Table 1 Fishes observed during routine monitoring in Bay-Delta near-shore shallow water habitat. (Continued) Sources: Bay minnow seine data from the IEP Delta Outflow/San Francisco Bay beach seine study, 1980 to 1986; Suisun Marsh otter trawl data from UCD Suisun Marsh study, 1979 to 1997; Delta minnow seine data from USFWS Beach Seine Study, 1976 to 1999; Delta electrofishing data from DFG Resident Fishes Monitoring Survey, 1995, 1997, and early 1999. Proportional abundances computed from recent data for UCD Suisun Marsh Study (1994 to 1997) and USFWS Beach Seine Study (1994 to 1999), or from all data otherwise. For completeness, fish species occurring in USFWS Beach Seine and UCD Suisun Marsh databases only before 1994 are also given, with asterisks indicating earlier observations. Parenthetical dates next to nonindigenous species names indicate latest plausible year of introduction given by Cohen and Carlton (1995) or L. R. Brown (personal communication). Classification follows Nelson

Taxon	Nat. Hist.[a]	SB	TSM	SD	EMS	EMF	EMS EMGT	EMS MIXED	EMS RIPAR	EMS SUBM	ER	ER EMGT	ER FLOAT	ER MIXED	ER RIPAR	ER SUBM
Amphistichus argenteus	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amphistichus koelzi	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cymatogaster aggregata	E	III	–*	I	–	–	–	–	–	–	–	–	–	–	–	–
Embiotoca jacksoni	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hyperprosopon argenteum	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hyperprosopon ellipticum	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hysterocarpus traski	F	I	II	I	I	II	III	I	I	I	II	III	–	–	I	I
Micrometrus minimus	M	III	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Phanerodon furcatus	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhacochilus toxotes	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhacochilus vacca	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pholidae																
Apodichthys flavidus	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pholis ornata	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ammodytidae																
Ammodytes hexapterus	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Clinidae																
Gibbonsia metzi	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Blenniidae																
Hypsoblennius gilberti	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gobiidae																
Acanthogobius flavimanus (1963)	E	III	IV	I	III	–	II	–	I	I	I	I	–	I	I	I
Clevelandia ios	E	III	–	I	–	–	–	–	–	–	–	–	–	–	–	–
Gillichthys mirabilis	E	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ilypnus gilberti	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lepidogobius lepidus	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tridentiger bifasciatus (1985)	E	–	IV	I	–	–	–	–	–	–	I	–	–	I	–	I
Tridentiger trigonocephalus (1962)	M	I	–	I	–	–	–	–	–	–	–	–	–	–	–	–
Order Pleuronectiformes																
Paralichthyidae																
Citharichthys stigmaeus	M	I	–	I	–	–	–	–	–	–	–	–	–	–	–	–
Paralichthys californicus	M	I	–*	–	–	–	–	–	–	–	–	–	–	–	–	–
Hypsopsetta guttulata	M	I	–	I	–	–	–	–	–	–	–	–	–	–	–	–
Platichthys stellatus	E	I	I	I	–	–	–	–	–	–	–	–	–	–	–	–
Pleuronectes vetulus	M	I	–	I	–	–	–	–	–	–	–	–	–	–	–	–
Psettichthys melanostictus	M	I	–	–	–	–	–	–	–	–	–	–	–	–	–	–

[a] "Natural History" Codes: A = anadromous; E = euryhaline; F = freshwater; M = marine.

Effects of Wetlands Restoration on the Production of Methyl Mercury in the San Francisco Bay-Delta System: Preliminary Results

Thomas H. Suchanek[1], Darell G. Slotton[2], Brenda S. Johnson[1], Shaun Ayers[2], and Douglas C. Nelson[3]

