Hull Fouling and Copper Tolerance – 2011 Scientific Review

I. What are Hull Fouling Organisms and Aquatic Invasive Species (AIS)?

Hull fouling organisms attach and grow on surfaces of boats that are exposed to the water (Sylvester et al. 2011). Boat owners are impacted by these species because they reduce the smoothness of the hull, creating friction or "drag," which increases fuel consumption for powerboats and slows sailboats (Schultz 2007).

Fouling species can be released from hulls and spread to new habitats by reproduction or hull cleaning operations (Coutts et al. 2010). Non-native species may outcompete native species, reducing overall biodiversity (Lawler et al. 2006). Examples include the Teredo shipworm that was introduced to San Francisco Bay, and the freshwater zebra mussel that was introduced to the Great Lakes and spread through much of the United States. These AIS have serious economic consequences, respectively costing the United States $205 million and $100 million annually in control costs, losses and damages (Pimental et al. 2000). Eradicating invasive species is typically difficult and costly (Meyerson and Reaser 2002).

II. How is Copper Used to Manage Hull Fouling and What are the Consequences?

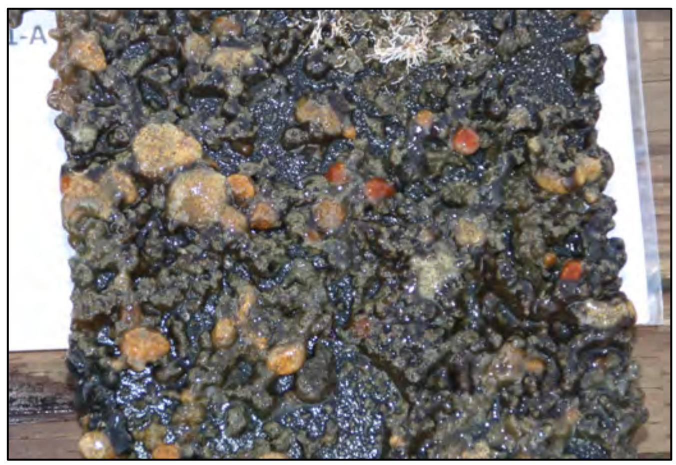
Copper is toxic to early life-stages of many marine species and has been used as an antifouling agent for centuries (Piola et al. 2009). Popular copper antifouling paints contain 20%-76% cuprous oxide and continuously leach the heavy metal from the coated hull into the surrounding water (Johnson and Miller 2002). Government reports indicate that copper antifouling paints impair water quality in some boat basins by causing dissolved copper levels to exceed 3.1 parts per billion (ppb) (CRWQCB-SDR 2005, Kiaune and Singhasemanon 2011).

However, copper is not only toxic to fouling species, but also to animals that live in the water basins where it accumulates. Scientific studies of mussels, oysters, scallops, sea urchins and crustaceans have found harmful effects by dissolved copper at levels found in southern California marinas. When exposed to dissolved copper at concentrations from 3.0 to 10.0 ppb, various species showed reduced or abnormal: embryo growth, development, swimming and survival; larval growth and survival; adult growth, spawning and survival; and adult digestive, reproductive and muscle tissues (Calabrese et al. 1984, Coglianese and Martin 1981, Fitzpatrick et al. 2008, Gould et al. 1988, Lee and Xu 1984, Lussier et al. 1985, MacDonald et al. 1988, Martin et al. 1981, Novelli et al. 2003, Redpath 1985, Stromgren and Nielsen 1991). Some of these studies and others (Krishnakumar et al. 1990, Redpath and Davenport 1988) found that many of the above effects became more severe and that feeding, respiration, and waste elimination of adult mussels were also affected at dissolved copper levels from 10.0 to 29.0 ppb. Copper has been shown to have adverse effects on salmon sensory processes (McIntyre et al. 2008). It also causes problems in the gills, kidneys, tissues and sensory receptors of fish in general (Hall et al. 1998).

III. Are Some Hull Fouling Species Tolerant of Copper's Toxicity and Why Does it Matter?

The ability to withstand a variety of conditions may allow non-native species to invade new environments (Fields et al. 2006). Some non-native fouling species have developed the ability to tolerate copper (Table 1). This may occur because antifouling paints eliminate individuals that are sensitive to copper, reducing competition for those that are tolerant, much like pesticide resistance. Thus, copper pollution may cause fundamental changes to local ecosystems that favor invasive species. (Piola and Johnston 2008)

Evidence is also beginning to appear for copper tolerance of some native fouling species (Crooks et al. 2011), suggesting that such pesticide resistance is becoming more common.



12 months' fouling on copper-coated test-panel, San Diego Bay. Scott Parker

Species that tolerate copper present two more risks. First, they can grow on hulls coated with copper paint and then be carried to other areas. Second, they can form a barrier over the toxic paint and provide a surface to which copper-sensitive species can attach and 'piggy-back' on hulls with toxic antifoulants (Dafforn et al. 2011). These two risks make controlling hull fouling more difficult and increase risks of transporting invasive species.

