# Supporting Material
# A Methodology for Ecosystem-Scale Modeling of Selenium

(Ecosystem-Scale Modeling of Selenium)

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# ECOSYSTEM-SCALE SELENIUM MODELING: DATA AND REFERENCES

## Compilation and Calculation of Kds and TTFs

Ratios derived here employ dry weight (dw) for media (particulate material and tissue). Datasets are temporally and spatially matched from 52 field studies that included water-column Se concentrations and particulate Se concentrations (Supplemental Table A). The $K_d$s typical of a variety of ecosystems (e.g., ponds, rivers, estuaries) are given. If a range was reported, a median is listed; if a series of data was reported, a mean is listed.

A compilation of experimental data for invertebrate physiological parameters allowed calculation of kinetic TTFs for invertebrates (particulate to invertebrate) (Supplemental Table B). Additional calculated TTFs from denoted field studies are shown in Supplemental Table C. A compilation of experimental data for fish physiological parameters allowed calculation of kinetic TTFs for fish (invertebrate to fish) (Supplemental Table D). Additional calculated TTFs from denoted field studies (invertebrate to fish except where noted as fish to fish) are shown in Supplemental Table D.

## Detailed Data Sets for Field Case Studies Used in Validation

Datasets (in dw) are temporally and spatially matched from 29 field locations (Supplement Tables E and F). Food webs focus on particulate material, invertebrates, and fish (Supplemental Table E) or birds (Supplement Table F). Predicted and observed Se concentrations for invertebrates, fish (whole-body or muscle), and bird eggs are shown. Data collection at most field case studies included all these media phases. Case studies that were not complete still yielded useful information in either validation of prey or predator Se concentrations. Sites illustrated are those exposed to selenium contamination. However, in three study area investigations (Kesterson Reservoir, McLeod River/Luscar Creek watershed, and the San Joaquin River), sites identified as reference sites are included.

Modeled invertebrate and fish species are identified under food webs (Supplemental Tables E and F). Bioaccumulation data for invertebrates (in dw) from field studies for comparison with biodynamic predictions were available for crustaceans (amphipods, copepods, generic zooplankton, *Daphnia*, crayfish); aquatic insects (mayfly, caddisfly, cranefly, stonefly, damselfly, corixid, chironomid); and freshwater and marine clams (*C. fluminea; C. amurensis,* respectively). Bioaccumulation data for fish (in dw) were available for freshwater minnow, sunfish, trout, sucker, catfish, sculpin, perch, silversides; shad; killifish, livebearers (sailfin molly and mosquitofish) and saltwater sturgeon, sargo, talapia, croaker, corvina, topsmelt, halibut, goby, turbot, perch, mullet, and anchovy. Bioaccumulation data for birds were included for coot, stilt, avocet, killdeer, gadwall, teal, mallard, grebe, dipper, sandpiper, scoter, scaup, gull, skimmer, rail, tern, egret, and heron (See main text Tables 3 and 4 and Supplemental Tables B, C, and D for more detailed information on species).

Prediction starts with an observed particulate Se concentration and uses a species-specific $TTF_{invertebrate}$ (see main text Tables 3 and 4 for details) to predict an invertebrate Se concentration (Supplemental Tables E and F). The type of particulate material that was collected varied among different case studies. Where data were available from multiple types of particulates, concentrations were averaged. In a few cases professional judgment was employed to eliminate unrepresentative particulate data (e.g. to avoid what were obviously sandy sediments or an obvious error in data reduction). Invertebrate Se concentrations are predicted using a subset of

$TTF_{invertebrate}$ shown in main text Table 3: amphipod, 0.9; zooplankton, 1.5; crayfish, 1.6; aquatic insects, 2.8; brine shrimp, 4.2; brine fly, 1.65; freshwater clam, 2.8; and marine clam 6.25. Where applicable to a specific species (i.e. for piscivores), an additional factor of 1.1 is applied to an invertebrate Se concentration to represent an interim transfer step of invertebrate to fish for a fish-eating bird or forage fish to predator fish. For the San Francisco Bay-Delta Estuary, an additional factor of 1.35 is applied to represent a food web from particulate material to copepod to mysid to striped bass. In a few cases, data for Se concentrations in diet were used to validate both fish and bird food webs, if, for example, a complete temporally matched data set was not available (e.g., Blackfoot River watershed, southeast Idaho).

Fish Se concentrations are predicted using a $TTF_{fish}$ of 1.1 (see main text Table 3) applied to the predicted invertebrate Se concentrations (Supplemental Table E). If data are available for more than one invertebrate food web, multiple fish concentrations are predicted. Ranges of fish Se concentrations and means of invertebrate and fish species for a site location are given for comparison. As noted in Supplemental Table E, individual identified species-specific food web Se concentrations or grand means of observed invertebrate and fish Se concentrations were used to derive correlations of observed to predicted Se concentrations (see main text Figures 3 and 4).

Bird egg Se concentrations are predicted using a 1.8 $TTF_{bird}$ applied to the predicted invertebrate Se concentration (Supplemental Table E). In complex food webs that consider birds consuming fish, an additional step applying a $TTF_{fish}$ of 1.1 is used.

Sites are noted in Supplemental Tables E and F (e.g., Belews Lake, Kesterson Reservoir) where Se exposure caused die-offs and deformities in fish or high rates of embryonic terata in birds (Skorupa, 1998; Ohlendorf, 2002). Conditions at these sites showed extensive ecosystem exposure and, at sites affecting birds, effects of general Se toxicity or poisoning (e.g,, emaciation, no nesting, dead adult birds). In modeling, these sites show predicted Se concentrations in tissue of predators above observed Se concentrations. Food avoidance by birds is a documented phenomenon in the laboratory (Heinz and Sanderson, 1990) and at contaminated sites such as Kesterson Reservoir (Ohlendorf, 1996; Ohlendorf et al., 1988). Heinz and Sanderson (1990) state that at 10 to 20 µg/g, Se-treated diets were avoided by mallards. Heinz and Fitzgerald (1993) state that high dietary concentrations of Se make birds sick, leading to reduced feeding, and ultimately to severe emaciation and death. Food avoidance by fish in laboratory experiments takes place in about the same range (13-14 µg/g) (Hodson et al., 1980; Finley, 1985).

## WILDLIFE SELENIUM CRITERIA: EXAMPLE CALCULATION

A reference dose (RfD) for Se can be derived from experimental feeding studies for adult mallards in which effects from maternally ingested Se were measured (Heinz, 1989; Sample et al. (1996)). The measured reproductive endpoint is avian egg hatchability. The example equation

$$RfD = (4\ \mu g/g\ \text{ww food as selenomethionine})\ (0.1\ \text{kg food/day}) \div 1\ \text{kg BW ww} \quad (1)$$

uses a No Observable Effect Level (NOEL) of 4 µg/g (laboratory chow at 10% moisture enriched with selenomethionine), an ingestion rate of 100 g/day, and a Body Weight (BW) of 1 kg. This ingestion rate is 10% of BW because a 1-kg mallard was tested. The derived RfD is 0.400 mg/kg-day or 400 µg/kg-day. The USEPA derived an avian tissue residue value (TRV) for Se by combining three endpoints (growth, reproduction, and mortality) for two test species ingesting invertebrates and sediment from terrestrial food webs (USEPA, 2007). The derived avian wildlife TRV for Se is 290 µg/kg-d [highest NOEL lower than lowest bounded Lowest

Observable Effect Level (LOEL) for reproduction, growth or survival], with a geometric mean of NOEL values of 606 µg/kg-day.

