SELENIUM UPDATE FOR NAMC-SWG: LATEST RESEARCH / INFORMATION

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North American Metals Council
Selenium Working Group (NAMC-SWG)

- 1st meeting Nov 3-4, 2006, Quebec
- 2nd meeting June 6, 2007, Saskatoon
- 3rd meeting November 16, 2007, Milwaukee
- 4th meeting June 11-12, 2008, Boise
- 5th meeting November 21, 2008, Tampa
- 6th meeting June 24, 2009, Calgary
- 7th meeting November 24, 2009, New Orleans
HUMAN HEALTH

- Insufficient dietary Se a “serious health constraint” for up to 1 billion people
- Cereals are dominant Se source for those on low protein diets
- Crop Se content constrained by underlying geology
- Rice from US and India had highest [Se], Egyptian rice most deficient
- “75% of the grains from the production and export pools would fail to provide 70% of daily recommended Se intakes”
Ralston NVC. 2008. Selenium health benefit values as seafood safety criteria. EcoHealth 5: 442-455
- Seafoods contain more Se than Hg, which may explain why no or positive effects on child development compared to fresh water fish with more Hg than Se
- Pregnant women should avoid foods with more Hg than Se
- *Hg:Se molar ratios need to be incorporated into food safety criteria* (i.e., not just Hg alone)

- Selenium deficiency alone does not explain Kashin-Beck Disease (KBD, whose symptoms include dwarfism, and which affect millions of people in China, Russia and North Korea)
- Selenium deficiency may be a co-factor – a disease of “deprivation” – only affects non-affluent, rural areas
TOXICITY / RISK ASSESSMENT

- American avocets, black-necked stilts, terns
- [Se] in livers variable by over 10x; influenced by species, region, reproductive stage, age, sex
- “need to sample multiple species and examine several factors to assess the impact of Se on wildlife”
- “where numerous contaminants, especially mercury, may be impairing waterbirds, the interpretation of deleterious effects because of Se contamination likely is confounded by a combination of its low-dose benefits, its interactions with mercury, and the potential toxic effects of several other contaminants”
Hardy RW, Oram LL, Möller G. In press. Effects of dietary selenomethionine on cutthroat trout (*Oncorhynchus clarki* bouvieri) growth and reproductive performance over a life cycle. *Arch Environ Contam Toxicol*

- 2.5 year feeding trial; [Se] in whole fish and eggs increased in proportion to dietary Se intake
- No differences in growth, food intake, survival or egg hatchability
- No toxicity of dietary selenomethionine up to 10 mg/kg Se supplemented diet
- “results suggest that cutthroat trout possess the capacity to increase the rate of excretion of Se sequestered in the body in proportion to whole body concentrations of Se”
- “…to maintain whole-body concentrations below toxic levels”

- Used $^{75}$Se as radiotracer
- Decreased mayfly fecundity with increasing maternal (postpartum) Se body burden
- Reduction in growth with elevated [Se]
- “results suggest that at environmentally feasible dietary Se concentrations insects are potentially affected by Se exposure, and that the current presumption that insects are simply conduits of Se to higher trophic levels is inaccurate”

- “a globally consistent regulatory approach to Se is feasible”

- Species-specific ERA must consider:
  - Possible high exposure via feeding habits
  - Inherent sensitivity
  - Demographics relative to susceptibility

- Consider biogeochemical transformation linked to trophic transfer through the food web

- Bioaccumulated Se guidelines imply that allowable water [Se] “would change from environment to environment”
Rigby MC, Deng X, Grieb TM, Teh SJ, Hung SSO. In press. Effect threshold for selenium toxicity in juvenile splittail, *Pogonichthys macrolepidotus* A. Bull Environ Contam Toxicol

- Authors previously derived whole body NOAEL and LOAEL of 9.0 and 12.9 mg/kg dw
- Reanalyzed raw data to derive EC\textsubscript{10} values:
  - Feed: 0.9 mg/kg dw
  - Muscle: 7.9 mg/kg dw
  - Liver: 18.6 mg/kg dw
  - Calculated whole body: 7.2 mg/kg dw [but noted conversion based on bluegill so may not be accurate]
- Three highest dietary [Se] excluded from analysis as deformities decreased > 6.6 mg/kg dw Se feed; other anomalies in the straight-line analysis
- Based on Se in food of splittails in San Francisco Bay, conclude “deformities may be expected” and have been reported

