ASSESSING THE TOXIC THREAT OF SELENIUM TO FISH AND AQUATIC BIRDS

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Abstract. A procedure is given for evaluating the toxic threat of selenium to fish and wildlife. Toxic threat is expressed as hazard, and is based on the potential for food-chain bioaccumulation and reproductive impairment in fish and aquatic birds, which are the most sensitive biological responses for estimating ecosystem-level impacts of selenium contamination. Five degrees of hazard are possible depending on the expected environmental concentrations of selenium, exposure of fish and aquatic birds to toxic concentrations, and resultant potential for reproductive impairment. The degree of hazard is given a numerical score: 5 = high hazard, 4 = moderate hazard, 3 = low hazard, 2 = minimal hazard, and 1 = no identifiable hazard. A separate hazard score is given to each of five ecosystem components; water, sediments, benthic macroinvertebrates, fish eggs, and aquatic bird eggs. A final hazard characterization is determined by adding individual scores and comparing the total to the following evaluation criteria: 5 = no hazard, 6-8 = minimal hazard, 9-11 = low hazard, 12-15 = moderate hazard, 16-25 = high hazard. An example is given to illustrate how the procedure is applied to selenium data from a typical contaminant monitoring program.

Introduction

The importance of selenium as an environmental contaminant has gained widespread attention among scientists, natural resource managers, and water quality regulators in the U.S. during the past two decades. Selenium mobilized from the combustion of coal at electric generating stations has contaminated several major reservoirs, leading to reproductive failure and elimination of entire communities of fish (Cumbie and Van Horn, 1978; Garrett and Inman, 1984; Woock and Summers, 1984; Woock *et al.*, 1985; Lemly, 1985a, 1993a). Irrigation of seleniferous soils has produced subsurface drainage that contaminated wetlands and poisoned fish and migratory birds at several locations in the western U.S. (Lemly, 1993b, 1994; Presser, 1994; Presser *et al.*, 1994). The U.S. Environmental Protection Agency and some states have formulated and adopted increasingly restrictive water quality standards for selenium because of these incidents of environmental contamination (NCDEM, 1986; USEPA, 1987; CEPA, 1992).

Most natural resource management agencies are aware of the toxic threat posed by selenium and many have implemented contaminant monitoring programs to measure selenium concentrations in water, sediments, and aquatic biota. Once these data are collected it is important to conduct an overall evaluation and determine the degree of hazard present in order to identify appropriate management actions. However, few agencies address this information need by performing a

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comprehensive hazard assessment. There likely are two reasons for this. First, it has been difficult for those conducting the monitoring programs to determine the toxicological significance of selenium residues in aquatic organisms. Taking time to locate, obtain, and interpret the results of selenium toxicity tests for a variety of aquatic species is a difficult task. Fortunately, this type of information synthesis has been done. Guidelines are now available for evaluating selenium in food-chain organisms and fish and wildlife tissues based on current toxicological information (Skorupa and Ohlendorf, 1991; Lemly, 1993c; Beyer *et al.*, 1996; Skorupa *et al.*, in press). Interpreting selenium residues, for the most part, is no longer a primary concern.

The second reason, which still persists, is the lack of a broadly applicable procedure for conducting an aquatic hazard assessment of selenium. This has left investigators on their own, struggling with selenium monitoring data and trying to come up with a reasonable approach for characterizing hazard. Several approaches have been tried. Early attempts relied on comparisons between waterborne concentrations measured in the field and concentrations that were toxic to aquatic organisms in the laboratory (Cumbie and Van Horn, 1978; Adams and Johnson, 1981; Lemly, 1982). However, the laboratory data did not adequately explain the greater toxic effects observed for fish in the field. Subsequent research on selenium indicated that food-chain bioaccumulation, dietary intake, and reproductive effects should be given high priority in hazard assessment (Woock and Summers, 1984; Garrett and Inman, 1984; Sorensen *et al.*, 1984; Lemly, 1985a, 1985b; Baumann and Gillespie, 1986; Gillespie and Baumann, 1986; Heinz *et al.*, 1987). Utilizing this and other information, some investigators have developed mathematical models to describe and predict selenium cycling and toxicity (e.g., Porcella *et al.*, 1991; Peterson and Nebeker, 1992; Bowie and Grieb, 199 1; Bowie, 1995). Models can be a useful tool for predicting toxicological risk. The major drawback is that these methods are relatively complex and, in order to provide reliable predictions, require considerably more information than would be available from a typical contaminant monitoring program. Thus, the potential for models to be routinely used in hazard assessment is limited.

Despite the large amount of new toxicity information generated during the past decade (e.g., USFWS, 1990a, 1990b; Figure 1), and the need to evaluate selenium hazards at many locations across the U.S. (Peterson and Nebeker, 1992; Presser *et al.*, 1994; Seiler and Skorupa, 1995), there is no common assessment method in use. This has resulted in confusion and frustration for those involved in hazard assessment of both site-specific and regional selenium contamination problems (Sylvester *et al.*, 1991; Presser *et al.*, 1994).

Field biologists and fish and wildlife managers would benefit by having an easily applied, scientifically credible procedure for conducting aquatic hazard evaluations of selenium. The procedure presented here was developed to address that information need. It includes the key parameters that are implicit in basic toxicological risk assessment such as concentration and exposure, but it also integrates biotic and