If a Se RfD of 400 µg/kg-day is assumed for modeling of effects to birds, then allowable $C_{food}$ for various species of birds can be calculated. Note that uncertainty factors could be applied to adjust the selected RfD downward for a margin of safety as is recommended in 1) a Canadian protocol for wildlife protection [Canadian Council of Ministers of the Environment (CCME), 1999]; and 2) the derivation of fish consumption advisories for humans (USEPA, 2000a). In an example deriving a wildlife criterion for lesser scaup, a bird of similar body weight to mallard of 1 kilogram, the ingestion rate is increased to 0.2 kg (20% of BW) and 0.3 kg (30% of BW) food/d based on increased feeding rates for wild birds. If 10% moisture is assumed in ingested food (similar to laboratory chow), then the calculated allowable $C_{food}$ is 2.0 µg/g ww and 2.2 µg/g dw at the lower feeding rate and 1.3 µg/g ww and 1.5 µg/g dw at the higher feeding rate. If the hypothetical ingested food is fish with a 75% moist content, then the allowable $C_{food}$ is 2.0 µg/g ww and 8.0 µg/g dw at the lower feeding rate and 1.3 µg/g ww and 5.3 µg/g dw at the higher feeding rate. In an example derivation for a smaller bird species, if a belted kingfisher weighs 0.148 kg, ingests 50 g fish/d (34% of BW) with a moisture content of 75%, then the allowable $C_{food}$ is

$$(400\ \mu g\ Se/kg\ BW\text{-}day)\ (0.148\ kg) \div 12.5\ g\ dw\ food/day = 4.74\ \mu g/g\ dw \qquad (2)$$

Thus, to successfully calculate allowable $C_{food}$, both the % BW ingested and the % moisture in food need to be specified. For watershed evaluation, the allowable $C_{food}$ is used as a dietary target and compared to 1) existing Se concentrations in dietary items of biologically appropriate food webs; or 2) predicted concentrations as a result of food web modeling. Equations can be added to consider mixtures of food (see main text Table 6).

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Supplemental Table A. Water-column Se concentrations, particulate Se concentrations (dw), and calculated $K_d$s from field studies. If a range was reported, a median is listed; if a series of data was reported, a mean is listed. [a) see example in text; b) means of Kds, water-column Se, and algae Se]

| $K_d$ | Ecosystem | Water-column Se (µg/L) | Particulate Se (µg/g dw) | Reference |
|---|---|---|---|---|
| 107 | San Diego Creek, California | 14.4 | 1.54 | Presser and Luoma, 2009 |
| 110 | Alamo River, California | 6.35 | 0.7 | LeBlanc and Schroeder, 2008 |
| 122 | Fording River, British Columbia, Canada | 18 | 2.2 | Harding et al., 2005 |
| 146 | San Joaquin River, California | 11 | 1.6 | Saiki et al., 1993 |
| 255 | San Diego Creek constructed pond, California | 20.4 | 5.2 | Presser and Luoma, 2009 |
| 256 | New River, California | 3.9 | 1.0 | LeBlanc and Schroeder, 2008 |
| 269 | Tulare Basin, evaporation ponds, California (range 109-500) | 2.2-49 | 0.45-19.4 | Moore et al., 1990 |
| 272 | Upper Newport Bay, California (range 101-776) | 0.29-3.5 | 0.17-0.39 | Presser and Luoma, 2009 |
| 276 | Mud Slough, California | 13 | 3.6 | Saiki et al. 1993 |
| 340 | Benton Lake (pool 2), Montana | 10.4 | 3.5 | Zhang and Moore, 1996 |
| 346 | Luscar Creek, Alberta Canada (range 220-514)[a] | 10.7 | 3.7 | Casey, 2005 |
| 355 | Kesterson Reservoir (SLD/pond 2), California (range 200-500) | 330 | 55-165 | Presser and Piper, 1998 |
| 359 | Salt Slough, California | 9.0 | 3.2 | Saiki et al. 1993 |
| 494 | Sage Creek, Idaho | 7.7 | 3.8 | Greater Yellowstone Coalition, 2005; 2006 |
| 500 | Benton Lake, Montana, pool 5 | 0.74 | 0.35 | Zhang and Moore, 1996 |
| 512 | Benton Lake, Montana, pool 1 channel | 20.3 | 10.4 | Zhang and Moore, 1996 |
| 591 | Elk River, British Columbia, Canada | 2.2 | 1.3 | McDonald and Stosher, 1998 |
| 611 | Lower Great Lakes, Lake Ontario | 0.18 | 0.11 | Ware, 2008 |
| 625 | East Allen Reservoir, Wyoming | 4.8 | 3.0 | Birkner, 1978 |
| 657 | Crow Creek at Toner, Idaho | 3.5 | 2.3 | Greater Yellowstone Coalition, 2005; 2006 |
| 667 | Meeboer Lake, Wyoming | 0.3 | 0.2 | Birkner, 1978 |
| 750 | Diamond Lake, Wyoming | 0.3 | 0.225 | Birkner, 1978 |
| 762 | Chevron Marsh (constructed), California (range 214-1241) | 5-9.8 | 2.1-6.7 | Hansen and others, 1998 |
| 767 | Miller's Lake, Colorado | 6.0 | 4.6 | Birkner, 1978 |
| 784 | San Diego Creek constructed marsh, California | 2.0 | 1.6 | Presser and Luoma, 2009 |
| 818 | Mac Mesa Reservoir, Colorado | 2.2 | 1.8 | Birkner, 1978 |
| 968 | Sweitzer Lake, Colorado | 9.4 | 9.1 | Birkner, 1978 |
| 968 | Desert Reservoir, Colorado | 12.5 | 12.1 | Birkner, 1978 |
| 1,104 | Mud River at Spurlock, West Virginia | 6.25 | 6.9 | USGS, 2008 |
| 1,196 | Salton Sea, California | 0.92 | 1.1 | California Resources Agency, 2006 |
| 1,224 | Twin Buttes Reservoir, Wyoming | 7.6 | 9.3 | Birkner, 1978 |
| 1,312 | Galett Lake, Wyoming | 0.8 | 1.05 | Birkner, 1978 |
| 1,341 | Angus Creek, Idaho | 0.82 | 1.1 | Greater Yellowstone Coalition, 2005; 2006; |

| $K_d$ | Ecosystem | Water-column Se (µg/L) | Particulate Se (µg/g dw) | Reference |
|---|---|---|---|---|
| | | | | Presser et al., 2004 |
| 1,388 | Lower Great Lakes, Hamilton Harbor | 0.67 | 0.93 | Ware, 2008 |
| 1,436 | Tulare Basin, evaporation ponds, California [b] | 8.8 | 11.8 | Fan et al., 2002 |
| 1,498 | Big Canyon Wash (sites 1 and 2), California | 21.5 | 32.2 | Presser and Luoma, 2009 |
| 1,579 | Cobb Lake, Colorado | 3.8 | 6.0 | Birkner, 1978 |
| 1,619 | Timber Lake, Colorado | 2.1 | 1.3 | Birkner, 1978 |
| 1,717 | Larimer HWY 9 pond, Colorado | 15.9 | 27.3 | Birkner, 1978 |
| 1,759 | Great Salt Lake, Utah | 0.54 | 0.95 | Marden, 2008 |
| 1,800 | Upper Mud River Reservoir at Palermo, West Virginia | 3.7 | 6.7 | USGS, 2008 |
| 1,818 | Crow Creek above Sage Creek, Idaho | 0.99 | 1.8 | Greater Yellowstone Coalition, 2005; 2006 |
| 1,941 | Wellington State Pond, Colorado | 1.7 | 3.3 | Birkner, 1978 |
| 1,943 | Thompson Creek, Idaho | 1.75 | 3.4 | GEI Consultants Inc., 2008 |
| 2,143 | Highline Reservoir, Colorado | 4.2 | 9.0 | Birkner, 1978 |
| 2,250 | Deer Creek, Idaho | 1.6 | 3.6 | Greater Yellowstone Coalition, 2005; 2006 |
| 2,798 | Belews Lake, North Carolina | 10.9 | 30.5 | Cumbie, 1984; Lemly, 1985 |
| 2,902 | Kesterson Reservoir (pond 8), California | 41 | 119 | Saiki and Lowe, 1987 |
| 3,044 | Hyco Reservoir, North Carolina | 6 -17 | 27 | Bowie et al., 1996 |
| 3,150 | Big Canyon Wash (site 3) California | 24 | 75.6 | Presser and Luoma, 2009 |
| 3,556 | Kesterson Reservoir (pond 11), California | 9.0 | 32 | Saiki and Lowe, 1987 |
| 4,000 | Delaware River (tidal freshwater), Delaware | 0.17-0.35 | 0.6-1.5 | Riedel and Sanders, 1998 |
| 6,500 | Great Marsh, Delaware | 0.01-0.06 | 0.3-0.7 | Velinsky and Cutter, 1991 |
| 7,817 | San Francisco Bay, California (1998-1999) | 0.114 | 0.823 | Cutter and Cutter 2004; Doblin et al., 2006 |
| 9,456 | Salton Sea estuary, Alamo River | 0.92 | 8.7 | LeBlanc and Schroeder, 2008 |
| 11,956 | Salton Sea estuary, Whitewater River | 0.92 | 11 | LeBlanc and Schroeder, 2008 |
| 13,788 | Outer San Francisco Bay, California (1998-1999) | 0.088 | 1.20 | Cutter and Cutter 2004; Doblin et al., 2006 |
| 15,000 | Xiamen Bay, Fujian Province, China | 0.08 | 1.2 | Liu et al., 1987 |
| 17,391 | Salton Sea estuary, New River, California | 0.92 | 16 | LeBlanc and Schroeder, 2008 |
| 21,500 | San Francisco Bay (1986;1995-96) (range 3,000-40,000) | 0.05-0.4 | suspended 0.3-8 | Presser and Luoma, 2006 |
| 18,942 | Lower Newport Bay, California (range 6,933-42,715) | 0.07-0.15 | 1.05-2.98 | Presser and Luoma, 2009 |

