Mercury Studies in the Sierra Nevada

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Sacramento, CA

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Please note: Some slides that were presented at the SFEI Bioaccumulation Workshop on Dec. 17, 2012 in Ricmond, CA, are not included in this version because they include unpublished data, in accordance with policies of the U.S. Geological Survey.

Cooperating Agencies

Federal

State

Local

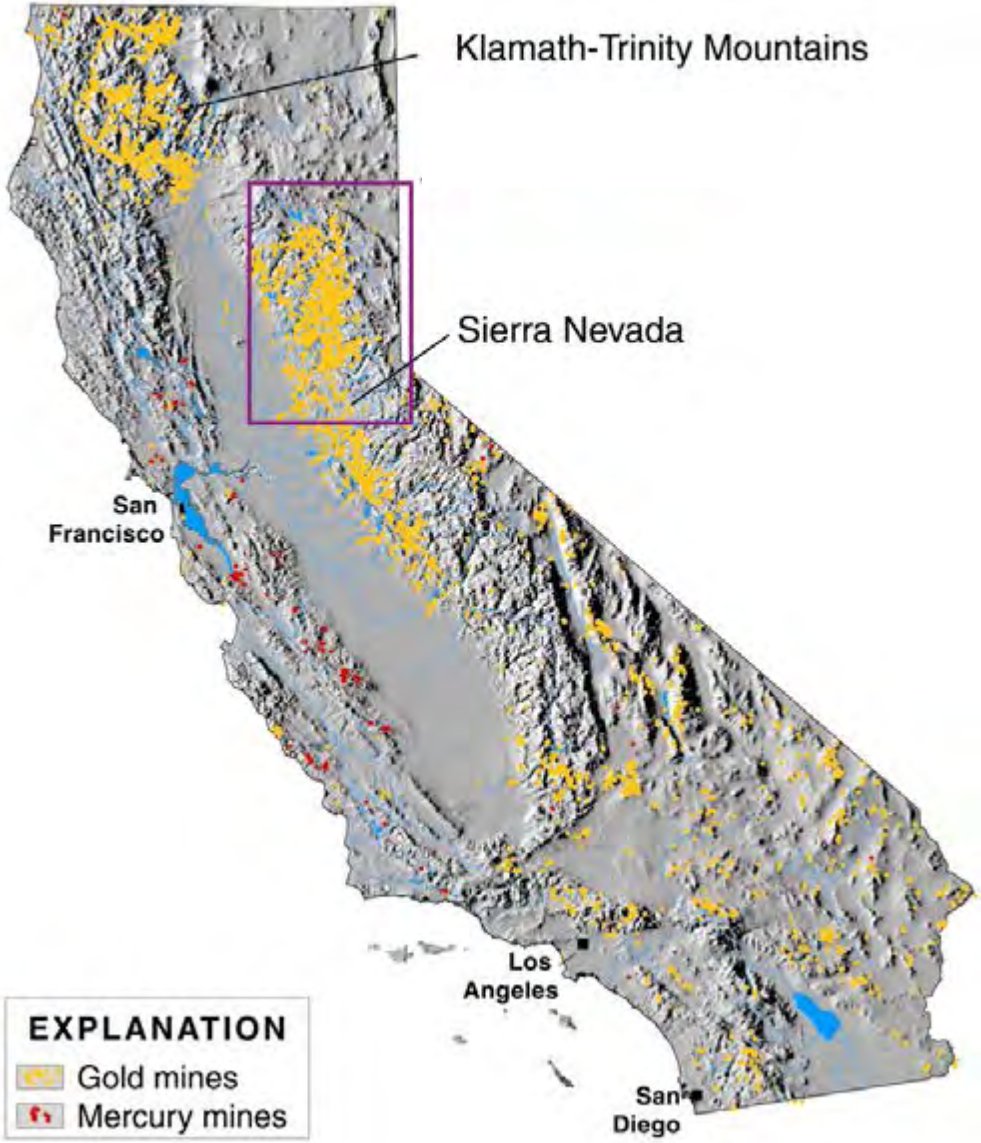
Hydraulic mining, Placer County, CA

Outline of Presentation

- Background
  - Mercury use and loss in historical gold mining & milling
- Past projects
  - Mercury bioaccumulation reconnaissance (UCD, SCRSD)
  - Abandoned Mine Land studies (USGS, BLM, USFS)
  - Upper Yuba River Studies Program (USGS, UCD, CALFED)
  - Food web study – Camp Far West Reservoir (USGS, SWRCB)
  - Bear River mercury bioaccumulation factor study (USGS, SWRCB, NCRCD, USEPA)
- Recent and ongoing projects
  - Erosion of mercury-contaminated mine wastes (USGS, BLM)
    - Deer Creek and South Yuba River / Humbug Creek
  - Sierra Nevada Mercury Impairment Project (USGS, UCD, SWRCB)
- Summary and Conclusions

HISTORICAL MINING:

