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## Dendroanalysis of metal pollution from the Sydney Steel Plant in Sydney, Nova Scotia

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## ABSTRACT

The Sydney Steel Plant emitted toxic pollutants into the local area for almost 100 years. Although no paper record exists of the amount and spatial variability of the pollutants emitted, a natural record exists locked in the annual growth of native tree species in the region. Studies have shown that temperate trees can incorporate local metal pollution into their annual rings, creating a temporal and spatial record of the pollution. Two abundant species were sampled within a 5-km radius of the steel plant site. Using dendrochronology, atomic absorption spectroscopy (AAS) and energy dispersive X-ray fluorescence (EDXRF) on white birch, *Betula papyrifera*, and eastern larch, *Larix laricina*, a new methodology was developed to determine levels of pollutants in a given year. Atomic absorption spectroscopy did not produce accurate results with the small sample sizes we were able to process, but energy dispersive X-ray fluorescence determined that the hardwood birch better incorporated both lead and zinc into annual rings than the softwood larch. The technique provides an interesting area for further study, because it provides a time efficient and repeatable method of analyzing chemicals stored in wood tissue.

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## Introduction

Most temperate trees develop a new ring of growth each year (Fritts, 1976), and a number of studies have illustrated that these trees often have the ability to take up and incorporate local pollution into their annual rings (e.g., Rolfe, 1974; Robitaille, 1981; Nabais et al., 2001). Dendroanalysis relies on the basic assumption that the chemical makeup of tree rings reflects to some degree the chemical signal from the environment during the year of ring formation (Watmough, 1999). Dendroanalysts have debated over whether bio-monitoring using tree rings is unreliable (Garbe-Schönberg et al., 1997; Martin et al., 2000), or in fact even feasible (Watmough et al., 1998; Medeiros et al., 2008). For dendroanalysis to be applied, certain conditions of tree ring chemistry must be understood and incorporated into the study (Nabais et al., 2001). Sampling methods, study species and analytical methods must be carefully chosen, although there is no consensus on how exactly these factors interact, creating a variety of ways to apply dendroanalysis (Watmough, 1999).

A limited number of previous studies have used elaborate X-ray dendroanalytical techniques employing, for example, synchrotron radiation (Punshon et al., 2003; de Vives et al., 2006) or three-axial scanning X-ray fluorescence spectrometry (Larsson and Helmisaari, 1998). These instruments are, however, not easily accessible, and are expensive and relatively complex to operate. This paper describes a dendroanalytical application of an energy dispersive X-ray fluorescence (EDXRF) device which is portable, relatively inexpensive, and straightforward to operate. Although EDXRF has been used to analyze lead and zinc in other environments, its resolution is not as high as the biannual resolution attempted in this study (Latimer et al., 1996).

We hypothesized that dendroanalysis using EDXRF could provide a long-term pollution record if we could find a suitable test site. We hoped to eventually create a map that would show the changes of pollutants across time and space, and to do this, we would need an instrument that could run the large number of samples that would be needed for such an effort. Because of the sample number issue, the analytical instrument would have to be both straightforward to operate and readily available. The portable EDXRF unit used in this study provided this easily accessible, relatively inexpensive method of running multiple tree samples. Although the EDXRF instrument model we used was developed for soil chemistry applications, it has also been used for other exploratory purposes, such as arsenic detection in human skin (Fleming and Gherase, 2007).

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**Fig. 1.** A diagram of Sydney with study sites (marked as solid dots) plotted in relation to the coke oven site. The solid lines represent the north–south and east–west axes dividing the four sample quadrants.

The Sydney Steel Plant was an important part of the history of the city of Sydney, Nova Scotia. From 1901 to 2000, the plant produced steel for global markets and provided employment opportunities for the local and immigrant communities (Caplan, 2005). The processes of converting iron ore to steel produced a variety of pollutants. Polychlorinated biphenols (PCBs), volatile organic compounds (VOCs), and metals were released throughout the time that the plant was functioning (AMEC Earth and Environmental, 2005). These toxicants have been of great concern to the city's residents, and today the "Sydney Tar Ponds" are a well-known environmental disaster. The known and extensive Tar Ponds pollution makes it an ideal candidate for testing our methodological hypothesis of using the EDXRF procedure to understand past chemical contaminants in the environment. This was particularly important, as there is no other clear, available, long-term record of the pollution emitted by the Sydney Steel plant. High levels of metals were emitted into the environment by the working plant through time, specifically lead, copper, zinc, arsenic and thallium (Hale, 2004) and then the wind distributed these toxicants across the greater Sydney region. The metals became the focal elements for our study for their prevalence and their detectability using EDXRF analysis.