**Supplemental Table B.** Experimental data for invertebrate physiological parameters and calculated kinetic TTFs for invertebrates (particulate to invertebrate in dw). [(a) assumed IR; b) chosen from Fowler and Benayoun, 1976; Zhang et al., 1990; and Okazaki and Panietz, 1981; c) calculated from 23 day half-life [efflux (/d) = 0.69/half-life (d)], Reinfelder et al., 1997; d) calculated from 52 day half-life; e) calculated from 70 day half-life; f) calculated from 10 day half-life.]

| Marine Environments | | | | | |
|---|---|---|---|---|---|
| Species | AE | IR | ke | TTF (AE X IR/ke) | Reference |
| copepod (*Acartia tonsa*) | 0.97 | 0.42[a] | 0.13 | 3.1 | Fisher and Reinfelder, 1991 |
| copepod (*Temora longicornis*) | 0.55 | 0.42 | 0.155 | 2.0 | Wang and Fisher, 1998 |
| copepod (*A. tonsa; T. longicornis*) | 0.8 | 0.42[a] | 0.19 | 1.8 | Wang et al., 1996b |
| copepod (*Oithona; Limnoithona*; *Tortanus; Acartia*; *T. longicornis*) | 0.50 | 0.42 | 0.155 | 1.35 | Schlekat et al., 2004 |
| mysid (*Neomysis mercedis*) | 0.61-0.73 | 0.45 | 0.25 | 1.1-1.3 | Schlekat et al., 2004 |
| amphipod (*Leptocheirus plumulosus*) | 0.45 | 0.20 | 0.15 | 0.6 | Schlekat et al., 2004 |
| clam (*Corbula amurensis*) | 0.45-0.80 | 0.25 | 0.025 | 4.5-8.0 | Schlekat et al., 2002 |
| clam (C. *amurensis*) | 0.36-0.54 | 0.25 | 0.025 | 3.6-5.4 | Lee et al., 2006 |
| clam (*Corbicula fluminea*) (also freshwater) | 0.29-0.81 | 0.05 | 0.010 | 1.45-4.05 | Lee et al., 2006 |
| clam (*Macoma balthica*) | 0.22-0.86 | 0.25 | 0.012[b] | 11.2 (using mean AE) | Luoma et al., 1992 |
| clam (*M. balthica*) | 0.54 (mean) | 0.25 | 0.030[c] | 4.5 | Luoma et al., 1992 |
| clam (*Puditapes philippnarum*) | 0.52-0.70 | 0.25[a] | 0.013[d] | 10-13.5 | Zhang et al., 1990 |
| clam (*Mercenaria mercenaria*) | 0.92 | 0.25[a] | 0.010[e] | 23 | Reinfelder et al., 1997 |
| oyster (*Crassostrea virginica*) | 0.45-0.70 | 0.25[a] | 0.069[f] | 1.6-2.5 | Reinfelder et al., 1997 |
| oyster (*Crassostrea rivularis*) | 0.55 | 0.45 | | | Ke and Wang, 2001 |
| oyster (*Saccostrea glomerata*) | 0.45 | 0.32 | | | Ke and Wang, 2001 |
| mussel (*Mytilus edulis)* | 0.31 | 0.27 | 0.022 | 3.8 | Wang et al., 1996a |
| mussel (*M. edulis*) | 0.72 | 0.27 | 0.022 | 8.8 | Reinfelder et al., 1997 |
| barnacle (*Balanus amphitrite*) | 0.63-0.79 | 0.40 | 0.014 | 18-22.6 | Wang et al., 1999 |
| barnacle (*Elminius modestus*) | 0.34-0.74 | 0.40 | 0.0137 | 9.9-21.6 | Rainbow and Wang, 2001 |
| Freshwater Environments | | | | | |
| Species | AE | IR | ke | TTF (AE X IR/ke) | Reference |
| zebra mussel (*Dreissena polymorpha*) | 0.28-0.46 | 0.42 | 0.026 | 4.5-7.4 | Roditi and Fisher, 1999 |
| clam (*Corbicula fluminea*) (also marine) | 0.29-0.81 | 0.05 | 0.010 | 1.45-4.05 | Lee et al., 2006 |

Supplemental Table C. Calculated TTFs from field studies for invertebrates (particulate to invertebrate in dw).

| Freshwater Environments | | |
|---|---|---|
| Invertebrate | Field TTF | Reference |
| mayfly (Baetidae; Heptageniidae; Ephemerellidae) | 2.7 | Casey, 2005 |
| caddisfly (Rhyacophilidae; Hydropsychidae) | 3.2 | Casey, 2005 |
| cranefly (Tipulidae) | 2.3 | Casey, 2005 |
| stonefly (Perlodidae/Perlidae; Chloroperlidae) | 2.6 | Casey, 2005 |
| aquatic insect (composite) | 3.2 | Harding et al, 2005 |
| damselfly (Coenagrionidae) | 2.6 | Birkner, 1978 |
| midge (*Chironomus* sp.) | 2.7 | Birkner, 1978; Saiki et al., 1993 |
| waterboatman (*Cenocorixa* sp.) | 2.14 | Birkner, 1978 |
| crayfish (*Procambarus clarki;* Astacidae*; Orconectes* sp.) | 1.5 | Birkner, 1978; Saiki et al., 1993 |
| *Daphnia* (*Daphnia magna*) | 1.9 | Besser et al., 1989 |
| amphipod (*Hyalella azteca; Gammarus fasciatus; Corophium* spp.) | 0.94 | Birkner, 1978; Saiki et al., 1993 |
| zooplankton (composite) | 1.5 | Saiki et al., 1993 |
| Saline or Marine Environments | | |
| Invertebrate | Field TTF | Reference |
| euphausiid (*Meganyctiphanes norvegica*) | 1.3 | Fowler and Benayoun 1976 |
| brine shrimp adult (*Artemia franciscana*) | 4.2 | Marden, 2008 |
| brine shrimp nauplius | 2.6 | Marden, 2008 |
| brine shrimp cysts | 2.2 | Marden, 2008 |
| brine fly adult (*Ephydra gracilis*) | 1.8 | Cavitt, 2007; Wurtzbach, 2007 |
| brine fly larvae | 1.5 | Cavitt, 2007; Wurtzbach, 2007 |

Supplemental Table D. Calculated kinetic or field TTFs for fish (invertebrate to fish in dw except where noted as fish to fish in dw). [a) rotifer to larval fish microcosm; b) with assumptions; c) experimental microcosm.]