[1]Department of Wildlife, Fish & Conservation Biology, UC Davis

[2]Department of Environmental Science & Policy, UC Davis

[3]Section of Microbiology, Division of Biological Sciences, UC Davis

Background

Mercury pollution and, particularly, the bioaccumulation of toxic methyl mercury in food webs, is a global problem impacting aquatic ecosystems and all consumers of aquatic organisms. The toxicity of mercury to higher order consumers of aquatic organisms is well documented, although its effects on reproduction, development, and juveniles of aquatic and aquatic-feeding species is only poorly understood. Mercury constitutes a significant potential human health hazard through consumption of fish caught from the San Francisco Bay-Delta (hereafter: Bay-Delta) and it has been identified by most California state agencies as an aquatic pollutant of great concern. Because of the widespread nature of mining-related bulk mercury contamination in California (see below), virtually every sub-region of the Bay-Delta and its watershed is affected. All of the named CALFED priority habitats and priority species (in addition to numerous others) are exposed to this ecosystem stressor.

During the past 150 years, large amounts of mercury coming from mines in the California Coast Range, as well as residual mercury from gold and silver mining in the Sierra Nevada, have been, and continue to be, deposited in Bay-Delta sediments (see Figure 1 for distribution of mines). The extensive Sacramento-San Joaquin Delta levee system that originated in the 1860s effectively isolated and converted ("reclaimed") wetlands for the production of agricultural crops and other uses, and in doing so dramatically altered the natural functioning of these wetlands. Many levees were likely constructed in locations which already contained considerable mercury deposits, and some of these historic, mercury-laden diked wetlands have long been isolated from normal tidal inundation. Upstream, mercury is still being released from contaminated watersheds and it continues to be transported to Delta environments by way of sediments, water, and organisms.

It is well known that newly flooded wetlands typically produce elevated levels of methyl mercury (Cox and others 1977; Bodaly and others 1984; Slotton 1991). This phenomenon occurs even under conditions in which *in situ* mercury concentrations are relatively low. In addition to the "new flooding" phenomenon of initially enhanced mercury methylation, wetland habitats have been found to promote mercury methylation at enhanced rates on an ongoing basis as well. Because some of the projected restoration projects for the San Francisco Bay-Delta system involve the intentional breaching of existing dikes and levees, with subsequent flooding or re-inundation of adjacent areas to create "restored" (reflooded) wetlands, there is a tangible risk that these restoration activities will increase levels of toxic methyl mercury entering the Bay-Delta ecosystem. Indeed, with natural breaching of some of the Bay-Delta levees (from storm and flooding events), there have likely been notable, but unquantified, increases in the level of methyl mercury production from these tracts. In addition, some source watersheds, depending on the distribution, nature, and magnitude of mining, likely contribute disproportionately to regional mercury loading, resulting in locally high concentrations of mercury. Environmental gradients in salinity, organic matter, and other toxic contaminants such as selenium, are known to affect mercury cycling and may also influence production of methyl mercury in the Bay-Delta.

Future restoration projects involving deliberate breaching of existing dikes and levees will likely result in a similar production of methyl mercury as a result of new flooding. Thus it is important that we quantify the potential risks of any future restoration project to the ecological health of the Bay-Delta system.

