Mercury Strategy for the Bay-Delta Ecosystem

A Unifying Framework for Science, Adaptive Management, and Ecological Restoration

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Public presentation by to the California Bay-Delta Program, Ecosystem Restoration Subcommittee, Resources Building Auditorium, Sacramento, CA, April 9, 2003

Academy of Natural Sciences, Estuarine Research Center

Experimental research on mercury in Florida Everglades

Coauthor David Krabbenhoft (USGS)

Applying mercury-202 to an experimental watershed in northwestern Ontario

Acknowledgments

Funding:

- California Bay-Delta Authority
- Association of Bay Area Governments

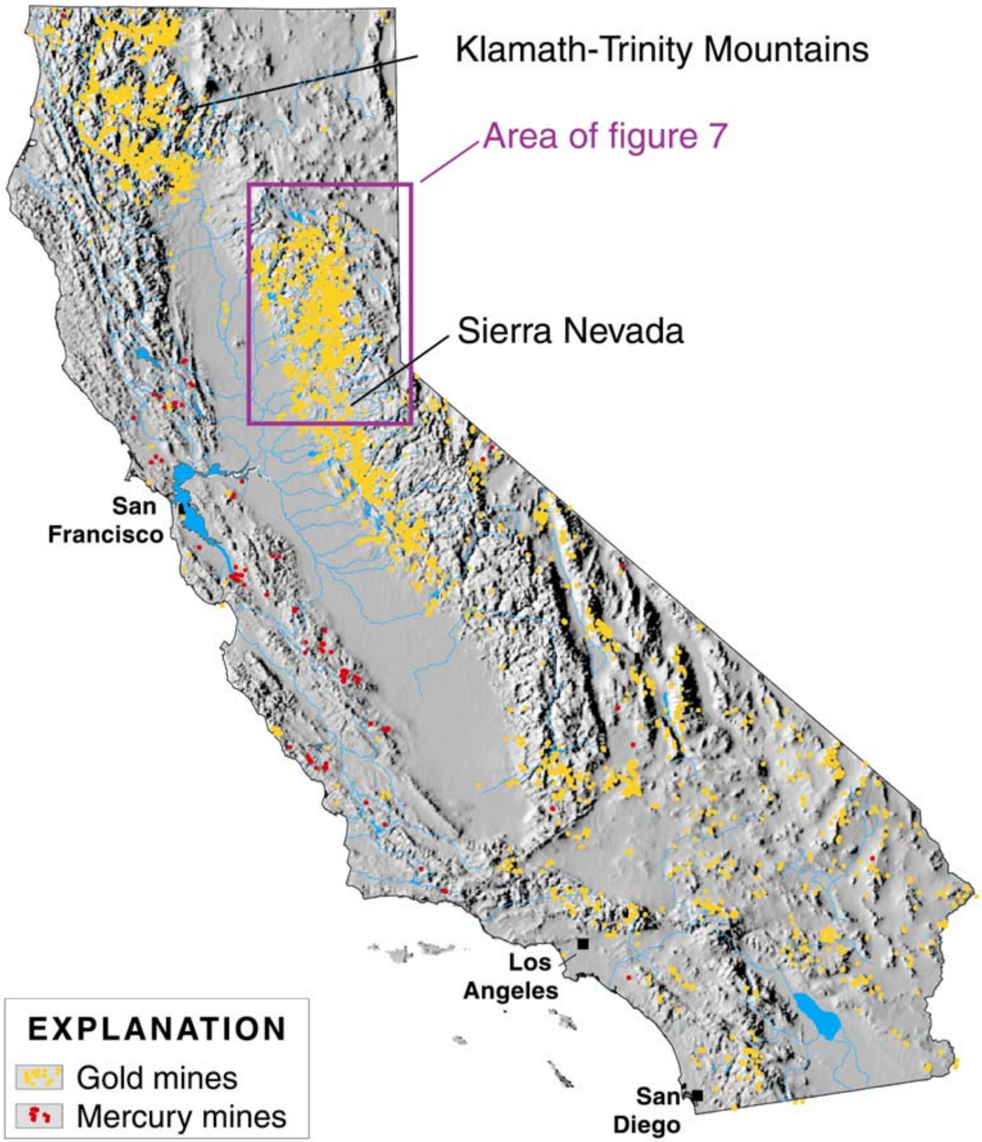
Input to the Strategy:

- Workshop speakers, group leaders, and participants

Presentation Outline

- The Bay-Delta System and watersheds: a mercury-contaminated ecosystem
- Restoration in a mercury-contaminated ecosystem: The need to focus on methylmercury
- Mercury strategy for the Bay-Delta Ecosystem
  - Development
  - Unifying themes
  - Core components
  - Linkages and integration

Sources of Mercury (Hg)



From USGS

Mining sources

Current and historic wastes from 239 known mines, most in Coast Range (inorganic Hg & MeHg)

Up to 3.6-million kg of Hg lost during precious-metal processing in Sierra Nevada during the late 1800's (Alpers & Hunerlach 2000)

Riverine inputs

Contaminated waterways in Coastal and Sierra ranges continue to export inorganic Hg and MeHg to the Bay-Delta

Natural abundance

High in Coast Ranges
Lower in Sierra Nevada

Hydraulic Gold Mining

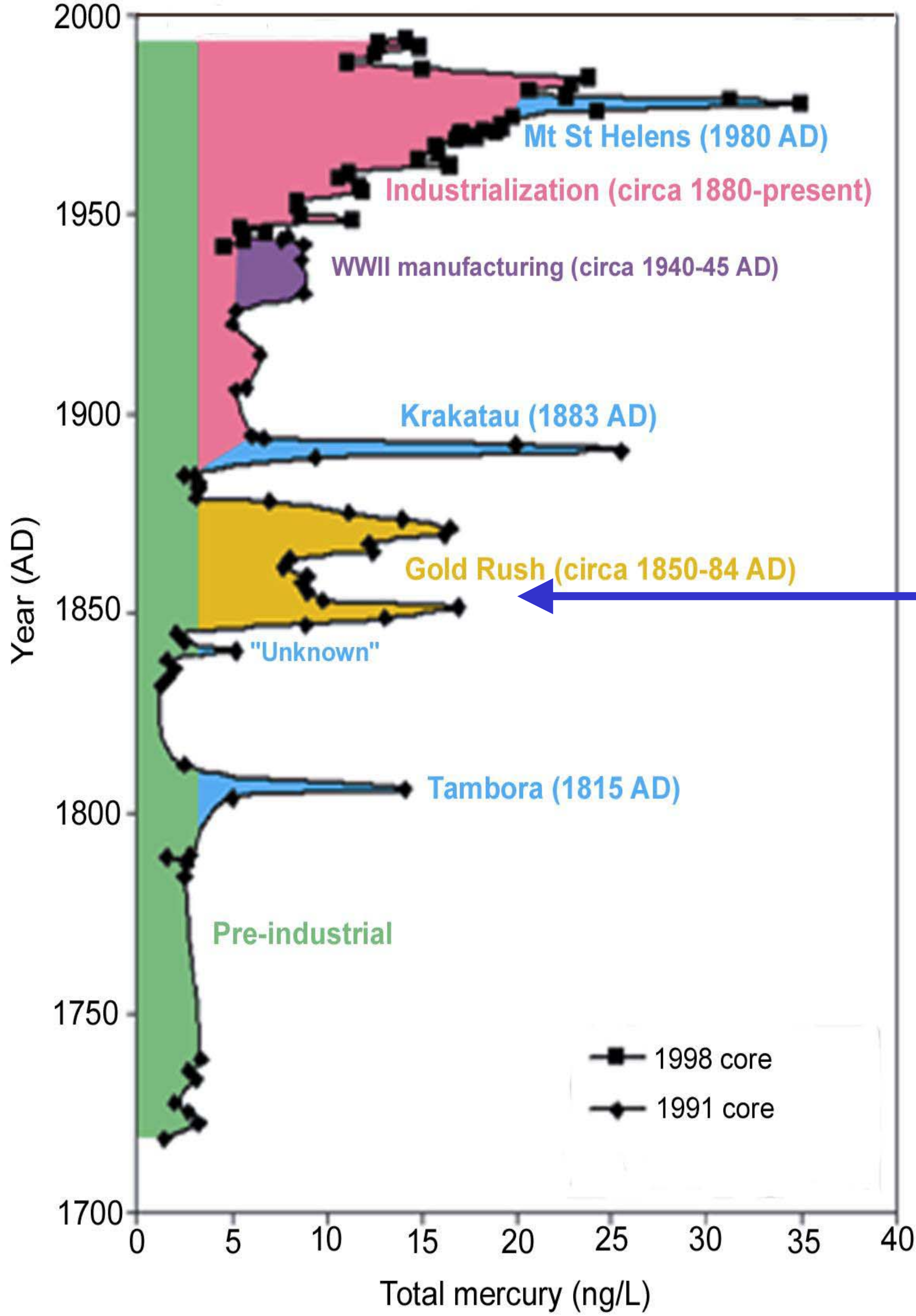
Monitors, circa 1880s

Sluices, circa 1870s

Tailings in stream bed

Modern sediment transport

Figure 2



A 270-year record of mercury deposition in glacial ice (Upper Fremont Glacier, Wyoming)

