Evaluation of the Effectiveness of Surface Coatings in Reducing Dislodgeable Arsenic from New Wood Pressure-Treated with Chromated Copper Arsenate (CCA)

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Background

Public awareness of wood treated with chromated copper arsenate or "CCA," a chemical preservative that prevents wood deterioration from insects and fungi, was heightened in 2001 when several environmental groups petitioned the U.S. Consumer Product Safety Commission (CPSC) to ban its use in playground equipment because of potential human health concerns. CCA and other pesticides are registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) by the U.S. Environmental Protection Agency (EPA). In March 2003, the EPA granted a request by manufacturers to cancel the registration of CCA for use in wood for most residential structures (e.g., playgrounds, decks, picnic tables, etc.) after December 30, 2003. While this action prohibits the future residential use of wood treated with CCA, it does not address the potential exposure to chemical residues (e.g., arsenic) from existing structures made with CCA-treated wood or from structures made with new CCA-treated wood from existing stock supplies that were available to consumers after the cancellation date. CCA was first produced over 60 years ago and in 1997 the American Wood-Preservers' Association (AWPA) estimated that there were over 85 million metric tons of "in service" CCA-treated wood in the U.S. (Cooper, 2004).

In an effort to find ways to mitigate exposure, CPSC staff in collaboration with the EPA, is evaluating the ability of surface coatings (e.g., deck stains, sealants, and paint) to reduce chemical migration from CCA-treated wood under natural weathering conditions. EPA and CPSC staff are conducting parallel studies employing similar methodologies with the primary differences being the study location (CPSC: Gaithersburg, Maryland; EPA: Research Triangle Park, NC) and the CCA wood source (CPSC is using new CCA-treated wood; EPA is using one-year old and seven-year old weathered CCA-treated wood). The studies began in August 2003. This report provides results through December 2004 from the CPSC staff study.

Materials and Methods

Surface coatings are being tested on small deck structures or "minidecks" made with new southern yellow pine boards treated to 0.4 pounds per cubic foot (pcf) with Ground Contact CCA-C only (i.e., water repellent was not part of the treatment). Each CCA-treated board was cut into several sections including two 48-inch long planks designated as Plank A and Plank B in Figure 1 (See TAB A for details of the experimental design). The planks were rinsed with tap water after cutting to remove excess sawdust. The end sections (AE and BE) of the board along with sections A1 and B1 of each plank (which formed the west section of each plank on the minidecks, see Figure 2) served as controls to account for variations in dislodgeable arsenic between planks.

*** These comments are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.**

Figure 1: Board Sections (nominal board length prior to cutting = 12' x 5/4? x 6?)

	Plank A			Plank B		
AE	A1	A2	AB	B1	B2	BE

End ↑ Tag

Each CCA-treated minideck consists of nine, 48-inch long planks which were randomly assigned so that no minideck had two planks from the same board (Figure 2). Two minidecks were similarly constructed using **non**-CCA-treated boards to measure for arsenic not associated with the wood such as that present in air, rain, etc. Only one of the two **non**-CCA minidecks was coated. All boards were positioned with the grain facing down.

Figure 2: Minideck Layout

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Plank	Sampling* Schedule		North	
1	1		West	East
2	2		West	East
3	3		West	East
4	1		West	East
5	2		West	East
6	3		West	East
7	1		West	East
8	2		West	East
9	3		West	East
			South	

*See Table 2 below.

After a weathering period of about 30 days, each CCA-treated minideck was randomly allocated a single surface coating that was applied per the manufacturer's instructions. Eight commercially available products (seven of which are the same as those tested by EPA) are being evaluated. Coating application was measured gravimetrically by calculating the difference between the starting aliquot and brush weight and the post-coating aliquot and brush weight. One CCA-treated minideck was left uncoated to serve as a negative control.

The types of commercially available surface coatings applied to the minidecks are described in Table 1 and include those characterized as penetrating, film-forming, and encapsulants (Williams and Feist, 1993; Williams, 1995; Knaebe, 1995). The U.S. Department of Agriculture (USDA) Forest Products Laboratory (FPL) has done extensive research on the ability of various surface coatings to protect wood decks from damage (e.g., cracking, raised grain, mildew/mold growth) caused by natural weathering (Williams and Feist, 1993; Williams, 1995; Knaebe, 1995). Penetrating finishes (e.g., oil-based semi-transparent stains, water repellents, and water-repellent preservatives) absorb into the wood allowing the wood to breathe so that the finish typically will not blister or peel even when the moisture content of the wood is high (Williams and Feist, 1993; Williams, 1995; Knaebe, 1995). Conversely, film-forming finishes (e.g., paints, latex and oil-based solid-color stains, and varnishes) form a thin layer when applied to a surface and most are not considered suitable for use on wood decks by FPL researchers because of their tendency to trap moisture leading to cracking and peeling (Williams and Feist, 1993; Williams, 1995).

Finally, some products are designed to encapsulate CCA, including one that forms a plastic coating on the wood surface and another that is a polymer.

Table 1. Surface Coatings

CPSC ID Number[a]	**Category**	**Base**	**Cover**	**Type**	**EPA ID Number**[b]
1	Paint	Water	Opaque	Film forming	9
2	Sealant	Oil	Clear	Penetrating	6
3	Stain	Oil	Clear	Penetrating	4
4	Sealant	Oil	Clear	Penetrating	1[c]
5	Other		Plastic	Encapsulant	11
7	Stain	Water	Solid (without tint)	Penetrating	*8*
8	Other		Polymer	Encapsulant	*12*
11[d]	Stain	Oil	Red Cedar	Penetrating	Not tested by EPA

[a]Note = The coating ID numbers are not sequential. CPSC ID number 6 refers to the control CCA-treated **uncoated** minideck. CPSC ID numbers 9 and 10 are two industrial coatings not readily available to consumers.
[b]The ID number designated by EPA for the same coating.
[c]This product is identical to the one tested by CPSC except it also contained a cedar pigment.
[d]CPSC ID number11 is identical to CPSC ID number 3 except it has an added red cedar pigment.

Wipe sampling and analysis are performed as previously described (Cobb, 2003). Briefly, polyester fabric wetted with 0.9% saline is used to wipe an area of 400 cm^2 with a sampling device designed by CPSC staff. Two 400 cm^2 sections (Figure 2: one east section and one west section) are designated on each plank for wipe testing. Only the west sections were wipe sampled prior to coating and serve as controls along with wipe samples from the closest end section of each board (e.g., according to Figures 1 and 2, the control for plank A consists of its west section A1 and the end section AE). Both sections (east and west) are wipe sampled post-coating according to the sampling schedule for each of the nine planks in the minidecks as shown in Table 2. For example, according to Schedule 1, CPSC staff sampled the east and west sections of only three planks (plank numbers 1, 4, and 7) on each minideck after one month of weathering. At 12 months, both sections of all nine planks on each minideck were sampled corresponding to Schedules 1, 2, and 3. Sampling of the **non**-CCA minidecks follows Schedule 1.

Table 2: Sampling Schedules

Schedule Number	Schedule
1	1 week and 1, 3, 6, 9, 12, 15, 18, 24 months
2	6, 12, 18, 24 months
3	12, 24 months

The minidecks are dry before sampling (i.e., at least two days after a significant precipitation defined as >0.1 inch rain within a 24 hr period). The extraction procedure involves placing the polyester wipes in a 10% nitric acid solution overnight at 60^{o} C. The extracts are analyzed for total arsenic using inductively coupled plasma (ICP) atomic emission spectroscopy. The detection limit for this method is 0.4 micrograms (µg) per sample.

The minidecks are exposed to natural weather conditions in an unshaded area at the CPSC test facility in Gaithersburg, MD (see photograph below). Weather data are collected on-site including: 1) irradiance (W/m^2); 2) temperature (°F); 3) precipitation duration (hours); 4) precipitation amount (inches); 5) dew point (°F); 6) precipitation type; 7) % humidity; 8) wind direction and speed; and 9) rain pH. Visual observations of each minideck are documented in writing and via digital photography prior to weathering and at each sampling time.

Results and Discussion[a]

In this study, the CPSC staff is evaluating the ability of eight commercially available surface coatings to reduce the migration of arsenic from new CCA-treated wood minidecks. The study only examines the effects of natural weathering – not physical abrasion. The Directorate for Epidemiology staff provided a detailed statistical analysis of the study (Tab A) focusing on the one-year time interval since this seemed the shortest practical interval for coating reapplication by consumers. CPSC staff estimated coating effectiveness in terms of 1) relative percent (percent of dislodgeable arsenic relative to the pre-coating amount) and; 2) absolute amount of arsenic on the hand in micrograms using a conversion factor of 0.076 previously established in CPSC staff studies (Table 3) (Levenson, 2003a, 2003b; Thomas, 2003a).

