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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
December, 2010

Find the full report and other attachments at http://www.epa.gov/region9/water/ctr

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

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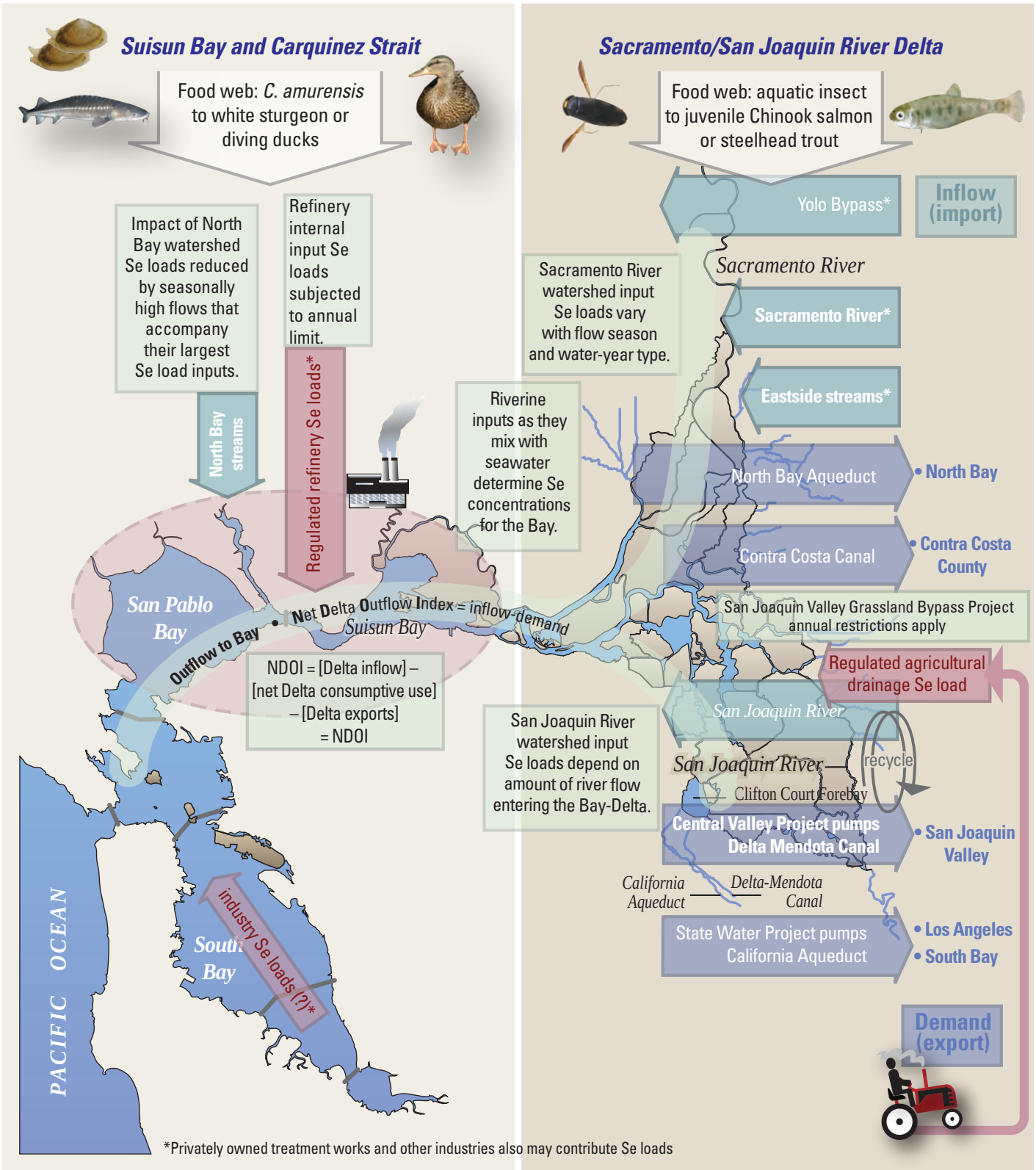

Figure 2. Conceptual details of sources of selenium, site-specific food webs, and hydrodynamic connections for the Bay-Delta.

