

## Selenium Fact Sheet

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Selenium is a natural element named after Selene, the Greek goddess of the moon. Selenium is required in the diets of both people and animals, is essential for some enzyme functions, protects against certain cancers, blocks the action of free radicals and helps stimulate the immune system. Selenium is found in common products such as dandruff shampoos (Selsun Blue™) and cosmetics (e.g., skin moisturizers). Selenium can also be a toxin and the difference between an effective or safe dose and a toxic dose of selenium is relatively small in most animals. Additionally, selenium can accumulate in the food chain, through uptake into plants on the land or through the action of sediment-dwelling organisms in an aquatic system. Several instances of selenium poisoning of fish and wildlife have occurred in the United States over the past several decades.

### History of Environmental Impacts of Selenium

Selenium can be toxic, particularly to livestock that eat plants that accumulate selenium to high levels. In fact, it is thought that Marco Polo's expedition across Asia in the 13th century lost many horses to selenium poisoning. Early settlers in the arid west (South Dakota and Wyoming, especially) also had problems with their livestock being poisoned by eating plants containing high levels of selenium.

Environmental impacts of selenium came to the public's attention with two high-profile incidents in the 1980s. Belews Lake, North Carolina, suffered a severe fish die-off and the loss of 16 of 20 species of fish as a result of 10 years of discharging ash from a coal-fired power plant directly into the lake. On the other side of the country, severe deformities were observed in birds at Kesterson Wildlife Refuge, California, which was contaminated with selenium in agricultural drainage water. Since then, it has become apparent that selenium can cause significant reproductive problems to fish and aquatic-dependent wildlife as a result of its ability to accumulate in the aquatic food web. However, it is also now known that selenium accumulation is highly dependent upon the type of selenium at the source, and the chemistry and biology of the receiving environment. In fact, simply increasing the level of selenium in the water does not always mean that fish or birds will be poisoned. Conditions have to be just right for selenium to accumulate to toxic levels.

### Accumulation in the Food Chain

Selenium accumulates in the aquatic food chain by first being converted to a chemical form that is most easily taken up by algae and bacteria in sediments. This conversion occurs most quickly in slow-moving water (such as lakes), which also provides more time for the algae and bacteria to be exposed. Therefore, selenium reaches higher levels in the food chain of lakes, reservoirs, wetlands, or the slow backwaters of rivers and streams, than it does in fast moving rivers. Selenium can increase in the algae and bacteria to levels much higher than in the water (known as bioaccumulation). Once the selenium is in these organisms, it is converted to an organic form

that is easily taken up by the invertebrates that feed on the algae and bacteria. The amount of selenium again increases so that invertebrates have more in their bodies than is found in the algae or bacteria. Fish that feed on these invertebrates may be affected if selenium reaches high enough levels. However, the fish themselves do not accumulate selenium to levels any higher than what is found in their food (the invertebrates). Birds, such as waterfowl or shorebirds, also feed on invertebrates and some, such as osprey or herons, feed on fish. Therefore, birds may be affected, too, if the invertebrates or fish they eat have accumulated high enough levels of selenium.

## Toxic Effects of Selenium

Selenium poisoning in fish or birds generally causes reproductive effects, as female reproductive organs are highly sensitive to its effects. Depending upon how much selenium is in the diet of the female, the embryos may die in the egg (fail to hatch). This is true particularly in birds. Other embryos may hatch out weak and/or deformed. In fish, deformities generally are curved and bent spines. Many of these deformed fish die soon after hatching. However, deformities can be caused in fish by many other factors besides selenium, even something as simple as high water temperatures. There is a natural deformity rate between 5 and 10 percent in both hatchery and wild fish. In birds, deformities of the beak or bill (crossed bills), extruding eyeballs (pop eyes), and skeletal deformities are most commonly caused by contaminants, including selenium and PCBs, among others. The percent of the fish or bird embryos that are affected and the severity of the effects are directly related to the amount of selenium in the diet. However, there are differences in sensitivity among various fish and bird species, so not all are equally affected at any given dose. In fish, the severity of effects likely is related to their spawning strategy; whether they spawn once a year or multiple times per year will affect the amount of selenium that is put into the egg. Fish may also be affected by a “winter stress syndrome” such that cold temperatures and reduced food sources cause the young fish to become more sensitive to the effects of selenium the following spring. In birds, the amount of selenium toxicity also depends upon how soon they begin to lay eggs after arriving in the nesting area. Selenium is rapidly metabolized and excreted so it is not stored in the body for very long. Therefore, if the bird starts laying its eggs within a week or two after arriving in an area, the egg selenium levels will be influenced more by where the bird came from than by where they are nesting.