Elevated atmospheric emissions & deposition evident during California Gold Rush

Schuster et al. 2002

The Aquatic Mercury Problem
a Methylmercury Problem

- Produced by sulfate-reducing bacteria in aquatic sediments and wetlands
- Readily crosses biological membranes
- Bioaccumulates in exposed organisms
- Biomagnifies in food webs
- Primary form (95-99%) in fish

The Aquatic Mercury Problem
a Methylmercury Problem

- Highly neurotoxic: Early life stages are most sensitive
- Methylmercury in the Bay-Delta ecosystem
  - Existing sources include mine wastes, tributaries (particularly Sacramento R), wetlands, and tidal marshes
  - Some restoration actions could increase production & abundance of methylmercury

Biomagnification in Food Chains

	Marine Bay		Wisconsin Lake	
	MeHg (ng/g)	% of HgT	MeHg (ng/g)	% of HgT
Predatory fish	2,300	>95	650	>95
Prey fish	450	93	100	>90
Invertebrates	150	45	20	29
Algae	7	10	4	13
Water	nd	nd	0.00005	5

HgT = total mercury

MeHg = methylmercury

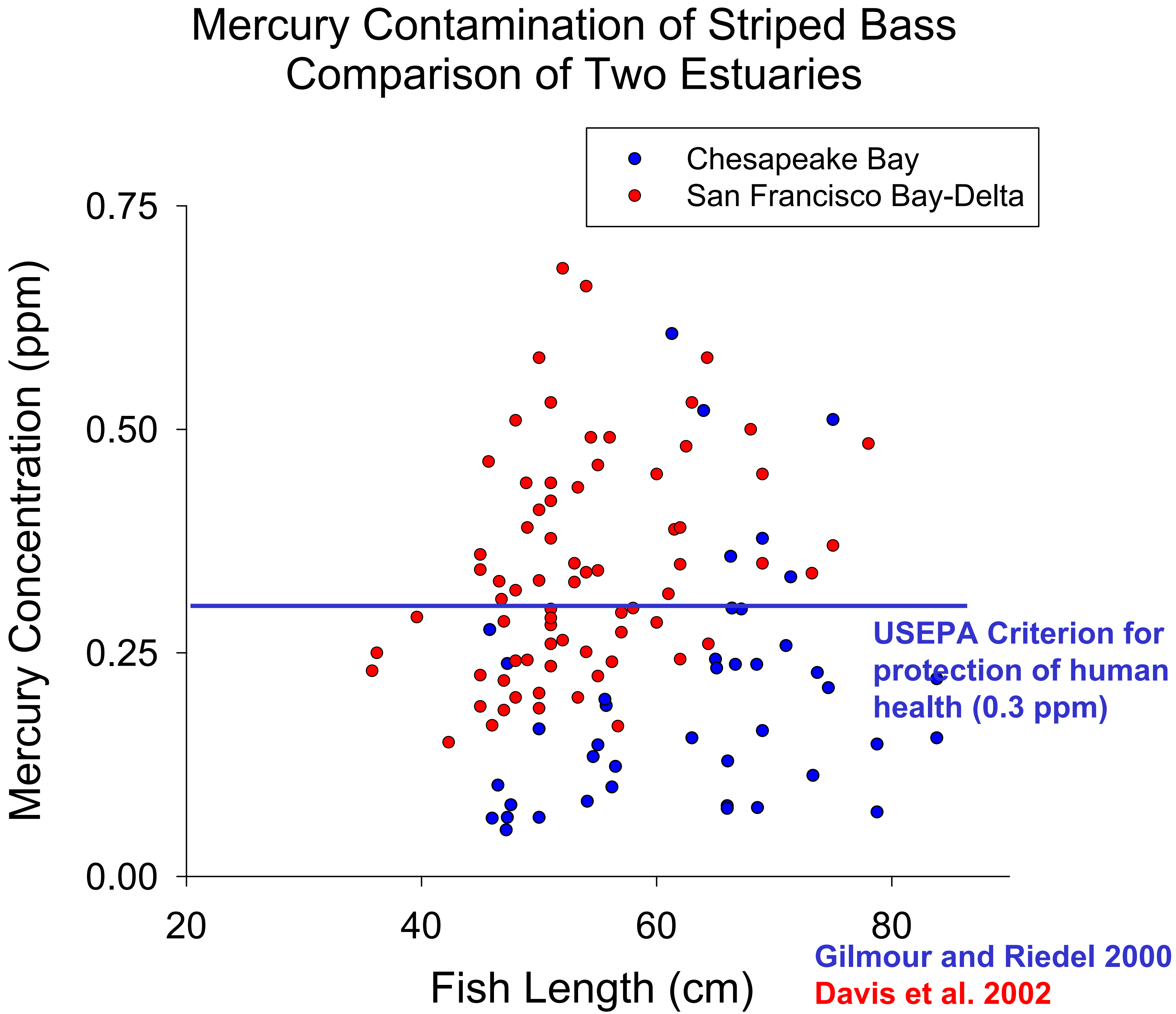
Source: Wiener et al. 2003

Methylmercury contamination and exposure can diminish success in achieving restoration goals by

1) adversely affecting the health and reproduction of native fish and wildlife
2) diminishing nutritional, economic, cultural, and recreational benefits from fisheries
3) posing health risks to human consumers of fish, shellfish, and wildlife
4) degrading the quality of water and sediment

Goals of CBDA Ecosystem Restoration Program, from Strategic Plan
(goals influenced by mercury)

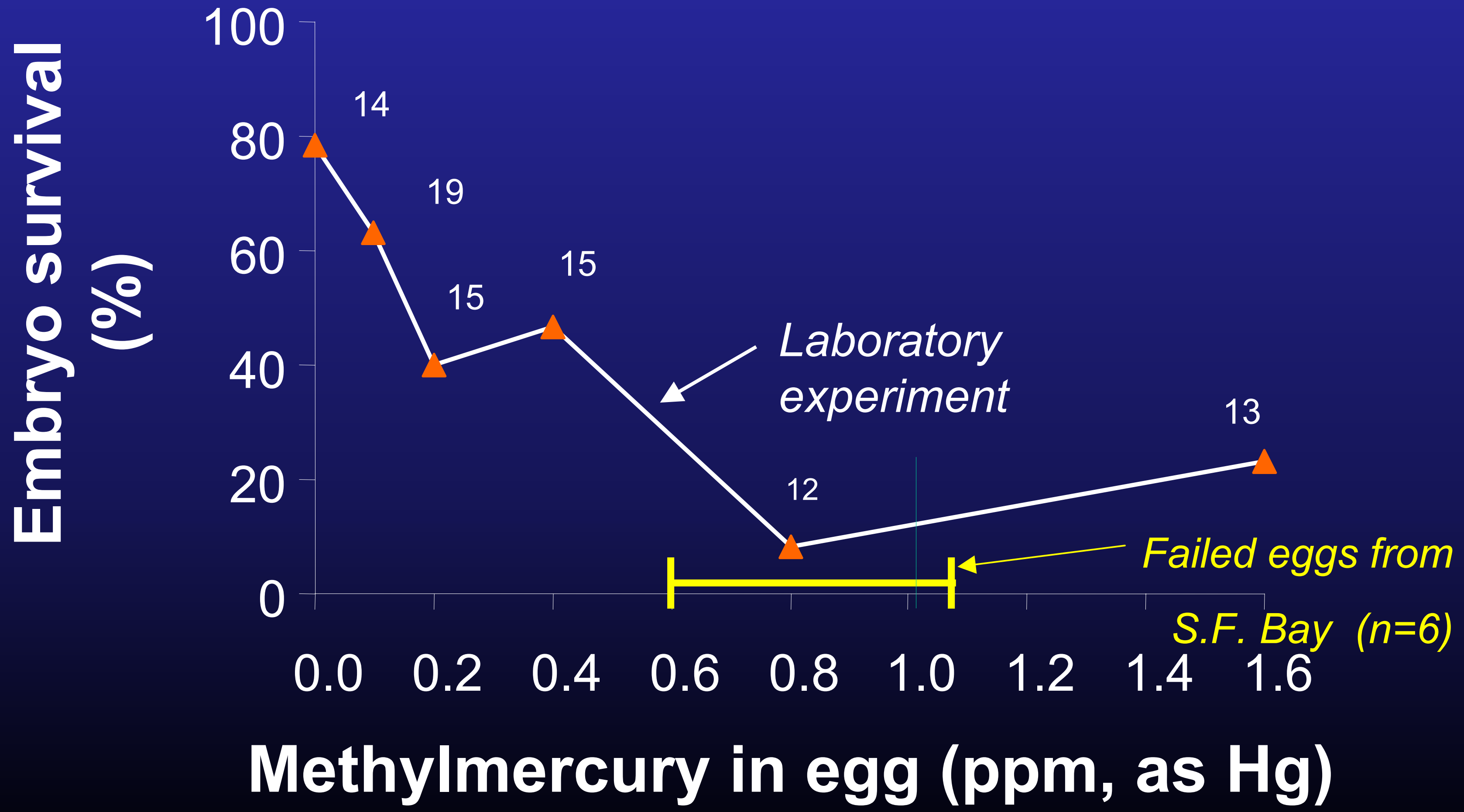
1) Assist and recover at-risk native species
2) Rehabilitate the Bay-Delta to support native aquatic and terrestrial communities
3) Maintain or enhance selected species for harvest
4) Protect and restore functional habitat for both ecological and public values
5) Prevent the establishment of additional non-native species
6) Improve or maintain water and sediment quality


