Impacts of Copper on Aquatic Ecosystems and Human Health

Exposure to copper concentrations can make fish lose their sense of smell and, therefore, reduce their appetite and food intake

By Frances Solomon

Copper is an essential trace nutrient that is required in small amounts (5-20 micrograms per gram (µg/g)) by humans, other mammals, fish and shellfish for carbohydrate metabolism and the functioning of more than 30 enzymes. It is also needed for the formation of haemoglobin and haemocyanin, the oxygen-transporting pigments in the blood of vertebrates and shellfish respectively. However, copper concentrations that exceed 20 micrograms per gram (µg/g) can be toxic, as explained by Heike Bradl (2005) and Wright and Welbourn (2002).

Copper has been known to humans for at least 6000 years. Its uses in alloys, tools, coins, jewelry, food and beverage containers, automobile brake pads, electrical wiring and electroplating reflect its malleability, ductility and electrical conductivity. The use of copper to kill algae, fungi and molluscs demonstrates that it is highly toxic to aquatic organisms. In fact, copper is one of the most toxic metals to aquatic organisms and ecosystems. This is just one of the reasons that environmentally sensitive mining practices are so important.

Copper is moderately soluble in water and binds easily to sediments and organic matter. Bioconcentration, which means that the concentration of copper is higher in plants and animals than in the water or sediments in which they live, is particularly high in animals found in the sediments at the bottom of a waterbody and in shellfish, such as oysters, that can filter materials from large volumes of water. However, copper does not biomagnify in food webs. Predators, as Heike Bradl (2005) and Wright and Welbourn (2002) explain in their textbooks, do not have higher tissue concentrations than their prey.

The most bioavailable and therefore most toxic form of copper is the cupric ion (Cu^{+2}). Fish and crustaceans are 10 to 100 times more sensitive to the toxic effects of copper than are mammals. Algae, especially blue-green algae species, are 1,000 times more sensitive to the toxic effects of copper than are mammals, as several authors, including Forstner and Wittman (1979), Hodson (1979) and Wright and Welbourn (2002), have demonstrated. This is an exception to the general principle that aquatic animals are more sensitive than aquatic plants to the toxic effects of metals.

A Matter of Life or Death

Fish and shellfish are exposed to copper via their gills and the water and sediments in which they live, as well as through the food chain. From the 1970s through the 1990s, the impacts of copper on fish were evident at the Britannia Beach Mine site in Squamish, British Columbia. The mine operated from 1905 until 1974, first as a copper mine and then as a copper-zinc mine starting in 1929. At that time, the Britannia Beach Mine was the biggest producer of copper in the British Commonwealth. The mine also produced acid rock drainage (ARD) when rain and snow came into contact with the sulfides in the exposed ores. After the mine was closed, 600 kilograms per day of copper, zinc and sulfuric acid leached from the mine site to Jane Creek, Britannia Creek and Howe Sound. Copper levels in the effluent were 20 milligrams per liter (mg/L), which violated the 15 mg/L effluent standard in the 1970s, as well as the current standard of 0.1 mg/L. In 1993, Environment Canada classified the Britannia Beach Mine site as the worst ARD site in Canada (Meech, 2007; Rector, 2007).

The continual discharge of metal-contaminated and ARD-contaminated effluent and groundwater resulted in a marine dead zone in Howe Sound. Almost no fish or shellfish were to be found. The discharge also triggered significantly reduced runs of chinook and chum salmon in Britannia Creek. The installation of a plug in 2001 to divert effluent away from Howe Sound, as well as a high density sludge lime treatment plant built in 2005 to neutralize ARD and precipitate metals from the effluent, have prevented the discharge of copper and low pH effluent to Howe Sound and its tributary creeks. Fish have now returned to these waterbodies.

The effects of copper on aquatic organisms can be directly or indirectly lethal. Gills become frayed and lose their ability to regulate transport of salts such as sodium chloride and potassium chloride into and out of fish. These salts are important for the normal functioning of the cardiovascular and nervous systems. When the salt balance is disrupted between the body of a copper-exposed fish and the surrounding water the death of the fish can result. The presence of dissolved organic carbon (DOC) in the water column provides some protection from the effects of copper on the gills because copper forms complexes with DOC and will therefore be less bioavailable. Copper toxicity to fish gills will be higher if the pH of the water is acidic, the water has low buffering capacity or the water is soft, i.e., has a low concentration of calcium ions. The lower toxicity of copper in hard water compared to soft water is due to the protective effects of calcium ions on and in living cells. Countries such as Canada have outilined Water Quality Standards for protection of aquatic life. These standards are stricter for soft water than for hard water (Bradl, 2005; Nriagu, 1980; Wright and Welbourn, 2002).

