SEDIMENT TOXICITY STUDY OF MARINE PILES TREATED WITH CCA-C

W. J. Baldwin, E. A. Pasek, P. D. Osborne
Hickson Corporation, 3941 Bonsal Road, Conley, GA 30027

SUMMARY

A study was undertaken to demonstrate the effects of 10-day exposure to sediments mixed with leachate from chromated copper arsenate Type-C (CCA-C) southern pine marine piles treated to a retention of 40 kg/m^3 (2.5 pcf) and untreated southern pine piles on the benthic amphipod, *Ampelisca abdita*. The biological endpoint used to establish effects was organism survival. Leachate obtained during a 28-day period was dosed onto both low organic carbon and high organic carbon sediments, and the *Ampelisca abdita* were exposed to each type of sediment dosed with concentrations of leachate ranging from 10 percent to 100 percent. The components of the CCA-C treatment, copper, chromium and arsenic, were measured during the preparation of the leachate, in sediment mixtures and in the overlying and interstitial water in the exposed vessels. The 10-day exposure was maintained under static conditions with continuous lighting to ensure maximum exposure to sediment. Results showed that leaching of copper, chromium and arsenic from properly treated and fixed CCA-C treated wood does not occur at concentrations which would adversely affect the survival of these organisms exposed to the sediment. Treated pile leachate also had no significant effect on water quality. The study is significant, in part, because its design imitated the natural marine environment more closely than other studies published on this topic.

Introduction

Wood is a renewable resource which has been used in marine applications for years. Preservatives introduced in the 1800's significantly extended the useful life of exposed wood by factors of 5 to 10 (Graham, 1991), and the development of the waterborne preservatives, including CCA, in the 1970's brought into widespread use treated wood products that industry experts maintain "can be safely used without any adverse effects on man, animals or the environment." (Webb and Gjovik, 1988).

However, the use of CCA in marine applications has recently come under increased scrutiny. There is concern that leaching of chromium, copper and arsenic from the wood could be toxic to both freshwater and marine life. This concern was exacerbated by the recent publication of studies sponsored by the Center for Plastics Recycling Research at Rutgers, the State University of New Jersey. One study, in particular, (Weis, et. al., 1992) implied that recycled plastics are less toxic than CCA-treated wood in marine environments. But criticism of that study, Breteler (1992) noted that the toxicity disappeared after several weeks even under the stagnant conditions of the test and more importantly pointed out several problems with the study design, including an unrealistic surface area-to-water volume ratio which precluded extrapolating observed toxicity differences to the real environment.

Although numerous studies show very high preservative retentions remaining in CCA-treated wood after considerable periods of time (Arsenault, 1975) CCA components do leach from wood. In fact, some leaching of copper, chromium and arsenic ions must occur in order for the treated wood to be toxic to the destructive organisms it is being protected against (Hartford, 1986).

It is known that leaching rates from treated wood are impacted by a number of factors, such as the ratios of copper, chromium and arsenic used in treatment, the pH of aquatic environments and the completeness of the preservative fixation process.

At issue are such questions as: Is the biocidal effect of CCA confined only to the wood itself or are toxic metals released into the environment at large? Are the levels of pollutant metals released through leaching sufficient to cause harm in the marine environment? What changes do the metals undergo in different aquatic environments? Is there clear evidence in the environment of significant pollution by CCA-treated wood?

There have been some very thorough studies of leaching in marine environments, but the primary focus has typically been on wood durability and other measures of preservative effectiveness. Numerous studies have examined treated wood in the form of sawdust, shavings or small coupons to accelerate the leaching process (Brooks, 1993). These studies are valuable for comparing different wood preservatives and leaching rates of various metals, but they cannot reasonably be extrapolated to predict leaching from full-sized commodities used in the environment.

This study was undertaken to provide quantitative answers to some of the questions raised about the environmental safety of CCA-C treated wood in marine environments and to fill a void in the body of research existing on this topic.

Materials

This study was conducted according to procedures outlined in "Protocol for Conduct of an Acute Marine Sediment Toxicity Test with Leachate from CCA-Treated Pilings on the Benthic Organism, *Ampelisca abdita*." (Springborn Laboratories, 1993).

<u>Pilings</u>

Six southern pine wood piles, each approximately 25 cm (10 in.) in diameter and 120 cm (4 ft.) long, were supplied to Springborn Laboratories from Hickson Corporation. Three of the piles (pile Numbers 8, 9 and 10) had been treated prior to shipment with CCA-Type C oxide to a retention of 40Kg/m^3 (2.5 pcf) which is the standard retention for marine piles in accordance with the American Wood-Preservers' Association (AWPA) commodity standard (C3-91) and verified by an American Lumber Standards Committee approved inspection agency. The chromotropic acid test (AWPA A3-91) was used to indicate the degree of hexavalent chromium fixation. The other three piles (pile Numbers 4, 6 and 7) were untreated. All six piles were stored in a cool, dry area until used.