Mercury Contamination of Striped Bass
Comparison of Two Estuaries
Chesapeake Bay
San Francisco Bay-Delta
Mercury Concentration (ppm)
0.75
0.50
0.25
0.00
20
40
60
80
Fish Length (cm)
USEPA Criterion for protection of human health (0.3 ppm)
Gilmour and Riedel 2000
Davis et al. 2002

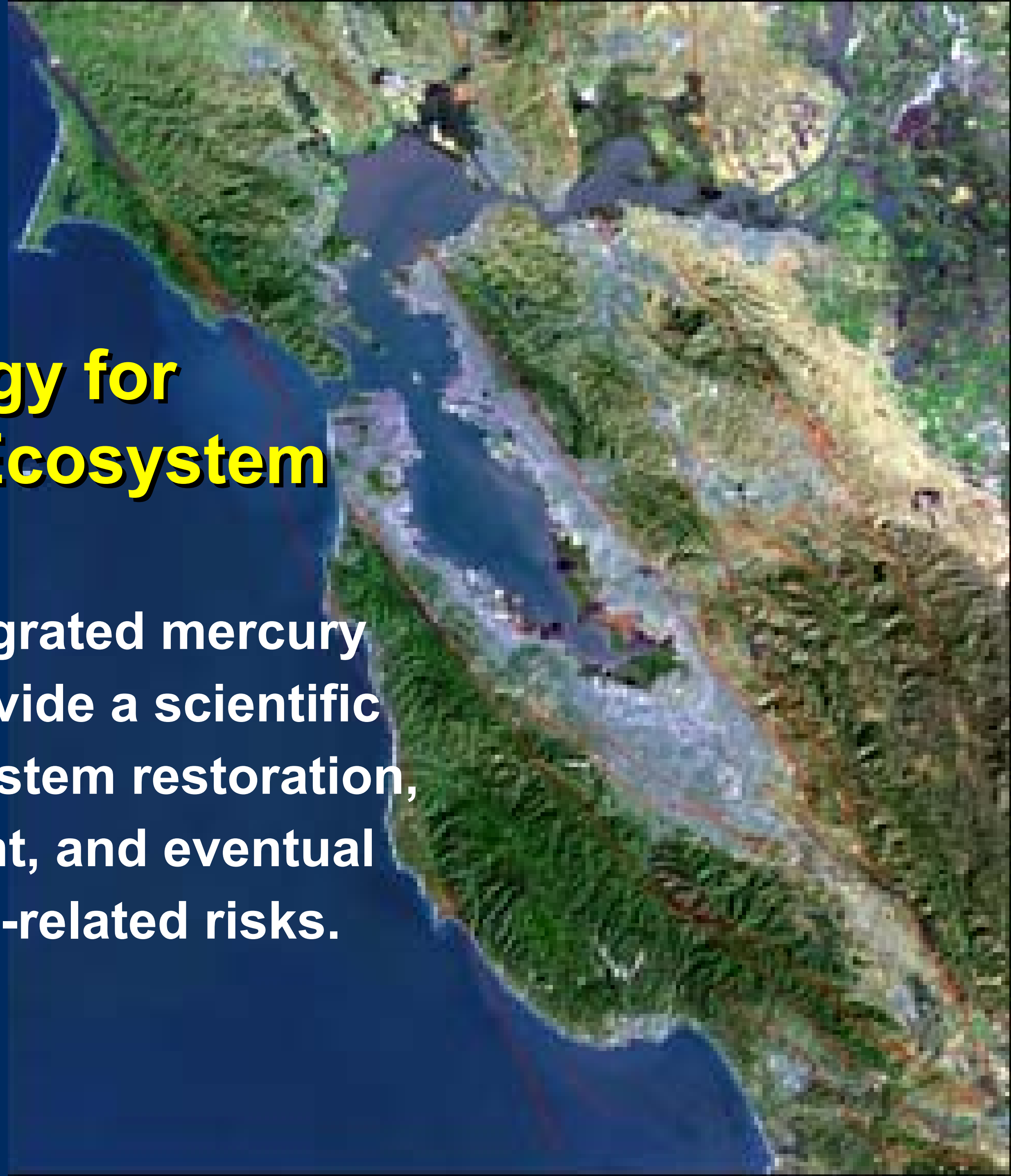
Methylmercury exposure: Is reproductive success being adversely affected in California clapper rails?

Laboratory data by Heinz (USGS)

Field data by Schwarzbach & Adelsbach (USFWS)



Mercury Strategy for the Bay-Delta Ecosystem



A framework for integrated mercury investigations to provide a scientific foundation for ecosystem restoration, adaptive management, and eventual reduction of mercury-related risks.

Development of the Mercury Strategy

- **Broad ownership:** Input from involved managers, scientists, and other stakeholders
- **Public workshops:** Topical group discussions to define
  - key management questions
  - critical information gaps
  - goals, objectives, and priorities

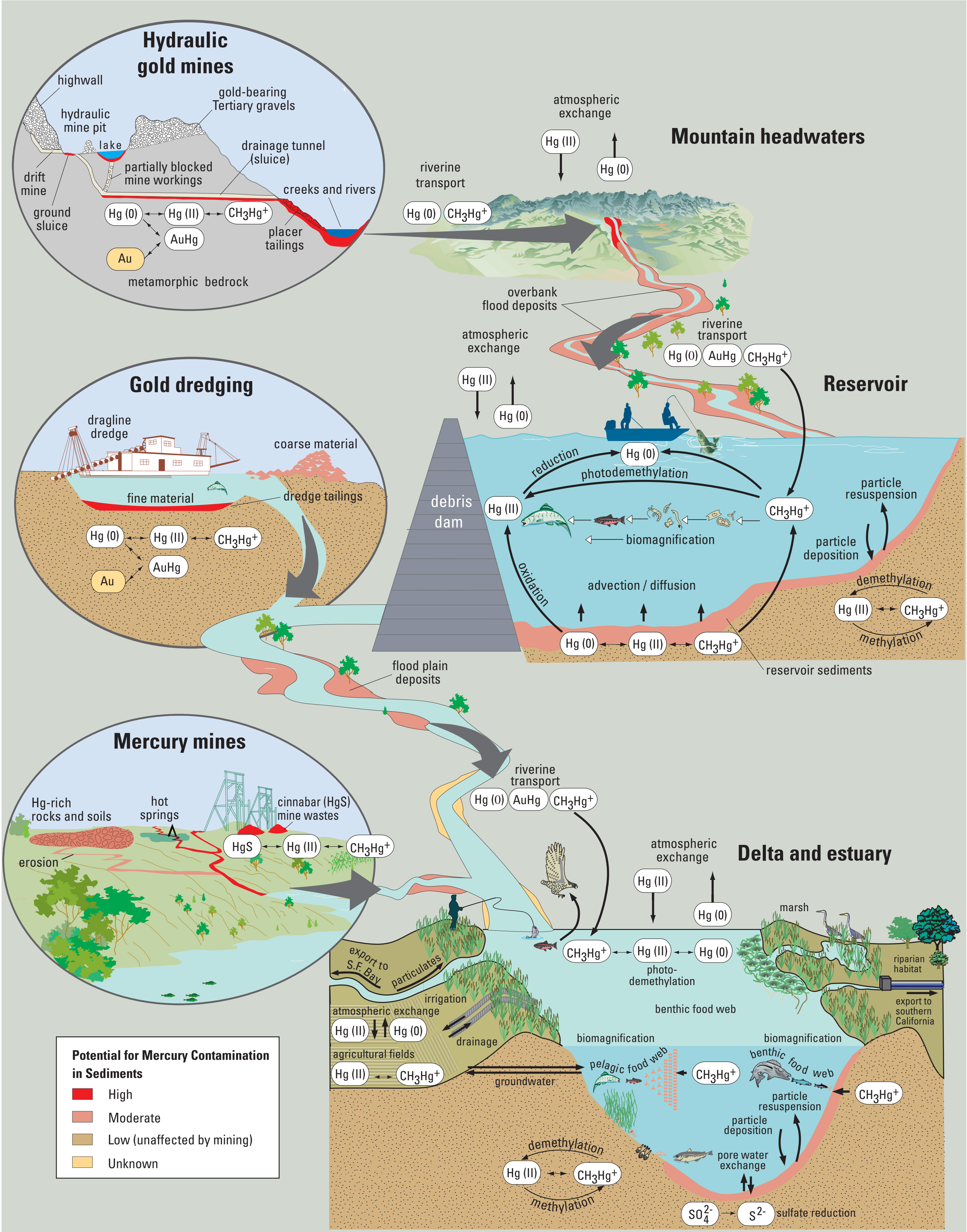
Development of the Mercury Strategy

- **Draft strategy:** Developed by small team of “outside” experts; review and further input by stakeholders
- **Adaptive management:** The optimal approach for applying rapid scientific advances (ecosystem-specific and external) to ecosystem management