[a]**M. Levenson, Ph.D. prepared all the figures and tables in this section (see TAB A for details).**

Table 3: Coating Effectiveness at One-Year

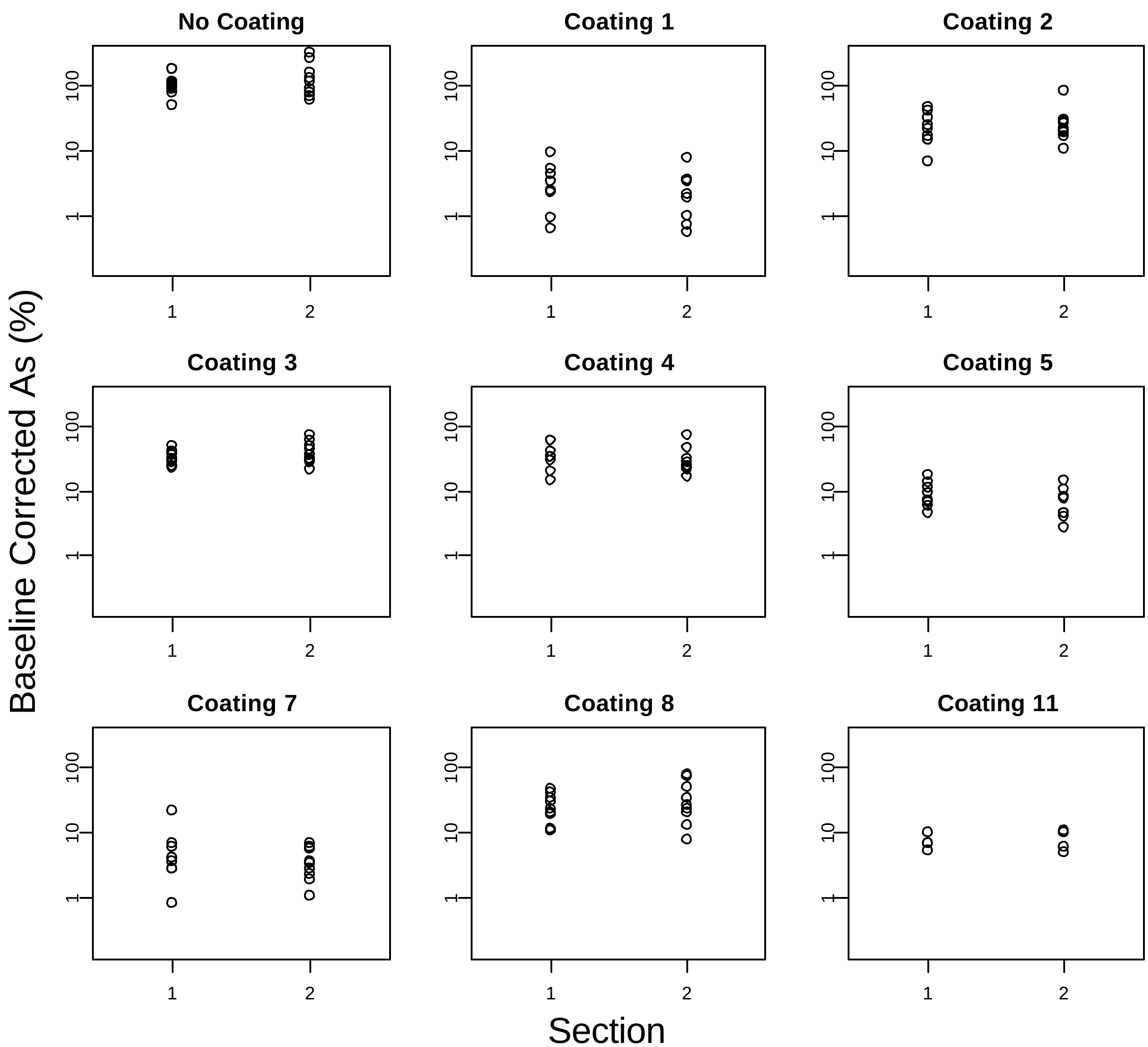
	Relative Percent (%)*		Absolute Amount As on Hand (µg)†	
CPSC ID	Estimate	Interval	Estimate	Interval
6**	107	(75, 154)	6.51	(4.54, 9.34)
3	36	(25, 52)	2.18	(1.52, 3.13)
4	31	(22, 45)	1.90	(1.33, 2.73)
8	25	(18, 36)	1.53	(1.07, 2.19)
2	22	(15, 31)	1.32	(0.92, 1.9)
5	7	(5, 11)	0.45	(0.32, 0.65)
11	7	(4, 12)	0.44	(0.25, 0.75)
7	4	(3, 5)	0.22	(0.15, 0.31)
1	2	(2, 3)	0.14	(0.1, 0.2)

* Percent of arsenic relative to the amount present prior to coating.
† The amount of arsenic that would be transferred to an adult human hand.
** Control CCA-treated minideck that was not coated.

The results after one year of weathering showed that, under the experimental conditions, all of the coatings reduced available arsenic to a level that was significantly different (p-value = < 0.05) than the control (uncoated CCA-treated minideck). Four coatings were statistically more effective than the others in reducing dislodgeable arsenic. These include coating # 1 (a film forming paint), coating # 5 (an encapsulant-type product), and two penetrating finishes: coating # 7 (a solid stain without added tint base) and coating #11 (a stain with red cedar pigment). Notably, coating # 11 with the cedar pigment performed better than coating # 3 (the same product without pigment) suggesting that the pigment component may enhance effectiveness. Photographs of the minidecks at the beginning of the study, after one year of weathering, and after 15 months of weathering are in TAB B.

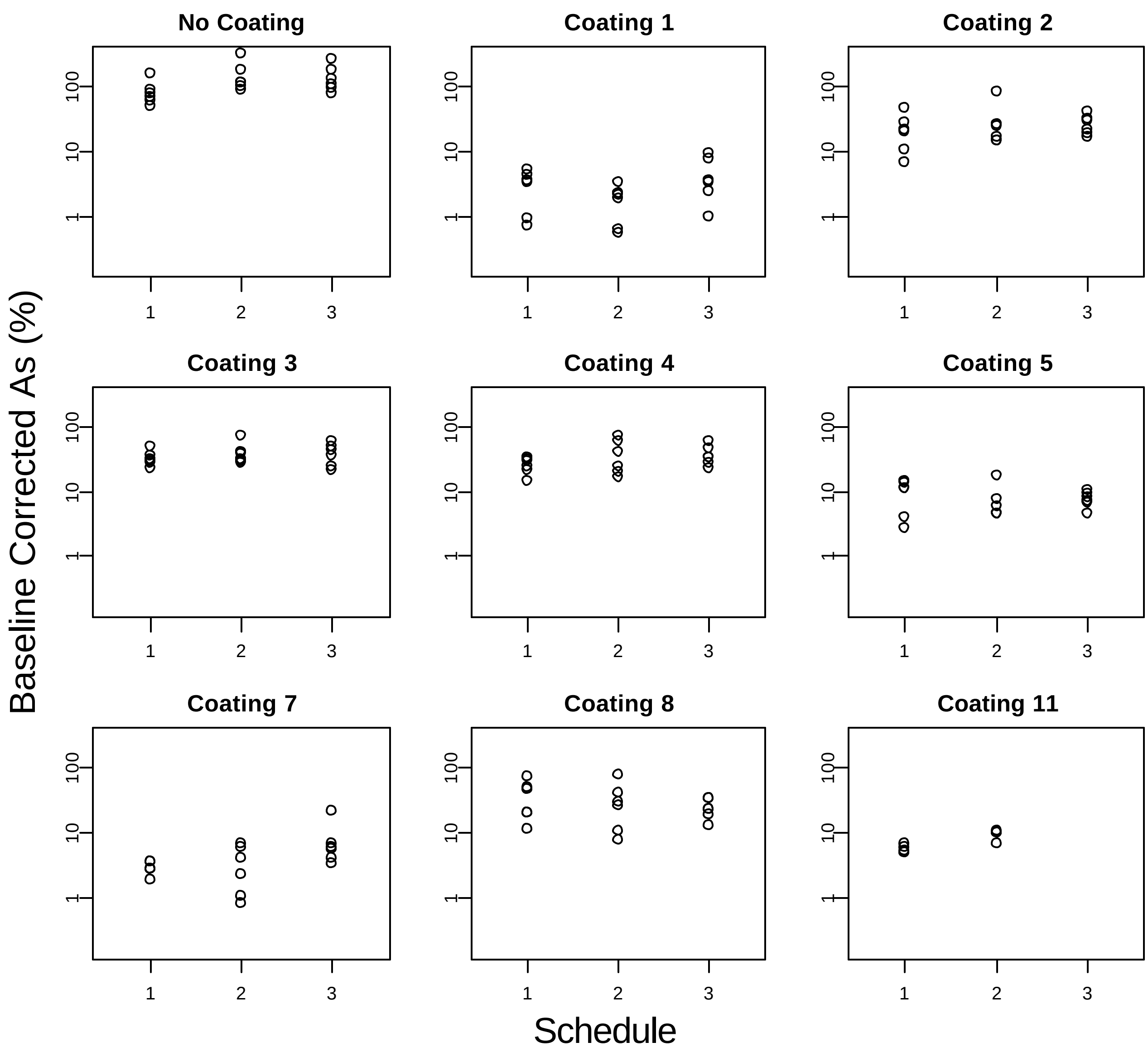
The CPSC staff examined two other variables in this study, the "section" or re-rub effect of the actual wipe test and the "sampling schedule effect," which relates to the total number of times a board was sampled. To address whether the actual wipe test to collect samples from the minidecks reduces the amount of available arsenic, baseline measurements were taken from the west side of each plank prior to coating the entire board (Figure 2). Measurements were then taken from both the east and west sides of the plank throughout the study at the designated sampling times. The results showed that after one year, there was no statistically significant difference (p-value = 0.62) between the west or "baseline" section measurements and the east or "post-coating" section measurements (Figure 3).

Figure 3: Baseline Adjusted Dislodgeable Arsenic at One Year by Section and Coating (Log Scale). (Section 1 = West Section, Section 2 = East Section)



Additionally, the study included three sampling schedules or time intervals for wipe-testing the boards (Figure 2 and Table 2) with schedule 1 being the most frequent – *i.e.*, boards in this group were sampled the most number of times. These data showed a small, statistically significant difference (p-value = 0.03) in the measured values between the three sampling schedules, with the greatest effect observed with sampling schedule 1 where the values were lower than either schedule 2 or 3 (Figure 4). Thus, it appears that the increased sampling frequency may have played a minor role in lowering measured arsenic levels.

Figure 4: Baseline Adjusted Dislodgeable Arsenic at One Year by Schedule and Coating (Log Scale).