The main objective of this project was to measure the metal concentrations of lead, copper and zinc in the environment of Sydney by analyzing annual wood increments utilizing the promising, rapid detection method of a portable EDXRF instrument. In order to accomplish this task, two smaller steps were undertaken. Project I utilized the more time-consuming method of atomic absorption spectroscopy (AAS) in an attempt to properly calibrate the time-efficient EDXRF analysis. In Project II, a preliminary EDXRF test was completed to compare the extent to which white birch (*Betula papyrifera*) and eastern larch (*Larix laricina*) incorporated metals into their annual ring tissue.

## Study area and field methods

### Study area and study site selection

All samples were taken within a 5-km radius of the former coke ovens site (N46°08.879', W060°10.376') in the heart of the Sydney Steel Plant grounds (Fig. 1). The sampling region was divided into four quadrants following the cardinal directions with axes centered on the coke ovens. In each quadrant, five sites were sampled, and dispersed as evenly as possible in a radial pattern across the quadrant. A specific site qualified as a sampling site if it was: (a) a natural forested area; (b) contained the two target species; and (c) was removed from direct residential and commercial contact. The target species were eastern larch and white birch, as previous reconnaissance determined these two species to be the most common across the region.

### Sampling

Once a sampling site was identified, distance and direction from the coke ovens were noted, and the two species were sampled at the site. A 5.1 mm increment borer was used to extract cores, with two cores collected per tree at approximate breast height (1.3 m). After the first core was sampled, the second core was taken directly (1 cm) below the first core. This sampling method allowed both cores to be as similar as possible in terms of ring width parameters and ring structures. This procedure was used because one core would be used for traditional dendrochronological analysis, while the second would be used in other analytical procedures. Cores were labeled and stored in clear plastic straws, then transported to the Mount Allison Dendrochronology Laboratory for further analysis.

## PROJECT I: EDXRF calibration using AAS

EDXRF allows for quick, precise, non-destructive analysis of elemental concentrations in a tree sample. However, as the instrument was originally intended for testing soil samples, it was not known if the concentrations reported by the procedure were accurate or if they needed to be calibrated. The method chosen to calibrate the EDXRF results was AAS, as it was expected to provide true absolute concentration values (e.g., Robitaille, 1981). Disadvantages of the AAS procedure are that it is destructive and relatively time-consuming in nature.

### Methods

#### Dendrochronological methodology

One core of larch and birch was cut into segments with a sterile scalpel blade. The segments weighed enough (approximately 0.5 g) to be analyzed with atomic absorption spectroscopy. The segments were approximately 1 cm in length and were cut based on mass requirements for analysis rather than annual boundaries. Each segment's temporal position was noted, and the segments were stored for later analysis.

#### Energy dispersive X-ray fluorescence methodology

The segments were then taken to the Mount Allison Medical Physics lab and analyzed using an Innov-X System Alpha-4000S EDXRF instrument (Innov-X Systems Canada, Mississauga, Ontario). Each sample was run under standard soil settings for 5 min. Throughout this time interval, the instrument bombarded the atoms of the wooden segment with X-rays. The emitted spectrum was then interpreted to reveal the composition and concentration of elements within the segment being analyzed (Murphy, 2006). The Innov-X instrument software calculates concentrations in parts per million (ppm) for any detected elements, including the three metals of interest – lead, zinc and copper.

