Bay Area Clean Water Agencies

A Joint Powers Public Agency

Leading the Way to Protect our Bay

May 20, 2010

State Water Resources Control Board
c/o Ms. Jeanine Townsend, Clerk to the Board
1001 I Street
Sacramento, CA 95814

Sent via electronic mail to commentletters@waterboards.ca.gov

SUBJECT: 2010 Integrated Report / Section 303(d) List

Dear State Water Resources Control Board Members:

On behalf of the Bay Area Clean Water Agencies ("BACWA"), thank you for the opportunity to comment on the proposed 2010 Integrated Report: Clean Water Act Section 303(d) List of Water Quality Limited Segments and Clean Water Act Section 305(b) Assessment of Surface Water Quality ("2010 303(d) List"). BACWA is a joint powers authority whose members own and operate publicly-owned treatment works and sanitary sewer systems that, collectively, provide sanitary services to over 6.5 million people in the nine county San Francisco Bay Area. BACWA members are public agencies, governed by elected officials and managed by professionals charged with protecting the environment and public health.

In 2008, BACWA submitted to the San Francisco Bay Regional Water Quality Control Board ("Regional Water Board") comments on proposed revisions to the 303(d) list of impaired waterbodies in the San Francisco Bay Region, which are attached to this letter and incorporated herein by reference. BACWA's comments offered substantial evidence to support removing selenium as an impairing pollutant for the San Francisco Bay. The Regional Water Board declined to delist San Francisco Bay for selenium because a human health advisory for the consumption of Bay-Delta ducks remains in place, and out of concerns of the impacts of selenium on wildlife and, specifically, on diving ducks and sturgeon. BACWA offers these comments to explain why the Regional Water Board's rationale for concluding that delisting the Bay for selenium is insufficient and should be carefully reviewed by the State Water Resources Control Board ("State Board"). BACWA believes that the sum of the available evidence indicates that the selenium concentration in the Bay is not impairing beneficial uses and therefore this pollutant/waterbody combination should be removed from the 2010 303(d) List before adoption by the State Board.

1. **Human Health: Threat to human health from consumption of diving ducks.**

In 1987 and 1988 California State Department of Health Services ("DOHS") issued an interim human health advisory for the consumption of diving ducks because tissue samples collected during this period exceeded the interim human health screening value of 2.5 µg/g wet weight. In 2008, the California Office of Environmental Health Hazard Assessment ("OEHHA") (formerly DOHS) revised the selenium reference dose and dietary background levels. Using these new factors and a consumption rate of 16 g/day for diving ducks (used in the original advisory), the new screening value becomes 14.8 µg/g wet weight. Recent data, from 2002 and 2005, show that the mean tissue concentrations in diving ducks is well below the screening value calculated using the newly adopted reference dose and dietary background levels.

In the response to these comments, the Regional Water Board agreed that application of the new exposure assumptions may lead to removal of the advisory, but declined to delist on the grounds that the "change in the advisory is not yet in place."[1] Section 3.4 of the State Board's listing policy requires that water segments be placed on the 303(d) List if a health advisory against the consumption of an edible resident organism is in place.[2] Section 4.4, however, provides that a segment may be delisted if either the health advisory has been removed or "the chemical or biological contaminant-specific evaluation guideline for tissue is no longer exceeded."[3] In light of limited agency resources and OEHHA's current failure to propose revisions based on new evidence, it appears unlikely that the advisory will be revised in the near future. BACWA, therefore, requests that the State Board not wait for OEHHA action. As shown in BACWA's 2008 comment letter, new exposure assumptions may be used to generate more appropriate screening values which, when compared to available tissue data, call into question the appropriateness of listing the Bay for selenium based on human health concerns.

2. Wildlife: Impact of selenium on diving ducks' egg hatchability and population decline.

As another basis for denying BACWA's request, the Regional Water Board cited stakeholder concerns that the overall decline in diving duck populations wintering in the Bay Delta may be linked to selenium.[4] BACWA's 2008 comments cited multiple peer-reviewed studies showing that the selenium burden in San Francisco Bay ducks does not appear to be causing declines in populations of diving ducks, or preventing the population from growing. In response, the Regional Water Board failed to offer evidence supporting their concern, and even noted that "the Bay seem[s] to be improving and [selenium concentrations] may have a lesser than expected impact on diving ducks."[5] Continued listing of the Bay on the basis of speculative harm to diving duck populations is contradictory to the State Board's 303(d) listing policy.

3. Wildlife: Impact to selenium on White Sturgeon growth and reproduction.

Currently, no fish tissue criterion for selenium has been adopted for California. BACWA's 2008 comments contain a discussion of available literature and, based upon a scientific analysis of the data in the literature, it appears that an appropriate threshold value for fish tissue should be approximately 12 μg/g dry weight. Only three out of forty-four sturgeon tissue samples collected by the San Francisco Estuary Institute's Regional Monitoring Program ("RMP") have exceeded this value.[6]

---

[1] San Francisco Bay Regional Water Quality Control Board, *Evaluation of Water Quality Conditions for the San Francisco Bay Region, Proposed Revisions to Section 303(d) List, Appendix D: Responses to Comments*, February 2009 ("Reponses to Comments"), pp. 52-53.
[2] California State Water Resources Control Board, *Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List*, September 2004, ("Listing Policy"), p. 5.
[3] Listing policy, p. 12.
[4] Responses to Comments, p. 53.
[5] Responses to Comments, p. 53.
[6] The Regional Water Board's basis for the assertion that seventeen percent of the available data for white sturgeon indicate exceedances of the 12 μg/g dry weight threshold is unclear. BACWA has been able to

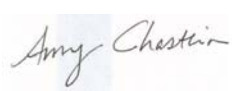
According to Table 4:1 of the listing policy three exceedances for this sample size warrant that a water segment be removed from the 303(d) List.[7]

The Regional Water Board also noted that the average selenium concentration in sturgeon samples (8.6 µg/g dry weight) exceeds the U.S. Environmental Protection Agency's ("USEPA") 2004 draft wildlife criterion of 7.91 µg/g dry weight, which was rejected by the US Fish and Wildlife Service as not being protective of wildlife. Since 1997, however, selenium concentrations in sturgeon tissue collected by the RMP have not exceeded the USEPA draft criterion. The average concentration in muscle tissue collected by the RMP ranged from 5.4 µg/g dry weight in 2000 and 2003, to 6.9 µg/g dry weight in 2006, the most recent sampling event (see attached comments). Moreover, the USEPA draft criterion was for juvenile sturgeon and should not be compared to the adult fish tissue samples collected in San Francisco Bay. Based upon the State Water Board's 1991 Selenium Verification Study data, juvenile sturgeon concentrations are expected to be two to three times lower than those in adult fish. Thus, if data were available for juvenile sturgeon in San Francisco Bay, one would expect the selenium tissue concentrations to be substantially lower than the draft EPA criterion, based on the data available for adult sturgeon.

As a result of the 303(d) listing of selenium, the Regional Water Board and North Bay permittees have dedicated more than two years and several millions of dollars of resources to develop a Total Maximum Daily Load ("TMDL"). The work done to date appears to show that river-borne selenium, from outside the Regional Water Board's jurisdiction, dominates loading in the North Bay. At this point it appears unlikely that the TMDL will lead to the development of regional management actions for selenium in the North Bay. Similarly, it appears that management actions may be unnecessary considering that evidence that San Francisco Bay's beneficial uses are not being impaired by selenium. We respectfully request that, prior to adoption of the 2010 303(d) List, the State Board carefully consider BACWA's 2008 comments and the evidence contained therein, which indicates that there is no clear impairment in San Francisco Bay as the result of selenium.

If you have any questions regarding BACWA's comments, please contact me by e-mail at achastain@bacwa.org, or by telephone at (415) 308-5172.

Sincerely,



Amy Chastain
Executive Director
BACWA

Attachment: BACWA Comments, submitted December 4, 2008.

---

review only RMP data, which comprises 44 samples, only seven percent of which were above the 12 µg/g dry weight threshold.

[7] Listing Policy, p. 14.

Bay Area Clean Water Agencies

Leading the Way to Protect Our Bay *P.O. Box 24055, MS 702*
A Joint Powers Public Agency *Oakland, California 94623*

December 4, 2008

Barbara Baginska
San Francisco Bay Regional Water Quality Control Board
1515 Clay Street, Suite 1400
Oakland, CA 94612-1482

Dear Ms. Baginska:

Response to the Notice of Availability of Proposed Revisions to the 303(d) List of Impaired Water Bodies in the San Francisco Bay Region

The Bay Area Clean Water Agencies (BACWA) would like to take this opportunity to provide comments on the proposed revisions to the 303(d) list of impaired water bodies in the San Francisco Bay Region. Pursuant to the letter dated October 30, 2008, the San Francisco Bay Regional Water Quality Control Board (Regional Water Board or SFRWQCB) is soliciting public comment on the proposed revisions to the list of impaired waters under section 303(d) of the Federal Clean Water Act (CWA).

We are submitting comments and are recommending that, based on new information and data and the establishment of new evaluation guidelines, the Regional Water Board reconsider the impairment assessment for selenium and find that selenium is not impairing the San Francisco Bay beneficial uses and should not be included on the 303(d) list as a pollutant/stressor. Our rationale for this is detailed below and is especially critical given the resources that are being expended on the development of a selenium total maximum daily load (TMDL) for North San Francisco Bay (NSFB).

The available evidence does not show that San Francisco Bay is currently impaired due to selenium. Our comments below provide a detailed analysis to support this point. There must be better strategies to address the planning and policy needs for selenium, such as re-issuing oil refinery permits and preventing impacts from agricultural drainage, without developing and implementing a TMDL for a pollutant that may not be currently impairing beneficial uses of the Bay.

We have reviewed the 303-d list, which is summarized below, followed by specific information as to how those findings have changed over the past two decades.

Currently, San Francisco Bay waterbodies are on the Section 303(d) list for selenium (as identified in **Table 1** below). The primary reasons identified for the listings include existing health consumption advisories for diving ducks, sediment toxicity, and egg hatchability in nesting diving birds (SFRWQCB 2006).

Table 1. 2006 CWA Section 303(d) List for Selenium in San Francisco Bay

San Francisco Water Body Name	Pollutant Stressor	Potential Source	Added in
Carquinez Strait	Selenium[1]	Industrial Point Sources Agriculture	1998
San Francisco Bay, Central	Selenium[1]	Industrial Point Sources Agriculture Natural Sources Exotic Species	1998
San Francisco Bay, South	Selenium[2]	Agriculture Domestic Use of Groundwater	1998
San Pablo Bay	Selenium[1]	Industrial Point Sources Agriculture Natural Sources Exotic Species	1998
Suisun Bay	Selenium[1]	Industrial Point Sources Natural Sources Exotic Species	1998
Castro Cove, Richmond (San Pablo Basin)	Selenium (sediment)	Urban Runoff/Storm Sewers Point Source	2002
Oakland Inner Harbor (both listings)	Selenium[1]	Industrial Point Sources Agriculture Natural Sources Exotic Species	2002

[1] – 303(d) list includes the following note: "Affected use is one branch of the food chain; most sensitive indicator is hatchability in nesting diving birds, significant contributions from oil refineries (control program in place) and agriculture (carried downstream by rivers); exotic species may have made food chain more susceptible to accumulation of selenium; health consumption advisory in effect for scaup and scoter (diving ducks); low TMDL priority because individual control strategy in place."

[2] – 303(d) list includes the following note: "A formal health advisory has been issued by OEHHA for benthic feeding ducks in South San Francisco Bay. This health advisory clearly establishes that water contact recreation beneficial use (REC-1) is not fully supported and standards are not fully met."

The water quality objectives identified in the Regional Water Board Water Quality Control Plan (Basin Plan) that are relevant to this assessment include the following narrative objectives for toxic substances:

> *Bioaccumulation: Many pollutants can accumulate on particles, in sediment, or bioaccumulate in fish and other aquatic organisms. Controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects on aquatic organisms, wildlife, and human health will be considered.*
>
> *Population and Community Ecology: All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce significant*

alterations in population or community ecology or receiving water biota. In addition, the health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors.

Toxicity: All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce other detrimental responses in aquatic organisms. Detrimental responses include, but are not limited to, decreased growth rate and decreased reproductive success of resident or indicator species. There shall be no acute toxicity in ambient waters. Acute toxicity is defined as a median of less than 90 percent survival, or less than 70 percent survival, 10 percent of the time, of test organisms in a 96-hour static or continuous flow test. There shall be no chronic toxicity in ambient waters. Chronic toxicity is a detrimental biological effect on growth rate, reproduction, fertilization success, larval development, population abundance, community composition, or any other relevant measure of the health of an organism, population, or community. Attainment of this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, or toxicity tests (including those described in Chapter 4), or other methods selected by the Water Board. The Water Board will also consider other relevant information and numeric criteria and guidelines for toxic substances developed by other agencies as appropriate. The health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors.

In addition, selenium criteria were promulgated for all San Francisco Bay/Delta waters in the National Toxics Rule (NTR). The NTR criteria specifically apply to San Francisco Bay upstream to and including Suisun Bay and Sacramento-San Joaquin Delta. The marine water quality objectives for toxic pollutants for surface waters for selenium are 5.0 ug/l (4-day average) and 20 ug/l (1-hr. average).