Test Organisms

Native *Ampelisca abdita* marine amphipods, collected from Wickford Cove, Wickford RI, were chosen for the study because of their wide distribution along the East Coast of North America (Mills, 1964) and because they are considered reasonable representatives of marine benthic invertebrates. Found from the intertidal zone to depths of 60m, *Ampelisca abdita* can survive relatively wide fluctuations in temperature (Bousfield, 1973) and a wide range of salinities (Bousfield, 1973, Nichols and Thompson, 1985, Hyland, 1981). Both a deposit and a suspension feeder (Enequist, 1980), *Ampelisca abdita* is in constant contact with particles and particle-bound contaminants at the sediment-water interface. The amphipods used in this study were cultured under static renewal conditions for a minimum of seven days prior to test initiation, using filtered natural seawater and sediment substrate collected from the organisms' natural environment.

Dilution Water

The dilution water used to prepare leachate solutions was seawater, also filtered, from the same source as the water used in the *Ampelisca abdita* cultures. Analysis for the presence of pesticides, polychlorinated biphenyls (PCBs) and metals, including copper, chromium and arsenic, detected none of these compounds present at concentrations considered toxic according to the United States Environmental Protection Agency (EPA) and the American Society for Testing and Materials (ASTM) standard practices (ASTM, 1980) and confirmed the acceptability of the dilution water for use during the conduct of bioassays.

Sediment

Two sediment types--one containing low organic carbon content and one containing high organic carbon content--were used during this study to evaluate the effects of the organic carbon content on the behavior (e.g., adsorption) of leachate obtained from the treated and untreated piles. Both types were natural sediments collected from locations generally considered to be isolated from industrial pollution. The low organic carbon (LOC) sediment, collected from Orleans, MA, had a total organic carbon content of 0.70 percent. The high organic carbon (HOC) sediment, collected from Eastham, MA, had a total organic carbon content of 5.2 percent. Both sediment types were analyzed for pesticides, PCBs and metals, including copper, chromium and arsenic, none of which were detected at concentrations considered toxic according to U.S. EPA and ASTM standard practices (ASTM, 1980), and the sediments were deemed to provide an acceptable substrate for use in this study.

Methods

Leachate Preparation

Samples of the dilution water (seawater) and both the LOC and HOC sediment types were analyzed to establish background concentrations of copper, chromium and arsenic. Leachate solutions were then prepared by supporting the six wood piles upright in leaching vessels (one pile per tank) and adding 240L of dilution water to each tank until all but the top 5 cm (2 in.) of each pile was submersed. Submersible Teel pumps--two per tank--continuously stirred the dilution water to simulate wave action which would occur in a natural marine environment. The leaching vessels were covered with tight-fitting lids to minimize evaporation during the leaching period.

On day seven of the 28-day leaching period, after four aliquots had been removed, the leachate solution in each tank was transferred to appropriately labeled, corresponding holding tanks, and the leaching tanks were refilled with fresh seawater, again to a volume of 240L. The same procedure was repeated on days 14, 21 and 28 of the leaching period, with leachate removed from the vessels being added to the previously collected leachate in the appropriately corresponding holding tanks. In total, approximately 960L of leachate was collected for each pile.

Sediment Preparation

Aliquots of LOC and HOC sediment samples were mixed with 100 percent leachate (as collected from the leaching vessels) and dilutions of 50 percent leachate and 10 percent leachate (leachate collected from the leaching vessels mixed with the appropriate proportions, respectively, of fresh seawater). For each of the six piles, six 20L glass aquaria were prepared and labeled. A volume of 1.6L of HOC sediment was added to three of the six aquaria for each pile; a volume of 1.6L of LOC sediment was added to the other three of the six aquaria for each pile.

For each pile, one of the three aquaria with HOC sediment was filled with 16L of the 10 percent prepared leachate solution, one with 16L of 50 percent leachate solution and one with 16L of 100 percent leachate solution. Likewise, for each pile, one of the three aquaria with LOC sediment was filled with 16L of 10 percent leachate solution, one with 50 percent and one with 100 percent.

The leachate/sediment solutions were mixed for 20 hours at a rate sufficient to maintain the sediment in suspension. Then the LOC and HOC sediment/leachate mixtures were allowed to stand undisturbed for approximately 18 hours, after which approximately 5L of overlying leachate solution were removed from each aquarium. The sediment/leachate mixtures remaining in the aquaria were transferred to 19L containers, where the leachate was allowed to drain through screen-covered holes in the container bottoms. The samples of LOC and HOC sediments which had been mixed with 100 percent leachate solutions were analyzed to determine concentrations of copper, chromium and arsenic.