#### Atomic absorption spectroscopy methodology

As the EDXRF procedure is non-destructive, the same samples were analyzed first with EDXRF and then taken to be analyzed with AAS. The wet weight of each wooden segment was obtained before any AAS processing. The segment was placed in a muffle furnace and was heated overnight at 550 °C, converting the sample to ash. After being cooled, the sample was weighed again for dry weight. In order to dissolve the ash, 1 mL of Aqua Regia (HCl:HNO<sub>3</sub> – 3:1) was added for 2–4 h on a hot plate set at 80 °C. Once only a salt remained, it was made into a 10 mL solution by diluting it in a volumetric flask using distilled, de-ionized water as a solvent. Standards for each metal were used to calibrate a Varian AAS instrument and then each 10 mL sample solution was run and values (in ppm) were acquired. Hollow cathode lamps were available to test for lead, zinc and copper.

### Results

#### Lead concentration comparison

Lead concentrations analyzed through AAS were difficult to interpret as there were both positive and negative values (Fig. 2). Generally, the values fluctuated around 0 ppm, indicating that lead was not detected using AAS. Using XRF, lead values were low, fluctuating around 1.5 ppm, yet they were still detected (Fig. 2). In each of the following comparisons, the dry weight value was lost for larch segment number five, so this data point has been excluded from the results. The wet weight was thought to be less precise, so it was not used.

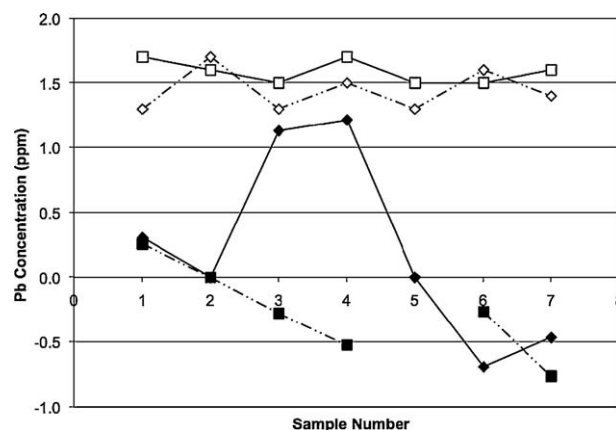


Fig. 2. Concentration of lead (ppm) in birch (solid lines) and larch (dashed lines) tree cores analyzed using AAS (solid markers) and XRF (open empty markers). Sample 1 is the youngest segment and sample 7 is the oldest for both larch and birch ( $n=7$ ).

#### Zinc concentration comparison

AAS values indicate that for birch, 13–18 ppm of zinc was in the more recent segments and then they peaked at 43 ppm in the middle segments before dropping again to 25 ppm in the oldest segments (Fig. 3). For larch, the AAS values begin at 23 ppm in the youngest segment and then decrease to values between 5 and 10 ppm for the older segments. The total range for larch is approximately 20 ppm. Fig. 3 illustrates that the XRF procedure produced concentrations of zinc varying between 5 and 10 ppm. The range is approximately 5 ppm, which is very different than the AAS results.

#### Copper concentration comparison

Copper was detected by AAS in both larch and birch, although it was very low and fluctuated a great deal (Fig. 4). The AAS range was 2 ppm, between 0 and 2 ppm for larch and 1 ppm, between 0 and 1 ppm for birch. Copper levels were too low to be detected by the XRF in both species for all samples (Fig. 4).

### Discussion

EDXRF has no zero value or reliable scale for this project as trees cannot be found with known metal concentrations to test in the EDXRF procedure. It was hoped that the AAS results would provide a consistent numerical factor to help calibrate the EDXRF results. As AAS determines absolute concentration, these values could theoretically be used to calibrate the EDXRF measurements. This factor