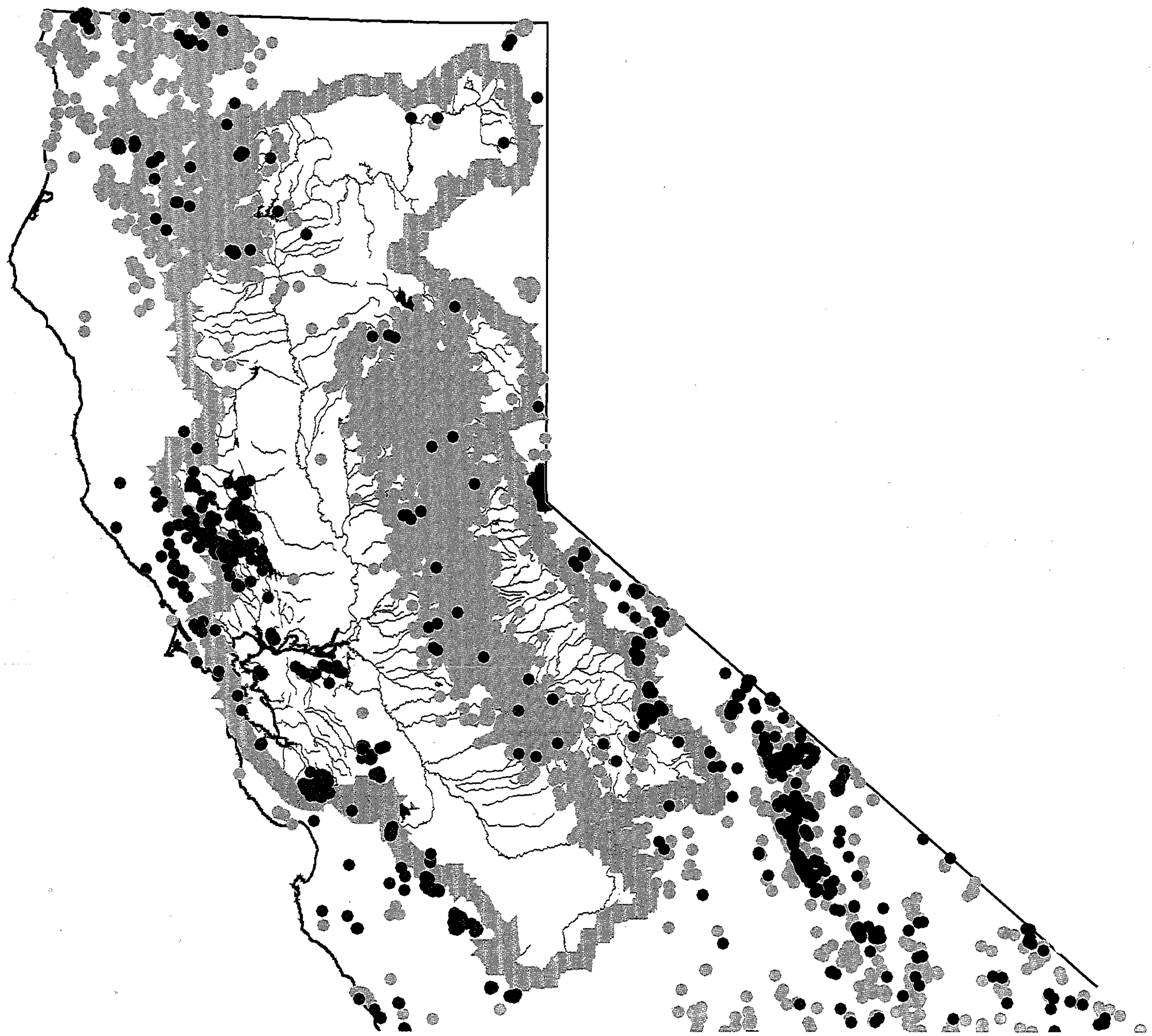

Figure 1 Distribution of mercury (red), gold (yellow) and silver (black) mines in northern California. Light gray line represents the CALFED Study Area boundary. Data from California Department of Mines and Geology.

OBJECTIVES

The goal of our project is to investigate Delta tracts that have been flooded inadvertently by storm events (over the past 1 to 75 years), together with additional representative sites throughout the region, to evaluate the potential impacts of projected restoration projects on biologically available mercury in different regions of the Bay-Delta system. These data will be used to make recommendations that are intended to improve water quality in this ecosystem, and hence minimize the exposure of biological resources to toxic mercury.

To accomplish this goal, our project focuses on two primary objectives:

1. Determine if methyl mercury distribution, production, and bioaccumulation vary along physical, chemical, and biological gradients that exist in the Delta (for example, watershed source, mercury source, time since reflooding, salinity gradient, selenium concentration, and vegetation type).
2. Determine if the restoration and rehabilitation (reflooding) of diked tidal wetlands further exacerbates the production and bioaccumulation of methyl mercury in the Delta.

APPROACH

We have chosen representative sites throughout the Delta at which we are evaluating historical mercury deposition (in cores) and the relative localized concentrations of biologically available mercury through the collection of key biological samples. At a subset of these sites, the potential for methyl mercury production is being further evaluated with a variety of sediment core experiments conducted in the laboratory.