Test Conditions
All test exposure vessels (3.8L glass jars) were labeled to identify the nominal concentration of leachate mixed with each sediment type (i.e., 10 percent, 50 percent and 100 percent) and the designated replicate. (Two replicate vessels were maintained for each sediment mixed with leachate, and three replicate test vessels were maintained for the LOC and HOC sediment controls.)

Test vessels were then positioned by stratified random design in a circulating water bath designed to maintain exposure temperatures at 20 $\pm$ 1 degree C. The test area was continuously illuminated by fluorescent lights within a range of 40-80 footcandles, taking advantage of the test organisms' natural response of burrowing below the sediment surface when exposed to light in order to maximize their exposure to the sediment.

One day prior to initiation of the 10-day exposure period, an 800 ml volume of the appropriate sediment-- approximately 5 cm (2 in.) in depth--was added to each of the labeled test vessels. Two liters of dilution water--a depth of about 11 cm (4 in.) --were added to the sediment; a turbulence reducer was used to minimize the disruption of the sediment layer. Interstitial water samplers were placed at appropriate sediment depth only in the test vessels containing sediment mixed with leachate from the CCA-C treated piles. The vessels were covered with plastic wrap and remained in the water bath overnight to allow suspended particles to settle.

Test Initiation
Twenty *Ampelisca abdita*, randomly selected from the culture vessels, were added to each test vessel. (Four of the 1560 amphipods added to the vessel did not burrow within one hour and were replaced by four additional randomly selected amphipods.) Test vessels were covered with plastic wrap and gentle aeration was provided over the 10-day exposure period. The amphipods were not fed during the exposure period.

Dissolved oxygen concentration, pH, salinity and temperature were measured at test initiation and daily thereafter in the overlying water in one replicate vessel for each treatment level and control. Daily measurements were made in alternating replicates.

Biological Measurements
The primary biological endpoint used to determine adverse effects during the definitive study was organism survival at test termination. After 10 days, live amphipods were isolated with a 0.5mm sieve and physically counted. Amphipods not accounted for were considered dead. Observations over the 10-day period of organism emergence from the sediment substrate were also recorded and generally considered to be associated with avoidance of a toxic or hazardous condition.

Analytical Measurements

Analyses for copper, chromium and arsenic were performed for the interstitial and overlying water in the vessels containing sediment mixed with leachate from treated piles in accordance with standard methods for the examination of water (APHA, AWWA, WPCF, 1985). Sediment samples were also analyzed for copper, chromium and arsenic (APHA, AWWA, WPCF, 1985). Both aqueous and sediment samples were also analyzed by an outside analytical laboratory.

Statistics

At the termination of the study, data obtained on organism survival were statistically analyzed to establish significant treatment level effects. Analyses were performed using the mean organism response in each replicate vessel. All statistical conclusions were made at the 95 percent level of certainty, except in the case of the Shapiro-Wilks Test and the Bartlett's Test, in which the 99 percent level of certainty was applied. The following procedures were used:

1. Significant differences in the percent survival were determined after arcsine square-root percentage transformation of the data.

2. The Shapiro-Wilks Test for normality (Weber et. al., 1989) was conducted to compare the observed sample distribution with a normal distribution. The assumption that observations are normally distributed must be validated before subsequent analyses, following parametric procedures, can be performed. If the data were not normally distributed, then a non-parametric procedure was issued for subsequent analyses.

3. As a check on the assumption of homogeneity of variance implicit in parametric statistics, data for each endpoint were analyzed using Bartlett's Test (Sokal and Rohlf, 1981).

4. Statistical comparison for survival was performed using the Bonferroni T-Test (Weber et. al., 1989), a parametric method, since this data set met the assumptions for normal distribution and homogeneity.

Results and Discussion

Biological Monitoring

The percent survival of *Ampelisca abdita* during the 10-day exposure to sediment mixed with leachate from the untreated piles and with leachate from treated piles are compared in Tables 1 and 2, respectively. Table 3 illustrates how these survival rates compared to the percent survival of amphipods during the 10-day exposure to the control sediments.

Comparison of these survival data established that leachate from untreated piles adversely affected organism survival, while leachate obtained from the treated piles did not effect organism survival. These data indicate that the constituents of the CCA-C treatment (i.e., copper, chromium and arsenic) were not present in the leachate at concentrations which would adversely affect the survival of the exposed organisms. Instead, the adverse effects observed during this study are presumed to be due to exposure to naturally occurring materials such as terpinene, camphene and pinene, all of which are present in wood prior to treatment. It is believed the toxic components of the wood were extracted or altered during the CCA-C treatment process. As a result, the leaching rate, or bioavailability, of these naturally-produced products were reduced for the treated piles relative to those piles which were not subjected to the treatment process.