Development of the Mercury Strategy

Philosophy of the Main Authors

- A flexible framework to facilitate sound science and originality
- Focus on processes affecting methylmercury abundance and exposure
- Strong linkages between management and science
- Emphasize performance measures and evaluation of outcomes



Hydraulic gold mines
highwall
hydraulic mine pit
lake
gold-bearing Tertiary gravels
drainage tunnel (sluice)
partially blocked mine workings
drift mine
ground sluice
creeks and rivers
Hg (0)
Hg (II)
CH3Hg+
AuHg
Au
placer tailings
metamorphic bedrock
Mountain headwaters
atmospheric exchange
riverine transport
overbank flood deposits
Reservoir
reduction
photodemethylation
biomagnification
oxidation
advection / diffusion
particle resuspension
particle deposition
demethylation
methylation
reservoir sediments
debris dam
Gold dredging
dragline dredge
coarse material
fine material
dredge tailings
flood plain deposits
Mercury mines
Hg-rich rocks and soils
hot springs
cinnabar (HgS) mine wastes
erosion
HgS
Delta and estuary
marsh
riparian habitat
export to southern California
export to S.F. Bay
particulates
irrigation
drainage
agricultural fields
groundwater
photo-demethylation
benthic food web
pelagic food web
pore water exchange
sulfate reduction
SO4 2-
S 2-
Potential for Mercury Contamination in Sediments
High
Moderate
Low (unaffected by mining)
Unknown

Modeling of Mercury Cycling in the Bay-Delta Ecosystem

next decade

Conceptual → **Predictive**

Descriptive — ***process based, numeric***

Initial emphasis: Increase understanding of ecosystem factors and processes (including management actions) controlling MeHg abundance and exposure, to build a foundation for modeling

Unifying Themes for a Science and Management Agenda

The Problem - methylmercury exposure

The Scientific and Management Goal or Challenge – to avoid increasing and if feasible, to reduce, exposure to methylmercury

Mercury Strategy – Core Components 1 and 2 (Sources)

Core Component (task)	Management Goal
1) Quantify & evaluate sources of Hg and MeHg	To identify Hg sources that contribute most to production & bioaccumulation of MeHg
2) Remediate Hg source areas	To identify remedial actions that can reduce loadings of Hg to surface waters and decrease exposure of biota to MeHg

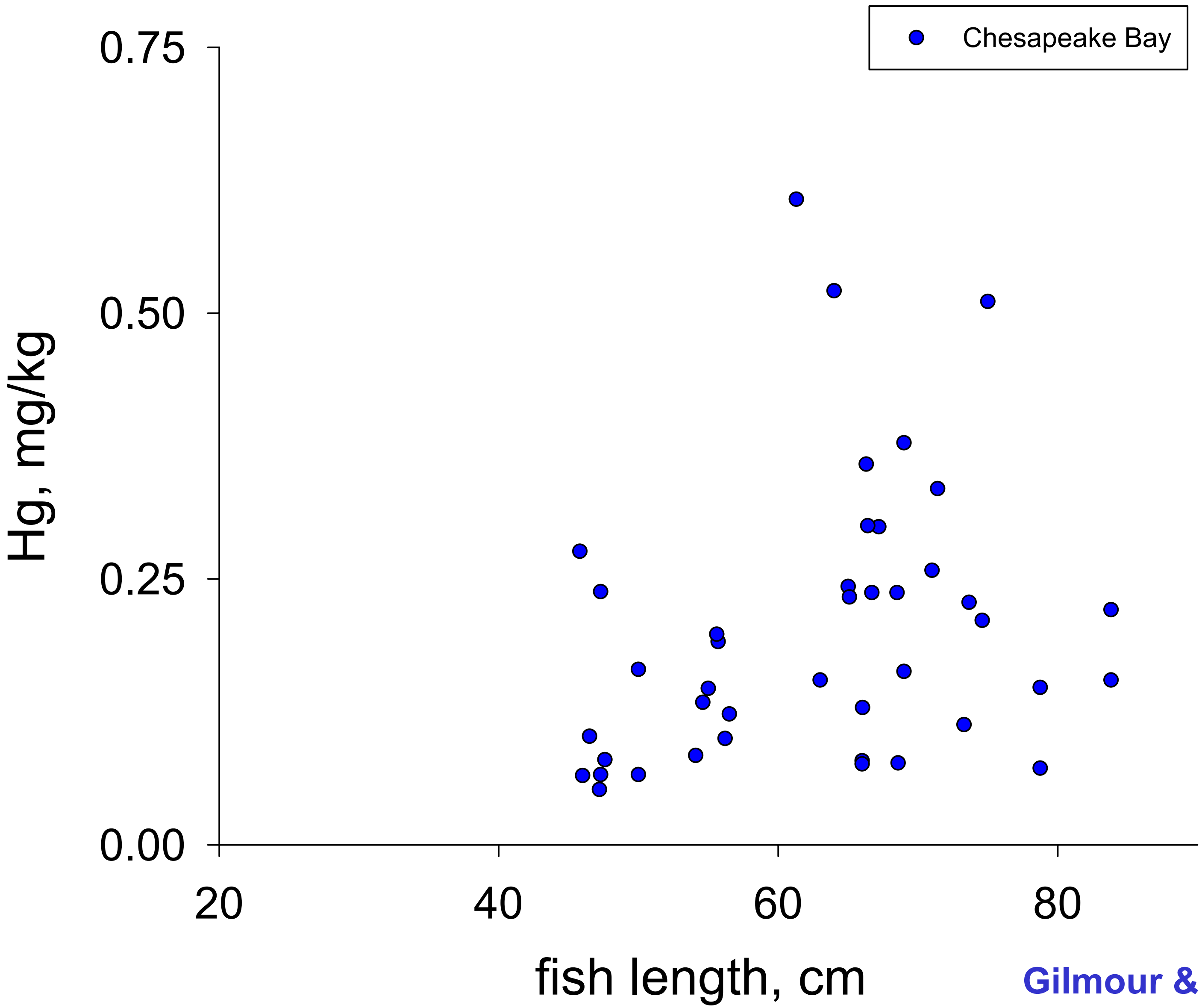
New Almaden Hg mine: mill site and tailings

The Atmosphere

A potentially significant source of mercury in fish

Atmospheric deposition of mercury can cause significant contamination of aquatic biota, as exemplified by high concentrations of mercury in game fish in many inland lakes and watersheds where atmospheric deposition is known to be the dominant source of mercury.

Mercury Contamination of Striped Bass
Comparison of Two Estuaries



Gilmour & Riedel 2000

Mercury Contamination of Striped Bass
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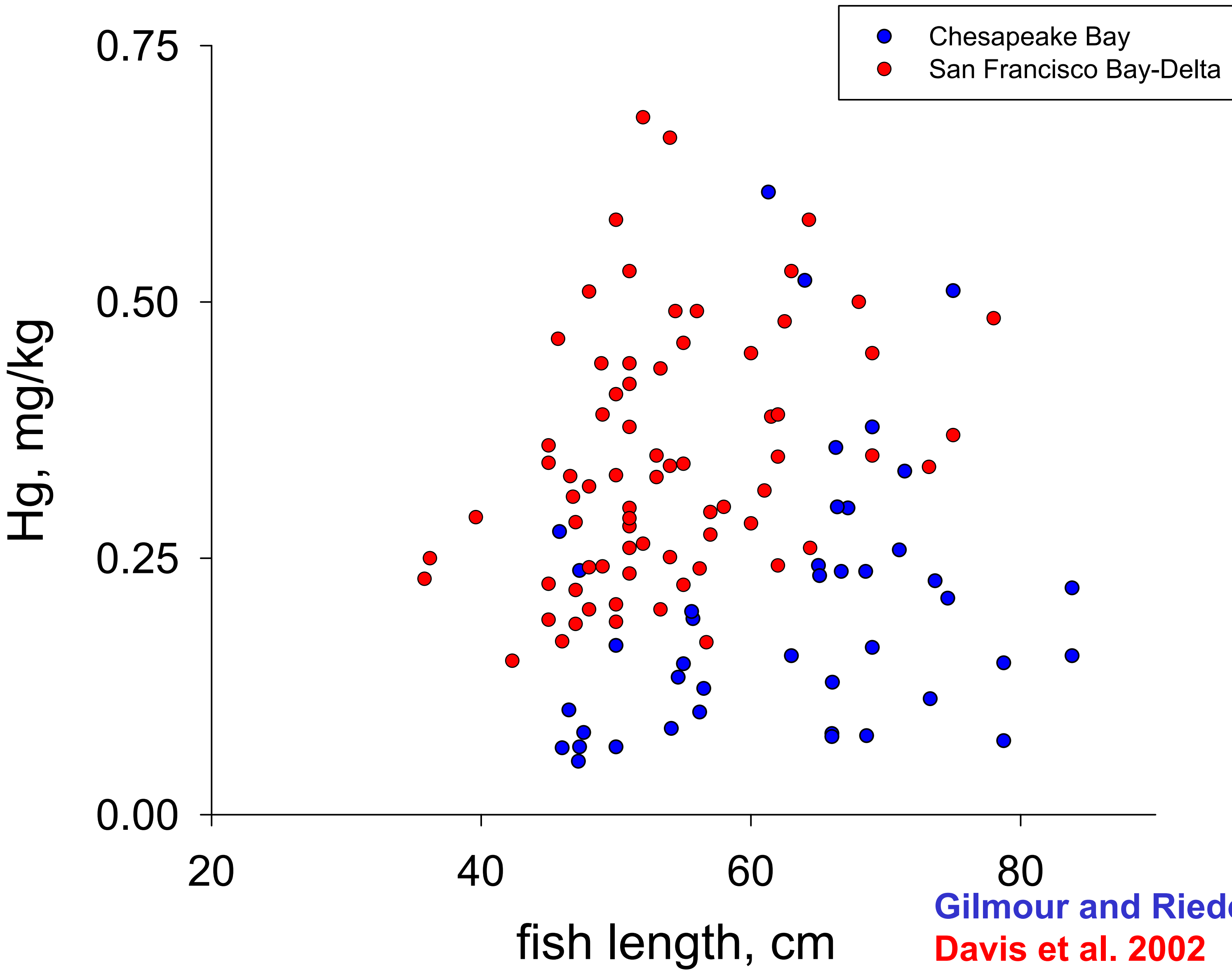


