Estuaries Vol. 19, No. 2A, p. 306–310 June 1996

The Effects of Using Wood Treated With Chromated Copper Arsenate in Shallow-Water Environments: A Review

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ABSTRACT: Studies published over the past several years have documented that copper, chromium, and arsenic leach from pressure-treated wood placed in estuaries, and that these toxic metals accumulate in nearby sediments and biota. We have found bioaccumulation and deleterious effects in the epibiotic ("fouling") community, particularly in poorly flushed areas and on new wood. The epibiota showed reduced species richness, diversity, and biomass. Barnacles and encrusting bryozoa that settled on new treated wood grew more slowly than those that settled on untreated wood or plastic substrate. In laboratory studies, trophic transfer of the contaminants from epibiota to their consumers has also been demonstrated. We have also found accumulation of the treatment metals in the fine-grained fraction of nearby sediments and in the benthic infauna. Infauna also had reduced species richness and diversity in sediments adjacent to treated-wood structures. While standard toxicity tests with amphipods did not demonstrate acute toxicity of these sandy sediments, sublethal effects on development were seen in juvenile mysids. Overall, the extent and severity of effects of pressure-treated wood in an estuary depends on the amount and age of the wood and the degree of dilution by water movements.

Introduction

In the course of developing shorelines, many wooden structures such as pilings and bulkheads have been placed in shallow-water estuarine environments. Since wood may decay or be attacked by boring organisms, methods of wood preservation have been developed. The favored method of preservation is pressure treatment with chromated copper arsenate (CCA), which is replacing pentachlophenol and creosote. In 1987, CCA accounted for over 90% of the United States market in treated lumber, an estimated 6.5 billion board feet. The three toxicants are pressurized into the wood (usually Southern yellow pine) in a process called "Wolmanizing." CCA Type C is the most commonly used and is composed of 47.5% CrO_3, 18.5% CuO, and 34% As_2O_3. The high temperature and pressure should cause "fixation" of the chemicals, which should then be resistant to leaching. Wood intended for marine use receives the highest amount: 1.5 lb ft^{-3} (24 kg m^{-3}) or 2.5 lb ft^{-3} (40 kg m^{-3}).

The extensive use of wood treated with CCA may pose a hazard to adjacent aquatic environments through leaching of toxicants. Each of the three metals is known to be toxic to aquatic biota. Arsenic is carcinogenic, mutagenic, and teratogenic, and readily taken up by phytoplankton (Sanders and Windom 1980). Chromium exists in the aquatic environment as chromate and is accumulated by phytoplankton (Sanders and Reidel 1987). Chromate, Cr (VI), is carcinogenic and mutagenic. Under reduced oxygen conditions it may be reduced to Cr(III), which is substantially less harmful. Copper is a micronutrient but can be toxic at higher levels, especially to algae and mollusks. The free Cu ion is the toxic form, while Cu tends to be >98% bound to organic material in the aquatic environment (Newell and Sanders 1986). In this paper, we review previously published laboratory and field studies on the effects of this construction material in estuaries.

Leaching Studies

Low to moderate amounts of the metals leach from CCA-treated wood. Warner and Solomon (1990) demonstrated that all three metals leach in

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fresh water, and that leaching is greatest at lower pHs. While all three metals leach in salt water, Cu is the most mobile (Cherian et al. 1979; Hegarty and Curran 1986). Leaching rates vary with salinity, but substantial leaching of all three elements was always noted (Sanders et al. 1994). Merkle et al. (1993) found significant leaching (about 1 μg cm^{-2} d^{-1} for Cu and As and 0.01 μg cm^{-2} d^{-1} for Cr over a 21-d period) from wood which had been certified as "properly treated" at 0.3 lb ft^{-3} (an order of magnitude less than the concentration in wood for marine uses). Rather than focusing on release into water, studies supported by wood preservers have looked at retention of the preservative in the wood and have found the same concentration after years as the wood had initially (Gjovik 1977). Such studies, which conclude that no leaching occurs, ignore the issue of scale, that is, the presence of toxic chemicals at parts-per-hundred level in the wood versus toxic effects of metals in the aquatic environment, which generally occur at the parts-per-million level or lower. A small percentage loss from the wood, which would not be noticed, can translate into a toxic level in the water.

