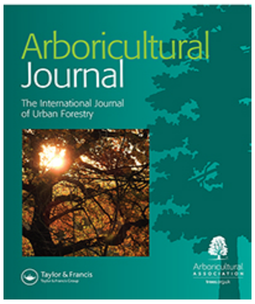

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Can silver and other heavy metal concentrations in leaves be used in order to identify tree root intrusion into sewage systems and storm-water drains?

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ABSTRACT

There is a growing awareness of the value of trees for climate adaptation, human health, and biodiversity in urban spaces, and methods for identifying and calculating the benefits of trees have been developed. However, tree roots frequently intrude into sewer pipes and storm-water drains, causing costly damage. Identifying the individual trees that cause damage would be helpful but has proved difficult. There is a need for non-destructive identification of root intruding trees, in order to evaluate the cost and benefits of individual trees. The concentrations of eight heavy metals (silver, gold, cadmium, lead, palladium, rubidium, antimony, and zinc) and of potassium were evaluated in 19 pairs of trees/shrubs in Malmö, southern Sweden. It was found that the concentrations of silver were approximately 28% higher in leaves from trees whose roots had entered sewers than in control trees. Trees whose roots intruded storm-water drains had slightly higher leaf potassium levels, while the concentrations of other elements did not differ from those in control trees. Thus, it may be possible to use the silver concentration in tree leaves to identify individuals with roots intruding into sewer systems. However, considerable differences were found between species, so further tests are required before the method can be adopted in practice.

KEYWORDS
Leaf concentration; metal uptake; broadleaved trees; urban trees; root growth

Background

Conflicts between urban tree roots and technical infrastructure are well-documented (e.g. Nichols, McCallum, & Lucke, 2017; Randrup, McPherson, & Costello, 2001; Sieghardt et al., 2005). Large trees that cool the environment, shade the ground, support a biodiverse insect and animal community may also intrude into pipes, destroy pavements and crack concrete foundations. The conflicts between the benefits and damage from trees are common and need to be addressed in a comprehensive way. In order to gain insight into this, the value of the individual tree needs to be assessed and compared against the estimated cost of damage caused by that tree.

Urban trees deliver large amounts of ecosystem services and are therefore an important feature of the green structure in cities. Studies have shown that urban trees have positive effects on human health (Bjork et al., 2008), storm-water retention (Bartens, Day,

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Harris, Wynn, & Dove, 2009), urban biodiversity (Kuhn, Brandl, & Klotz, 2004), air quality, and the local climate (Akbari & Konopacki, 2004; Svensson & Eliasson, 1997). Some of these benefits are very difficult to value, while others are easier. Monetary calculations of the value of urban trees are used in practice, and there are a number of available models for estimating the values of urban trees. The approach employed ranges from listing the ecosystem services supplied by trees to modelling the monetary values of trees using the iTree tool developed by the US Forest Service (https://www.itreetools.org/).

Calculations of the cost of damage caused by tree roots to urban infrastructure are less common. Root intrusion into storm drains and sewer pipes is difficult to detect and rectify and results in costly damage (Randrup et al., 2001). For example, the annual cost of root intrusion was estimated to be €6 million in Sweden in 2003 (Orvesten, Kristoffersson, & Stål, 2003) and €28.4 million euro year^{-1} in Germany in 2009 (Bennerscheidt, Stutzel, Strechenbach, & Schmiedener, 2009). The high total costs related to tree root intrusion into sewer systems may encourage sewer system owners to remove large numbers of trees based on economic calculations of the damage alone. There is thus a need for a managerial assessment tool that can calculate the costs for an individual tree, but before this can be applied the trees causing root intrusion needs to be identified. To make a rational decision on which trees to remove and which to save, the balance between costs and benefits needs to be calculated for individual trees. If only the individual trees causing damage can be identified and removed, much can be gained from targeted actions and from the benefits deriving from the remaining trees.