A revised impairment assessment and delisting of selenium from the Section 303(d) list for San Francisco Bay is warranted for the following reasons:

- *Substantial Reductions in Oil Refinery Loads* - Individual control strategies have substantially reduced selenium loadings from the oil refineries since the original listings in 1998 and 2002. The load reductions addressed the more bioavailable form of selenium, selenium (IV). The assessment of impairment should be based on the most recent data that have been collected since the refinery reductions were implemented.
- *Shifts in the Food Web* – Selenium bioaccumulates in certain branches of the food web. The food web of NSFB has shifted since the original listings due to the invasion of the overbite clam (*Corbula amurensis*). As discussed below, this will

change where and how selenium accumulation occurs in higher levels of the food web. The impairment assessment should focus on data collected in the past five years, to account for these changes.

- *Bioaccumulation of Pollutants in Aquatic Life Tissue* - New scientific information and data on the selenium concentration in the tissues of diving ducks, white sturgeon, and nesting diving bird eggs has become available that shows tissue levels of selenium that are protective of both wildlife and the health of human consumers.

- *Human Health* - In June 2008, the California Office of Environmental Health Hazard Assessment (OEHHA 2008) revised the selenium reference dose. This results in recommended fish and duck tissue selenium concentration goal that is being attained throughout the Bay. OEHHA has not gone through the administrative process to re-evaluate the advisory based on new information.

- *Water Column* - The current water quality objective for selenium, 5 µg/L, is attained throughout San Francisco Bay. Even the more stringent goal of 2 µg/L is attained throughout the Bay. The single exception too this is Alviso Slough, at the interface of the Guadalupe River. A Baywide TMDL is not necessary or appropriate to address exceedance in a single slough of South San Francisco Bay.

- *Water/Sediment Toxicity*- New scientific information and data has become available that clarifies there are no toxic effects observed that have been linked to selenium concentrations in water or sediment.

I. Recent Changes: Food Webs and Oil Refinery Loads

The implementation of local control programs at the oil refineries in 1998 in NSFB resulted in a significant decrease in the loads of highly-bioaccumulative selenium(IV) species from those point sources (Tetra Tech 2008a). These reductions were achieved without the development and implementation of a TMDL. They resulted in measurable reductions in the receiving water concentrations of selenium(IV) in NSFB. The evidence for impairment due to selenium in San Francisco Bay was not clear prior to these reductions; the reductions were ordered as a precautionary measure. Ever since the reductions have taken place, new information from monitoring in fish and diving duck tissues helps clarify that the Bay is not impaired.

The benefits of refinery load reductions may have been offset, to some degree, by changes in the food web. Starting in the mid 1980s, the food web in the bay as been greatly affected by the invasion of the overbite clam, *Corbula amurensis* (Linville et al., 2002). These clams are a significant food item for sturgeon and have a tendency to biomagnify selenium concentrations in their tissues over concentrations observed in other dietary items (Stewart et al., 2004). Despite the exacerbating effect of this food web shift, selenium levels in sturgeon do not appear to exceed concentrations that pose an ecological or human health risk. In light of the recent changes in selenium loads and food web structure, it is best to assess the current levels of impairment based on the most recent data.

II. Human Health

The risk guidance use to develop tissue targets that are protective of human health have changed since the original listings. In 1985 the SWRCB, as part of the Subsurface Agricultural Drainage Program, commissioned a Selenium Verification Study (SWRCB 1991). This study was conducted by California Department of Fish and Game. The study, among other things, monitored the selenium concentration in diving ducks and recreationally important fish species from the San Francisco Bay.

Figure 1 shows the selenium concentration in tissue of diving ducks (surf scoters) and white sturgeon collected from the San Francisco Bay complex from 1986 to 1990 in relation to California Department of Health Services' then Interim Human Health Screening Values (SWRCB 1991) which were:

- 2.5 μg /g (wet weight) for diving ducks; and
- 2.0 μg /g (wet weight) for white surgeon

As is evident from this early data, the selenium level in diving ducks and white sturgeon exceeded the Human Health Interim Screening Values. Consequently, in 1987 and 1988, the California Department of Health Services issued health advisories for the consumption of diving ducks and white sturgeon (Fan and Lipsett 1988). In response to the issuance of the human health advisories related to diving ducks and white sturgeon consumption, the Regional Water Board listed portions of San Francisco Bay on the Section 303(d) List for selenium (SFRWQCB 1998).

In June 2008, the OEHHA changed the selenium reference dose (Rfd) to 5 μg per day (for a 70 Kg standard adult body weight) from the previous 3 μg per day. Additionally, the OEHHA changed the selenium background dietary level to 114 μg per day from the previous 170 μg per day (OEHHA 2008).

Considering a diving duck tissue consumption rate of 16 g per day (used in the 1987-1988 advisory) and a white sturgeon consumption rate of 32 g per day (currently recommended by the OEHHA), the new selenium advisory level for diving ducks and fish are calculated as follows:

New Diving Duck Tissue Advisory Level =

$$\frac{(Rfd\ x\ 70) - Background\ Dietary\ Level, 114\ \mu g/day}{Tissue\ Consumption\ Rate, 16\ g/day}$$

$$\frac{350-114}{16} = 14.8\ \mu g/g \text{ wet weight}$$

New Fish Tissue Advisory Level =

$$\frac{(Rfd\ x\ 70) - Background\ Dietary\ Level, 114\ \mu g/day}{32} = \frac{350 - 114}{32} = 7.4\ \mu g/g\ wet\ wt.$$

In 2002 and 2005, the Regional Monitoring Program (RMP) monitored the selenium concentration in the diving ducks. Although the results are not published yet, data was obtained from Ms. Jennifer Hunt of the San Francisco Estuary Institute (SFEI 2008). This RMP data includes selenium concentrations in the greater scaup as well. The selenium concentrations in white sturgeon was obtained from RMP 1997, 2000, 2003, and 2006 annual reports (SFEI RMP Annual Reports).

Figure 2 and **Figure 3** show the recent diving ducks and white sturgeon selenium tissue concentrations in relation to the new, 2008 OEHHA tissue advisory levels, respectively. As is evident from the data, the diving ducks and white sturgeon tissue concentrations of selenium have been well below the 2008 OEHHA tissue advisory levels since the mid 1990's. Therefore, there is no evidence of human health impairment of San Francisco Bay due to selenium.

Thus, delisting on the basis of human health is warranted under the SWRCB Water Quality Policy for Developing California's Clean Water Act Section 303(d) List (September 2004) (Listing Policy), Section 4.4 Health Advisory, which states that water segments or pollutants shall be removed from the Section 303(d) List if the health advisory used to list the water segment has been removed or the chemical or biological contaminant-specific evaluation guideline for tissue is no longer exceeded. It is important to give the public accurate information as to which chemicals are of concern in fish tissue, and which are not, so that priorities for pollutant control programs can be understood.

III. Water Column

The numeric water quality objectives are attained throughout San Francisco Bay. The selenium water quality criteria promulgated for San Francisco Bay upstream to and including Suisun Bay and Sacramento-San Joaquin Delta are 5.0 ug/l (4-day average) and 20 ug/l (1-hr. average). However, Lemly and Skorupa (2007) critiqued this criterion and suggested that the criterion should be lowered to 2 µg/L.

The RMP has been monitoring the water column selenium concentration in the San Francisco Bay. From 2002 to 2006, the highest concentration observed in the water column of the open Bay was 1.15 µg/L. The Bay-wide average concentration for 2007 was 0.10 µg/L, slightly lower than the long-term average of 0.12 µg/L (see attached **Figure 6** from the SFEI 2008 Pulse of the Estuary Report). Even if the RWQCB adopted Lemly and Skorupa (2007) suggested criterion of 2 µg/L, the San Francisco Bay ambient concentration is well below this level and no evidence of impairment is evident based on waterborne selenium concentrations.

The only exception to this is in Alviso Slough, at the margin of South San Francisco Bay, where selenium concentrations in the water column of the Slough exceed 5 µg/L. If this is a cause of impairment, then a focused source assessment and control program is a more appropriate tool than a Baywide TMDL.

IV. Water/Sediment Toxicity

There is currently no evidence linking water and sediment toxicity to selenium in San Francisco Bay. Under the California Bay Protection and Toxic Cleanup Program (BPTCP), the SWRCB commissioned a study entitled "Sediment Quality and Biological Effects in San Francisco Bay." (SWRCB 1998) This study observed sediment toxicity to amphipods and/or sediment pore water toxicity to sea urchin embryo at several segments of the Bay. In 2002, this observed toxicity resulted in the SWRCB designating specific segments of the Bay as impaired due to selenium concentrations in sediment and adding those sites to the Section 303(d) List.

Although segments of the Bay were included on the Section 303(d) List for selenium in 2002, there are no established selenium sediment concentration toxicity thresholds. However, Gandesbery (1998) and Gandesbery, et al (1999), proposed an ambient selenium sediment concentration screening value of 0.64 µg/g dw. This value was used to distinguish "ambient" from "contaminated" sites. The Bay segments in which the sediment selenium concentration exceeded the 0.64 µg/g dw were designated as "contaminated" or having elevated selenium concentrations. However, it is important to note that "elevated selenium concentration" in sediment does not establish a cause for toxicity due to selenium.

In fact, the sediment samples that showed toxicity in the BPTCP study (SWRCB 1998) had several other contaminants, such as copper, chromium, mercury, lead, nickel, PAH, and PCB, the concentrations of which exceeded the established toxicity thresholds. The limited toxicity identification studies of these BPTCP sediment samples confirmed toxicity due to copper, chromium, and mercury. None of these studies confirmed selenium as the source of the observed toxicity.

Abu-saba and Ogle (2005), after a thorough review of the BPTCP data and the basis of Section 303(d) listing of these segments of the Bay, concluded, "Based upon the overwhelming weight of evidence presented…it is concluded that selenium is not impairing the BPTCP sites that were added to the Section 303(d) List in 2002 and delisting these sites for impairment by selenium is warranted."

Currently, the United States Forest Service (USFS) and the United States Fish and Wildlife Service (USFWS) recommends 2 µg/g dw as a selenium sediment toxicity threshold (Lemly 2008).

The RMP has extensively monitored sediment selenium concentrations in San Francisco Bay. **Figure 4** presents the recent (2005 – 2006) selenium sediment concentration in North San Francisco Bay in relation to the USFS and USFWS's recommended sediment selenium concentration toxicity threshold. The data clearly show that the NSFB sediment selenium concentration is well below the USFS and USFWS sediment selenium concentration toxicity threshold of 2 μg /g dw. South Bay sediment selenium concentrations are also below the 2 μg/g dw toxicity threshold for the same period. In 2005, the mean selenium concentration (+/- SD) of South Bay sediments was 0.56 +/- 0.36 μg/g dw (range was from 0.36 μg/g to 1.58 μg/g dw Se). Mean sediment selenium concentrations in South Bay for 2006 were 0.13 +/- 0.02 μg/g dw (range was from 0.10 μg/g to 0.15 μg/g dw Se).Therefore, the current sediment selenium concentration does not justify a cause for finding of aquatic life impairment for all Bay segments.

V. Bioaccumulation of Pollutants in Aquatic Life Tissue

Because selenium primarily accumulates through diet, not water, measurements of selenium concentrations in fish and bird tissue provides a direct link to assessment of impairment of effects due to selenium. Therefore, tissue based assessments provide an appropriate means of assessing compliance with narrative objectives for toxic substances. Section 6.1.3 of the Listing Policy allows for the selection of alternative guidelines to interpret narrative water quality objectives and protect beneficial uses.

The SWRCB Selenium Verification Study (SWRCB 1991) raised the possibility of fish and diving duck reproductive impairment due to excessive selenium exposure in the bay. The data showed that the adult sturgeon selenium tissue concentration was near levels suspected to cause reduction in reproductive success. Similarly, the selenium concentration in the diving ducks was at or near levels of probable teratogenesis and possible reduction in egg hatching success. Consequently, in 2006, the SFRWQCB added egg hatchability in diving ducks as a Section 303(d) listing criterion for selenium (SFRWQCB 2006). Although the reproductive success of fish (white sturgeon) was not a listing criterion for Section 303(d) listing for selenium, it has been a concern for the SFRWQCB since the Selenium Verification Study (SWRCB 1991) was completed.

(i) Role of Selenium in Population Decline of Diving Ducks

The Selenium Verification Study (SWRCB 1991) raised a concern that selenium in San Francisco Bay may be a possible factor in the population decline of diving ducks. The USFWS staff has also raised this concern as recently as September 16, 2008 (SFRWQCB 2008).

DeVink, et al (2008), studied the impacts of selenium on the body condition and reproduction in boreal breeding scaup, scoters, and ring-necked ducks. They concluded, "Moreover, higher concentrations in scoters do not appear detrimental to female body condition or breeding prosperity. Therefore, we believe that selenium is likely not the cause of decline or lack of population recovery of scaups or scoters." The diving ducks (scoters) liver selenium concentration in DeVink, et al, (2008) study averaged 32.6 μg/g dw with a range of 4 to 75 μg/g dw. These concentrations are comparable to the San Francisco Bay scoter liver selenium concentration observed in the 1990 sampling program (SWRCB 1991) (time of elevated selenium concentration in diving ducks). In the 2002 and 2005 RMP sampling program, the selenium concentration in the San Francisco Bay surf scoter muscle tissue dropped about 60 percent from the 1990 level (SFEI 2008). RMP did not analyze liver for selenium; however, it can be assumed that the selenium concentration in liver also dropped correspondingly. Therefore, it is reasonable to predict that the concentration of selenium in San Francisco Bay scoter liver is currently below 32.6 µg/g dw linked with no impacts on the condition or breeding prosperity of diving ducks and the observed decline or lack of population recovery (DeVink, et al, 2008).

Therefore, the most current available data show that the selenium concentration in San Francisco Bay does not appear to be impacting the body condition and the breeding success of the San Francisco Bay diving ducks.

