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## Test of Tree Core Sampling

# 1 Test of Tree Core Sampling for Screening of Toxic 2 Elements in Soils from a Norwegian Site

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18

## Test of Tree Core Sampling

### 19 **Abstract.**

20 Tree core samples have been used to delineate organic subsurface plumes. In 2009 and 2010,  
21 samples were taken from trees growing on a former dump site in Norway and analyzed for  
22 arsenic(As), cadmium(Cd), chromium(Cr), copper(Cu), nickel(Ni) and zinc(Zn).  
23 Concentrations in soil were in averages 30 mg/kg dw for Zn, 2 mg/kg dw for Cu, and < 1  
24 mg/kg dw for Cd, Cr, As and Ni. The concentrations in wood samples from the polluted test  
25 site were compared to those derived from a reference site. For all except one case, mean  
26 concentrations from the test site were higher than those from the reference site, but the  
27 difference was small and not always significant. Differences between tree species were  
28 usually higher than differences between reference and test site. Furthermore, all these  
29 elements occur naturally, and Cu, Ni and Zn are essential minerals. Thus, all trees will have a  
30 natural background of these elements, and the occurrence alone does not indicate soil  
31 pollution. For the interpretation of the results, a comparison to wood samples from an  
32 unpolluted reference site with same species and similar soil conditions is required. This  
33 makes the tree core screening method less reliable for heavy metals than, e.g., for chlorinated  
34 solvents.

35

36

37

38 **Keywords:** Heavy metal; Soil; Wood; Polluted; Plant uptake; Monitoring

39

40

## **Test of Tree Core Sampling**

### **41 1 Introduction**

42

43 Biomonitoring for heavy metals is an established technique (Markert 1993, Markert et al.  
44 1999). Mosses, lichens, but also trees and tree rings have been sampled to determine the  
45 concentration level of heavy metals in the environment (Gratani, Crescente, and Varone  
46 2008, Markert and Wtorova 1992, Monticelli et al. 2009, Migeon et al. 2009).  
47 Phytoscreening is a new term and was given for the use of vegetation samples to screen  
48 subsurface pollution (Sorek et al. 2008). The technique to take tree cores to track pollution  
49 plumes below surface has been found to be a simple, fast, noninvasive and inexpensive  
50 screening method (Vroblesky, Nietch and Morris 1999, Ma and Burken 2002, Schumacher,  
51 Struckhoff and Burken 2004, Gopalakrishnan et al. 2007, Trapp et al. 2007, Sorek et al.  
52 2008, Larsen et al. 2008). The principle is that roots take up pollutants from soil or shallow  
53 groundwater. With the transpiration stream, the contaminants are transported above the  
54 surface and into the stem, where they adsorb to the wood and other plant parts. Wood is  
55 sampled with a tree corer and analyzed for the pollutants. Elevated concentrations in wood  
56 indicate subsurface contamination (Vrobelsky et al. 1999). The method is rapid, simple,  
57 cheap, and allows a high sample number in short time without heavy equipment. Tree core  
58 sampling is thus seen as a reliable and inexpensive alternative method for investigating and  
59 monitoring the extent of shallow pollutants (Larsen et al. 2008). Subsequently, tree core  
60 sampling was recommended for initial screening of an area (Sorek et al. 2008) and for  
61 assessing the presence of pollutants (Larsen et al. 2008), and the method is used frequently in  
62 practice now (unpublished engineering work). However, so far all studies have dealt with

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63 chlorinated solvents, such as trichloroethylene (trichloroethene, TCE), tetrachloroethene  
64 (PCE) and trichloroethane.

65

66 The purpose of this study was to test the tree core method for toxic elements, such as arsenic  
67 and heavy metals. Arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and  
68 zinc (Zn) are frequent pollutants in soil, mainly from human activities but also from natural  
69 sources. At elevated levels, all these are toxic to humans and wildlife, and their occurrence in  
70 soil is regulated by legal standards in most countries. Their dissolution in soil solution and  
71 the subsequent uptake into vegetation depends on chemical speciation (and thus pH and  
72 redox potential), on organic matter, clay content, and on the concentration of other ions  
73 (Barber 1995, Hough et al. 2004, US EPA 2005, Swartjes et al. 2007, Legind and Trapp  
74 2010). The bioavailable fraction in soils may decrease with time, leading to reduced uptake  
75 (Kirkham 2006). Fungi may facilitate transport to roots (Smith et al. 2010).

76

77 The individual elements may - depending on their xylem or phloem transport - move  
78 preferably into different plant parts, i.e. roots, stem, leaves and fruits (Thorne, Walke and  
79 Maul 2005). Wood was sampled because it is protected from aerial deposition, it is available  
80 throughout the whole year (samples were taken in winter) and it does not change much with  
81 time (as leaves do). A disadvantage is that little is known about the uptake of toxic elements  
82 into wood since most studies focus on edible plant parts such as fruits or leaves. Thus, data  
83 about accumulation of toxic elements in wood are needed, also for an assessment of the  
84 feasibility of phytoextraction.