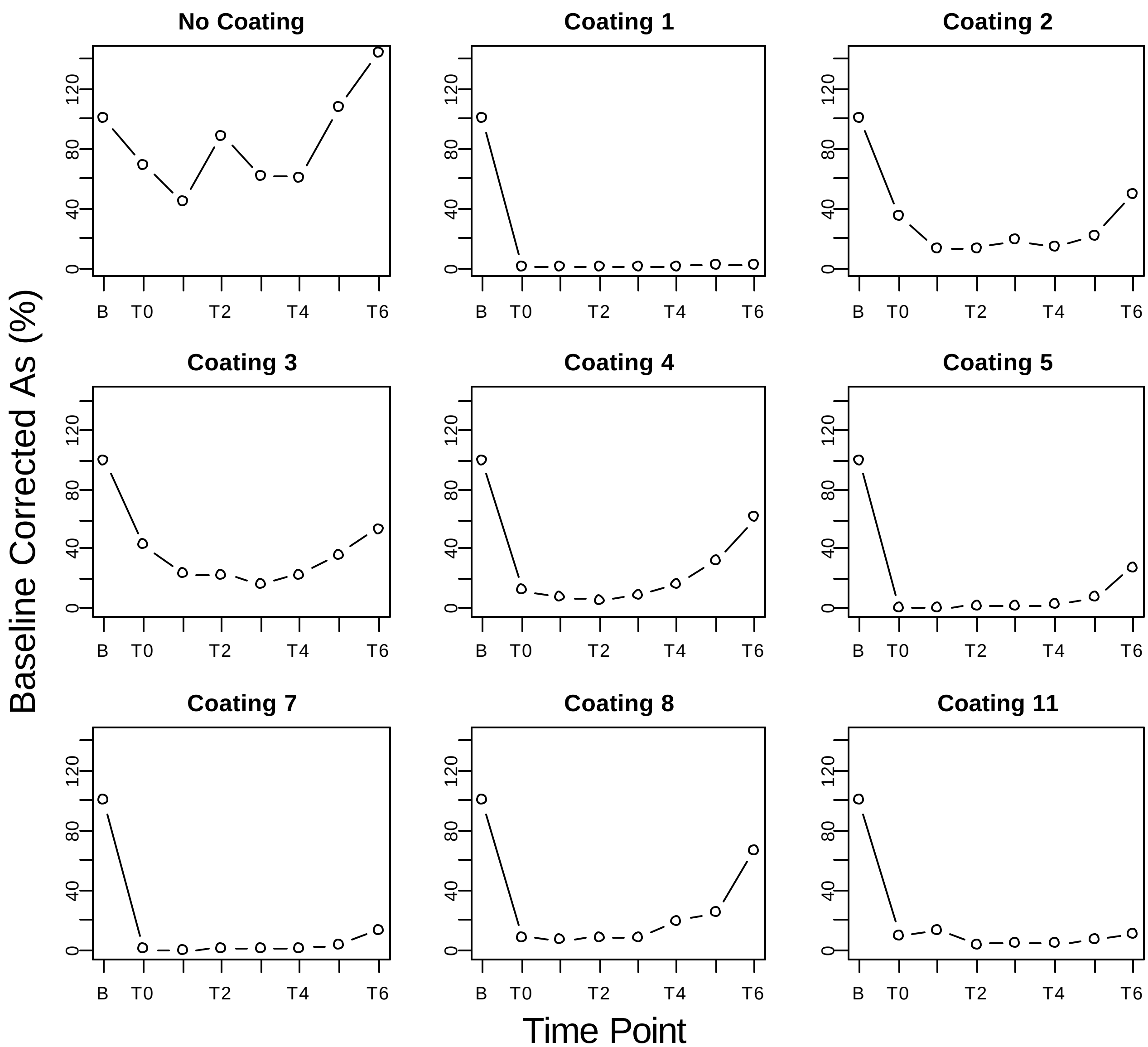


Schedule 1 = 1 week and 1, 3, 6, 9, 12, 15, 18, 24, months
Schedule 2 = 6, 12, 18, 24 months
Schedule 3 = 12, 24 months

As stated above, four coatings were statistically more effective than the others in reducing arsenic migration after one year of weathering including a film-forming paint (coating # 1). However, studies by the U.S.D.A. Forest Products Laboratory show that paint products typically do not penetrate the wood but form a film on its surface which may crack, peel, or chip (Williams and Feist, 1993; Lebow, 2002). Based on this information, film-forming products have not been recommended for use on CCA-treated wood by CPSC, EPA, and others because consumers may sand or scrape the wood which could potentially increase their exposure to the wood components including the wood preservative chemicals (Williams and Feist, 1993; Williams, 1995; Lebow, 2002). In fact, visual observations of the minideck treated with the paint (coating # 1) showed small areas of cracking or chipping on some of the boards which resulted from weathering only (TAB B). Presumably, abrasion from actual use of a coated CCA-treated wood structure could worsen this effect. These observations validate CPSC staff concerns about the use of film-forming products on CCA-treated wood.

Recent results show that arsenic levels are significantly higher after 15 months of weathering compared to 12 months on some of the coated minidecks (Figure 5). Increased levels of dislodgeable arsenic are evident on the minidecks coated with coating numbers 3, 4, and 8 (Table 4). The estimated levels of dislodgeable arsenic are less precise because according to the experimental design fewer measurements were collected at 15 months than at 12 months – i.e., at 15 months three of the nine planks were wipe tested according to Schedule 1 and at 12 months all nine planks were wipe tested according to schedules 1, 2, and 3 (Figure 2, Table 2). Dislodgeable arsenic levels were also higher on the uncoated CCA-treated control minideck (Table 4, Figure 5), which may not be unusual since Stilwell et al., (2003) observed a relatively constant reduction in arsenic release from CCA-treated boards after a year of natural weathering, but during the second year of testing, arsenic levels returned to initial levels or greater, possibly from surface erosion and weathering.

Figure 5: Mean Baseline Adjusted Dislodgeable Arsenic over Time by Coating.



Key for time points: B = baseline, T0 = 2 weeks, T1 = 1 month, T2 = 3 months, T3 = 6 months, T4 = 9 months, T5 = 12 months, and T6 = 15 months.

Table 4: Coating Effectiveness at 15 Months

	Relative Percent (%)		Absolute Amount As on Hand (μg)†	
CPSC ID	Estimate	Interval	Estimate	Interval‡
6**	144	(77, 268)	8.71	(4.67, 16.26)
3	54	(29, 101)	3.29	(1.76, 6.13)
4	62	(33, 117)	3.79	(2.03, 7.07)
8	67	(36, 125)	4.05	(2.17, 7.56)
2	50	(27, 93)	3.01	(1.62, 5.62)
5	27	(15, 51)	1.66	(0.89, 3.1)
11	11	(5, 24)	0.69	(0.32, 1.47)
7	14	(7, 26)	0.84	(0.45, 1.56)
1	2	(1, 3)	0.11	(0.06, 0.21)

* Percent of arsenic relative to the amount present prior to coating.
† The amount of arsenic that would be transferred to an adult human hand.
‡ The intervals reflect only the uncertainty in the coating estimates and not those of the baseline average and the conversion factor.
**Control CCA-treated minideck that was not coated.

Previous studies, each with its own limitations, have shown that surface coatings can reduce the leaching or release of chemicals from CCA-treated wood (Lebow, 2002; Lebow et al., 2003; Maas et al., 2003; Stilwell, 1999). In one study, individual CCA-treated boards were brushed with either one of three coating regimens before exposure to simulated rainfall episodes over a three week period to approximate the national average rainfall (Lebow, 2002). The coatings tested in this study were: 1) a latex primer followed by one coat of outdoor latex paint; 2) an oil-based primer followed by one coat of oil-based paint; or 3) two coats of a penetrating oil deck stain that also contained a water repellent (Lebow, 2002). While this study was preliminary and only examined the effects of one aspect of weathering – *i.e.*, simulated rainfall, the results showed that all of these surface treatments were over 99% effective in reducing the leaching of arsenic, chromium, and copper compared to controls or uncoated boards (Lebow, 2002). It was suggested that the effectiveness of the coatings was related to their ability to limit water movement into and out of the wood (Lebow, 2002).

A follow-up study examined the effects of ultraviolet (UV) radiation (via a xenon-arc weathering chamber) and water repellent content on chemical release from CCA-treated wood exposed to simulated rainfall (Lebow et al., 2003). These data showed that the water repellent significantly reduced the release of arsenic, chromium, and copper in the runoff water collected from the CCA-treated wood, but no difference was observed between the three concentrations of water repellent tested (1%, 3%, and 5%). Additionally, UV exposure produced a significant increase in chemical leaching from both coated and uncoated boards which was considered possibly due to fiber loss from surface erosion and the increased surface area caused by weathering (Lebow et al., 2003).

In a field study of almost 800 sites across the U.S. where volunteers collected samples from in-service residential structures (*e.g.*, decks, playsets, picnic tables, etc.) made with CCA-treated wood using a standard wipe-sample kit, Maas et al., (2003) concluded that water sealants reduce arsenic release, but are only effective for six months, whereas stains and paints are effective for up to two years. However, the variables considered (*e.g.*, treatment, age, region, sun exposure, and structure type) in this study were not controlled making these data difficult to interpret. For example, the age, geographic location, and level of sun exposure of the structures treated with water sealants are not identified so the conclusion made about water sealant effectiveness may be due to these other factors as well. Also, the paint and sealant data were combined due to small sample size, making it difficult to determine which product types were most effective.

While surface coating formulations frequently change and the precise component(s) (*e.g.*, binder, pigment, repellent, etc.) that play a role in reducing chemical release from CCA-treated have not been well defined (Lebow et al., 2003), this CPSC staff study showed that all of the coatings tested after one year of weathering were effective in significantly reducing dislodgeable arsenic. EPA found similar results in its study – i.e., applying surface coatings to weathered CCA-treated wood under natural weather conditions in North Carolina reduces dislodgeable arsenic for about one year (U.S.E.P.A., 2005). The rank effectiveness of several identical products tested in each study (Table 1) tracked each other closely with the film-forming products working best, although film-formers are not recommended because of their tendency to crack or peel.

Preliminary results from the 15-month sampling interval in the CPSC staff study suggest that some of the coatings are beginning to fail as evidenced by the increased arsenic release on CCA-treated minidecks coated with these products. The CPSC staff intends to monitor the minidecks for up to two years from the initial coating to determine if this trend continues. It should also be emphasized that the results from this study are representative of a single wood source (new CCA-treated wood) weathered in one geographic location (Mid-Atlantic U.S.) with no physical "wear and tear" component.