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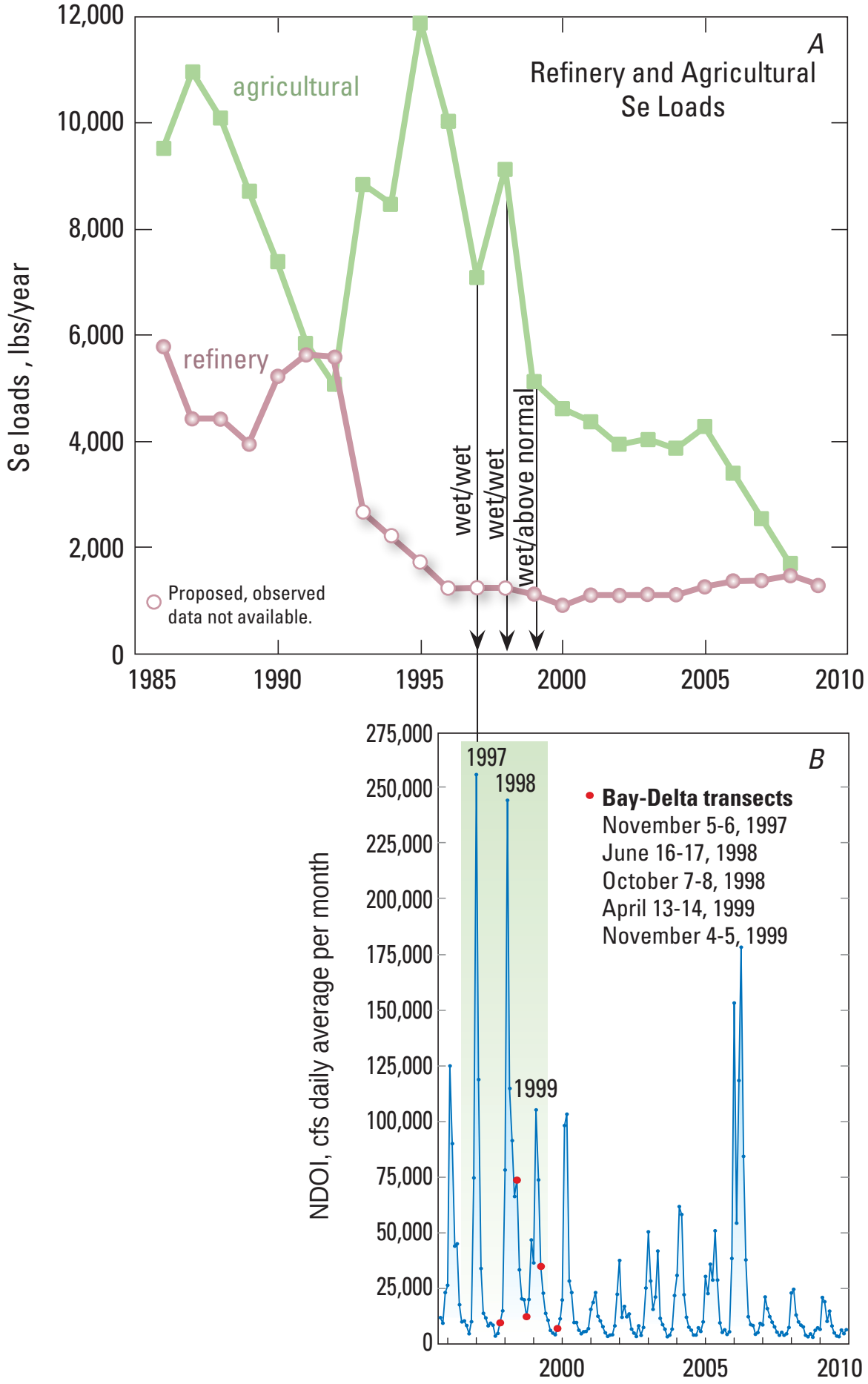

Figure 3. Refinery and agricultural selenium loads (1985-2009) (*A*) and flow conditions (1996-2009) (*B*).