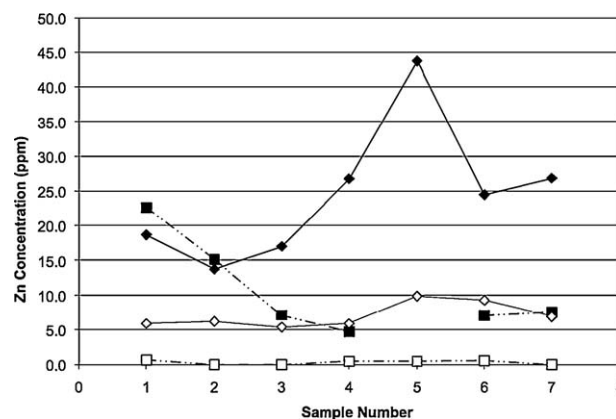
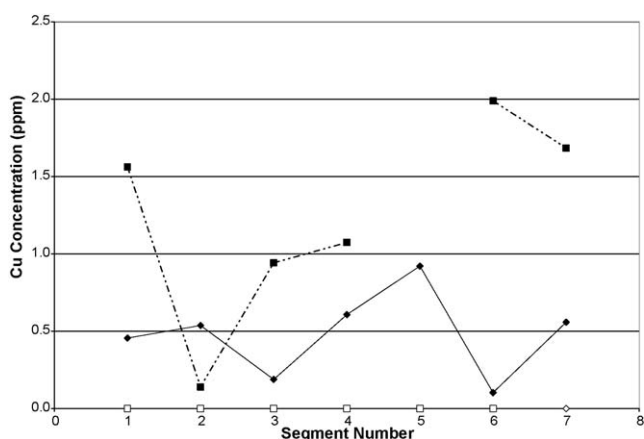


Fig. 3. Concentration of zinc (ppm) in birch (solid lines) and larch (dashed lines) tree cores analyzed using AAS (solid markers) and XRF (open empty markers). Sample 1 is the youngest segment and sample 7 is the oldest for both larch and birch ( $n=7$ ).





**Fig. 4.** Concentration of copper (ppm) in birch (solid lines) and larch (dashed lines) tree cores analyzed using AAS (solid markers) and XRF (open markers). Sample 1 is the youngest segment and sample 7 is the oldest for both larch and birch ( $n=7$ ).

would then be used on all further XRF values for calibration, but ultimately our analysis did not allow for this approach.

In the lead, zinc and copper analyses, there was no consistency between the AAS values and the EDXRF values. In each run, both larch and birch AAS values were found in the same range, yet there was no consistency as to whether the EDXRF values or the AAS values were higher. The trends between the larch and birch samples in both the EDXRF and AAS values did not match in any form, indicating that the two sets of analytical results did not mimic each other in a sufficiently accurate way to produce a calibration factor. Without any consistency, AAS cannot be used to calibrate the EDXRF values.

Lead concentrations did not register using AAS in this test. The negative values in the data are indicative of an experimental problem and may be due to the error range for the instrument when detecting such low levels of lead. The settings on the muffle furnace were not in temperature units, leading to an approximation of the temperature reached by the furnace. Due to the inaccuracy of the muffle furnace temperature, the temperature may have increased to a point where lead became volatile and left the sample, leaving none to be detected by AAS.

Zinc and copper concentrations were detected by both the AAS and EDXRF procedures, yet the EDXRF values were low or even undetectable. The values for the two methods were difficult to compare for this reason, especially for copper. Zinc has the closest relationship between EDXRF and AAS for any of the three metal tests, but still there was no clear pattern to calculate a calibration factor.

Overall, this method did not provide the desired calibration factor, with a major reason being the sample size tested ( $N=1$  for each species). No replicates were completed (due to the limited segment mass) and only one core was run for each species (due to time and expense). The low sample numbers allow for a lot of imprecise data that cannot be interpreted. If this method were to be successful, many more cores and trees should be sampled and run through both AAS and EDXRF. Zinc should be the focal metal, as it showed the most promising results for linking the two metal analyses methods. Muffle oven temperature should also be closely monitored throughout the heating process.

The major result obtained from Project I is that since no reliable calibration factor could be determined, EDXRF results in Project II should not be interpreted as correct absolute values, but rather viewed with respect to relative changes or differences across samples.

**Table 1**

Dendrochronological analysis of tree age for all larch and birch tree cores within a 5-km radius of the coke oven site. The samples in bold were chosen for further analysis.