Survival of *Ampelisca abdita* exposed to sediment mixed with leachate from both the treated and untreated piles was unaffected by the organic content of the sediment, as shown in Figures 1 and 2, respectively. No significant effect on organism emergence was observed in any of the exposure vessels for either the treated sediment, the untreated sediment or the controls throughout the exposure period.

Water Quality Measurements

Results of the water quality parameters, measured in the solutions containing sediment mixed with leachate from treated and untreated piles, are summarized in Tables 4 and 5, respectively. These data demonstrate that the measured parameters were generally consistent between the water overlying the sediment mixed with treated and untreated pile leachate. In addition, the quality of the overlying water in the exposure vessels (Table 6) was comparable to the water quality established for the controls.

Concentrations of copper, chromium and arsenic in naturally occurring water and sediment as well as in the leachates and treated sediments, established that some variability occurred between measured amounts due to the behavior of the three metals in natural environmental conditions (e.g., seawater, sediment and wood). Although the variability observed was consistent with expectations of naturally occurring environmental conditions, reliable and useful trends were established which can be used to understand the general leaching and adsorptive properties associated with CCA-C treated wood and subsequent exposure in natural marine environments.

Analytical Measurements

Analyses for total elemental copper established that treated piles released approximately 530mg copper/m^2 of exposed wood over 28 days. Mixing the leachate with LOC and HOC sediments resulted in adsorption of copper in the LOC sediment and to a slightly greater degree in the HOC sediment. Analysis of water in the exposure vessels demonstrated that the copper bound to both the LOC and HOC sediments remained bound and did not desorb into the interstitial or overlying water.

Analyses for total elemental chromium demonstrated that treated piles generally released little or no chromium over 28 days. Mixing the leachate with LOC sediment resulted in negligible uptake of chromium into sediment and only a minimal amount of chromium adsorbed to the HOC sediment. Analyses of the interstitial water in the exposure vessels demonstrated that chromium present in the sediment generally did not move into interstitial water but did move into overlying water from both LOC and HOC sediments.

Analyses for total elemental arsenic demonstrated that approximately 60 mg arsenic/m^2 of treated wood surface area leached from the treated piles. Arsenic did not appear to adsorb onto sediment of either type and, in almost all cases, was not observed in interstitial or overlying water.

Conclusions

The results of this study quantitatively support the wood preserving industry's contention that leaching of copper, chromium and arsenic from wood treated with CCA-Type C and fixed according to AWPA standards does not adversely affect the survival of *Ampelisca abdita* exposed to these elements in marine sediment environments. In addition, the quantities of copper, chromium and arsenic released were shown not to adversely affect water quality. This study was designed to approximate natural field conditions as closely as possible under laboratory conditions. There continues to be a need for additional studies using commodity-sized CCA-treated products in natural marine environments.

Literature

American Wood-Preservers' Association. Book of Standards. Woodstock, MD.

APHA, AWWA, WPCF., 1985. Standard methods for the examination of water and wastewater. Method 3030, Method 3111 B. and 3113 A. 16th Edition, Washington, D.C. 2168 pp.

ASTM, 1980. Standard practice for conducting toxicity test with fishes, macroinvertebrates and amphibians. Standard E729-80, 25 pp.

Arsenault, R.D., 1975. CCA-treated wood foundations: A study of permanence, effectiveness, durability and environmental considerations. Proc. American Wood-Preservers' Association. 71: 126-147.

Bousfield, E.L., 1973. Shallow-water gammaridean amphipods of New England. Cornell University Press.

Breteler, R.J., 1992. Critique provided on behalf of the American Wood Preservers Institute, Vienna, VA.

Brooks, K.M., 1993. Literature review and assessment of the environmental risks associated with the use of CCA and ACZA treated wood products in aquatic environments. Prepared for Western Wood Preservers Institute. Vancouver, WA.

Enequist, P., 1980. Zool. Bidrag. Fran Uppsala, 28: 297-492.

Graham, J.S., 1991. Pressure-treated wood effect on marina environment. World Marina '91 Proceedings First International Conference/ASCE. Long Beach, CA. Sept. 4-8, 1991.

Hartford, W.H., 1986. The practical chemistry of CCA in service. Proc. American Wood-Preservers' Association. 82: 28- 45.

Hyland, J.L., 1981. Comparative structure and response to (petroleum) disturbance in two nearshore infaunal communities. Ph.D. Thesis, University of R.I., 141 pp.