| Fish Species | Kinetic TTF | Field or lab TTF | Experimental Physiological Parameters | Reference |
|---|---|---|---|---|
| mangrove snapper (*Lutjanus argentimaculatus*) | 1.1 | | ke 0.031; IR 5%; 69% AE | Xu and Wang, 2002 |
| striped bass (juvenile) (*Morone saxatilis*) | 0.89 | | ke 0.08; IR 17%; 42% AE | Baines et al., 2002 |
| Chinese mudskipper (*Periophthalmus cantonensis*) | 0.84 | | ke 0.019; IR 5%; 32% AE | Ni et al., 2005 |
| smooth toadfish (*Tetractenos glaber*) | 0.80 | | ke 0.015-0.032; assumed IR 7-10%; AE 24% | Alquezar et al., 2007 |
| gilthead sea bream (*Sparus auratas*) | 0.6 | | ke 0.13; assumed IR 10%; AE 77% | Mathews and Fisher. 2008 |
| sea bass (from bream) (*Dicentrarchus labrax*) | 1.1 | | ke 0.06; assumed IR 10%; AE 64% | Mathews and Fisher. 2008 |
| fathead minnow[a] (*Pimephales promelas*) | 1.0[b] | | ke 0.025; assumed IR 5%; AE 50% | Bennett et al.,1986 |
| fathead minnow adult | 0.71-1.8[b] | | ke 0.014;assumed IR 5%;AE 20-50% | Bertram and Brooks, 1986 |
| bluegill (fry/juvenile)[c] (*Lepomis macrochirus*) | 0.51[b] | | ke 0.035; AE 36% assumed IR 5% | Besser et al., 1993 |
| bluegill (fry/juvenile) | 0.61[b] | | ke 0.041; assumed IR 5% AE 50% | Cleveland et al., 1993 |
| bluegill (juvenile) | | 1.15 (lab) | | Lemly, 1993 |
| bluegill | | 1.06 | | Saiki et al., 1993 |
| white sturgeon (*Acipenser transmontanus*) | | 1.7 | | Presser and Luoma, 2006 |
| white sturgeon | | 0.6-1.3 (mean 0.9) | | Stewart et al., 2004 |
| yellowfin goby (Acanthogobius flavimanus) | | 1.2 | | Stewart et al., 2004 |
| starry flounder (*Platichthys stellatus*) | | 1.6 | | Stewart et al., 2004 |
| leopard shark (*Triakis semifasciata*) | | 0.52 | | Stewart et al., 2004 |
| striped bass | | 0.8 | | Stewart et al., 2004 |
| western mosquitofish (*Gambusia affinis*) | | range 0.71-1.8 (mean 1.2) | | Saiki et al., 1993 |
| western mosquitofish | | 1.3 | | Saiki et al., 2008 |
| largemouth bass | | range 0.95-1.1 | | Saiki et al., 1993 |

| Fish Species | Kinetic TTF | Field or lab TTF | Experimental Physiological Parameters | Reference |
|---|---|---|---|---|
| (*Micropterus salmoides*) | | (mean 1.0) | | |
| sailfin molly (*Poecilia latipinna*) | | 1.4 | | Saiki et al., 2008 |
| rainbow trout (*Oncorhynchus mykiss*) | | range 0.71-1.1 (mean 0.91) | | Casey, 2005 |
| rainbow trout | | 1.04 | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| cutthroat trout (*Oncorhynchus clarkii*) | | 1.0 | | McDonald and Stosher, 1998 |
| cutthroat trout from dace | | range 0.87-0.99 (mean 0.93) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| cutthroat trout from sculpin | | range 0.95-1.0 (mean 0.98) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| cutthroat trout | | range 0.97-1.53 (mean 1.25) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| brook trout (*Salvelinus fontinalis*) | | 0.77 | | Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| brown trout (*Salmo trutta*) | | range 1.18-1.45 (mean 1.32) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| mottled sculpin (*Cottus bairdi*) | | range 1.23-1.66 (mean 1.45) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| longnose dace (*Rhinichthys cataractae*) | | range 1.41-1.65 (mean 1.53) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| chub (*Gila* sp.) (Utah chub is common in Idaho) | | range 1.03-1.38 (mean 1.21) | | Greater Yellowstone Coalition, 2005; 2006; Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004 |
| redside shiner (*Richardsonius balteatus*) | | 1.5 | | Greater Yellowstone Coalition, 2005; 2006 |
| mountain whitefish (*Prosopium williamsoni*) | | 1.31 | | Greater Yellowstone Coalition, 2005; 2006 |
| sucker (*Catostomus* sp.) (Utah and mountain suckers are common in Idaho) | | 0.97 | | Greater Yellowstone Coalition, 2005; 2006 |

Supplemental Table E. Model validation for prediction of invertebrate and fish (whole-body or muscle) Se concentrations. Predicted and observed Se concentrations are shown. If data are available for more than one invertebrate food web, multiple fish concentrations are predicted. Ranges of fish Se concentrations and means of invertebrate and fish species for a site location are given for comparison. As noted below, individual identified species-specific food web Se concentrations or grand means of observed invertebrate and fish Se concentrations were used to derive correlations of observed to predicted Se concentrations (see main text Figures 3 and 4). Additional details of data interpretation are described in the main text. [ND = no data available; ** = die-offs and potential food avoidance by fish; mt whitefish = mountain whitefish; wt mosquitofish = western mosquitofish; CA killifish = California killifish; CA halibut = California halibut; spt sand bass = spotted and bass]