Biological Effects

While there have been numerous laboratory and field studies on effects of each of the three metals on aquatic organisms, there has been very little work on the effects of treated wood leachates on biota. In fresh water subject to simulated acid rain, the copper leached was far in excess of the LC_{50} for *Daphnia magna* (Buchanan and Solomon 1990). The LC_{50} for this species was 0.036 mg Cu l^{-1}, which represented only about 2% of the original copper leachate concentrations. Leachates from treated wood from differing species of trees all failed 96-h LC_{50} tests using fish (Environchem Special Projects Inc. 1992).

In our laboratory studies, wood leachates were toxic to a variety of estuarine biota, including fiddler crabs (*Uca pugilator*), green algae (*Ulva lactuca*), fish (*Fundulus heteroclitus*) embryos, and sea urchin (*Arbacia punctulata*) sperm and embryos (P. Weis et al. 1991, 1992). The toxic effects of wood that had been previously immersed in water for a few weeks were less, probably reflecting decreased leaching over time. One of the most sensitive organisms was the mud snail, *Ilyanassa obsoleta,* which upon exposure to CCA leachates quickly retracted into their shells and remained inactive on the bottom of the tank. If they were placed in clean water they recovered. After a few days in water with CCA wood, they died. This phenomenon has been reported for other gastropods after copper exposure (Glude 1957; Harry and Aldrich 1963).

In an estuary, there are different pathways by which chemicals leaching from treated wood can affect aquatic biota. They can dissolve in water and be taken up by biota. Uptake from water would be expected to be greatest by the epibiotic ("fouling") organisms that live directly on the wood. The chemicals can also be adsorbed onto nearby sediments and then be taken up to benthic infaunal organisms. Consumers of the epibiotic or infaunal animals could accumulate the chemicals through food-chain transfer. The amount of water flow and dilution in an estuary, and the amount and age of the CCA wood should be major influences on the degree to which leachates from CCA wood will accumulate in and affect local biota.

Epibiota: The "Fouling Community"

Green algae (*Ulva lactuca* and *Enteromorpha intestinalis*), collected from CCA-treated bulkheads in Southampton, New York, had Cu, Cr, and As levels significantly higher than in specimens collected from nearby rocks (J. Weis and P. Weis 1992a). For example, *Enteromorpha* from the dock had about 55 μg g^{-1} Cu, 6 μg g^{-1} Cr, and 4.7 μg g^{-1} As, while the same species from nearby rocks had about 14 μg g^{-1} Cu, 2.5 μg g^{-1} Cr, and 1 μg g^{-1} As. Levels in *Ulva* were similar. To investigate the effects of differential water flow regimes, algae (*Ceramium* sp.), oysters (*Crassostrea virginica*), barnacles (*Balanus eburneus*), and mussels (*Brachydontis recurvis*) were collected from a CCA-treated dock in an open-water environment and from bulkheads in a poorly flushed residential canal adjoining Santa Rosa Sound, Pensacola Beach, Florida, and were analyzed for Cu, Cr, and As. Reference organisms were collected from nearby rocks in open water. Organisms living on the open-water dock had significantly elevated concentrations of contaminants. For example, in *Ceramium,* the Cu increased from about 1 μg g^{-1} to 3 μg g^{-1} wet weight, and the As increased from about 3 μg g^{-1} to 5.5 μg g^{-1}. However, those organisms living on wood inside the canal had considerably higher concentrations, demonstrating that areas with more wood and less water flow permit greater accumulation of the metals. The highest concentrations were seen in organisms growing on new (1-yr-old) wood in the canal. For example, barnacles growing on rocks had about 1 μg g^{-1} Cu wet weight, those on the open-water dock had about 3 μg g^{-1}, those in the canal had about 10 μg g^{-1}, and those on new wood inside the canal had over 80 μg g^{-1}, indicating there is greater leaching and bioaccumulation from new wood and in poorly flushed environments (P. Weis et al. 1993a). Macroalgae, barnacles, and bivalve mollusks have all been used previously to monitor metals in coastal waters (Bryan and Hummerstone 1973; Goldberg et al. 1978; Phillips and Rainbow

