SUPPORTING INFORMATION

Emerging opportunities in management of selenium contamination

Samuel N. Luoma*
John Muir Institute of the Environment*
University of California, Davis
122C The Barn
One Shields Avenue
Davis, CA 95161
snluoma@ucdavis.edu
and
U. S. Geological Survey
MS 465, 345 Middlefield Road
Menlo Park CA 94025
650 329-4481*

Theresa S. Presser
U. S. Geological Survey,
345 Middlefield Road
Menlo Park CA 94025
tpresser@usgs.gov
650 329-4512

SI 1. Selenium Toxicity

Selenium is an essential element for all animals, but the margin of safety is narrow between Se concentrations that are essential and those that are toxic, especially for wildlife (1). The narrow window between essentiality and toxicity means there is little room for maneuverability in managing ecological risks from Se. Small changes in exposure hold great potential for ecological damage. The standardized toxicity tests traditionally used to establish the concentration at which Se elicits toxicity suggest the opposite, however. Dissolved toxicity tests with Se suggest thresholds for ecological risk should be in the 100's of µg/L (2,3). Dietary toxicity tests (4) and field observations of adverse effects on birds (5) and fish (6) are documented in freshwater systems at dissolved concentrations as low as 2 – 5 µg/L. The disparity between dissolved toxicity tests and field observation is the single greatest cause of the differences among jurisdictions in managing Se.

Biogeochemical processes convert Se to concentrations at the base of the food web orders of magnitude greater than in water and passage of that Se through the food web is the source of Se exposure. Therefore, ecosystems will be badly damaged by dietary exposure before dissolved Se concentrations reach levels that themselves are dangerous to animals. Dissolved toxicity tests cannot predict the concentration at which that damage will occur. Similarly, the convention traditionally used to quantitatively link Se bioaccumulation by animals to Se in the environment is the Bioaccumulation Factor (BAF): the ratio of Se in animal tissue to dissolved Se concentrations. BAFs for Se vary by orders of magnitude with concentration, transformation, environment, and species (7), making BAFs of little value in either explaining or predicting Se bioaccumulation into food webs.

Dietary exposures show that, in birds, the first signs of toxicity include failure of the eggs to hatch and occurrence of deformities in young (5). In fish, failure of eggs to hatch, deformities or damage in embryos, and teratogenesis are also early signs of toxicity (6). These effects correlate with Se concentrations in the organism, with the strongest correlations occurring between concentrations in the egg and the onset of effects (5). However, the concentration at which occurs the effect of Se on the ability of a species to produce viable young cannot be determined by acute or dissolved toxicity

testing. Reproductive toxicity also means that species-specific demographics will be especially important in determining risks to populations.

Therefore, exposure via diet must be considered in order to evaluate risks from Se in nature. This is the single greatest deviation from the conventional risk assessment paradigm.

References

1. Hilton, J. W.; Hodson, P. V.; Slinger, S. J. The requirement and toxicity of selenium in rainbow trout (***Salmo gairdneri***). ***J. Nutr.*** **1980**, ***110*** (12), 2527-2535.

2. ***Ambient Water Quality Criteria for Selenium – 1987***. United States Environmental Protection Agency: Washington, DC, 1987; EPA-440/5-87-006.

3. ***Aquatic Life Water Quality Criterion for Selenium – 2004***. United States Environmental Protection Agency, Washington, DC, 2004; EPA-82-D-04-001.

4. Hoffman, D.J.; Heinz, G.H. Embryotoxic and teratogenic effects of selenium in the diet of mallards. ***J. Toxicol. Environ. Health***. **1988**, ***24*** (4)**,** 477-490.

5. Skorupa, J.P.; Selenium poisoning of fish and wildlife in nature: lessons from twelve real-world examples. In ***Environmental Chemistry of Selenium***; Frankenberger, W.T. Jr. Engberg, R.A., Eds.; Marcel Dekker Inc.: New York 1994; pp 315-354.

6. Lemly, A.D. ***Selenium assessment in aquatic ecosystems: a guide for hazard evaluation and water quality criteria***; Springer-Verlag: New York, 2002.

7. McGeer, J. C.; Brix, K. V.; Skeaff, J. M.; DeForest, D. K.; Brigham, S. I.; Adams, W. J. Inverse relationship between bioconcentration factor and exposure concentration for metals: implications for hazard assessment of metals in the aquatic environment. ***Environ. Toxicol. Chem***. **2003**, ***22*** (5), 1017-1037.

SI 2 References for Figure 2.

1. Schlekat, C.E.; Purkerson, D.G.; Luoma, S.N. Modeling selenium bioaccumulation through arthropod food webs in San Francisco Bay, California. ***Environ. Toxicol. Chem.*** **2004**, ***23*** (12), 3003-3010.

2. Wang, W.-X.; Fisher, N.S. Accumulation of trace elements in a marine copepod. ***Limnol. Oceanogr.*** **1998**, ***43*** (2), 273-283.