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Statistical Experimental Design[1] **TAB A**

The CPSC staff CCA mitigation experiment was designed to compare the effectiveness of various coatings at reducing the arsenic available for transfer to human skin, also referred to as dislodgeable arsenic. Based on previous CPSC staff studies of sampling wood for dislodgeable arsenic, several factors were accounted for in the design of the experiment (CPSC 2003a, CPSC 2003b). These factors included (1) the large variability in dislodgeable arsenic both within and among samples of CCA-treated wood and (2) the reduction in dislodgeable arsenic from prior sampling of the CCA-treated-wood surfaces. Also, various controls and blanks were employed to standardize results and ensure that the measured arsenic derived from the wood.

The experiment involved the use of *minidecks*, small deck-like structures, exposed to natural weathering (see Materials and Methods section). A single coating was applied to each minideck. A minideck consists of nine planks of wood. Two sections were defined on each plank: a *west* section and an *east* section. Figure A1 displays a graphical representation of a minideck. The planks were cut from boards (nominal 12’x5/4’’x6”). Each board provided two planks. Figure A2 displays a graphical representation of a board. Sections A1 and A2 would form one plank, and sections B1 and B2 would form a second plank. Sections A1 and B1 were positioned as the west sections of their respective planks. Likewise, sections A2 and B2 were positioned as the east sections of their respective planks.

Figure A1: Minideck Sections and Sampling Schedule.

Plank	Sampling Schedule		North	
1	1		West	East
2	2		West	East
3	3		West	East
4	1		West	East
5	2		West	East
6	3		West	East
7	1		West	East
8	2		West	East
9	3		West	East
			South	

Figure A2: Board Sections.

	Plank A			Plank B		
AE	A1	A2	AB	B1	B2	BE

End Tag

[1] Prepared by Mark Levenson, Ph.D., Directorate for Epidemiology

The end sections, the sections AE and BE, would not be used in the construction of the minideck, but these sections and the west sections were sampled at the same time, prior to the coating of the minidecks. The west section and the end section would be used for controls for each plank to account for the variations in dislodgeable arsenic among the planks. The east sections were not sampled prior to the coating of the minideck, and thus, would not experience any reduction of arsenic from the sampling. For example, a plank may be made of sections A1 and A2 with section A1 positioned in the west section of the plank and section A2 positioned in the east section of the plank. In this example; the end section AE and the west section A1 would act as controls for the east section A2. For all sampling after the application of the coatings, both the west and the east sections were each sampled. Section AB, a short section, was not used.

Initially, the study called for seven minidecks constructed of CCA-treated wood. Thirty-two CCA-treated boards from a single source (see Materials and Methods section) were randomly allocated for the construction of the seven minidecks. The randomization had the restriction that no two planks from a single board were allocated to the same minideck, thus reducing the effect of the variability among boards in comparing results from different minidecks. Six coatings were randomly assigned to the seven CCA-treated-wood minidecks, and one minideck remained uncoated to act as a control.

Two minidecks were constructed of wood that was not treated with CCA. These minidecks were used as controls. Boards were randomly allocated to these minidecks as was done for the CCA-treated-wood decks. One of these minidecks remained uncoated. The planks of the other minidecks were each coated with a distinct coating used for CCA-treated-wood minidecks.

After the assignment of boards and planks to the minidecks, a decision was made to create two additional CCA-treated-wood minidecks to evaluate additional coatings. Additional wood was allocated for these minidecks. One of these minidecks was coated with a single coating as was done for the initial seven CCA-treated-wood minidecks. The other minideck had three coatings applied to distinct planks. Two of these coatings were not intended for wood surfaces and are not considered in the analysis below. The third coating, intended for wood surfaces, was applied to four of the nine planks.

Following the coating of each minideck, as prescribed by the protocol, the planks were sampled following one of three sampling schedules. The schedules are given in Table A1. Figure A1 displays the allocation of the planks to the sampling schedules. The use of the three sampling schedules allowed for the effect of sampling on the dislodgeable arsenic to be determined. Both the west and east sections were sampled at the scheduled times. For the coating applied only to four planks of a CCA-treated-wood minideck, two of the four planks were sampled at schedule 1 and the other two were sampled at schedule 2.

The sampling was performed with the sampling template developed by CPSC staff using a wet polyester wipe that is a surrogate for the human hand (CPSC 2003c). The results from the surrogate could be related to the amount of arsenic transferred to a human hand using calibration studies performed by CPSC staff (CPSC 2003b). The experiment made use of boards from a single source of wood and entailed natural weathering at a single location in Maryland (see Materials and Methods section). No mechanical wear representing usage of the minidecks was employed. Therefore, caution must be used in generalizing the results to other wood sources, weathering conditions, and wear conditions. However, the results should provide information on the effectiveness of various coatings, particularly in conjunction with the results of the parallel EPA experiment.

Table A1: Sampling Schedules.

Schedule Number	Schedule
1	2 weeks and 1, 3, 6, 9, 12, 15, 18, 24 months
2	6, 12, 18, 24 months
3	12, 24 months

Statistical Analysis and Results

Outcome Measures

The results were statistically analyzed to determine the effectiveness of the coatings at reducing dislodgeable arsenic over a period of one year. The one-year period was chosen for the first summary report because it was considered the shortest practical interval for a consumer to reapply a coating. Staff felt that if coatings could not be effective for one year, their usefulness would be limited. By the design of the experiment, all planks were sampled at one year. During the preparation of this report, 15-month results became available. By the design of the experiment, only three planks per minideck were sampled at 15 months. The analysis below concentrates on the one-year results, but a brief analysis of the 15-month results is also given.

Two outcome measures were used: (1) the amount of dislodgeable arsenic and (2) the percent of dislodgeable arsenic relative to the baseline dislodgeable arsenic. The second measure, referred to as the baseline adjusted arsenic, was derived from the first measure by dividing the measured arsenic amount for each plank by the corresponding measured baseline arsenic amount for the plank (Equation A1). The baseline amount was the average of the west section and end section measurements taken prior to the application of the coatings for the plank.

$$R_p = \frac{A_p}{B_p} \qquad \text{(A1)}$$

Where: R_p = Baseline adjusted dislodgeable arsenic for plank p (%)

A_p = Dislodgeable arsenic for plank p (µg)

B_p = Dislodgeable arsenic for baseline of plank p (µg)

Qualitatively, the unadjusted and adjusted results were similar. There were several large measurements in the unadjusted results that corresponded to large baseline measurements, and thus, they are less extreme in the adjusted measurements. Most of these measurements were for the uncoated minideck. An alternative adjustment was considered. The alternative adjusted measure was equal to the difference between the measured arsenic amount and the measured baseline arsenic amount for each plank (Equation A2). The adjustment based on the difference did not normalize the extreme measurement as well as the adjustment based on the quotient.

$$D_p = A_p - B_p \qquad \text{(A2)}$$

Where: D_p = Alternative baseline adjusted dislodgeable arsenic for plank *p* (µg)

A_p = Dislodgeable arsenic for plank *p* (µg)

B_p = Dislodgeable arsenic for baseline of plank *p* (µg)

As stated in the Materials and Methods section, the detection limit for arsenic was 0.4 µg per sample. Prior to the statistical analysis, arsenic amounts below the detection limit were assigned the value of one-half the detection limit, equal to the value of 0.2 µg. To produce more homogeneous variances for statistical analyses, the log transformation of the measurements was used.

Figure A3 displays the mean of the baseline adjusted arsenic measurements across time for each coating. Table A2 gives the definitions for the time-point codes. The means were calculated on the log scale and were back-transformed to the original scale. Note that due to the sampling schedules, the means at different time-points were based on different numbers of measurements.

Except for the minideck with no coatings, the values across time for each coating form a smooth pattern, one that does not rapidly fluctuate across time. Within the first year, the largest measurements occurred at the T5, the one-year time point. Because the T5 results represent the highest, although not extreme, values in the first year, the statistical analysis focused on the T5 time point.

Figure A4 displays the means of the baseline adjusted measurements on the log scale across time for each coating. On the log scale certain trends are more apparent. For example, coating 5 appeared to have increasing arsenic levels with increasing time. However, note that the level was still low for the coating at T5.

Table A2: Time Points.

Code	Time
B	Baseline
T0	2 weeks
T1	1 month
T2	3 months
T3	6 months
T4	9 months
T5	12 months
T6	15 months

Section and Schedule Effects

At the one-year time point, there were nine measurements from the west section and nine measurements from the east section available for each minideck. The west section measurements differ from those from the east section in that they received a single sampling prior to coating. The measurements can also be classified into three classes corresponding to the three sampling schedules. The planks measured at sampling schedule 1 were sampled the most, whereas, those measured at sampling schedule 3 were sampled only at the one-year time point.

Figures A5 and A6 display the section and sampling schedule effects on the one-year time-point measurements. From Figure A5, it does not appear that the west and east section measurements differed from each other. However, from Figure A6, there do appear to be some small differences in the measurements among the three sampling schedules. Schedule 1 measurements for various coatings appeared to have slightly lower values. This may come from the fact that these measurements come from planks that were sampled the greatest number of times.

A regression model was fit to test the statistical significance of the sections and schedule effects. The model had the log of the baseline adjusted measurements as the dependent variable and variables for the section, schedule, and coating factors as the independent variables (Equation A3). Based on the model, the coating effect was statistically significant (p-value= < 0.01), the section effect was not statistically significant (p-value= 0.62), and the schedule effect was statistically significant (p-value=0.03). The model showed that the largest effect of the sampling schedule came from sampling schedule 1. The measurements from sampling schedule 1 were lower than those from the other two sampling schedules. However, as seen from Figure A6, the effect was not large. An interaction term between the coating and schedule effects was added to the model given in Equation A3 to examine whether the effect of the schedule varied among the coatings. The interaction term was not significant (p-value= 0.22).

$$\log(R_p) = Coating + Section + Schedule \qquad \text{(A3)}$$

Where: R_p = Baseline adjusted dislodgeable arsenic for plank p (%)
$Coating$ = Coating effect (9 levels)
$Section$ = Section effect (2 levels)
$Schedule$ = Schedule effect (3 levels)

Coating Effectiveness Estimates

Estimates and confidence intervals of the effectiveness of the coatings at the one-year time point were determined. In the estimation, it was assumed that there were no section and schedule effects. With this assumption, all 18 measurements at the one-year time point (two sections times nine planks) for a minideck were considered replicates. Because, as described above, there was a small schedule effect, the variance estimate based on the 18 measurements would slightly over-estimate the true variance of the measurements. This results in a small over-estimation of the uncertainty in the effectiveness estimates.