Mills, E.L., 1964. The biology of an ampeliscid amphipod crustacean sibling species pair. Journal of the Fisheries Research Board of Canada. 24(2): 305-355.

Nichols, F.H. and Thompson, J.K., 1985. Mar. Ecol. Prog. Ser. 24: 83-97.

Sokal, R.R. and Rohlf, F.J., 1981. Biometry. 2nd Edition. W.H. Freeman and Company, New York. 859 pp.

Springborn Laboratories, Inc., 1993. Environmental Sciences Division, Wareham, MA. SLI Report No. 93-4-4730. Sediment bound CCA-C leachate 10-day/repeated exposure toxicity to *Ampelisca abdita* under static conditions. 56-76.

Webb, D.A. and Gjovik, L.R., 1988. Treated wood products, their effect on the environment. Proc. American Wood-Preservers' Association. 84: 254-259.

Weber, C.I. et. al. (eds.)., 1989. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. 2nd ed. EPA/600/4/89/001. Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency. Cincinnati, OH.

Weis, P. et. al., 1992. Toxicity of construction materials in the marine environment: a comparison of chromated copper arsenate treated wood and recycled plastic. Arch., Environ. Contam. Toxicol. 22: 99- 106.

TABLE 1. Percent survival of amphipods (*Ampelisca abdita*) during the 10-day exposure to sediment mixed with leachate from the untreated piles.

Leachate Solution Concentration[a] %		Exposure Day										
		0	1	2	3	4	5	6	7	8	9	10
Untreated Pile Number 4												
HOC	100	100	100	100	98	95	95	95	90	85	80	65
	50	100	100	98	98	95	83	80	75	68	68	68
	10	100	100	98	95	95	95	95	90	85	80	65
LOC	100	100	100	100	98	95	90	90	85	85	85	70
	50	100	100	93	93	88	85	85	75	70	70	50
	10	100	100	100	100	93	85	85	83	75	73	55
Untreated Pile Number 6												
HOC	100	100	100	98	93	90	85	85	78	75	60	38
	50	100	100	93	90	85	73	70	68	63	63	48
	10	100	100	93	90	78	70	70	60	60	60	48
LOC	100	100	100	100	98	98	95	95	93	88	83	73
	50	100	100	100	98	98	95	95	93	85	85	68
	10	100	100	100	95	85	83	83	75	73	73	60
Untreated Pile Number 7												
HOC	100	100	100	95	95	90	90	85	78	73	70	55
	50	100	100	100	95	95	88	88	83	73	70	55
	10	100	100	98	98	98	83	80	75	75	70	48
LOC	100	100	100	93	90	90	83	83	80	80	78	75
	50	100	100	98	93	93	83	83	73	68	68	53
	10	100	100	100	100	100	100	100	100	100	95	93

[a]Concentration (%) of leachate mixed with natural sediment.

TABLE 2. Percent survival of amphipods (*Ampelisca abdita*) during the 10-day exposure to sediment mixed with leachate from the CCA-C treated piles.

Leachate Solution Concentration[a] %	Exposure Day										
	0	1	2	3	4	5	6	7	8	9	10
Treated Pile Number 8											
HOC 100	100	100	100	100	98	98	98	98	98	98	85
50	100	100	100	100	100	100	100	100	100	100	83
10	100	100	100	100	100	100	100	100	100	100	93
LOC 100	100	100	100	100	100	100	100	100	100	98	82
50	100	100	98	98	98	98	98	98	98	98	90
10	100	100	90	88	88	83	83	80	78	78	73
Treated Pile Number 9											
HOC 100	100	100	100	98	95	95	93	93	93	93	83
50	100	100	100	100	100	100	100	100	100	100	98
10	100	100	100	100	95	95	95	93	90	90	78
LOC 100	100	100	98	98	98	98	98	98	98	95	85
50	100	100	100	98	95	95	95	92	90	90	88
10	100	100	93	85	85	75	70	70	70	70	60
Treated Pile Number 10											
HOC 100	100	100	100	100	100	98	98	98	98	95	88
50	100	100	100	100	100	100	100	100	100	100	88
10	100	100	100	100	93	93	88	88	88	88	73
LOC 100	100	100	100	98	98	98	98	98	98	98	98
50	100	100	100	100	100	100	100	100	98	98	55
10	100	100	98	98	98	93	93	93	93	93	48

[a]Concentration (%) of leachate mixed with natural sediment.

TABLE 3. Percent survival of amphipods (*Ampelisca abdita*) during the 10-day exposure to the control sediments.