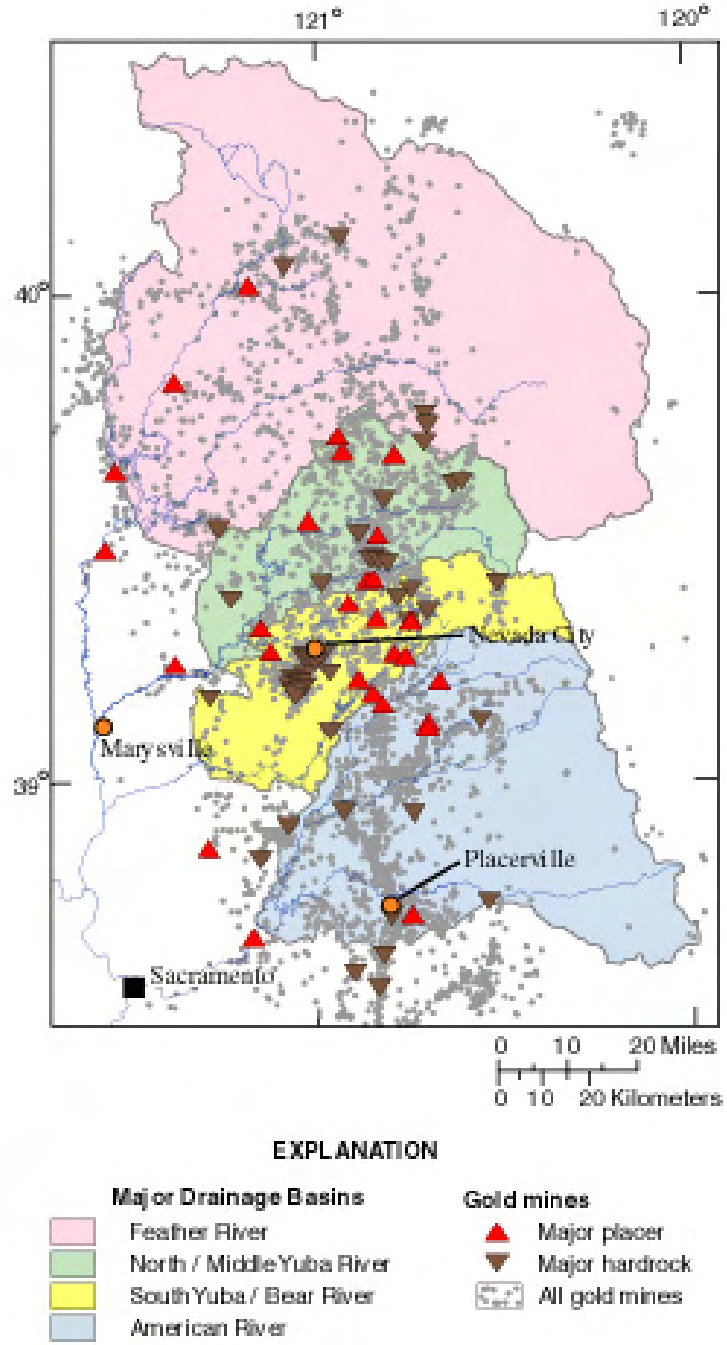
Gold & Mercury



USGS Fact Sheet 2005-3014

- More than 220,000,000 lbs mercury (Hg) produced from 239 mines in California
- Approx. 73,000,000 lbs Hg lost to atmosphere from furnaces at Hg mines
- Approx. 26,000,000 lbs Hg used in Calif. gold mining

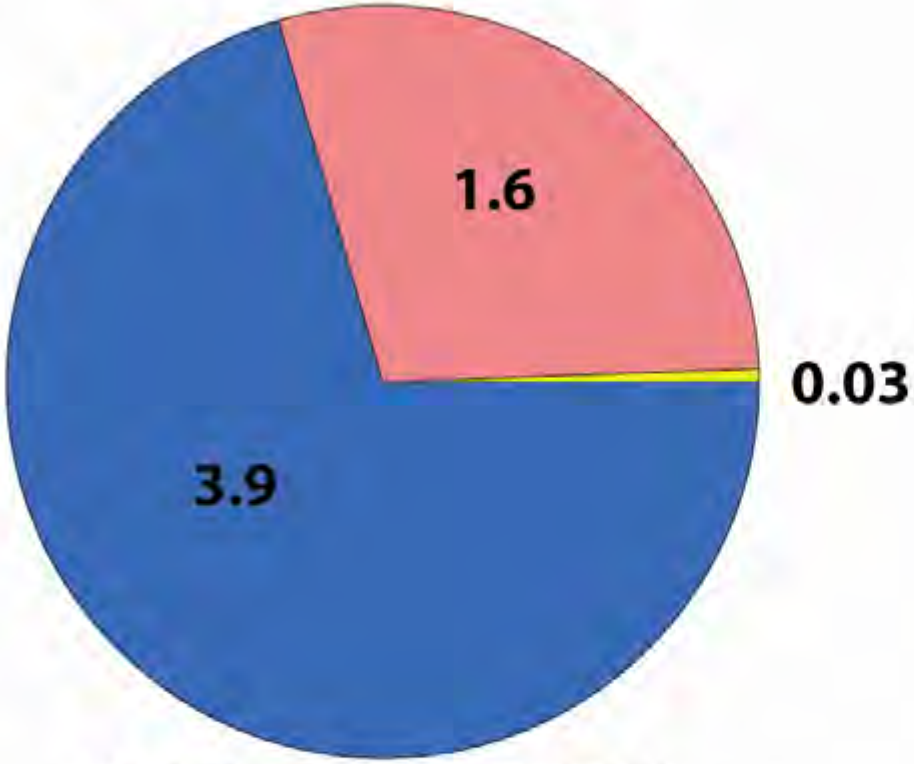
(Churchill, 2000)

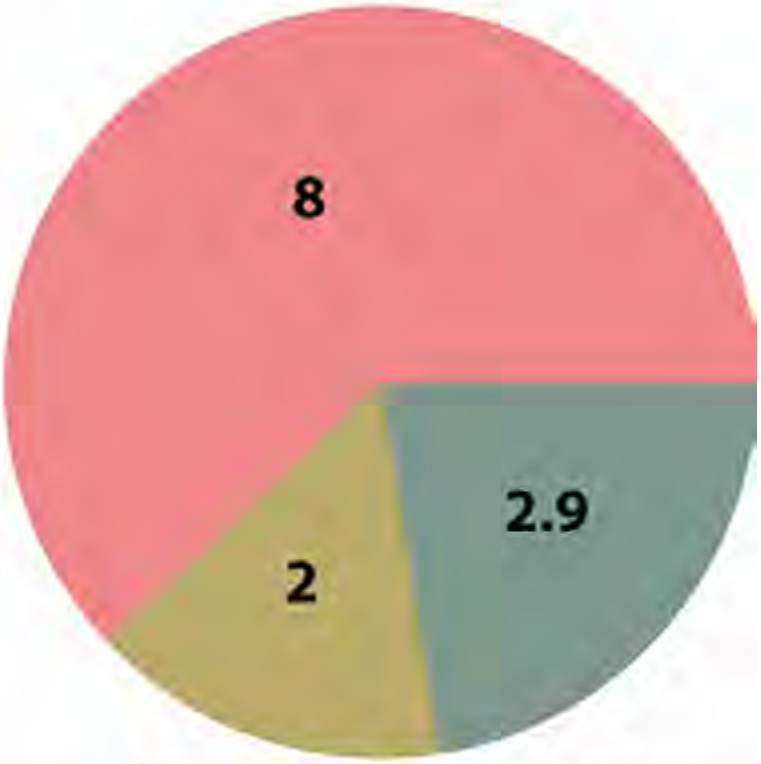


GOLD MINING AND MERCURY USE IN THE NORTHERN SIERRA NEVADA

- Highest intensity of hydraulic mining (placer gravel deposits) in Bear-Yuba watersheds
- Approx. 10,000,000 lbs of mercury lost during gold processing in Sierra Nevada (USGS, 2000; Churchill, 2000)
- Significant gold dredging in all rivers draining Sierra Nevada