85

## Test of Tree Core Sampling

86 Wood from trees (mainly birch, willow and poplar) growing on a former dump site was  
87 sampled and analyzed for As, Cd, Cr, Cu, Ni and Zn. The concentrations were compared to  
88 those from trees of the same species growing outside the contaminated area. The objectives  
89 of this study were to determine typical concentration levels in wood and to test the tree core  
90 sampling method for the screening of subsurface pollution with toxic elements (focus on  
91 heavy metals).

92

### 93 2 Methods

94

#### 95 2.1 Test site

96 The *Møringa* (former) dump site near Horten, Norway, is an artificial half-island at the Oslo  
97 fjord created by the dumping of waste. From the 19th century until 1993, it has received  
98 waste oil, oil distillery waste, welding slags, blowing sand and building residues, originating  
99 from ship yards, oil recycling, ship and aircraft maintenance, and lead battery production.  
100 Investigations of the site between 1992 and 2005 (Amundsen et al. 2005) revealed that the  
101 site is contaminated with large amounts of heavy metals, petroleum products, polycyclic  
102 aromatic hydrocarbons and polychlorinated biphenyls. On the site, wild-type pioneer  
103 vegetation consisting of grassland and trees (such as willow, poplar, birch and cherry) has  
104 developed.

105

106 The depth of the waste deposit is approximately 3 m. The cover at the Møringa waste site  
107 consists of 0.2 to 0.5 m clean soil. The concentrations of the elements of interest in this cover  
108 are unknown but it can be assumed that they are close to natural soil (background levels).

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109 All soil samples from the site are composite samples (30-50 kg), where each was taken from  
110 deep (2-4 meters) pits of an area of about 16 m<sup>2</sup> (4 x 4 meter). The main aim of the sampling  
111 in 2004 (Amundsen et al. 2005) was to investigate the leaching potential of toxic elements in  
112 the waste to predict the future influence of the waste site on the local marine environment.  
113 Most waste samples were therefore collected from the lower part between groundwater table  
114 and 1 m above groundwater table, but some were also taken from the upper part of the  
115 deposited waste. Eight risk zones were mapped, each with relatively homogeneous waste  
116 filling (Fig. 1). Concentrations of toxic elements in deposited material from the eastern part  
117 of the landfill (Ø1, Ø2 and Ø3) are significantly higher than in most of the western areas (V4  
118 to V8) (Tab. 1), but the concentration level of pollutants seems to be quite uniform with  
119 depth.

120

121 <Figure 1>

122 <Table 1>

123

### 124 2.2 Tree core sampling

125 Tree core sampling was performed at the Møringa site on the 8<sup>th</sup> and 9<sup>th</sup> of July 2009 and on  
126 the 30<sup>th</sup> of March 2010. Trees were sampled in the eastern part of the site which is densely  
127 covered by trees. Sampled tree species were predominantly birches (*Betula sp.*) and willows  
128 (*Salix caprea*), but included also cherry (*Prunus sp.*), aspen (*Populus tremula*), ash (*Fraxinus*  
129 *excelsior*) and mountain ash (*Sorbus aucuparia*) in the first campaign. Only willow (*Salix*  
130 *caprea*) and poplar (*Populus tremula* and other poplar species) were sampled in the second  
131 campaign. Reference samples were taken 20 to 50 m outside the area of the dump site, and at  
132 a location about 10 km away. All reference samples were closer to urban area (Møringa

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133 peninsula is the remotest place in this area), and contamination from other sources than  
134 dumped waste can not be excluded.

135

136 All tree cores were taken at a stem height of 1 m using a 6 mm increment borer (Suunto,  
137 Finland). Tree cores had a length of 6 cm, where the outer centimeter (containing the bark)  
138 was discarded to avoid atmospheric influence. Only in 2009, the next centimeter (cm 1-2  
139 towards stem center) was used for mixed samples, and cm 2-6 made up an individual sample.  
140 Mixed samples were collected in order to represent subareas, including between 3 and 9  
141 individual tree cores. The aim here was to test whether the analysis of one mixed sample (i.e.  
142 several trees in the area of interest) instead of many individual samples (one per tree) is an  
143 appropriate method for subsurface characterization, as this would save laboratory efforts.  
144 During the second campaign, wood from cm 1 to 5 was used as sample, and two replicates  
145 from each tree were taken.

146

147 2.3 Extraction and chemical analysis

148

149 Soil samples were dried at 40 °C to constant weight, extracted with aqua regia (concentrated  
150 hydrochloric acid: concentrated sulfuric acid 3:1) and analyzed using ICP-AES (Amundsen  
151 et al. 2005).