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| Belews Lake** (main reservoir, 1975-1984) North Carolina (Cumbie, 1984; Lemly, 1985) (converted from ww except suspended) | suspended particulate> insect>sunfish, bass | 30.5 | 1.5<br>2.8<br>2.8 | 45.8<br>85.4<br>85.4 | 51 zoo- +phytoplankton<br>93 insect<br>54 mollusk<br>53 crustacean<br>70 annelid | 1.1 | 94 for insectivores (16 fish species extripated) | 70 bluegill, redear sunfish, warmouth, pumpkinseed<br>81 largemouth bass (mean 72) (16 species extirpated) |
| Cienega de Santa Clara, Colorado River Delta (Garcia-Hernandez et al., 2000; 2001) | bed sediment>adult brine shrimp, crayfish>fish | 1.6 | 4.2<br>1.6 | 6.7<br>2.6 | 5.0 brine shrimp<br>3.5 crayfish | 1.1<br>1.1 | 7.4<br>2.9<br>(mean 5.2) | 8.6 sailfin molly<br>1.7 largemouth bass<br>2.1 striped mullet<br>2.5 common carp<br>(mean 3.7) |
| Elk Valley, Alexander Creek, British Columbia, Canada (Orr et al., 2006) | sediment, algae> insect>trout | 2.7 | 2.8 | 7.6 | 9.6 mayfly<br>4.5 stonefly<br>3.4 caddisfly<br>(mean 5.8) | 1.1 | 8.4 | 4.9 cutthroat trout |
| Elk Valley, Barns Lake wetland, British Columbia, Canada (Orr et al., 2006) | algae> insect>trout | 4.4 | 2.8 | 12.3 | 11.1 mayfly<br>5.9 cranefly<br>(mean 8.5)<br>8.2 beetle | ND | ND | |
| Elk Valley, Elk River (below Michel Creek), British Columbia, Canada (McDonald and Strosher, 1998) | attached algae>benthic invertebrate>trout | 1.3 | 2.8 | 3.6 | 4.3 benthic | 1.1 | 4.0 | 5.3 cutthroat trout<br>4.2 mt whitefish<br>4.1 bull trout<br>(mean 4.5) |
| Elk Valley, Fording River (above Swift Creek), British Columbia, Canada (McDonald and Strosher, 1998) | attached algae>benthic invertebrate>trout | 1.6 | 2.8 | 4.5 | 10.7 benthic | 1.1 | 5.0 | 9.1 cutthroat trout |
| Elk Valley, Fording River | sediment>insect>trout | 8.8 | 2.8 | 24.6 | 18.4 mayfly | 1.1 | 27.1 | 38.5 cutthroat trout |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| (oxbow), British Columbia, Canada (Orr et al., 2006) | | | | | 33 caddisfly<br>28.4 chironomid<br>(mean 26.6) | | | |
| Elk Valley, Fording River, British Columbia, Canada (Harding et al., 2005) | particulate>insect | 2.2 | 2.8 | 6.2 (from below) | 7.1 (mayfly, stonefly, caddisfly, cranefly) | ND | ND | See bird case studies |
| Elk Valley, Fording River, British Columbia, Canada (Kennedy et al., 2000) | particulate>insect >trout | 2.2 (from above) | 2.8 | 6.2 | ND | 1.1 | 6.8 | 12.5 cutthroat trout (6.7-41) |
| Elk Valley, Fording River, British Columbia, Canada (Orr et al., 2006) | sediment, algae> insect>trout | 2.9 | 2.8 | 8.1 | 7.1 mayfly<br>6.9 stonefly<br>8.9 caddisfly<br>(mean 7.6) | 1.1 | 8.9 | 8.2 cutthroat trout |
| Elk Valley, Goddard Marsh, British Columbia, Canada (Orr et al., 2006) | sediment>insect>trout | 26 | 2.8 | 72.8 | 42.6, 29.5 dragonfly<br>165.4 caddisfly<br>66.6 mayfly<br>(mean 76) | ND | ND | |
| Elk Valley, Line Creek, British Columbia, Canada (Orr et al., 2006) | sediment, algae> insect>trout | 2.15 | 2.8 | 6.0 | 7.3 mayfly<br>2.7 stonefly<br>5.4 caddisfly<br>(mean 5.1) | 1.1 | 6.6 | 7.0 cutthroat trout |
| Hyco Reservoir** (1986-1987) North Carolina (Bowie et al., 1996) | phytoplankton>insect> bluegill | 27 | 2.8 | 76 | 70 benthic insects | 1.1 | 84 | 50 1986 bluegill<br>70 1987 bluegill<br>mean 60 (38-75% reductions in fish densities) |
| Illco Pond (1996), Kendrick Reclamation Project, Natrona County, Wyoming (Ramirez and Dickerson. 1999; See et al.,1992) | pondweed>insect | 6.6 | 2.8 | 18.5 | 25 composite insect | 1.1 | 20.4 | 23.4 common carp |
| Imperial National Wildlife Refuge, Lower Colorado River (Lusk, 1993; Martinez, 1994) | sediment, detritus, aufwuch>clam, crayfish | 4.0 | 2.8<br>1.6 | 11.2<br>6.4 | 10.5 clam<br>(*C. fluminea*) (6-26)<br>7.7 crayfish (2-36) | ND | ND | See bird case studies |
| Kesterson Reservoir** (1983), pond 2 | sediment, algae, detritus>insect> | 58 | 2.8 | 162 | 180 dragonfly, damselfly, chironomids | 1.1 | 178 | 224 wt mosquitofish (other species |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| (Saiki and Lowe, 1987) | mosquitofish | | | | | | | extirpated) |
| Kesterson Reservoir** (1983), pond11 (Saiki and Lowe, 1987) | sediment, algae, detritus>insect> mosquitofish | 18 | 2.8 | 50 | 41 dragonfly, damselfly, chironomid | | | |
| Kesterson Reservoir** (1984), ponds 2, 7, and 11, (Schuler et al., 1990; Ohlendorf and Hothem, 1995) | sediment, diatom,algae> insect> | 35.3 | 2.8 | 99 | 18.6 corixid (59-130)<br>98 damsel (50-160)<br>69 dragonfly (48-110)<br>59 beetle (12-110)<br>102 diptera l(76-180)<br>(72 mean insect) | ND | ND | See bird case studies |
| Kesterson Reservoir** (1983), (Ohlendorf et al., 1986) | algae>zooplankton, insect> mosquitofish (all other species died) | 43.5 | 1.5<br>2.8 | 65<br>122 | 85 net plankton<br>22 corixid<br>139 chironomid<br>122 dragonfly<br>175 damselfly<br>(mean insect 114) | 1.1<br>1.1 | 71.5<br>134<br>(mean 103) | 170 wt mosquitofish (115-283) (other species extirpated) |
| Kesterson Reservoir area reference site (Volta Wasteway), California (Saiki and Lowe, 1987) | sediment>plankton, insect> mosquitofish | 0.34 | 1.4<br>2.8 | 0.48<br>0.95 | 2.8 net plankton<br>1.7 damselfly | 1.1<br>1.1 | 0.53<br>1.1<br>(mean 0.79) | 1.4 wt mosquitofish |
| McClean Lake area (Vulture Lake), northern Saskatchewan, Canada (Muscatello and Janz, 2009) | sediment, algae, net plankton (153 micron)>insect>fish | 1.3 | 2.8 | 3.6 | 1.6 chironomid<br>3.1 caddisfly<br>1.6 dragonfly<br>(mean 2.1)<br>0.86 leech<br>0.52 snail | 1.1 | 4.0 | 1.3 northern pike<br>3.4 white sucker<br>4.2 stickleback<br>11 burbot<br>(mean 5.0) |
| McLeod River/Luscar Creek watershed, Alberta, Canada (Casey, 2005) | sediment, biofilm, algae>insect > trout, whitefish | 3.7 | 2.8 | 10.4 | 10.1 mayfly<br>11.8 caddisfly<br>8.4 cranefly<br>9.4 stonefly<br>(mean insect 10) | 1.1 | 11 | 8.9 rainbow trout<br>14.6 brook trout<br>8.2 bull trout<br>11.6 mt whitefish<br>(mean 10.8) |
| McLeod River/Luscar Creek watershed reference site (Deerlick Creek), Alberta, Canada (Casey, 2005) | sediment, biofilm> insect > trout | 0.6 | 2.8 | 1.7 | 6.2 mayfly<br>3.8 caddisfly<br>3.3 stonefly<br>2.4 cranefly<br>(mean insect 3.9) | 1.1 | 1.85 | 1.8 rainbow trout |
| Miller's Lake, Colorado (Birkner, 1978) | algae>insect, crayfish> fathead | 4.6 | 2.8<br>1.6 | 12.9<br>7.4 | 18.8 chironomid<br>9.9 corixid | 1.1<br>1.1 | 14.2<br>8.1 | 11 fathead minnow (8.7-16.6) |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| | | | | | (mean insect 14.4)<br>11.3 crayfish | | (mean 11.2) | |
| Newport Bay (lower), California (Presser and Luoma, 2009) | particulate> copepod> pelagic fish | 2.05 | 1.5 | 3.1 | ND | 1.1 | 3.4 | 3.9 CA killifish<br>2.6 topsmelt<br>1.5 CA halibut<br>1.6-2.3 goby<br>2.2 spt. sandbass<br>2.7 diamond turbot<br>2.0 staghorn sculpin<br>1.2 surfperch<br>(mean 2.5) |
| Newport Bay (upper), California (Presser and Luoma, 2009) | particulate> mysid, clam>pelagic fish | 1.5 | 0.9<br>2.8 | 1.4<br>4.2 | 4.8 amphipod<br>6.1 bivalve<br>2.9 clam<br>4.4 mussel<br>(mean 4.5)<br>8.4 isopod<br>6.1 crab<br>6.2 snail | 1.1<br>1.1 | 3.6<br>4.6<br>(mean 4.1) | 3.4 topsmelt<br>3.3 diamond turbot<br>3.0 anchovy<br>4.0 CA halibut<br>5.5 striped mullet<br>5.8 CA killifish<br>4.0-5.1 goby<br>3.2 spt. sand bass<br>1.6 staghorn sculpin<br>1.8 surfperch<br>(4.07 mean) |
| Rasmus Lee Lake** (1994), Kendrick Reclamation Project, Natrona County, Wyoming (Ramirez and Dickerson. 1999; See et al.,1992) | pondweed> insect> | 30 | 2.8 | 84 | 93 composite insect | ND | ND | See bird case studies |
| Red Draw Reservoir, Big Spring, Texas (USEPA 2000b) | periphyton> snail, chironomid> silverside, minnow, killifish | 3.1 | 2.8 | 8.7 | 12.4 chironomid<br>2.2 snail (up to 8.8) | 1.1 | 9.6 | 11.8 inland silverside (7.0-18)<br>8.2 sheepshead minnow (5.9-16.3)<br>8.0 Gulf killifish (4.1-11.7)<br>(mean 9.3) |
| Salton Sea, California (California Resources Agency, 2006) | sediment, algae> amphipod, corixid | 1.1 | 0.9<br>2.8 | 0.99<br>3.1 | 1.6 amphipod<br>2.3 corixid | ND | ND | See bird case studies |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| Salton Sea, California (California Resources Agency, 2006) | sediment, algae> pileworm>fish | | 6.0 (site specific) | 6.6 | 6.6 pileworm | 1.1 | 7.3 | 8.1 largemouth bass<br>8.8 sargo<br>9-10 redbelly talapia<br>12 Gulf croaker<br>12 orangemouth corvina<br>3.2 channel catfish<br>(mean 8.9) |
| San Diego Creek watershed (lower San Diego Creek), California (Presser and Luoma, 2009) | particulate> insect, crayfish, clam | 2.8 | 2.8<br>1.6<br>2.8 | 7.8<br>4.5<br>7.8 | 7.5 corixid<br>5.8 crayfish<br>7.5 clam<br>4.9 snail | ND | ND | See bird case studies |
| San Diego Creek watershed (marsh A), California (Presser and Luoma, 2009) | particulate> insect | 2.2 | 2.8 | 6.2 | 5.6 dragonfly<br>4.2 backswimmer<br>(mean insect 4.9) | ND | ND | |
| San Diego Creek watershed (marsh B), California (Presser and Luoma, 2009) | particulate> zooplankton, insect, crayfish>fish | 5.3 | 1.5<br>1.6<br>2.8 | 8.0<br>8.5<br>14.8 | 6.8 zooplankton<br>12.1 crayfish<br>11 chironomid<br>11.6 corixid<br>10.2 dragonfly<br>(10.9 mean insect)<br>5.3 snail<br>7.6 freshwater clam | 1.1<br>1.1<br>1.1 | 8.8<br>9.4<br>16.3<br>(mean 11.5) | 13 mixed fish<br>10.1 wt mosquitofish<br>19 common carp<br>(mean 14) |
| San Francisco Bay-Delta Estuary (1989—1997), California (Presser and Luoma, 2006) | particulate>clam> sturgeon | 2.0 | 6.25 | 12.5 | 13.5 (maximum 20)<br>(*C. amurensis*, in 1995-1997) | 1.1 | 13.8 | 15 (2-50) white sturgeon in 1989-1990 |