(ii) Egg Hatchability

As discussed earlier, the Selenium Verification Study (SWRCB 1991) results showed that the selenium concentration in diving ducks was at or near levels of probable teratogenesis and/or reduction in egg hatchability. At that time, there were no well-established selenium egg concentration teratogenesis (embryo) or egg hatchability success thresholds. Skorupa (2005) recommended an avian egg threshold of 8 µg/g dw (derived from a geometric mean of 6 µg/g no observed adverse-effect level [NOAEL] and 10 µg/g lowest observed adverse-effect level [LOAEL]). The Great Salt Lake Water Quality Steering Committee (2008) recommended to the Utah Water Quality Board an avian egg threshold of 12.5 µg/g dw. DeVink, et al (2008), used 9 µg/g dw as a threshold for avian embryonic malfunction for eggs. Stanley, et al (1996), reported a selenium egg concentration threshold of about 5 µg/g wet weight (7.5 µg/g dw) for Mallards. Their results also showed that selenium concentrations in Mallard eggs at approximately 3.5 µg/g wet weight (about 5 µg/g dw) improved duckling weight gain, duckling survival, and reproduction compared to the control.

The United States Geological Service Western Ecological Research Center in Vallejo, California, has been involved with collecting and analyzing San Francisco Bay diving ducks (surf scoters) eggs for selenium concentration. Recently, Wainwright-De La Cruz, et al (2008), reported a mean egg selenium concentration of 1.71 ± 0.122 µg/g dw for diving ducks. Hothem, et al (1995), analyzed selenium in wading bird eggs from the San Francisco Bay complex and reported a mean selenium concentration of 3.9 ± 0.9 µg/g for black-crowned night heron and 3.9 ± 0.7 µg/g for snowy egret.

Figure 5 presents the egg selenium concentration of diving ducks and wading birds in San Francisco Bay in relation to selenium toxicity and stimulatory concentration thresholds. As is evident from this data, the mean selenium concentration in eggs of the diving ducks and other wading birds in the San Francisco Bay is well below current teratogenesis/egg hatchability/duckling growth, survival, and production thresholds. In fact, the mean selenium concentration in the eggs appears to be in the range of beneficial effects on reproduction and survival of the ducklings (Stanley, et al, 1995). Furthermore, the egg mean selenium concentration of diving ducks in the San Francisco Bay complex is approximately 40 percent lower than the concentration in eggs of diving ducks in Canada, which has been shown to have no impact on the breeding prosperity of the diving ducks (DeVink 2008).

The above-discussed Wainwright-De La Cruz, et al (2008) and Hothem, et al (1996) data, in fact, confirms the SWRCB Selenium Verification Study (SWRCB 1991) observation, "USFWS studies suggest that waterfowl leaving San Francisco Bay and feeding on a low-selenium diet on the way to their breeding grounds may still breed successfully even though they accumulated high levels of selenium in recent years." Therefore, there is no evidence that the current selenium concentrations in the San Francisco Bay complex are causing harmful impacts on diving and wading bird egg hatchability or reproductive success.

(iii) Impacts of Selenium on San Francisco Bay Fisheries

In response to the USFWS and the National Marine Fisheries Service (NMFS) comments (FWS and NMFS 2000), the USEPA (2004) originally proposed a numeric fish tissue criterion of 7.9 μg/g dw as a tissue selenium target. Lemly and Skorupa (2007) critiqued this proposed value and suggested that the target should be lowered to 5.8 μg/g dw, mainly, because of Winter Stress Syndrome concerns. The USEPA's (2004) proposed fish numeric target was based upon whole body concentration of selenium in juvenile Bluegill. Lemly (1993) discovered that this species was more sensitive to selenium exposure in winter than in summer. In response to the Lemly and Skorupa (2007) critique, the USEPA decided to investigate the effect of Winter Stress Syndrome on bluegill. Recently, the USEPA (2008) issued the results of this study. The study concluded that (a) the juvenile bluegill did not decrease in body condition factor and lipid content (Winter Stress Syndrome) as reported by Lemly (1993); (b) the toxicity of selenium to juvenile bluegill was approximately 1.9 times less than observed by Lemly (1993); i.e., the new toxicity threshold for bluegill is approximately 11.1 μg/g dw compared to 5.8 μg/g proposed by Lemly (1993); and (c) most importantly, the USEPA (2008) study showed that under a similar temperature and exposure period, bluegill receiving a natural diet accumulated 2.5 times less selenium compared to an artificial diet spiked with seleno-L-methionine, the diet employed by Lemly (1993). Although the USEPA has not yet revised its proposed fish numeric criterion of 7.9 μg/g dw, it appears that Lemly and Skorupa's (2007) suggested fish numeric criterion of 5.8 μg/g dw should be revised upward in the range of 9 to 11 μg/g dw. This revised target would still be conservative considering the fact that the bluegill's natural feeding behavior will allow 2.5 times less selenium accumulation compared to the laboratory test conditions of Lemly (1993) and USEPA (2004).

Tetra Tech (2008) performed a thorough review of selenium fish toxicity studies and calculated the effect thresholds for each study/ species (**Table 3**). However, note that 14 out of 19 studies considered by Tetra Tech involve fish species that are not indigenous to NSFB. It is important to evaluate the toxicological impacts to resident bay species as part of a determination of impairment. Bluegill, channel catfish (fingerlings), fathead minnows, and rainbow trout do not inhabit the NSFB. Therefore, the thresholds for these species are not specifically applicable as fish tissue numeric targets for NSFB. Further, it appears that the freshwater species (bluegill, channel catfish, fathead minnow, rainbow trout) are generally more sensitive to selenium than the Bay resident species. Therefore, to use these freshwater species to develop selenium numeric fish tissue targets for the NSFB may result in over protection. Additionally, a fish tissue target for species not found in NSFB would be of little use since these target fish species are rarely, if ever, caught in NSFB and would be useless for verification of compliance with the fish tissue numeric target.

The species of most concern for NSFB are Sacramento splittail; the sturgeon is a species of concern for the entire Bay. The feeding behavior of these two species exposes them to significant levels of selenium compared to other resident species of the NSFB. For example, striped bass bioaccumulates selenium approximately 10 times less than white sturgeon (SWRCB 1991).

Barbara Baginska (2008) recently proposed a fish tissue numeric target of 6.0 µg/g dw for the protection of fishery resources of the San Francisco Bay. This target is based, in part, on the Linville (2006) study. TetraTech Inc. (2008b), using the same data, arrived at an adult white sturgeon toxicity threshold of 6.2 µg/g dw.

We agree with Baginska (2008) and Tetra Tech (2008) that white sturgeon is the most appropriate species for the fish tissue numeric target because (a) white sturgeon is a resident species of NSFB; (b) the feeding behavior, including a significant portion of their diet as bivalves, exposes this species to relatively high concentrations of selenium in their diet; (c) muscle tissue can be obtained for selenium analysis without killing the specimens; (d) the RMP has developed a good historical database on the muscle tissue concentration of selenium over several years; and (e) this species has been tested for acute and chronic toxicity (Linville 2006, and Tashjian, et al, 2008).

However, we do not agree that the proposed Barbara Baginska's 6 µg/g dw or TetraTech's 6.2 µg/g dw is a valid numeric target because our review of Linville (2006) data results in a substantially different numeric target.

Linville (2006) exposed female adult white sturgeon to diets containing either 1.4 µg/g dw (control) or 34 µg/g dw selenium (treatment) for about six months. The test end points were reproductive performance (fecundity, fertilization success, and neurulation), weight and length of larvae and larvae developmental abnormalities (ederma and skeleton deformities: Lordosis, kiphosis and scoliosis). Linville (2006) found that 34 µg/g dw dietary selenium exposure of adult female white sturgeon had no significant impact on reproductive performance and weight or length of larvae compared to control. Parallel to the maternal exposure experiments she also microinjected white sturgeon larvae with seleno-L-methonine. The test end points were the same as the material exposure experiments. There were significant effects on larval deformities in both experiments. Linville (2006) concluded, "A hazard threshold of 3 to 8 µg/g in developing white sturgeon is suggested for this species."

Linville (2006) toxicity threshold (3 to 8 µg/g dw) and the resulting Baginska (2008) proposed fish tissue numeric target (6 µg/g dw) appear to be based upon the pooled maternal exposure and direct larvae microinjection results. Our review of Linville (2006) study shows that pooling the larval microinjection data with the maternal exposure data results in the toxicity threshold substantially biased low. Although, the larvae direct microinjection experiment may have academic utility, it is not applicable to the Bay's natural conditions because (a) larvae in the Bay are not microinjected with seleno-L-methionine; instead, the larvae in the Bay are exposed to selenium from the yolk sac in a natural complex form; and (b) the larvae in the Bay are not instantly exposed to a toxic selenium-L-methionine concentration; instead, the larvae in the Bay gradually obtain selenium from the yolk sac over a period of several days if not weeks. Microinjection most likely overwhelmed the larvae with a toxic dose, which is not representative of the more gradual natural selenium exposure larvae actually experience.

The discussion in paragraphs (a) and (b) above explain why Linville (2006) observed 45 to 70 percent more mortality of larvae in microinjection experiments compared to maternal exposure and overall, the larval development abnormalities were two to three times more in microinjection experiments compared to maternal dietary exposure.

Clearly, the maternal dietary exposure experiments are more applicable to the Bay's natural conditions than the larvae direct microinjection.

Our review of Linville (2006) maternal dietary exposure data (**Table 2**) shows that the Treatment T1 (larvae selenium concentration of 11.6 µg/g) is NOAEL (zero abnormalities). Since Treatment T3 produced more larvae abnormalities (13 percent) compared to Treatment T1 (0 percent) at a substantially lower selenium concentration (7.75 vs. 11.6 µg/g), Treatment T3 cannot be considered the LOAEL. Because the LOAEL can not be lower than the NOAEL, in this case, treatment T2 (larvae selenium concentration of 18.4 µg/g) becomes the LOAEL. Therefore, the associated adult muscle tissue NOAEL and LOAEL are 9.95 µg/g dw and 15.30 µg/g dw, respectively (see **Table 2** under the column titled, Larvae & Muscle). The resulting white sturgeon larvae development toxicity threshold, in terms of adult muscle tissue concentration, is 12 µg/g dw (geometric mean of 9.95 and 15.3 µg/g dw). This threshold is lower than Tashjian, et al (2006) for juvenile white sturgeon (20.3 µg/g dw).

This choice of LOAEL value from the Linville (2006) data is supported by the general rule in evaluating data on ecological risk that is it not feasible to describe population impacts below an approximately 20% effect level (as is true for the development of water quality standards and evaluation of toxicity tests) (Suter et al., 2000). Therefore, the choice of the T2 effect level is generally supported by the toxicological literature, and the choice of NOAEL and average for the threshold concentration logically follow.

Tashjian, et al (2006), conducted an extensive study on the effects of selenium on chronic toxicity in juvenile white sturgeon. The study end points were survival, growth, behavioral effects, activity level, and liver, gill and muscle tissue histopathology. The results show that for all test end points, the selenium dietary exposure toxicity threshold (geometric mean of NOAEL and LOAEL) is 14.0 µg/g dw. The corresponding muscle tissue concentration threshold is 20.3 µg/g dw.

Since our calculated Linville (2006) toxicity threshold for white sturgeon muscle tissue (12 µg/g dw) is lower than Tashjian (2006) for juvenile white sturgeon (20.3 µg/g dw), it should be protective of all the end points studied in Linville (2006) and Tashjian (2006) combined.

Recently, USFWS staff raised the concern of impacts of selenium on population decline of green sturgeon (SFRWQCB 2008). Currently, Kueltz (2008) at University of California Davis is investigating impacts of selenium on green sturgeon under a CALFED funded project. The final report is not published yet; however, we obtained preliminary data from the Semiannual Project Report No. 2 to CALFED (Kueltz 2008).

Kueltz (2008) microinjected newly hatched larvae of green sturgeon with seleno-L-methionine at 8 µg/g dw body burden. Percent mortality and abnormalities were observed at full absorption of yolk stage. Additionally, Kueltz (2008) investigated the effects of dietary exposure of selenium on juvenile green sturgeon.

The preliminary report shows that (a) for juvenile green sturgeon the selenium dietary exposure toxicity threshold is about 20 µg/g dw; this threshold is higher than reported by Tashjian, et al (2008), for juvenile white sturgeon (14 µg/g dw); and (b) the preliminary larvae seleno-L-methionine data indicates that the selenium toxicity threshold most likely would be in the range of 10 to 12 µg/g dw,. However, the microinjection of green sturgeon larvae with seleno-L-methionine is not representative of NSFB natural conditions and results in an overly-conservative toxicity threshold, which is not appropriate for the NSFB TMDL. In general, fish impairment should be assessed based on effects observed through dietary pathways (instead of, for example, microinjection experiments).

Figure 7 compares the current selenium muscle tissue concentration of adult white sturgeon with our calculated toxicity threshold (12 µg/g dw) from Linville (2006) data. **Figure 8** compares the current selenium dietary exposure from NSFB bivalves to the Tashjian, et al (2008)-reported dietary exposure toxicity threshold. As is evident from Figures 7 and 8, the current selenium muscle tissue concentration of white sturgeon and its selenium dietary exposure are well below these toxicity thresholds. Therefore, the best available data suggests that selenium concentration in they Bay does not have harmful impacts on the Bay's fishery resources.

Recently Beckon (2008) presented a paper at the CALFED Conference on the toxicity of selenium to salmonids. After review and re-analysis of Hamilton, et al (1990), Beckon concludes, "Salmon suffer 10 percent mortality due to selenium at a fish tissue concentration of about 1.8 µg/g (whole body dw). These data suggest that selenium may have killed about one quarter of the young Chinook salmon migrating down the San Joaquin River."