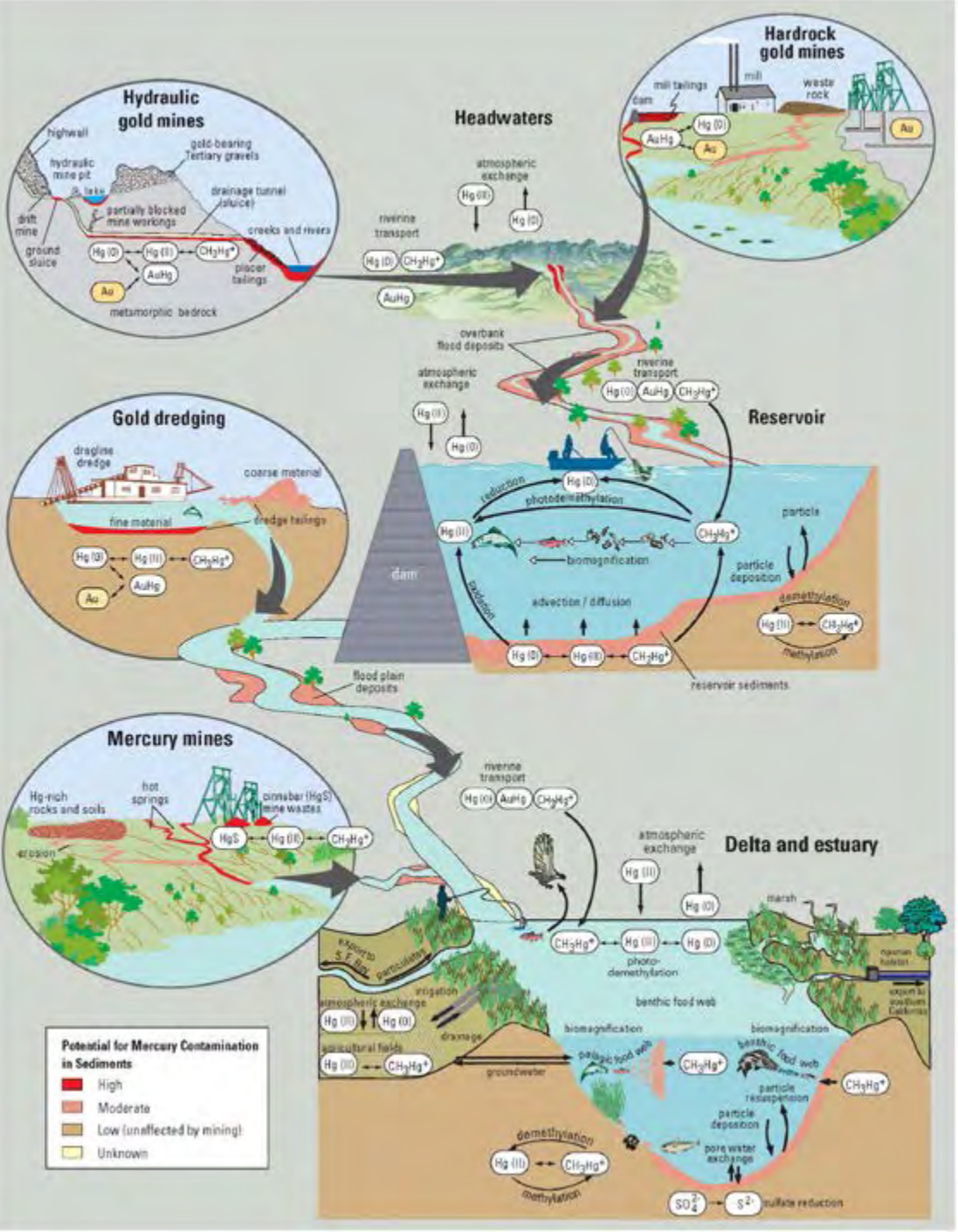
USGS Fact Sheet 2005-3014





Churchill, 2000; USGS Fact Sheet 2005-3014

TRANSPORT AND TRANSFORMATION OF MERCURY



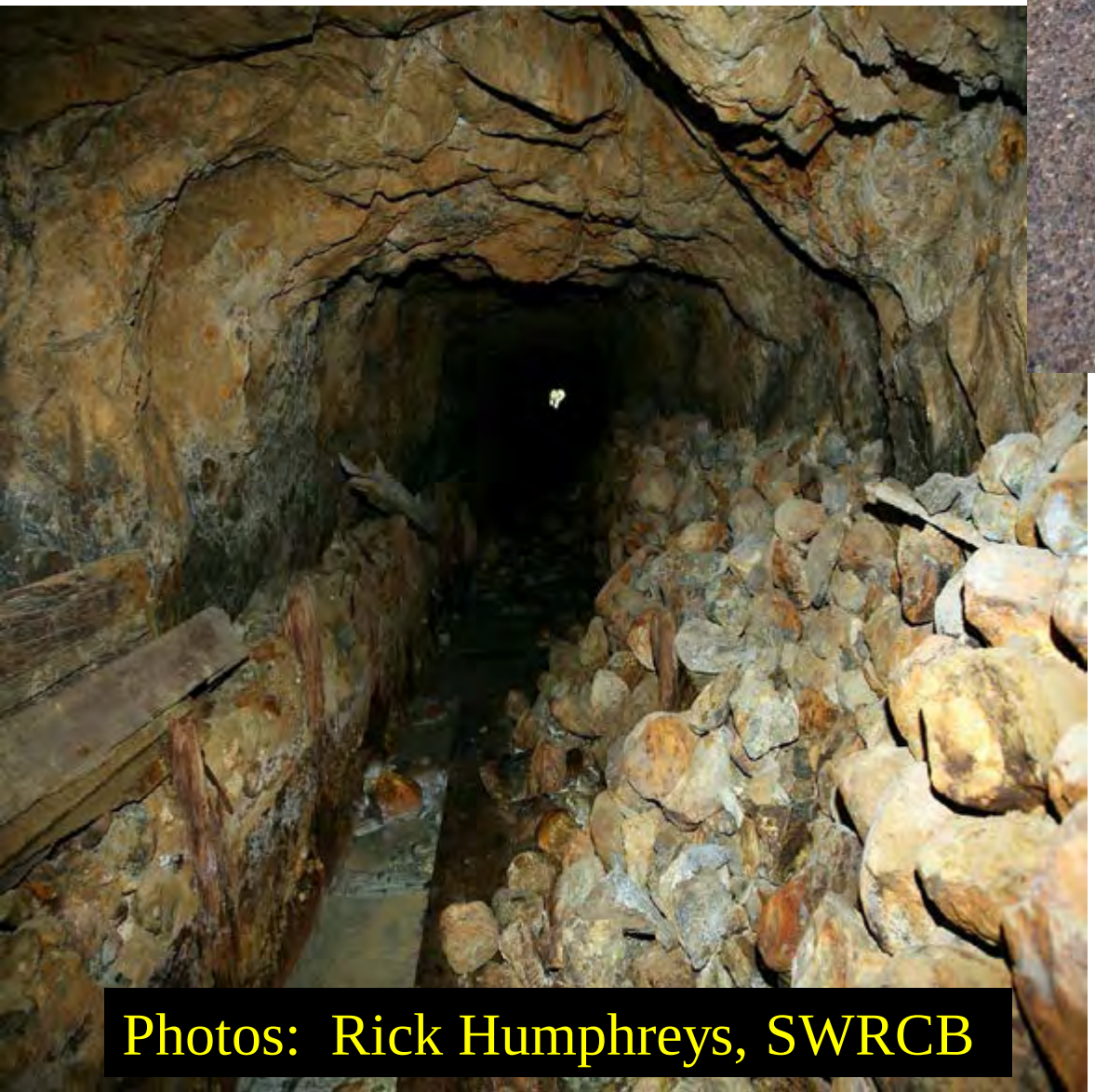
ENVIRONMENTS:

- Hydraulic and hardrock gold mines – Sierra Nevada
- Mercury mines – Coast Ranges
- Mountain streams above reservoirs
- Foothill reservoirs
- Rivers below reservoirs – gold dredging environments
- Floodplain deposits
- San Francisco Bay-Delta estuary

USGS Fact Sheet 2005-3014

Hydraulic mining, Malakoff Diggins, Nevada County, CA, circa 1880

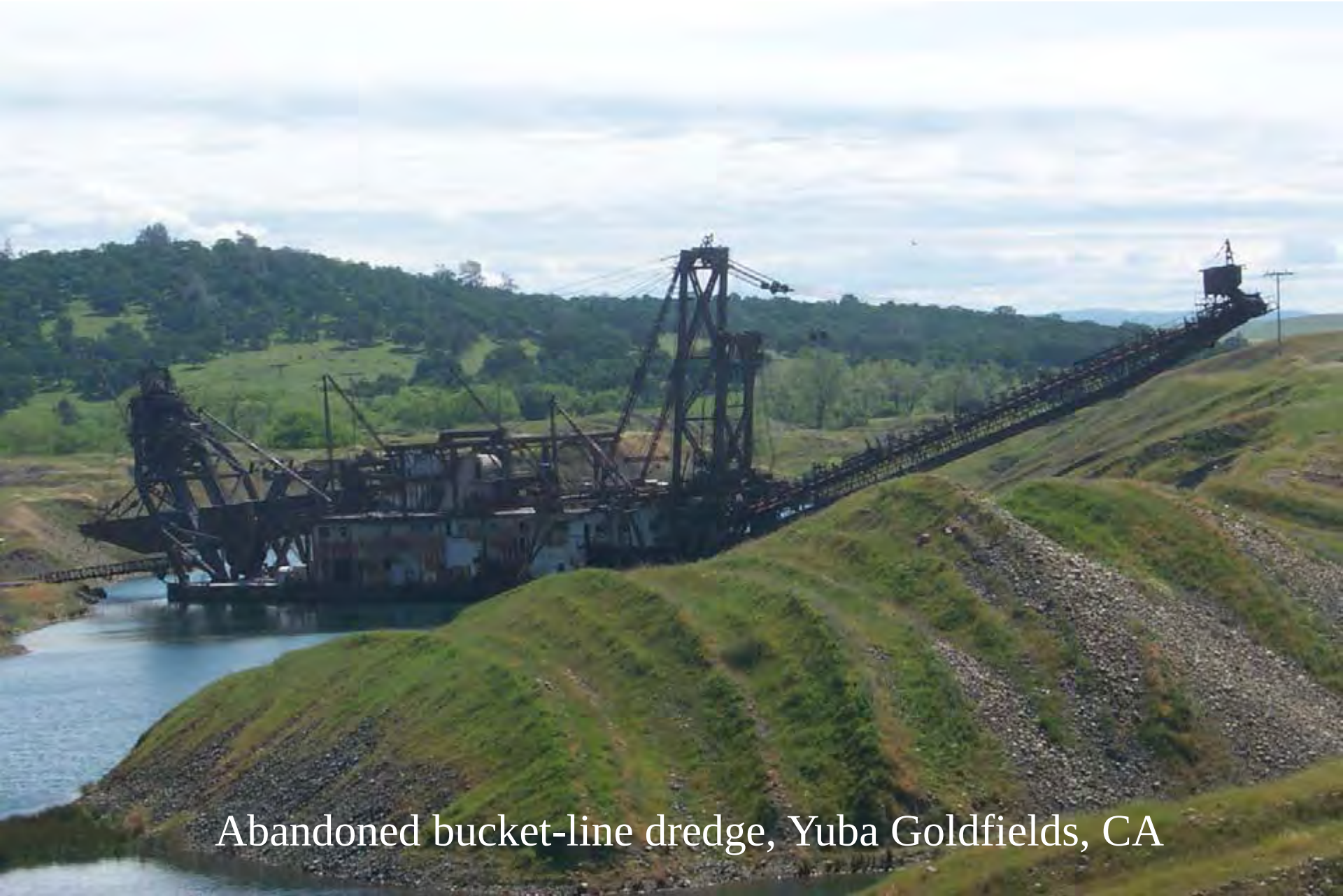
Sluice Tunnels



Photos: Rick Humphreys, SWRCB

- Sluices recovered gold.
- Mercury was used to “catch” fine gold.
- Mercury was lost during sluicing.
- Mercury is still found in sluices and their foundations today.

Cleaning amalgam from stamp mill, Empire Mine, Nevada County, California, 1900



Abandoned bucket-line dredge, Yuba Goldfields, CA

UC Davis study (1997)