- Screening level RA based on available data
- Focus on diversity and abundance of native fish and bird populations in the study area
- Three levels of risk determined for different areas:
  - Fish and bird populations: negligible risk far-field
  - Fish and bird populations: uncertain risk (data gaps)
  - Rainbow trout “may be at risk” near-field (Luscar Creek watershed) – elevated [Se] in eggs, laboratory effects studies; but macroinvertebrates below dietary Se threshold

Work done by David DeForest
GENERAL

- [Se] in weed plants increased progressively with [selenate-Se] in soil.
- Symptoms of Se “poisoning” in plants: change in leaf colour, burning of leaf tips and margins, delayed flowering
- Se-rich plant biomass from seleniferous areas could be used to supplement animal feeds in Se-deficient areas
- Regular cultivation of certain oilseed crops and weeds may provide a means of remediating soils contaminated with elevated [Se]

- “selenoprotein structures in coal’s precursors (bacteria and algae and possibly higher plants) make Se bonding in coal unique from that of the other trace elements”
- “likely that much of the Se is organically bonded in the coal structure”
- “Se will also coprecipitate with sulfides in reducing environments”
RECENT PUBLICATIONS/REPORTS (cont’d)


- Long-term debate regarding natural and anthropogenic Se at regional and local scales
- Major marine biogenic source for atmospheric Se; much greater than anthropogenic sources for their sampling locations (North America and Europe – not all coastal, e.g., Colorado)
- “contribution of naturally emitted atmospheric Se may be significant in urban and industrial areas and should be taken into account for further studies”

- Great Salt Lake unique ecosystem
- About 1% of Se associated with anoxic bottom sediment periodically solubilized into upper brine layer where can potentially be incorporated into biota
- This amount not significant compared to external loadings, thus sediment primarily a sink, not a source

- First attempt to understand trace element diel dynamics (diurnal changes) in Great Salt Lake wetlands
- Se cyclically introduced to and/or removed from water column
- “Overestimation of Se loads in wetlands may occur if water quality monitoring is performed predominantly during daylight periods.”

- Effective reactive barrier for suppression of Hg release – Se at “non-toxic” levels
- Nano-Se can also reveal location of Hg contamination by change in optical properties


- Canadian prairies underlain with seleniferous shale but low Se release (mostly as selenate) due to high soil drainage and relatively low level of irrigation compared to California = negligible risk at present
RECENT EVENTS

Kemess Dolly Varden Trout Effects Study
- USEPA reviewed study and obtained a similar EC\textsubscript{10}: 56.2 mg/kg dw eggs; egg to muscle relationship consistent with data compiled for 17 other species

Selenium and Desert Pupfish
- John Besser (USGS) stated at SETAC Pellston (Feb 2009) that statistics underlying conclusion presented at SETAC meetings in November deficient and test inconclusive

Selenium and Cattle Deaths
- August 2009 deaths of 18 cattle near JR Simplot Idaho phosphate mine – due to Se?

USEPA SAB & Se Effects from Coal Mining
- Ad hoc panel being formed to provide expert advice to USEPA Region 3 on draft assessment of ecological impacts from surface coal mining
NOTABLE FROM SETAC 2009
Platform Sessions

- Robin Reash: *The Bioaccumulation of Selenium from Coal Fly Ash: A Review*
  - Total Se not predictive of [Se] solution
  - Fish exposed to Se have osmotic imbalance
  - USEPA new regulatory determination combustion products

- David DeForest: *Review of Selenium Tissue Thresholds for Fish: Endpoint and Life Stage Considerations*
  - Maternal transfer studies are most relevant for developing and applying a tissue-based Se threshold
  - Important that fish tissue Se monitoring coincide with monitoring in water and/or the food chain

- Lana Miller et al.: *The Effect of Chronic Selenium Exposure on Oxidative Stress Biomarkers, Energy Reserves and the Physiological Stress Response of Rainbow Trout and Brook Trout*
  - No large differences between rainbow and brook trout due to Se exposure in the parameters measured.
Conley et al.: Selenium Bioaccumulation and Maternal Transfer in the Mayfly Centroptilum triangulifer in a Life-Cycle, Periphyton-Biofilm Trophic Assay

- 46% of body burden to eggs
- ≈ 11 mg/kg dw periphyton is dietary threshold
- Second generation effects? Unexpected truncated limbs