| San Francisco Bay-Delta Estuary (2000-2001), California (Presser and Luoma, 2006) | particulate> copepod>mysid> striped bass | 1.0 | 1.3 and 1.35 (two-steps) | 1.8 | 4.5 zooplankton<br>2.2 mysid<br>1.8 amphipod<br>1.7 isopod<br>2.2 shrimp | 1.1 (from mysid) | 2.0 | 2.0 striped bass |
| San Francisco Bay-Delta Estuary (2000-2001), | particulate>clam> sturgeon | 1.0 | 6.25 | 6.2 | 10.8 (clam, *C. amurensis*) | 1.1 | 6.8 | 8.0 white sturgeon |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| California (Presser and Luoma, 2006) | | | | | | | | |
| San Joaquin River at Hills Ferry, California (Saiki et al., 1993) | particulate> amphipod, zooplankton, insect, crayfish >bluegill, bass | 1.6 | 1.5<br>0.9<br>2.8<br>1.6 | 2.4<br>1.4<br>4.5<br>2.6<br>(mean 2.7) | 4.3 zooplankton<br>2.8 amphipod<br>4.1 chironomid<br>1.9 crayfish<br>(mean 3.3) | 1.1 | 3.0 (based on mean of predicted invertebrates) | 2.7 bluegill<br>2.4 largemouth bass<br>(mean 2.6) |
| San Joaquin River reference site (at Durham), California (Saiki et al., 1993) | particulate> amphipod, zooplankton, insect, crayfish >bluegill, bass | 0.61 | 1.5<br>0.9<br>2.8<br>1.6 | 0.92<br>0.55<br>1.7<br>0.98<br>(mean 1.04) | 1.8 zooplankton<br>1.1 amphipod<br>1.6 chironomid<br>1.3 crayfish<br>(1.45 mean ) | 1.1 | 1.1 based on mean) | 1.9 bluegill<br>1.7 largemouth bass<br>(mean 1.8) |
| San Joaquin River reference site (at Lander), California (Saiki et al., 1993) | particulate> amphipod, zooplankton, insect, crayfish >bluegill, bass | 0.25 | 1.5<br>0.9<br>2.8<br>1.6 | 0.38<br>0.22<br>0.70<br>0.40<br>(0.42 mean ) | 1.3 zooplankton<br>1.3 amphipod<br>1.0 chironomid<br>0.74 crayfish<br>(1.1 mean ) | 1.1 | 0.46 based on mean) | 1.4 bluegill<br>1.8 largemouth bass<br>(mean 1.6) |
| San Joaquin River tributary (Mud Slough) California (Saiki et al., 1993) | particulate> amphipod, zooplankton, insect, crayfish >bluegill, bass | 3.6 | 1.5<br>0.9<br>2.8<br>1.6 | 5.4<br>3.2<br>10.1<br>5.8<br>(mean 6.1) | 4.4 zooplankton<br>3.7 amphipod<br>6.9 chironomid<br>3.2 crayfish<br>(mean 4.6) | 1.1 | 6.7 (based on mean of predicted invertebrates) | 4.3 bluegill<br>4.0 largemouth bass<br>(mean 4.2) |
| San Joaquin River tributary (Salt Slough) California (Saiki et al., 1993) | particulate> amphipod, zooplankton, insect, crayfish >bluegill, bass | 3.2 | 1.5<br>0.9<br>2.8<br>1.6 | 4.8<br>2.9<br>9.0<br>5.1<br>(mean 5.45) | 5.4 zooplankton<br>3.3 amphipod<br>7.2 chironomid<br>4.4 crayfish<br>(mean 5.1) | 1.1 | 6.0 ((based on mean of predicted invertebrates) | 5.0 bluegill<br>6.9 largemouth bass<br>(mean 6.0) |
| Savage River watershed, Blacklick Run (atmospheric ) western Maryland (Mason et al., 2000) | periphyton, bryophyte>crayfish insect>sculpin, dace>trout | 0.78 | 1.6<br>2.8 | 1.25<br>2.2 | 0.89 crayfish<br>7.8 mayfly<br>6.2 caddisfly<br>1.3 cranefly<br>2.7 stonefly<br>2.3 dragonfly<br>2.4 dobsonfly<br>(mean insect 3.8) | 1.1<br>1.1 | 1.4<br>2.4<br>(mean 1.9) | 2.0 mottled sculpin<br>1.3 longnose dace<br>1.4-1.7 brook trout<br>(mean 1.6) |
| Savannah River (D-area Power Plant) (coal ash | sediment>insect> chubsucker | 20.7 | 2.8 | 58 | 56.9 benthic | 1.1 | 62.6 | 70.3 lake chubsucker |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| drainage swamp microcosms) South Carolina (Hopkins et al., 2004) | | | | | | | | |
| Sweitzer Lake**, Colorado (Birkner, 1978) | particulate>zooplankton, insect, crayfish >killifish, minnow, mixed fry | 9.1 | 1.5<br>2.8<br>1.6 | 13.6<br>25.5<br>14.6 | 42.5 plankton<br>45 damselfly<br>27 chironomid<br>(mean insect 36)<br>20 crayfish | 1.1<br>1.1<br>1.1 | 15<br>28<br>16.1<br>(mean 19.7) | 32 plains killifish<br>26 mixed fry<br>(mean 29)<br>(progressive mortality of 7 species of stocked fish) |
| Thompson Creek downstream of Thompson Mine, Idaho (GEI Consultants, 2008) | sediment, detritus>insect>sculpin, trout | 3.2 | 2.8 | 9.0 | 11.5 insect | 1.1 | 9.9 | 15.6 slimy sculpin<br>13.8 cutthroat/ rainbow trout<br>(mean 14.7) |
| Thompson Creek downstream of Thompson Mine, Idaho (GEI Consultants, 2008) | sediment, detritus>insect>sculpin, trout | 6.3 | 2.8 | 17.6 | 13.9 insect | 1.1 | 19.4 | 11.4 slimy sculpin<br>7.8 cutthroat/ rainbow trout<br>(mean 9.6) |
| Thompson Creek downstream of Thompson Mine, Idaho (GEI Consultants, 2008) | sediment, detritus> insect>sculpin, trout | 4.3 | 2.8 | 12.0 | 17.9 insect | 1.1 | 13.2 | 18.9 slimy sculpin<br>14.0 cutthroat/ rainbow trout<br>(mean 16.4) |
| Thompson Creek upstream of Thompson Mine, Idaho (GEI Consultants, 2008) | sediment, detritus> insect>sculpin, trout | 1.8 | 2.8 | 5.0 | 7.2 insect | 1.1 | 5.5 | 13.5 slimy sculpin<br>10.0 cutthroat/ rainbow trout<br>(mean 11.8) |
| Thompson Creek upstream of Thompson Mine, Idaho (GEI Consultants, 2008) | sediment, detritus> insect>sculpin, trout | 2.1 | 2.8 | 5.9 | 9.6 insect | 1.1 | 6.5 | 10.9 slimy sculpin<br>7.8 cutthroat/ rainbow trout<br>(mean 9.4) |
| Tulare Basin Pond** (Sam Andrews), San Joaquin Valley, California (Moore et al., 1990) | sediment, algae> adult brine shrimp, insect, brine fly larvae | 4.4 | 4.2<br>2.8<br>1.5 | 18.5<br>12.3<br>6.6 | 20.6 brine shrimp<br>8.1 brine fly larvae<br>7.5 damselfly | ND | ND | See bird case studies |
| Tulare Basin Pond** (Westfarmers), San Joaquin Valley, California | sediment, algae>adult brine shrimp, brine fly larvae, insect, | 5.45 | 4.2<br>1.5<br>2.8 | 22.9<br>8.2<br>15.3 | 25.5 brine shrimp<br>21.7 fly larvae<br>41.1 corixid | ND | ND | See bird case studies |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| (Moore et al., 1990) | | | | | 80 damselfly<br>(mean insect 61) | | | |
| Tulare Basin Pond** (Stone Land Company), California (Moore et al., 1990) | sediment, algae>adult brine shrimp, insect | 0.75 | 4.2<br>2.8 | 3.2<br>2.1 | 3.4 brine shrimp<br>2.3 corixid | ND | ND | See bird case studies |
| Tulare Basin Pond** (Carmel Ranch) San Joaquin Valley, California (Moore et al., 1990) | sediment, algae>adult brine shrimp, insect, brine fly larvae | 0.40 | 4.2<br>2.8<br>1.5 | 1.7<br>1.1<br>0.60 | 3.9 brine shrimp<br>4.4 brine fly larvae<br>2.5 corixid | ND | ND | See bird case studies |
| Twin Buttes Reservoir, Wyoming (Birkner, 1978) | sediment, algae>zooplankton, amphipod, insect> darter, killifish, fathead minnow, mixed fry | 9.3 | 1.5<br>0.9<br>2.8 | 14<br>8.4<br>26.0 | 15.4 plankton<br>11 amphipod<br>16 corixid<br>18 damselfly<br>34 chironomid<br>(mean insect 23) | 1.1<br>1.1<br>1.1 | 15.4<br>9.2<br>28.6<br>(mean 17.7) | 42 Iowa darter<br>22 plains killifish<br>34 fathead minnow<br>22 mixed fry<br>(mean 30) |
| Uncompahgre River watershed, Arizona and Colorado Dry Creek, DRY1 (Butler et al., 1994) | sediment, algae> insect>sucker, dace, chub | 2.45 | 2.8 | 6.9 | NA | 1.5 | 10.4 | 2.0 bluehead sucker<br>5.9 flannelmouth sucker<br>4.9 white sucker<br>9.7 speckled dace<br>8.1 roundtail chub<br>(mean 6.1) |
| Uncompahgre River watershed, Arizona and Colorado Loutsenhizer Arroyo, LZA 1 (Butler et al., 1991; 1994; 1996) | sediment, algae>insect, crayfish> sucker, dace, sunfish | 5.5 | 2.8<br>1.6 | 15.4<br>8.8 | 26 invertebrates (some insects)<br>14 crayfish | 1.1<br><br>1.1 | 16.9<br>9.7<br>(mean 13.3) | 9.0 bluehead sucker<br>17 flannelmouth sucker<br>28 speckled dace (18 mean)<br>37 green sunfish<br>(all mean 22.8) |
| Upper Blackfoot River watershed, southeast Idaho (Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004) | sediment>insect > sculpin, dace | 2.5 | 2.8 | 7.0 | 12.1 benthic (some cranefly) | 1.1 | 7.7 | 7.7 mottled sculpin<br>9.3 longnose dace<br>(mean 8.5) |
| Upper Blackfoot River watershed, southeast | sediment>insect> sculpin, dace> | 2.5 | 2.8 | 7.0 | 12.1 benthic (some cranefly) | 1.1<br>and | 8.5 | 13.2 cutthroat trout<br>13.4 brook trout |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g dw) | $TTF_{fish}$ (wb or muscle) | Predicted fish Se (wb or muscle) (µg/g dw) | Mean observed fish Se (wb or muscle) (µg/g dw) |
|---|---|---|---|---|---|---|---|---|
| Idaho (Hamilton and Buhl, 2004; 2005; Hamilton et al., 2004) | trout | | | | | 1.1 | | (mean 13.3) |
| Upper Blackfoot River watershed, southeast Idaho (Greater Yellowstone Coalition 2005;2006) | attached algae>insect > sculpin, dace | 4.1 | 2.8 | 11.4 | 7.8 (cranefly, caddisfly, dragonfly, mayfly, stonefly, shrimp) | 1.1 | 12.5 | 11.4 mottled sculpin<br>15.6 longnose dace<br>(mean 13.5) |
| Upper Blackfoot River watershed, southeast Idaho (Greater Yellowstone Coalition 2005; 2006) | attached algae>insect> sculpin, dace> trout | 4.1 | 2.8 | 11.4 | 7.8 (cranefly,caddisfly, dragonfly, mayfly, stonefly, shrimp) | 1.1<br>and<br>1.1 | 13.8 | 8.6 cutthroat trout<br>12.6 brown trout<br>(mean 10.6) |
| Upper Mud Reservoir (left fork), West Virginia (USGS, 2008; West Virginia Department of Environmental Protection, 2009) | suspended material>insect, crayfish, clam | 1.7 | 2.8<br>1.6<br>2.8 | 4.8<br>2.7<br>4.8 | 10.5 dragonfly<br>5.6 crayfish<br>17.5 clam<br>8.5 snail | ND | ND | |
| Upper Mud Reservoir above Palermo, (right fork) West Virginia [USGS, 2008; West Virginia Department of Environmental Protection (WVDEP), 2009] | suspended material>insect, crayfish, clam>bluegill, green sunfish, crappie | 6.7 | 2.8<br>1.6<br>2.8 | 19.0<br>10.9<br>19 | 16.5 dragonfly<br>12.1 crayfish<br>30.7 clam<br>36.6 snail | 1.1 | 20.9<br>12.0<br>29.7<br>(mean 20.9) | 28 bluegill (USGS)<br>26 bluegill (WVDEP)<br>20 green sunfish<br>20.4 crappie<br>(mean 22.1) |

