# Ecosystem-Scale Selenium Modeling in Support of Fish and Wildlife Criteria Development for the San Francisco Bay-Delta Estuary, California

## Administrative Report

*Figures 1 through 12*

U.S. Department of the Interior
U.S. Geological Survey
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Find the full report and other attachments at http://www.epa.gov/region9/water/ctr


Figure 1. Map of the San Francisco Bay-Delta Estuary.

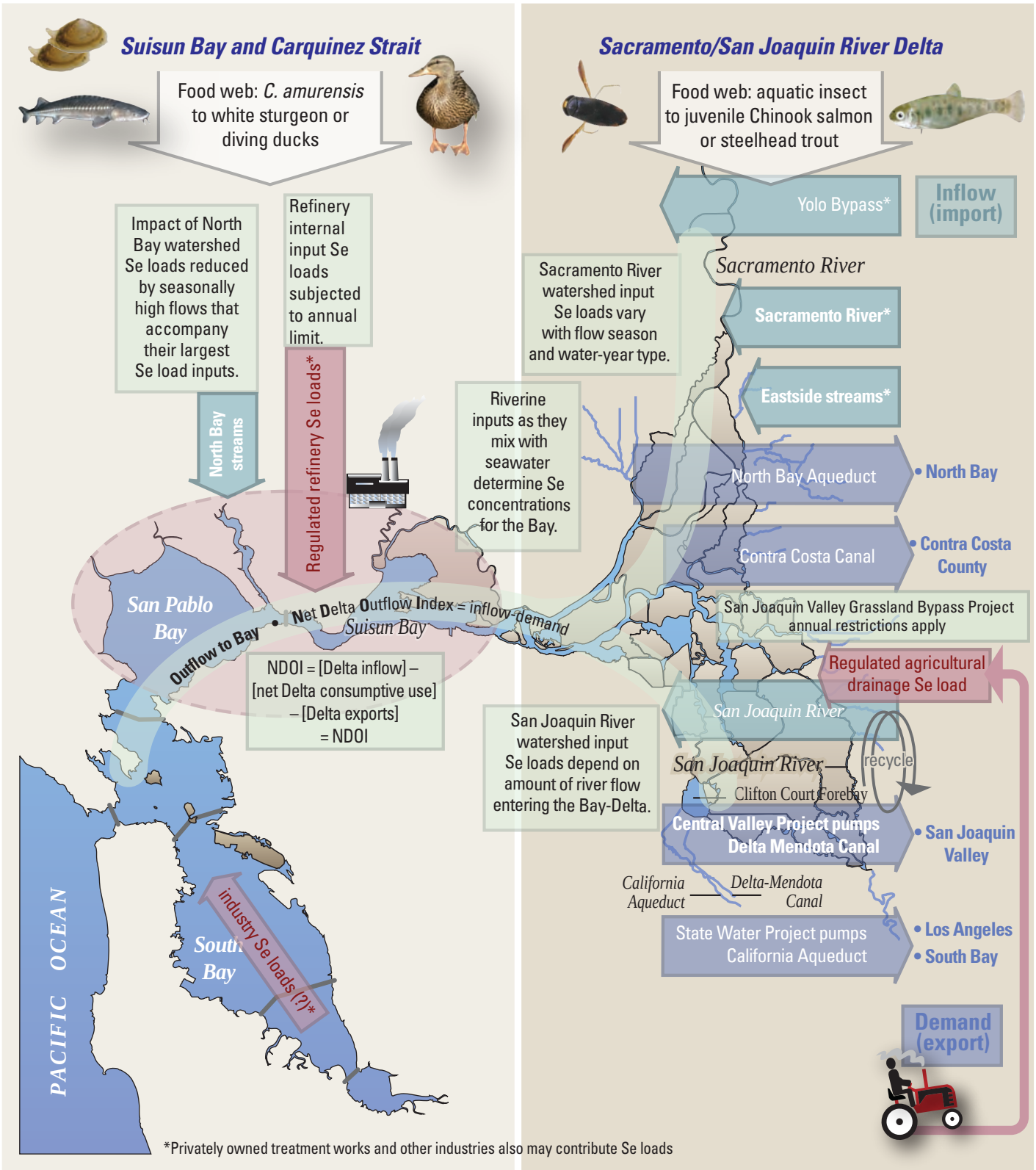



Figure 2. Conceptual details of sources of selenium, site-specific food webs, and hydrodynamic connections for the Bay-Delta.