Larch			Birch		
Tree	Oldest ring	Age	Tree	Oldest ring	Age
<b>7ADL711</b>	<b>1927</b>	<b>79</b>	7ADLC01	1939	67
7ADL712	1943	63	7ADLC02	1935	71
7ADL721	1955	51	7ADLC11	1948	58
7ADL722	1940	66	7ADLC12	1951	55
			<b>7ADLC13</b>	<b>1913</b>	<b>93</b>
			7ADLC21	1937	69
			7ADLC22	1937	69
			7ADLC31	1976	30
			7ADLC32	1957	49
7AEL701	1923	83	7AELC01	1960	46
7AEL702	1937	69	7AELC02	1961	45
7AEL711	1979	27	<b>7AELC11</b>	<b>1951</b>	<b>55</b>
7AEL712	1983	23	7AELC12	1966	40
7AEL721	1960	46	7AELC21	1966	40
7AEL722	1951	55	7AELC22	1960	46
<b>7AEL741</b>	<b>1983</b>	<b>23</b>	7AELC31	1952	54
7AEL742	1989	17	7AELC32	1950	56
<b>7AFL701</b>	<b>1933</b>	<b>73</b>	<b>7AFLC01</b>	<b>1960</b>	<b>46</b>
7AFL702	1951	55	7AFLC02	1951	55
7AFL711	1985	21	7AFLC11	1983	23
7AFL712	1988	18	7AFLC12	1974	32
7AFL731	1960	46	7AFLC21	1961	45
7AFL732	1969	37	7AFLC22	1952	54
7AFL733	1978	28	7AFLC31	1963	43
			7AFLC32	1956	50
			7AFLC41	1936	70
7AGL701	1957	49	7AGLC01	1938	68
7AGL711	1967	39	7AGLC02	1954	52
7AGL712	1963	43	7AGLC11	1967	39
7AGL721	1938	68	7AGLC12	1966	40
7AGL722	1920	86	7AGLC21	1921	85
<b>7AGL731</b>	<b>1944</b>	<b>62</b>	7AGLC22	1907	99
7AGL732	1949	57	7AGLC31	1951	55
			<b>7AGLC32</b>	<b>1952</b>	<b>54</b>
			7AGLC41	1942	64
			7AGLC42	1947	59

**Project II: Hardwood and softwood comparison**

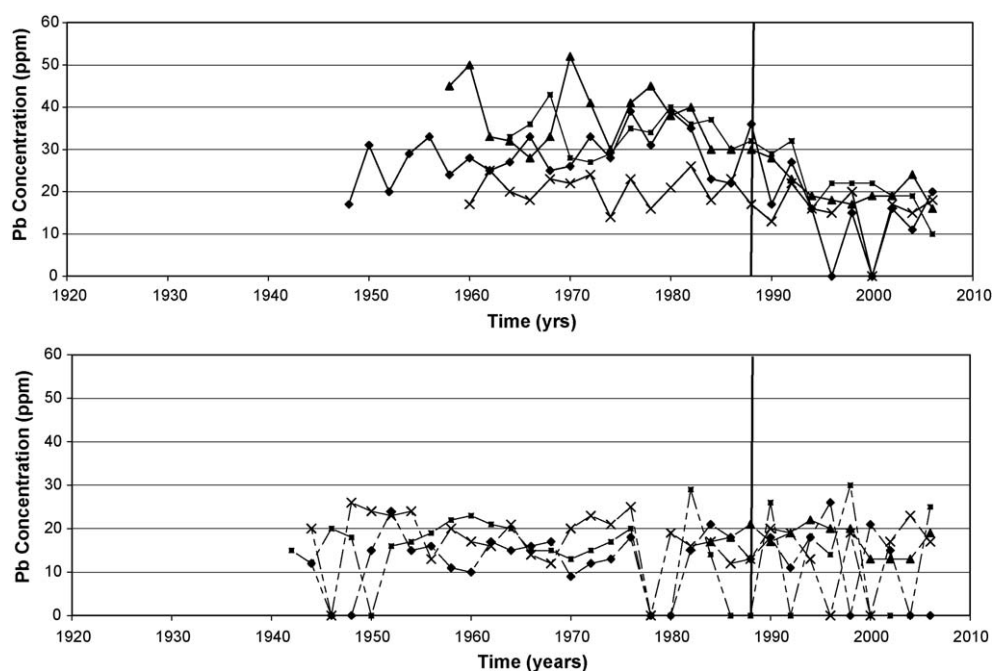
The purpose of this experiment was to compare the metal-uptake ability of the most abundant hardwood tree species found in Sydney (*B. papyrifera*) with that of the most common softwood species (*L. laricina*). The Project II test was conducted to determine which should be the focal tree species for a future project of generating a pollution map through time in Sydney.