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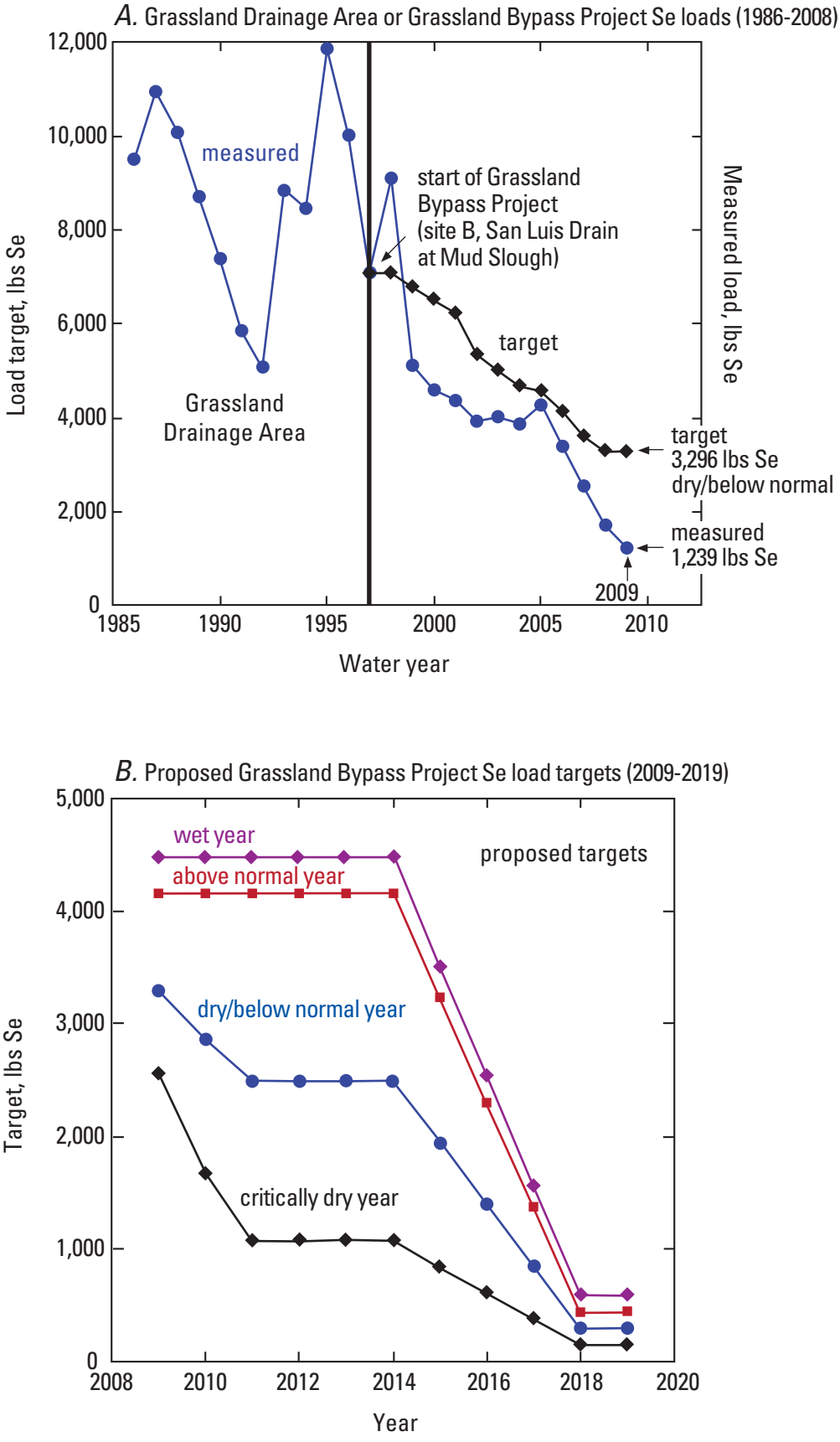

Figure 4. Grassland Bypass Project selenium loads (1997-2009) (*A*) and proposed selenium load targets (2009-2019) (*B*).