3. Reinfelder, J.R.; Wang, W.-X.; Luoma, S.N.; Fisher, N.S. Assimilation efficiencies and turnover rates of trace elements in marine bivalves: a comparison of oysters, clams and mussels. ***Mar. Biol.*** **1997**, ***129*** (3), 443-452.

4. Lee, B.-G.; Lee, J.-S.; Luoma, S.N. Comparison of selenium bioaccumulation in the clams ***Corbicula fluminea*** and ***Potamocorbula amurensis***: A bioenergetic modeling approach. ***Environ. Toxicol. Chem.*** **2006**, ***25*** (7), 1933–1940.

5. Luoma, S.N.; Johns, C.; Fisher, N.S.; Steinberg, N.A.; Oremland, R.S.; Reinfelder, J.R. Determination of selenium bioavailability to a benthic bivalve from particulate and solute pathways. ***Environ. Sci. Technol.*** **1992**, ***26*** (3), 485-491.

6. Roditi, H.A.; Fisher, N.S. Rates and routes of trace elements uptake in zebra mussels. ***Limnol. Oceanogr.*** **1999**, ***44*** (7), 1730–1749.

7. Schlekat, C.E.; Lee, B.-G.; Luoma, S.N. Assimilation of selenium from phytoplankton by three benthic invertebrates: effect of phytoplankton species. ***Mar. Ecol. Prog. Ser.*** **2002**, ***237***, 79-85.

8. Wang, W.-X.; Fisher, N.S.; Luoma, S.N. Kinetic determinations of trace element bioaccumulation in the mussel ***Mytilus edulis***. ***Mar. Ecol. Prog. Ser.*** **1996**, ***140*** (1-3) 91-113.

9. Zhang, G.H.; Hu, M.H.; Huang, Y.P. Se uptake and accumulation in marine phytoplankton and transfer of Se to the clam ***Puditapes philippinarum. Mar. Environ. Res.*** **1990**, ***30*** (3), 179-190.

10. Rainbow, P.S.; Wang, W.-X. Comparative assimilation of Cd, Cr, Se and Zn by the barnacle ***Elminius modestus*** from phytoplankton and zooplankton diets. ***Mar. Ecol. Prog. Ser.*** **2001**, ***218***, 239–248.

11. Wang, W.-X.; Qiu, J.-W.; and Qian, P.-Y. The trophic transfer of Cd, Cr, and Se in the barnacle ***Balanus amphitrite*** from planktonic food. ***Mar. Ecol. Prog. Ser.*** **1999**, ***187***, 191-201.

12. Mathews, T.; Fisher, N.S. Trophic transfer of seven trace metals in a four-step marine food chain. ***Mar. Ecol. Prog. Ser.*** **2008**, ***367***, 23-33.

13. Alquezar, R.; Markich, S.J.; Twining, J.R. Comparative accumulation of ^{109}Cd and ^{75}Se from water and food by an estuarine fish (***Tetractenos glaber***). ***J. Environ. Radioact.*** **2008**, ***99*** (1), 167-180.

14. Ni, I.-H.; Chan, S.M.; Wang, W.-X. Influences of salinity on the biokinetics of Cd, Se, and Zn in the intertidal mudskipper ***Periophthalmus cantonensis***. ***Chemosphere*** **2005**, ***61*** (11), 1607-1617.

15. Baines, S.B.; Fisher, N.S.; Stewart, R. Assimilation and retention of selenium and other trace elements from crustacean food by juvenile striped bass (***Morone saxitilis***). ***Limnol. Oceanogr.*** **2002**, ***47*** (3), 646–655.

16. Bennett, W.N; Brooks, A.S.; Boraas, M.E. Selenium uptake and transfer in an aquatic food chain and its effects on fathead minnow larvae. ***Arch. Environ. Contam. Toxicol.*** **1986**, ***15*** (5), 513–517.

17. Bertram, P.E.; Brooks, A.S. Kinetics of accumulation of selenium from food and water by fathead minnows. ***Water Res.*** **1986**, ***20*** (7), 877–884.

18. Besser, J.M.; Canfield, T.J.; La Point, T.W. Bioaccumulation of organic and inorganic selenium in a laboratory food chain. ***Environ. Toxicol. Chem.*** **1993**, ***12*** (1), 57–72.

19. Cleveland, L.; Little, E.E.; Buckler, D.R.; Wiedmeyer, R.H. Toxicity and bioaccumulation of waterborne and dietary selenium in juvenile bluegill (***Lepomis macrochirus***). ***Aquat. Toxicol***. **1993**, ***27*** (3-4), 265–280.

20. Xu, Y.; Wang, W.-X., , Exposure and potential food chain transfer factor of Cd, Se, and Zn in marine fish ***Lutjanus argentimaculatus***. ***Mar. Ecol. Prog. Ser.*** **2002**, ***238***, 173-186.