First, the percentages of dislodgeable arsenic relative to the baseline amount were estimated. The relative percent estimates were based on a regression model of the log of the baseline adjusted measurements on a coating factor variable (Equation A4). Simultaneous intervals were calculated based on the standard errors of the estimates using the Scheffe method (Montgomery 2001). This ensures that the intervals for any subset of coatings simultaneously contain their respective values with 95 percent confidence. Thus, for example, if two intervals do not overlap, then the corresponding estimates are statistically different with a p-value less than 0.05. The anti-log transformation was applied to the estimates and intervals to express the results on the original scale.

$$\log(R_p) = \mathit{Coating} \qquad \text{(A4)}$$

Where: R_p = Baseline adjusted dislodgeable arsenic for plank p (%)
Coating = Coating effect (9 levels)

Estimates of the absolute amount of dislodgeable arsenic that would be transferred to a human hand were based on the corresponding relative percent estimates. Each relative percent estimate was multiplied by two scalars: (1) the average value of the baseline measurements from all the CCA-treated-wood minidecks (79.8 µg**)** and (2) the conversion factor from the wet-polyester surrogate to the human (0.076) (Equation A5) (CPSC 2003b). The average value of the baseline measurements was calculated on the log scale and back-transformed to the original scale and is thus equivalent to the geometric mean of the measurements.

$$A_c = R_c \; B \; C \qquad \text{(A5)}$$

Where: A_c = Absolute dislodgeable arsenic on human hand estimate for coating c (µg)
R_c = Relative dislodgeable arsenic estimate for coating c (%)
B = Average of all baseline measurements (79.8 µg)
C = Conversion factor from wet-polyester surrogate to the human hand (0.076)

Table A3 provides the estimates and 95 percent simultaneous confidence intervals of the effectiveness of the coatings ordered from least effective to most effective. Note that the confidence intervals for the absolute amount of arsenic on the human hand reflect only the uncertainty in the coating estimates and not those of the baseline average and the conversion factor.

The estimates and intervals are displayed graphically in Figures A7 and A8. To compare coating effectiveness, it is enough to look at the relative percent results, since the absolute amount results are a rescaling of these. As can be seen from Table A3 or Figure A7, the intervals for all the coatings do not overlap the uncoated interval. Thus, at one year, all eight coatings reduced the dislodgeable arsenic as compared to no coating. In fact, the upper bounds of the intervals for all the coatings were below 50 percent, except for one which was 52 percent. The effectiveness of the coatings, 5, 11, 7, and 1, were statistically better than the remaining coatings, 3, 4, 8, and 2.

These results reflect only a single wood source and weathering condition and do not entail any physical wear representing usage.

Table A3: Coating Effectiveness at One Year.

	Relative Percent (%)*		Absolute Amount As on Hand (µg)†	
CPSC ID	**Estimate**	**Interval**	**Estimate**	**Interval‡**
6 (No Coating)	107	(75, 154)	6.51	(4.54, 9.34)
3	36	(25, 52)	2.18	(1.52, 3.13)
4	31	(22, 45)	1.9	(1.33, 2.73)
8	25	(18, 36)	1.53	(1.07, 2.19)
2	22	(15, 31)	1.32	(0.92, 1.9)
5	7	(5, 11)	0.45	(0.32, 0.65)
11	7	(4, 12)	0.44	(0.25, 0.75)
7	4	(3, 5)	0.22	(0.15, 0.31)
1	2	(2, 3)	0.14	(0.1, 0.2)

* Percent of arsenic relative to the amount present prior to coating.
† The amount of arsenic that would be transferred to an adult human hand.
‡ The intervals reflect only the uncertainty in the coating estimates and not those of the baseline average and the conversion factor.

Untreated-Wood MiniDecks

The results from the two minidecks constructed of untreated wood were analyzed to determine if there were any sources of arsenic other than the CCA-treated wood that would affect the results. Figure A9 displays the results for the two untreated-wood minidecks. Deck 8 was not coated. Each of the planks of Deck 9 was coated with a one of the distinct coatings evaluated on the CCA-treated-wood minidecks. Many of the measurements for the two minidecks were below the detection limit. As mentioned above, such measurements were assigned the value of 0.2 µg. For the two minidecks, the two highest measurements throughout the year were 5.2 µg and 2.1 µg. The mean value over all the measurements, including the re-assignment of values below the detection limit, was 0.5 µg. As seen in Figure A9, it appears that the final time point at one year had the highest arsenic values. The mean value for the one-year time point was 0.83 µg, which corresponds to the value of 0.063 µg on the hand scale. This hand-scale value is an order of magnitude lower than any of the estimates for the CCA-treated-wood minidecks.

15-Month Data

As mentioned earlier, the 15-month data became available while this report was being written. By the design of the experiment, the 15-month data consist only of three planks per minideck (per the sampling 1 schedule). Including both the west and east section of each plank, there were six measurements per minideck for the 15-month time point

From Figure A3, the amount of dislodgeable arsenic appears to be increasing for most coatings. These increases are particularly apparent for coatings 3, 4, and 8. Noteworthy, the uncoated minideck showed a considerable increase in the arsenic level at the 15-month time point, as well.

The effectiveness of the coatings at 15 months was calculated in the same manner as it was at one year. Because there were fewer measurements at 15 months than at one year, the estimates are less precise, as indicated by the wider confidence intervals. Table A4 gives the estimates and confidence intervals. The coatings are presented in the table in the same order as they were in Table A3.

For the three most effective coatings at one-year, coatings 1, 7, and 11, there was little change in the estimated dislodgeable arsenic between one year and 15 months.

Table A4: Coating Effectiveness at 15 Months.

	Relative Percent (%)		**Absolute Amount As on Hand (µg)†**	
CPSC ID	**Estimate**	**Interval**	**Estimate**	**Interval‡**
6 (No Coating)	144	(77, 268)	8.71	(4.67, 16.26)
3	54	(29, 101)	3.29	(1.76, 6.13)
4	62	(33, 117)	3.79	(2.03, 7.07)
8	67	(36, 125)	4.05	(2.17, 7.56)
2	50	(27, 93)	3.01	(1.62, 5.62)
5	27	(15, 51)	1.66	(0.89, 3.1)
11	11	(5, 24)	0.69	(0.32, 1.47)
7	14	(7, 26)	0.84	(0.45, 1.56)
1	2	(1, 3)	0.11	(0.06, 0.21)

* Percent of arsenic relative to the amount present prior to coating.
† The amount of arsenic that would be transferred to an adult human hand.
‡ The intervals reflect only the uncertainty in the coating estimates and not those of the baseline average and the conversion factor.

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CPSC (U.S. Consumer Product Safety Commission). 2003a. Statistical Analyses of CCA Wood Study Phases I and II. Memorandum from Mark S. Levenson, to Patricia M. Bittner, Project Manager. In: Briefing Package, Petition to Ban Chromated Copper Arsenate (CCA)-Treated Wood in Playground Equipment (Petition HP 01-3). February 2003. U.S. Consumer Product Safety Commission. Washington, DC. Available at http://www.cpsc.gov/library/foia/foia03/brief/cca4.pdf.

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Montgomery, DC, 2001. *Design and Analysis of Experiments*, John Wiley & Sons.

Figure A3: Mean Baseline Adjusted Dislodgeable Arsenic over Time by Coating.