152

153 Wood samples from the first campaign were extracted using an autoclave. The wood samples  
154 were dried at 75-85 °C to constant weight. Between 0.5 and 0.8 g of the dried sample was  
155 weighed into 100 ml blue cap bottles, then 10 ml 65% HNO<sub>3</sub> and 10 ml miliQ water were



## Test of Tree Core Sampling

156 added. The sample was autoclaved for 30 min at 125 °C and cooled to room temperature  
157 afterwards. 5 ml 30 % H<sub>2</sub>O<sub>2</sub> were added and the sample was placed on a sand bath for 20 min  
158 without cap. The sample was quantitatively transferred to a 50 ml volumetric flask. MiliQ  
159 water was added to the total volume of 50 ml. The flasks were shaken for 1 min and the  
160 sample was then filtered into a plastic (PE) bottle for storage at room temperature. Before  
161 analysis, 7 ml of sample was transferred to a test tube and then analyzed using ICP-OES.

162

163 Some samples of the first campaign had unusually high concentrations of Cu, Ni and Zn, and  
164 we found that the procedure erratically contaminated samples during extraction. Even though  
165 these samples could be identified, the results for Ni and Cu from the first campaign were  
166 discarded (the results for Zn could be used, though with a high DL, because the  
167 concentrations were sufficiently above the laboratory background), and the method was  
168 optimized and changed to sand bath extraction for the second campaign.

169

170 For the sand bath method, wood samples were dried as before. Between 0.5 to 0.8 g of the  
171 dried sample were weighed into a 50 ml volumetric flask. Then 10 ml 65 % HNO<sub>3</sub> was  
172 added, and the flask was placed on a sand bath for 2 hours at 70-80 °C. Samples were then  
173 removed and cooled at room temperature for 10 min. Afterwards, 2.5 ml 30 % H<sub>2</sub>O<sub>2</sub> were  
174 added and the samples were placed back on the sand bath until the gas reaction was  
175 completed. The procedure was repeated with additional 2.5 ml 30 % H<sub>2</sub>O<sub>2</sub>. MiliQ water was  
176 added to get 50 ml volume. After shaking for 1 min, approximately 5 ml of sample were  
177 transferred to a centrifuge glass, shaken and emptied. The rest of the sample was transferred  
178 to the same centrifuge glass and centrifuged for 10 min with 2500 rpm. The supernatant was

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179 transferred to plastic (PE) bottles for storage at room temperature. For analyses, 7 ml of  
180 sample were transferred to test tubes and then analyzed at ICP-OES.

181

182 The methods were validated by comparison to the referenced soil standard QC Loam Soil  
183 (Sigma Aldrich, DK). All concentrations for soil and wood are given for the dry weight  
184 (dw).

185

### 186 2.4 Statistics

187 The main question of the study was whether the concentration of toxic elements in wood  
188 from trees on contaminated sites is elevated, compared to reference sites. This was tested  
189 using a one-tailed t-test with an error probability of 0.05 ( $\alpha = 5\%$ ). The distribution of the  
190 experimental data was tested using the Kolmogorov-Smirnov (KS) test for continuous  
191 distributions, implemented in the software Crystal Ball. Three distributions were tested,  
192 namely normal, log-normal and uniform (rectangular) distribution. The assumption of  
193 equality of sample distribution and tested distribution was rejected if the distance between  
194 both was above a critical distance  $D_{crit}$ . These critical distances were taken from Sachs  
195 (1991). For calculation of mean, standard deviation, minimum, maximum, F-test and t-test,  
196 values below detection limit were replaced by 1/2 detection limit. The data for Ni and Cu  
197 from the first campaign were not statistically analyzed, as well as the results for As from the  
198 second campaign, which were close or below to detection limit.

199

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200 The statistical difference between the measured concentration in the mixed sample and the  
201 concentrations in the corresponding individual samples was tested using the “one-value t-  
202 test” (Bahrenberg, Giese and Nipper 1990). The tested t-value is

203

204 
$$t_{test} = \frac{|x - a|}{s / \sqrt{n}}$$

205

206 hereby, x is the mean of the individual samples ( $n \geq 3$ ) and a is the concentration of the mix  
207 sample ( $n = 1$ , i.e. the fixed value). The null hypothesis  $H_0$  is rejected if  $t_{test}$  is above the t-  
208 distributed  $t_{crit}$  with degree of freedom (df) = n-1 and  $\alpha = 5\%$ .