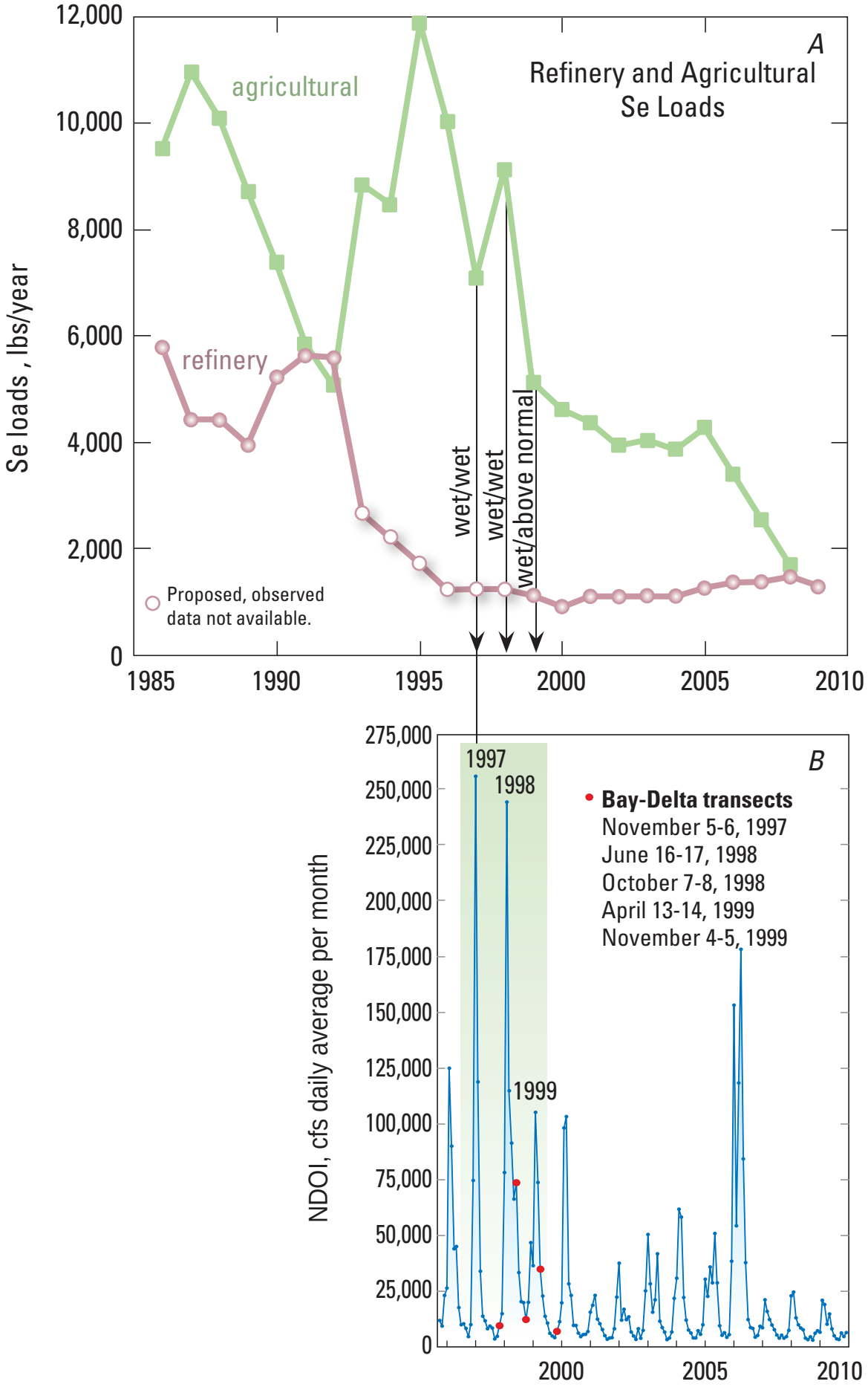



Figure 3. Refinery and agricultural selenium loads (1985-2009) (*A*) and flow conditions (1996-2009) (*B*).