Photos courtesy of and with permission from Justin Conley
David Janz et al: *Principles and Recommendations for Embryo-Larval Deformity Analyses in Fish Exposed to Selenium*

- Frequency/severity of embryo-larval deformities in fish diagnostic for Se toxicity when used in WOE approach
- QA/QC procedures essential (reduce uncertainty)

Canton et al: *Selenium Tissue Thresholds: Predicting Fish Population and Community Effects in the Field*

- Laboratory reproductive effects thresholds not always predictive of population-level effects in field (habitat nb)

DeBruyn et al.: *The Role of Density Dependence in Translating Individual-level Se Toxicity to Population-Level Effects*

- Some scope for population processes to compensate for individual-level effects
- However, dose-response curve for Se is very steep, so population-level threshold cannot be much greater than individual-level threshold
Harry Ohlendorf et al.: *Site Assessment for Development of a Tissue-Based Site-Specific Objective for Selenium*
- Process of setting site-specific objective
- Process as important as technical aspects

Sam Luoma et al.: *Ecosystem-Scale Biodynamic Model Assists Development of a Tissue-Based Site-Specific Objective for the Newport Bay Watershed, California*
- Model as structured framework to understand the data
- Model allows elimination of outliers re management options
- Vary TTFs and Kds to determine relationship of water to tissue
- Choose your tissue concentration and determine the corresponding water concentration

They refer to 5 mg/kg dw as a threshold
Platform Sessions (cont’d)

- Bill Hopkins re maternal transfer of Se in amphibians – important and overlooked
- Laura Lockard re toxicity of coal-ash derived Se to southern leopard frog larvae with food limitations
- Robin Stewart re appropriate BAFs for Hg and Se – one step at a time: lab, field and modeling
- Se leaching from quantum dots (2 presentations)
- Using synchotron radiation to understand cellular metabolism of Se
Poster Sessions

- More from Lana Miller re Se biomarkers and adult trout
- Bioindicators of Se deficiency and toxicity
  - nothing new; recommend treatment by anaerobic biological reduction (active and passive)
- Need for site-specific criteria and remediation actions
  - focus on coal and Tennessee coal ash spill
  - dredging post-spill will release Se
  - previous to spill elevated Se in fish above 7.91 but no permit restrictions
  - need NDPES permit for coal power plants
- Se bioaccumulation in various areas / species
  - High water [Se]; low fish tissue [Se]
- Tissue types for fish tissues (from NAMC-SWG white paper) and another poster on selenocompounds in juvenile white sturgeon
Poster Sessions (Cont’d)

- Use of field-based mesocosms (2 posters)
  - Fathead minnows: more eggs, lower hatching success
  - Wild and caged lake chub: fed *in situ* benthos and spiked clean food

- Chironomids
  - Sediments not water (selenate) source of body Se
  - Selenite in water $\rightarrow$ selenomethionine in chironomids (but organisms do not synthesize selenomethionine)

- Two posters on Se speciation in Japanese fish

- *Adult zebrafish fed Se had impaired swimming*

- Posters and presentations on Hg-Se interactions

Steve Canton
Se, birds and uranium mining

- Se to levels of potential concern in loons, ducks, geese but abundance too low to determine repro. success

- Tree swallows good indicators (high site fidelity, eat benthos) – no effects to their reproductive success

Huddleston et al. *Enhancement of selenium removal in constructed wetland treatment system receiving flue gas desulfurization water at a coal fired power plant*

- Add sucrose to constructed wetland treatment systems → significant enhancement of nitrate and Se
Poster Sessions (Cont’d)

- Tuberty et al. *Effects from the catastrophic rupture of a coal fly ash settling pond in Kingston, TN*
  - Se in fish “legacy selenium from decades of unregulated release…TVA Kingston plant”
  - Fish Se at and beyond Lemly thresholds; “may increase drastically” with dredging

- Nelson et al. *Effects of salt and selenium from saline seeps on waterfowl and shorebirds using Hailstone National Wildlife Refuge in Montana*
  - Crop-fallow farming practices
  - “potential to cause complete reproductive failure in sensitive species of waterfowl and shorebirds”
  - “Plans are underway to remove the reservoir to eliminate selenium and salinity risks” (dam removal to more natural flow-through system)

Avocet eggs to 47 mg/kg dw Se; 20 mg/kg dw is threshold for effects from Kesterton; avocet not most sensitive bird species
Thank you for Listening!
Other Questions / Discussion?

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