Field collections for this project were initiated in fall 1998, with extensive sampling throughout October and November. Biological sampling across trophic levels was conducted at 29 sites throughout the Delta (Figure 2) and across gradients of several key parameters, which may be important in methyl mercury production. At each site we attempted to seine small fishes, trap crayfish and collect bivalves and amphipods. Biota were analyzed for total mercury using standard cold vapor atomic absorption spectrometry at our UC Davis Environmental Mercury Laboratory.

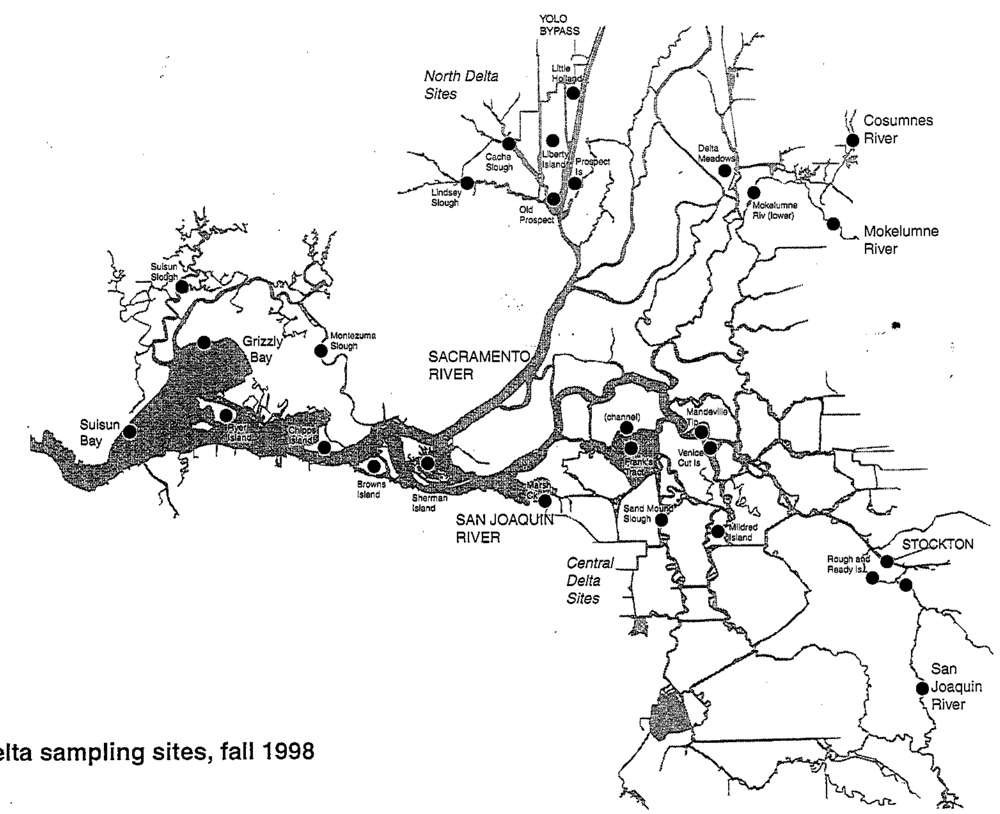

Figure 2 Delta sampling sites, fall 1998

Preliminary Results

Distribution of Biota

Our focus is on organisms most likely to have accumulated their mercury burdens at or very near the site captured. As opposed to wide ranging adult fish, these include smaller, more sedentary taxa such as sculpins, gobies, logperch, crayfish, clams, and small invertebrates. Not all biota of interest were obtainable at all sites studied, so comparisons among sites is somewhat restricted for many species. Two taxa that were moderately abundant across most sites were crayfish (benthic omnivores) and silversides (planktivores).