The most likely reason why tree roots enter sewer systems and storm-water drains is to gain access to water and nutrients. Urban trees often face harsh growing conditions in terms of moisture and nutrient availability, compaction, and heat stress. The low soil moisture content in urban soils is mainly due to extensive drainage, high evapotranspiration, low water-holding capacity, and more or less impermeable surface cover (Burghardt, 1994). There is also high spatial variation in nutrient concentrations in urban soils (Pavao-Zuckerman, 2008; Schleuß, Wu, & Blume, 1998), with nutrient-rich old soils mixed with nutrient-poor agricultural soils, earthy fill material, and rubble. Urban soils are often compacted, (Kozlowski, 1999; Randrup, 1997), which further reduces the available water and oxygen (Archer & Smith, 1972) and imparts high physical resistance to root growth (Harris, 1971). Oxygen deprivation is another factor limiting root growth in urban environments (Jim, 1993). However, many of these adverse factors interact and make identification of the most decisive factor difficult.

Previous research on root intrusion into pipes has mainly focused on technical solutions, such as root-proofing and testing of joints between different pipe sections (Lu, Burn, & Whittle, 2000; Stål, Rolf, & Ridgers, 2005), development of liner material to mend pipes from the inside, and different mechanical and chemical methods for removing roots once they are inside pipes.

Most roots enter pipes through cracks and defective joints (Randrup et al., 2001). It has been found that plant roots can enter most types of pipes, including storm drains and sewers (Östberg, Martinsson, Stal, & Fransson, 2012). It has also been suggested that roots may force their way into intact joints (Ridgers, Rolf, & Stål, 2006; Stål et al., 2005) but the main entrance route is through cracks and leaky joints. Poplar and willow species are reported to have a higher capacity for root intrusion than other tree species

(Orvesten et al., 2003), but the roots of many tree species and some bushes are able to enter pipes (Östberg et al., 2012).

According to Swedish standards, a sewer pipe joint needs to resist a pressure of 0.55 MPa (Ridgers et al., 2006). However, an oak root can exert a radial pressure of 1.23 MPa (Strechenbach, Bennerscheidt, & Stutzel, 2009), which is more than twice the pressure pipe joints are designed to resist. This large discrepancy indicates that root intrusion can potentially be achieved by many different tree species (Ridgers et al., 2006).

This study develops a method to identify individual trees causing root intrusion into sewer pipes and storm-water drains. With increasing awareness of the value of urban trees, identification of trees that cause damage is very important, so that trees are not removed unnecessarily. An accurate method for identifying the individual trees responsible for root intrusion into pipes would also enable studies of the factors behind root intrusions and the ability of different species to cause root intrusions. This could result in the formulation of effective measures to reduce the risk of tree roots entering pipes.

Theoretical background

The chemistry of the plant reflects the chemistry of the water taken up by the plant. Consequently, tissue from a tree that uses the contents of a sewer or storm-water pipe as a source of water and nutrients will reflect the chemistry of that source. Heavy metals are suitable candidates to analyse in plant tissue in order to monitor the concentrations in the soil or other growth media. The heavy metals in sewage and storm-water originate from the products used and produced by humans in the area these systems serve, and thus the concentration may vary widely between different cities and different areas of a city. If a tree root has entered a pipe, the tree will take up any metals present in the pipe contents and will thus have higher concentrations of these metals than non-intruding trees.

One heavy metal that is present in sewage and is generally very rare in soils is silver. Silver is taken up by plants, although the uptake is normally very low (Krizkova et al., 2008; Ratte, 1999), and may be toxic to poplar cuttings at 1 mg L^{-1} and to *Arabidopsis* seedlings at 0.05 mg L^{-1} (Wang et al., 2013). The use of silver has increased in recent years, due to its growing use as a disinfectant in, e.g. sportswear. The silver released during washing of clothes and in showers is transported to the sewage system. Silver can be enriched to some extent in urban soils compared with rural soils, due to historical use in, e.g. the photographic industry (Andersson & Ladenberger, 2010), but in most areas, the silver concentration is higher in sewer contents than in urban soils. In addition, there is a constant supply in sewers, compared with the static level in soils, resulting in the available amount of silver being much higher in sewer contents than in soils.