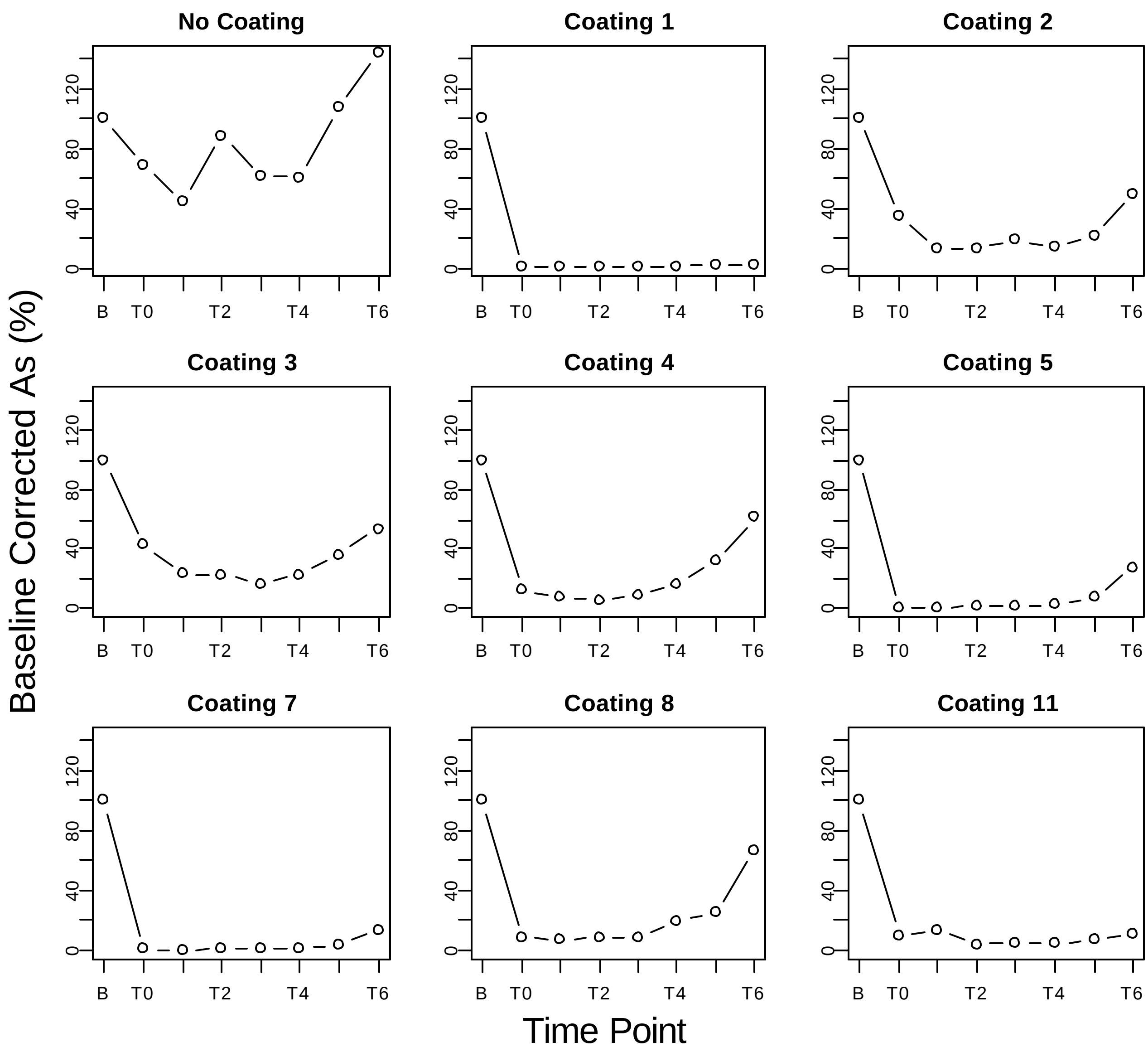


Figure A4: Mean Baseline Adjusted Dislodgeable Arsenic over Time by Coating (Log Scale).

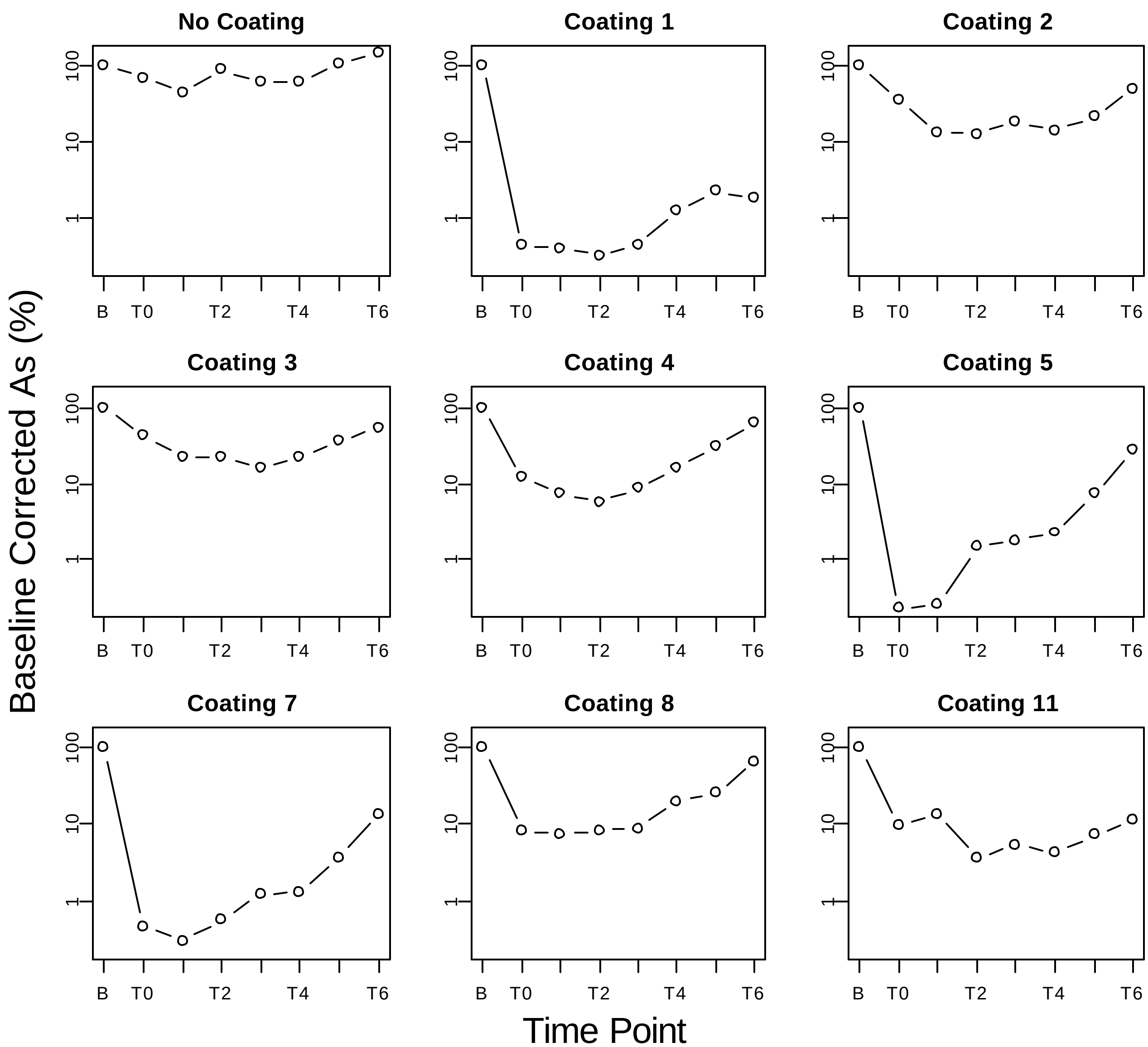


Figure A5: Baseline Adjusted Dislodgeable Arsenic at One Year by Section and Coating (Log Scale).
(Section 1 = West Section, Section 2 = East Section)

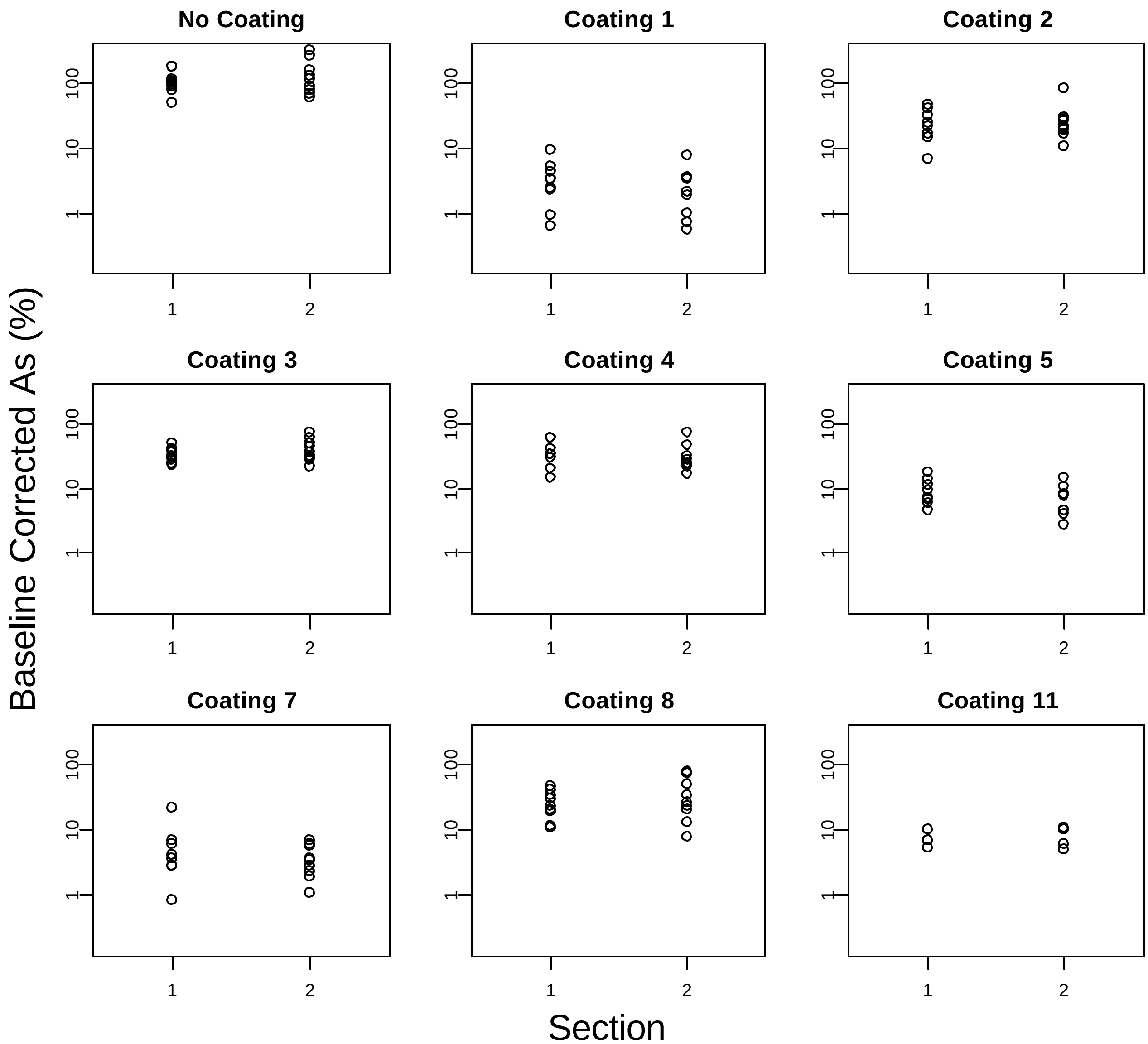


Figure A6: Baseline Adjusted Dislodgeable Arsenic at One Year by Schedule and Coating (Log Scale).