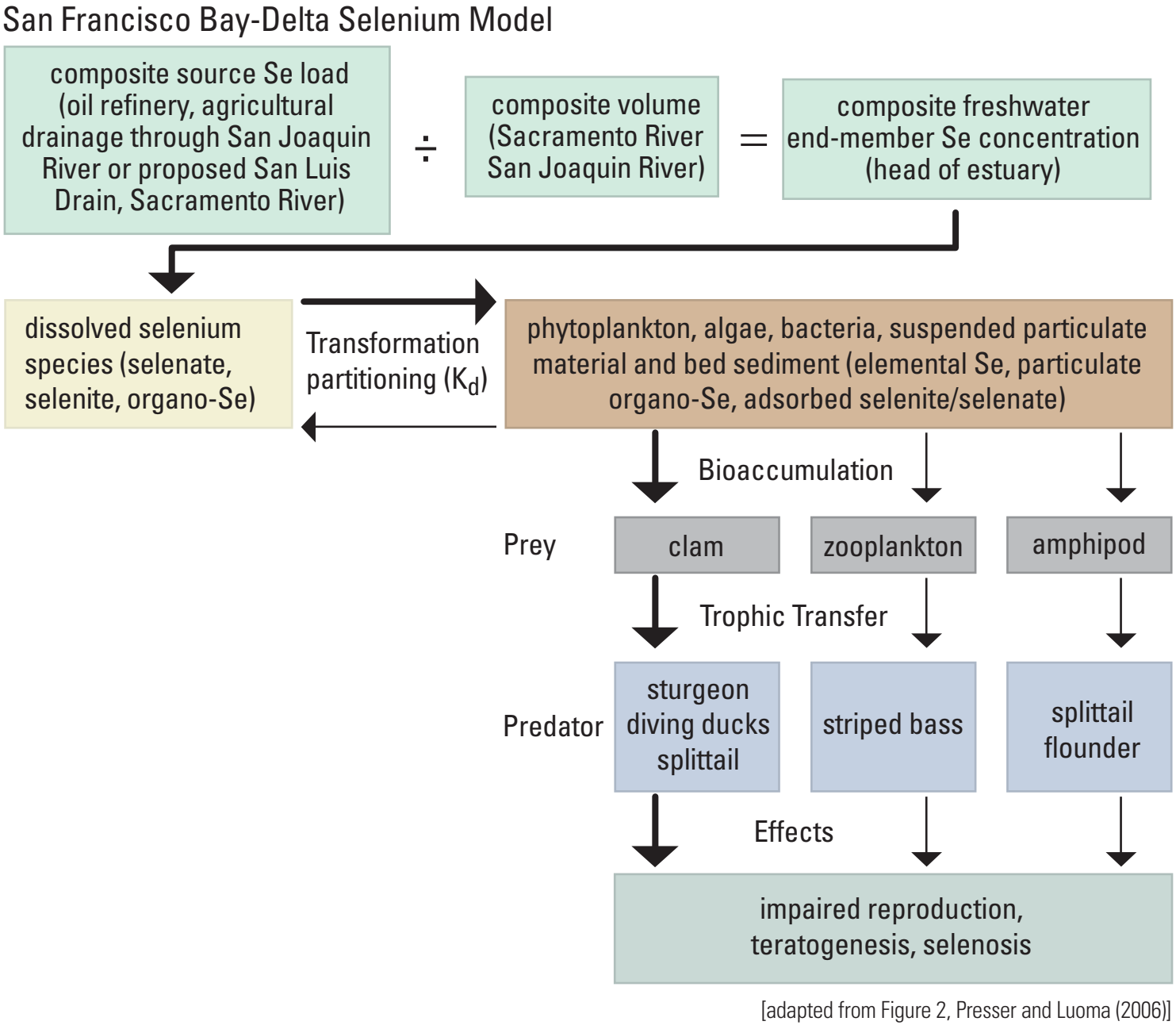

Figure 5. San Francisco Bay-Delta Selenium Model from Presser and Luoma (2006).