Rare earth metals, such as elements of the platinum group (rubidium and platinum), might be used to identify individual trees causing root intrusion into storm-water pipes (Ek, Morrison, & Rauch, 2004). The main source of rubidium and platinum in the urban environment is from the use of catalysts in car engines. The rare earth metals are very stable and not toxic, properties which make them suitable for monitoring uptake from storm-water sources.

The aim of this study was to find a method for identifying tree individuals that have roots intruding into sewer systems and storm-water drains. The hypotheses tested were that: 1) leaves of trees that have their roots in sewer pipes have higher

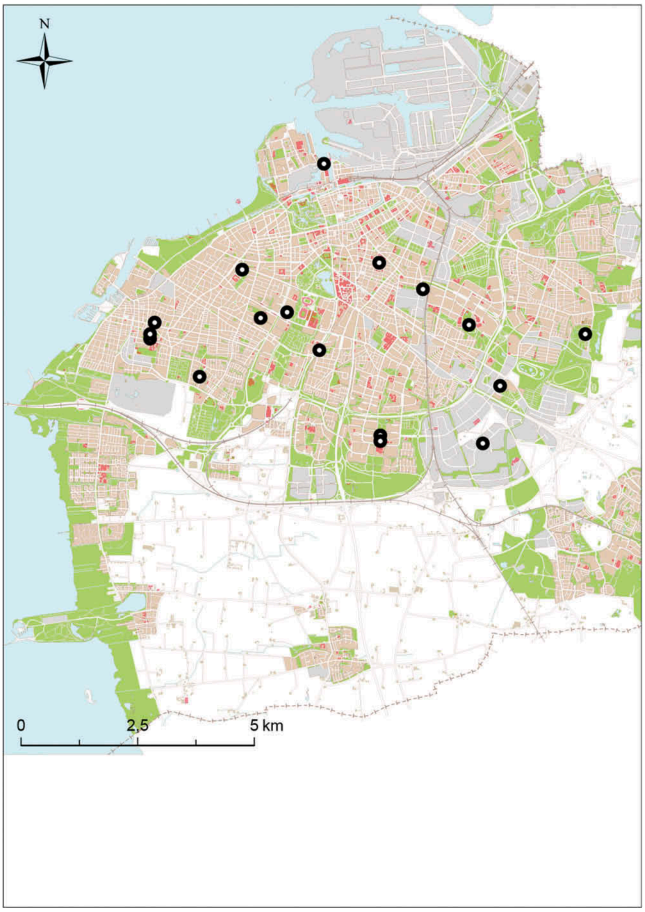

Figure 1. Site map of Malmö, Sweden showing the location of the sampled trees.

concentrations of silver than leaves of trees whose roots have not entered sewers; and 2) leaves of trees that have their roots in storm-water drains have higher concentrations of platinum and rubidium than leaves of trees whose roots have not entered storm-water drains.

Materials and methods

Site and tree selection

The study was performed in a paired design, where trees were chosen using a database of the trees in Malmö, Sweden (55°36′N, 13°0′E). The Malmö tree database contains information on the location of the trees and the tree species, and is linked to a map of the location of confirmed root intrusions recorded using internal filming of the pipes. The recording is done during a continuous inspection of pipe conditions and is part of Malmö city authority's management regime. Nineteen detected root intrusions were chosen as the basis for the present study. Trees or bushes were considered likely to have caused root intrusion if they were located in close proximity (within 1 m) to a confirmed

Figure 2. Example screen-shots from the Malmö tree database.

root intrusion and if there were no other trees within 15 m of the root intrusion. As a control, a second tree or bush of the same species and of similar age, growing under similar conditions, was selected to represent the control in the pair (Table 1). The control individual was always located at a distance from the point of the root intrusion and with the sampled tree located between it and the intrusion point, to ensure that the roots of the control had not reached the pipe.