Crayfish

We collected two species of crayfish: (1) *Procambarus clarkii* (the introduced Louisiana swamp crayfish which typically constructs burrows in muddy substrata), and (2) *Pacifasticus leniusculus* (the introduced signal crayfish which is usually found in rocky habitats and faster moving water). At most sites we captured only one species, but we are hopeful that future sampling will generate more sites with both species to facilitate interspecific comparisons.

- Concentrations of mercury in crayfish were not uniform throughout the Delta. Some sites exhibited relatively low mercury concentrations, whereas mercury in crayfish at other sites was notably elevated. We observed a nearly five-fold range in mercury concentrations for *Pacifasticus* and about a 16-fold range in *Procambarus*, with the highest concentrations over 2.0 ppm dry weight (wt) (Figure 3).

- Elevated mercury concentrations in crayfish occurred at locations in and downstream of the Cosumnes River and at many North Delta sites exposed to Yolo Bypass and Sacramento River flows (in other words, Little Holland Tract, Liberty Island, Cache Slough, Lindsey Slough and Old Prospect tracts). Elevated mercury levels in *Pacifasticus* were also observed in channels near Frank's Tract and Mandeville Island.

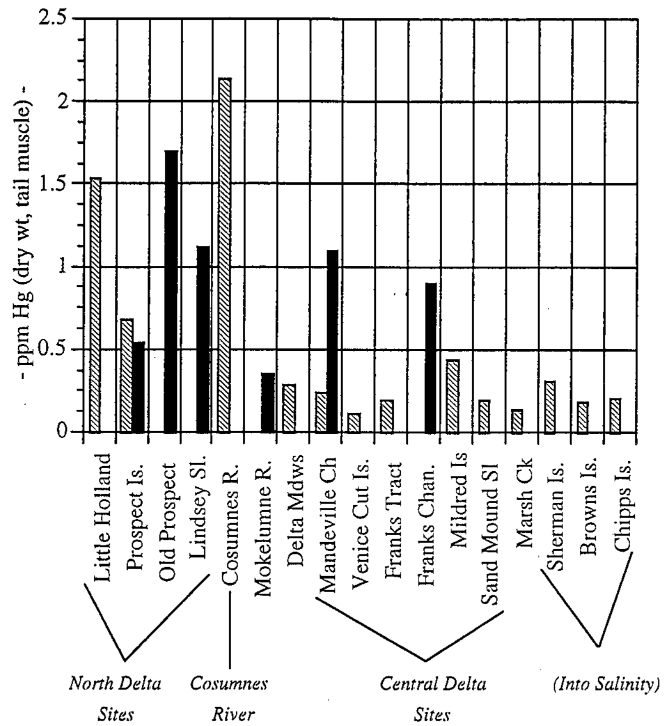

Figure 3 Mean mercury in two species of crayfish (*Procambarus* = striped bars and *Pacifasticus* = solid bars) at 17 Delta sites

- There is no clear relationship between the concentration of mercury in crayfish and time since flooding of a particular tract. Some of the preliminary data (Figure 4) may suggest a possible peak within the Old Prospect tract, which has an age since flooding of 36 years. However, peaks seen in the preliminary data are also confounded by the fact that Little Holland Tract and Old Prospect are both in the path of water flowing through the Yolo Bypass in winter, some of which originates in the mercury-rich coast range. More intensive sampling, with more replicates and from other variously aged tracts will be needed to elucidate this pattern further.

Effects of Wetlands Restoration on the Production of Methyl Mercury in the San Francisco Bay-Delta System: Preliminary Results