1988; Ho 1990). Tissues of oysters living inside a canal, which had highly elevated copper levels (over 150 $\mu g\ g^{-1}$, a 12-fold increase over controls), were often green in color (P. Weis et al. 1993b), although the oysters exhibiting the green coloration were not always those with the greatest copper concentration. Oysters did not accumulate the other metals to such a great extent. Arsenic in reference oysters was about 6 $\mu g\ g^{-1}$ and in canal oysters was about 10 $\mu g\ g^{-1}$, a difference that is statistically significant, but not as high as that for Cu. Other investigators have noted that oysters bioaccumulate Cu to a greater degree than other metals (Schuster and Pringle 1969). In our study, oysters living inside the canal had an increased prevalence of a pathological condition of the digestive diverticula. This pathology has previously been noted in oysters exposed to a variety of stressors, including copper (Couch 1984). The canal oysters also had an increased incidence of micronuclei in gill cells (Weis et al. 1995), indicating a genotoxic response. Chromium and arsenic are both genotoxic (Tkeshelashvili et al. 1980; Nakamuro and Sayato 1981).

Settlement of Epibiota: Community Composition

The community that formed on panels of CCA-treated wood, control wood, and recycled plastic "lumber" placed in an estuary were investigated in Southampton, New York (J. Weis and P. Weis 1992b). The community that settled on CCA-treated boards had significantly lower species richness (one-half to two-thirds) and diversity (Shannon-Wiener index), and only about half the biomass than the community on untreated wood or recycled plastic. Organisms that settled on the treated wood had elevated concentrations (by an order of magnitude) of all three metals (this was new wood not previously immersed). In particular, barnacles, encrusting bryozoans, and algae were inhibited from settling on treated wood, and once larvae had settled, the bryozoans and barnacles grew more slowly than those that settled on the other substrates. For example, barnacles grew to 11 mm diameter on control wood and to 8 mm on treated wood (J. Weis and P. Weis 1992b). Wood that had leached for 1 mo did not inhibit settlement as much as new wood. The community that settled on treated wood soaked for 2 mo was similar in species number, biomass, and diversity to control (untreated wood) panels, although there was still a significant bioaccumulation of metals (J. Weis and P. Weis 1996).

Sediments

Sediments adjacent to and at varying distances from CCA-treated bulkheads, which were parallel to the shoreline, were analyzed for the three elements. Sediments adjacent to bulkheads in New York and New Jersey estuaries had very low percentages of fine-grained particles (silt and clay often 1% or less) due to the hydrographic regime—water movements scour the area adjacent to the hard structure. There were very high concentrations of the three metals associated with these fine particles (100–2,000 $\mu g\ g^{-1}$). Sediments further away from the bulkheads (10 m away), and therefore in deeper water, had higher percentages of silt and clay (up to 60%), but lower concentrations of the metals in the fine fraction (P. Weis et al. 1992). Higher metal levels were found in sediments in poorly flushed areas than in more open-water environments. The highest metal concentrations were found in sediments adjacent to the newest bulkhead.

Benthos

Fiddler crabs (*U. pugilator*) collected from intertidal burrows close to CCA-treated wood had elevated (approximately doubled) metal levels, as did the sediments in which they resided (J. Weis and P. Weis 1992a). This implies that sediments can be a route of exposure to benthic biota. The overall contamination of bulk sediments adjacent to the bulkheads is low because fine particles compose such a small part of the sandy sediments. Yet, the crabs had elevated Cu, Cr, and As levels, indicating that some fraction of the metals are indeed bioavailable. There is evidence that metals may be more bioavailable in sandy as compared with silty sediments (Rule and Alden 1990). Selective deposit-feeders in sandy sediments could seek out the rare fine particles to ingest, and thus could acquire a high body burden from contaminated fine particles. Metal concentrations in subtidal benthic polychaete worms (*Neanthes succinea*) in sandy sediments adjacent to the open-water bulkhead in Santa Rosa Sound, Florida, had elevated metal levels that decreased (about fivefold) with distance from the wood (J. Weis and P. Weis 1994).

Sediments adjacent to the bulkheads in Santa Rosa Sound were tested for their toxicity. Acute bioassays with amphipods (*Ampelisca abdita*) were negative. However, juvenile *Mysidopsis bahia* maintained in sediments taken from the immediate vicinity of the bulkheads had retarded development of sexual maturity compared to mysids in reference sediments or in sediments collected further away from the wood. Baldwin, Pasek, and Osborne (unpublished data) also found no toxicity to *Ampelisca* of sediments that received CCA leachates. Similarly, Wendt et al. (in press) found no toxicity of sediments near docks (in a very well-flushed area) in a rotifer assay or in an assay utilizing bioluminescence of marine bacteria.