Most individuals selected were of white willow (*Salix alba*), which is one of the most common tree/bush species in Malmö. The size and age of the selected trees and bushes varied, but they were all well established and had been growing at the site for more than 5 years. Of the 19 cases of root intrusion included in the study, nine were intrusions into sewers and 10 were intrusions into storm-water drains, with a pair of trees selected in each case. Ten different plant species were included in the study: Swedish whitebeam (*Sorbus intermedia*), horse chestnut (*Aesculus hippocastanum*), ash (*Fraxinus excelsior*), black poplar (*Populus* x *canadensis*), bush rose (*Rosa* sp.), plane (*Platanus* × *hispanica)*, lilac (*Syringa vulgaris)*, sweet cherry (*Prunus avium*), rowan (*Sorbus aucuparia*), and white willow (*Salix alba*).

Site and tree information

All storm-water drains at the intrusion sites were made from concrete, while the sewer pipes were made from concrete or PVC, although one very old sewer pipe was made from clay (Table 1). The location of the sites and the ground cover were recorded on-site. The ground cover was hard surface asphalt/concrete slabs, or grass (Table 1). Eight sites were situated in residential areas close to a school or a kindergarten, four were situated

Table 1. Description of the trees included in the study and their surrounding environment: Site, species, location, size at sampling (circumference at 1 m above ground), surface cover, pipe type, and pipe material (Cnc – concrete, PVC- polyvinylchloride, Clay).

Site	Species	Location	Stem circum-ference (cm)	Surface cover	Pipe type	Pipe material
Brodda park	White willow	Park	30	Grass	Storm-water	Cnc
Madrialgången	Rowan	Cycle path	10	Grass	Storm-water	Cnc
Mottettens förskola	White willow	Pre-school	50	Grass	Storm-water	Cnc
Ärtholm/pildam	Poplar	Next to road	40	Grass	Storm-water	Cnc
Kyrkrosvägen	Horse chestnut	Biking path	17	Grass	Storm-water	Cnc
Bellevue allé	White willow *	Park Biking path	20	Grass	Storm-water	Cnc
Bellevue skola	London plane	Pre-school	40	Grass	Storm-water	Cnc
Agnesfridsvägen	White willow	Next to road	25	Hard cover	Storm-water	Cnc
Kantyxegatan	White willow	Next to road	35	Hard cover	Storm-water	Cnc
Högaholmsförskola	White willow	Pre-school	Bush	Grass	Storm-water	Cnc
Bergaskolan	London plane	School yard	50	Hard cover	Sewer	PVC
Bergaskolan	Lilac	Bike parking	Bush	Grass	Sewer	Cnc
Husie Kyrkoväg	White willow *	Cycle path/ school yard	40	Grass	Sewer	Cnc
Annelundsskolan	White willow	Pre-school	30	Grass	Sewer	Cnc
Rosengårdsskolan	Roses	School yard	Bush	Hard cover	Sewer	Cnc
Linneskolan	Sweet cherry	School yard	20	Hard cover	Sewer	Clay
Malmö Högskola	Swedish whitebeam	Next to road	15-25	Hard cover	Sewer	Cnc
Folkparken	Horse chestnut	Park	35	Grass	Sewer	PVC
Slottsstaden	Ash	School yard	25	Hard cover	Sewer	Cnc

**pruned*

alongside a small cycle path, four were situated next to a road, and two were in a park. The pipes were located at depths between 1 m and 3 m, and were between 150 and 300 mm in diameter.