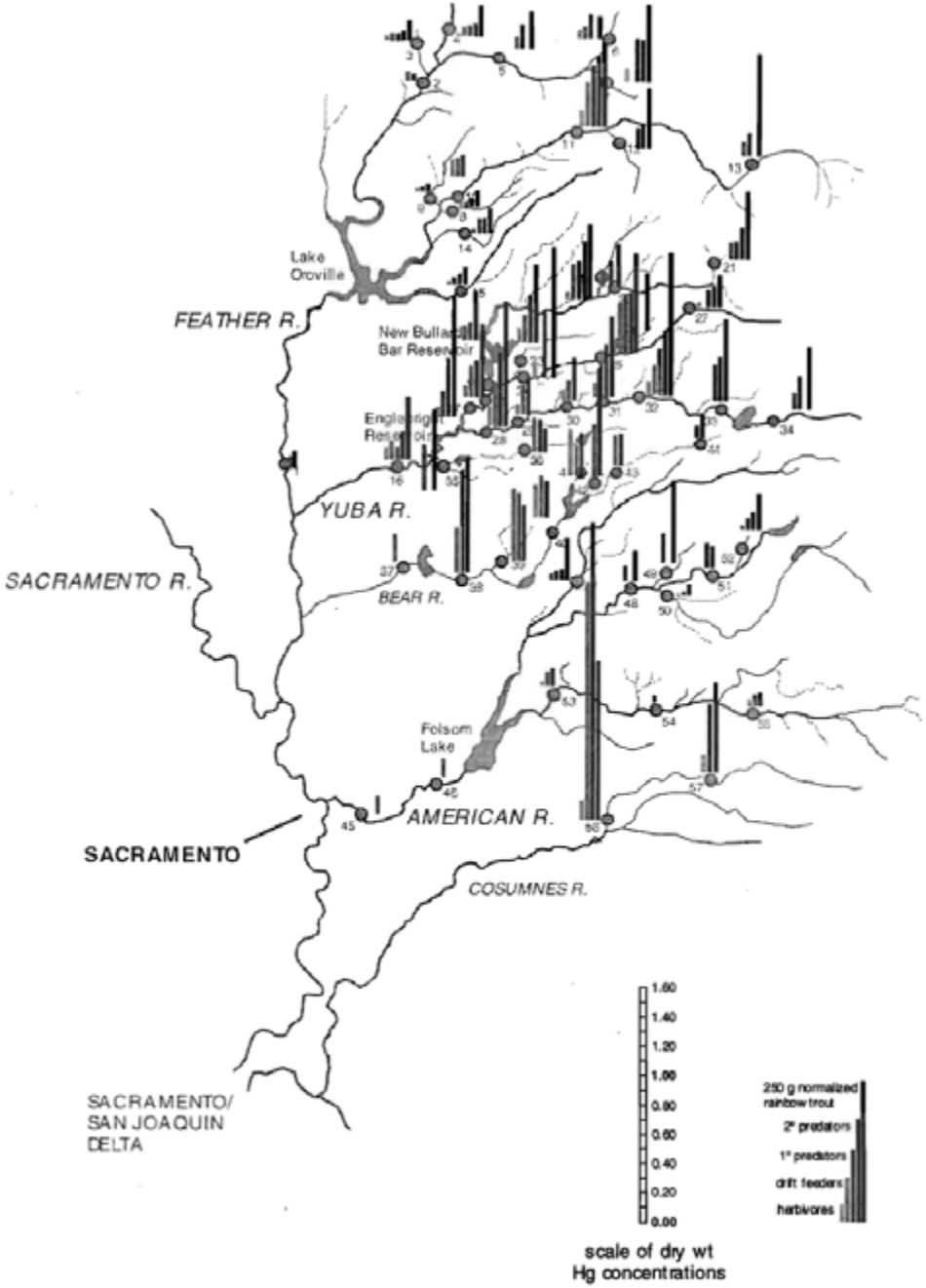
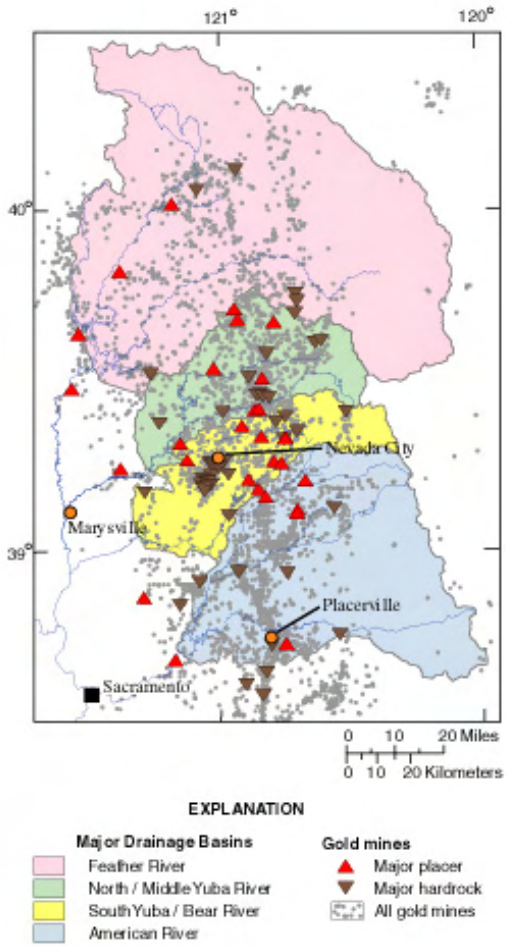


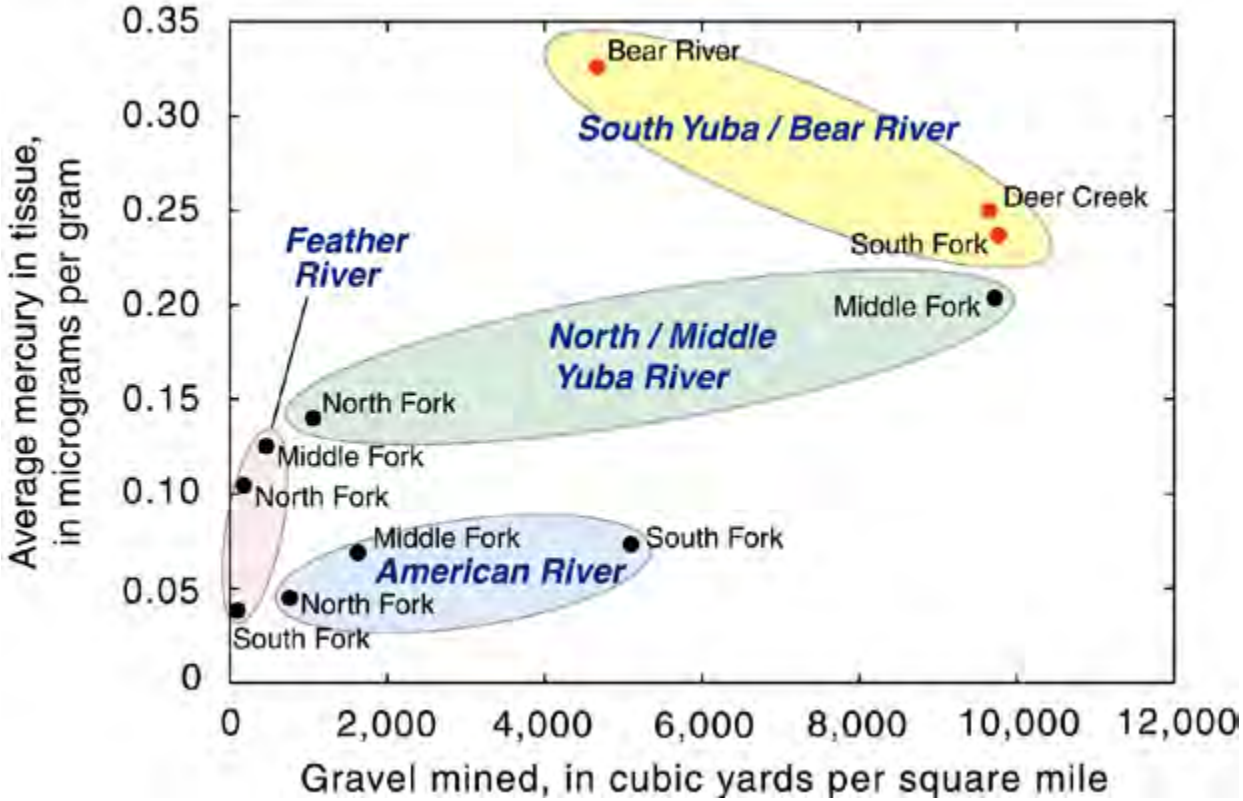
Fig. 3. Superimposed Sierra Nevada biotic mercury data for all major trophic categories

- Sampled 57 sites in northern Sierra Nevada
- Analyzed Hg bioaccumulation in several trophic levels including insects and rainbow trout

Slotton et al. (1997)