Control Solution	Exposure Day										
	0	1	2	3	4	5	6	7	8	9	10
HOC A	100	100	100	100	100	100	100	100	100	100	80
B	100	100	100	100	100	100	100	95	95	95	75
C	100	100	100	100	100	100	100	95	95	95	75
LOC A	100	100	100	100	100	100	100	100	95	95	90
B	100	100	100	95	95	95	95	95	95	90	90
C	100	100	100	100	100	100	95	95	95	95	95

TABLE 4. Results of the water quality parameters measured daily in alternating replicates, in the CCA-C treated pile leachate test solutions during the 10-day exposure of amphipods (*Ampelisca abdita*).						
Leachate Solution Concentration %			Dissolved Oxygen Concentration (mg/L)	Salinity (‰)	Temperature (°C)	pH
Treated Pile Number 8						
HOC[a]	100	Mean[c]	6.6 (0.52)	31 (0.79)	20 (0.70)	NA[d]
		Range	5.2 - 7.1	30 - 32	19 - 21	7.3 - 8.0
	50	Mean	6.9 (0.36)	32 (0.98)	20 (0.70)	NA
		Range	6.2 - 7.3	30 - 34	19 - 21	7.4 - 8.2
	10	Mean	7.0 (0.22)	32 (0.91)	20 (0.70)	NA
		Range	6.5 - 7.3	31 - 34	19 - 21	7.4 - 8.0
LOC[b]	100	Mean	7.1 (0.22)	31 (0.67)	20 (0.60)	NA
		Range	6.7 - 7.5	30 - 32	19 - 21	7.6 8.1
	50	Mean	7.0 (0.40)	31 (0.67)	20 (0.60)	NA
		Range	6.1 - 7.5	30 - 32	19 - 21	7.7 - 8.2
	10	Mean	7.0 (0.34)	32 (0.67)	20 (0.60)	NA
		Range	6.1 - 7.5	30 - 32	19 - 21	7.7 - 8.2
Treated Pile Number 9						
HOC	100	Mean	6.7 (0.35)	31 (0.79)	20 (0.70)	NA
		Range	6.2 - 7.2	30 - 32	19 - 21	7.3 - 8.1
	50	Mean	6.7 (0.53)	31 (0.67)	20 (0.70)	NA
		Range	5.6 - 7.4	30 - 32	19 - 21	7.2 - 8.0
	10	Mean	6.9 (0.31)	31 (0.92)	20 (0.60)	NA
		Range	6.2 - 7.4	30 - 33	19 - 21	7.5 - 7.9
LOC	100	Mean	6.9 (0.42)	32 (0.87)	20 (0.63)	NA
		Range	6.2 - 7.5	31 - 34	19 - 21	7.7 - 8.1
	50	Mean	7.1 (0.40)	31 (1.1)	20 (0.63)	NA
		Range	6.4 - 7.7	30 - 34	19 - 21	7.7 - 8.2
	10	Mean	7.1 (0.27)	32 (1.0)	20 (0.63)	NA
		Range	6.8 - 7.7	30 - 34	19 - 21	7.6 - 8.2

Leachate Solution Concentration %			Dissolved Oxygen Concentration (mg/L)	Salinity (‰)	Temperature (°C)	pH
Treated Pile Number 10						
HOC	100	Mean Range	6.4 (0.89) 4.2 - 7.1	31 (0.67) 30 - 32	20 (0.63) 19 - 21	NA 7.1 - 7.9
	50	Mean Range	7.0 (0.20) 6.7 - 7.2	32 (0.81) 30 - 33	20 (0.54) 19 - 21	NA 7.5 - 8.1
	10	Mean Range	6.8 (0.24) 6.4 - 7.3	31 (0.67) 30 - 32	20 (0.56) 19 - 21	NA 7.5 - 8.0
LOC	100	Mean Range	7.0 (0.36) 6.2 - 7.5	31 (1.0) 30 - 34	20 (0.70) 19 - 21	NA 7.6 - 8.2
	50	Mean Range	7.1 (0.35) 6.2 - 7.5	31 (1.1) 30 - 34	20 (0.63) 19 - 21	NA 7.7 - 8.2
	10	Mean Range	7.0 (0.40) 5.9 - 7.5	32 (1.0) 30 - 34	20 (0.60) 19 - 21	NA 7.7 - 8.2

TABLE 4 (cont.) Results of water quality parameters measured daily in alternating replicates, in the CCA-C treated pile leachate test solutions during the 10-day exposure of amphipods

[a]HOC = High Organic Carbon Sediment
[b]LOC = Low Organic Carbon Sediment
[c]Mean values are presented with the standard deviation in parentheses.
[d]NA = Not applicable

TABLE 5. Results of the water quality parameters measured daily in alternating replicates, in the untreated pile leachate test solutions during the 10-day exposure of amphipods (*Ampelisca abdita*).