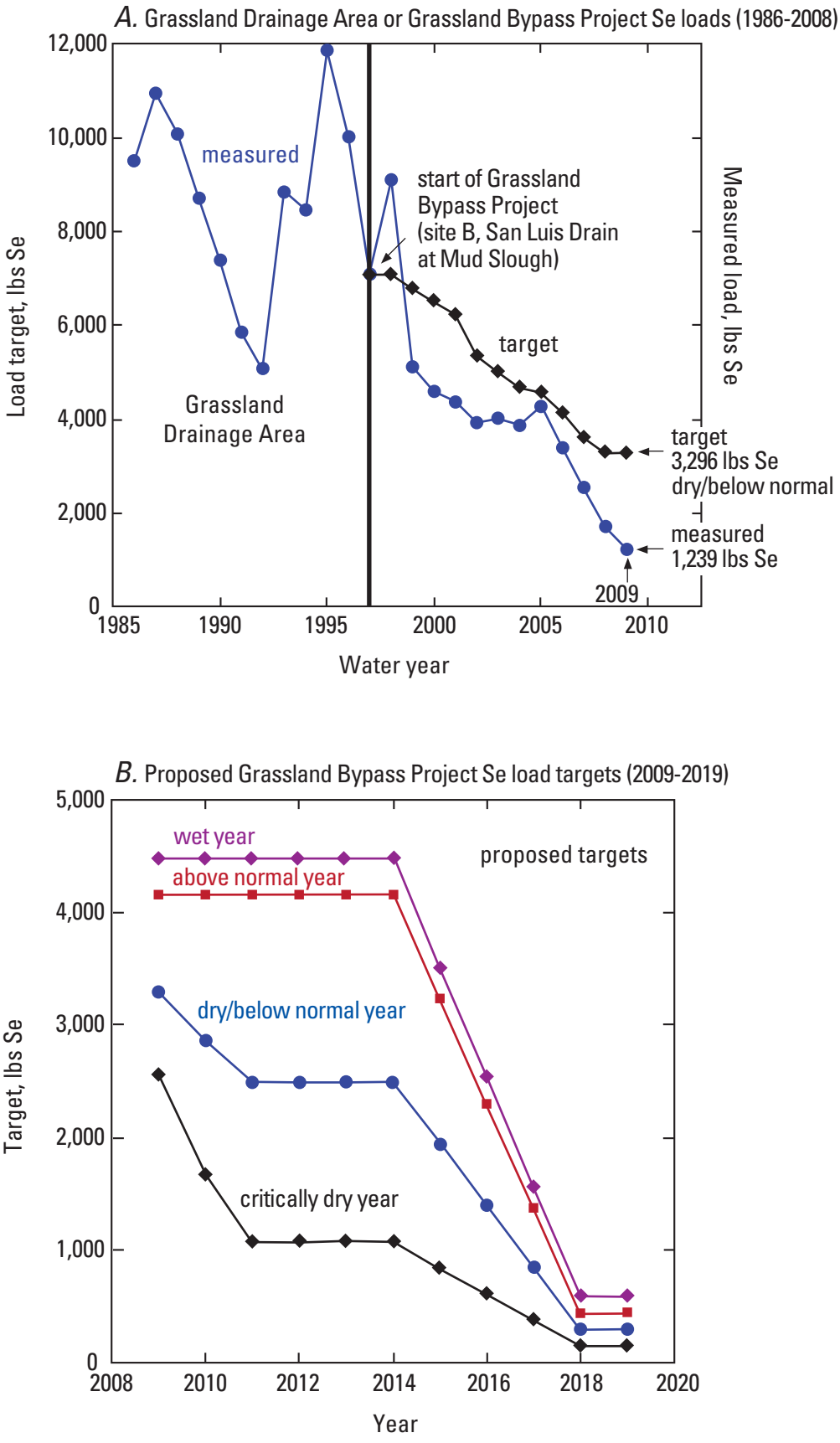



Figure 4. Grassland Bypass Project selenium loads (1997-2009) (*A*) and proposed selenium load targets (2009-2019) (*B*).

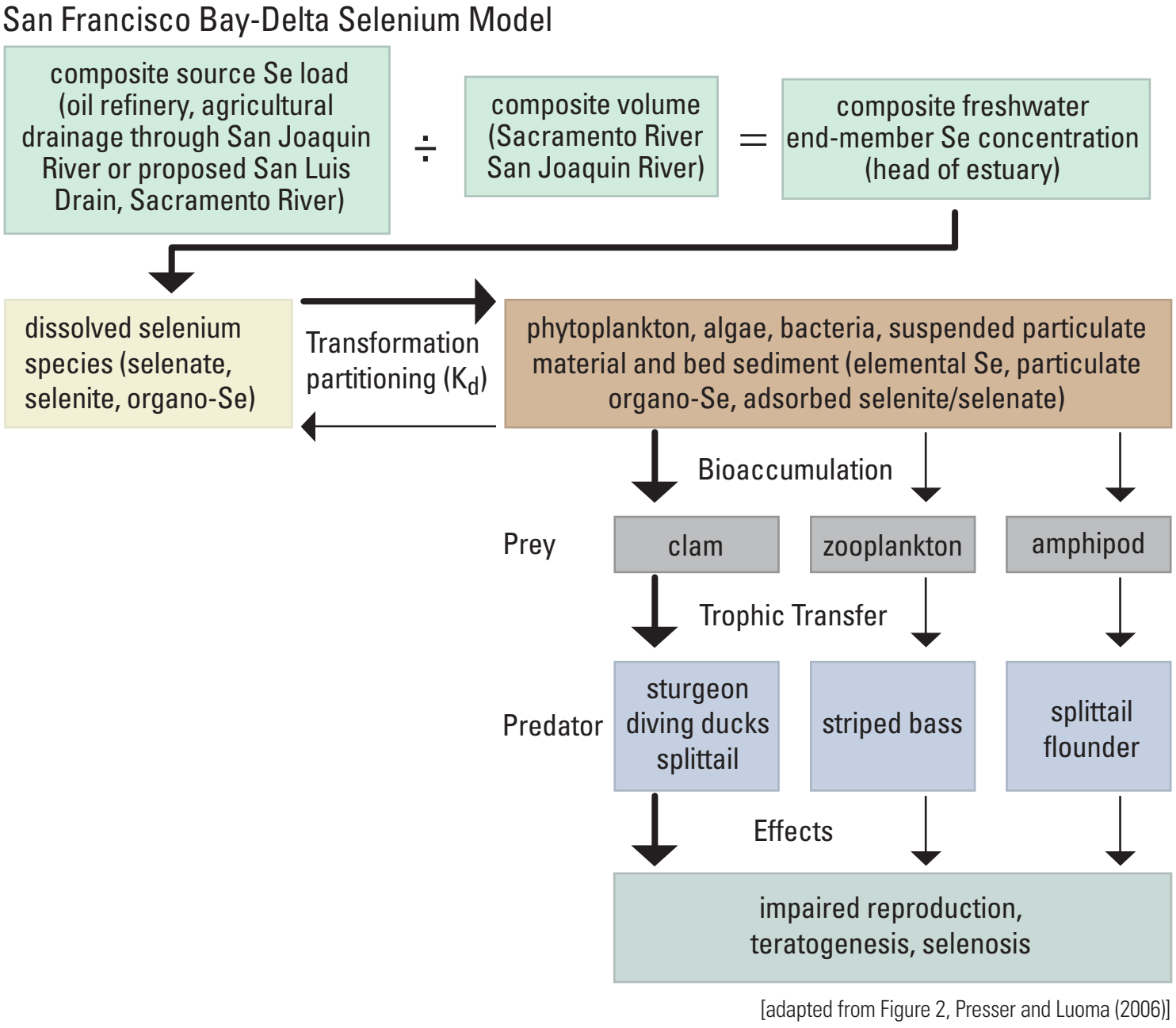



Figure 5. San Francisco Bay-Delta Selenium Model from Presser and Luoma (2006).