MINING AND MERCURY IN BIOTA



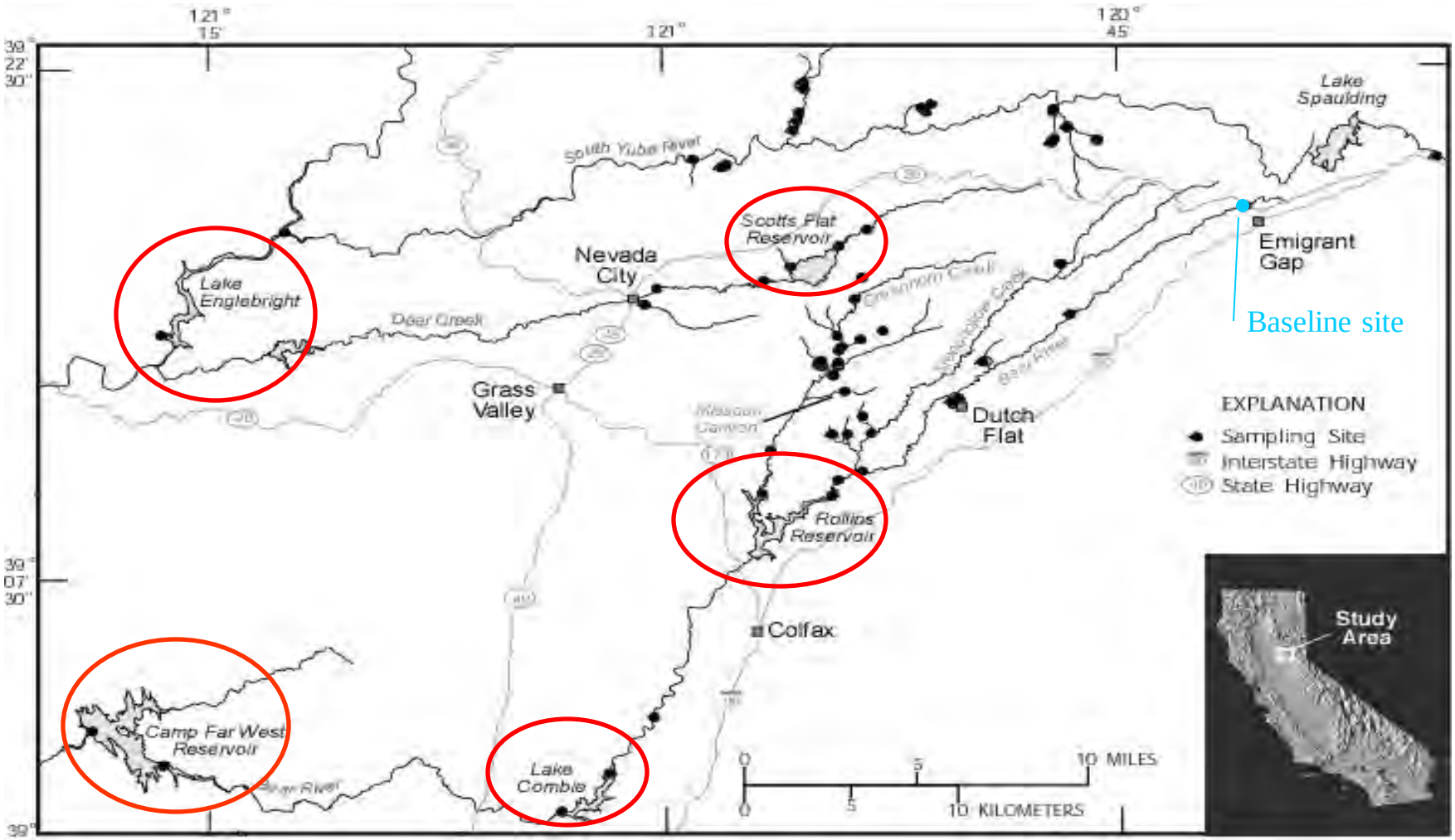


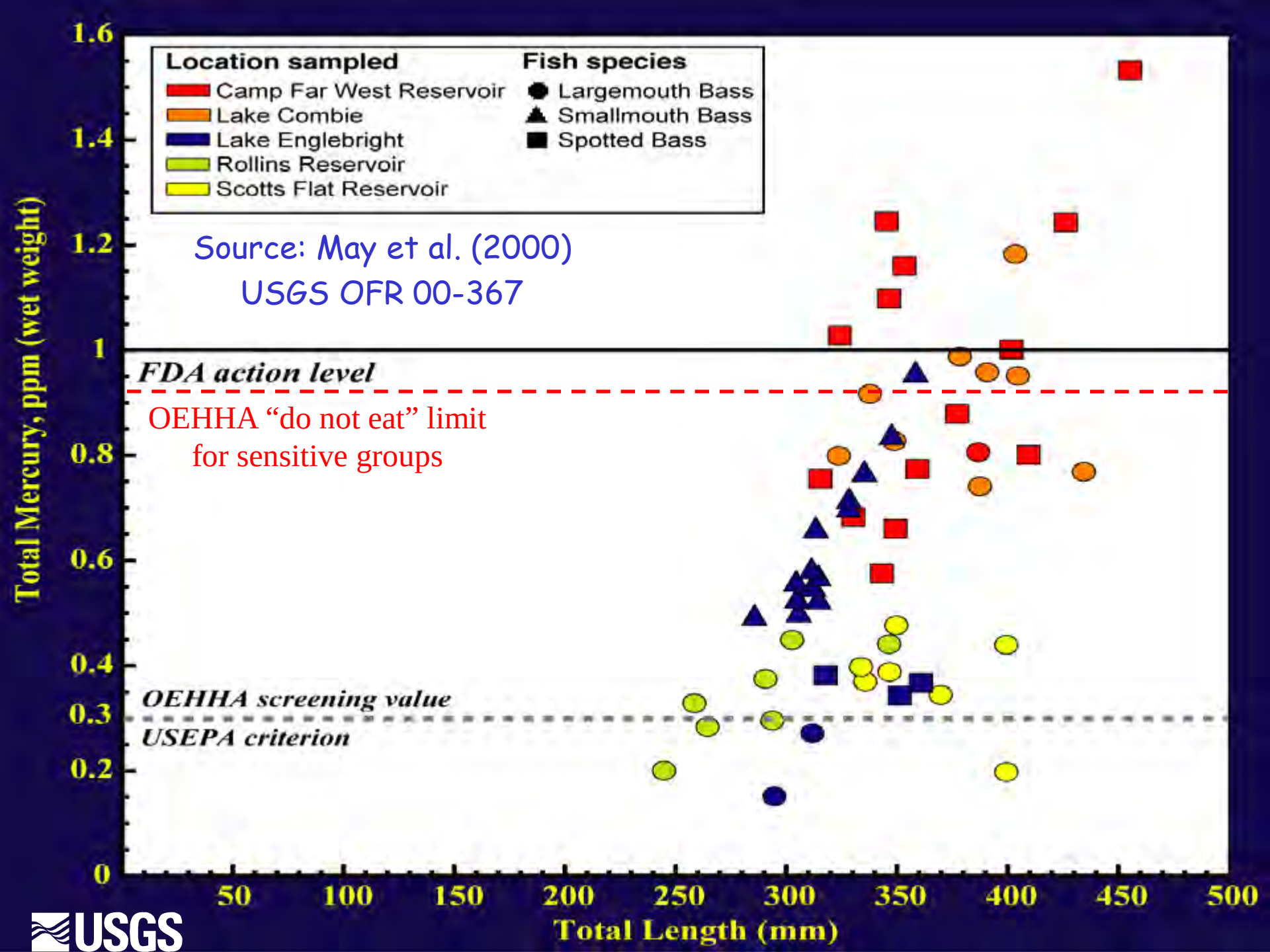
Bear-Yuba watersheds (yellow and green) highest in biotic mercury (Slotton et al., 1997) and most intensely mined (Alpers and Hunerlach, 2000)

