Development of Selenium TMDL for North San Francisco Bay
A Complex Puzzle in a Dynamic System

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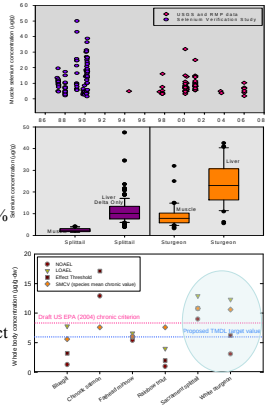
Signs of a Problem

The water quality of North San Francisco Bay is impaired due to selenium, despite meeting the current numeric water quality objective of 5µg/L. This is because concentrations in Bay biota are higher than levels commonly associated with toxicity and reproductive impairment in fish and other wildlife species. Selenium concentrations are highest in species like white sturgeon, Sacramento splittail and diving ducks feeding on sediment-dwelling (benthic) organisms. A Total Maximum Daily Load (TMDL) which is a water quality attainment strategy, is currently under development by the San Francisco Bay Water Board.

Fish Exposure

Selenium concentrations in fish

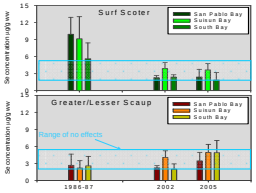


Toxicity thresholds in juvenile fish

- Sturgeons are anadromus long-lived fish found year-round in the estuary
- Benthic organisms, including invasive *Corbula amurensis,* are the main component in sturgeon diet
- *C. amurensis* was found to exceed 70% of their stomach volume
- Reproductive biology may contribute to bioaccumulation – Se is transferred to and stored in developing eggs
- Tissue concentrations range from 1.8 to 32 µg/g dw and exceed known effect thresholds
- Sturgeon population in the estuary is vulnerable to Se as a clam-eating bottom feeder

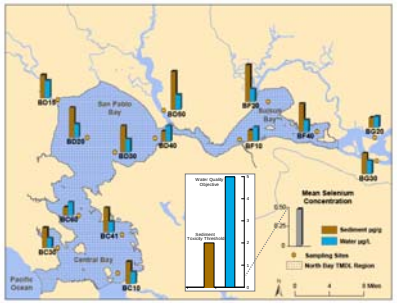
White sturgeon is likely the most affected species in the North Bay

Diving Ducks Exposure



- Almost 80% of diving ducks wintering in the lower Pacific Flyway are found in the San Francisco Bay estuary
- Diving ducks feed mostly on benthic mollusks, shellfish and crustaceans
- Clams, including *C. amurensis* in scoter diet can vary from 25% to 100%
- Ducks exhibit rapid elimination rates for Se, and after approximately 70 days are capable of reducing their tissue concentrations to background levels
- No reproductive effects have been found for muscle tissue concentrations in the range 2.1 – 5.7µg/g-ww, (Lemly 1998)
- **New data:** Se in eggs of scoters from North San Francisco Bay found in Canadian breeding grounds are less than 2 µg/g and, thus, well below levels of concern (5µg/g) for sensitive species (*USGS, pers. comm.*)

Selenium in the System



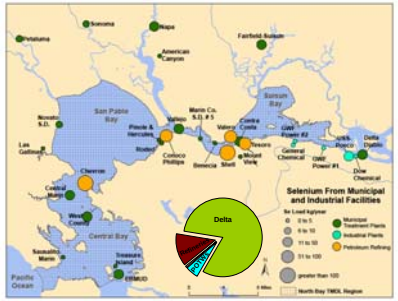
Speciation and Bioavailability

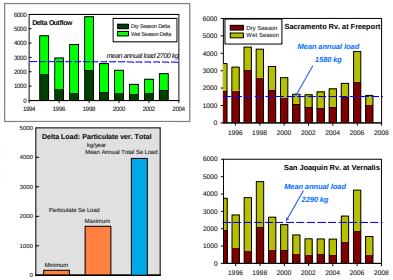
Selenium occurs naturally in San Francisco Bay in four oxidation states and the most common species include: selenate Se^{+6} (SeO_4^{-2}), selenite Se^{+4} (SeO_3^{-2}) elemental selenium (Se^0), and organic selenide (Se^{-2}). Oxidation state is one of the key factors determining the fate of selenium in the environment.

