Ecological Assessment of Selenium in the Aquatic Environment

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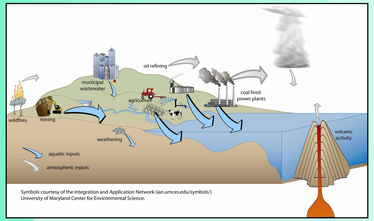
selenium
34
Se
78.96

46 Scientists, Managers, Policy Makers; 4 continents; 5 countries

Executive Summary Booklet available from SETAC (www.setac.org/node/265)

Book (in press with SETAC Press) available in early 2010

Potential Sources of Selenium (Se) to Aquatic Systems



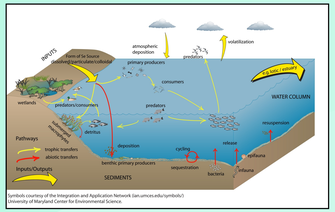
Problem Formulation

Se is a growing problem of global concern

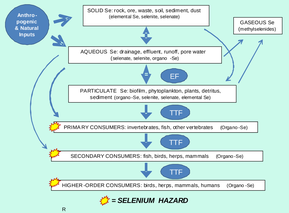
Diet is the primary pathway of Se exposure for both invertebrates and vertebrates

Traditional methods for predicting toxicity on the basis of exposure to dissolved concentrations do not work for Se because the behavior and toxicity of Se in aquatic systems are highly dependent upon site-specific factors, including food web structure and hydrology

Se toxicity is primarily manifested as reproductive impairment due to maternal transfer resulting in embryotoxicity and teratogenicity in egg-laying vertebrates (fish, birds, amphibians, reptiles)



Partitioning of selenium amongst environmental compartments in a typical aquatic system



Conceptual model depicting selenium dynamics and transfer in aquatic ecosystems. EF = enrichment function; TTF = trophic transfer function.

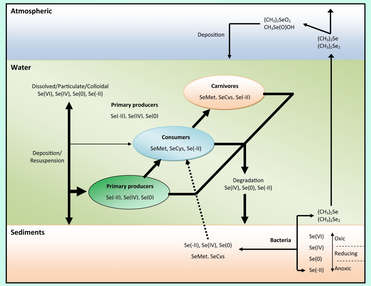
Environmental Partitioning, Bioaccumulation and Trophic Transfer

Se speciation is critical to understand its mobility, transformation, partitioning in the environment, and potential risk to aquatic ecosystems

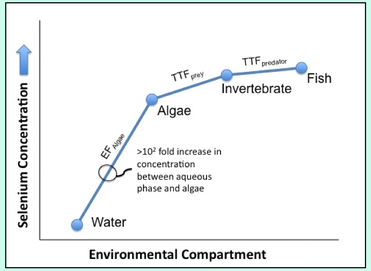
Se uptake is facilitated across most biological membranes (a non-passive, carrier-mediated process), making its partitioning unique among metalloid contaminants

The single largest step in the bioaccumulation of Se occurs at the base of food webs, characterized by an 'enrichment function'; thermodynamic or equilibrium-based principles are not appropriate for predicting Se bioaccumulation at the base of food webs

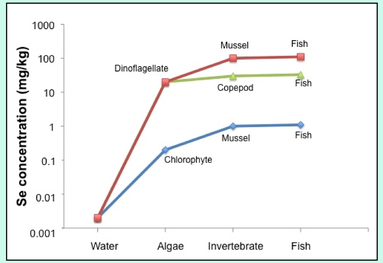
Se bioaccumulation by primary producers and predators varies widely among species based on both ecology and physiology (biodynamics); uptake by individual species and in steps of the food web can be described by a trophic transfer function



Selenium species associated with major processes in aquatic systems



Selenium enrichment and trophic transfer in aquatic food webs. Enrichment function (EF_{algae}) represents the increase in Se concentration between water and the base of the aquatic food web (e.g., algae). Trophic transfer function represents the increase in Se concentration between algae and invertebrates (TTF_{prey}) and invertebrates and fish ($TTF_{predator}$)



Selenium accumulation in different species of algae, invertebrates, and fish. TTFs are for a chlorophyte food web in fresh waters and a dinoflagellate food web in an estuary. Both food webs have a bivalve as the invertebrate, and use an average fish TTF of 1.1. The estuarine food web also illustrates the outcome for a copepod with a lower TTF from algae than a mussel.

Toxic Effects

A key aspect of Se toxicity is the narrow range between dietary essentiality and toxicity

Differences in species sensitivities to Se may be related to differences in reproductive physiology, dynamics of Se transfer from diet or body tissues to eggs, and / or differences in capacity to metabolize organic Se to more reactive oxidized species

Protection of top predators may not guarantee protection of all biota situated lower in the food web

Aquatic-dependent mammals do not appear to be as sensitive as fish or birds to dietary organic Se exposure

The most sensitive toxicity endpoint in birds is embryo mortality

The most sensitive toxicity endpoints in fish larvae are teratogenic deformities such as skeletal, craniofacial and fin deformities, and various forms of edema

Embryo mortality and severe development abnormalities can result in impaired recruitment of individuals into populations

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U.S. Utility Water Act Group

Risk Assessment

Population-level effects from Se in natural ecosystems are difficult to detect. This difficulty reflects differences in species sensitivity as well as food web complexities and demographics where population level effects are suspected. Se contamination of Belews Lake, Hyco and Kesterson Reservoirs (USA) resulted in whole-ecosystem exposures that had significant adverse population-level impacts. Few such widespread impacts on populations have been definitively documented in other ecosystems; however, population-level effects have been suspected at several other sites including San Francisco Bay (USA) and Lake Macquarie (Australia)

Risk assessment starts with reviewing available data on Se concentrations in various media, but more certainty in assessment of potential adverse effects is realized when Se measurements are made in reproductive tissue

A single, universal dissolved water quality value is inappropriate for predicting toxicity. The dissolved Se concentration benchmark that is necessary to protect one site may be either insufficiently protective or unnecessarily protective at another site

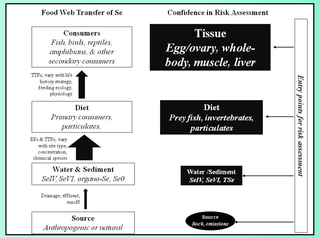
There is consensus that fish and bird eggs are the critical media in terms of assessing or predicting Se toxicity at a given location, and measured concentrations in these tissues are most strongly linked to adverse effects

The vulnerability of a species is the product of its sensitivity to Se in its eggs, its propensity to transfer Se from its body into its eggs, and its propensity to accumulate Se from its environment, as affected by its diet choices and intake rates, and by site-specific factors controlling the transfer of Se into and within the food web

For reliable prediction of effect thresholds across a range of sites, numeric benchmarks for egg concentrations provide the greatest certainty. The more distantly connected a possible measurement medium is to the egg concentrations, the less certainty that the associated numeric benchmark will be appropriate across sites

For site-specific assessment of Se risks to fish, the field collection of ripe females or newly laid embryos for laboratory examination of larval effects is a reliable indicator of Se risks when the effect measure is related to the egg Se concentration

Se requires site-specific risk assessments to a much greater extent than many other contaminants, including adequate quality assurance / quality control of chemical and biological analyses



Conceptual pathway of Se transfer in aquatic ecosystems (left) and relative certainty with which Se concentration in environmental compartments can be assessed in making accurate characterizations of risk. The size of the arrows in the left column indicates the relative rates of transfer and the size of the compartment in the right column indicates the relative confidence for deriving estimated risks.