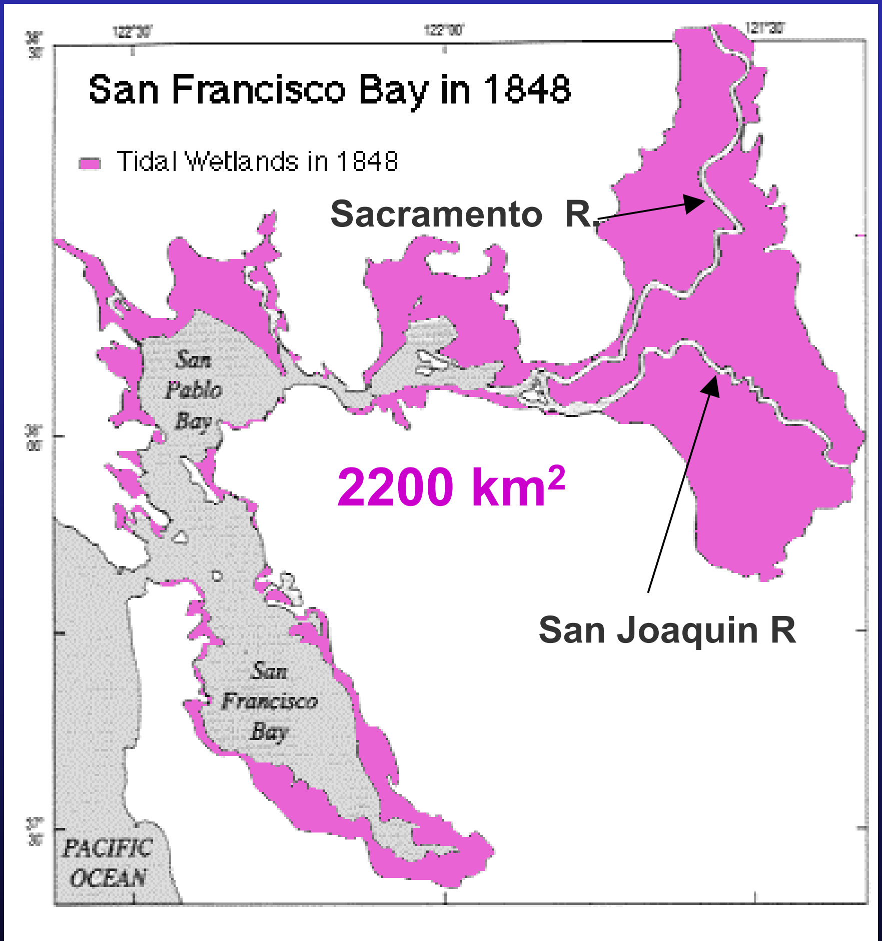
Gilmour and Riedel 2000
Davis et al. 2002

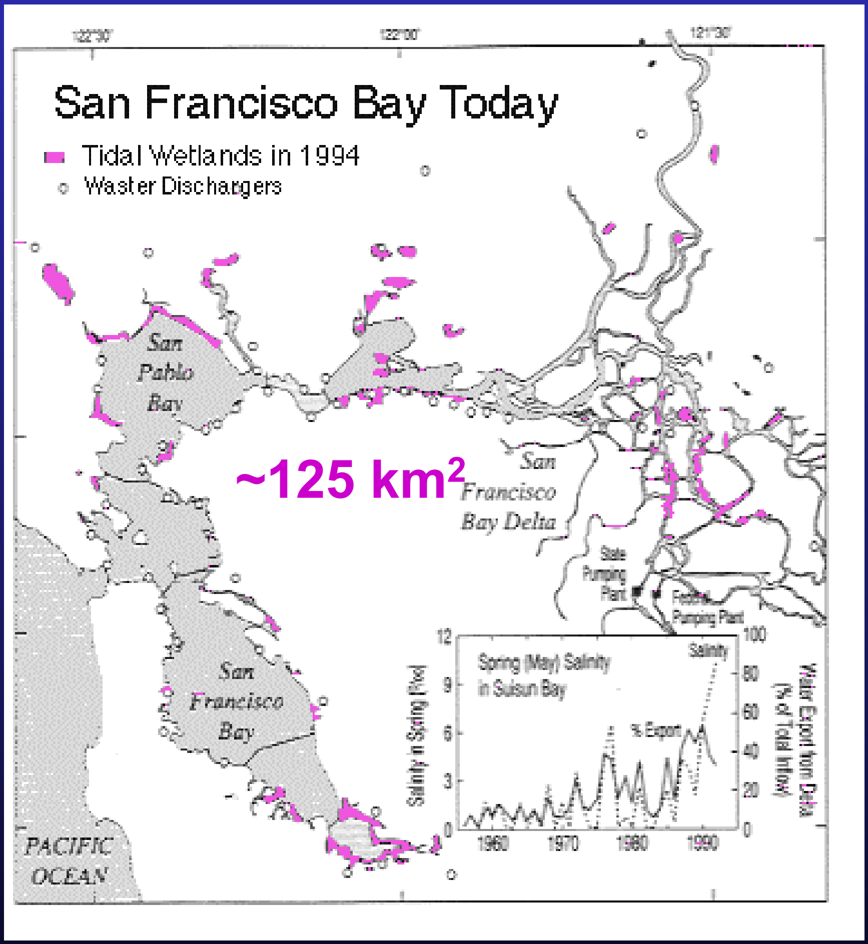
Mercury Strategy – Core Component 3 (Effects of Restoration)

Core Component (task)	Management Goal
3) Quantification of effects of ecosystem restoration on MeHg exposure	To understand the effects of ecosystem restoration in wetland and floodplain habitats on production and bioaccumulation of MeHg

Restoration of Bay-Delta Wetlands

(95% loss from 1848 to 1994)





Source: F.H. Nichols, USGS

Declines in abundance & distribution of many plant and animal species

Restoration in the Bay-Delta Ecosystem

It could exacerbate the mercury problem

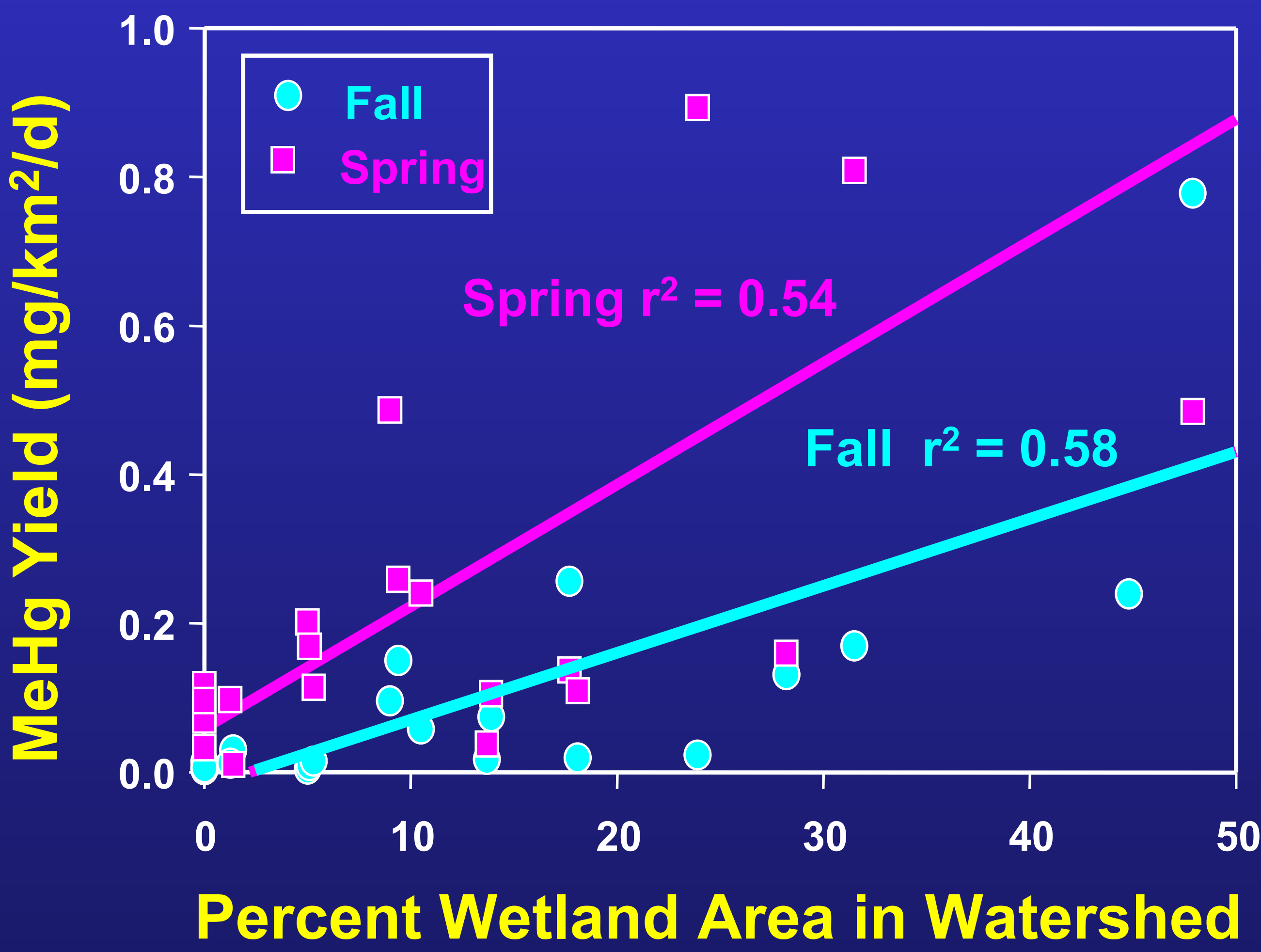
Type of restoration project	Expected effect on Hg cycling	
	Mobilization and loads	Methylation of mercury
Dam removal	X	--
Channel reconstruction	X	--
Wetland restoration	--	X
Floodplain restoration and inundation	X	X