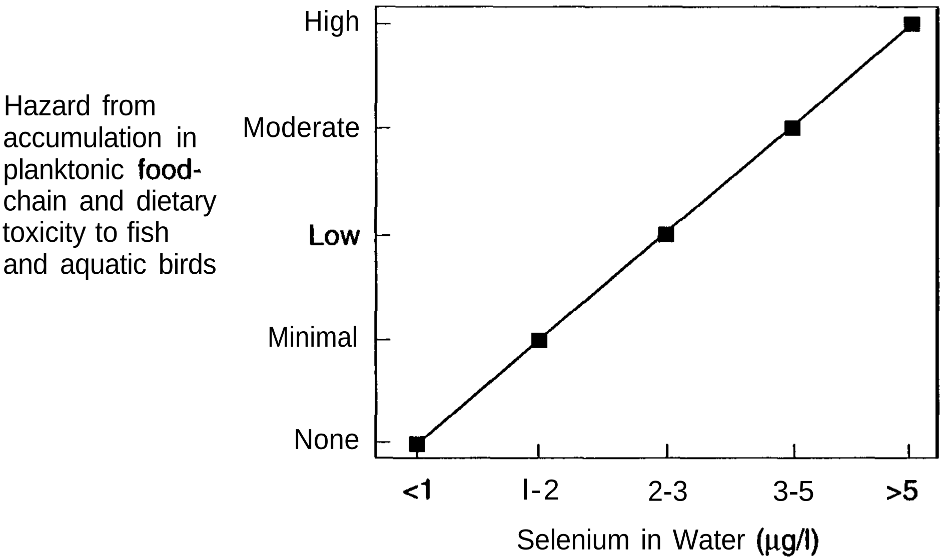

Figure 1. Hazard profile for selenium accumulation from water into the planktonic food chain, and resultant dietary toxicity to fish and aquatic birds. Waterborne concentrations are for 0.45 μm filtered samples. This and subsequent hazard profiles (Figures 2-5) are based on a synthesis of toxicity, bioaccumulation, and sediment data from Traversy *et al.*, 1975; Adams and Johnson, 1977; Birkner, 1978; Cumbie, 1978; Cumbie and Van Horn, 1978; Goettl and Davies, 1978; Cherry *et al.*, 1979; Furr *et al.*, 1979; Guthrie and Cherry, 1979; Holland, 1979; Duke Power Company, 1980; Hilton *et al.*, 1980; Nassos *et al.*, 1980; Speyer, 1980; Hilton and Hodson, 1983; Hodson and Hilton, 1983; Nriagu and Wong, 1983; Rudd and Turner, 1983; Sorensen and Bauer, 1983, 1984a, 1984b; Turner and Rudd, 1983; Bryson *et al.*, 1984; Garrett and Inman, 1984; Hicks *et al.*, 1984; Martin and Hartman, 1984; Sager and Cofield, 1984; Sorensen *et al.*, 1982a, 1982b, 1983a, 1983b, 1984; Wiener *et al.*, 1984; Woock, 1984; Woock and Summers, 1984; Finley, 1985; Lemly, 1985a, 1993a, 1993d; Winger and Andreason, 1985; Woock *et al.*, 198.5, 1987; Baumann and Gillespie, 1986; Bennett *et al.*, 1986; Byrne and DeLeon, 1986; Foe and Knight, 1986; Gillespie and Baumann, 1986; Hamilton *et al.*, 1986, 1990; Kleinow and Brooks, 1986; Ohlendorf *et al.*, 1986a, 1986b, 1987, 1988, 1989, 1990; Saiki, 1986; TUGCO, 1986; White *et al.*, 1986, 1987; Heinz *et al.*, 1987, 1988, 1989, 1990; Presser and Ohlendorf, 1987; Saiki and Lowe, 1987; Thompson and Watling, 1987; Barnum and Gilmer, 1988; Boyum and Brooks, 1988; Gillespie *et al.*, 1988; Hoffman and Heinz, 1988; Hoffman *et al.*, 1988, 1991; Ogle *et al.*, 1988; Smith *et al.*, 1988; Sorensen, 1988; Stephens *etal.*, 1988, 1992; Besser *et al.*, 1989, 1993; Coughlan and Velte, 1989; Dubowy, 1989; Hothem and Ohlendorf, 1989; Ogle and Knight, 1989; Ohlendorf, 1989; Pyron and Beitinger, 1989; Williams *et al.*, 1989; Fairbrother and Fowles, 1990; Ingersoll *et al.*, 1990; Kiffney and Knight, 1990; Schuler *et al.*, 1990; Schultz and Hermanutz, 1990; USFWS, 1990a, 1990b; Allen, 1991; Cutter, 1991; Home, 1991; Omes *et al.*, 1991; Peltz and Waddell, 1991; Riedel et *al.*, 1991; Skorupa and Ohlendorf, 1991; Crane *et al.*, 1992; Hernmanutz, 1992; Hermanutz *et al.*, 1992; Waddell and Stanger, 1992; Cleveland *et al.*, 1993; Coyle *et al.* 1993; Goede, 1993; Hallock and Hallock, 1993; Heinz, 1993; Heinz and Fitzgerald, 1993a, 1993b; Maier and Knight, 1993; Olson and Welsh, 1993; Saiki *et al.*, 1993; Hamilton and Waddell, 1994; King *et al.*, 1994; Presser *et al.*, 1994; Sanders and Gilmour, 1994; Stanley *et al.*, 1994; Welsh and Maughan, 1994; and Skorupa *et al.*, in press.

abiotic cycling components that are essential for site-specific hazard evaluation of selenium. The method generates numerical scores that can be compared between years and across sites and locations, thereby providing a consistent approach for evaluating hazard. The assessment focuses on food-chain bioaccumulation and reproductive impairment in fish and aquatic birds, which are the most sensitive biological endpoints for determining potential ecosystem-level impacts of selenium (Lemly, 1993a, 1993c).

Definition of Toxic Threat

In the context of this assessment procedure, toxic threat is expressed as the hazard to fish and aquatic birds that use a specific habitat known or suspected of being contaminated with selenium. Hazard is characterized from two types of information: (1) the degree of selenium contamination present, which is used as an estimate of the expected environmental concentration, and (2) the extent of fish and wildlife exposure to potentially toxic selenium concentrations. Exposure can be difficult to characterize precisely. However, the data set required for assessment helps with this problem because it specifies the use of egg selenium concentrations. This focuses the assessment on the reproductive cycle, which is the critical period of exposure necessary for toxic impacts. Hazard is maximized when the degree of contamination is high and exposure occurs during the breeding season.

Five categories of hazard are recognized in the procedure based on the potential for reproductive impairment in fish and aquatic birds. High hazard denotes an imminent, persistent toxic threat sufficient to cause complete reproductive failure in most species of fish and aquatic birds. Moderate hazard indicates a persistent toxic threat of sufficient magnitude to substantially impair, but not eliminate reproductive success; some species will be severely affected while others will be relatively unaffected. Low hazard denotes a periodic or ephemeral toxic threat that could marginally affect the reproductive success of some sensitive species, but most species will be unaffected. Minimal hazard indicates that no toxic threat is identified but concentrations of selenium are slightly elevated in one or more ecosystem components (water, sediment, invertebrates, fish, birds) as compared to uncontaminated reference sites; continued comprehensive environmental monitoring is recommended. No hazard denotes that no toxic threat is identified and selenium concentrations are not elevated in any ecosystem component; periodic baseline reconnaissance monitoring is recommended.

Data Requirements

The procedure requires a set of data for selenium concentrations measured in five ecosystem components – water (0.45 μm filtered samples), sediments, benthic macroinvertebrates, fish eggs, and aquatic bird eggs. Incomplete data sets, i.e., one or more ecosystem components missing, will weaken the predictive power of the assessment but it can still be performed. Depending on species and time of year, bird eggs and gravid fish ovaries may be difficult or impossible to obtain. In this case, selenium can be measured in bird livers and whole-body samples of fish, and the results converted to approximate egg concentrations using the following conversion factors: bird egg selenium = bird liver selenium x 0.33; fish egg selenium = fish whole-body selenium x 3.3 (Lemly and Smith, 1987; Skorupa *et al.,* in press). When nesting birds are sampled it is desirable to collect eggs of species that use a localized feeding area which represents the study site and thus the local conditions of exposure to dietary selenium. Species such as American coots (*Fulica americana*), grebes (*Podilymbus* spp.), and dabbling ducks (Anus spp.) are good choices in this regard. With fish, species that are resident in the area will suffice. Depending on location, minnows (Cyprinidae), sunfish (Centrarchidae), suckers (Catostomidae), catfish (Ictaluridae), and trout (Salmonidae) should be readily available and easy to sample. For some species, particularly cyprinids in streams, it will probably be necessary to select large individuals in order to obtain sufficient egg mass for analysis. Migratory species of birds and fish that could have recently arrived (within 2 weeks) at the study site from distant locations should be avoided because they may not have had time to accumulate tissue residues of selenium that reflect local exposure conditions (Heinz *et al.*, 1990).

Data for the procedure can be from a one-time sampling effort or from an ongoing monitoring program of considerable duration. However, if the later case exists, it is recommended that the most recent data (l-2 years) be used since it would yield the best estimate of current hazard. Eggs are a key component in the assessment because of the fact that reproductive success is the most sensitive biological response for determining selenium toxicity to fish and aquatic birds (Lemly, 1993c). Selenium ingested in the diet is readily transmitted to developing eggs from the parent, where it can cause teratogenic deformities and embryomortality. Complete reproductive failure can occur with no observable toxic effects on the adults (Gillespie and Baumann, 1986; Woock *et al.*, 1987; Heinz *et al.*, 1987, 1989; Coyle *et al.*, 1993). The procedure thus incorporates a sensitive indicator that reflects the mode of toxicity responsible for the most serious community- and ecosystem-level effects.

In order for the assessment to be reliable, the data for selenium concentrations must also be reliable. Analytical methods used to determine selenium should be sensitive and under strict, documented quality control. Methods for water and tissues should have limits of detection in the sub-μg/l range and sub-μg/g range respectively. This is important because an error of only 1 μg/l or 1 μg/g in measured concentrations could cause the hazard rating for an environmental component to fall in the wrong category. Propogation of this error throughout the five environmental components used in the procedure could result in an inappropriate final hazard characterization. Acceptably sensitive analytical methods include neutron activation, hydride-generation atomic absorption spectrophotometry, and cathodic stripping voltammetry (McKown and Morris, 1978; Jarzabek and Kublik, 1982; Brooks *et al.*, 1983). Tissue and sediment preparation techniques appropriate for