Bear-Yuba AML Project (USGS-USFS-BLM)

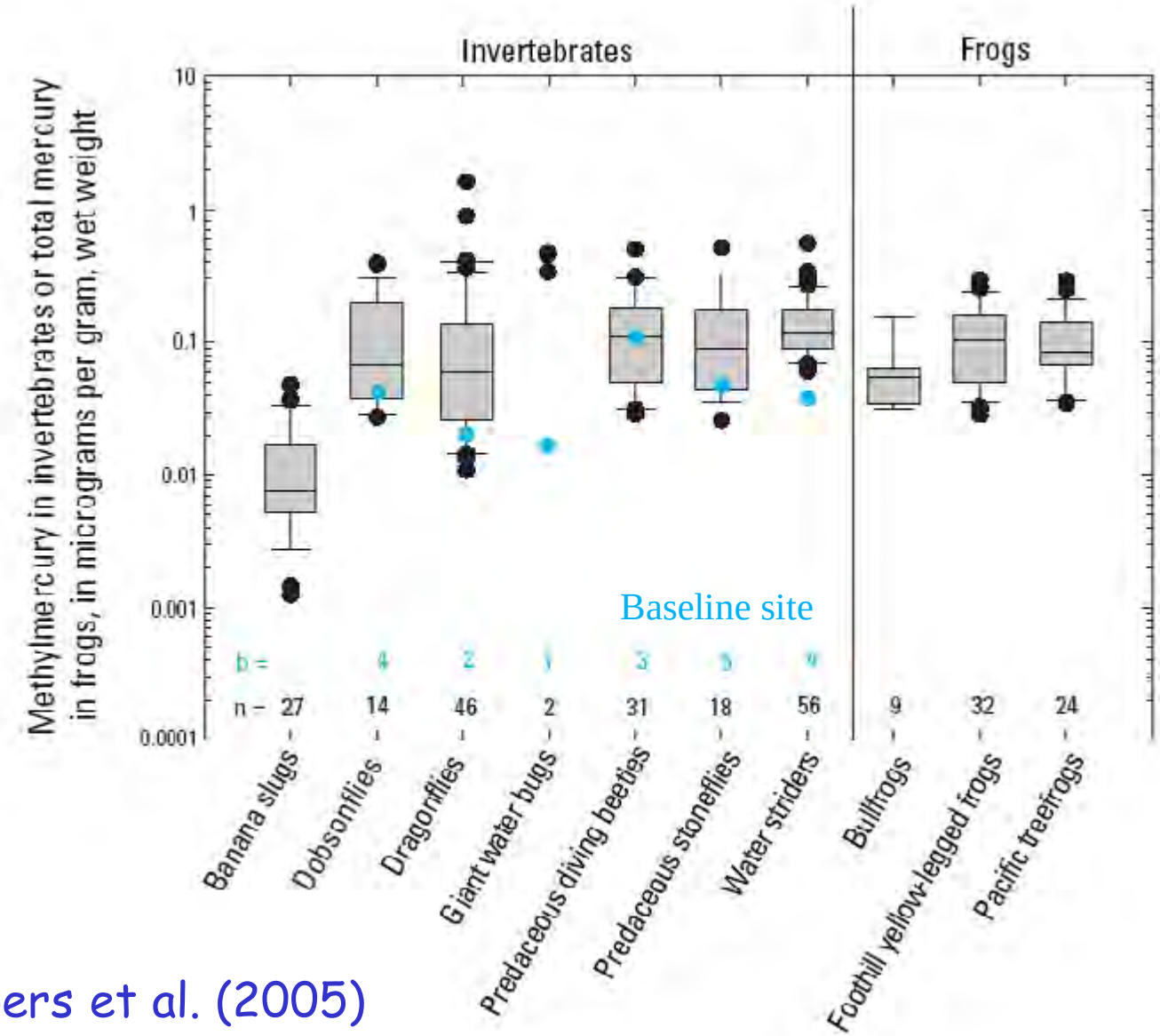
- **Objectives:** Identify and characterize contaminated "hot spots" as remediation targets.
- **Approach:** Determine Hg and MeHg in water, sediment, and biota in vicinity of historical hydraulic placer-gold mines (initial sampling 1999–2004)
- **Results:**
  - First fish consumption advisories in Sierra Nevada (2000, 2003)
    - Bear River, South Yuba River, and Deer Creek watersheds
  - Remediation of 3 Hg "hot spots"
    - Polar Star Mine (2000) EPA
    - Sailor Flat (2003) U.S. Forest Service
    - Boston Mine (2006) BLM
  - Ongoing follow-up investigations at other sites

SAMPLING SITES, BEAR-YUBA, 1999




Location sampled
Camp Far West Reservoir
Lake Combie
Lake Englebright
Rollins Reservoir
Scotts Flat Reservoir
Fish species
Largemouth Bass
Smallmouth Bass
Spotted Bass
Source: May et al. (2000)
USGS OFR 00-367
FDA action level
OEHHA "do not eat" limit
for sensitive groups
OEHHA screening value
USEPA criterion
Total Mercury, ppm (wet weight)
Total Length (mm)
0
0.2
0.3
0.4
0.6
0.8
1
1.2
1.4
1.6
50
100
150
200
250
300
350
400
450
500
USGS

Methylmercury in invertebrates and frogs



Source: Alpers et al. (2005)