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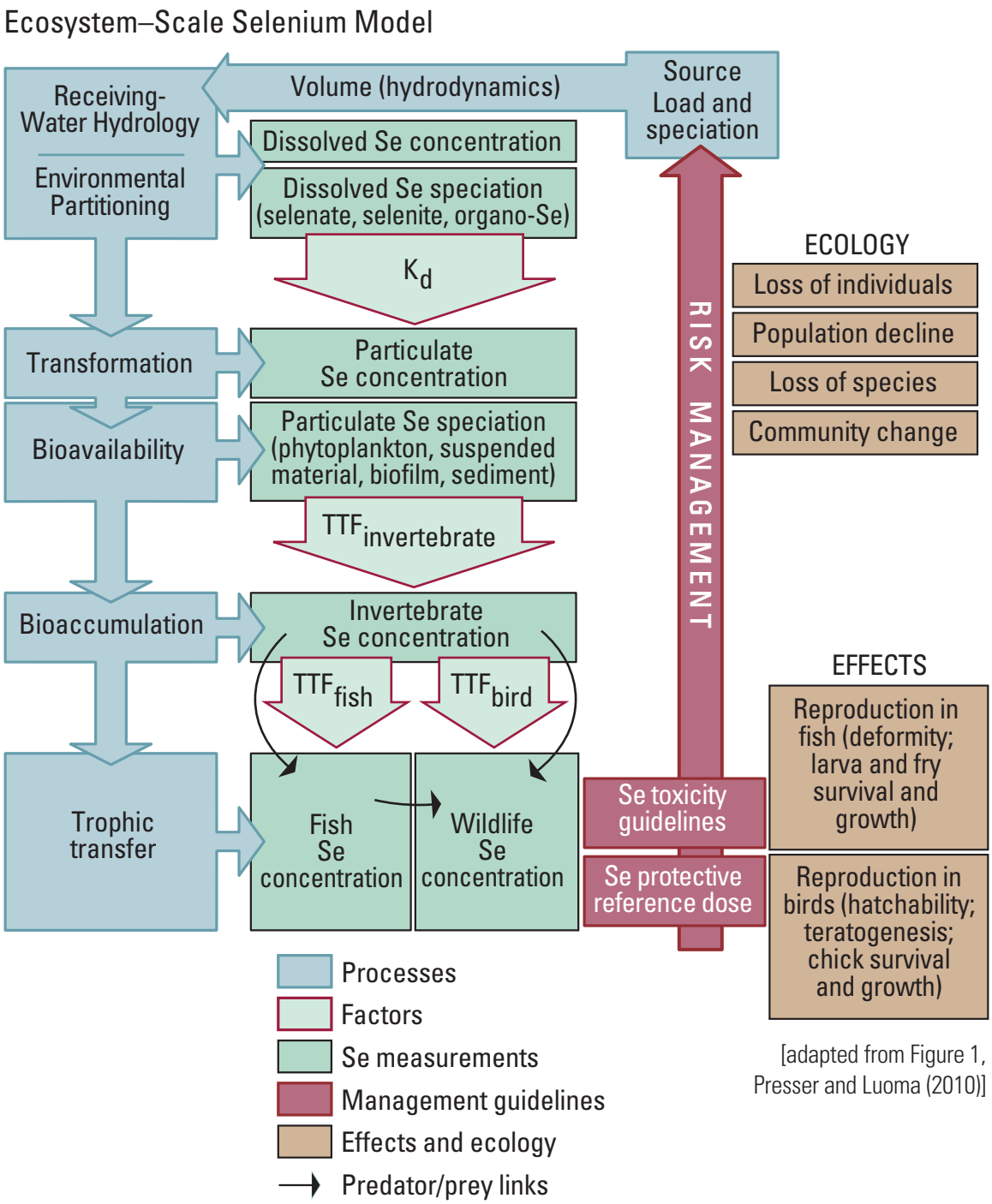

Figure 6. General ecosystem-scale selenium model from Presser and Luoma (2010). [K_d = empirically determined environmental partitioning factor between water and particulate material; TTF = biodynamic food web transfer factor between an animal and its food.]

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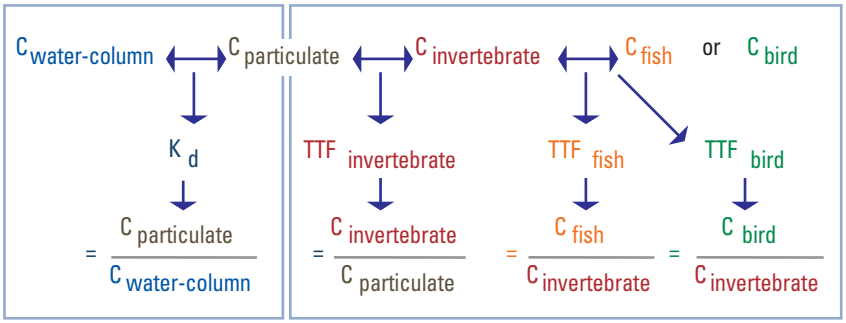
A. Quantifying Processes