Potential for local adverse ecological effects increases with the higher proportion of selenite and organic selenide present in dissolved and/or particulate phase.

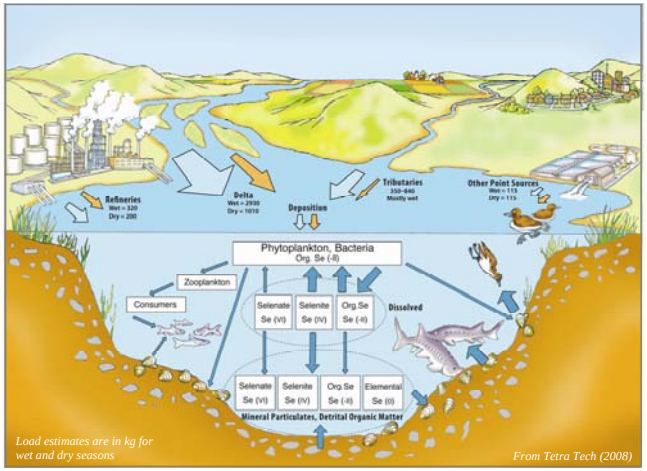
However, particulate selenium is the bioavailable form of toxicological importance.

Delta inputs: 5-fold local point sources





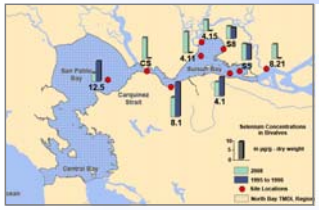
Selenium Transformations and Cycling in North San Francisco Bay



Selenium uptake into higher trophic level biota is primarily from the particulate phase

Role of Invasive Clams

- Benthic organisms can accumulate selenium in tissue and serve as a major pathway for predators that are mostly dependent on the benthos for their food.
- The means for nearly all selenium transfer to bivalves is dietary exposure through particulate material, whether as part of algal tissue, or associated with organic or mineral matter.
- *C. amurensis* is frequently the dominant species in the benthic community with maximum densities reaching ~16,000 individuals/m^2 (Chauvaud et al., 2003).
- Intake of Se by *C. amurensis* from dissolved phase is less than 2%. Se in water column is only marginally important to bioaccumulation by fish.



Species	Assimilation Efficiency [%]	Loss Rate [day^{-1}]
C. amurensis	36-80	0.023-0.025
M. copepods	50-53	0.155
N. mercedis	73	0.250

After Stewart et al., 2004, Lee et al., 2006

Invasive bivalve species such as *C. amurensis* intensify the level of exposure to fish and diving ducks. They typically magnify Se by a factor of 5 to 8 compared to concentrations found in particulate phase.

They ingest and assimilate particulate selenium at high efficiencies and exhibit much lower loss rates than native bivalves and crustaceans.

What Makes the Puzzle so Complex?

- Existing numeric water quality objective is not protective of Bay wildlife.
- Ambient selenium in the system may be adequate to result in notable bioaccumulation in fish.
- Sacramento River alone may deliver to the Delta 200 to 1000 kg of particulate selenium per year depending on flows.
- Allowing more environmental flows from the San Joaquin River may increase the potential for selenium laden agricultural drainage to reach the North Bay.
- Loads of selenium carried by local tributaries and discharged through the Delta are largely uncontrollable.
- Phytoplankton and bacteria transform selenium into the particulate form that is preferentially taken by bivalves. Yet, composition, and temporal and spatial trends in phytoplankton blooms are not well understood and difficult to model.
- Changes in population of *C. amurensis* due to predation and natural growing cycle are additional complicating factors that make prediction of bioaccumulation potential difficult.

References:

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Tetra Tech. 2008. *Conceptual Model for Selenium in North San Francisco Bay.* Technical Memorandum #4 developed for SFWQCB.

Selenium TMDL Project website:
http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/seleniumtmdl.shtml

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