209

210

## Test of Tree Core Sampling

### 211 3 Results

212

213 Table 2 shows the overall characterization of the wood samples from Møringa. Highest  
214 concentrations were measured for zinc, followed by copper (2<sup>nd</sup> campaign only). The other  
215 elements (As, Cd, Cr, Ni) had similar concentrations, most of them below 1 mg/kg. The  
216 concentration results from the first campaign were typically more log-normal than normal  
217 distributed, which makes a statistical analysis with parametrical methods critical. For all  
218 results from the second campaign, normal distribution could be accepted. The measured  
219 concentration level was for all elements quite similar in campaign one and two. Only  
220 cadmium showed distinctly higher values in wood from the second campaign. The reason is  
221 that exclusively willows and poplars were sampled, and those species showed the highest  
222 cadmium uptake of all trees that were sampled at the site.

223

224 Table 3a shows the comparison of results from reference and test site from the first  
225 campaign. The mean values of arsenic from reference and test site were significantly  
226 different, but it should be noted that all values from the reference site were below DL. The  
227 concentrations of cadmium were far higher in willow wood than in birch wood. The  
228 difference between reference and test site was significant for both birch and willow. For  
229 chromium, concentrations in willow wood were also higher than in birch wood, and elevated  
230 at the test site, though not significant. For zinc, a significant difference was found only for  
231 willow wood, even though concentrations in birch were higher.

232

233 From campaign one, it became obvious that willow and poplar trees took up most elements in  
234 higher concentration than birch, cherry and ash. Also, the difference of concentrations in

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235 wood from the test site, compared to those from the reference site, was more pronounced.  
236 This was the reason to choose willow and poplar, both from the family *Salicaceae*, as  
237 preferred species for the second campaign. In the second campaign (Table 3b), Cu was found  
238 to be significantly increased in the wood from the test site. The concentration for Cd were  
239 elevated in samples from test site for willows and reduced for poplar. Ni and Zn were  
240 elevated in samples from the test site, and only significantly for poplar. The mean  
241 concentrations of Cr were similar in all samples.

242

243 The test for differences between mixed samples taken during the first campaign (cm 1-2, first  
244 campaign only) and the individual samples, by which the mixed sample was composed,  
245 yielded that in about half of the cases there was a significant difference (one-value t-test,  $\alpha =$   
246 5%), and in the others not. Mixed samples can reduce the sample number, but due to the  
247 relatively small differences between trees from reference sites and those from the test site, a  
248 high sample number is preferable, to get better statistics.

249

250 <Table 2>

251 <Table 3 ab>

252

253

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### 254 4 Discussion

255

#### 256 4.1 Differences in uptake between test and reference site

257 The main objective of the study was to test the feasibility of phytoscreening for toxic  
258 elements. This was done by comparing concentrations of As, Cd, Cr, Cu, Ni and Zn in wood  
259 samples from the Møringa dump site (test site) with concentrations in samples from nearby  
260 reference sites. The results (Table 3) show that in all except one case (Cd in poplar wood),  
261 the average concentrations of the investigated toxic elements were higher in wood from the  
262 test site. This is promising. However, the differences were sometimes very small, and  
263 individual trees from the reference site may show much higher content than trees from the  
264 test site. Figure 2 shows some typical results. Figure 2 a (Cr in willow wood) displays a  
265 situation where the mean concentrations in wood from the test site (0.41 mg/kg) is much  
266 higher than those in wood from the reference site (0.24 mg/kg). Still, the second highest  
267 concentration of all samples was measured in wood from a reference tree, and the difference  
268 of the means is statistically not significant (Tab. 3a). Contrary, Figure 2 b (Cu in willow)  
269 shows an example where this difference is statistically significant. Indeed, the concentration  
270 level in wood from the test site is clearly elevated. Nonetheless, individual trees from the  
271 reference site may have concentrations above individual trees from the test site. This  
272 demonstrates that the method - if applied - requires sampling of a many trees to avoid false  
273 conclusions.

274

275 Elevated concentrations of toxic elements in trees from contaminated sites were also reported  
276 by other authors.

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277

278 Arsenic in tree rings was measured and related to pollution by Markovic et al. (2009). The  
279 concentration in individual tree rings varied largely over the years. The average concentration  
280 of arsenic in poplar wood was 12.9 mg/kg in wood from the less polluted and 20.2 mg/kg in  
281 wood from the more polluted site. In a study with birch growing on a chromite processing  
282 waste site and willows growing on a sewage disposal site, Cr was poorly taken up into the  
283 aerial part of the plant (i.e. all values, including wood, were below DL = 5 mg/kg). Cr was  
284 measurable only in the roots. Zinc levels in wood from contaminated sites were above 200  
285 mg/kg (Pulford, Watson and McGregor 2001).