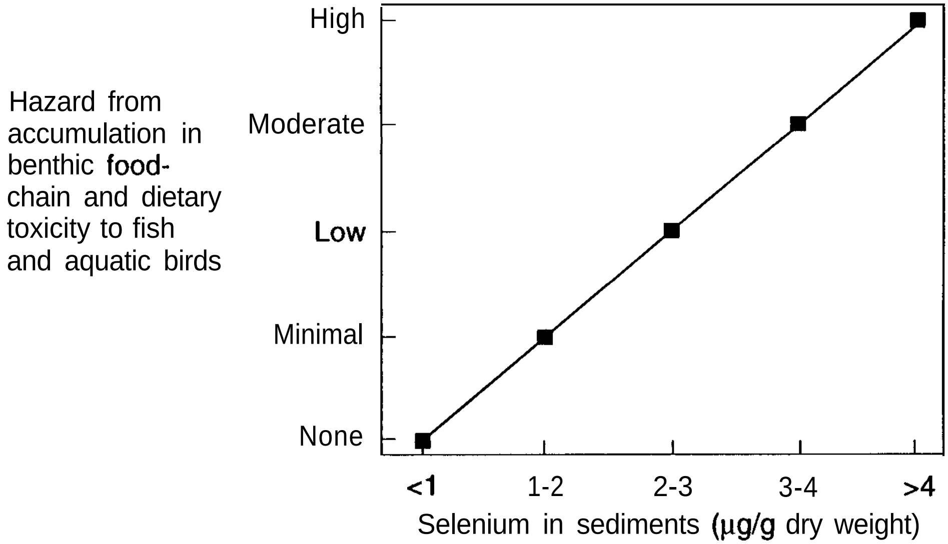

Figure 2. Hazard profile for selenium accumulation from sediments into the benthic food chain, and resultant dietary toxicity to fish and aquatic birds.

use with these methods are available (e.g., Grant, 1981; May, 1982; Krynitsky, 1987; Fio and Fujii, 1988; Brumbaugh and Walther, 1989). Analytical methods such as inductively-coupled argon plasma spectroscopy (ICAP) should be avoided if possible. Although ICAP scans are good for reconnaissance-level monitoring to identify field sites of concern, the detection limits are generally too high and the precision too low for determining concentrations to be used in the hazard assessment. Establishing a contract for selenium measurements with a reputable environmental laboratory is a desirable, cost effective alternative to developing in-house analytical chemistry capabilities.

Conducting an Assessment

Selenium concentrations measured in samples collected from a study site are compared to hazard profiles (Figures l-5). These profiles are based on the results of extensive field and laboratory studies of selenium, and reflect the most current information on bioaccumulation and toxic thresholds (see references for Figure 1). Waterborne concentrations are compared to the profile for water, sediments to sediments, and so forth. A hazard rating is determined for each of the five ecosystem components based on where the highest concentrations of selenium in the samples fall on the hazard scale (high, moderate, low, minimal, none). Individual hazard ratings are then given a numerical score: high hazard = 5, moderate hazard = 4, low hazard = 3, minimal hazard = 2, and no identifiable hazard = 1. A final haz-

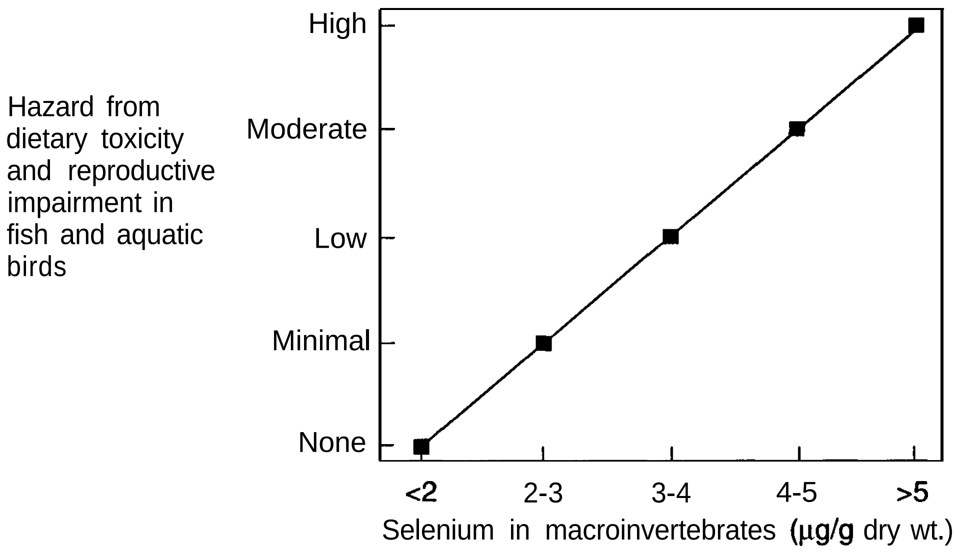

Figure 3. Hazard profile for dietary toxicity and reproductive failure in fish and aquatic birds from ingestion of selenium-contaminated macroinvertebrates.

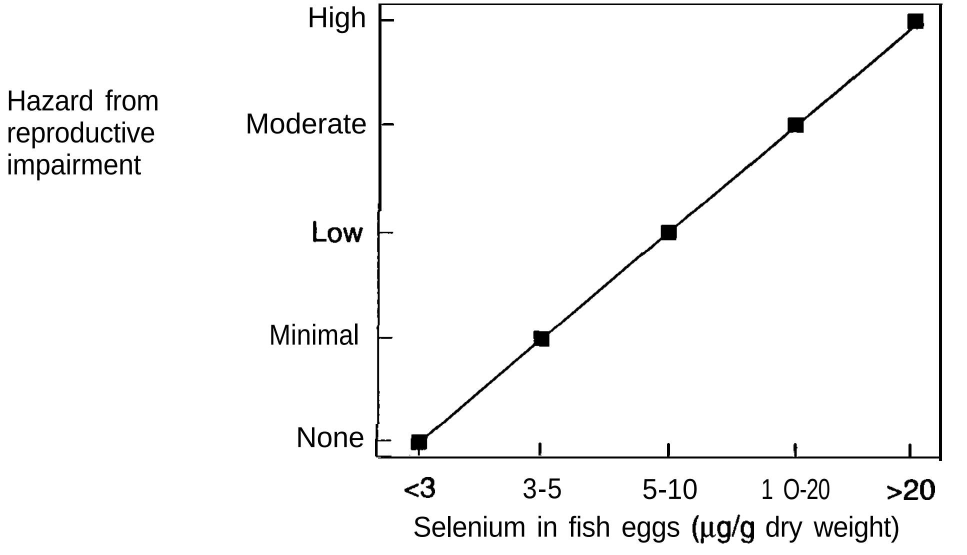

Figure 4. Hazard profile for selenium-induced reproductive impairement in fish.

ard characterization is determined by adding together the five individual scores and comparing the total to the following evaluation criteria: 5 = no hazard, 6-8 = minimal hazard, 9-l 1 = low hazard, 12-15 = moderate hazard, 16-25 = high

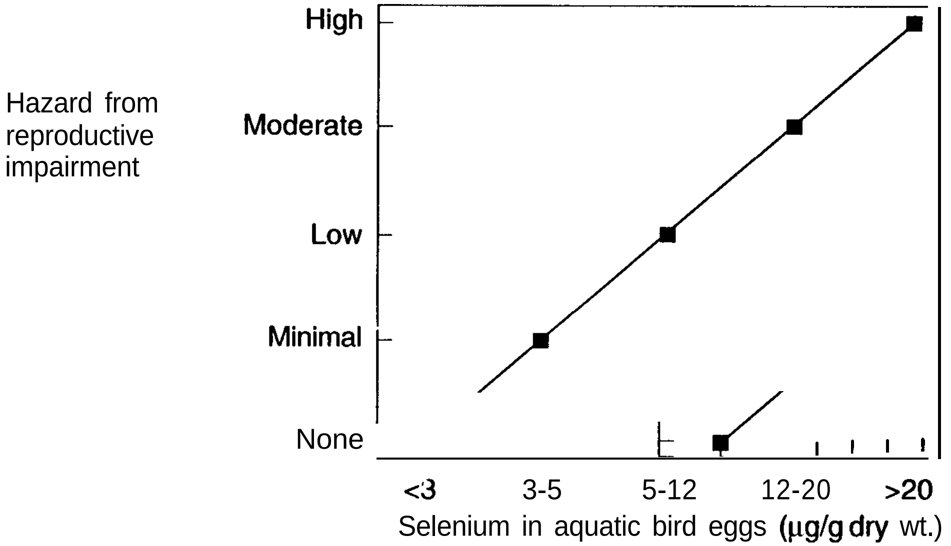

Figure 5. Hazard profile for selenium-induced reproductive impairment in aquatic birds.

hazard. The assessment thus integrates hazard component scores and provides an ecosystem-level evaluation.