However, our analysis of the same data (Hamilton, et al, 1990), contradicts some of Beckon's (2008) key conclusions. Hamilton, et al (1990), conducted two separate experiments on the effect of selenium on the survival of Chinook salmon in fresh water and in brackish water. The test organism (larvae/finglerling) were separately exposed to three diets: (a) control, which was prepared from mosquito fish caught from a low selenium reference station; the selenium concentration of this diet was 1.0 µg/g dw; (b) San Luis Drain diet (SLD), which was prepared from mosquito fish caught from a selenium-contaminated environment; the exposure concentration of this diet ranged from 3.2 to 35.4 µg/g dw; and (c) selenium-DL-methionine (SeMet), which was prepared from selenium-DL-methionine; the exposure concentration ranged from 3.2 to 35.4 µg/g, similar to the SLD diet. The test organisms were separately exposed in the two test conditions, fresh water and brackish water. The survival was measured after 30, 60, and 90 days. Our review of Hamilton, et al (1990), data extracted from their Tables 3, 4, and 6 shows the following:

1. At a whole body dw selenium concentration in the range of 1.7 to 2.0 µg/g, dietary exposure concentration of 3.2 µg/g (SeMet diet), selenium actually increased the survival rate of Chinook salmon in this experiment compared to the control. This conclusion contradicts the Beckon (2008) conclusion that whole body dw of 1.8 µg/g causes an unacceptable level of mortality in Chinook salmon.

2. At a whole body dw selenium concentration in the range of 4.0 to 5.4 µg/g, dietary exposure concentration of 5.3 to 9.6 µg/g (SLD and SeMet diets), there was no significant (= 0.05) effect on the survival of Chinook salmon when compared to the control. This concentration is about two times higher than what Beckon (2008) designated as lethal to about 25 percent of Chinook salmon.

3. The fresh water dietary exposure toxicity threshold for Chinook salmon is in the range of 7 µg/g dw (SLD diet) and 13 µg/g dw (SeMet diet).

4. There was no effect on the survival of Chinook salmon larvae/fingerlings in brackish water (Bay conditions) up to a dietary selenium exposure concentration of 35.4 µg/g dw (SLD and SeMet diets).

5. The brackish water dietary exposure toxicity threshold for growth (length and weight) for Chinook salmon is in the range of 7 µg/g dw (SLD diet) and 25.4 µg/g dw (SeMet diet). Note that the SLD diet was found to have elevated concentrations of boron, chromium, and strontium compared to the control and SeMet diets which might have increased observed SLD diet toxicity compared to the control and SeMet diets.

Another important finding from Hamilton, et al (1990), is that Chinook salmon larvae/fingerling do not biomagnify selenium; i.e., the dietary selenium exposure generally reflects the whole body selenium concentration (burden).

The Chinook salmon larvae/fingerling food mostly consists of insects, amphipods (zooplankton), etc. (Beckon and Maurer 2008). The available data on the selenium concentration of particulates and zooplankton in the NSFB (TetraTech Inc. 2008) shows that the dietary selenium exposure concentration for Chinook salmon in the NSFB are well below the selenium toxicity threshold calculated from Hamilton, et al (1990), study (attached **Figures 9** and **10**). Therefore, the current dietary exposure concentration of selenium in the Bay does not appear to impair the survival and growth of Chinook salmon.

Summary

Based on the above technical discussion, we find that the current, available data on selenium concentrations in water, sediment, diving duck muscle, bird eggs, and fish tissue support delisting of selenium in San Francisco Bay. To support this finding, we have compared available data to the selected screening criteria/guidelines and then compared this to the Listing Policy[1]. Based on this new information and data, we evaluated whether the a) water segment would be placed on the 303(d) list if a new impairment assessment were to be completed and/or; b) whether the analysis would support a delisting of the water segment.

The result of the comparison that was completed as a part of this analysis is summarized in **Table 6.**

Table 6. Screening exceedances for selenium; San Francisco Bay

Matrix	Screening Criterion	Period of Record	Exceedances/ Samples	Impairment[7]	Delisting[8]
Water[1]	5 ug/L	2002-2006	0/167	No	Yes
Sediment[2]	2 mg/kg dw	2005-2006	0/54	No	Yes
Diving duck muscle[3]	14.8 mg/kg ww	2002-2005	0/40	No	Yes
Bird eggs (mean)[4]	8 mg/kg dw	1995-2008	0/181	No	Yes
Fish fillet (human health)[5]	7.4 mg/kg ww	2000-2006	0/19	No	Yes
Fish muscle (fish exposure)[6]	12 mg/kg dw	2000-2006	1/19	No	Yes

[1] – San Francisco Bay Region, Water Quality Control Plan (Basin Plan), 2007
[2] – Lemly, 2008
[3] – OEHHA guidelines, calculated in this memorandum
[4] – Skorupa, 2005
[5] - OEHHA guidelines, calculated in this memorandum
[6] – Calculated from Linville (2006) as part of this memorandum
[7] – Determination made pursuant to Section 3 and Table 3.1 of the SWRQCB Listing Policy, 2004

[1] The data were compared to the Listing Policy to determine if they met the requirements in Section 3 (California Listing Factors – **Table 4**) and/or 4 (California Delisting Factors – **Table 5**).

[8] – Determination made pursuant to Section 4 and Table 4.1 of the SWRQCB Listing Policy, 2004

Additional information is provided below.

Water Column (Section 4.1 of the Listing Policy)
A finding to delist may be made for any pollutant water-body combination for which there are a sufficient number of samples that do not exceed the water quality criteria (NTR in this case). The water column concentrations were compared to the NTR criteria consistent with Policy Table 4.1 for the purposes of assessing exceedances. This assessment indicated that there were 0 exceedances out of 167 samples.

Water/Sediment Toxicity (Section 4.6 of the Listing Policy)
A finding to delist may be made if the water/sediment toxicity or associated water or sediment quality guidelines are not exceeded using the binomial distribution as set forth in the Policy. The sediment concentrations were analyzed consistent with Policy Table 4.1 for the purposes of assessing exceedances. This assessment indicated that there were 0 exceedances out of 54 samples.

Human Health (Section 4.4 of the Listing Policy)
A finding to delist may be made if a health advisory used to list the water segment has been removed of the chemical or biological contaminant-specific evaluation guideline for tissue is no longer exceeded. Even though the duck consumption advisory is still in effect (since OEHHA has not yet prioritized the review of the advisory), the selenium concentrations in diving ducks were compared to the OEHHA 2008 tissue advisory levels consistent with Policy Table 4.1 for the purposes of assessing exceedances. This assessment indicated that there were 0 exceedances out of 40 samples.

Bioaccumulation of Pollutants in Aquatic Life Tissue (Section 4.5 of the Listing Policy)
A finding to delist may be made if the numeric pollutant-specific evaluation guidelines are not exceeded using the binomial distribution consistent with Policy Table 4.1. For this analysis bird eggs, fish fillets, and fish muscle were evaluated.

The selenium concentrations in bird eggs were analyzed consistent with Policy Table 4.1 for the purposes of assessing exceedances. This assessment indicated that there were 0 exceedances out of 181 samples.

The selenium concentrations in fish fillets (human health) were analyzed consistent with Policy Table 4.1 for the purposes of assessing exceedances. This assessment indicated that there were 0 exceedances out of 19 samples.

The selenium concentrations in fish muscle (fish exposure) were analyzed consistent with Policy Table 4.1 for the purposes of assessing exceedances. This assessment indicated that there was 1 exceedance out of 19 samples.

Recommendation

The results indicate that there is no clear evidence for impairment by selenium in San Francisco Bay. In fact, the available evidence indicates that selenium is not impairing San Francisco Bay. As such, BACWA would recommend that San Francisco Bay be delisted for selenium. We recognize that there are water quality planning and policy needs for selenium, including: 1) reissuance of refinery permits; 2) prevention of impacts from agricultural drainage and water management in the Central Valley; and 3) investigation of the anomalously high water column concentrations of selenium in Alviso Slough. All of the needs can be met with more appropriate and effective strategies than a TMDL. BACWA would be happy to work the with the Regional Water Board in development of the most appropriate and effective water quality attainment strategy for selenium.

Sincerely:

Michele M Pla
Executive Director

Cc: Tom Mumley, SF Bay Regional Water Board
Naomi Feger, SF Bay Regional Water Board
BACWA Executive Board
Bhupinder Dhaliwal, CCCSD
Nirmela Arsem, Chair BACWA Lab Committee
Rob Cole, Chair BACWA Permits Committee

Table 2 From Linville (2006)

Se (µg/g; dw) in adult tissues and their progeny related to incidence of developmental defects

Exposure	Fish/ Progeny ID	Liver	Muscle	Ovarian	Egg	Larvae[1]	Percent Developmental Defects[*]
Control	C3	1.33	1.28	1.49	2.46	2.43	0[†]
Control	C4	0.80	1.22	1.65	1.61	1.69	0
Control	C5	2.16	1.48	1.38	2.68	2.67	0
Treatment	T1	8.72	9.93	6.53	11.00	11.6	0
Treatment	T2	11.60	15.30	13.20	20.50	18.4	27.78 ± 2.94
Treatment	T3	11.00	11.10	5.74	7.61	7.75	13.33 ± 3.33

Table 3-18. Se concentrations (µg/g; dw) in liver, muscle, ovarian tissue, and eggs from female white sturgeon exposed to either control (*ca.* 1.4 µg/g) or treatment (*ca.* 34 µg/g) dietary Se for approximately six months during vitellogenesis (described in Chapter 2). Se concentration and occurrence of developmental defects are shown for the progeny of each female (n = 25 – 30 larvae for stage 36; n = 60 - 90 larvae for stages 40 and 45).

[1]Newly hatched larvae (stage 36)
[*]Occurrence of edema and/or skeletal deformities at the end of yolk sac development
[†]Data from stage 36 only, due to very low hatch

Appendix B - 27

Table 3-3
Summary of selenium toxicity studies evaluated in this review.

Fish	Study	Water Type	Life stage	Liver[1] NOAEL (mg/kg-dw)	Liver[1] LOAEL (mg/kg-dw)	Muscle[1] NOAEL (mg/kg-dw)	Muscle[1] LOAEL (mg/kg-dw)	Whole Body NOAEL (mg/kg-dw)	Whole Body LOAEL (mg/kg-dw)	Effect Threshold (mg/kg-dw) Liver	Effect Threshold (mg/kg-dw) Muscle	Effect Threshold (mg/kg-dw) Whole Body	Endpoint
bluegill	5	fresh	Juvenile	[illegible]	[illegible]	[illegible]	[illegible]	4.7	7.1	20.3	9.5	9.9	BW, L
bluegill	7	fresh	Adult	[illegible]	[illegible]	[illegible]	[illegible]	10.0	15.6	28.4	15.4	13.9	R
bluegill	10	fresh	Adult	12.3	26.0	5.6	13.4	[illegible]	[illegible]	17.9	7.0	7.1	R
bluegill	32	fresh	Adult	4.0	37.7	1.2	7.2	[illegible]	[illegible]	14.3	2.9	3.0	BW, R, S
bluegill	53	fresh	Juvenile	[illegible]	[illegible]	[illegible]	[illegible]	1.3	7.4	11.2	2.9	3.2	S, BW, L
channel catfish	18	fresh	Adult	7.4	12.5	[illegible]	[illegible]	[illegible]	[illegible]	9.6	2.8	2.7	S
channel catfish	15	fresh	Fingerling	-	-	3.0	3.6	[illegible]	[illegible]	-	3.3	3.3	BW
chinook salmon	23	fresh	Larvae[2]	[illegible]	[illegible]	[illegible]	[illegible]	5.4	10.8	24.5	8.4	7.6	BW, L
chinook salmon	29	brackish	Juvenile[2]	[illegible]	[illegible]	[illegible]	[illegible]	12.6	23.2	48.9	19.3	12.1	BW, L, S
fathead minnow	9	fresh	Larvae	-	[illegible]	-	[illegible]	-	62.5	-	-	-	BW
fathead minnow	56	fresh	Juvenile	[illegible]	[illegible]	5.7	6.6	5.4	9.6	30.3	6.1	6.6	BW
fathead minnow	67	fresh	Egg	-	-	-	-	1.6	18.5	-	-	6.6	D
rainbow trout	75	fresh	Larvae	[illegible]	[illegible]	[illegible]	[illegible]	1.2	2.3	7.8	1.8	1.7	BW, L
rainbow trout	38	fresh	Juvenile	103.2	167.2	-	-	[illegible]	[illegible]	173.8	-	53.1	BW, FG, R
rainbow trout	39	fresh	Juvenile	42.0	95.6	-	-	[illegible]	[illegible]	63.2	-	19.1	BW, R, FG
rainbow trout	41	fresh	Juvenile[3]	21.0	21.7	[illegible]	[illegible]	1.5	4.0	28.0	2.1	2.8	BW, FG
Sacramento splittail	74	fresh	Juvenile	23.0	26.8	10.1	15.1	[illegible]	[illegible]	24.9	12.3	10.8	D
white sturgeon	55	fresh	Adult	1.4	10.4	1.3	12.1	[illegible]	[illegible]	2.6	4.6	6.3	D
white sturgeon	74	fresh	Juvenile	22.0	37.4	22.8	36.8	14.7	22.5	28.7	29.0	18.2	BW, SA

Notes:
1 - shaded cells represent concentrations predicted from measurements in other tissues (see Appendix A)
2 - only results from the [illegible] dietary exposure part of the study are used here
3 - data from the low carbohydrate diet were not used as the authors reported that reduced weight of fish on this diet was likely due to food avoidance, not toxicity
BW = Body Weight
D = Deformities
FG = [illegible]
L = Length
R = Reproduction
S = Survival
SA = Swimming Activity

From Tetra Tech (2008)

Table 3 From Tetra Tech Inc. (2008)

Table 3.1 Measured Exceedances for Placement of 303(d) List

MINIMUM NUMBER OF MEASURED EXCEEDANCES NEEDED TO PLACE A WATER SEGMENT ON THE SECTION 303(D) LIST FOR TOXICANTS. *Null Hypothesis: Actual exceedance proportion ≤ 3 percent.* *Alternate Hypothesis: Actual exceedance proportion > 18 percent.* *The minimum effect size is 15 percent.*	
Sample Size	List if the number of exceedances equal or is greater than
2 – 24	2*
25 – 36	3
37 – 47	4
48 – 59	5
60 – 71	6
72 – 82	7
83 – 94	8
95 – 106	9
107 – 117	10
108 – 129	11

* Application of the binomial test requires a minimum sample size of 16. The number of exceedances required using the binomial test at a sample size of 16 is extended to smaller sample sizes.