*Methods*

*Dendrochronological methodology*

In Project II, instead of sampling the coke oven site, birch and larch from the five sites in each quadrant were measured and the age of each tree at diameter breast height (1.3 m) was obtained (Table 1). Each core measured, was first glued into a slotted mounting board and sanded to a fine polish (600 grit). The ring widths of the cores were measured using a 63× light microscope coupled to a Velmex stage measuring system, which measured annual tree rings to a precision of 0.001 mm. This measurement provided information on both the age of the core and the tree's annual radial growth rate. The oldest trees of each species were then used in the remaining EDXRF procedure.

To prepare for the EDXRF procedure, the unmounted second core was aligned against the fully prepared and sanded first core. The parallel extraction of cores from the trees allowed for an easily



**Fig. 5.** Lead concentrations analyzed using EDXRF for one birch (top graph) and one larch (bottom graph) tree core from each quadrant of the study site. Larch and birch from the same quadrant have the same style of data point marker (northeast quadrant = diamond markers northwest quadrant = triangle markers, southwest quadrant = square markers and southeast quadrant = "X" markers). The bold vertical line marks 1988, the year the coke ovens were shut down.

detectable similarity in ring widths. The polished core was therefore used as a template to determine ring boundaries under the microscope on the unprepared core. Ring boundaries were located on the unprepared cores, which then were cut in two-year segments using a sterile scalpel blade.

In total, the eight oldest cores from the four quadrants (four birch and four larch) were cut into biannual segments to be analyzed by EDXRF. The larch and birch within each quadrant were generally taken from the same site to maintain consistency of local emission concentrations through time. The exception was in the northeast quadrant, where larch was from one site and the birch was from another site 2.4 km away.

#### Energy dispersive X-ray fluorescence methodology

EDXRF analysis was undertaken in a similar manner as in Project I. This time the segments analyzed were biannual segments and each segment was analyzed for 3 min, not 5. The shorter run time allowed for relatively high precision while maximizing the number of segments analyzed. Due to the shorter measurement time and the smaller size of segments, elemental detection limits were higher for Project II. Limits of detection were defined using the  $3\sigma$  calculation method, and varied slightly between different segments. Average limits of detection for lead and zinc in both birch and larch cores are presented in Table 2.

#### Results

Lead and zinc values are shown in the final results, as they were the only two metals consistently detected.

**Table 2**

Values for the limit of detection (LOD) of lead and zinc for birch and larch cores.

Limit of detection	Lead (ppm)	Zinc (ppm)
Birch	12	18
Larch	13	13

#### Pollutant record length

In terms of record length, the birch provided the longest record, from 1928 to 2006. The birch cores had a common interval dating back 42 years across the four quadrants. Larch cores had segments extending from 1940 to 2006, but all larch cores had a common interval of only 21 years.

#### Lead EDXRF results

All birch exhibited concentrations of lead in a range from 12 to 52 ppm, and only one segment contained a concentration less than the limit of detection (Table 2) for the EDXRF instrument. Larch lead concentrations ranged from 10 to 30 ppm, when excluding the segments, which had a concentration less than the LOD (Fig. 5).