The intervals for the final hazard characterization are based on the scores for individual components but they are not a simple average or a midpoint. For example, a final hazard rating of "low" can occur even though each of the individual components was rated "minimal". The rationale for this is that three distinct routes of exposure are possible for selenium (water, planktonic food-chain, detrital food-chain). Based on field evidence, the hazard from all three together should be greater than if each is considered separately. Thus, the aggregate hazard for the environment as a whole can be greater than the hazard for the individual components. This is analogous to synergism, i.e., the parts (hazard) are not simply additive.

Depending on the needs of the investigator, the procedure can be applied to data collected for a single sampling site or to pooled data from a monitoring effort covering a large area. The procedure can thus address several levels of landscape scale and provide site-specific as well as regional assessment of selenium hazard. Comparisons can be made between locations and years, and follow-up assessments can be made to evaluate the success of management actions and cleanup activities at selenium contaminated sites.

The procedure was recently used to evaluate the toxic threat of selenium to fish and migratory birds at Ouray National Wildlife Refuge, Utah (Lemly, 1995). The example given here was taken from that evaluation. Data for selenium concentrations were obtained from the records of a contaminant monitoring program (Stephens *et al.*, 1988, 1992; Peltz and Waddell, 1991; Waddell and Stanger, 1992).

Table I
Data set for aquatic hazard assessment of selenium at Ouray National Wildlife Refuge, Utah

Site and environmental component	Selenium concentration[a]	Evaluation by component: Hazard[b]	Evaluation by component: Score	Totals for the site: Score	Totals for the site: Hazard
Leota Bottom					
Water	<1–3	Low	3		
Sediments	0.7-1	None	1		
Invertebrates	1-3	Minimal	2		
Fish eggs	2-4	Minimal	2		
Bird eggs	2-7	Low	3		
			11	11	Low
Roadside Ponds					
Water	9-93	High	5		
Sediments	7-41	High	5		
Invertebrates	12-72	High	5		
Fish eggs	75-120	High	5		
Bird eggs	12-120	High	5		
			25	25	High
Sheppard Bottom					
Water	3-4	Moderate	4		
Sediments	0.63	Low	3		
Invertebrates	3-33	High	5		
Fish eggs	8-27	High	5		
Bird eggs	1-17	Moderate	4		
			21	21	High

[a] Selenium concentrations in μg/l (parts per billion) for water; μg/g (parts per million) dry weight for sediments, invertebrates, and eggs.
[b] Hazard ratings were determined by comparing selenium concentrations to hazard profiles given in Figures 1-5.

Three managed wetlands on the Refuge were examined and separate hazard assessments were generated for each of these locations (Table I). The ratings given to the sites ranged from low hazard to high hazard, reflecting differences in waterborne selenium concentrations and associated influences on the sediment-detrital food pathway and dietary exposure of fish and migratory birds. Corrective actions have been prescribed and implemented at the high hazard sites and the procedure can soon be used to begin evaluating the success of these actions in reducing selenium hazards.

Conclusions

The assessment procedure provides a straightforward, consistent approach to evaluate the toxic threat of selenium using a set of data from routine contaminant monitoring. Toxic threat, expressed as hazard, is characterized from sensitive endpoints linked to important biological effects. Although the method is simple and easy to carry out, it is based on a large body of field and laboratory research data on selenium cycling and toxicity in aquatic ecosystems. This, combined with the integrative nature of the method, i.e., utilizing information from five ecosystem components, should make it a useful tool for assessing the toxic threat of selenium to fish and wildlife.

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References

Adams, W. J. and Johnson, H. E.: 1977, 'Survey of the Selenium Content in the Aquatic Biota of Western Lake Erie', *Journal of Great Lakes Research 3,* 10–14.

Adams, W. J. and Johnson, H. E.: 1981, 'Selenium: A Hazard Assessment and a Water Quality Criterion Calculation', in: Branson, D. R. and Dickson, K. L. (eds.), *Aquatic Toxicology and Hazard Assessment: Fourth Conference,* American Society for Testing and Materials Publication ASTM STP 737, pp. 124–137.

Allen, K. N.: 1991, 'Seasonal Variation of Selenium in Outdoor Experimental Stream-Wetland Systems', *Journal of Environmental Quality 20, 865-868.*

Barnum, D. A. and Gilmer, D. S.: 1988, 'Selenium Levels in Biota from Irrigation Drainwater Impoundments in the San Joaquin Valley, California', *Lake and Reservoir Management 4,* 181-186.

Baumann, P. C. and Gillespie, R. B.: 1986, 'Selenium Bioaccumulation in Gonads of Largemouth Bass and Bluegill from Three Power Plant Cooling Reservoirs', *Environmental Toxicology and Chemistry* **5**, 695–701.

Bennett, W. N., Brooks, A. S. and Boraas, M. E.: 1986, 'Selenium Uptake and Transfer in an Aquatic Food Chain and its Effects on Fathead Minnow Larvae', *Archives of Environmental Contamination and Toxicology* **15,** **5** 13-5 17.

Besser, J. M., Huckins, J. N., Little, E. E. and La Point, T. W.: 1989, 'Distribution and Bioaccumulation of Selenium in Aquatic Microcosms', *Environmental Pollution 62, l-12.*

Besser, J. M., Canfield, T. J. and La Point, T. W.: 1993, 'Bioaccumulation of Organic and Inorganic Selenium in a Laboratory Food Chain', *Environmental Toxicology and Chemistry 12, 57-92.*

Beyer, W. N., Heinz, G. H. and Redmon, A. W.: 1996, *Environmental Contaminants in Wildife: Interpreting Tissue Concentrations,* Lewis Publishers, Boca Raton, FL.

Birkner, J. H.: 1978, 'Selenium in Aquatic Organisms from Seleniferous Habitats', *Ph.D. Dissertation,* Colorado State University, Fort Collins, CO.