286

287 < Figure 2 ab >

288

### 289 4.2 Differences between tree species

290 The difference between tree species (birch and willow, willow and poplar) was for two heavy  
291 metals (Cd and Cr) larger than the difference between test and reference site. For two heavy  
292 metals (Ni and Zn), the variation due to species was approximately as large as the difference  
293 between the sites, and only for two elements (As and Cu) the site was mainly determining the  
294 concentrations in wood. This means that for a comparison between reference and test site, the  
295 same tree species must be chosen. This will not always be possible.

296

297 Some tree species (e.g., willow) were better suited than others (e.g., birch). In the study of  
298 Migeon et al. (2009), who measured the uptake of heavy metals into 25 tree species growing  
299 on polluted soils, cadmium was highest in Salicaceae family members, identical to our

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300 finding. Under unpolluted conditions, the normal Cd concentration level in plants is 0.1  
301 mg/kg and the maximum is 0.2 mg/kg (Kirkham 2006). In our study, concentrations in wood  
302 were below this range, except for *Salicaceae* (willow and poplar). Large variations between  
303 species were also found at a French site (Migeon et al. 2009) for Cd, Cr and Zn, and less for  
304 Cu. Concentrations varied with age of the tree ring (Monticelli et al. 2009), and Hagemeyer  
305 and Schäfer (1995) found a variation of the concentrations of cadmium, lead and zinc with  
306 season. Riddell-Black, Pulford and Stewart (1997) found a certain natural variability of the  
307 accumulation even within the same species. Arsenic uptake into needle trees was measured  
308 by Haug, Reimer and Cullen (2004). Spruce tree samples from an arsenic-rich site had total  
309 As concentrations between 0.04 and 0.13 mg/kg, i.e., even below the values obtained here,  
310 while concentrations in Douglas pine were much higher, up to 176 mg/kg in stem. The  
311 concentration in new-grown stem was higher than in old stem.

312

313 Copper, nickel and zinc are essential micronutrients. According to Marschner (1995), the  
314 average concentration of copper in plant shoots that is sufficient for adequate growth is 6  
315 mg/kg dw. Concentrations of copper found in wood from Møringa ranged from 0.5 to 5  
316 mg/kg. Average concentration of nickel in plant shoots that are sufficient for adequate  
317 growth are about 0.1 mg/kg (dw). Nickel concentrations in wood from the Møringa site  
318 ranged from 0.12 to 0.75 mg/kg. Zinc concentrations in dry shoot of 20 mg/kg are required  
319 for growth (Marschner 1995). Measured concentrations in wood ranged from < 10 to 97  
320 mg/kg. Plants can not grow without a certain minimum level of these elements (Marschner  
321 1995). The presence of these metals alone can therefore never be a proof for soil or  
322 groundwater pollution. Furthermore, it is likely that the uptake of the essential elements is



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323 enzyme-regulated and thus follows Michaelis-Menten kinetics (Barber 1995, Chen et al.  
324 2008, Trapp et al. 2008). This means that the uptake decreases with higher environmental  
325 concentrations (Markert et al. 1999). It also follows that the concentration differences in  
326 wood will be smaller than those in soil, making the detection of subsurface contamination  
327 from differences in wood concentrations more difficult.

328

### 329 4.3 Limitations

330

331 Concentrations of heavy metals in soil at the Møringa site were determined in a separate  
332 study, and only at few sample points. It is therefore not possible to compare concentrations in  
333 trees to those in soil, i.e., a correlation of concentrations is not possible. Furthermore, the  
334 waste with high pollutant concentrations was covered with a less-polluted layer of soil, which  
335 was thick enough so that the trees probably were not in contact with the more toxic  
336 underground. Only few soil samples were taken from the cover (Tab. 1).

337

338 In order to allow a conclusion on the subsurface pollution level from vegetation samples, the  
339 bioavailability of the toxic elements should not be different. Kirkham (2006) reports that the  
340 pH of the soil is usually the most important factor that controls uptake, with low pH favoring  
341 Cd accumulation. High phosphate and zinc concentrations decrease Cd uptake. The reference  
342 site should thus have very similar conditions to the test site (e.g., soil type, pH, nutrient  
343 supply, tree species, weather), except, of course, the concentrations of toxic elements. This  
344 turned out to be difficult for the Møringa site. A difference in pH is likely, because the waste  
345 at the site was partly mixed with bricks, cement debris etc. which leads to alkaline pH (pH 7

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346 to 9), while normal forest has typically pH 5 to 6. Furthermore, the area along the coast is  
347 densely populated, and urban waste (such as defect TVs) was found all around, also on the  
348 reference area. A fence was close by (eventually releasing zinc, cadmium, nickel and  
349 chromium), and a road. Generally, it will be difficult to find totally unpolluted soils in urban  
350 areas, and thus well-suited reference sites. Also, no soil samples were taken and analyzed  
351 from the reference site, so neither concentrations nor soil conditions are known.