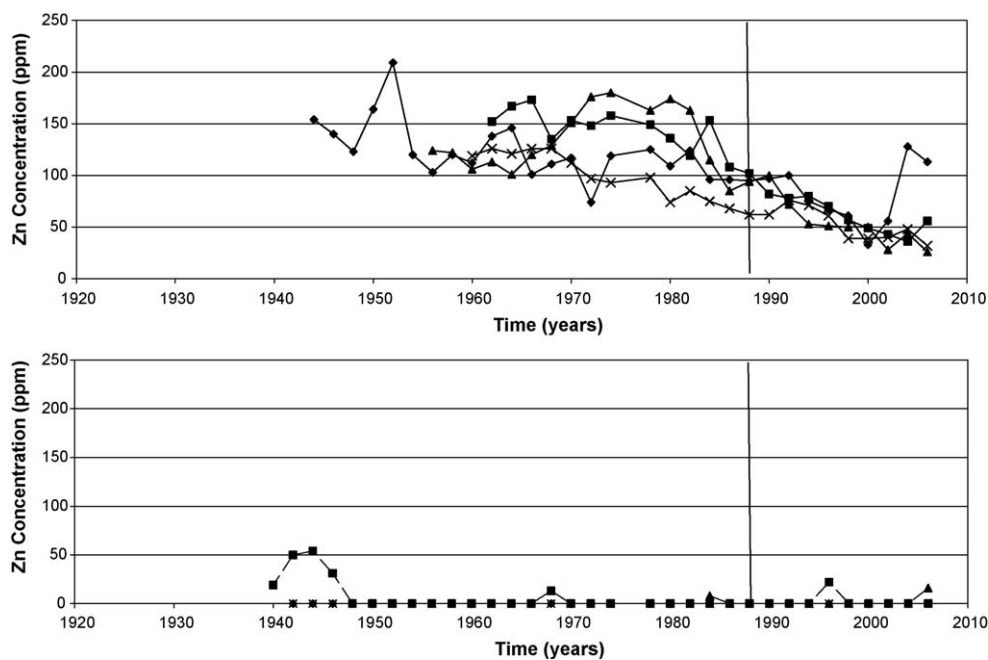
#### Zinc EDXRF results

The zinc concentrations for larch were low in all cores. Almost all segments had zinc concentrations less than the LOD (Fig. 6). Only two larch cores had detectable zinc levels ranging from 8 to 54 ppm. Birch results were in the range of 26–209 ppm, with a decreasing trend to present day in all cores over time (Fig. 6).

#### Discussion

##### Lead

Lead uptake into annual rings divided the larch and birch species into two separate general ranges. Both species had concentrations ranging to 0 due to concentrations less than the LOD (Fig. 5). However, the majority of birch segments exhibited lead concentrations in the 25–45 ppm concentration range. The larch segments generally exhibited a lower range of 10–25 ppm (Fig. 5). Two birch cores illustrated a strong decreasing trend from the late 1960s to 2006. This decreasing trend is not mimicked in the other birch samples, where they are more constant and closer to the larch range of concentration values (Fig. 5).



**Fig. 6.** Zinc concentrations analyzed using EDXRF for one birch (top graph) and one larch (bottom graph) tree core from each quadrant of the study site. Larch and birch from the same quadrant have the same style of data point marker (northeast quadrant = diamond markers, northwest quadrant = triangle markers, southwest quadrant = square markers and southeast quadrant = "X" markers). The bold vertical line marks 1988, the year the coke ovens were shut down.

### Zinc

The EDXRF results were again grouped into two general ranges by species. Larch concentrations were generally below detectable levels, and so clustered near 0 ppm. Birch on the other hand had continually detectable zinc levels in a general range of 30–160 ppm. Two samples strongly exhibited a downward trend through time. The two other birch cores had a less distinct pattern, but seemed to mimic a decreasing overall trend through time.

### Larch–birch comparison

As samples from each quadrant were taken from the same or similar sites, one might expect both species to contain the same concentration of lead and zinc, since their exposure would be approximately the same through time. The distinct groupings within the results between the two species indicate that birch and larch have different metal-uptake abilities.

In each quadrant, the birch samples registered a higher level of lead and zinc than the larch samples. This indicates that with the same exposure to pollution, birch trees incorporate a higher concentration of the metals into their annual rings. This result can probably be best explained by the anatomical differences between hardwood and softwood cell structures. The bulk of the cells in the xylem of softwood trees are tracheids. Hardwood xylem is mostly composed of fibers and vessels. Hardwood fibers have thicker cell walls and fewer pits (for lateral liquid movement) than softwood tracheids. These characteristics of hardwood fibers would allow for less liquid movement between rings, and therefore less metal movement within that liquid between adjacent rings. Hardwoods would be better able to trap the metals taken up in a given year into the annual ring structure. Furthermore, although hardwoods vessels and softwood tracheids are both water conducting cells, the hardwood vessels contain no end walls, allowing for much less upward and downward resistance in a particular ring, but good resistance between rings. More water would therefore be able to move within hardwood vessels of the active growth year ring, leading to more metal uptake in hardwoods in a given year than softwoods with the same exposure to root water pressure levels.