Controls on Methylmercury Exposure

- **Bay-Delta ecosystem:** Widespread mercury contamination in watersheds, Delta, and Bay

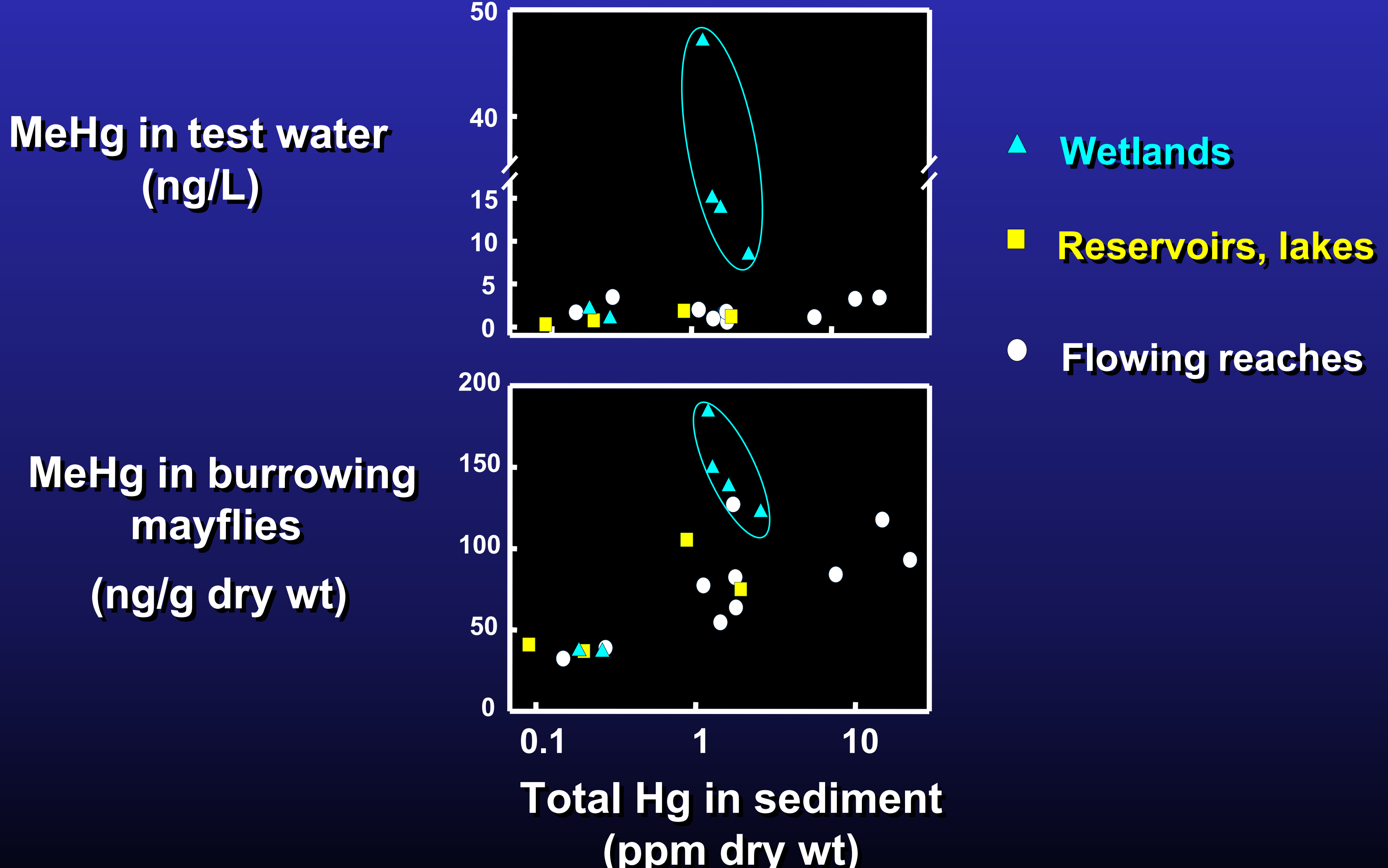
- **Assumption in strategy development:** Changes in bioavailability or net methylmercury production have much greater potential to increase methylmercury exposure than do changes in spatial distribution of total (mostly inorganic) mercury in this ecosystem

Wetlands: Primary sources of methylmercury in Wisconsin watersheds



(Hurley et al. 1995)

Methylmercury (MeHg) Production in Riparian Wetlands
Sudbury River, Massachusetts



(Naimo et al. 2000)

Flooding: Effect on Methylmercury Production

(Experimental Lakes Area, northwestern Ontario)

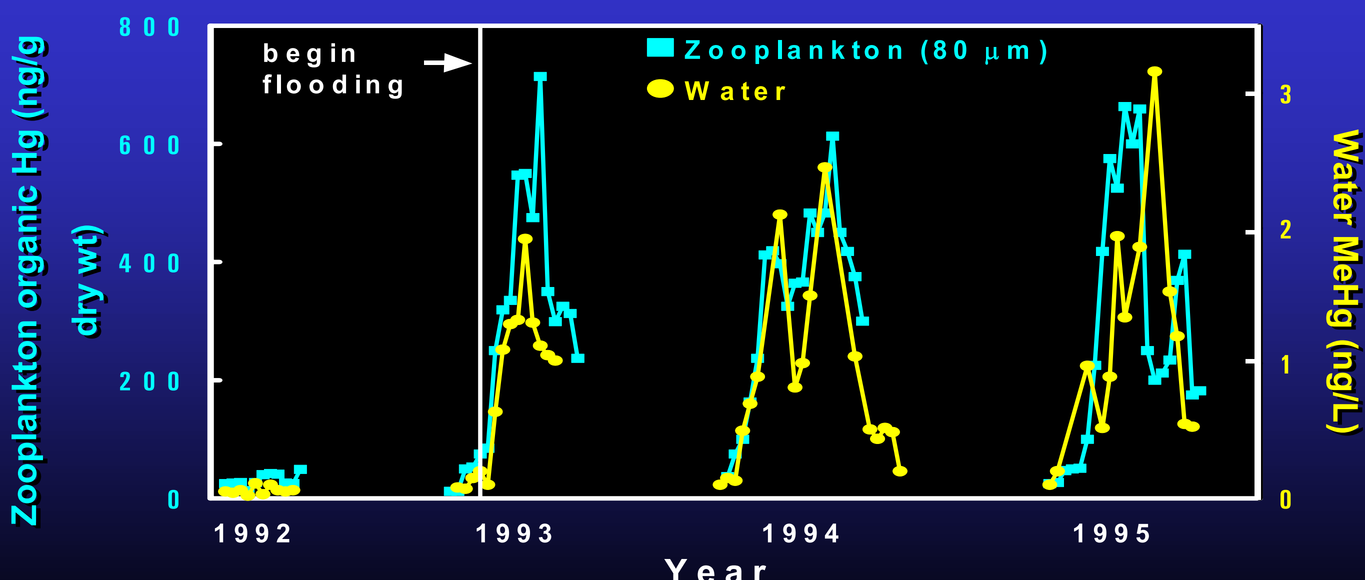
Pre-flood wetland

Post-flood wetland (no Hg added)