Bowie, G. L.: 1995, 'Aquatic Toxicity Model (ATM). Biogeochemical and Foodweb Models – Selenium Version 1 .0',. Electric Power Research Institute, Lafayette, CA.
Bowie, G. L. and Grieb, T. M.: 1991, 'A model Framework for Assessing the Effects of Selenium on Aquatic Ecosystems', *Water, Air, and Soil Pollution* **57–58**, *13-22.*
Boyum, K. W. and Brooks, A. S.: 1988, 'The Effect of Selenium in Water and Food on *Daphnia* Populations', *Archives of Environmental Contamination and Toxicology 17,* 555–560.
Brooks, R. R., Willis, J. A. and Liddle, J. R.: 1983, 'Optimum Conditions for Hydride Generation of Selenium and its Determination by Atomic Absorption Spectrophotometry', *Journal of the Association of Official Analytical Chemists 66,* 130–134.
Brumbaugh, W. G. and Walther, M. J.: 1989, 'Determination of Arsenic and Selenium in Whole Fish by Continuous-Flow Hydride Generation Atomic Absorption Spectrophotometry', *Journal of the Association of Official Analytical Chemists* **72**, 484–486.
Bryson, W. T., Garrett, W. R., Mallin, M. A., MacPherson, K. A., Pat-tin, W. E. and Woock, S. E.: 1984, 'Roxboro Steam Electric Plant 1982 Environmental Monitoring Studies. Volume II. Hyco Reservoir Bioassay studies', *Technical Report,* Carolina Power and Light Company, New Hill, NC.
Byrne, C. J. and Deleon, I. R.: 1986, 'Trace Metal Residues in Biota and Sediments from Lake Pontchartrain', Louisiana. *Bulletin of Environmental Contamination and Toxicology 37,* 151–158.
CEPA (California Environmental Protection Agency): 1992, 'Derivation of Site-Specific Water Quality Standards for Selenium in San Francisco Bay', *Technical Report,* CEPA, Oakland, CA.
Cherry, D. S., Guthrie, R. K., Sherberger, F. F. and Larrick, S. R.: 1979, 'The Influence of Coal Ash and Thermal Discharges upon the Distribution and Bioaccumulation of Aquatic Invertebrates', *Hydrobiologia 62, 257-267.*
Cleveland, L., Little, E. E., Buckler, D. R. and Wiedmeyer, R. H.: 1993, 'Toxicity and Bioaccumulation of Waterborne and Dietary Selenium in Juvenile Bluegill *(Lepomis macrochirus), Aquatic Toxicology 27,* 265–280.
Coughlan, D. J. and Velte, J. S.: 1989, 'Dietary Toxicity of Selenium-Contaminated Red Shiners to Striped Bass', *Transactions of the American Fisheries Society* **118**, 400–408.
Coyle, J. J., Buckler, D. R., Ingersoll, C. G., Fairchild, J. F. and May, T. W.: 1993, 'Effect of Dietary Selenium on the Reproductive Success of Bluegills *(Lepomis macrochirus), Environmental Toxicology and Chemistry* **12**, 551–565.
Crane, M., Flower, T., Holmes, D. and Watson, S.: 1992, 'he Ttoxicity of Sselenium in Eexperimental Ffreshwater Ponds', *Archives of Environmental Contamination and Toxicology* **23**, 440–452.
Cumbie, P. M.: 1978, 'Belews Lake Environmental Study Report: Selenium and Arsenic Accumulation', *Technical Report 78-04,* Duke Power Company, Charlotte, NC.
Cumbie, P. M. and Van Horn, S. L.: 1978, 'Selenium Accumulation Associated with Fish Mortality and Reproductive Failure', *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* **32**, 612–624.
Cutter, G. A.: 1991, 'Selenium Biogeochemistry in Reservoirs. Vol. 1: Time Series and Mass Balance Results'. *Report EPRI EN-7281,* Electric Power Research Institute, Palo Alto, CA.
Dubowy, P. J.: 1989, 'Effects of Diet on Selenium Bioaccumulation in Marsh Birds', *Journal of Wildlife Management* **53**, 776–781.
Duke Power Company: 1980, 'Toxic Effects of Selenium on Stocked Bluegill *(Lepomis macrochirus)* in Belews Lake, North Carolina, April-September 1979. *Technical Report,* Duke Power Company, Charlotte, NC.
Fairbrother, A. and Fowles, J.: 1990, 'Subchronic Effects of Sodium Selenite and Selenomethionine on Several Immune Functions in Mallards', *Archives of Environmental Contamination and Toxicology 19, 836-844.*
Finley, K. A.: 1985, 'Observations of Bluegills Fed Selenium-Contaminated *Hexagenia* Nymphs Collected from Belews Lake', North Carolina, *Bulletin of Environmental Contamination and Toxicology 35, 816825.*
Fio, J. L. and Fujii, R.: 1988, 'Comparison of Methods to Determine Selenium Species in Saturation Extracts of Soils from the Western San Joaquin Valley', California. *Open-File Report 88–458*, U.S. Geological Survey, Sacramento, CA.

Foe, C. and Knight, A. W.: 1986, 'Selenium Bioaccumulation, Regulation, and Toxicity in the Green Alga, *Selenastrum capricornutum,* and Dietary Toxicity of the Contaminated Alga to *Daphnia magna'*. In Selenium in the Environment – Proceedings of the First Annual Environmental Symposium, pp. 77-88. *Publication No. CAT1/860201.* California State University, Fresno, CA.

Furr, A. K., Parkinson, T. F., Youngs, W. D., Berg, C. O., Gutenmann, W. H., Pakkala, I. S. and Lisk, D. J.: 1979, 'Elemental Content of Aquatic Organisms Inhabiting a Pond Contaminated with Coal Fly ash', New *York Fish and Game Journal 26,* 154-l 6 1.

Garrett, G. P., and Inman, C. R.: 1984, 'Selenium-Induced Changes in the Fish Populations of a Heated Reservoir', *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 38,* 291–301.

Gillespie, R. B. and Baumann, P. C.: 1986, 'Effects of High Tissue Concentrations of Selenium on Reproduction by Bluegills', *Transactions of the American Fisheries Society* 115, 208–213.

Gillespie, R. B., Baumann, P. C. and Singley, C. T.: 1988, 'Dietary Exposure of Bluegills (*Lepomis macrochirus)* to (75) Se: Uptake and Distribution in Organs and Tissues', *Bulletin of Environmental Contamination and Toxicology* **40**, 771–778.

Goede, A. A.: 1993, 'Selenium in Eggs and Parental Blood of a Dutch Marine Wader', *Archives of Environmental Contamination and Toxicology* **25**, 79–84.

Goettl, J. P., Jr. and Davies, P. H.: 1978, 'Water Pollution Studies', *Job Progress Report – Federal Aid Project F-33-R-13.* Colorado Division of Wildlife, Fort Collins, CO.

Grant, A. B.: 1981, 'Observations on Analysis of Selenium in Plant and Animal Tissues and in Soil Samples', New *Zealand Journal of Science* **24**, 65–79.

Guthrie, R. K. and Cherry, D. S.: 1979, 'Trophic Level Accumulation of Heavy Metals in a Coal Ash Basin Drainage System', *Water Resources Bulletin* **15**, 244–248.

Hallock, R. J. and Hallock, L. L.: 1993, 'Detailed Study of Irrigation Drainage in and Near Wildlife Management Areas, West-Central Nevada, 1987–90. Part B. Effect on biota in Stillwater and Fernley Wildlife Management Areas and Other Nearby Wetlands. *Water-Resources Investigations Report 92–4024B.* U.S. Geological Survey, Carson City, NV.

Hamilton, S. J., Palmisano, A. N., Wedemeyer, G. A. and Yasutake, W. T.: 1986, 'Impacts of Selenium on Early Life Stages and Smoltification of Fall Chinook Salmon', *Transactions of the North American Wildlife and Natural Resources Conference* **51**, *343-356.*

Hamilton, S. J., Buhl, K. J., Faerber, N. L., Wiedmeyer, R. H. and Bullard, F. A.: 1990, 'Toxicity of Organic Selenium in the Diet of Chimook Salmon', *Environmental Toxicology and Chemistry* **19**, 347–358.

Hamilton, S. J. and Waddell, B.: 1994, 'Selenium in Eggs and Milt of Razorback Sucker *(Xyrauchen texanus*) in the Middle Green River, Utah', *Archives of Environmental Contamination and Toxicology 27,* 195-201.

Heinz, G. H.: 1993, 'Re-Exposure of Mallards to Selenium after Chronic Exposure', *Environmental Toxicology and Chemistry 12, 1691-1694.*

Heinz, G. H. and Fitzgerald, M. A.: 1993a, 'Overwinter Survival of Mallards Fed Selenium', *Archives of Environmental Contamination and Toxicology* **25**, 90–94.

Heinz, G. H. and Fitzgerald, M. A.: 1993b, 'Reproductionof Mallards Following Overwinter Exposure to Selenium', *Environmental Pollution 81,* 117–122.

Heinz, G. H., Hoffman, D. J. and Weller, D. M. G.: 1987, 'Reproduction in Mallards Fed Selenium', *Environmental Toxicology and Chemistry* **6**, 423–433.

Heinz, G. H., Hoffman, D. J. and Gold, L. G.: 1988, 'Toxicity of Organic and Inorganic Selenium to Mallard Ducklings', *Archives of Environmental Contamination and Toxicology 17, 561-568.*

Heinz, G. H., Hoffman, D. J. and Gold, L. G.: 1989, 'Impaired Reproduction of Mallards Fed an Organic Form of Selenium', *Journal of Wildlife Management* **53**, 418–428.

Heinz, G. H., Pendleton, G. W., Krynitshy, A. J. and Gold, L. G.: 1990, 'Selenium Accumulation and Elimination in Mallards', *Archives of Environmental Contamination and Toxicology* **19**, 374–379.

Hermanutz, R. 0.: 1992, 'Malformation of the Fathead Minnow (Pimephales promelas) in an Ecosystem with Elevated Selenium Concentrations', *Bulletin of Environmental Contamination and Toxicology* **49**, 290–294.

Hermanutz, R. O., Allen, K. N., Roush, T. H. and Hedtke, S. F.: 1992, 'Effects of Elevated Selenium Concentrations on Bluegills (*Lepomis macrochirus)* in Outdoor Experimental Streams', *Environmental Toxicology and Chemistry* **11**, 217–224.