Log Scale

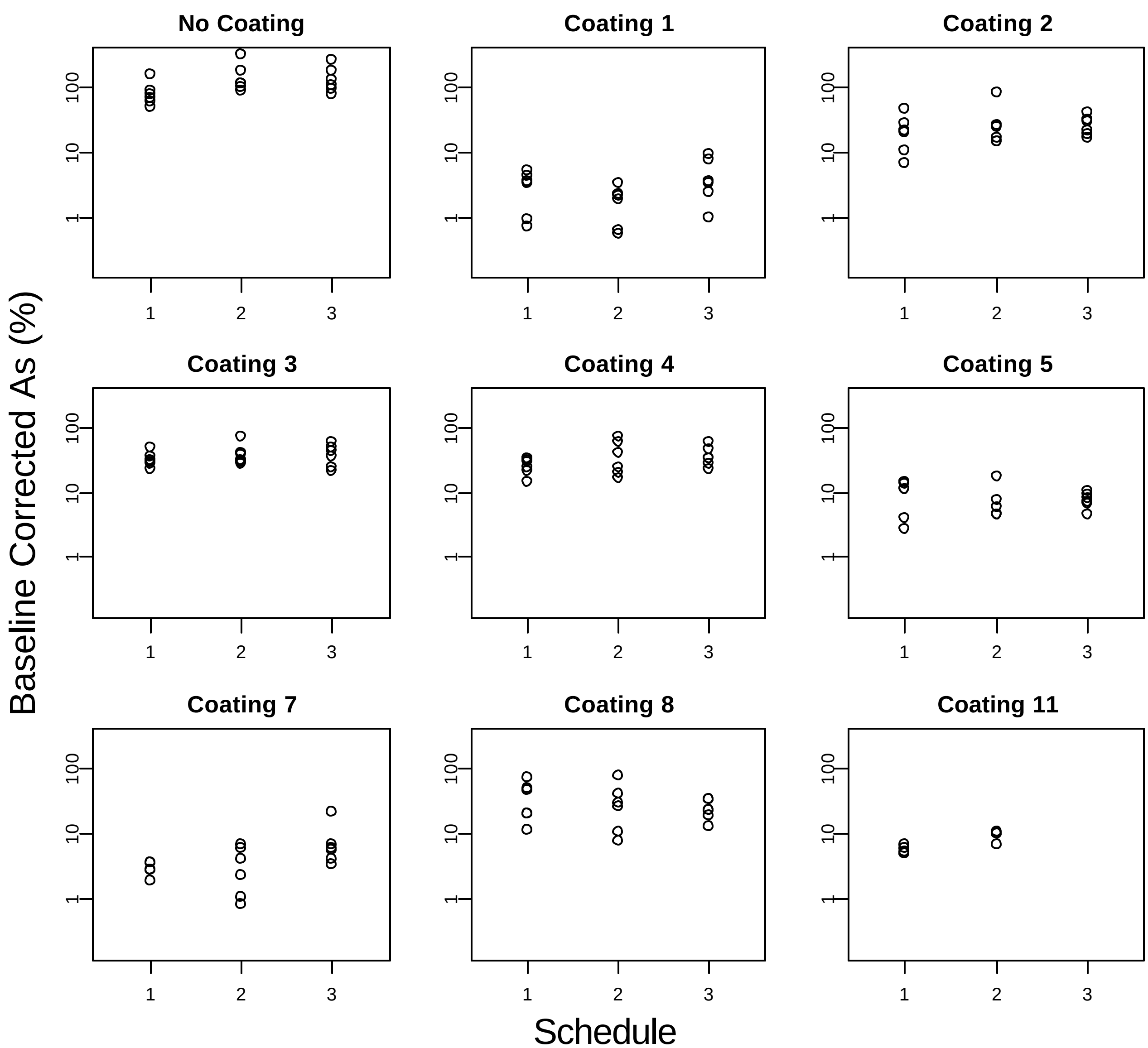


Figure A7: Estimates and 95% Confidence Intervals of Relative Percent Effectiveness of Coatings at One Year.

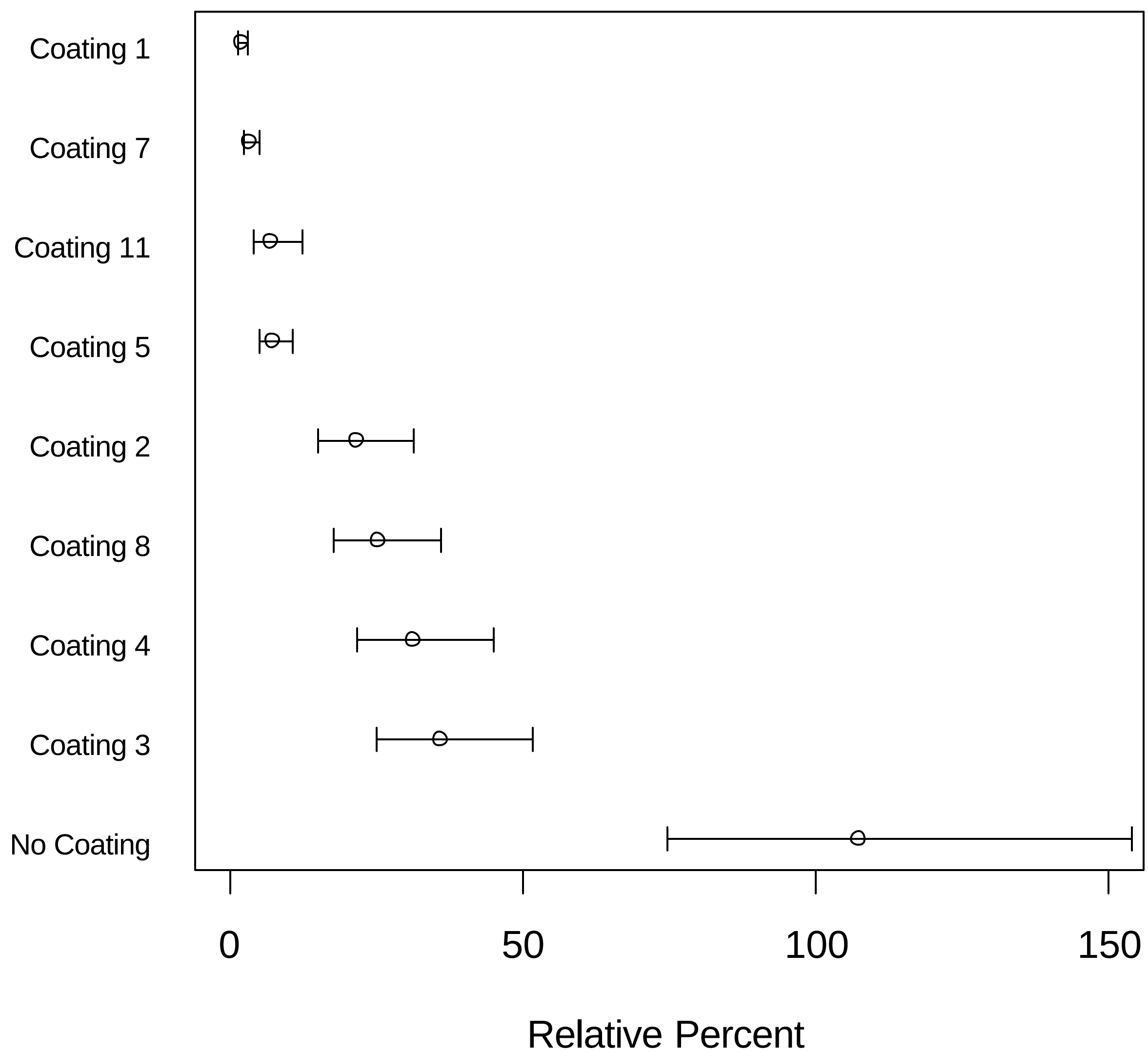
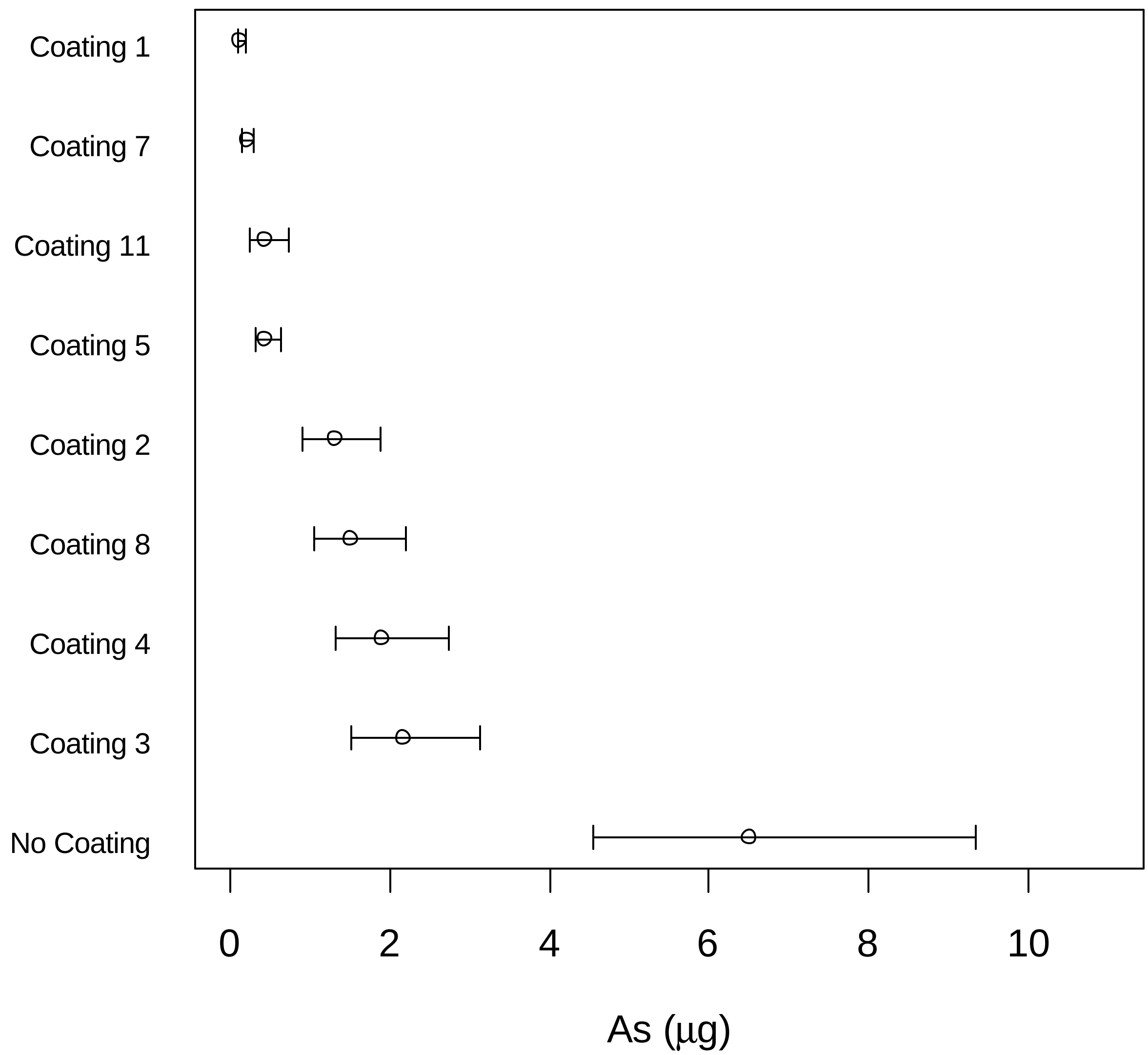
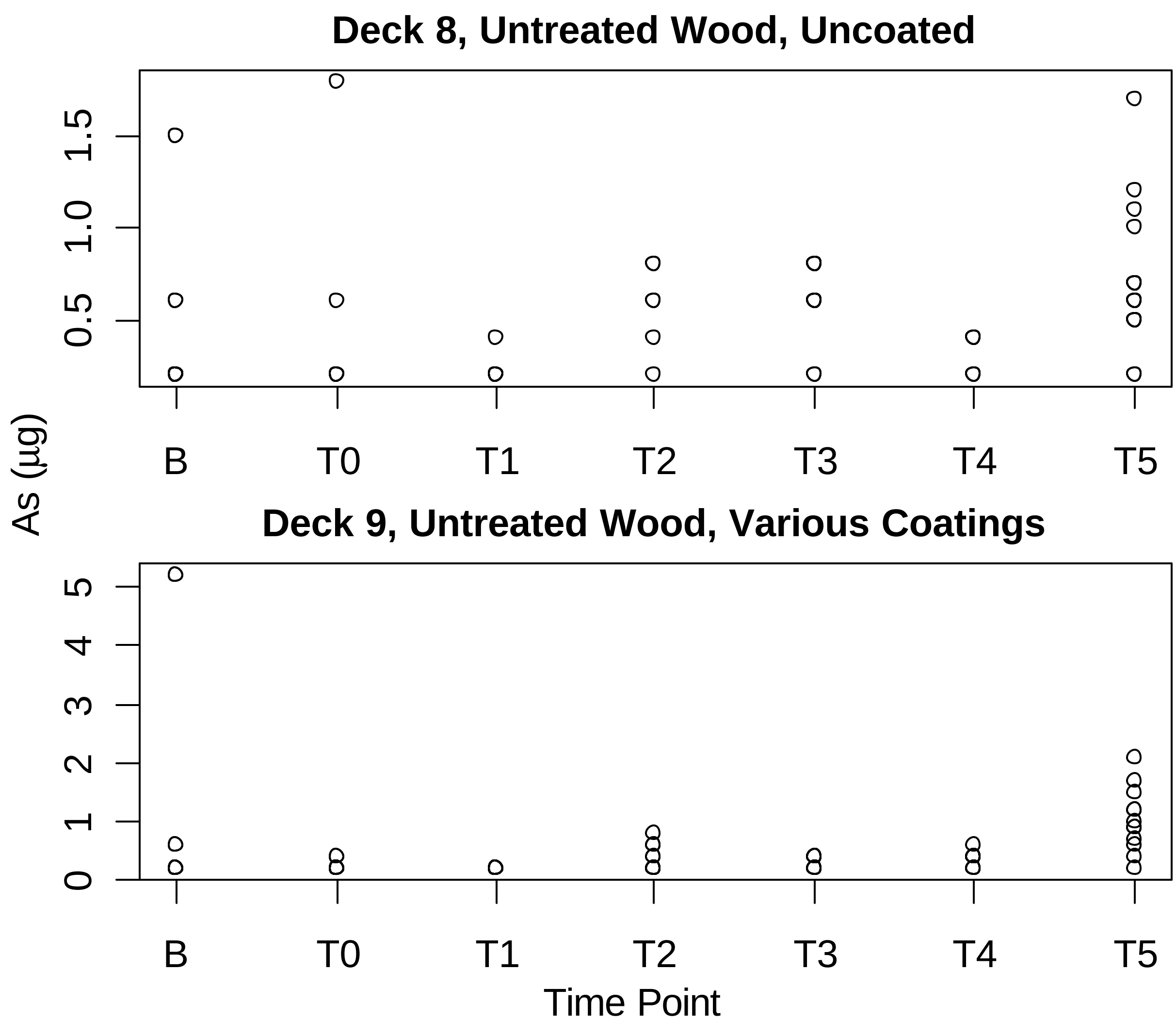