Pre sampling and leaf analysis

Initially, an extended analysis of silver (Ag), gold (Au), cadmium (Cd), potassium (K), phosphorus (P), lead (Pb), palladium (Pd), platinum (Pt), rubidium (Rb), antimony (Sb), and zinc (Zn) concentrations were performed on a few leaf samples from trees that had caused root intrusions, in order to select relevant elements for further analyses. All elements apart from platinum were detected in the leaves, but the phosphorus, palladium, and antimony concentrations were either below the detection limit or not considered relevant based on the results of the initial analysis, and were therefore removed from the study.

Main leaf sampling and analysis

Leaves were collected from the south-facing, sun-exposed part of the crown of each tree/bush on 23 September 2010. In a few cases, leaves had to be collected from a slightly different direction for practical reasons, but sun-exposed leaves were always collected. The leaves were washed using distilled water on-site to remove any deposits that might interfere with the analysis. At the laboratory, the leaves were dried at 70°C for a minimum of 3 days to constant weight and stored at 40°C until analysis. For the analysis, the leaf samples were dissolved in concentrated nitric acid using a microwave oven and then analysed (ICP-MS, Perkin Elmer) for the elements identified as relevant in the initial analysis.

Data on the concentrations of silver, gold, cadmium, lead, rubidium, and zinc, and on the potassium concentration in the surface soil at 11 sites close to the trees, were taken from an earlier study (Andersson & Ladenberger, 2010). Soil samples in that study were collected under the rootzone, at approximately 2–15 cm depth depending on the depth of the root zone at the site. The samples were extracted using nitric acid (7 M) and analysed for the total content of the elements using ICP-MS (Perkin Elmer).

Data treatment and statistics

Differences in leaf concentrations of elements between trees whose roots had intruded into sewer pipes or stormwater drains and their paired control trees were tested using paired t-tests. Differences in concentrations of elements between trees whose roots had entered sewer pipes and trees whose roots that entered storm-water drains were also tested using paired t-tests. The relationship between heavy metal levels in soil and in leaves was tested using linear regression. The relationship between heavy metal levels in leaves from trees with roots growing into sewers or storm-water pipes and surface cover at the growing site (grass or hardcover) was analysed using t-test. All statistical analyses were performed using SPSS 22.0, (IBM statistics).

Results

Intrusions into sewer pipes

Leaves from trees whose roots had entered sewer pipes had higher silver concentrations (0.0091 ± 0.0041 µg Ag g^{-1} dw) than leaves from control trees (0.0071 ± 0.0030 µg g^{-1} dw, Table 2). The silver concentrations in leaves from trees with roots intruding into sewer pipes were also significantly higher ($p = 0.036$, t-test) than those in leaves from trees with roots intruding into storm drains (0.0049 ± 0.0013 µg g^{-1} dw).

Intrusions into storm drains

The concentrations of the different elements analysed did not differ significantly between trees that had entered storm drains and their paired control trees (Table 3). Moreover, ground cover had no impact on the amount of potassium taken up by these trees (ANOVA $p = 0.48$, Kruskal–Wallis non-parametric test $p = 0.32$). However, there were higher potassium ($p = 0.046$), cadmium ($p = 0.021$), and zinc ($p = 0.032$) concentrations in leaves of trees whose roots had entered storm drains than in leaves of trees whose roots had entered sewer pipes. A similar trend was detected for the control trees, with higher levels of Cd ($p = 0.030$) in control trees close to storm drains than in control trees close to sewer pipes, and there was an indication of differences in the potassium level ($p = 0.067$) and zinc level ($p = 0.056$). The leaf potassium concentration in control trees close to sewer pipes varied between 4.9 and 13.9 mg g^{-1} dw and the leaf potassium variation in trees causing root intrusion into sewers was between 5.4 and 13.5 mg g^{-1} dw. The leaf potassium concentration in the trees close to storm drains varied between 8.3 and

Table 2. Mean metal concentration (μg g^{-1}) in leaves from urban trees causing root intrusions into sewers or storm-water pipes and control trees of the same species and similar age. Mean difference between intruding and control trees, and between trees intruding into sewers and storm-water pipes, and the p-values (paired t-test).