Source: Kelly et al. 1997

Effect of Flooding on Methylmercury Production

MeHg in Zooplankton and Water



Sources: Kelly et al. 1997; Paterson et al. 1998

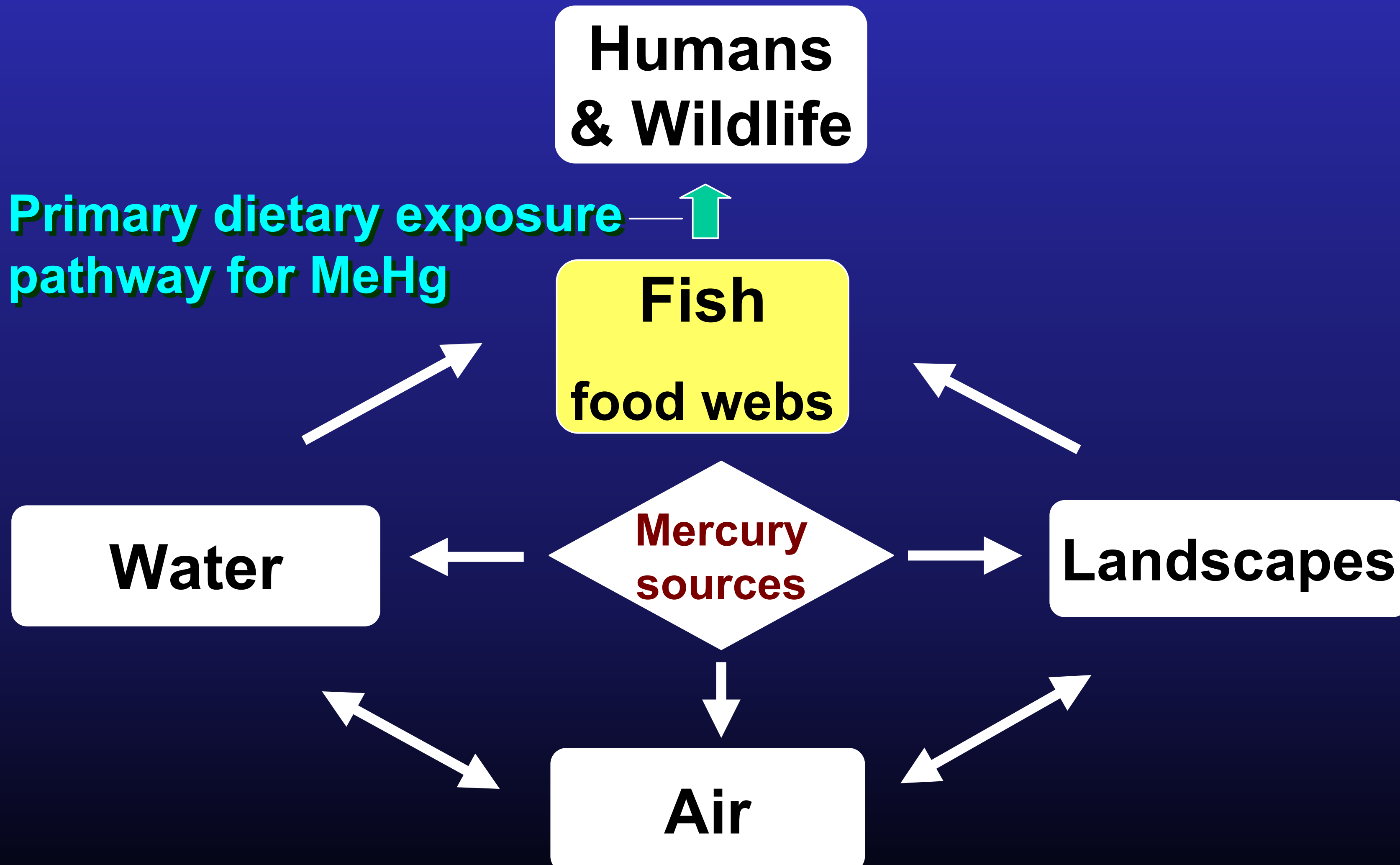
Mercury Strategy – Core Component 4

(Monitoring, Health-Risk Assessment, Risk Communication)

Core Component (task)	Management Goals
4) Monitor mercury in fish, assess health risks, and provide fish-consumption advice	(A) To protect human health by assessing and reducing exposure to methylmercury-contaminated fish (B) To provide a performance measure to gage methylmercury contamination of the ecosystem during restoration

Methylmercury in Fish and Aquatic Biota

(a performance measure for adaptive management)



Complexities in Interpreting Mercury Levels in Gamefish

- Spatiotemporal variation in size, age, and trophic position of fish
- Long response time (insensitive indicator of change)
- Large uncertainty in estimates of mean or size-adjusted mercury concentration

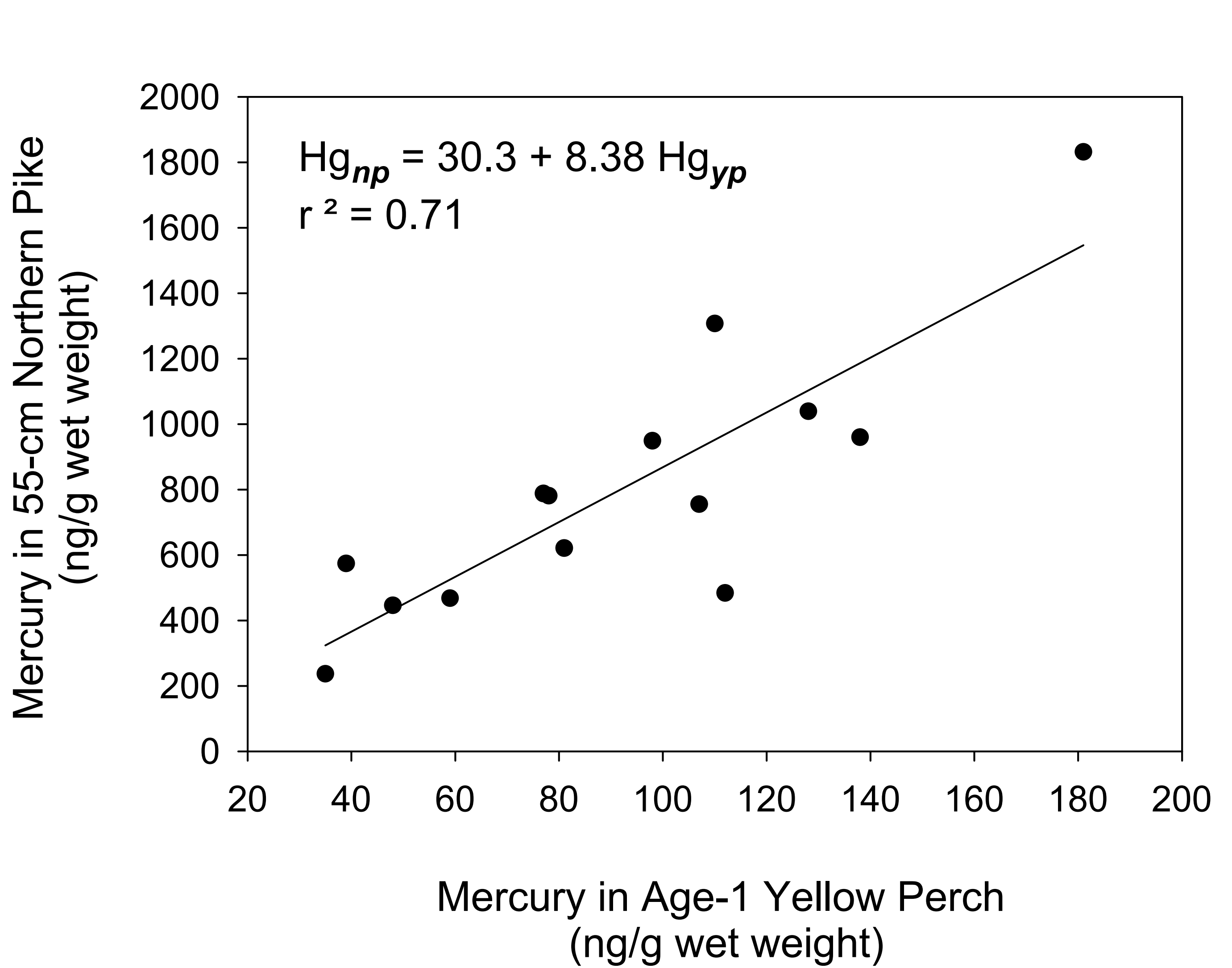
Biosentinel Approach to Monitoring

(Example: 1-year old yellow perch as an indicator of MeHg in aquatic food webs)

- **Regionally widespread and often abundant**
- **Important in trophic transfer of MeHg**
- **Constrained diet (first-year perch)**
- **Precise estimates of mean [Hg] in whole fish**

Interpretation: Variation in Hg concentrations in age-1 perch reflects spatial or temporal variation in the abundance of methylmercury

Age-1 Yellow Perch as an Indicator of Mercury in 55-cm Northern Pike (northern Minnesota lakes)



Precision Compared: Biosentinel (Perch) and Game Fish (N. Pike)

(concentrations in ng/g wet weight or ppb)

	Hg in age-1 perch			Hg in 55-cm pike		
Lake	Mean	95%CI	N	Estimate	95% CI	N
Mukooda	35	34-36	12	237	186-288	23
Tooth	121	113-129	12	1307	890-1726	29
Ryan	182	165-199	20	1832	789-2875	49