352

353 Concentrations in wood were generally low, typically factor 100 or more lower than  
354 concentrations in soil. At the same time, sample volumes were necessarily small (< 1 g).  
355 Subsequently, the measured concentrations for some elements (As, Ni) were often close to or  
356 even below the detection limit. The use of another analytical instrument (ICP-MS, AAS with  
357 graphite oven) might improve the limit of determination. Also, from this aspect, the  
358 measurement of leaves might be superior, because concentrations are generally higher than in  
359 wood (Vandecasteele et al. 2008, Harada et al. 2010). On the other hand, atmospheric  
360 deposition is often an important source for heavy metals in leaves (Gratani et al. 2008) and  
361 could disturb the phytoscreening. Indeed, atmospheric deposition (Gratani et al. 2008, Legind  
362 and Trapp 2010) could be one reason for the often small difference of concentrations in  
363 samples from test- and reference site.

364

365 Toxic elements are also toxic to trees (Marschner 1995). Perhaps, trees avoid growth in  
366 polluted soil and extend their roots preferably into cleaner soil areas. Also, maybe trees  
367 cannot grow at all in highly polluted soils, which mean in turn that trees cannot be used as  
368 indicator for such high pollution. The method is therefore restricted to a certain concentration

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369 range, limited by detection limit at the lower end and by severe toxic effects at the higher  
370 end.

371

372 Uptake from soil into roots is most likely from the bioavailable pool (McLaughlin 2002).  
373 This means, elevated levels in wood do not necessarily indicate elevated total concentrations  
374 in soil. This can, of course, also be seen as an advantage of the method, because it directly  
375 tracks the fraction of the chemical that is freely available for uptake, toxicity and leaching.  
376 Legal standards, however, are typically based on total concentration in soil, e.g., in Denmark  
377 (Miljøstyrelsen 2009).

378

379 Toxic metals reside often in soil layers close to the surface and are therefore available for  
380 hand-driven borers. It is probably easier and more certain to determine the heavy metal  
381 concentrations of soil samples, instead of using the indirect analysis of wood samples. On the  
382 other hand, trees do integrate over a large volume (up to  $> 100 \text{ m}^3$  root zone per tree) and  
383 smooth out inhomogenities of soil contamination. Also, they yield directly the bioavailable  
384 (and thus toxic and mobile) fraction.

385

## 386 **5 Conclusions**

387

388 We tested phytoscreening of toxic elements and heavy metals for an abandoned waste site,  
389 by comparing concentrations in wood samples from the test site with concentrations in  
390 samples from reference sites. In all except one case, the concentrations of the investigated  
391 toxic elements were higher in wood from the test site. However, toxic elements occur in

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392 higher or lower amounts in any soil. Subsequently, the elements were also present in  
393 reference samples. The uptake underlies natural variations and depends on tree species and  
394 soil properties. Consequently, the differences between contaminated test site and (nominally)  
395 unpolluted reference site were not always statistically significant.

396

397 Although it is too early to judge the feasibility of the tree core method for toxic metals, it  
398 became already apparent that the method is more difficult to use than for chlorinated  
399 solvents, which are purely anthropogenic compounds. In particular, the occurrence of a toxic  
400 element in wood alone can not be used as criterion for subsurface pollution, a statistically  
401 sound comparison to samples from a well-suited reference site (same tree species, same age,  
402 similar soil properties, non-polluted) is necessary. This increases the efforts and the  
403 uncertainty of the method.

404

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409

410

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## Test of Tree Core Sampling

547 Tables and Figures

548

549 **Table 1.** Total concentration in soil (mg/kg) measured at Møringa (Amundsen et al. 2005).

Sample	As	Cd	Cr	Cu	Ni	Zn
Ø1-2	61	14	200	1500	130	7300
Ø1-1+2	69	20	170	1700	120	5100
Ø2-1+2+3	75	16	170	3700	190	9800
Ø2-4+5	15	2.2	49	860	42	3900
Ø3-1+3	44	8	130	2500	120	6000
Ø3-2+4	28	9.5	76	1400	120	3000
V4 bottom	5	1.3	81	3700	160	540
V4 sand	5	0.2	71	76	560	450
V5 bottom	21	3.9	100	4000	63	3900
V5 top	15	3	99	1100	88	11000
V6-1+2+3	5	1.4	58	280	410	1000
V6-4+5	5	0.2	110	18	2300	320
V 7 1+2	5	0.9	92	140	460	790
V 7 4+5	5	1.8	150	940	260	1400

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## Test of Tree Core Sampling

553 **Table 2.** Description of the the wood samples from Møringa, first campaign (n = 71) and second  
554 campaign (n = 68). Concentrations in mg/kg dry weight; std = standard deviation; min = minimum;  
555 max = maximum; DL = detection limit (mg/kg dw); <DL =number of samples below DL.