					Sewer vs. Storm water	
Sewer	Control	Intruding	Paired difference	p-value	Control	p-value
Silver	0.0071 ± 0.003	0.0091 ± 0.004	0.0020	<0.014	−0.008	0.62 ns
Gold	0.033 ± 0.035	0.024 ± 0.017	−0.009	0.21 ns	0.013	0.26 ns
Cadmium	0.26 ± 0.47	0.20 ± 0.38	−0.06	0.26 ns	−0.95	0.03
Lead	0.019 ± 0.018	0.015 ± 0.012	−0.004	0.39 ns	−0.95	0.49 ns
Rubidium	6.1 ± 5.2	5.9 ± 3.9	−0.20	0.84 ns	−0.99	0.78 ns
Zinc	47.39 ± 56.8	33.5 ± 25.6	−13.85	0.38 ns	−79.8	*0.056*
Potassium (mg g^{-1})	9.8 ± 3.4	10.1 ± 3.5	0.3	0.55 ns	−3.3	*0.067*
Storm-water					**Intruding**	
Silver	0.0085 ± 0.0087	0.0049 ± 0.001	−0.003	0.66 ns	0.004	0.04
Gold	0.020 ± 0.015	0.016 ± 0.010	−0.002	0.49 ns	0.007	0.24 ns
Cadmium	1.21 ± 0.95	1.10 ± 0.88	−0.094	0.24 ns	−0.91	0.02
Lead	0.06 ± 0.17	0.11 ± 0.17	0.042	0.09 ns	−0.09	0.13 ns
Rubidium	7.09 ± 3.2	7.74 ± 3.80	0.567	0.52 ns	−1.83	0.47 ns
Zinc	127.2 ± 84.7	159.4 ± 137.9	28.3	0.29 ns	−125	0.03
Potassium (mg g^{-1})	13.1 ± 2.3	14.4 ± 3.9	1.2	0.36 ns	−4.36	0.04

ns (non-significant)

Table 3. Mean silver concentration in different species of trees growing in urban soils in the City of Malmö, Sweden.

Species	Number of individuals	Silver concentration ($\mu g\ g^{-1}$)
Swedish whitebeam	2	0.014
Horse chestnut	4	0.010
Ash	2	0.009
Willow	16	0.006
Sweet cherry	2	0.006
Lilac	2	0.006
Rowan	2	0.005
Poplar	2	0.005
Rose	2	0.004
Plane	4	0.004

17.7 mg g^{-1} dw, and in trees with roots entering storm drains potassium concentrations varied between 8.3 and 20.8 mg g^{-1} dw.

Differences between tree species

There was a positive relationship between the concentration of silver in soil and that in tree leaves when one outlier tree was removed from the analysis (Figure 3). With the outlier removed, 53% of the variation in leaf silver concentration was attributable to differences in the soil silver concentration, while when the outlier was included only 14% of the variation in leaf silver concentration was explained by the soil concentration. It was found that different tree species took up silver to differing extents (Table 3). However, the number of replicates was very low and this finding should be treated with caution.

Discussion

Leaf silver concentrations were found to be 28% higher in trees and bushes whose roots had entered a sewer pipe than in other non-intruding trees of the same species growing under similar conditions. This 28% difference can be considered rather reliable under the prevailing study conditions relative to the variation in soil silver concentrations. Thus, an elevated silver concentration in the leaves of a city tree indicates that the tree's roots have entered a sewer pipe. This method may, therefore, be used to identify trees and bushes causing root intrusion into belowground infrastructure. The method has the advantage that is not destructive and can be applied without damaging the plants or the pipes.