For sample sizes greater than 129, the minimum number of measured exceedances is established where α and $\beta \le 0.2$ and where $|\alpha - \beta|$ is minimized.

α = Excel® Function BINOMDIST(n-k, n, 1 – 0.03, TRUE)
β = Excel® Function BINOMDIST(k-1, n, 0.18, TRUE)
where n = the number of samples,
k = minimum number of measured exceedances to place a water on the section 303(d) list,
0.03 = acceptable exceedance proportion
0.18 = unacceptable exceedance proportion

Source: SWRCB 2004

Table 4 From SWRCB (2004)

Table 4.1 - Measured Exceedances for Delisting

MAXIMUM NUMBER OF MEASURED EXCEEDANCES ALLOWED TO REMOVE A WATER SEGMENT FROM THE SECTION 303(D) LIST FOR TOXICANTS. *Null Hypothesis: Actual exceedance proportion ≥ 18 percent.* *Alternate Hypothesis: Actual proportion < 3 percent of the samples* *The minimum effect size is 15 percent.*	
Sample Size	Delist if the number of exceedances equal or is less than
28 - 36	2
37 – 47	3
48 – 59	4
60 – 71	5
72 – 82	6
83 – 94	7
95 – 106	8
107 – 117	9
108 – 129	10

For sample sizes greater than 129, the maximum number of measured exceedances allowed is established where α and $\beta \leq 0.10$ and where $|\alpha - \beta|$ is minimized.

α = Excel® Function BINOMDIST(k, n, 0.18, TRUE)
β = Excel® Function BINOMDIST(n-k-1, n, 1 – 0.03, TRUE)

where n = the number of samples,
k = maximum number of measured exceedances allowed
0.03 = acceptable exceedance proportion
0.18 = unacceptable exceedance proportion

Source: SWRCB 2004

Table 5 From SWRCB (2004)

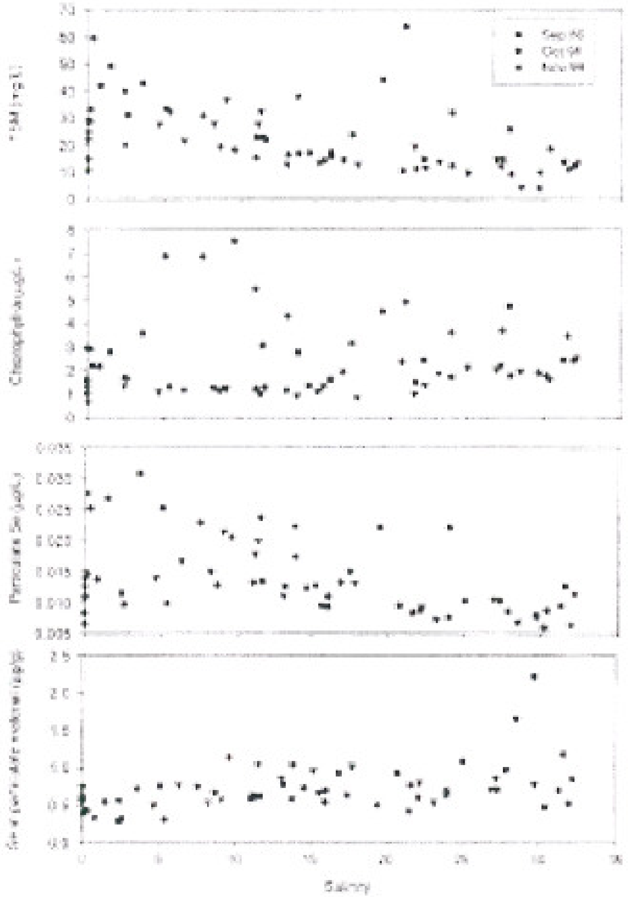


Figure 3-5 Low flow: Transects of TSM, chlorophyll-a, particulate selenium and selenium in particulate material (September 1986, October 1998, and November 1999; Doblin et al. 2006 and electronic database provided by Dr. Cutter).

Figure 9 from TetraTech Inc. (2009)

Appendix B - 31

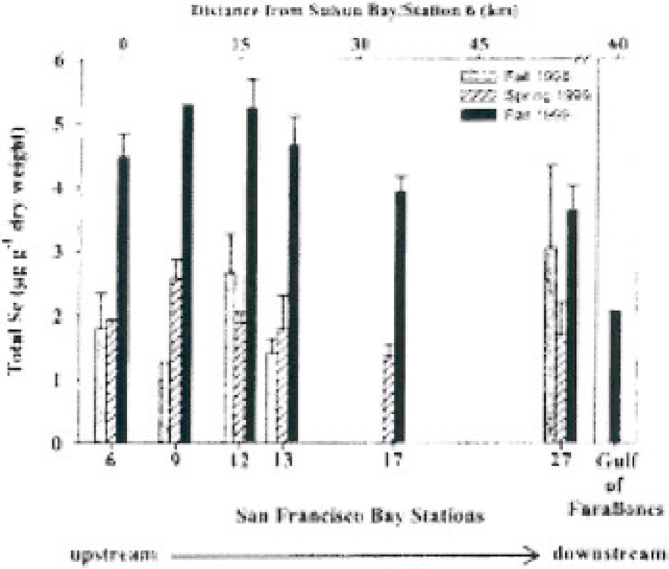


Figure 3-11 Zooplankton data collected in NSFB compared with a reference site in the Gulf of Farallones. Figure reproduced from Purkerson et al. (2003).

Figure 10 from TetraTech Inc. (2008c)

Appendix B - 32

REFERENCES

1. Abu-Saba, K. and Scott Ogle (2005), Selenium in San Francisco Bay, Conceptual Model/Impairment Assessment; Clean Estuary Partnership (Bay Area Clean Water Agencies), Oakland, California.

2. Baginska, B. (2008), North San Francisco Bay Selenium Total Maximum Daily Load Draft Numeric Target; Advisory Committee Meeting No. 3, September 16, 2008; San Francisco Bay Regional Water Quality Control Board, Oakland, California.

3. Beckon, W. 2008. Toxicity of Selenium to Salmonids. Abstracts; 5th Biennial CALFED Science Conference, October 22-24, 2008, Sacramento, California.

4. Beckon, W. and T. Mauer (2008), Species at Risk from Selenium Exposure in the San Francisco Estuary. U.S. Department of the Interior, Fish and Wildlife Service Final Report to USEPA Interagency Agreement No. DW14922048-01-0, March 2008.

5. DeVink, J. M., R. Clark, S. Slattery and M. Wayland (2008), Is Selenium Affecting Body Condition and Reproduction in Boreal Breeding Scaup, Scoters and Ring-Necked Ducks? Environmental Pollution 152, 116-122 (2008).

6. Fan, A. M., and M. J. Lipsett (1988), Human health Evaluation of Findings on Selenium in Ducks obtained from Selenium Verification Study (1986 – 1987); Update of Health Advisories; California Department of Health Services, Berkeley, California.

7. FWS/NMFS (2000), Final Biological Opinion on the Effects of the U.S. Environmental Protection Agency's "Final Rule for the Promulgation of Water Quality Standards: Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California;" USFWS and USNMFS (2000); Washington, D.C., U.S. Department of the Interior.

8. Gandesbery. T. (1998), Ambient Concentrations of Toxic Chemicals in Sediments; Memorandum: Water Boards Staff, from Tom Gandesbery, March 1998; File No.: 1150.0.

9. Gandesbery, T., F. Hetzel, R. Smith, and L. Riege (1999), Ambient Concentrations of Toxic Chemicals in San Francisco Bay Sediments: Summary; In 1997 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances; San Francisco Estuary Institute, Oakland, California, pp. 140-147.

10. Great Salt Lake Water Quality Steering Committee Majority Recommendation to the Utah Water Quality Board for a Numeric Selenium Standard in the Open Water of Great Salt Lake (2008); www.nature.org/wherewework/northamerica/state/utah/files/no_effect_se_standard_for

11. Hamilton, S., K. Buhl, N. Faerber, R. Wiedmeyer and F. Bullard; Toxicity of Organic Selenium in the Diet to Chinook Salmon (1990). Environmental Toxicology and Chemistry, Volume 9, 347-358 (1990).

12. Hothem, R., D. Roster, K. King, T. Koelsen, K. Marois, and S. Wainwright (1995); Special and Temporal Trends of Contaminants in Eggs of Wading Birds from San Francisco Bay, California; Environmental Toxicology and Chemistry, Volume 14, No. 8, 1319-1331 (1995).

13. Kueltz, D. (2008), Semiannual Project Report No. 2 to Matt Nobriga; CALFED Science Program (nobriga@calwater.ca.gov).

14. Lemly, D. (1993), Metabolic Stress During Winter Increases the Toxicity of Selenium to Fish; Aquat. Toxicol. 22:133-158 (1993).

15. Lemly, D. and J. Skorupa (2007), Technical Issues Affecting the Implementation of U.S. Environmental Protection Agency's Proposed Fish Tissue-Based Aquatic Criterion for Selenium; Integrated Environmental Assessment and Management, Volume 3, No. 4, 552-558 (2007).

16. Lemly, D. (2008), U.S. Forest Service; Southern Research Station Fisheries Research Unit, 1650 Ramble Road, Blacksburg, Virginia 24080; dlemly@fs.fed.us (Personal Communication).

17. Linville, R., S.N. Luoma, L. Cutter, and G.A. Cutter (2002), Increased selenium threat as a result of the invasion of the exotic bivalve *Potamocorbula amurensis* into the San Francisco Bay-Delta. *Aquatic Toxicol* 57: 51-64 (2002).

18. Linville, R. (2006), Effects of Excess Selenium on the Health and Reproduction of White Sturgeon (Acipenser transmontanus): Implications for San Francisco Bay-Delta; Ph.D. Dissertation, University of California Davis, 2006.

19. OEHHA (2008), Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Fish; California State Office of Environmental Health Hazard Assessment; California Environmental Protection Agency, Sacramento, California (June 2008).

20. SFEI (1997-2006), Regional Monitoring Program Annual Reports, 1997-2006; San Francisco Estuary Institute, Oakland, California; www.sfei.org

21. SFEI (2008), Ms. Jennifer Hunt, Environmental Scientist Personal Communication; San Francisco Estuary Institute, Oakland, California; www.sfei.org

22. SFEI (2008), Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary (2008).

23. SFBRWQCB (1998), 1998 CWA Section 303(d) List of Water Quality Limited Segments; San Francisco Bay Regional Water Quality Control Board, Oakland, California.

24. SFBRWQCB (2006), 2006 CWA Section 303(d) List; San Francisco Bay Regional Water Quality Control Board, Oakland, California.

25. SFBRWQCB (2007). San Francisco Bay Region (Region 2) Water Quality Control Plan (Basin Plan), 2007. California Regional Water Quality Control Board San Francisco Bay Region. January 18, 2007.

26. SFBRWQC (2008); North San Francisco Bay Selenium Total Maximum Daily Load; Advisory Committee Meeting No. 3, September 16, 2008; San Francisco Regional Water Quality Control Board, Oakland, California.

27. Skorupa, J. (2005), Hazards of Selenium for Aquatic Life; U.S. Fish and Wildlife Service; www.wvmdtaskforce.com/proceedings/05/pptskorupa.pdf

28. Stanley, T., G. Smith, D. Hoffman, G. Heinz and R. Rosscoe (1996), Effects of Boron and Selenium on Mallard Reproduction and Duckling Growth and Survival; Environmental Toxicology and Chemistry, Volume 15, No. 7, 1124-1132 (1996).

29. Stewart, R., S. N. Luoma, C. E. Schelkat, M. A. Doblin, and K. A. Heib (2004), Food Web Pathway Determines How Selenium Affects Aquatic Ecosystems: A San Francisco Bay Case Study. *Environ. Sci. Technol.* 38: 4519-4526 (2004).

30. Stewart, R.,(2008), Personal communication, arstewar@usgs.gov

31. Suter, G.W.II, R. A. Efroymson, B.E. Sample, and D.S. Jones. 2000. Ecological Risk Assessment for Contaminated Sites. Lewis Publishers, Boca Raton, FL. 438 pp.

32. SWRCB (1991) Selenium Verfication Study, 91-2-WQ (1991); State Water Resources Control Board, Sacramento, California.

33. SWRCB (1998), Sediment Quality and Biological Effects in San Francisco Bay: Bay Protection and Toxic Clean-up Program; Final Technical Report; State Water Resources Control Board, Sacramento, California.

34. SWRCB (2004) Policy for Developing California's Clean Water Action, Section 303(d) List, September 2004; California State Water Resources Control Board, Sacramento, California.