Element	Campaign	mean	std	min	max	DL	<DL
As	1	0.32	0.24	0.23	1.64	0.45	57
Cd	1	0.18	0.26	0.015	1.01	0.03	30
Cd	2	0.66	0.31	0.15	1.49	0.03	0
Cr	1	0.23	0.26	0.06	1.94	0.04	0
Cr	2	0.40	0.26	0.06	1.17	0.11	3
Cu	2	2.17	1.06	0.49	5.28	0.97	1
Ni	2	0.29	0.17	0.12	0.75	0.24	23
Zn	1	28.6	18.0	4.1	92.6	8.1	6
Zn	2	33.1	13.5	14.2	96.9	0.48	0

556

557

## Test of Tree Core Sampling

558 **Table 3a.** Mean of measured concentrations (mg/kg dw) of elements in wood samples from Møringa,  
 559 first campaign; R is reference site (nominally low polluted) and T is test site (high polluted). Significant  
 560 differences in bold ( $\alpha = 5\%$ ).

	all trees n = 71		birch n = 34		willow n = 16	
	R	T	R	T	R	T
As	0.23	<b>0.39</b>	0.23	<b>0.32</b>	0.23	<b>0.47</b>
Cd	0.14	0.18	0.015	<b>0.035</b>	0.33	<b>0.71</b>
Cr	0.19	0.26	0.13	0.15	0.24	0.41
Zn	25.4	30.0	33.1	39.8	15.0	<b>24.7</b>

561

562

563 **Table 3b.** Mean of measured concentrations (mg/kg dw) of elements in wood samples from Møringa,  
 564 second campaign; R is reference site (nominally low polluted) and T is test site (high polluted).  
 565 Significant differences in bold ( $\alpha = 5\%$ ) or italic ( $\alpha = 10\%$ ).

	willow n = 44		poplar n = 24	
	R	T	R	T
Cd	0.69	0.76	<i>0.62</i>	0.51
Cr	0.34	0.35	0.48	0.49
Cu	1.95	<b>3.05</b>	1.33	<b>1.66</b>
Ni	0.29	0.34	0.14	<b>0.29</b>
Zn	32.0	36.4	27.0	32.5

566

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568

## Test of Tree Core Sampling

569 Figure legends

570

571 **Figure 1.** Map of the Møringa peninsula with risk zones and soil sampling points (Amundsen et al.  
572 2005) and areas of tree core sampling, July 2009 and March 2010.

573

574 **Figure 2.** Example results from the tree core analysis (mg/kg dw); top: Cr in willow wood (1<sup>st</sup>  
575 campaign); below: Cu in willow wood (2<sup>nd</sup> campaign). x-axis indicates location of trees (Fig. 1): Ref  
576 refers to reference site; Ø refers to eastern part of the site, V to western part. Results from individual  
577 replicates are shown.

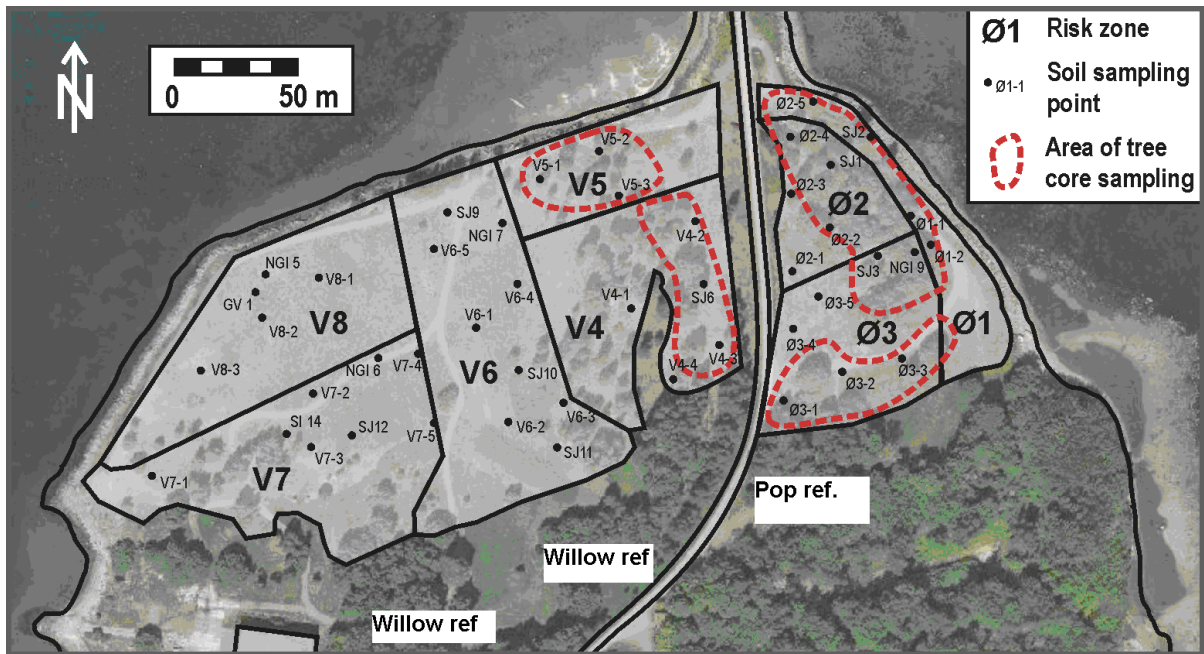
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# Test of Tree Core Sampling