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



[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

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

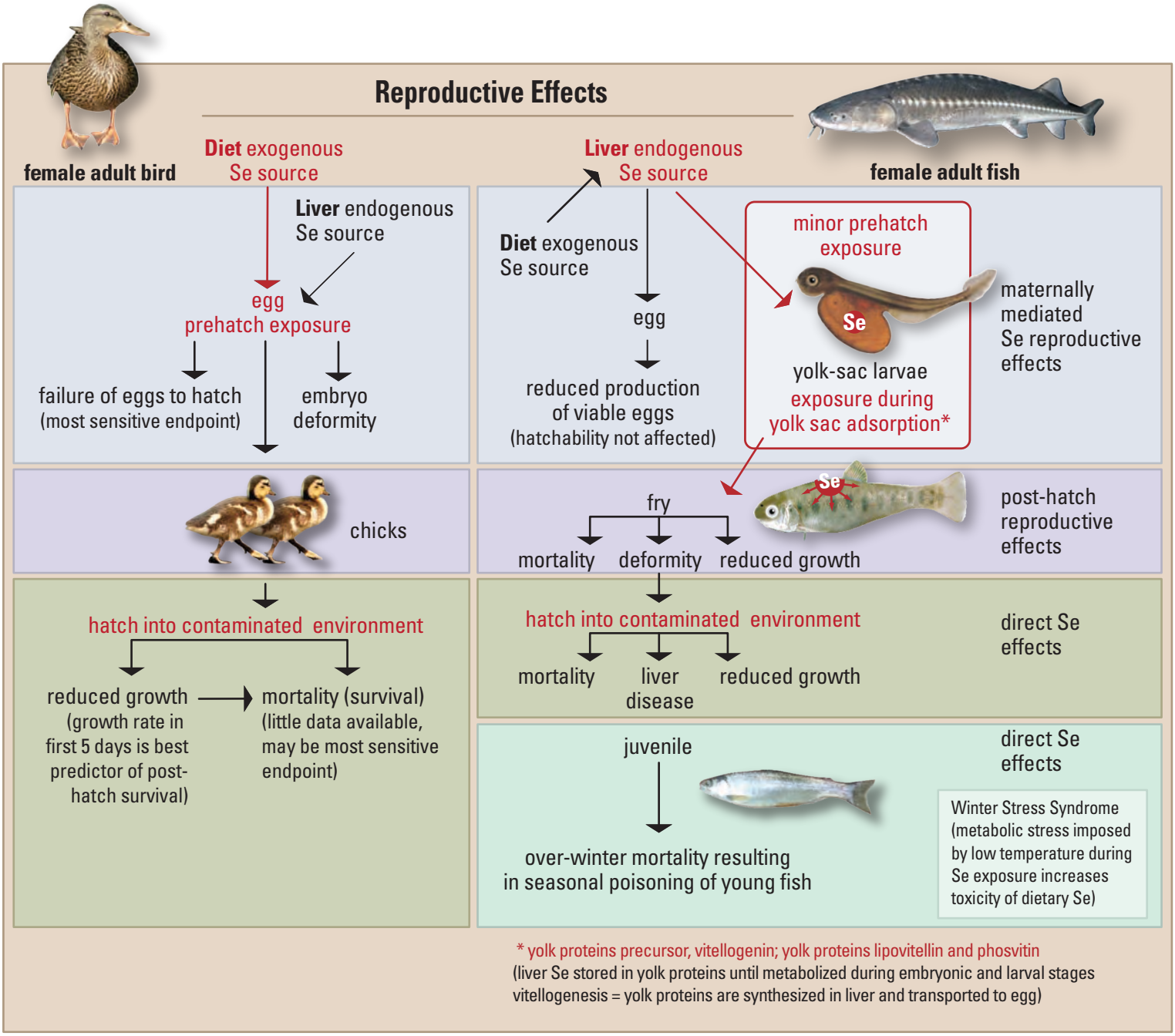
If longer food web

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

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.

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Site-Specific Model Approach

Within specified salinity and residence time

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	

*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.