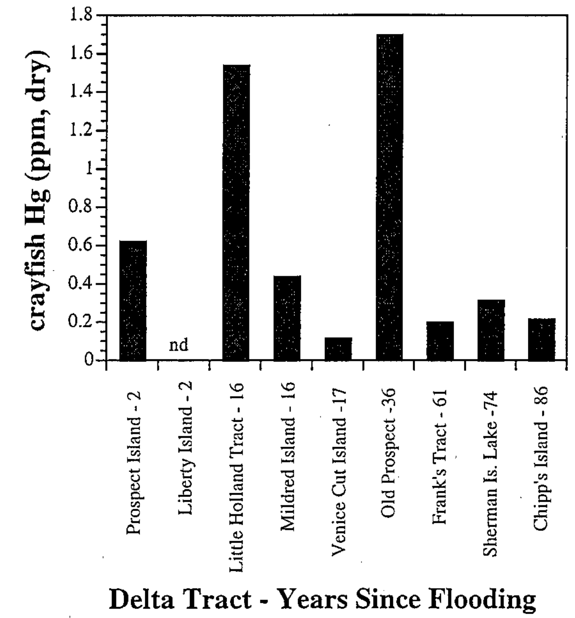

Figure 4 Mercury in crayfish as a function of "years since flooding" in Delta tracts. The letters "nd" indicate no data available.

Fishes

We collected 15 species of small fishes by seining, but in these preliminary results we report only on the introduced inland silverside, *Menidia beryllina*, which was the most ubiquitous species collected (Figure 5). Other species collected include threadfin shad (*Dorosoma petenense*, introduced), bigscale logperch (*Percina macrolepida*, introduced), prickly sculpin (*Cottus asper*, native), red shiner (*Notropis lutrensis*, introduced), shimofuri gobi (*Tridentiger bifasciatus*, introduced), yellowfin goby (*Acanthogobius flavimanus*, introduced), tule perch (*Hysterocarpus traski*, native), mosquitofish (*Gambusia affinis*, introduced), and juveniles of the following species: bluegill sunfish (*Lepomis macrochirus*, introduced), redear sunfish (*Lepomis microlophus*, introduced), white crappie (*Pomoxis annularis*, introduced), largemouth bass (*Micropterus salmoides*, introduced), striped bass (*Morone saxatilis*, introduced), and splittail (*Pogonichthys macrolepidotus*, native).

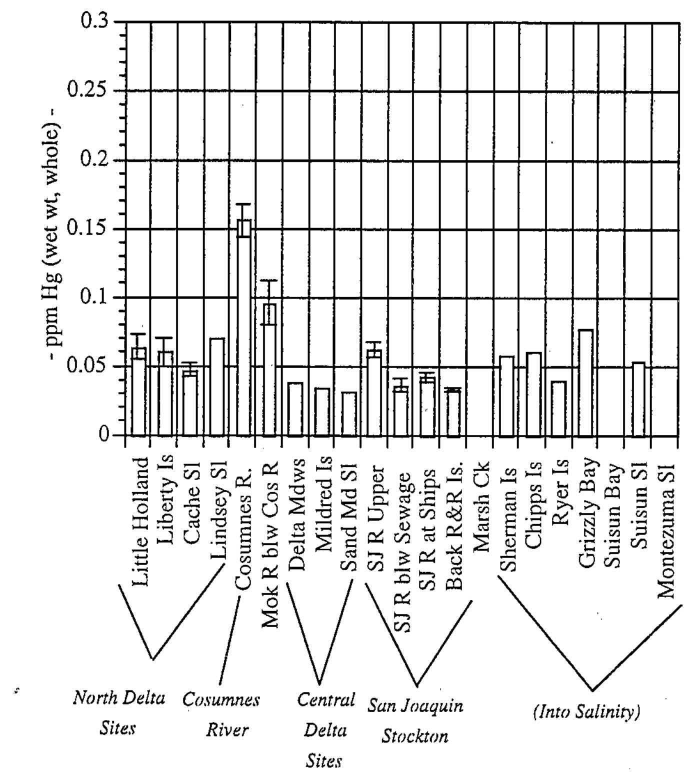

Figure 5 Mean mercury in multi-individual, whole body composites of silversides for size class 2 (45 to 60 mm length) at 18 Delta sites ± standard deviation for sites with three replicates

- As with crayfish, silversides exhibited elevated mercury levels in the Cosumnes River. Concentrations remained notably elevated well downstream of the Cosumnes River confluence, in the lower Mokelumne River. Somewhat surprisingly, silversides also exhibited higher mercury concentrations in the San Joaquin River above Stockton than at or below that urban site. Slightly elevated concentrations from the Suisun and Grizzly Bay area may be indicative of a salinity-enhancement effect or localized mercury deposits.