35. Tashjian, D. S. Teh, A. Sogomonyan and S. Hung (2006), Bioaccumulation and Chronic Toxicity of Dietary L-selenomethionine in Juvenile White Sturgeon (Acipenser transmontanus); Aquatic Toxicology 79:401-409 (2006).

36. Tetra Tech, Inc. (2008a), Technical Memorandum No. 2, Conceptual Model of Selenium in North San Francisco Bay (August 2008); Tetra Tech, Inc., 3746 Mt. Diablo Boulevard, Lafayette, California.

37. Tetra Tech, Inc. (2008b), Technical Memorandum No. 3, Conceptual Model of Selenium in North San Francisco Bay (August 2008); Tetra Tech, Inc., 3746 Mt. Diablo Boulevard, Lafayette, California.

38. Tetra Tech, Inc. (2008a), Technical Memorandum No. 4, Conceptual Model of Selenium in North San Francisco Bay (August 2008); Tetra Tech, Inc., 3746 Mt. Diablo Boulevard, Lafayette, California.

39. USEPA (1985) Guidelines for deriving numerical water quality criteria for the protection of aquatic organisms and their uses; USEPA, 822-R-85-100. Office of Research and Development, Duluth, MN.

40. USEPA (2002) National Recommended Water Quality Criteria 2002; U.S. EPA 822-R-02-047, Office of Water, Washington, D.C.

41. USEPA (2004), Draft Aquatic Life Criteria Document for Selenium; Fed. Reg. 69(242):75541-75546.

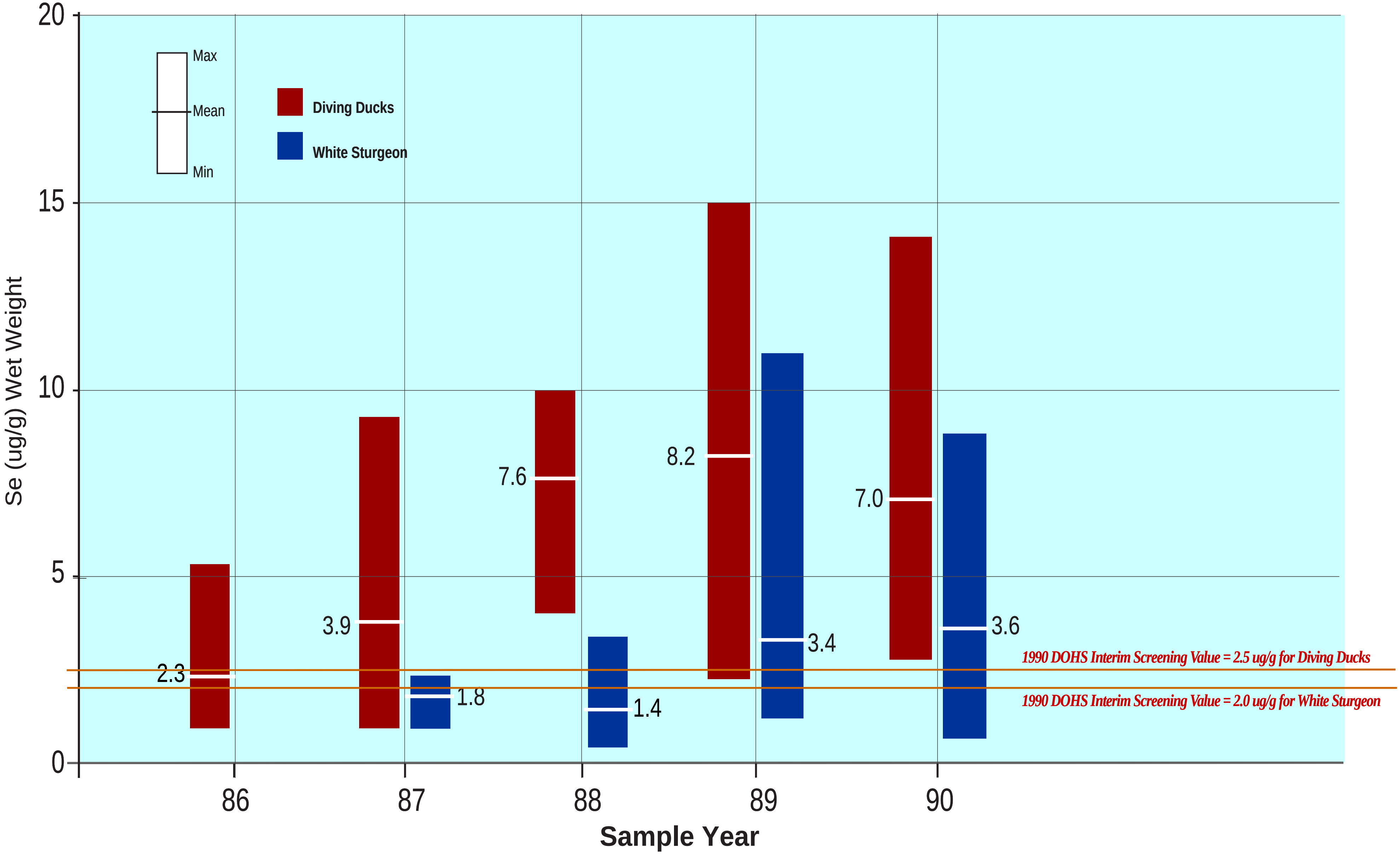
42. USEPA (2004), Draft Aquatic Life Water Quality Criteria for Selenium, 2004; U.S. Environmental Protection Agency EPA-822-D-04-001, Washington, D.C.,

43. USEPA (2008), Effects of Selenium on Juvenile Bluegill Sunfish at Reduced Temperature; EPA-822-R-08-020, September 2008; U.S. Environmental Protection Agency Office Water, Washington, D.C.

44. Wainwright-De La Cruz, S. E., J. Y. Takeawa, A. Miles, J. M. Eadie, E. C. Palm and M. T. Wilson (2008), The Influence of the Winter Habitat Use and Diet on Selenium Risks for Surf Scoters (Melanitta perspicillata) in the San Francisco Bay Estuary, Abstracts; 5th Biennial CALFED Science Conference, October 22-24, 2008, Sacramento, California.

Figure 1

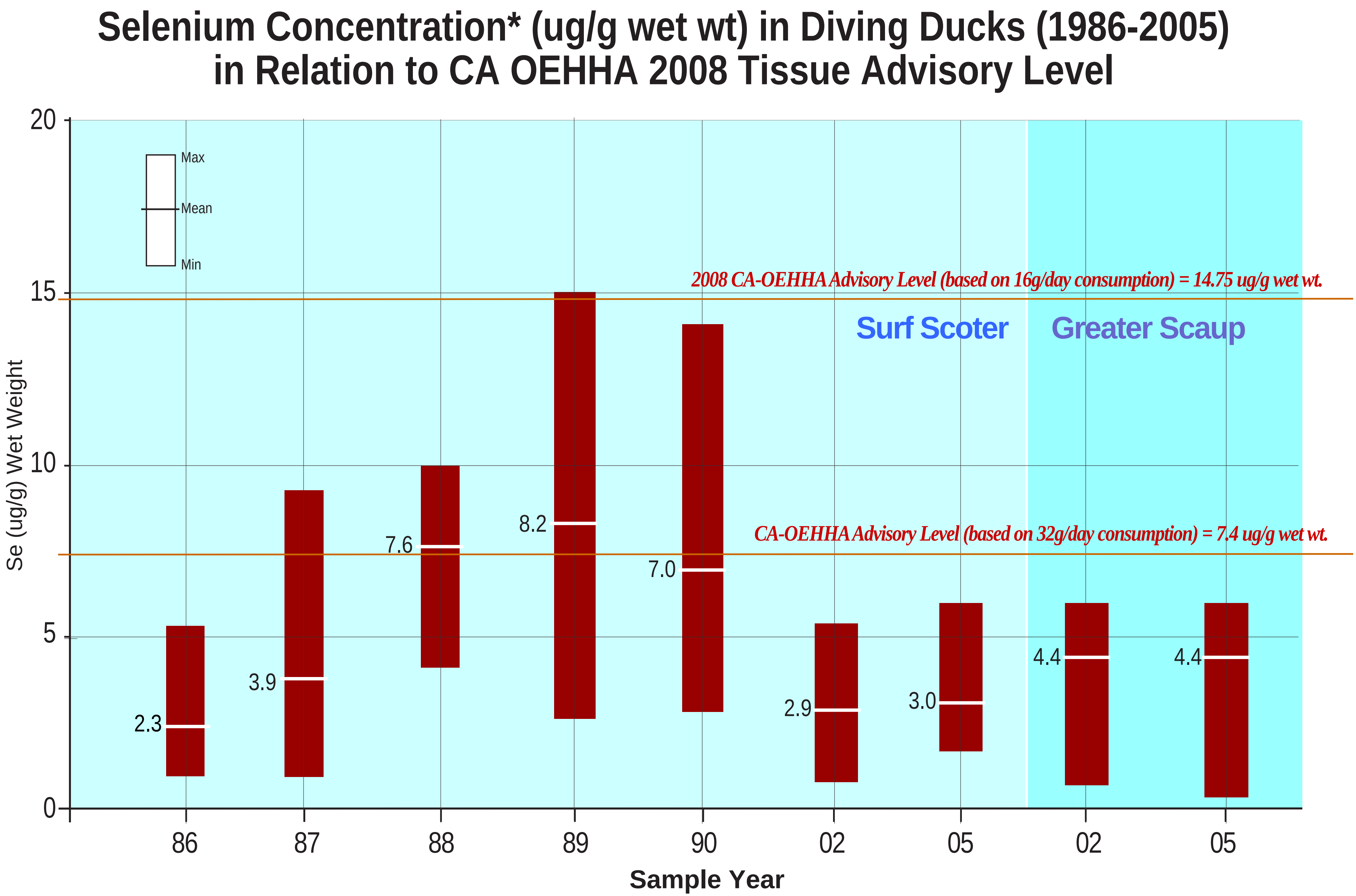
Selenium Concentration* (ug/g wet wt) in Diving Ducks and White Sturgeon (1986-1990) in Relation to CA DOHS 1990 Interim Screening Value



* In muscle tissue, average and range

SOURCE: Selenium Verification Study. (SWRCB 1991)

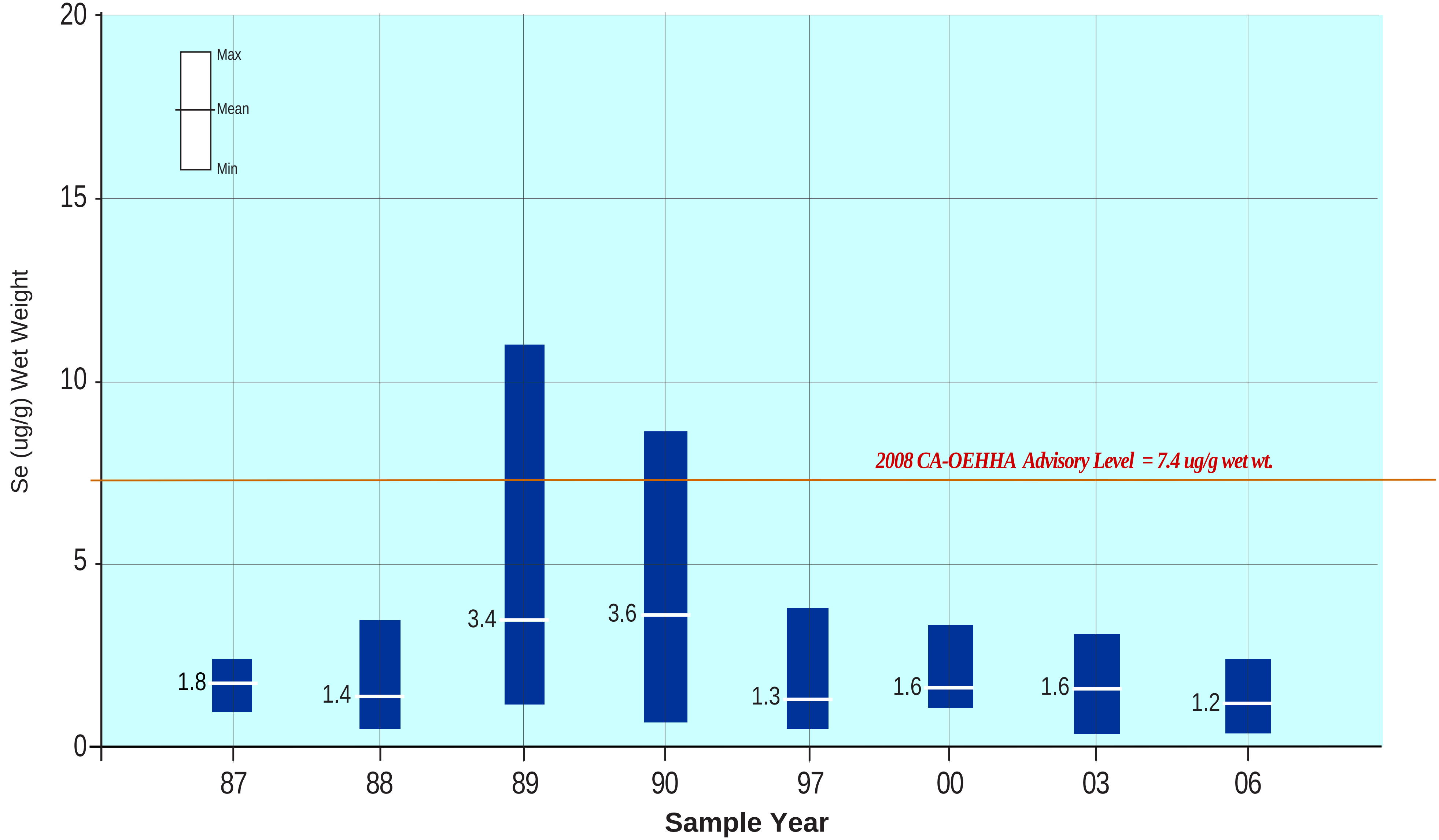
Figure 2



* In muscle tissue, average and range
SOURCE: Selenium Verification Study. (SWRCB 1991) and (SFEI 2008)