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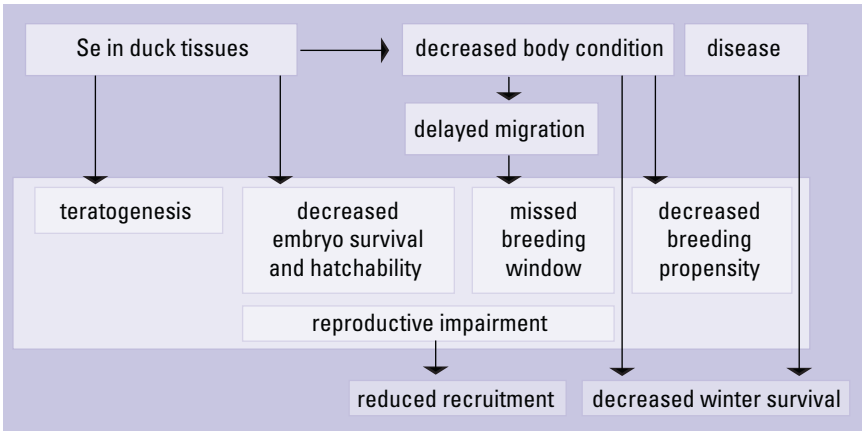
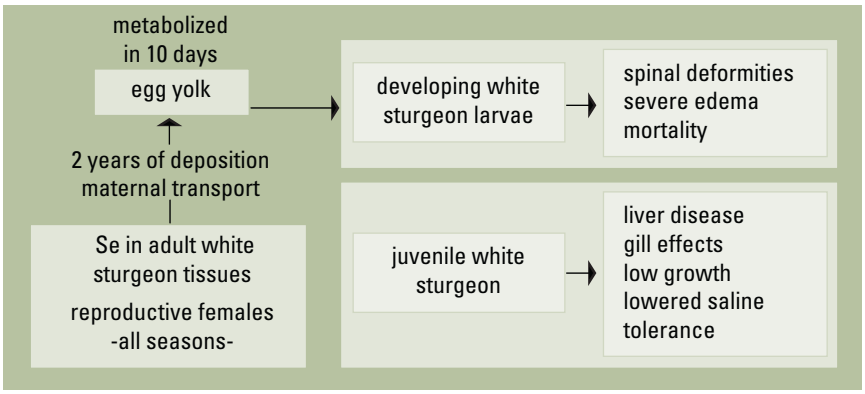
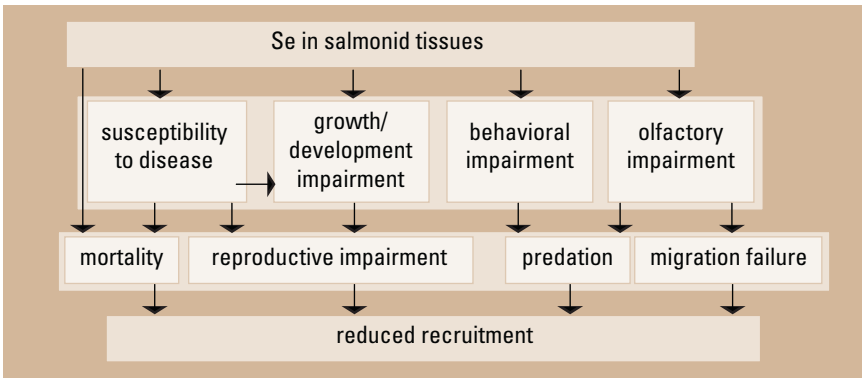
A.
Diving duck
Se effects model



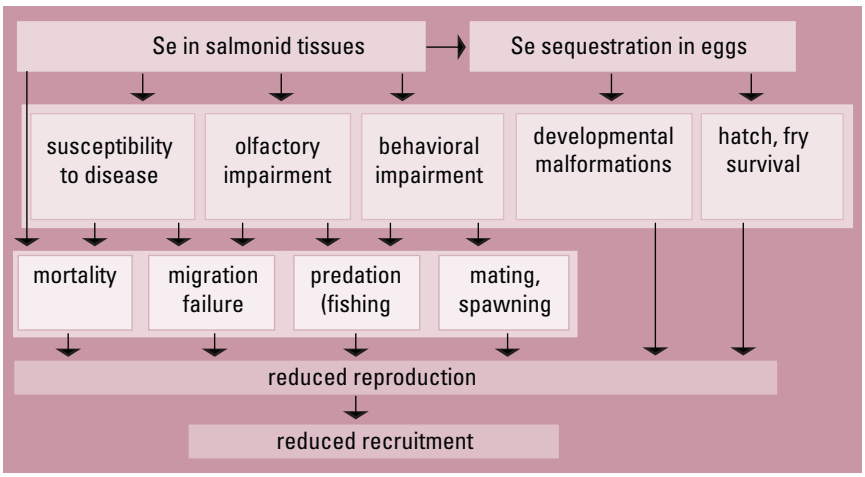
B.
White sturgeon
Se effects model



C.
Juvenile salmonids
(downstream migration)
Se effects model



D.
Salmonids
(upstream migration)
Se effects model



[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*).