Hicks, B. D., Hilton, J. W. and Ferguson, H. W.: 1984, 'Influence of Dietary Selenium on the Occurrence of Nephrocalcinosis in the Rainbow Trout, *Salmo gairdneri* Richardson', *Journal of Fish Diseases* **7**, 379–389.

Hilton, J. W. and Hodson, P. V.: 1983, 'Effect of Increased Dietary Carbohydrate on Selenium Metabolism and Toxicity in Rainbow Trout *(Sulmo gairdneri)*', *Journal of Nutrition 113, 1241-1248.*

Hilton, J. W., Hodson, P. V. and Slinger, S. J.: 1980, 'The Requirement and Toxicity of Selenium in Rainbow Trout *(Salmo gairdneri)*', *Journal of Nutrition* **110**, 2527–2535.

Hodson, P. V. and Hilton, J. W.: 1983, 'The Nutritional Requirements and Toxicity to Fish of Dietary and Waterborne Selenium', *Ecological Bulletin 35*, 335–340.

Hoffman, D. J. and Heinz, G. H.: 1988, 'Embryotoxic and Teratogenic Effects of Selenium in the Diet of Mallards', *Journal of Toxicology and Environmental Health* **24**, 477–490.

Hoffman, D. J., Ohlendorf, H. M. and Aldrich, T. W.: 1988, 'Selenium Teratogenesis in Natural Populations of Aquatic Birds in Central California', *Archives of Environmental Contamination and Toxicology 17, 5 19-525.*

Hoffman, D. J., Sanderson, C. J., Lecaptain, L. J., Cromartie, E. and Pendleton, G. W.: 1991, 'Interactive Effects of Boron, Selenium, and Dietary Protein on Survival, Growth, and Physiology in Mallard Ducklings', *Archives of Environmental Contamination and Toxicology* **20**, 288–294.

Holland, E. A.: 1979, 'Arsenic and Selenium in the Water, Sediments, and Biota near a Coal-Fired Power Plant – Belews Lake, North Carolina'. *Master's Thesis,* University of North Carolina, Chapel Hill, NC.

Horne, A. J.: 1991, 'Selenium Detoxification in Wetlands by Permanent Flooding: I. Effects on a Macroalga, an Epiphytic Herbivore, and an Invertebrate Predator in the Long-Term Mesocosm Experiment at Kesterson Reservoir, California', *Water, Air, and Soil Pollution* **57–58**, 43–52.

Hothem, R. L. and Ohlendorf, H. M.: 1989, 'Contaminants in Foods of Aquatic Birds at Kesterson Reservoir, California, 1985', *Archives of Environmental Contamination and Toxicology* **18**, 773–786.

Ingersoll, C. G., Dwyer, F. J. and May, T. W.: 1990, 'Toxicity of Inorganic and Organic Selenium to *Daphnia magna* (Cladocera) and *Chironomus riparius* (Diptera)', *Environmental Toxicology and Chemistry9,* 1171-1181.

Jarzabek, G. and Kublik, Z.: 1982, 'Determination of Traces of Selenium (IV) by Cathodic Stripping Voltammetry at the Hanging Mercury Drop Electrode', *Analytica Chimica Acta 143, 121-I 30.*

Kiffney, P. and Knight, A.: 1990, 'The toxicity and Bioaccumulation of Selenate, Selenite and Seleno-L-Methionine in the Cyanobacterium *Anabaena flos-aquae*', *Archives of Environmental Contamination and Toxicology* **19**, 488–494.

King, K. A., Custer, T. W. and Weaver, D. A.: 1994, 'Reproductive Success of Barn Swallows Nesting Near a Selenium-Contaminated Lake in East Texas, USA', *Environmental Pollution 84, 53-58.*

Kleinow, K. M. and Brooks, A. S.: 1986, 'Selenium Compounds in the Fathead minnow. 1. Uptake, Distribution, and Elimination of Orally Administered Selenate, Selenite, and L-Selenomethionine', *Comparative Biochemistry and Physiology* **83C**, *6169.*

Krynitsky, A. J.: 1987, 'Preparation of Biological Tissues for Determination of Arsenic and Selenium by Graphite Furnace Atomic Absorption Spectrometry', *Analytical Chemistry 59, 1884-1886.*

Lemly, A. D.: 1982, 'Response of Juvenile Centrarchids to Sublethal Concentrations of Waterborne Selenium. I. Uptake, Tissue Distribution, and Retention', *Aquatic Toxicology 2, 235-252.*

Lemly, A. D.: 1985a, 'Toxicology of Selenium in a Freshwater Reservoir: Implications for Environmental Hazard Evaluation and Safety', *Ecotoxicology and Environmental Safety* **10**, 314-338.

Lcmly, A. D.: 1985b, 'Ecological Basis for Regulating Aquatic Emissions from the Power Industry: The Case with Selenium', *Regulatory Toxicology and Pharmacology* **5**, 465–486.

Lemly, A. D. and Smith, G. J.: 1987, 'Aquatic Cycling of Selenium: Implications for Fish and Wildlife', *Fish and Wildlife Leaflet 12.* U.S. Fish and Wildlife Service, Washington, DC.

Lemly, A. D.: 1993a, 'Teratogenic Effects of Selenium in Natural Populations of Freshwater Fish', *Ecotoxicology and Environmental Safety 26,* 181–204.

Lemly, A. D.: 1993b, 'Subsurface Agricultural Irrigation Drainage: The Need for Regulation', *Regulatory Toxicology and Pharmacology 17, 157-180.*

Lemly, A. D.: 1993c, 'Guidelines for Evaluating Selenium data from Aquatic Monitoring and Assessment Studies', *Environmental Monitoring and Assessment 28, 83-100.*

Lemly, A. D.: 1993d, 'Metabolic Stress During Winter Increases the Toxicity of Selenium to Fish', *Aquatic Toxicology 27,* 133-158.

Lemly, A. D.: 1994, 'Irrigated Agriculture and Freshwater Wetlands: A Struggle for Coexistence in the Western United States', *Wetlands Ecology and Management 3, 3-15.*

Lemly, A. D.: 1995, 'Hazard of Selenium to Fish and Migratory Birds at Ouray National Wildlife Refuge, Utah'. *Technical Report.* Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Maier, K. J. and Knight, A. W.: 1993, 'Comparative Toxicity and Bioconcentration of Selenium by the Midge *Chironomus decorus* Exposed to Selenate, Selenite, and Seleno-DL-mMthionine', *Archives of Environmental Contamination and Toxicology 25,* 365–370.

Martin, D. B. and Hartman, W. A.: 1984, 'Arsenic, Cadmium, Lead, Mercury, and Selenium in Sediments of Riverine and Pothole Wetlands of the North Central United States', *Journal of the Association of Official Analytical Chemists 67,* 1141-l 146.

May, T. W.: 1982, 'Recovery of Endogenous Selenium from Fish Tissues by Open System Dry Ashing', *Journal of the Association of Official Analytical Chemists 65,* 1140-l 145.

McKown, D. M. and Morris, J. S.: 1978, 'Rapid Measurement of Selenium in Biological Samples using Instrumental Neutron Activation Analysis', *Journal of Radioanalytical Chemistry* **43**, 411–420.

Nassos, P. A., Coats, J. R., Metcalf, R. L., Brown, D. D. and Hansen, L. G.: 1980, 'Model Ecosystem, Toxicity, and Uptake Evaluation of ^{75}Se-Selenite', *Bulletin of Environmental Contamination and Toxicology 24, 752-758.*

NCDEM (North Carolina Division of Environmental Management): 1986, 'North Carolina Water Quality Standards Documentation: The Freshwater Chemistry and Toxicity of Selenium With an Emphasis on its Effects in North Carolina'. *Report No. 86–02.* North Carolina Department of of natural Resources and Community Development, Raleigh, NC.