- The preliminary data do not suggest any strong trends in the concentration of mercury in silversides as a function of time since the flooding of a particular tract (Figure 6). The variability in mercury concentrations in silversides is considerably less than that for crayfish. And, we were unable to collect silversides for some of the intermediate aged tracts such as Old Prospect Island, where crayfish exhibited the highest mercury concentrations. Additional sampling during 1999 will provide further evidence to evaluate the influence of this parameter on mercury uptake.

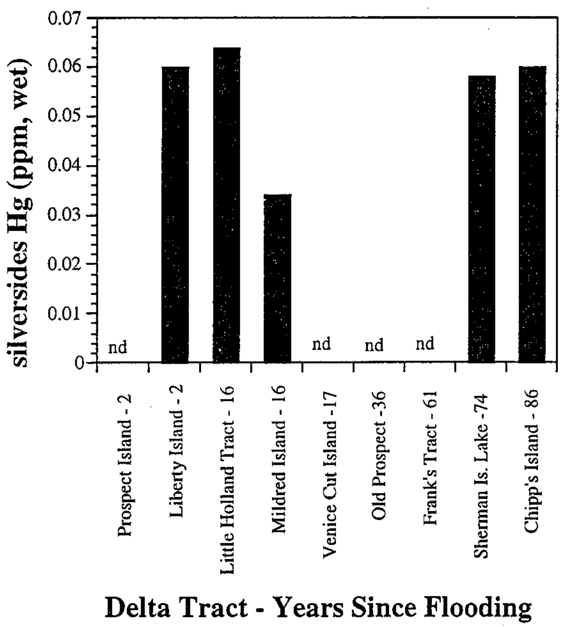

Figure 6 Mercury in silversides as a function of "time since flooding" in Delta tracts. The letters "nd" indicate no data available.

Conclusions

Contrary to some previous assumptions, preliminary data from a single field season with limited replication suggest that mercury concentrations in biota are not uniform throughout the Delta. In fact they may vary widely, by as much as 10- to 20-fold within taxa and among sites. There are numerous gradients that could contribute to the variability in mercury concentrations in biota among various Delta sites. These potential gradients include source regions of riverine inputs (Sierra compared to Coast Range), chemical composition of mercury sources (originating from different mine sites or different regions within individual mines), time since flooding, salinity, extent of vegetation coverage, plant community or stage of succession, sediment resuspension, speed and direction of current flow and presence of other contaminants, among others. The preliminary results indicate that proximity to key watershed mercury source regions may be an important factor influencing relative mercury bioavailability. Further sampling is necessary to test the significance of these various gradients on the production and bioaccumulation of mercury within various Delta habitats. The next phase in our analysis will also include establishment and sampling from *ex situ* microcosm experiments to determine potential local rates of mercury methylation.

Relevance to Bay-Delta Management-level Decisions

Regions demonstrating enhanced mercury bioavailability may not be the most desirable locations for large-scale wetland restoration efforts, particularly if similar habitat options are available at alternate sites. Regions exhibiting relatively low mercury bioaccumulation may suggest sites for alternative restoration and rehabilitation plans. At sites where there is already a commitment for restoration, it may be possible to modify engineering plans to minimize the mercury-related consequences of the projects. For example, alternate levee breeching schemes may be possible at several of these sites, with dramatically lower mercury source water and suspended sediment present on one side as compared to the other. The McCormick-Williamson Tract and Prospect Island appear to offer exactly this type of alternative. These kinds of specific alternatives will be investigated in greater detail in ongoing work. We may also be able to develop additional management options aimed at the minimization of mercury bioaccumulation, both at individual restoration sites and regionally. The initial findings of this project confirm that mercury considerations should be addressed in wetlands restoration plans for the Bay-Delta system.

References

Bodaly RA, JWM Rudd and RJP Fudge. 1984. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. *Canadian Journal of Fisheries and Aquatic Sciences* 41:682–91.