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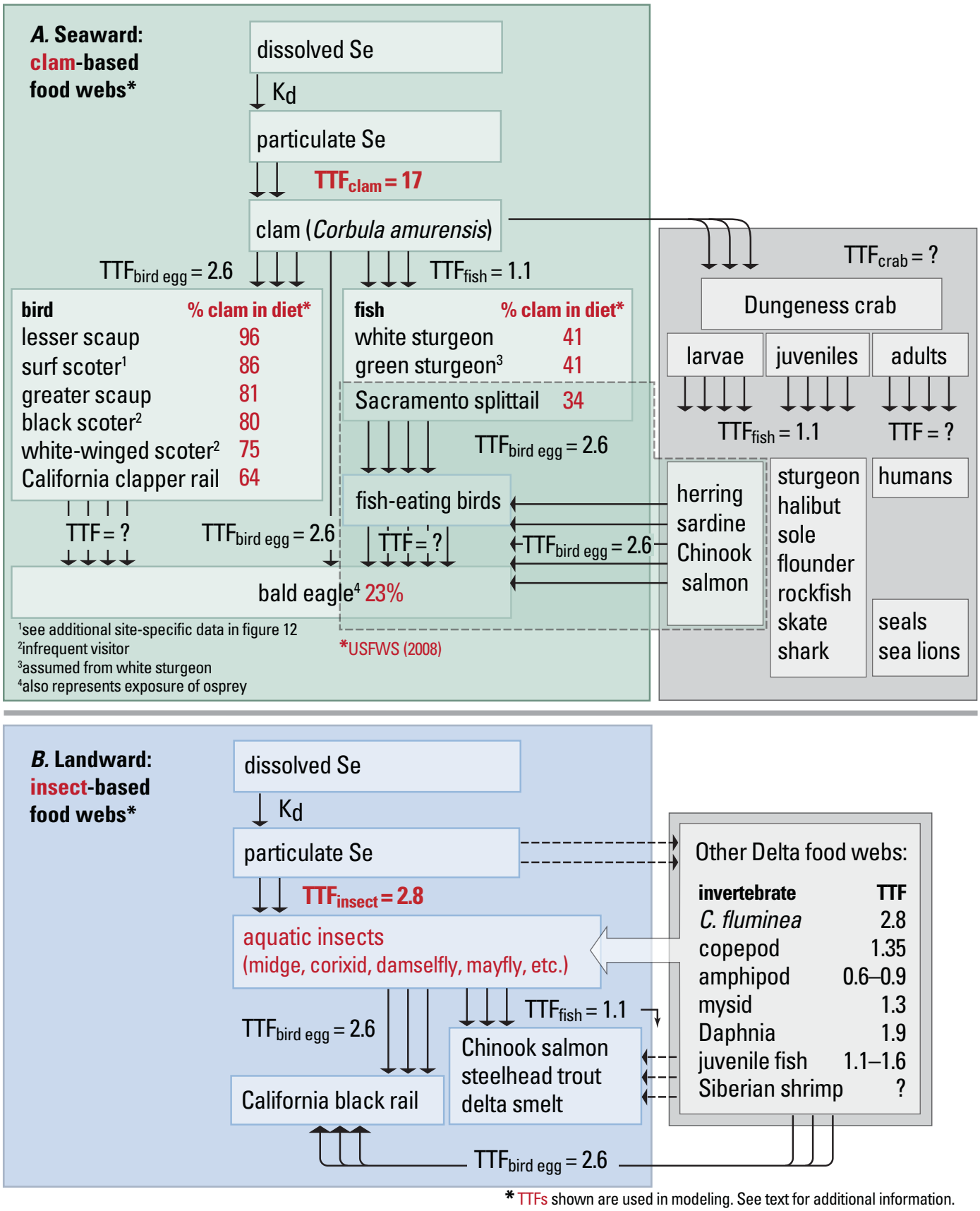

Figure 11. Conceptual details of seaward clam-based food webs (*A*) and landward aquatic insect-based food webs (*B*) for modeling of the Bay-Delta.

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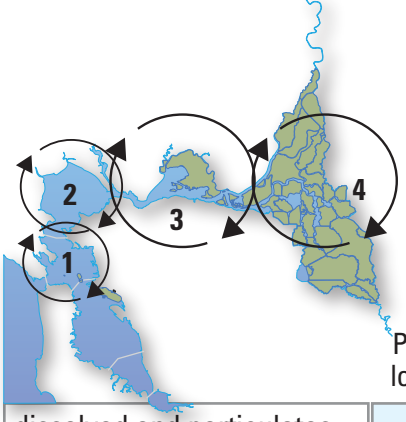

Species at Risk: Exposure and Habitat Use

	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 surf scoter a, b black scoter c white-winged scoter c greater scaup b lesser scaup b	1, 2, 3 ↓ 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.