Nriagu, J. 0. and Wong, H. K.: 1983, 'Selenium Pollution of Lakes Near the Smelters at Sudbury, Ontario', *Nature 301, 55-57.*

Ogle, R. S., Maier, K. J., Kiffney, P., Williams, M. J., Brasher, A., Melton, L. A. and Knight, A. W.: 1988, 'Bioaccumulation of Selenium in Aquatic Ecosystems', *Lake and Reservoir Management 4, 165-173.*

Ogle, R. S. and Knight, A. W.: 1989, 'Effects of Elevated Foodborne Selenium on Growth and Reproduction of the Fathead Minnow (*Pimephales promelas)*', Archives of *Environmental Contamination and Toxicology* **18**, 795–803.

Ohlendorf, H. M.: 1989, 'Bioaccumulation and Effects of Selenium in Wildlife', in: *Selenium in Agriculture and The Environment,* pp 133-l 77. *Special Publication No. 23.* Soil Science Society of America, Madison, WI.

Ohlendorf, H. M., Hoffman, D. J., Saiki, M. K. and Aldrich, T. W.: 1986a, 'Embryonic Mortality and Abnormalities of Aquatic Birds: Apparent Impacts of Selenium from Irrigation Drainwater', *Science of the Total Environment* **52**, 49–63.

Ohlendorf, H. M., Hothem, R. L., Bunck, C. M., Aldrich, T. W. and Moore, J. F.: 1986b, 'Relationships Between Selenium Concentrations and Avian Reproduction', *Transactions of the north American Wildlife and Natural Resources Conference* **51**, 330–342.

Ohlendorf, H. M., Hothem, R. L., Aldrich, T. W. and Krynitsky, A. J.: 1987, 'Selenium Contamination of the Grasslands, a Major California Waterfowl Area', *The Science of the Total Environment 66, 169-183.*

Ohlendorf, H. M., Kilness, A. W., Simmons, J. L., Stroud, R. K., Hoffman, D. J. and Moore, J. F.: 1988, 'Selenium Toxicosis in Wild Aquatic Birds', *Journal of Toxicology and Environmental Health* **24**, 67–92.

Ohlendorf, H. M., Hothem, R. L. and Welsh, D.: 1989, 'Nest Success, Cause-Specific Nest Failure, and Hatchability of Aquatic Birds at Selenium-Contaminated Kesterson Reservoir and a Reference Site',. *The Condor 91, 787-796.*

Ohlendorf, H. M., Hothem, R. L., Bunck, C. M. and Marios, K. C.: 1990, 'Bioaccumulation of Selenium in Birds at Kesterson Reservoir, California', *Archives of Environmental Contamination and Toxicology* **19**, 495–507.

Olson, M. M. and Welsh, D.: 1993, 'Selenium in Eared Grebe Embryos from Stewart Lake National Wildlife Refuge, North Dakota', *Prairie Naturalist 25,* 119-126

Ornes, W. H., Sajwan, K. S., Dosskey, M. G. and Adriano, D. C.: 1991, 'Bioaccumulationof Selenium by Floating Aquatic Plants', *Water; Air, and Soil Pollution 5758, 53-57.*

Peltz, L. A. and Waddell, B.: 1991, 'Physical, Chemical, and Biological Data for Detailed Study of Irrigation Drainage in the Middle Green River Basin, Utah, 1988-89, with selected data for 1982-87'. *Open-File Report 91–530,* U.S. Geological Survey, Salt Lake City, UT.

Peterson, J. A. and Nebeker, A. V.: 1992, 'Estimation of Waterborne Selenium Concentrations that are Toxicity Thresholds for Wildlife', *Archives of Environmental Contamination and Toxicology 23,* 154–162.

Porcella, D. B., Bowie, G. L., Sanders, J. G. and Cutter, G. A.: 1991, 'Assessing Se Cycling and Toxicity in Aquatic Ecosystems', *Water; Air; and Soil Pollution 57-58, 3-l 1.*

Presser, T. S.: 1994, 'The Kesterson Effect', *Environmental Management* **18**, 437–454.

Presser, T. S. and Ohlendorf, H. M.: 1987, 'Biogeochemical Cycling of Selenium in the San Joaquin Valley, California', *Environmental Management* 11, 805-821.

Presser, T. S., Sylvester, M. A., and Low, W. H.: 1994, 'Bioaccumulation of Selenium from Natural Geologic Sources in the Western States and its Potential Consequences', *Environmental Management* **18**, 423–436.

Pyron, M. and Beitinger, T. L.: 1989, 'Effect of Selenium on Reproductive Behavior and Fry of Fathead minnows', *Bulletin of Environmental Contamination and Toxicology* **42**, 609–613.

Riedel, G. F., Ferrier, D. P. and Sanders, J. G.: 1991, 'Uptake of Selenium by Freshwater Phytoplankton', *Water, Air, and Soil Pollution 57-58,* 23–30.

Rudd, J. W. M. and Turner, M. A.: 1983, 'The English-Wabigoon River System. V. Mercury and Selenium Bioaccumulation as a Function of Aquatic and Primary Productivity', *Canadian Journal of Fisheries and Aquatic Sciences 40, 225 l-2259.*

Sager, D. R. and Cofield, C. R.: 1984, 'Differential Accumulation of Selenium Among Axial Muscle, Reproductive and Liver Tissues of Four Warmwater Fish Species', *Water Resources Bulletin 20, 359-363.*

Saiki, M. K.: 1986, 'A Field Example of Selenium Contamination in an Aquatic Food Chain'. In Selenium in the Environment – Proceedings of the First Annual Environmental Symposium, pp. 67-76. *Publication No. CAT1/860201.* California State University, Fresno, CA.

Saiki, M. K. and Lowe, T. P.: 1987, 'Selenium in Aquatic Organisms from Subsurface Agricultural Drainage Water, San Joaquin Valley, California', *Archives of Environmental Contamination and Toxicology* 16, 657-670.

Saiki, M. K., Jennings, M. R. and Brumbaugh, W. G.: 1993, 'Boron, Molybdenum, and Selenium in Aquatic Food Chains from the Lower San Joaquin River and its Tributaries, California', *Archives of Environmental Contamination and Toxicology* **24**, 307–3 19.

Sanders, R. W. and Gilmour, C. C.: 1994, 'Accumulation of Selenium in a Model Freshwater Microbial Food Web', *Applied and Environmental Microbiology* **60**, 2677–2683.

Schuler, C. A., Anthony, R. G. and Ohlendorf, H. M.: 1990, 'Selenium in Wetlands and Waterfowl Foods at Kesterson Reservoir, California, 1984', *Archives of Environmental Contamination and* Toxicology 19, 845-853.

Schultz, R. and Hermanutz, R.: 1990, 'Transfer of Toxic Concentrations of Selenium from Parent to Progeny in the Fathead Minnow *(Pimephales promelas)', Bulletin of Environmental Contamination and Toxicology 45, 568-573.*

Seiler, R. L. and Skorupa, J. P.: 1995, 'Identification of Areas at Risk for Selenium Contamination in the Western United States'. In *Water Resources at Risk,* pp. LL-85-LL94. American Institute of Hydrology, Denver, CO.

Skorupa, J. P. and Ohlendorf, H. M.: 1991, 'Contaminants in Drainage Water and Avian Risk Thresholds'. In *The Economics and management of Water and Drainage in Agriculture* (A. Dinar and D. Zilberman (eds.), pp. *345-368.* Kluwer Academic Publishers, Boston, MA.

Skorupa, J. P., Ohlendorf, H. M., and Hothem, R. L.: in press, 'Interpretive guidelines for selenium-exposed waterbirds', *Journal of Wildlife Management.*

Smith, G. J., Heinz, G. H., Hoffman, D. J., Spann, J. W. and Krynitsky, A. J.: 1988, 'Reproduction in Black-Crowned Night-Herons Fed Selenium', *Lake and Reservoir Management 4,* 175–180.

Sorensen, E. M. B.: 1988, 'Selenium Accumulation, Reproductive Status, and Histopathological Changes in Environmentally Exposed Redear Sunfish', *Archives* **of** ***Toxicology*** *61, 324-329.*

Sorensen, E. M. B., Harlan, C. W. and Bell, J. S.: 1982a, 'Renal Changes in Selenium-Exposed Fish', *The American Journal of Forensic Medicine and Pathology 3, 123-l 29.*

Sorensen, E. M. B., Bauer, T. L., Bell, J. S. and Harlan, C. W.: 1982b, 'Selenium Accumulation and Cytotoxicity in Teleosts Following Chronic, Environmental Exposure', *Bulletin of Environmental Contamination and Toxicology* **29**, 688–696.