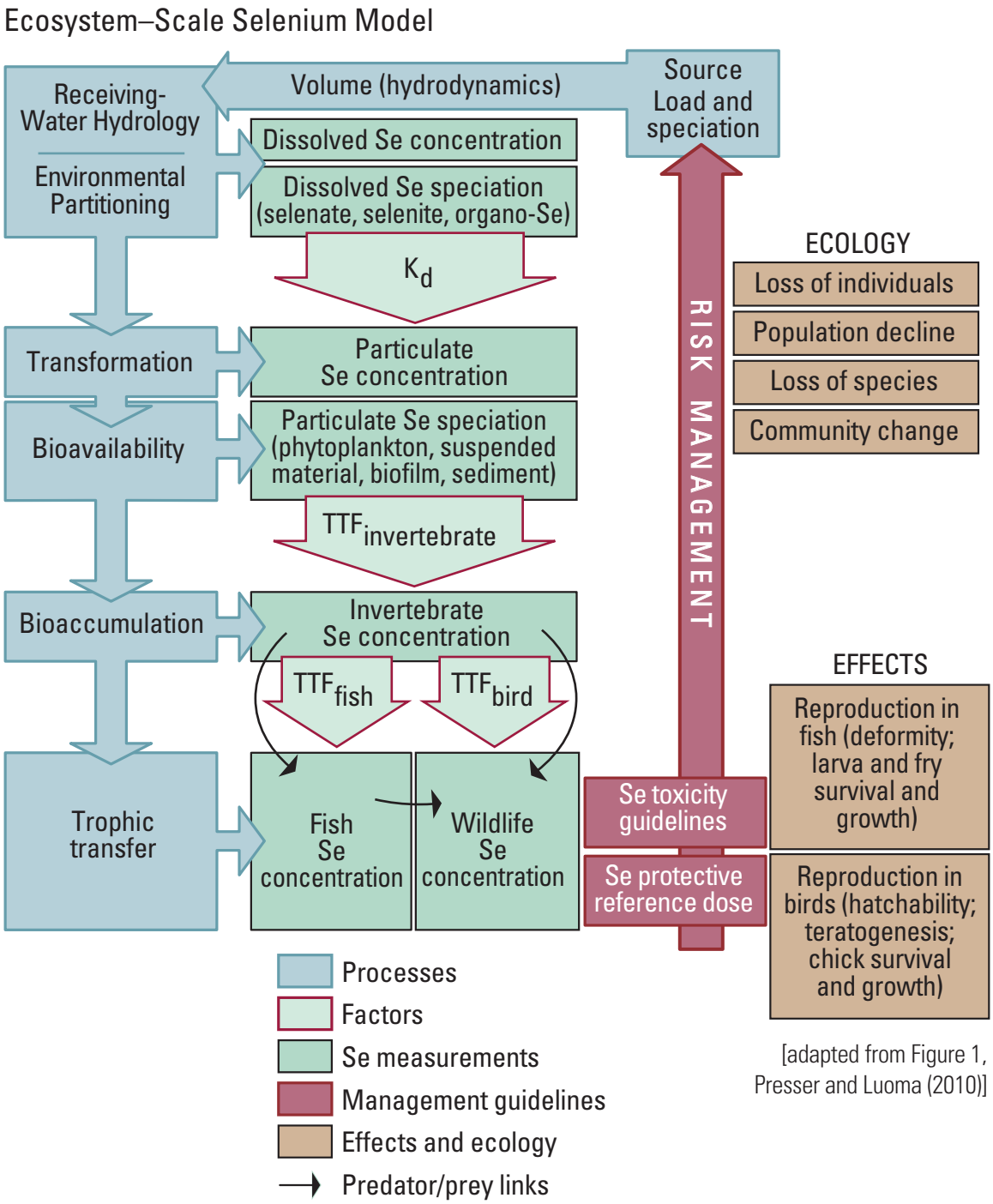
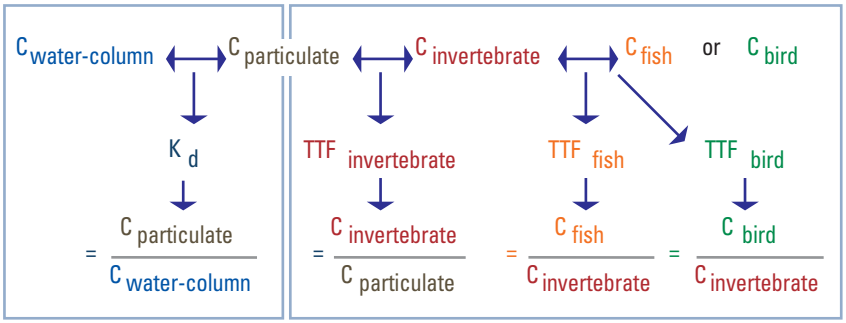



Figure 6. General ecosystem-scale selenium model from Presser and Luoma (2010). [$K_d$ = empirically determined environmental partitioning factor between water and particulate material; TTF = biodynamic food web transfer factor between an animal and its food.]