Cox JA, J Carnahan, J DiNuzio, J McCoy and J Meister. 1977. Source of mercury in fish in new impoundments. *Bulletin of Environmental Contamination and Toxicology* 23:779–83.

Slotton DG. 1991. Mercury bioaccumulation in a newly impounded northern California reservoir [dissertation]. Davis (CA): University of California, Davis. 363 p. Available from: Division of Environmental Studies, University of California, Davis.

Lessons from the Home of the Chinese Mitten Crab

Zachary Hymanson, DWR, Johnson Wang, National Environmental Sciences, Inc., and Tamara Sasaki, California Department of Parks and Recreation

Since its initial detection in South San Francisco Bay in 1992, major increases have occurred in both the abundance and distribution of the Chinese mitten crab, *Eriocheir sinensis*. Estimates of abundance from crabs entrained at the Central Valley Project Tracy Fish Collection Facility increased dramatically from dozens in 1996 to tens of thousands in 1997 to over three quarters of a million in 1998 (Siegfried 1999). Veldhuizen and Stanish (1999) and Veldhuizen and Hieb (1998) reported the mitten crab has been detected throughout the midsection of the Central Valley from Colusa to Merced, as well as San Pablo, Suisun, and South San Francisco bays, and most of the tributaries to these bays.

The introduction and establishment of the Chinese mitten crab in the Sacramento-San Joaquin Estuary is by no means a unique event. The estuary is described as one of the most cosmopolitan estuaries in the world (Nichols and others 1986), while recent analyses by Cohen and Carlton (1998) document the dramatic rate at which introduced organisms have become established in the estuary with no signs of remission in sight (Figure 1). The mitten crab continues to receive major attention, however, because of its conspicuous presence over a broad area and because of real or potential threats it imposes on the flora, fauna, and infrastructure of the estuary and associated watershed (Table 1). In addition, the California Fish and Game Commission continues to consider the contentious issue of establishing a commercial fishery for the mitten crab, and the impacts such a fishery could have on other native species and neighboring states.

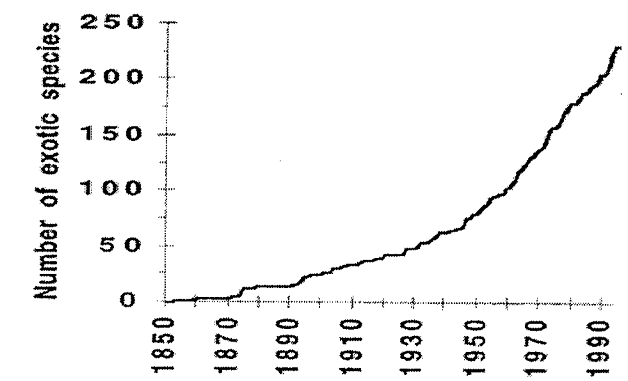

Figure 1 Cumulative number of introduced species established in the Sacramento-San Joaquin Estuary, illustrating the rate of introductions between 1850 and 1990. Total number of species in 1990 is 234. Adapted from Cohen and Carlton (1998).

Limitations in our knowledge of the biology and ecology of the Chinese mitten crab are a substantial constraint to understanding the full extent of any potential impact. Such knowledge is also important to determining appropriate responses, if any, to address the identified concerns. Under this premise we received permission to complete a fact-finding trip to eastern China, home of the mitten crab. In particular, we sought information relating to the real and potential impacts associated with the crab's presence in California (Table 1). Between 7 and 17 May 1999 we visited areas along the Yangtze River between Shanghai and Hefei (Figure 2). We also met with local officials and researchers associated with the Shanghai Fisheries Bureau and the Anhui Province Fisheries Bureau in Hefei. Professor Zhao was our local host and guide during our stay in China. Professor Zhao is the former director of the Anhui Province Fisheries Bureau and director of the Anhui Weiqing Aquatic Products Company, a leading producer of cultured mitten crabs. Over the last 20 years Professor Zhao's research has focused on the biology and culture of the Chinese mitten crab.