The difference in leaf silver concentration between trees and bushes with their roots in sewer pipes and their controls was statistically verified, although this should be considered in relation to the difference between different species. For example, leaf silver concentrations were 50% higher in willow and horse chestnut than in a plane. Thus, the differences in silver uptake between plant species need to be corrected for when identifying root-intruding plants using this method. Unfortunately, reliable data on silver concentrations in different plant species are scarce. One study has reported average uptake of silver to be approximately 1 mg/kg (Sagiroglu, Sasmaz, & Sen, 2006),

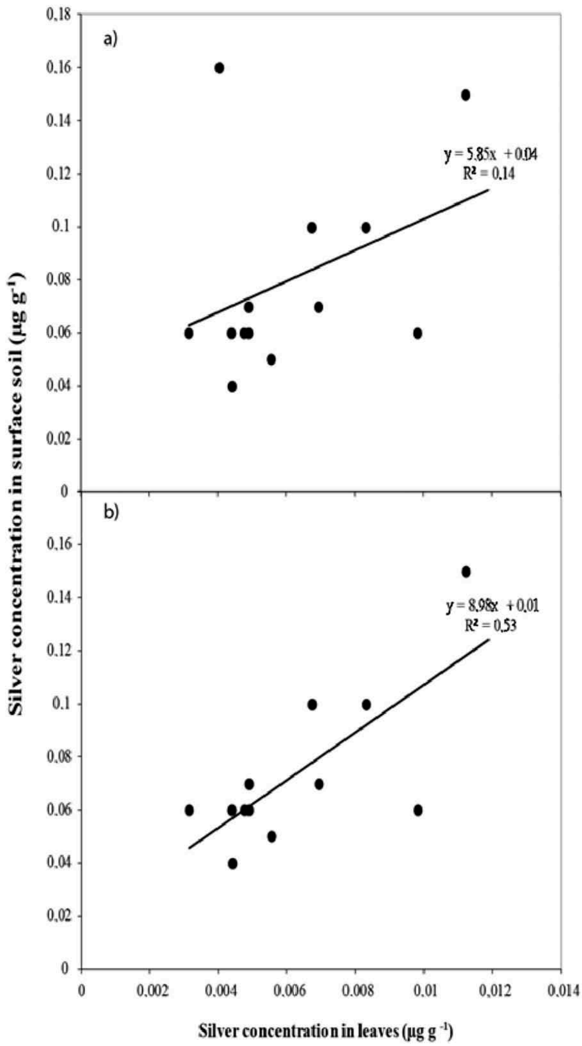

Figure 3. (a) The relationship between the silver concentration in leaves of woody species growing in urban soils in Malmö and the silver concentration in surface soil near the tree growing sites. (b) The corresponding relationship with one outlier tree removed from the analysis.

while another shows a silver uptake of 126 mg/kg (Anderson, Stewart, Wreesmann, Smith, & Meech, 2003). Moreover, the uptake in both these studies was induced using chelating agents and is most likely far above the uptake levels found under normal conditions. Hyper-accumulation of silver in *Brassica juncea* and *Medicago sativa* has been reported, with *Brassica juncea* accumulating up to 12.4 wt-% silver and *Medicago sativa* up to 13.6 wt-% under favourable conditions and with high availability of silver in the growth medium (Harris & Bali, 2008). The leaf concentrations (<0.001 mg/kg) detected in that study were much lower and the potential variation among plant species was higher than in the present study.

To make this identification method useful in practice, we would need to create a database on silver levels in different tree species growing in urban soils, to enable educated comparisons of the silver concentrations in different tree and bushes and identify the root-intruding specimens. An alternative approach would be to take additional samples from a reference tree in the same environment as the potentially damaging tree.