Leachate Solution Concentration %			Dissolved Oxygen Concentration (mg/L)	Salinity (‰)	Temperature (°C)	pH
Untreated Piling Number 4						
HOC[a]	100	Mean[c]	7.0 (0.18)	31 (0.65)	20 (0.54)	NA[d]
		Range	6.8 - 7.3	30 - 32	19 - 21	7.4 - 7.9
	50	Mean	6.8 (0.19)	31 (0.67)	20 (0.70)	NA
		Range	6.4 - 7.1	30 - 32	19 - 21	7.5 - 8.0
	10	Mean	6.5 (0.78)	31 (0.67)	20 (0.54)	NA
		Range	4.4 - 7.2	30 - 32	19 - 21	7.3 - 7.9
LOC[b]	100	Mean	7.0 (0.29)	31 (0.60)	20 (0.60)	NA
		Range	6.3 - 7.4	30 - 32	19 - 21	7.7 - 8.0
	50	Mean	7.1 (0.16)	31 (0.65)	20 (0.60)	NA
		Range	6.8 - 7.3	30 - 32	19 - 21	7.7 - 8.1
	10	Mean	7.1 (0.20)	31 (0.65)	20 (0.60)	NA
		Range	6.8 - 7.4	30 - 32	19 - 21	7.6 - 8.3
Untreated Pile Number 6						
HOC	100	Mean	7.0 (0.10)	31 (0.94)	20 (0.60)	NA
		Range	6.9 - 7.2	30 - 33	19 - 21	7.4 - 7.7
	50	Mean	6.8 (0.33)	31 (0.87)	20 (0.60)	NA
		Range	6.0 - 7.1	30 - 33	19 - 21	7.4 - 7.8
	10	Mean	6.7 (0.31)	31 (0.79)	20 (0.60)	NA
		Range	6.2 - 7.2	30 - 33	19 - 21	7.3 - 7.8
LOC	100	Mean	7.1 (0.12)	31 (0.75)	20 (0.60)	NA
		Range	6.9 - 7.3	30 - 32	19 - 21	7.6 - 8.1
	50	Mean	6.9 (0.34)	31 (0.65)	20 (0.60)	NA
		Range	6.0 - 7.3	30 - 32	19 - 21	7.7 - 8.0
	10	Mean	7.0 (0.22)	32 (0.54)	20 (0.60)	NA
		Range	6.5 - 7.3	30 - 32	19 - 21	7.6 - 8.1

TABLE 5 (cont.) Results of the water quality parameters measured daily in alternating replicates, in the untreated pile leachate test solutions during the 10-day exposure of amphipods (*Ampelisca abdita*).

Leachate Solution Concentration %			Dissolved Oxygen Concentration (mg/L)	Salinity (‰)	Temperature (°C)	pH
Untreated Pile Number 7						
HOC	100	Mean	6.9 (0.27)	31 (0.70)	20 (0.60)	NA
		Range	6.5 - 7.4	30 - 32	19 - 21	7.2 - 7.8
	50	Mean	6.7 (0.59)	31 (0.70)	20 (0.78)	NA
		Range	5.6 - 7.8	30 - 32	19 - 21	7.4 - 7.8
	10	Mean	6.8 (0.72)	31 (0.60)	20 (0.54)	NA
		Range	4.7 - 7.4	30 - 32	19 - 21	7.4 - 7.9
LOC	100	Mean	7.2 (0.10)	31 (0.70)	20 (0.63)	NA
		Range	7.1 - 7.4	30 - 32	19 - 21	7.7 - 8.2
	50	Mean	7.0 (0.47)	31 (0.70)	20 (0.54)	NA
		Range	5.6 - 7.3	30 - 32	19 - 21	7.7 - 8.3
	10	Mean	7.1 (0.21)	31 (0.69)	20 (0.54)	NA
		Range	6.7 - 7.3	31 - 33	19 - 21	7.6 - 8.2

[a]HOC = High Organic Carbon Sediment
[b]LOC = Low Organic Carbon Sediment
[c]Mean values are presented with the standard deviation in parentheses.
[d]NA = Not applicable

TABLE 6. Results of the water quality parameters measured daily in alternating replicates, in the control solutions during the 10-day exposure of amphipods (*Ampelisca abdita*).