580 Figures

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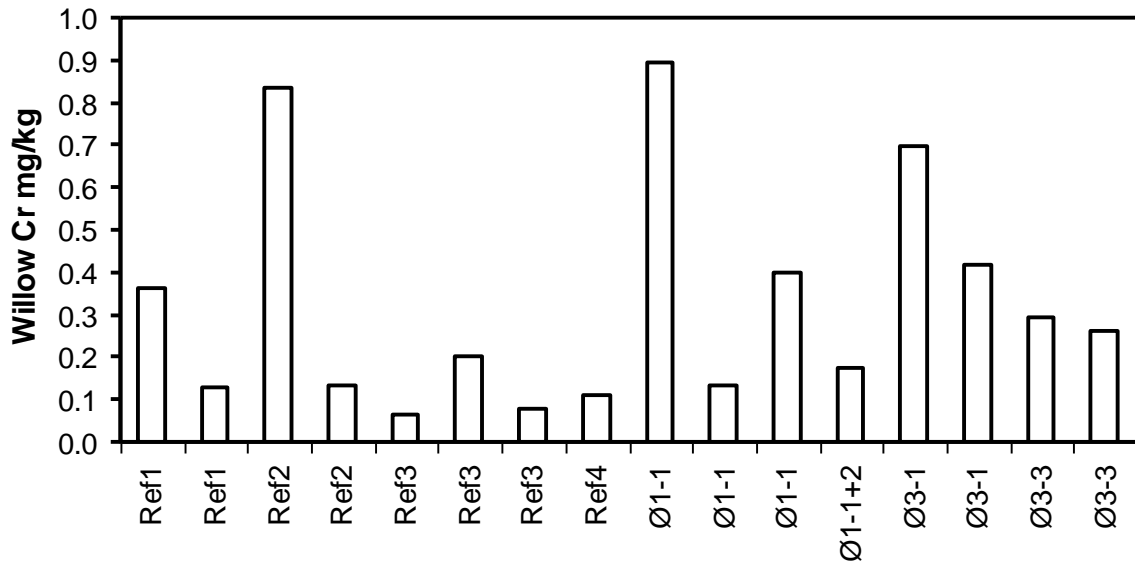
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583 **Figure 1**

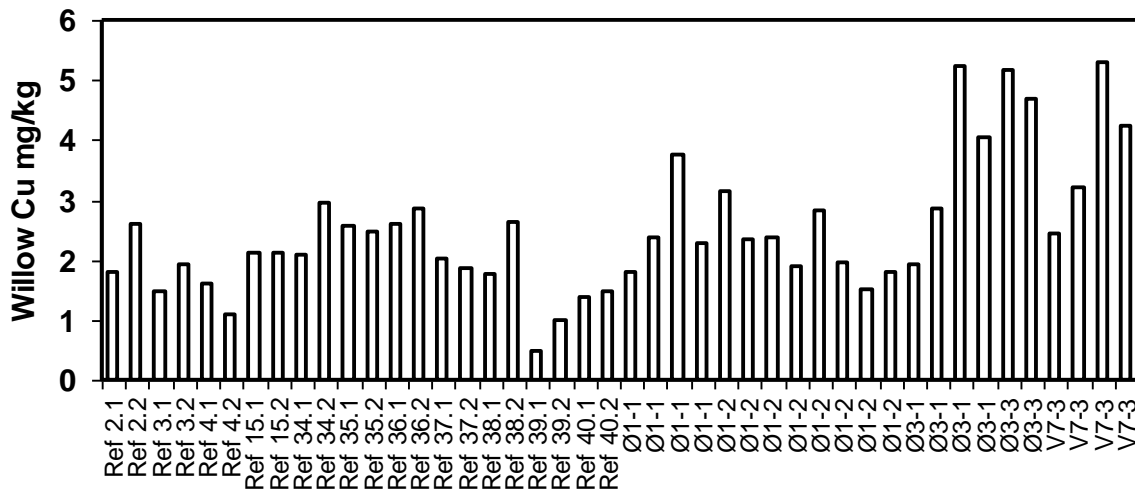
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# Test of Tree Core Sampling



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587 **Figure 2 ab**

588