*A.* Quantifying Processes

| Environmental partitioning | Foodweb biodynamics |
|---|---|
| • site hydrology<br>• speciation<br>• particulate type | • assimilation efficiency (AE)<br>• ingestion rate (IR)<br>• efflux ($k_e$)<br>$C_{prey} = (AE)\,(IR)\,(C_{particulate})/k_e$<br>$C_{predator} = (AE)\,(IR)\,(C_{prey})/(k_e)$<br>$TTF = (AE)\,(IR)/(k)$ |




[adapted from Figure 2, Presser and Luoma (2010)]

*B.* Modeling Equations

$C_{invertebrate} = (C_{particulate})\,(TTF_{invertebrate})$
$C_{fish} = (C_{invertebrate})\,(TTF_{fish})$
$C_{bird} = (C_{invertebrate})\,(TTF_{bird})$

Combined Equations

$C_{fish} = (C_{particulate})\,(TTF_{invertebrate})\,(TTF_{fish})$
$C_{bird} = (C_{particulate})\,(TTF_{invertebrate})\,(TTF_{bird})$

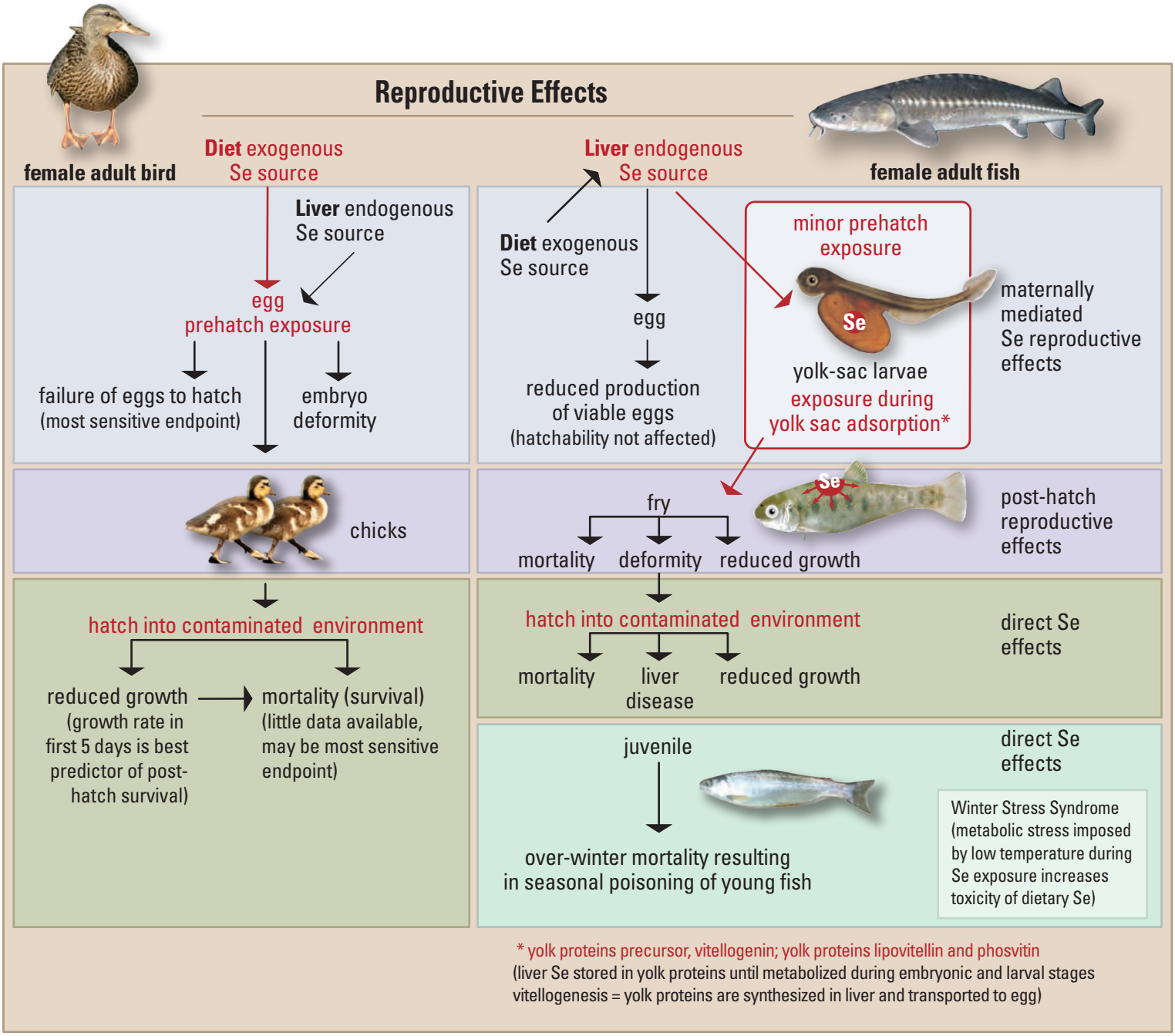
If longer food web

$C_{bird} = (C_{particulate})\,(TTF_{invertebrate})\,(TTF_{fish})\,(TTF_{bird})$
$C_{bird} = (C_{invertebrate})\,(TTF_{fish})\,(TTF_{bird})$