Copper also adversely affects olfaction (sense of smell) in fish. Detection of odours occurs when dissolved odorant molecules bind with olfactory receptor molecules. The direct contact of fish olfactory tissues with the surrounding water facilitates copper uptake. Copper can affect olfaction by competing with natural odorants for binding sites, by affecting activation of the olfactory receptor neurons or by affecting intracellular signalling in the neurons (Baldwin et al., 2003).

Fish rely on their sense of smell to find food, avoid predators and migrate. Salmon migrate hundreds or thousands of kilometres from the Pacific Ocean back to the river or stream where they were born; spawning then occurs in the "home" river or stream. Successful homing depends on olfaction (McIntyre et al., 2008).

Brief exposure to copper at environmentally realistic concentrations can impair the function of olfactory receptor neurons in coho salmon; longer exposures can kill these neurons, as demonstrated by Baldwin et al. (2003). When juvenile coho salmon were exposed for 30 minutes to 20 µg/L copper, electrophysiological recordings from the olfactory tissues indicated an 82% reduction in olfactory response (McIntyre et al., 2008). Exposure of juvenile

The effects of copper on aquatic organisms can be direct or indirect

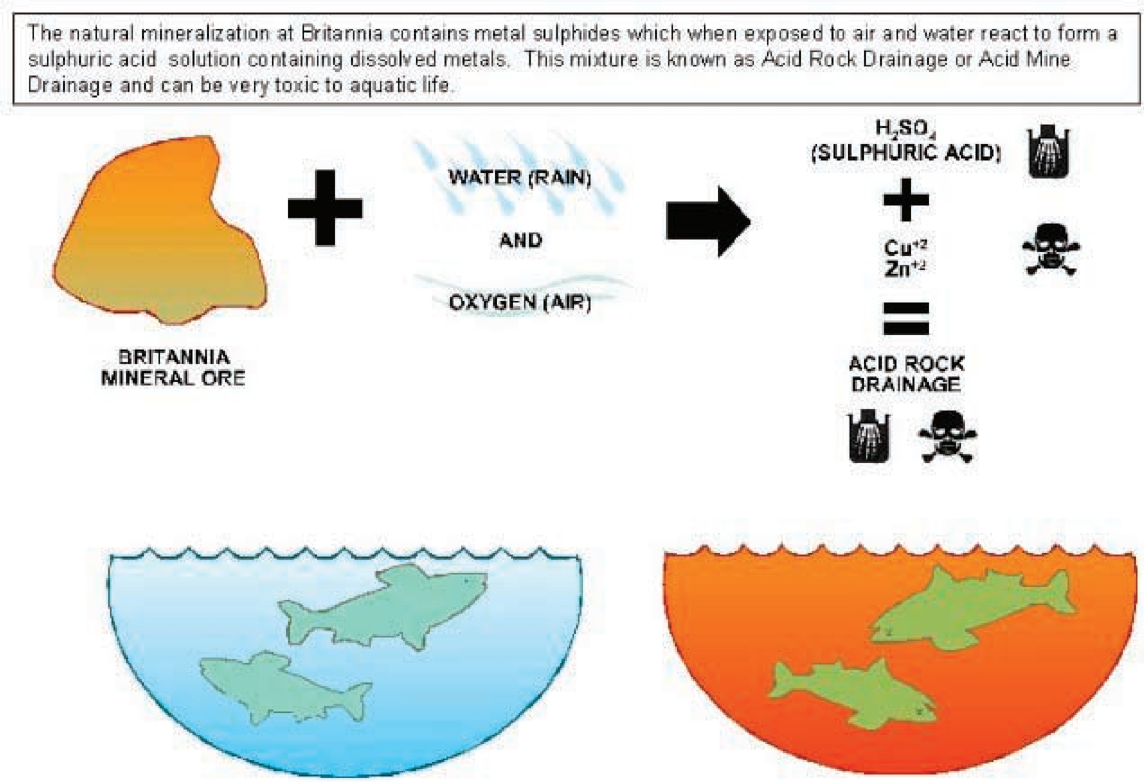
coho salmon for seven days to copper concentrations ranging from 5-20 µg/L caused a concentration-dependent reduction in olfactory response. The lowest concentration of copper caused at least a 20% loss of olfactory function. These data suggest that periodic, non-point source contamination of salmon habitats with copper could interfere with olfactory function in natural waterbodies and therefore interfere with olfactory-mediated behaviours, such as homing, that are important for the survival and migration of salmon (Sandahl et al., 2004).