Sediment Type		Dissolved Oxygen Concentration (mg/L)	Salinity (‰)	Temperature (°C)	pH
HOC[a]	Mean[c]	6.4 (0.29)	31 (1.1)	20 (0.65)	NA[d]
	Range	5.9 - 6.8	30 - 33	19 - 21	7.6 - 7.9
LOC[b]	Mean	7.0 (0.16)	31 (0.67)	20 (0.54)	NA
	Range	6.7 - 7.2	30 - 32	19 - 21	7.6 - 8.1

[a]HOC = High Organic Carbon Sediment
[b]LOC = Low Organic Carbon Sediment
[c]Mean values are presented with the standard deviation in parentheses.
[d]NA = Not applicable

Figure 1. Survival of amphipods (*Ampelisca abdita)* following the 10-day exposure to natural seawater and high organic carbon (HOC) sediments mixed with leachate from untreated and CCA treated piles.

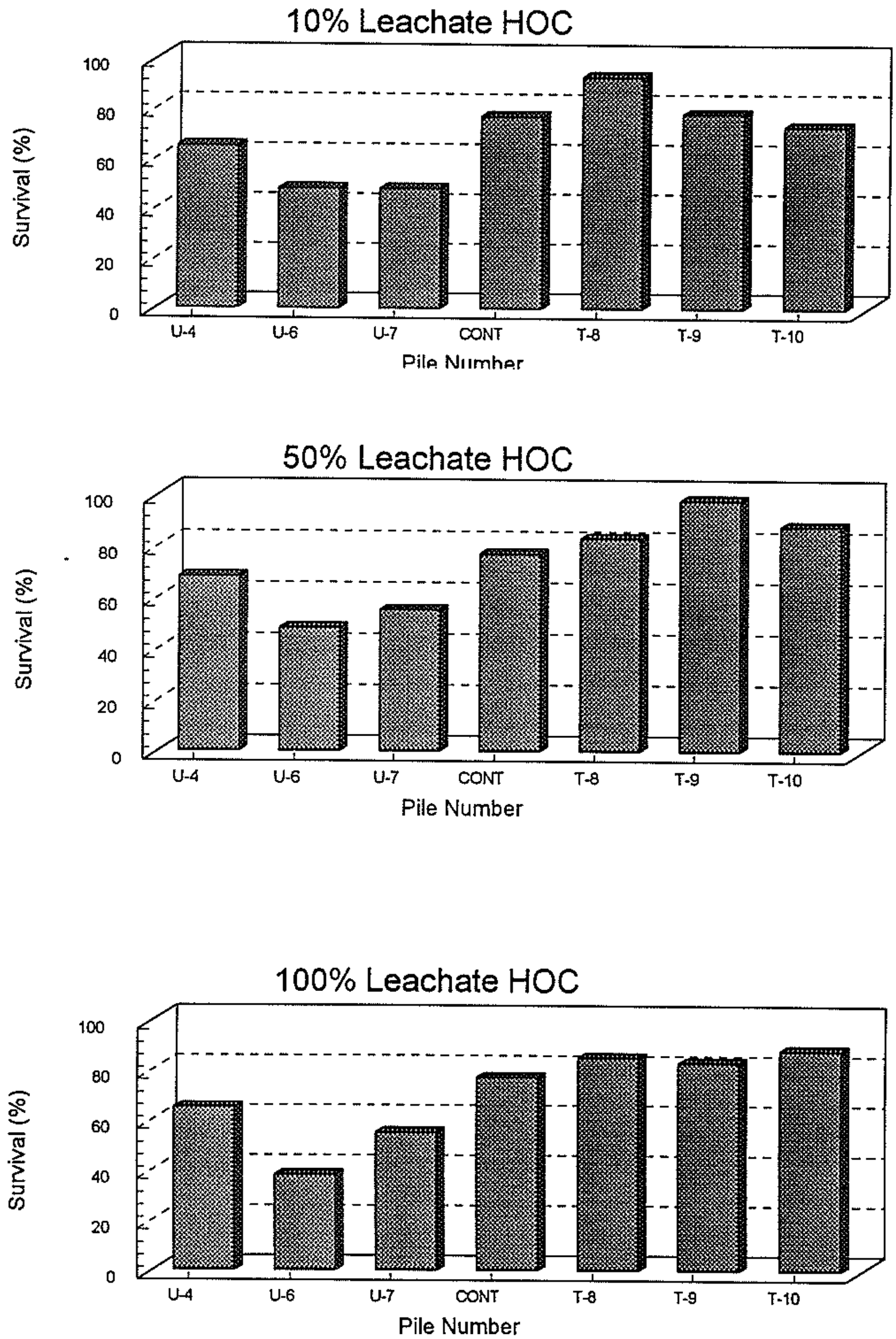

Figure 2. Survival of amphipods (*Ampelisca abdita)* following the 10-day exposure to natural seawater and low organic carbon (LOC) sediments mixed with leachate from untreated and CCA treated piles.