Figure 3

Selenium Concentration* (ug/g wet wt.) in White Sturgeon (1987- 2006) in Relation to CA OEHHA 2008 Tissue Advisory Level

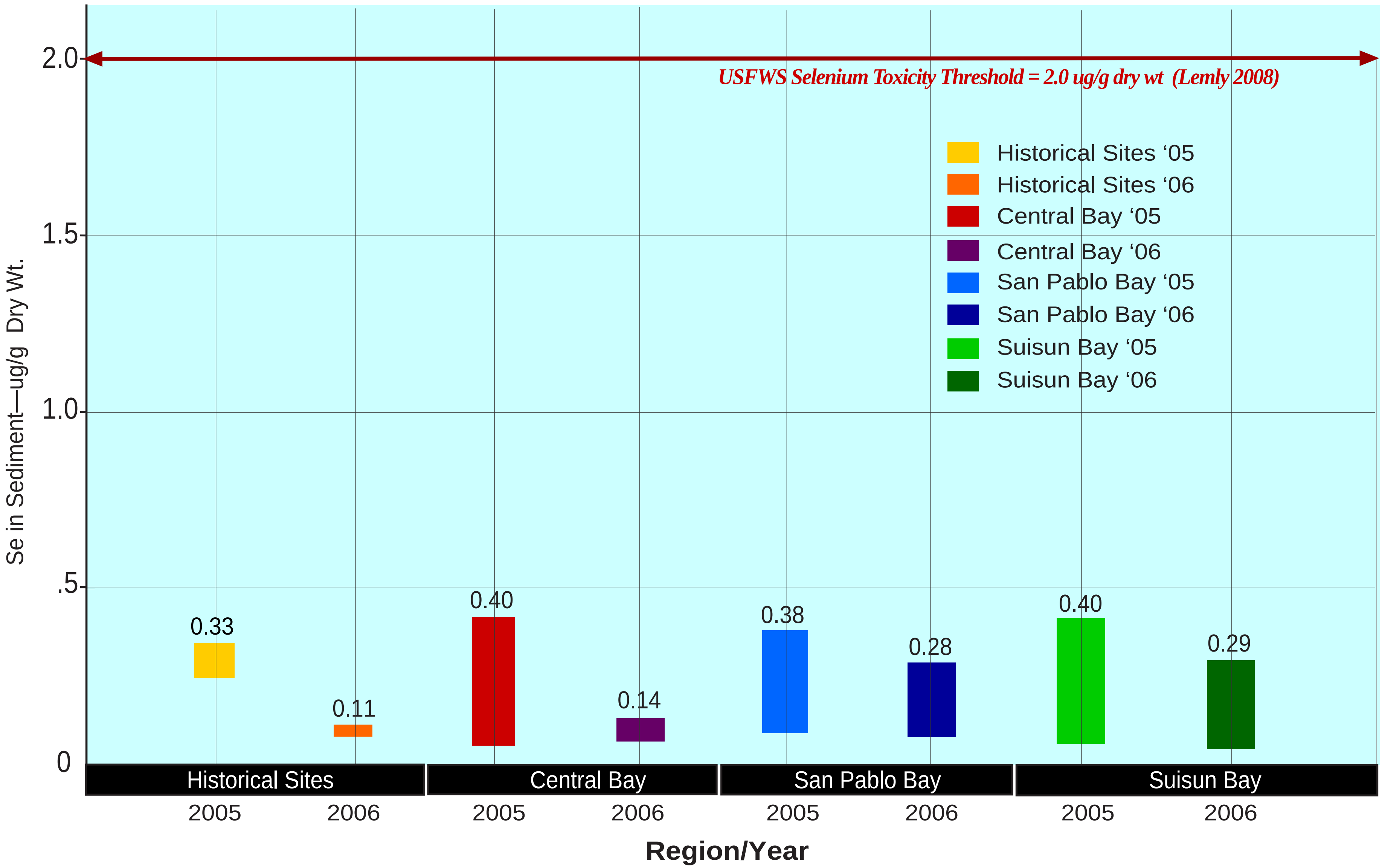


* In muscle tissue, average and range

SOURCE: Selenium Verification Study. (SWRCB 1991) and RMP Annual Report 1997-2006

Figure 4

Selenium Concentration range (ug/g dry wt.) in Sediments (Surface) from North San Francisco Bay (2005 - 2006) in relation to USFWS Selenium Toxicity Threshold



* Source 2005-2006 RMP Annual Reports.

Figure 5

Selenium Concentration (ug/g dry wt.) in eggs of Diving Ducks and Wading Birds from San Francisco Bay complex in relation to egg Selenium concentration Thresholds

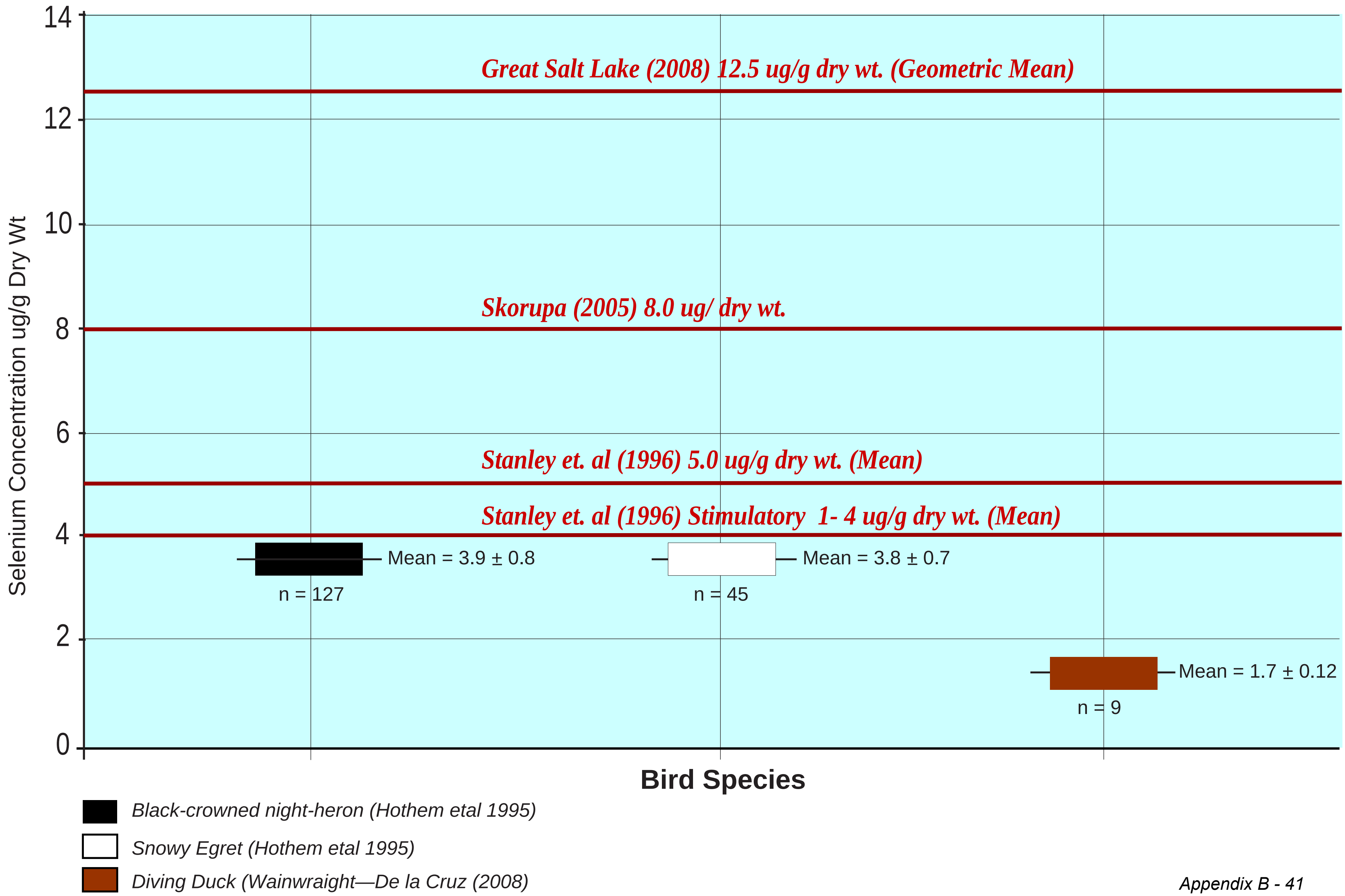
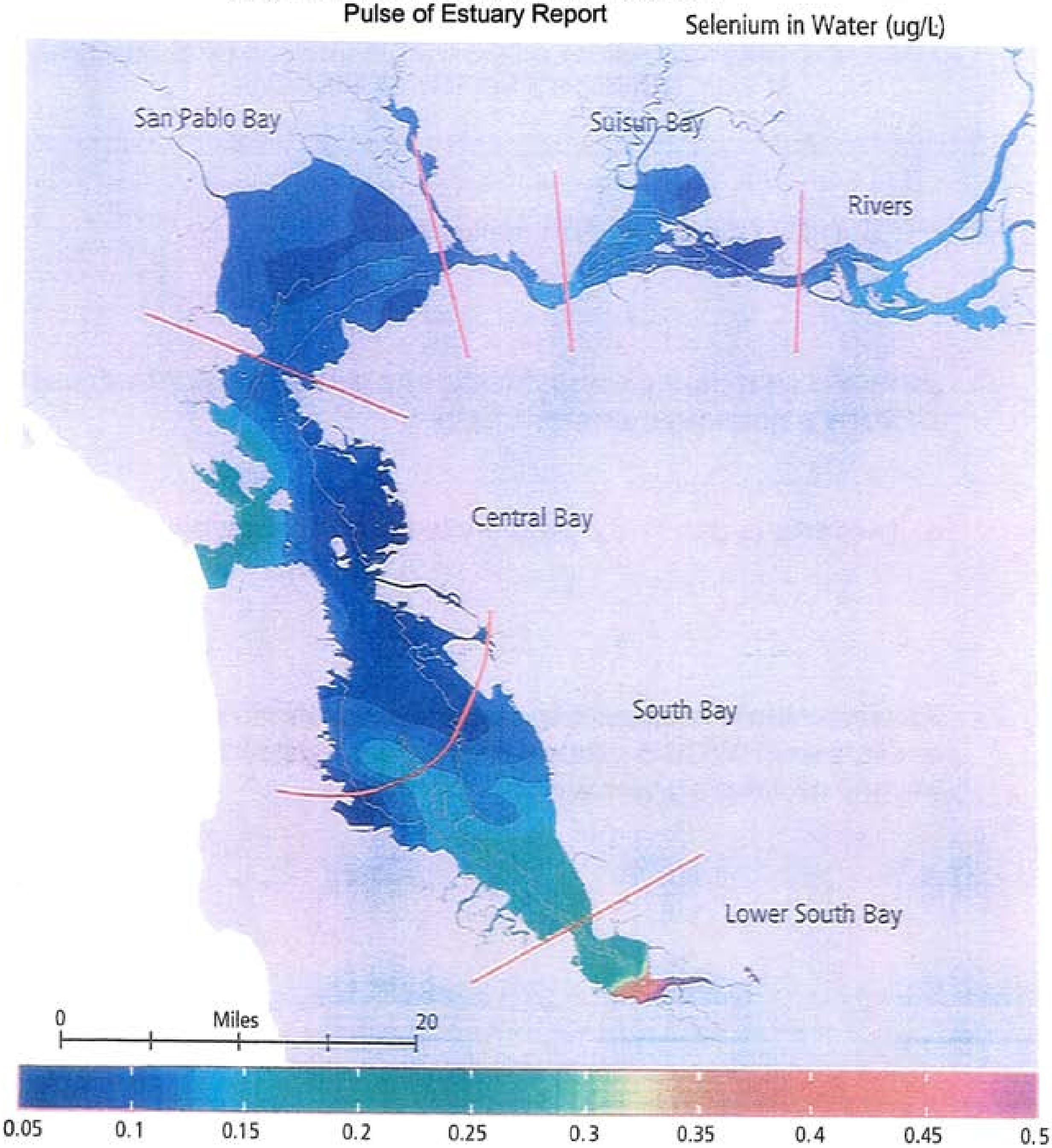