**Supplemental Table F.** Model validation for prediction of invertebrate and bird egg Se concentrations. Predicted and observed Se concentrations are shown. [ND = no data available; max = maximum); ** = embryonic terata and potential food avoidance; blk-nk stilt = black-necked stilt; red-wg blackbird = red-winged blackbird]

| Location | Food Web | Mean observed particulate Se (µg/g dw) | $TTF_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g, dw) | $TTF_{bird\ egg}$ | Predicted bird egg Se (µg/g, dw) | Mean observed bird egg Se (µg/g, dw) |
|---|---|---|---|---|---|---|---|---|
| Converse County (uranium mine wastewater irrigates grasslands), Wyoming (Ramirez and Rogers, 2002) | soil>grass> grasshopper> blackbird | 3.1 soil<br>12.7 grass | | | 12.8 grasshopper (11-20) | 1.8 | 23.0 | 17.4 red-wg blackbird (13.2-22) |
| Elk Valley, Fording River, British Columbia, Canada (Harding et al., 2005) | particulate>insect> dipper, sandpiper | 2.2 | 2.8 | 6.2 | 7.1 (mayfly, stonefly, caddisfly, cranefly) | 1.8 | 11.2 | 8.4 American dipper<br>7.3 spotted sandpiper |
| Goose Lake** (1994), Kendrick Reclamation Project, Natrona County, Wyoming (Ramirez and Dickerson. 1999; See et al.,1992) | pondweed>insect>avocet | 37.6 | 2.8 | 105 | 52.6 (composite insect) | 1.8 | 189 | 40.8-111 eared grebe (embryonic terata) |
| Great Salt Lake, Ogden/Antelope Islands, Utah (Cavitt, 2007; Wurtzbach, 2007) | seston>brine fly larvae> shorebirds | 0.95 | 1.5 | 1.4 | 1.4 brine fly larvae<br>1.7 brine fly adults | 1.8 | 2.5 | 2.7 American avocet and blk-nk stilt |
| Great Salt Lake, Utah (Marden, 2008; Conover, 2009) | seston>brine shrimp>gull | 0.95 | 3.0 | 2.8 | 2.8 brine shrimp (4.0 adults; 2.4 nauplius; 2.1 cyst) | 1.8 | 5.0 | 3.0 California gull |
| Imperial National Wildlife Refuge, Lower Colorado River (Lusk, 1993; Martinez, 1994) | particulate>crayfish, clam> bird | 4.0 | 1.6<br>2.8 | 6.4<br>11.2 | 7.7 crayfish (2-36)<br>10.5 clam (*C. fluminea*) (6-26) | 1.8 | 20.2<br>11.5 | 5.2 l. lesser nighthawk<br>8.7 gr een heron (developing eggs)<br>10.3; 8.6 green heron<br>9.9 pied-billed grebe<br>8.7 least bittern |
| Kesterson Reservoir** (1984) (ponds 2, 7, and 11), California (Schuler et al., 1990; Ohlendorf and Hothem, 1995) | particulate>insect> aquatic and terrestrial birds (grebes and coots not nesting) | 35.3 | 2.8 | 99 | 98 damselfly<br>69 dragonfly<br>59 adult beetle<br>102 diptera larvae<br>19 corixid | 1.8 | 178 | 25 blk-nk stilt (max 64)<br>16 American avocet (max 61)<br>33 killdeer (max 50)<br>21 gadwall (max 26)<br>14 cinnamon teal (max 37)<br>10 mallard (max 19)<br>15 western meadowlark (24)<br>6 tri-color blackbird (max 9.6) |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | TTF $_{invertebrate}$ | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g, dw) | TTF $_{bird\ egg}$ | Predicted bird egg Se (µg/g, dw) | Mean observed bird egg Se (µg/g, dw) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 4.4 cliff swallow (max 9) (embryonic terata) |
| Kesterson Reservoir** (1983), California (Ohlendorf et al., 1986) | algae, plants>insect> grebe, coot, duck, stilt (grebes and coots not nesting) | 43.5 | 1.4<br>2.8 | 61<br>122 | 85 net plankton<br>22 corixid<br>139 chironomid<br>122 dragonfly<br>175 damselfly | 1.8 | 220 | 81 eared grebe(72-110)<br>54 American coot (34-110)<br>9.9 duck (mallard, northern pintail, cinnamon teal, gadwall) (2.2-46)<br>32.7 blk-nk stilt (12-74) (embryonic terata) |
| Kesterson Reservoir area reference site (Volta Wildlife Area) (Ohlendorf et al., 1986) | plankton>insect>grebe, duck, stilt, avocet | | | | 2.0 net plankton<br>1.7 insects | 1.8 | 3.6<br>3.1<br>(mean 3.4) | 1.9 eared grebe<br>1.2 mallard<br>0.84 gadwall<br>1.6 blk-nk stilt<br>1.4 American avocet |
| Newport Bay (upper), California (Presser and Luoma, 2009) | particulate> copepod, amphipod>avocet, stilt, killdeer, rail | 0.20<br>1.5 | 1.4 | 0.28<br>2.1 | | 1.8 | 0.50<br>3.8 | 5.3 American avocet<br>5.1 blk-nk stilt<br>2.6 killdeer<br>3.7 clapper rail |
| Newport Bay (upper), California (Presser and Luoma, 2009) | particulate> copepod, amphipod>topsmelt> tern, skimmer, grebe | 0.20<br>1.5 | 1.4 and 1.1<br>1.4 and 1.1<br>(two-steps) | 0.31<br>2.3 | | 1.8<br>1.8 | 0.56<br>4.2 | 4.4 least tern<br>3.1 black skimmer<br>5.8 pied-billed grebe |
| Rasmus Lee Lake** (1994), Kendrick Reclamation Project, Natrona County, Wyoming (Ramirez and Dickerson. 1999; See et al., 1992) | pondweed>insect> avocet | 30 | 2.8 | 84 | 93 composite insect | 1.8 | 167 | 85.9 American avocet (embryonic terata) |
| Salton Sea, California (California Resources Agency, 2006) | particulate>amphipod, insect, pileworm> bird | 1.1 | 0.6<br>2.8<br>7.4 | 0.66<br>3.1<br>8.1 | 1.6 amphipod<br>2.3 corixid<br>6.6 pileworm | 1.8 | 2.9<br>5.6<br>11.9 | 2.8 Caspian tern<br>3.6 white-faced ibis<br>5.3 snowy egret<br>6.0 black skimmer<br>6.3 great egret<br>6.7 night heron |
| Salton Sea, California (California Resources Agency, 2006) | particulate>insect>fish> bird | 1.1 | 2.8 and 1.1<br>(two-steps) | 3.4 | 8.1 largemouth bass<br>8.8 sargo<br>9-10 redbelly | 1.8 | 6.1 | 2.8 caspian tern<br>3.6 white-faced ibis<br>5.3 snowy egret<br>6.0 black skimmer |