Benthic community analysis revealed reductions in species richness, total numbers of organisms, and diversity (Shannon-Wiener index) in the sediments adjacent to the bulkheads in Santa Rosa Sound compared to reference sediments (J. Weis and P. Weis 1994). The mean number of species in reference site sediments was 11, in sediments by an open-water bulkhead it was 6, and in sediments by the bulkhead inside the canal it was less than 2.

Trophic Transfer

A variety of motile animals, including grass shrimp, crabs, gobies, and amphipods, are frequently found associated with wood in the field, probably feeding on epibiota. This provides a mechanism for wood-derived contaminants to pass into parts of the estuarine food web. Mud snails (*I. obsoleta*) were maintained in clean seawater and provided with green algae (*Ulva lactuca* or *Enteromorpha intestinalis*) collected from CCA-treated wood or from nearby rocks for food. Within 1 wk, some snails feeding on algae from the wood had retracted into their shells and lay inactive on the bottom of the containers; they subsequently died (J. Weis and P. Weis 1992a). This response is similar to that seen in snails exposed directly to leachates from the wood (P. Weis et al. 1991). After four weeks, all experimental snails were either retracted or dead, while all control snails were still active.

Oysters collected from CCA-treated wood in the Florida canal were provided as food for carnivorous snails (*Thais haemastoma*). Control snails were fed oysters collected from rocks at the reference site. Snails provided with the canal oysters gradually ate less and gained less weight than the snails eating reference oysters. The experimental snails increased their body burden of copper about fourfold over the 8 wk (J. Weis and P. Weis 1993), and attained body burdens comparable to that of snails collected from a CCA-treated bulkhead (over 150 $\mu g\ g^{-1}$ wet weight). Juvenile spot (*Leiostomus xanthurus*) and pinfish (*Lagodon rhomboides*) collected inside the canal had significantly higher concentrations of Cu (about 2.5 $\mu g\ g^{-1}$) and As (about 1.5 $\mu g\ g^{-1}$) than did fish from the reference site (about 0.5 $\mu g\ g^{-1}$ and 0.2 $\mu g\ g^{-1}$). It is likely that these body burdens were obtained partly from their food.

Discussion

We have found uptake and deleterious effects of leachates from CCA-treated wood in estuaries in the Northeast and Gulf coasts. High concentrations of metals, particularly copper, accumulated in epibiota living directly on the wood. The epibiota had reduced community diversity and growth on panels submerged in the water, and had an elevated incidence of abnormalities. The contaminants may be transferred to their consumers, with deleterious effects. Metals leached from the wood are adsorbed onto fine-grained sediment particles nearby, from which they can be accumulated by nearby benthic organisms. Infaunal communities near the wood can exhibit reductions in diversity. The extent and severity of effects in any area will depend on the amount of wood present, its age, and the degree of dilution by water movements. One would predict minimal effects in a well-flushed system with pilings, but more severe impacts in a poorly flushed system with many bulkheads. Since leaching and toxicity is greatest when the wood is new, the environmental impact of CCA-treated wood could be reduced significantly if it were leached out for a few months before being marketed.

The extent of the United States Environmental Protection Agency policy regarding this product (which is not considered a pesticide, although the preservatives are) is to recommend that there be available a Consumer Information Sheet advising purchasers not to inhale sawdust, nor to use the wood for a food-preparation surface, or burn it in their fireplaces. This focus on human health ignores environmental impacts of this product, which is a concentrated source of metals that are toxic to a wide variety of organisms. However, some agencies at the state and local levels, including the State of New Jersey, are restricting the use of this product in the interest of protecting the shallow-water estuarine environment.

Acknowledgments

We appreciate the hospitality of the Department of Natural Sciences of Southampton College, New York, and of the United States Environmental Protection Agency Environmental Research Laboratory in Gulf Breeze, Florida. We are grateful for the technical assistance of Lisa Coohill, Christine Salomon, and Theodore Proctor, and for the financial support from the United States Geological Survey-Water Resources Research Institute Program, the P.A.D.I. Foundation, and the New Jersey Sea Grant Program.

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Received for consideration, December 2, 1994
Accepted for publication, April 12, 1995