Overall, the birch cellular anatomy would allow for more water and metal mobility in only the current year, and therefore, capture metals into only the current annual ring, compared to larch tissue of the same year (Kramer and Kozłowski, 1979). These differences in anatomy could help explain the difference in metal concentration.

The EDXRF values presented are not calibrated for tree wood and so are not accurate in an absolute sense. However, the relative differences between the values are valid, and indicate strong trends. For example, it cannot be said that the peak value for lead was exactly 52 ppm in the northeast quadrant. However, it can be said that the average difference between birch and larch lead concentrations was approximately 57%, for a given location over the lifetime of the trees. To improve the concentration data, future efforts should be taken to standardize these values. This may be accomplished by analyzing the effect of segment mass and size, or by determining baseline levels of the metals by sampling and analyzing trees taken from isolated, uncontaminated areas.

### Historical trends

Both lead and zinc EDXRF results illustrated a decreasing trend with time (Figs. 5 and 6). This trend is indicative of the known historical pollution in the area. The key year in this trend is 1988, which is when the coke ovens were shut down (Barlow and May, 2000). If a smaller amount of pollutant was emitted for the trees to potentially incorporate into their ring structures, the ring concentrations should continue to decrease after this known year. This seems to be the case, as slow leaching of pollutants out of the soil continues to decrease the amount of encapsulated metal through time.

In the lead analysis, two birch cores illustrated a drop from fluctuating around 40 ppm to fluctuating around 20 ppm after 1988. In the zinc analysis, each core had concentrations over 100 ppm, that steadily decreased after 1988 to values less than 60 ppm. In each case, the fluctuations between each two-year segment were not statistically significant as they were likely due to measurement uncertainties associated with the EDXRF method throughout the

whole length of record. However, the overall decreasing trend was apparent and striking as it matched the expected historical timeline of concentration depletion in Sydney.

In comparing lead and zinc results between the two projects, we found that Project II concentrations were much higher than those from Project I. All samples for Project I were taken from the coke oven site, which is arguably the most polluted location in all the study sites. However, trees sampled from this area had only been growing at the coke ovens since they had been shut down and demolished. Therefore, Project I trees were younger, and not exposed to the same high levels of airborne emissions as trees in the other sites potentially were.

## Conclusion

The main objective of this study was to measure the past metal concentrations of pollutants within the environment of a site by analyzing tree cores using an EDXRF method. In this regard, the results were promising enough that further exploration is warranted.

Two important methodologies have been developed in the course of this study. First, the alignment of core samples for accurate biannual separation has been successfully tested. Second, the use of a portable energy dispersive X-ray fluorescence unit for analyzing samples seems appropriate for large sample numbers due to its time efficient and non-destructive analysis. The two methodologies introduced here aid in reaching the ultimate goal of mapping the pollution both temporally and spatially.

In Project I, it was determined that atomic absorption spectroscopy did not provide a practical method for EDXRF calibration. AAS may be a useful technique for EDXRF calibration, but more samples, time and money are required. Future efforts should be made to standardize the EDXRF values, if they cannot be calibrated directly. Methods for practical standardization include comparing the data to segment mass or baseline concentrations in trees taken from unpolluted areas outside the study site.

Without calibration, the EDXRF values of Project II are not accurate but the relative difference between values is valid and illustrates the promise of the technique. The relative difference between birch and larch illustrate that, for both lead and zinc, the hardwood birch is better able to incorporate these metals into its annual growth.

Using birch as the focal tree species and looking into new methods of standardization, the EDXRF methodology development will continue. A final goal of these developments will be to produce an accurate, long-term map of pollution through the duration of the steel plant's lifetime and over a wider spatial dimension throughout the city of Sydney.

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