Figure 6
From San Francisco Estuary Institute (2008)
Pulse of Estuary Report

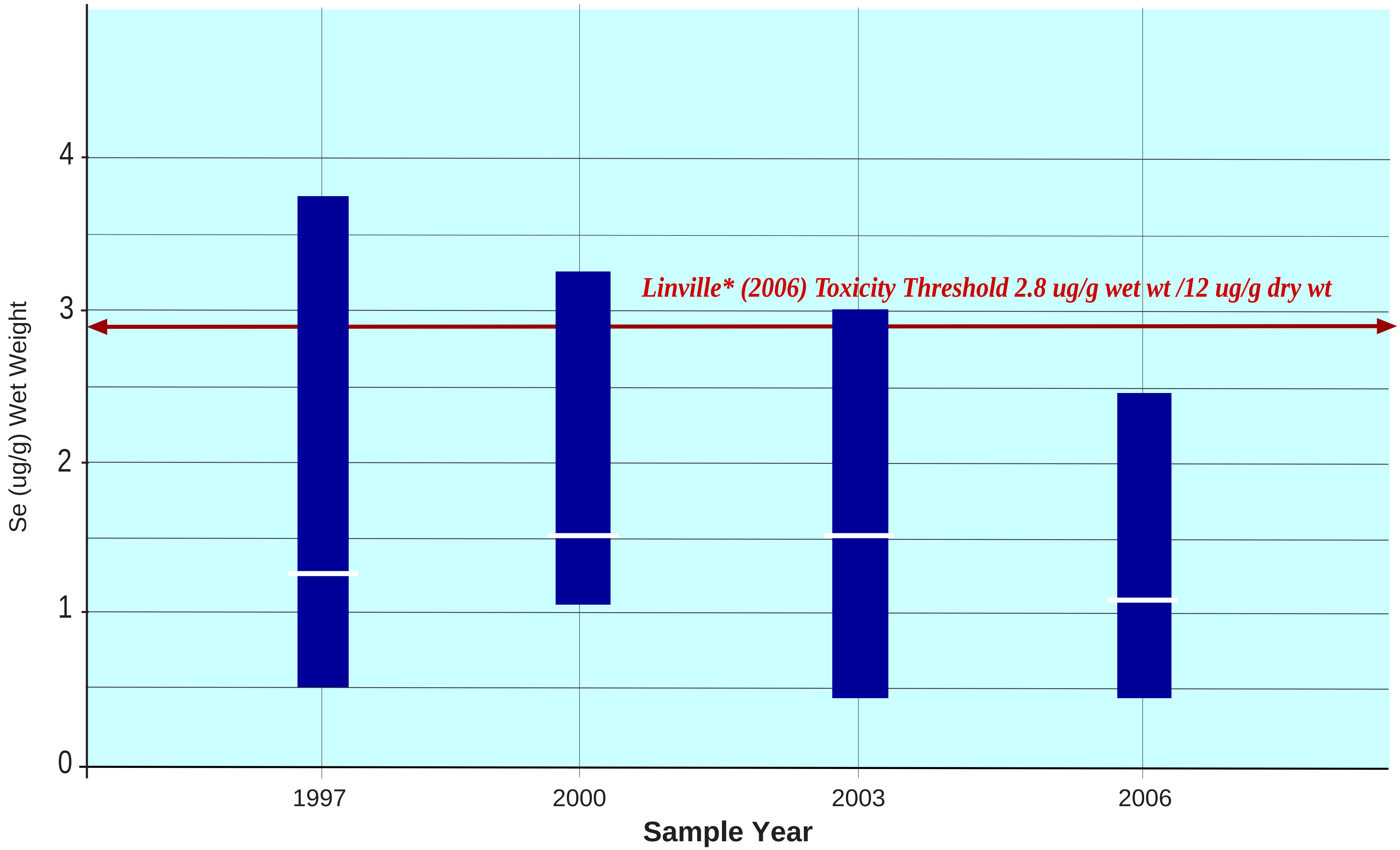


Footnote: Plot based on 167 RMP data points from 2002 – 2007. The maximum concentration was 1.2 µg/L at a historical station in the Southern Sloughs in 2002. Data are for total selenium.

Selenium concentrations in water are well below the water quality objective established by the California Toxics Rule. However, concerns still exist for human exposure as indicated by a duck consumption advisory and for wildlife exposure as indicated by studies on early life-stages of fish. The highest concentration observed in water from 2002 to 2007 was 1.15 µg/L, much lower than the CTR objective (5 µg/L). The Lower South Bay had a higher average concentration over this period (0.25 µg/L) than the other Bay segments, which had strikingly consistent average concentrations (all other averages were between 0.12 and 0.13 µg/L). The Bay-wide average concentration in 2007 (0.10 µg/L) was slightly below the long-term average (0.12 µg/L).

Figure 7

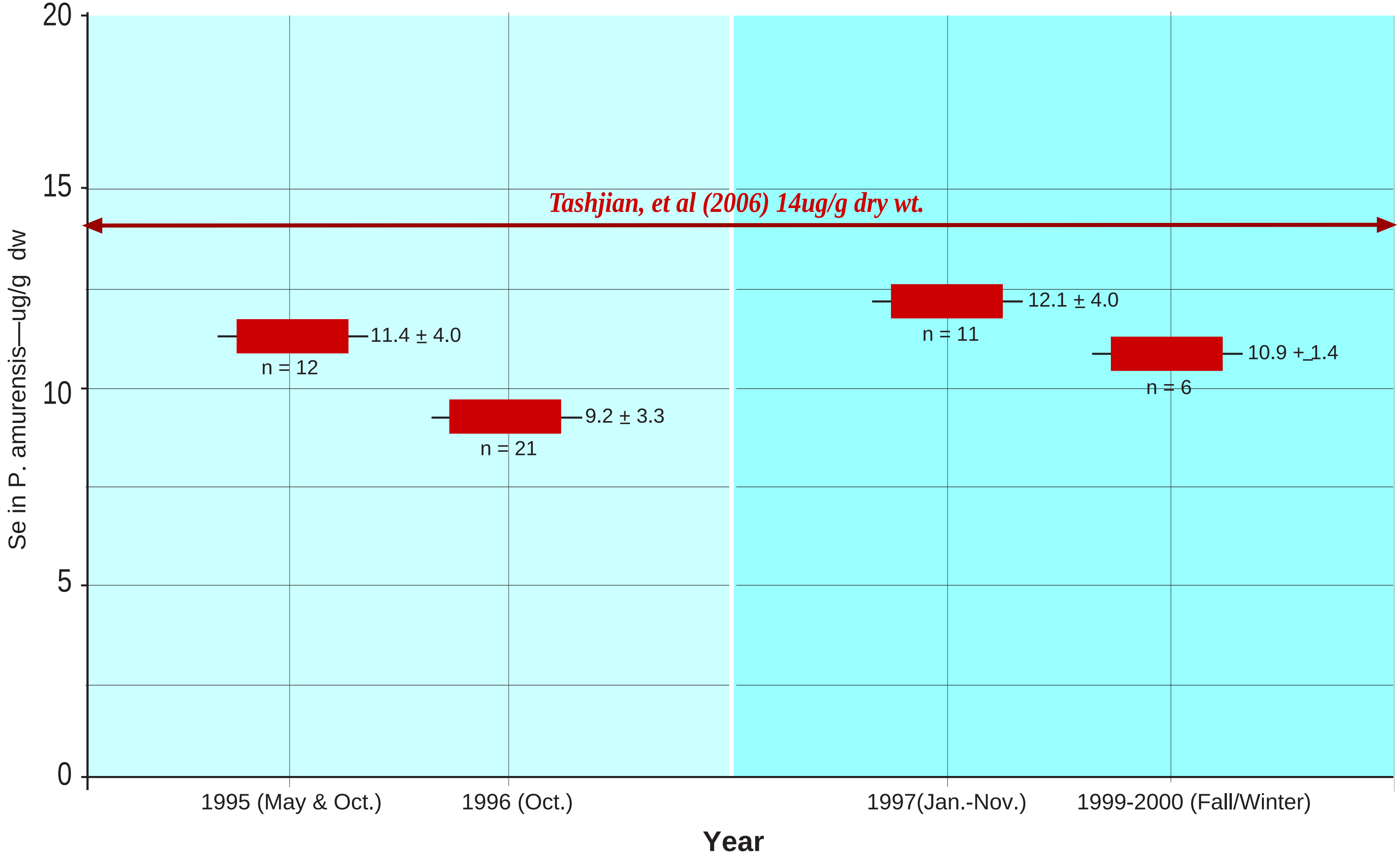
Selenium Concentration (ug/g wet wt.) in Adult White Sturgeon in San Francisco Bay (1997-2006) in Relation to Linville* (2006) Toxicity Threshold



*Our calculated value from Linville (2006) maternal experiments. (see text)
SOURCE: RMP Annual Report 1997-2006: muscle tissue, average and range.

Figure 8

Selenium Concentration* (ug/g dry wt.) in P. amurensis from North San Francisco Bay in Relation to Selenium Dietary Exposure Threshold



* Mean ± s

SOURCE: Linville et. al. (2002), Stewart et. al (2004) and Stewart (2008)

Figure 9 from TetraTech Inc. (2009)

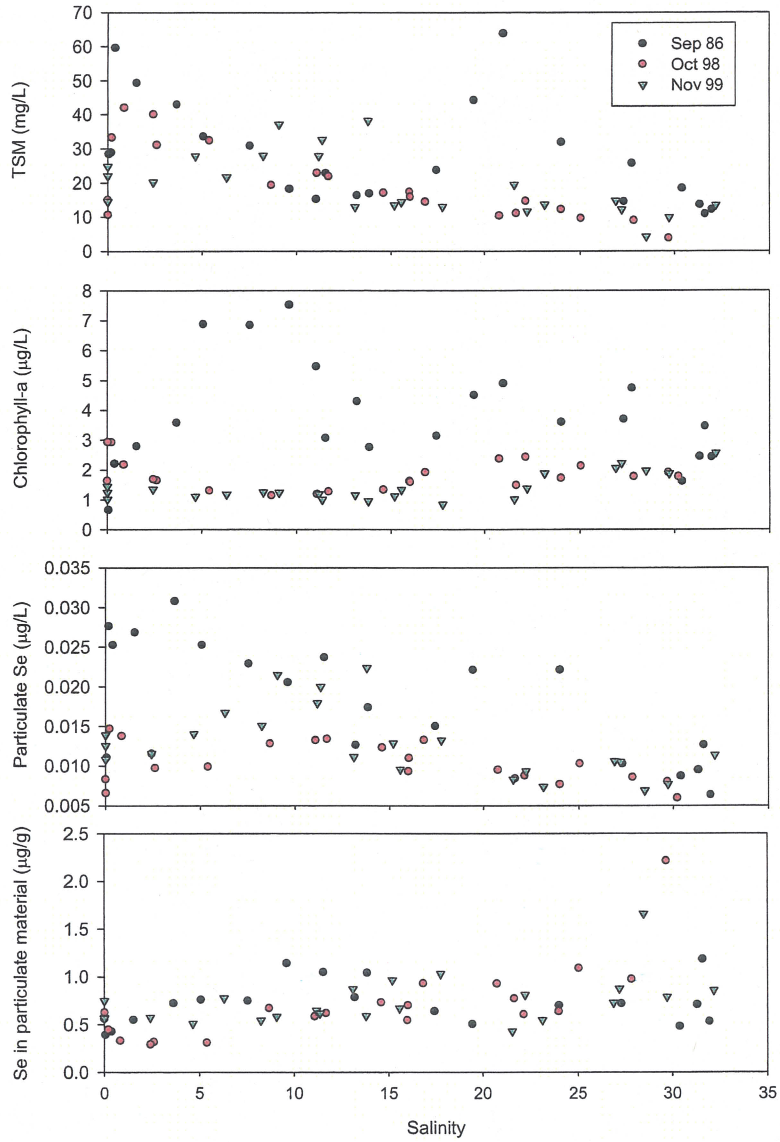


Figure 3-5 Low flow: Transects of TSM, chlorophyll-a, particulate selenium and selenium in particulate material (September 1986, October 1998, and November 1999; Doblin et al. 2006 and electronic database provided by Dr. Cutter).

Figure 10 from TetraTech Inc. (2008c)

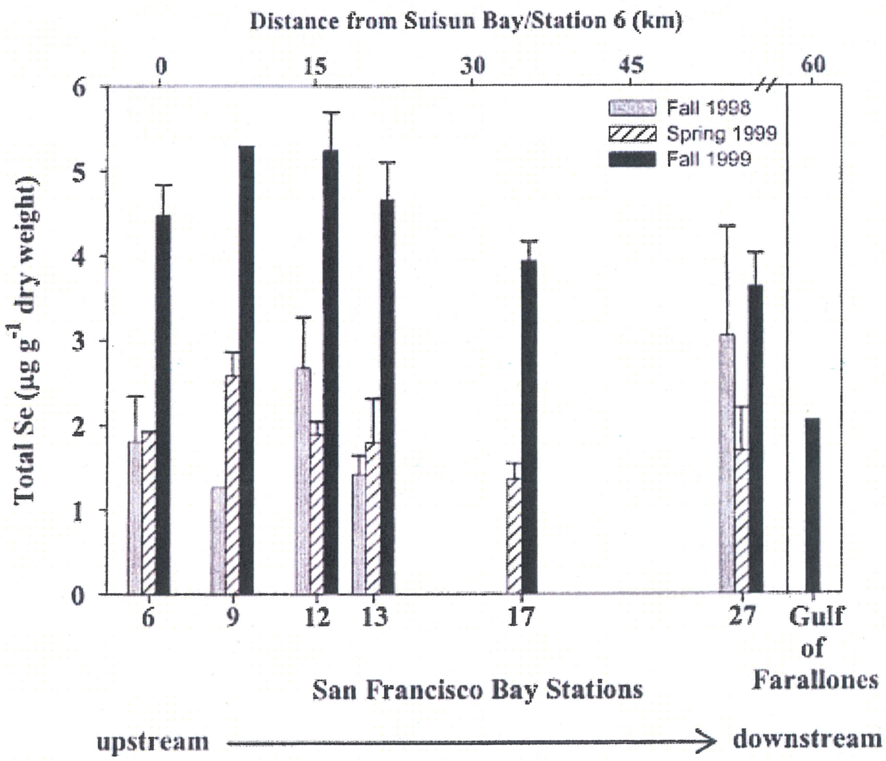


Figure 3-11 Zooplankton data collected in NSFB compared with a reference site in the Gulf of Farallones. Figure reproduced from Pukerson et al. (2003).