| Location | Food Web | Mean observed particulate Se (µg/g dw) | TTF invertebrate | Predicted invertebrate Se (µg/g dw) | Mean observed invertebrate Se (µg/g, dw) | TTFbird egg | Predicted bird egg Se (µg/g, dw) | Mean observed bird egg Se (µg/g, dw) |
|---|---|---|---|---|---|---|---|---|
| | | | | | talapia<br>12 Gulf croaker<br>12 orangemouth corvina<br>3.2 channel catfish | | | 6.3 great egret<br>6.7 night heron |
| San Diego Creek watershed (lower San Diego Creek), California (Presser and Luoma, 2009) | particulate> insect, crayfish, clam> avocet, stilt, killdeer, grebe, coot | 1.2 | 1.6<br>2.8<br>2.8 | 1.9<br>3.4 | 7.5 corixid<br>5.8 crayfish<br>4.9 snail<br>7.5 clam | 1.8 | 3.4<br>6.1 | 2.8 American avocet<br>6.9 blk-nk stilt<br>9.5 killdeer<br>5.8 pied-billed grebe<br>5.2 American coot |
| Tulare Basin Pond** (Sumner Peck), California (Moore et al., 1990) | particulate>brine shrimp | 6.0 | 2.8<br>4.2 | 16.8<br>25.2 | 54.2 brine shrimp<br>100 damselfly<br>250 fly larvae<br>25.7 beetle<br>43.9 corixid | 1.8 | 45.4 | 60 American avocet<br>67 blk-nk stilt<br>(embryonic terata) |
| Tulare Basin Pond** (Westfarmers), California (Moore et al., 1990) | particulate>brine shrimp> shorebird, grebe | 5.45 | 2.8<br>4.2 | 15.3<br>22.9 | 25.5 brine shrimp<br>80 damselfly<br>21.7 fly larvae<br>41.1 corixid | 1.8 | 41.2 | 20.8 American avocet<br>28 blk-nk stilt<br>74 eared grebe<br>(embryonic terata) |
| Upper Blackfoot River watershed, southeast Idaho (Ratti et al., 2006) | sediment>insect> bird | | | | 7.8 (assumed from Greater Yellowstone Coalition data; see Supplemental Table E) | 1.8 | 14 | 10.7 common snipe<br>8.6 American coot<br>8.1 killdeer<br>8.1 eared grebe<br>8.0 cinnamon teal<br>8.0 mountain bluebird<br>7.2 red-wg blackbird<br>7.2 yellow-headed blackbird<br>6.9 marsh wren<br>6.7 western grebe<br>plus other species |