Translation to Water-Column Concentration

$C_{water} = (C_{fish}) \div [(TTF_{fish})\,(TTF_{invertebrate})\,K_d]$
$C_{water} = (C_{bird}) \div [(TTF_{bird})\,(TTF_{invertebrate})\,K_d]$

Figure 7. Quantifying processes (*A*) and modeling equations (*B*) for ecosystem-scale selenium modeling.




## Chronic Effects in Adults

- compromised body condition (low body mass; edema)
- oxidative stress (increased susceptibility to disease due to suppressed immune system)
- decreased winter survival
- decreased reproductive fitness (decreased breeding propensity; reduced recruitment)
- behavioral impairment (missed breeding window; delayed timing of departure)
- lowered saline tolerance and gill effects in fish

Figure 8. Ecotoxicology and effects of selenium for fish and birds.

## Site-Specific Model Approach

*A.* seaward site-specific

| foodweb ➡ | fish guidline*wb µg/g dw guideline ➡ | $TTF_{sturgeon}$ ➡ | predicted invertebrate µg/g dw ➡ | $TTF_{C.amurensis}$ ➡ | predicted particulate µg/g dw ➡ | $K_d$ ➡ | predicted dissolved µg/L |
|---|---|---|---|---|---|---|---|
| sturgeon/ *C. amurensis*/ suspended particulate material | Se in predator (sturgeon) | species-specific prey to predator trophic transfer factor | Se in prey *C. amurensis* | species-specific particulate to prey biodynamic trophic transfer factor | Se in food for prey (suspended particulate material) | emperical salinity-specific partitioning factor for dissolved and suspended particulate Se | Se in dissolved |
| | from USFWS or assumed from literature | ⬇ calculated from measured sturgeon muscle Se; measured clam Se (North Bay matched dataset) | | ⬇ **IR** calculated from measured suspended-particulate material (or C) from transects and literature filtration rate; **AE** calculated from measured particulate species from transects and literature bioavail-ability; **ke** assumed from literature for *C. amurensis* | | ⬇ calculated from transects of measured dissolved Se and suspended particulate Se for transects | |