Figure A8: Estimates and 95% Confidence Intervals of Absolute Dislodgeable Arsenic of Coatings at One Year.*



*The amount of arsenic that would be transferred to an adult human hand.

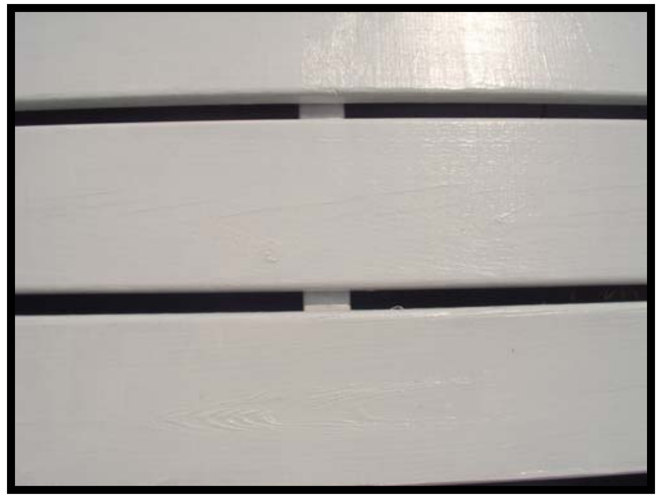
Figure A9: Dislodgeable Arsenic for Untreated Minidecks.



TAB B Minideck Photos

Coating 1

2 week



12 months

15 months

Coating 4

2 week

12 months

15 months

Coating 3

2 week

12 months

15 months

Coating 2

2 week

12 months

15 months

Coating 7

2 week

12 months

15 months

Coating 5

2 week

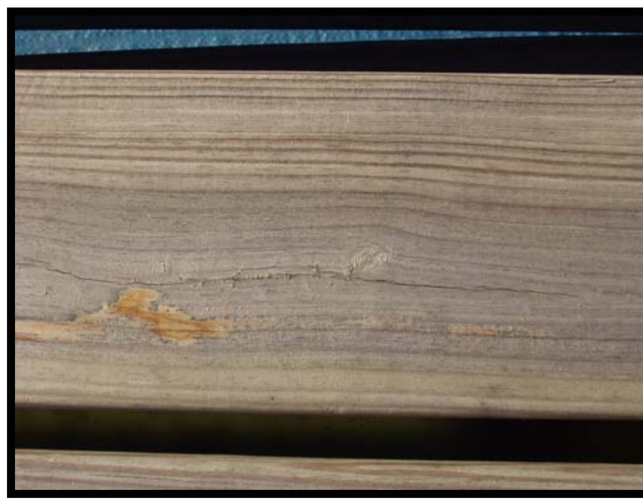
12 months

15 months

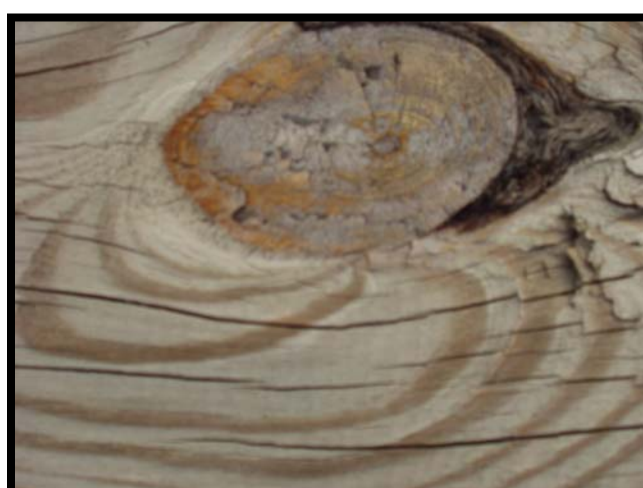
Coating 8

2 week

12 months

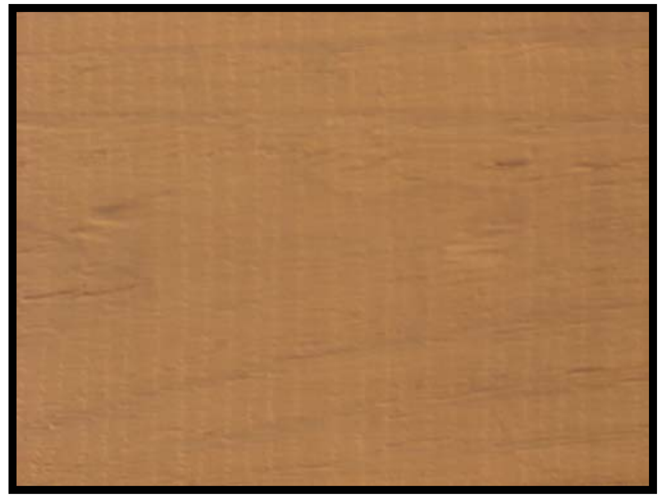


15 months



Coating 11

3 months



12 months

15 months

No Coating
CCA

2 week

12 months

15 months

No Coating, Non-CCA


2 week


12 months


15 months

Coated, Non-CCA

2 week

12 months

15 months