of different trees do not need to be combined. When longer emission series are available, research on the combined effects of climate and emissions could provide more detailed information on the growth of trees in industrial areas.

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