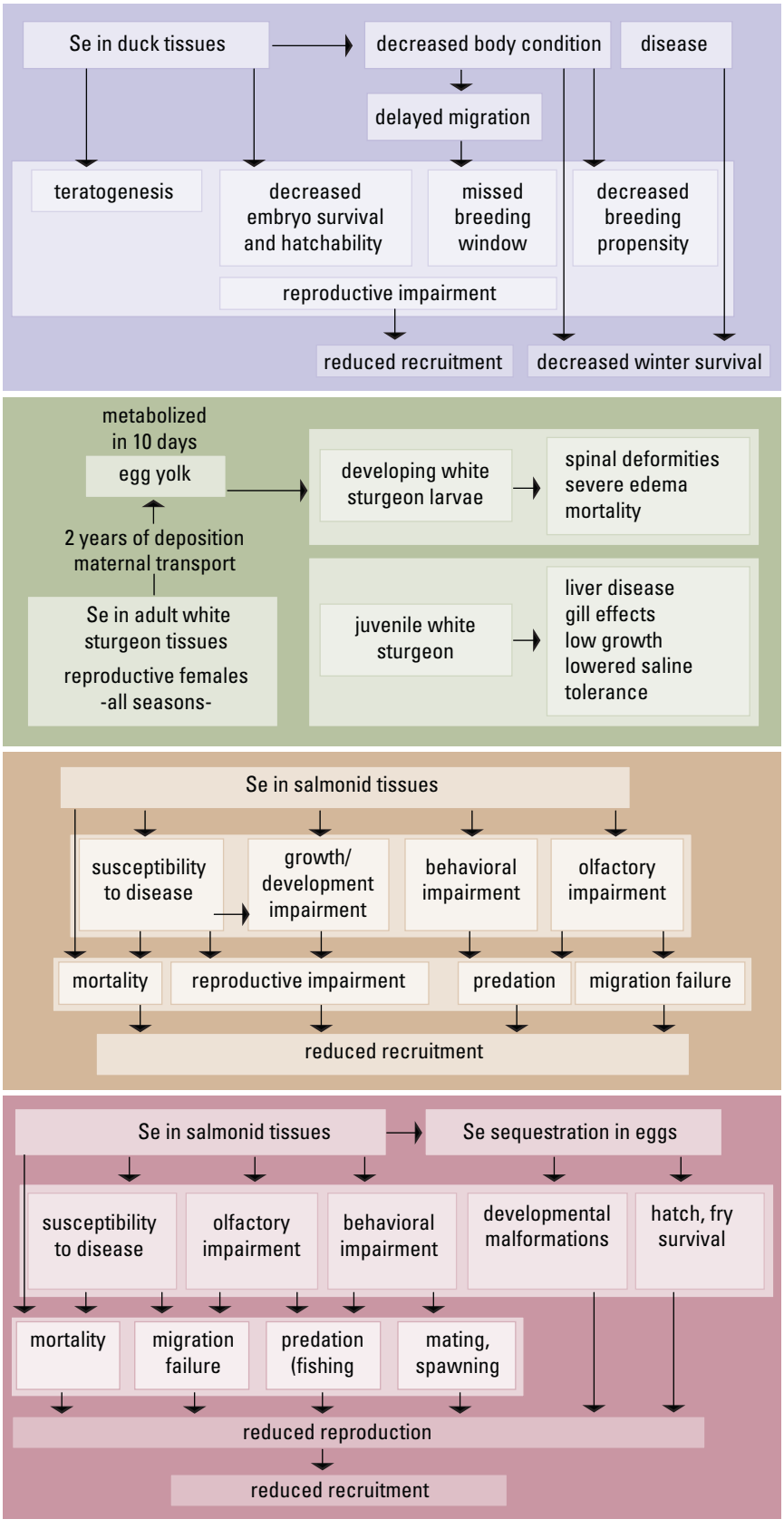
*B.* landward site-specific

| foodweb ➡ | fish guidline*wb µg/g dw guideline ➡ | $TTF_{salmon}$ ➡ | predicted invertebrate µg/g dw ➡ | $TTF_{aquatic\ insect}$ ➡ | predicted particulate µg/g dw ➡ | $K_d$ ➡ | predicted dissolved µg/L |
|---|---|---|---|---|---|---|---|
| Chinook salmon/ insect/ suspended particulate material | Se in predator (salmon) | species-specific prey to predator trophic transfer factor | Se in prey aquatic insect | species-specific particulate to prey biodynamic trophic transfer factor | Se in food for prey (suspended particulate material) | emperical salinity-specific partitioning factor for dissolved and suspended particulate Se | Se in dissolved |
| | from USFWS or assumed from literature | ⬇ generic field-derived for fish | | ⬇ generic field-derived for aquatic insect | | ⬇ calculated from transects of measured dissolved Se and suspended particulate Se for transects | |

Within specified salinity and residence time

*USEPA, USFWS, or assumed from literature; wb = whole body, dw = dry weight.

Figure 9. Site-specific modeling approach for Bay-Delta seaward (*A*) and landward (*B*) locations.




[adapted from Figure 7, Presser et al. (in review)]

Figure 10. Selenium effects models for diving ducks (*A*), white sturgeon (*B*), and juvenile salmonids (*C* and *D*).

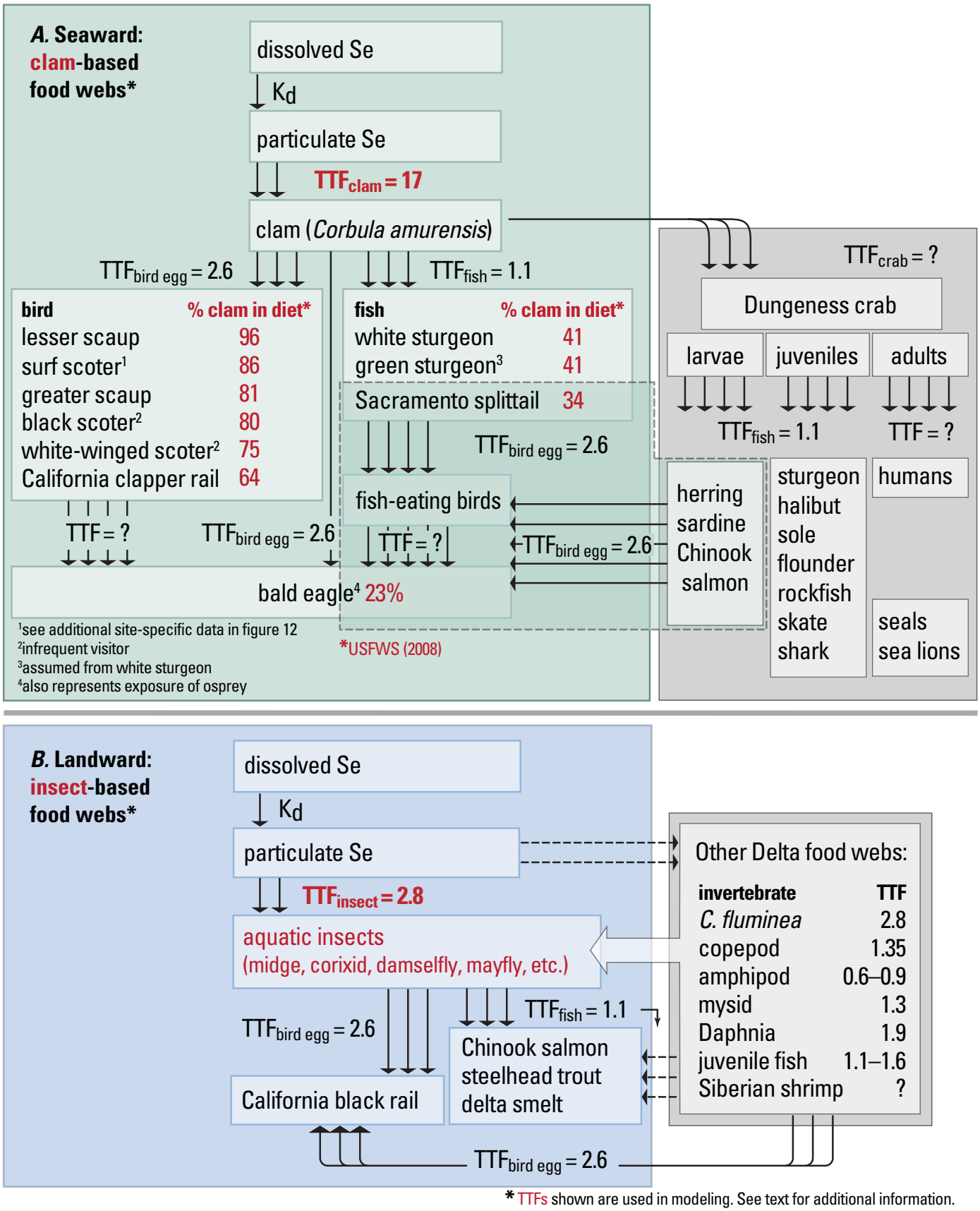
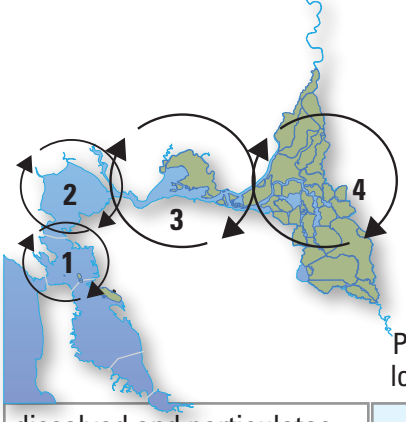