The silver levels found in the leaves of trees and bushes responsible for root intrusions were lower than levels reported previously in plants growing on soils fertilised with sewage sludge. The silver concentration in willow growing in sludge was 0.012–0.014 μg g^{-1} dw (Hasselgren, 2008), which is almost twice as high as the concentrations in the urban trees analysed in the present study. However, in the study by Hasselgren (2008) the soil silver concentration was 10 times higher than the concentration in the leaves. In a study of beech trees growing in a forest soil, the concentration of silver in the leaves varied from 0.019 μg g^{-1} dw early and to 0.008 μg g^{-1} dw in late August (re-calculated from Tyler & Olsson, 2006). In a study of *Picea abies* and *Abies sibirica* growing in unfertilised forest soil, the silver levels reported for leaves are similar or even slightly higher than those in the present study, e.g. the needles contained 0.01 μg g^{-1} dw (Silkina & Vinokurova, 2009). In *Abies fabri* growing on acid soils along an altitudinal gradient, the leaf concentration of silver was 0.015 μg g^{-1} dw (Sun et al., 2011), indicating that soil pH is an important factor for silver uptake. Hyper-accumulating native Turkish tree species (*Euphorbia macroclada, Verbascum cheiranthifolium* Boiss, and *Astragalus gummife*) were shown to have higher twig and root concentrations of silver, up to 0.5 μg g^{-1} biomass (Sagiroglu et al., 2006).

Soils in urban Malmö exhibit a larger variation in silver concentrations than soils in the rural surroundings (Andersson & Ladenberger, 2010). This variation in silver concentrations in urban soils could interfere with leaf silver analysis and must be considered when attempting to identify trees and bushes causing root intrusion. The silver content in surface urban soil in Malmö varies between 0.04 and 0.17 mg kg^{-1} soil, with extreme values of 0.33 and 0.56 mg kg^{-1} soil. These levels are comparable to those reported for sewage sludge-fertilised soil in the study by Hasselgren (2008). The large variation is probably due to a patchy pollution pattern and perhaps also to high variation in pH. Analysis of the soil in combination with leaf sampling is thus very important, so that the silver content in the soil can be taken into account. However, the interference from soil silver concentrations could be compensated for by deducting the concentration in a control tree that has no contact with any sewer pipe, but growing in a similar soil, from the concentration determined in the tree under investigation. An alternative approach is to take a soil sample at the same time as the leaf samples and compensate for the uptake from the soil. To conclude, this method needs to be refined before it can be used in practice.

It was found that trees and bushes with roots intruding into storm-water drains could not be identified from their leaf platinum and rubidium concentrations, as the amounts of these rare earth metals taken up are very low and variable. None of the elements tested in this study proved useful for identifying trees and bushes whose roots had intruded into storm-water drains.

The potassium level in leaves was higher when the tree/bush had access to storm-water. Potassium is a very mobile element and is taken up passively by trees via the water uptake, thus it could be expected to be more available if the tree has a continuous supply of storm-water. The potassium levels in leaves of some trees were below the optimum (Bergman, 1988), indicating a potassium deficiency. This lower potassium level could be a result of higher growth rates in the trees causing root intrusion, leading to dilution of potassium in plant tissue.

There were differences in silver uptake among the different tree and bush species analysed. The uptake was also related to the soil silver concentration, and thus the levels in the soil may interfere with the results. Analysing the leaves of control plants to determine background levels and analysing silver concentrations in the soil might help overcome these problems. To conclude, analysing silver levels in leaves in order to identify trees whose roots have entered sewer pipes may be a useful method, but needs to be refined before it can be used in practice. The method would not be viable if the use of silver in commercial products is restricted in the future.

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Disclosure statement

No potential conflict of interest was reported by the author.

Geological information

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Notes on contributor

Ann-Mari Fransson is an associate professor in Plant ecology working with urban trees and soil plant interactions at the Swedish Agricultural University. She received her PhD from Lund University under the supervision of Germud Tyler and Bo Bergkvist. Fransson published a number of papers on nutrient uptake and dynamics in grassland and forest soils and in later years on vegetation in urban green infrastructure and urban forests.

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