## Regulatory Limits

Because of the site-specific and complex nature of uptake and accumulation of selenium in the food web and the resulting inability to predict risk to fish or birds based solely on selenium water concentrations, the U.S. EPA is proposing to regulate selenium based on fish tissue concentrations and has published a draft water quality criterion based on whole body tissue concentrations in fish (as opposed to just filet or organ tissue concentrations that are sometimes used for other purposes). The criterion includes a method to account for winter stress syndrome. Measurements of elevated selenium in water or sediment are useful triggers for determining when to collect fish samples to assess whether selenium has accumulated to toxic levels in a particular ecosystem. If water or sediment levels are noted as increasing but fish tissue concentrations have not yet reached a critical value, it may be prudent to note whether the system has a high risk for potential selenium effects. A high risk system would have a continuing source of selenium (rather than a single event); the receiving water would be a slow-moving river, lake, or wetland; it

would have sediments rich in organic material; and the types of invertebrates that are present would be species known to rapidly accumulate selenium to high levels.

## Ecosystem Recovery

The ability of animals to regulate the amount of selenium in their bodies and to excrete it quickly also allows ecosystems to recover rapidly once the sources of selenium are stopped or reduced. Fish populations and the diversity of fish species in Belews Lake, for example, where coal ash discharges occurred for 10 years (1975–1985), recovered in a little less than a decade to pre-discharge levels even without dredging the contaminated sediments. However, the types of species present were different than before the discharge started. In another example, in 1987, selenium was added to 11 Swedish lakes to counteract the effects of elevated mercury. By the second year, perch from four of the lakes had completely disappeared, yet their populations recovered rapidly once the selenium water concentrations were reduced. However, because selenium is accumulated in aquatic food webs as a result of sediment-based processes, full recovery of aquatic systems depends upon the rate at which full removal (or burial) of selenium in sediments occurs.

## Summary

In summary, selenium is a naturally occurring element that is required in the diets of all animals and is toxic at high doses. Toxicity is primarily to the reproductive system, causing organisms to die in the egg or to have weak and deformed offspring. The environmental levels of selenium at which toxicity occurs in fish and birds are highly dependent upon specific chemical and biological attributes of a site and cannot be predicted from water or sediment concentrations alone. As such, U.S. EPA suggests using fish tissue concentrations to monitor the effects of selenium. Finally, because of selenium's high environmental mobility and relatively rapid elimination from the body, both animals and the ecosystems in which they live can recover rapidly (within years, not decades) from the effects of selenium once the source is controlled and sediment levels are reduced.

## Suggested Reading

Selenium: Dietary Exposure, Trophic Transfer and Food Web Effects. 2008. pp. 327–353. In: *Metal Contamination in Aquatic Environments: Science and Lateral Management*. S.N. Luoma and P.S. Rainbow. Cambridge University Press.

Ecotoxicology of Selenium by H.M. Ohlendorf. 2003. pp. 465–501. In: *Handbook of Ecotoxicology*. D.J. Hoffman, B.A. Rattner, G.A. Burton, and J. Cairns (eds). Lewis Publishers, Boca Raton, FL.

Selenium Poisoning of Fish and Wildlife in Nature: Lessons from Twelve Real-World Examples by J Skorupa. 1998. pp. 315–354. In: *Environmental Chemistry of Selenium*. W.T. Frankenberger and R.A. Engberg (eds). CRC Press, Boca Raton, FL.