Reduced olfaction leads to reduced appetite and food intake, which in turn contribute to reduced growth of salmon and other fish (McIntyre et al., 2008). These are examples of sublethal effects that are eventually lethal; smaller or weaker fish will be less resistant to disease and to predation. Furthermore, reduced olfaction decreases the ability of fish of any size to detect predators, thereby causing them to be more vulnerable to predation.

Hard water and buffered water do not protect fish against copper impacts on olfaction. DOC levels of 0.1-6.0 mg/L were found to partially restore olfactory capacity in salmon that were exposed to copper (McIntyre et al., 2008).

Rainbow trout are particularly sensitive to the toxic effects of copper and other metals. Very low levels of copper (1.4 µg/L) produce a physiological stress response, characterized by hyperactivity, increased blood levels of the stress hormone cortisol and synthesis of the metal-detoxifying protein metallothionein in the liver (Taub, 2004).

Copper can impact populations and ecosystems as well as individual aquatic organisms. For example, when sea scallops were exposed to environmentally realistic concentrations of copper, i.e., 10-20 µg/L, sperm and egg production decreased. Copper also causes reduced sperm and egg production in many species of fish, such as fathead minnows, as well as early hatching of eggs, smaller fry (newly hatched fish) and increased incidence of abnormalities and reduced survival in the fry (Taub, 2004). Although the



Ecological Impacts of Acid Rock Drainage at the Britannia Beach Mine Site

individual adult sea scallops and adult fish might not be harmed by copper, the adverse effects of copper on reproductive potential will lead to smaller populations in subsequent generations.

Because copper is an algaecide, used to control nuisance algae in lakes and rivers, it is not surprising that it causes decreased algal growth when inadvertently discharged to a waterbody. Because algae are at the base of food chains, the amount of algal biomass present in an aquatic ecosystem will affect the amount of food available for aquatic animals including zooplankton, insects, shellfish, fish and aquatic mammals. Additionally, insects such as mayflies that do not tolerate polluted water will disappear and other species of insects that can tolerate polluted water will appear.

A change in the composition of the insect community will affect which species of shellfish and fish are present. The high toxicity of copper to algae creates a ripple effect throughout the ecosystem and demonstrates that changing one part of an ecosystem will affect the entire ecosystem (Odum, 1971; Taub, 2004; Wright and Welbourn, 2002).

Impacts on Human Health

Humans are exposed to copper via inhalation of particulate copper (typical of occupational exposure), drinking copper-contaminated water and eating copper-contaminated food. However, the toxicity of copper to humans is relatively low compared to other metals such as mercury, cadmium, lead, and chromium. When a person is exposed to copper levels above the essential levels needed for good health, the liver and kidneys produce metallothionein This low molecular weight protein binds with the copper to form a complex that is water-soluble and can be excreted. Additionally, the availability of copper is low in many foods due to the tendency of copper to bind with organic matter.

Copper is present in normal human serum (the liquid part of blood) at concentrations of 120-140 µg/L. Signs of toxicity will be seen if the copper concentration rises significantly above this range (Bradl, 2005; Wright and Welbourn, 2002).

Consequently, the Canadian Federal Drinking Water standard for copper is based on the taste of the water, not on protection of human health. The standard is 1000 µg/L, compared to 1 µg/L for mercury, 5 µg/L for cadmium, 10 µg/L for lead and 50 µg/L for chromium (Wright and Welbourn, 2002). Nevertheless, the high toxicity of copper to aquatic organisms and ecosystems warrants source control and treatment measures to prevent and reduce the discharge of copper from operating, closed and abandoned mines to surface water and groundwater. ■

Frances Solomon is an Adjunct Professor at the Norman B. Keevil Institute of Mining Engineering, University of British Columbia, Vancouver, B.C. For further information on the toxic effects of copper and other metals that are mined or emitted as by-products of mining, register for the online EduMine course entitled "Metal Mining Discharges – Impacts and Controls." EduMine and the University of British Columbia Mining Studies Institute will offer a three-day classroom version of this course from October 21-23, 2009.

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