Sorensen, E. M. B. and Bauer, T. L.: 1983, 'Hematological Dyscrasia in Teleosts Chronically Exposed to Selenium-Laden Effluent', *Archives of Environmental Contamination and Toxicology 12,* 135–141.

Sorensen, E. M. B., Bell, J. S. and Harlan, C. W.: 1983a, 'Histopathological Changes in Selenium-Exposed Fish', *The American Journal of Forensic Medicine and Pathology 4,* 111–123.

Sorensen, E. M. B., Bauer, T. L., Harlan, C. W., Pradzynski, A. H. and Bell, J. S.: 1983b, 'Hepatocyte Changes Following Selenium Accumulation in a Freshwater Teleost', *The American Journal of Forensic Medicine and Pathology 4, 25-32.*

Sorensen, E. M. B. and Bauer, T. L.: 1984a, 'Planimetric Analysis of Redear Sunfish (*Lepomis microlophus)* Hepatopancreas Following Selenium Exposure', *Environmental Toxicology and Chemistry 3, 159-165.*

Sorensen, E. M. B. and Bauer, T. L.: 1984b, 'A Correlation Between Selenium Accumulation in Sunfish and Changes in Condition Factor and Organ Weight', *Environmental Pollution 34, 357-366.*

Sorensen, E. M. B., Cumbie, P. M., Bauer, T. L., Bell, J. S. and Harlan, C. W.: 1984, 'Histopathological, Hematological, Condition-Factor, and Organ Weight Changes Associated with Selenium Accumulation in Fish from Belews Lake, North Carolina', *Archives of Environmental Contamination and Toxicology 13, 153-l 62.*

Speyer, M. R.: 1980, 'Mercury and Selenium Concentrations in Fish, Sediments, and Water of Two Northwestern Quebec Lakes', *Bulletin of Environmental Contamination and Toxicology 24, 427-432.*

Stanley, T. R., Jr., Spann, J. W., Smith, Cl. J. and Rosscoe, R.: 1994, 'Main and Interactive Effects of Arsenic and Selenium on Mallard Reproduction and Duckling Growth and Survival', *Archives of Environmental Contamination and Toxicology* **26**, 444–45 1.

Stephens, D. W., Waddell, B. and Miller, J. B.: 1988, 'Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Middle Green River Basin, Utah, 1986-87'. *Water-Resources Investigations Report 88–4011,* U.S. Geological Survey, Salt Lake City, UT.

Stephens, D. W., Waddell, B., Peltz, L. A. and Miller, J. B.: 1992, 'Detailed Study of Selenium and Selected Elements in Water, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Middle Green River Basin, Utah, 1988-90'. *Water-Resources Investigations Report 92–4084*, U.S. Geological Survey, Salt Lake City, UT.

Sylvester, M. A., Deason, J. P., Felts, H. R. and Engberg, R. A.: 1991, 'Preliminary Results of the Department of the Interior's Irrigation Drainage Studies', in: Proceedings of the 1990 Billings Land Reclamation Symposium on Selenium in Arid and Seimarid Environments, Western United States, (R. C. Severson, S. E. Fisher, Jr., and L. P Gough (eds.), pp. 115-122. *Circular 1064.* U.S. Geological Survey, Denver, CO.

TUGCO (Texas Utilities Generating Company): 1986, 'Martin Creek Reservoir Selenium Monitoring Program'. *Technical Report,* Texas Utilities Generating Company, Dallas, TX.

Thompson, G. A. and Watling, R. J.: 1987, 'Bioaccumulation Potential of Heterotrophic Bacteria for Lead, Selenium, and Arsenic', *Bulletin of Environmental Contamination and Toxicology 38,* 1049–1054.

Traversy, W. J., Goulden, P. D., Sheikh, Y. M. and Leacock, J. R.: 1975, 'Levels of Arsenic and Selenium in the Greatl Lakes Rregion', *Scientific Series No. 58.* Environment Canada, Burlington, ON.

Turner, M. A. and Rudd, J. W. M.: 1983, 'The English-Wabigoon River System. III. Selenium in Lake Enclosures: Its Geochemistry, Bioaccumulation, and Ability to Reduce Mercury Bioaccumulation', *Canadian Journal of Fisheries and Aquatic Sciences 40,* 2228–2240.

USEPA (United States Environmental Protection Agency): 1987, 'Ambient Water Quality Criteria For Selenium – 1987'. *Technical Report No. EPA-440/5–87–006,* Office of Water Regulations and Standards, USEPA, Washington, DC.

USFWS (United States Fish and Wildlife Service): 1990a, *Agricultural Irrigation Drainwater Studies in Support of the San Joaquin Valley Drainage Program – Final Report.* USFWS, National Fisheries Contaminant Research Center, Columbia, MO.

USFWS (United States Fish and Wildlife Service): 1990b, *Effects of Irrigation Drainwater Contaminants on Wildlife.* USFWS, Patuxent Wildlife Research Center, Laurel MD.

Waddell, B. H. and Stanger, M. C.: 1992, 'The Influence of Selenium on Incubation Patterns and Nesting Success of Waterbirds at Ouray National Wildlife Refuge, Utah'. *Contaminant Report R6/400S/92,* U.S. Fish and Wildlife Service, Salt Lake City, UT.

Welsh, D. and Maughan, 0. E.: 1994, 'Concentrations of Selenium in Biota, Sediments, and Water at Cibola National Wildlife Refuge', *Archives of Environmental Contamination and Toxicology* **26**, 452–458.

White, D. H., King, K. A., Mitchell, C. A. and Mulhern, B. M.: 1986, 'Trace Elements in Sediments, Water, and American Coots (Fulica americana) at a Coal-Fired Power Plant in Texas, 1979-1982, *Bulletin of Environmental Contamination and Toxicology 36, 376-383.*

White, J. R., Hoffman, P. S., Hammond, D. and Baumgartner, S.: 1987, 'Selenium Verification Study – 1986'. *Technical Report,* California Department of Fish and Game, Sacramento, CA.

Wiener, J. G., Jackson, G. A., May, T. W. and Cole, B. P.: 1984, 'Longitudinal Distribution of Trace Elements (As, Cd, Cr, Hg, Pb, and Se) in Fishes and Sediments in the Upper Mississippi River', in: *Contaminants in the Upper Mississippi River* (J. G. Wiener, R. V. Anderson, and D. R. McConville (eds.), pp. 139–170. Butterworth Publishers, Stoneham, MA.

Williams, M. L., Hothem, R. L. and Ohlendorf, H. M.: 1989, 'Recruitment Failure in American Avocets and Black-Necked Stilts Nesting at Kesterson Reservoir', California, 1984–1985. *The Condor* **91**, 797–802.

Winger, P. V. and Andreason, J. K.: 1985, 'Contaminant Residues in Fish and Sediments from Lakes in the Atchafalaya River Basin (Louisiana)', *Archives of Environmental Contamination and Toxicology* **14**, 579–586.

Woock, S. E.: 1984, 'Accumulation of Selenium by Golden Shiners *Notemigonus crysoleucas*: Hyco Reservoir N.C. cage study, 1981-1982'. *Technical Report,* Carolina Power and Light Company, New Hill, NC.

Woock, S. E. and Summers, P. B.: 1984, 'Selenium Monitoring in Hyco Reservoir (NC) Waters (1977-1981) and Biota (1977–1980)', in: Workshop Proceedings: The Effects of Trace Elements on Aquatic Ecosystems. *Publication EA-3329.* Electric Power Research Institute, Palo Alto, CA. pp. 6-l to 6-27.

Woock, S. E., Bryson, W. T., MacPherson, K. A., Mallin, M. A. and Partin, W. E.: 1985, 'Roxboro Steam Electric Plant – Hyco Reservoir 1984 Bioassay Study'. *Technical Report,* Carolina Power and Light Company, New Hill, NC.

Woock, S. E., Garrett, W. R., Partin, W. E. and Bryson, W. T.: 1987, 'Decreased Survival and Teratogenesis During Laboratory Selenium Exposures to Bluegill, *Lepomis macrochirus*', *Bulletin of Environmental Contamination and* Toxicology **39**, 998–1005.