IV. What Does Copper Tolerance Research Tell Us?

Several studies suggest that some invasive fouling species are displaying copper tolerance, which is generally determined in two ways. The first looks at the ability of different species to attach directly onto toxic copper paint (Floerl et al. 2004, Dafforn et al. 2008, Jelic-Mrcelic et al. 2006). The second looks at the ability of native versus non-native species to survive in copper-polluted waters (Crooks et al. 2011, Piola and Johnston 2006a and b, Han et al. 2008, Piola and Johnston 2009).

Floerl et al. (2004) in Australia compared growth of the invasive bryozoan *Watersipora subtorquata* on surfaces with a copper coating. They also studied the ability of less copper-tolerant fouling species to grow on this non-native species. *W. subtorquata* covered as much as 64% of test-panel surfaces that had copper paint. Twenty-two species that did not grow on the toxic paint grew on *W. subtorquata*. All fouling species were 248 times more abundant on *W. subtorquata* than on the copper surfaces!

Watersipora subtorquata. Luis A. Solorzano. www.lasphotos.com

Dafforn et al. (2008) compared attachment rates of native versus non-native species on test-panels in various environments. They compared ability of different species to attach to copper-treated and untreated panels. The invasive bryozoan *W. subtorquata* and the tubeworm *Hydroides elegans* dominated copper-treated plates in a recreational harbor. In contrast, native species were less successful at attaching to antifouling coatings.

Crooks et al. (2011) concluded that the high prevalence of non-native species in copper-polluted environments is the result of copper tolerance. They allowed species to settle naturally on panels in San Francisco Bay. The panels were then placed in varying dissolved copper concentrations in the lab and later returned to the bay. With increasing copper treatments, native species significantly declined. Non-native species did not change.

Piola and Johnston (2006a) tested ability of four non-native bryozoans to settle, survive and grow in water that was contaminated with various copper levels. *Bugula neritina* and *W. subtorquata* were the most tolerant and represented the greatest invasion risk. *W. subtorquata* in particular, can “shut down” and lie dormant until conditions improve.

Piola and Johnston (2006b) measured *B. neritina's* ability to settle, survive and grow in different concentrations of copper in Australia. Colonies from a copper-polluted harbor had more resistance to copper in the lab than colonies from an unpolluted bay. Each colony was then divided and some of each were returned to both environments. Colonies originating from the copper-polluted harbor fared worse in the unpolluted bay than colonies originating from the bay. The investigators suggested that copper tolerance was only an advantage for non-native species in copper-polluted environments and that changes caused by humans may make it easier for invasive species to spread in marine waters.

Another study by Piola and Johnston (2009) found that non-native bryozoan species grew faster than native bryozoan species in copper-polluted water in the lab. They also found that settlement rates of native species on copper-painted panels in the field were lower than those of non-native species.

A Korean study (Han et al. 2008) compared growth of two species of *Ulva* green algae in different concentrations of copper. The native species was more sensitive to copper than the alien species in terms of growth, color and metabolic activities.

V. Conclusions

The studies presented above show some impacts of copper pollution on marine life and indicate that some hull-fouling species have developed copper tolerance. This has multiple impacts on boat owners and harbor ecosystems. Copper-tolerant species: a) are able to attach directly on copper paints; b) may facilitate the transport of less tolerant species by providing a protective barrier over the toxic paint; and c) have a competitive advantage when dislodged or spawned into copper-polluted waters. Further, this tolerance may provide an advantage for non-native fouling species that can more readily colonize boat hulls coated with copper antifouling paint and dominate in copper-polluted harbors.

Such studies can provide insights for designing policies to address copper pollution and invasive hull-fouling species, and increase the chances of success when they are put into effect.

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Table 1. Examples of common nuisance species in California that have been tested for tolerance to copper. Along with each species' name, the table lists its invasion status. Here they are described as being native or exotic. A third category (not shown here) is cryptogenic and means the origin is unknown.

Copper Tolerant Species	Type of Fouling Organism	Invasion Status
Watersipora subtorquata [4, 8, 37]	Encrusting Bryozoan	Non-native [2, 4, 8]
Bugula neritina [36, 37]	Branching Bryozoan	Non-native [5, 8]
Bugula pacifica [4]	Branching Bryozoan	Native [4, 22, i]
Styela clava [4, 8]	Solitary Club Tunicate	Non-native [2, 4, 23]
Ciona intestinalis [4]	Solitary Vase Tunicate	Non-native [4, 23]
Ciona savignyi [4]	Solitary Transparent Tunicate	Non-native [4, 8]
Diplosoma listerianum [8]	Colonial Tunicate	Non-native [41]
Hydroides elegans [38]	Tube worm	Non-native [2, 8]
Balanus crenatus [4]	Barnacle	Native [4, 30, ii]

[i] Distribution does not extend south of the Channel Islands [38]
[ii] Distribution does not extend south of Santa Barbara [30]

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