Figure 11. Conceptual details of seaward clam-based food webs (*A*) and landward aquatic insect-based food webs (*B*) for modeling of the Bay-Delta.




## Species at Risk: Exposure and Habitat Use

| | Primary location | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| dissolved and particulates partitioning/transformation | 1, 2, 3, 4 | high-flow season | | | | | | low-flow season | | | | | |
| *C. amurensis* Se (µg/g dry wt.) data: 12/1995–11/1996 | 1, 2, 3 | spawning | | | | | recovery | | | | | 20 ppm | |
| migratory birds<br>surf scoter a, b<br>black scoter c<br>white-winged scoter c<br>greater scaup b<br>lesser scaup b | 1, 2, 3<br>↓<br>1, 2, 3, 4 | surf scoter in Central Bay over wintering (staging) | | | | | migration north to breed | | | surf scoter in Suisun and San Pablo Bay | | | |
| clapper rail* | 1, 2, 3 | breeding | | | | | | | | | | | |
| bald eagle (assumed resident) | 1, 2, 3 | breeding | | | | | | | | | | | |
| white sturgeon *(100 yrs)*+ d | 2, 3 | upstream spawning | | | | | | | | | | | |
| | | 2 year internal egg maturation | | | | | | | | | | | |
| green sturgeon** *(50 yrs)*+ e | 1, 2, 3 | upstream spawning | | | | | | | | | | | |
| Chinook salmon* *(3–7 yrs)*+ winter-run | 1, 2, 3, 4 juveniles (4) | migration upstream | | | | upstream spawning | | | | | | | |
| | | emigration to ocean | | | | | | | emigration to ocean | | | | |
| Chinook salmon* *(3–7 yrs)*+ spring-run | | emigration to ocean | | | migration upstream | | | | | upstream spawning | | | |
| Central Valley steelhead trout (winter run)** *(4–7 yrs)*+ | 1, 2, 3, 4 juveniles (4) | migration | | | | emigration | | | | Chipps Island | | | migration |
| | | upstream spawning | | | | | | | | | | | (ESU 12)++ |
| Central CA Coast steelhead trout (winter run)** *(4–7 yrs)*+ | 1, 2 juveniles (2) | migration | | | | emigration | | | | | | | |
| | | upstream spawning | | | | | | | | | | | (ESU 9)++ |
| Sacramento splittail*** *(5 yrs)* | 2, 3, 4 | spawning in upper Delta | | | | | | | | | | | |
| | | spawning in estuary | | | | | | | | | | | |
| delta smelt** *(1 yr)*+ | 3, 4 | spawning in mixing zone | | | | | | | | | | | |

*listed as endangered
**listed as threatened
***listed as of concern
+Typical lifespan
++Evolutionarily Significant Unit (ESU)

a. 50% of surf scoter population overwinters in Bay
Suisun Bay diet is 89% *C. amurensis*
San Pablo Bay diet is 71% *C. amurensis*
Central Bay diet is *V. philippinarum* and soft-bodied prey
b. arrive in Canada in late May and immediately breed

c. infrequent visitor
d. females require about two years for eggs to mature; small fraction move up rivers to spawn in late winter and early spring
e. more marine than white sturgeon, juveniles spend 2—3 years in estuary before migrating to sea

Figure 12. Exposure and habitat use for predators at risk, patterns of *C. amurensis* selenium concentrations (1996), and hydrologic categories that may relate to environmental partitioning of selenium for the Bay-Delta.