Mercury Strategy – Core Component 5

(Assessment of Ecological Risk)

Core Component (task)	Management Goal
5) Assess ecological risk	To protect fish and wildlife from adverse effects of methylmercury exposure

Risks to Fish-Eating Wildlife

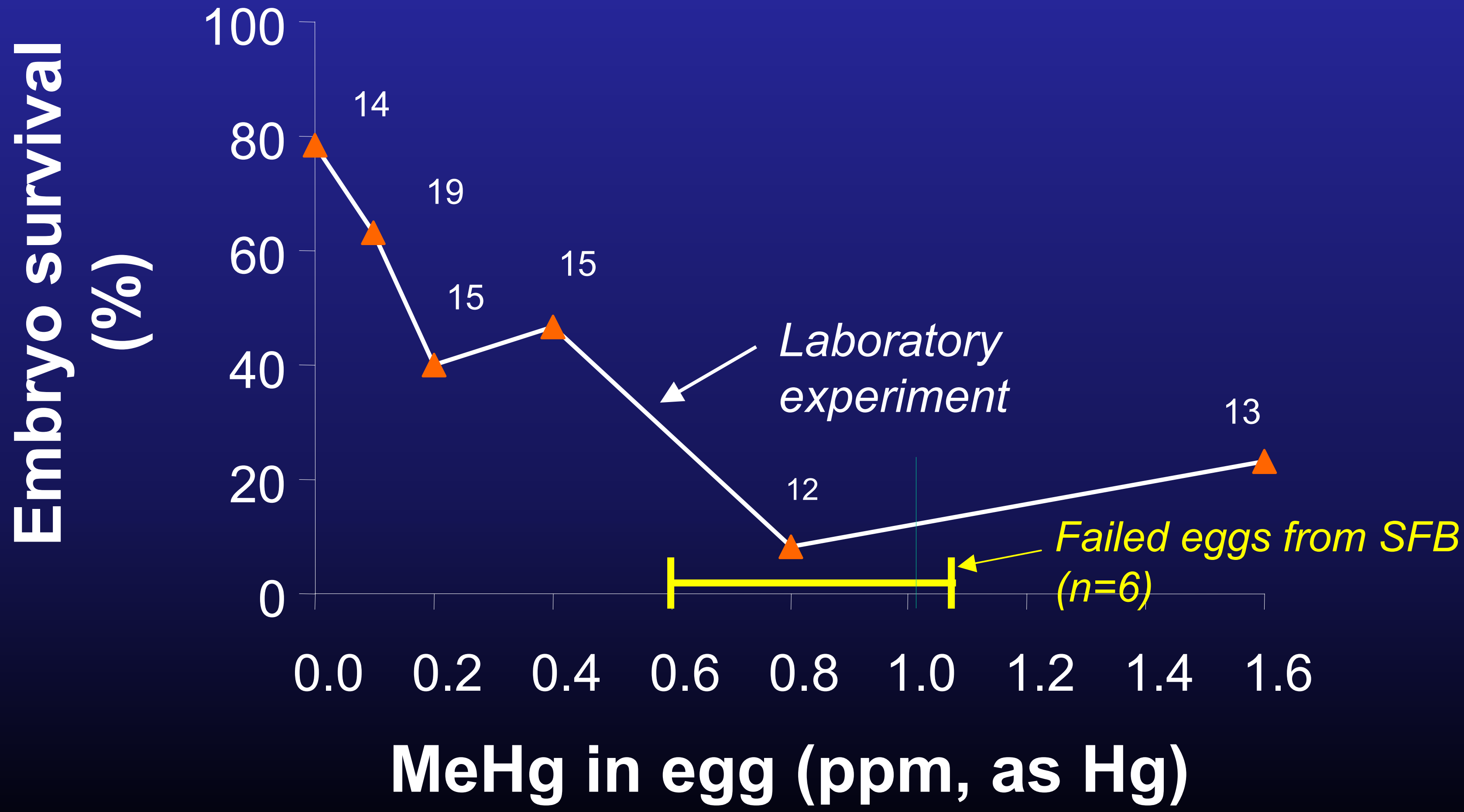
Daily fish consumption (g/kg of body mass)

Common loon		Adult female human (US)	
Chick	220 - 410	Median	0.6
Adult	190	95th percentile	2.2

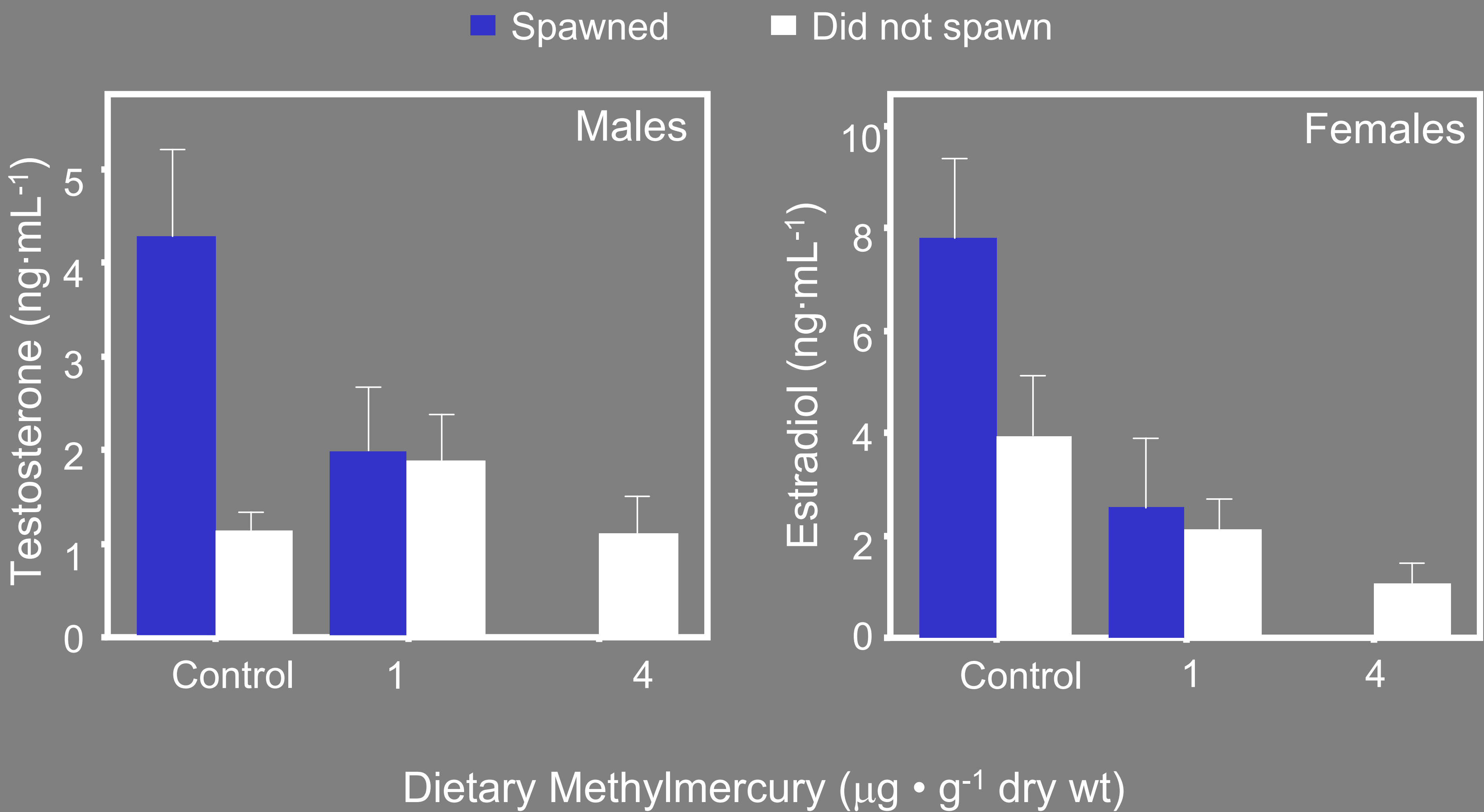
Methylmercury exposure: Is reproductive success being affected in California clapper rails?

Laboratory data by Heinz (USGS)

Field data by Schwarzbach & Adelsbach (FWS)



Reproductive Failure in Fathead Minnows Experimentally Exposed to Dietary Methylmercury



Source: Drevnick and Sandheinrich (submitted for In publication)

Mercury Strategy – Core Component 6

(approaches for reducing MeHg contamination)

Core Component (task)	Management Goal
6) Identify and test potential manage-ment approaches for reducing MeHg contamination	To identify and evaluate potential landscape management approaches for reducing production and abundance of MeHg in the ecosystem and associated biotic exposure

The Scientific & Management Challenge: Reducing Exposure to Methylmercury

Approach	Objective	Strategy component
Source reduction	Decrease mercury inputs to environment and mass available for methylation	1 & 2
Fish advisories	Reduce dietary exposure in humans	4
Landscape management (largely untested)	Decrease methylmercury production in ecosystems	6

The Landscape Management Approach

A major challenge for science and management

Can terrestrial and aquatic landscapes be managed to decrease production of methylmercury?

The Mercury Strategy: Core Components and Linkages