Data Synthesis and Site Prioritization

Station map ID	Station Name	Water				Sediment			Invertebrates						Frogs	
		Hg - UNF	Hg - FIL	MeHg - UNF	MeHg - FIL	Inorganic THg	THg (Lab)	MeHg (Lab)	Aquatic Bugs	Dragonflies	Damselflies	Crawfish Bodies	Stoneflies	Water striders	Foothill Yellow-Legged Frogs	Pacific Tree Frogs
Headwaters																
BY61	GREENHORN C NR HEADWATERS NR SCOTTS FLAT RES CA	0.49	1.8	0.04												
Sailor Flat / Tom and Jerry																
BY106	SAILOR FLAT MINE MAIN DR GULCH 01 NR QUAKER HILL CA	[illegible]	[illegible]	[illegible]		[illegible]	0.03	0.02				0.33		0.73		0.45
BY105	SAILOR FLAT MINE MAIN DRAINAGE TO GREENHORN C, GULCH 03, CA	1.0	3.6	1.6	1.0											
BY129	TOM AND JERRY MINE DR AT TUNNEL INLET NR NEVADA CITY CA	1.8		2.6												
BY130	TOM AND JERRY MINE DR AT TUNNEL OUTLET NR NEVADA CITY CA	0.50		0.20		[illegible]			1.2	2.6	0.20	0.80		1.0		1.2
BY131	TOM AND JERRY MINE DRAINAGE POND NR NEVADA CITY CA	2.2	6.7	0.26						0.20		0.89		0.89		
Buckeye																
BY22	BUCKEYE FLAT MINE DR .1 MI AB GREENHORN C					1.0						0.50		0.80	0.88	
BY66	BUCKEYE FLAT MINE MAIN DR .45 MI AB GREENHORN C	0.1	0.34						0.88			0.80		0.87		1.0
BY23	BUCKEYE FLAT MINE N DRAIN TO GREENHORN C GRASS VALLEY CA	[illegible]	[illegible]	1.1			0.7	0.03	0.74					0.81		
BY116	BUCKEYE FLAT MINE POND DR .15 MI AB SF GREENHORN C	0.95	3.55						4.1	1.1		0.89		1.1		
BY24	BUCKEYE FLAT MINE S DRAIN TO SF GRNHRN C GRASS VALLEY CA	[illegible]	[illegible]	[illegible]			0.86	1.2		3.9		1.2		1.6		
BY25	BUCKEYE FLAT MINE UPPER DRAIN	0.29	0.4	0.40	1.00				1.1			0.60		0.72		
Boston Mine																
BY20	BOSTON MINE TUNNEL OUTLET NR GRASS VALLEY CA	1.4	1.1	0.88	1.3	[illegible]	[illegible]	0.20	1.8	[illegible]		3.3		2.1		1.8
BY21	BOSTON MINE WETLANDS POND NR GRASS VALLEY CA	1.1	0.87	2.4			0.83	2.2		0.47		1.7		0.88		
South Fork Greenhorn Creek																
BY113	SF GREENHORN C .8 MI AB GREENHORN C NR NEVADA CITY CA								1.0		0.98		0.98	0.92	1.0	
BY114	SF GREENHORN C .7 MI AB GREENHORN C NR NEVADA CITY CA	[illegible]	[illegible]	1.6	0.5				0.57		1.0		1.7	1.0	1.0	
BY115	SF GREENHORN C BL BOSTON MINE NR NEVADA CITY CA	0.83	2.3	0.76	0.88	1.0				5.1	3.1		3.8	1.8	3.1	
Poore Mine																
BY06	POORE MINE CREEK AB TUNNEL NR GRASS VALLEY CA	1.2	0.05	0.38					0.33	0.73				0.95	0.90	
BY87	POORE MINE CREEK BL TUNNEL NR GRASS VALLEY CA	0.33	0.27	0.56		1.0										
BY86	POORE MINE GROUND SLUICE NR GRASS VALLEY CA	0.05	0.05	0.20		4.0		0.4								
BY89	POORE MINE PIT LAKE NR GRASS VALLEY CA	0.34	0.26	1.1		1.0										
BY90	POORE MINE SEEP ABOVE GROUND SLUICE NR GRASS VALLEY CA		0.06						2.0			0.36		1.1		0.90
BY91	POORE MINE TUNNEL EFFLUENT NR GRASS VALLEY CA	1.1	0.18	1.0					0.89	0.43	0.88		0.48	1.2		0.88
Starr Mine																
BY122	STARR MINE TUNNEL INFLOW NR GRASS VALLEY CA	0.22	0.19	0.20												
BY123	STARR MINE TUNNEL MIDWAY NR GRASS VALLEY CA	24	1.6	[illegible]		[illegible]	[illegible]	6.1								
BY124	STARR MINE TUNNEL OUTLET NR GRASS VALLEY CA	[illegible]	1.3	7.6	0.80				0.80	0.68				1.0	1.0	1.2
BY140	STARR PIT POND NR GRASS VALLEY CA									0.21		2.3		0.83		
Missouri Canyon																
BY144	COON HOLLOW C DR TUNNEL OUTLET NR DUTCH FLAT CA									0.82		1.1		1.5		
BY146	MISSOURI CYN 1.6 MI AB GREENHORN C NR CHICAGO PK CA					1.0			3.1			1.1		1.8		
BY75	MISSOURI CYN C 1.2 MI AB GREENHORN C NR CHICAGO PK CA	0.42	0.14	1.0		5.0	1.0	0.77	0.33	1.4	2.3		3.0	1.1	1.5	0.88
BY145	MISSOURI CYN C TRIB NR CHICAGO PARK CA											1.1		3.0		
BY147	NF MF MISSOURI CYN NR CHICAGO PARK CA								0.7	4.8	5.9	1.8		2.0	2.7	
Greenhorn Creek - Mainstem																
BY55	GREENHORN C 0.1 MI BL SAILOR FLAT WEST DRAIN NR NEVADA CITY CA													0.90		
BY57	GREENHORN C 0.3 MI BL SAILOR FLAT WEST DRAIN NR NEVADA CITY CA										0.45		0.42	0.73		
BY62	GREENHORN C .3 MI AB BUCKEYE FORD NR NEVADA CITY CA	1.9	1.0	0.28												
BY60	GREENHORN C BL BUCKEYE DRAIN NR NEVADA CITY CA													0.79		
BY63	GREENHORN C AB SF GREENHORN C NR NEVADA CITY CA												1.0		0.80	
BY56	GREENHORN C BL SF GREENHORN C NR NEVADA CITY CA					1.0				0.21			1.1		0.92	
BY100	GREENHORN C .2 MI BL THE NARROWS					1.0				1.5	1.0			0.83		
Integrator																
BY59	GREENHORN C AT YOU DEL RD NR NEVADA CITY CA	0.90	0.88	1.0	0.87	1.0							0.56	1.0	0.36	

[c], concentration values normalized to median for individual sites. Mercury ratings: blue, very low; green, low; yellow, moderately high; orange, high; red, extremely high. Station name abbreviations: AB, above; BL, below; C, Creek; CA, California; CYN, Canyon; DR, Drain; MI, miles; N, north; NR, near; PK, Park; RD, Road; RES, Reservoir; S, south; SF, South Fork; TRIB, tributary; THg, total mercury; MeHg, methylmercury; UNF, unfiltered; FIL, filtered; Lab., laboratory;

- Concentrations of each type of Hg and MeHg analysis (water, sediment, biota) compared with median among sites in watershed

Source: Alpers et al. (2005) USGS SIR 2004-5251

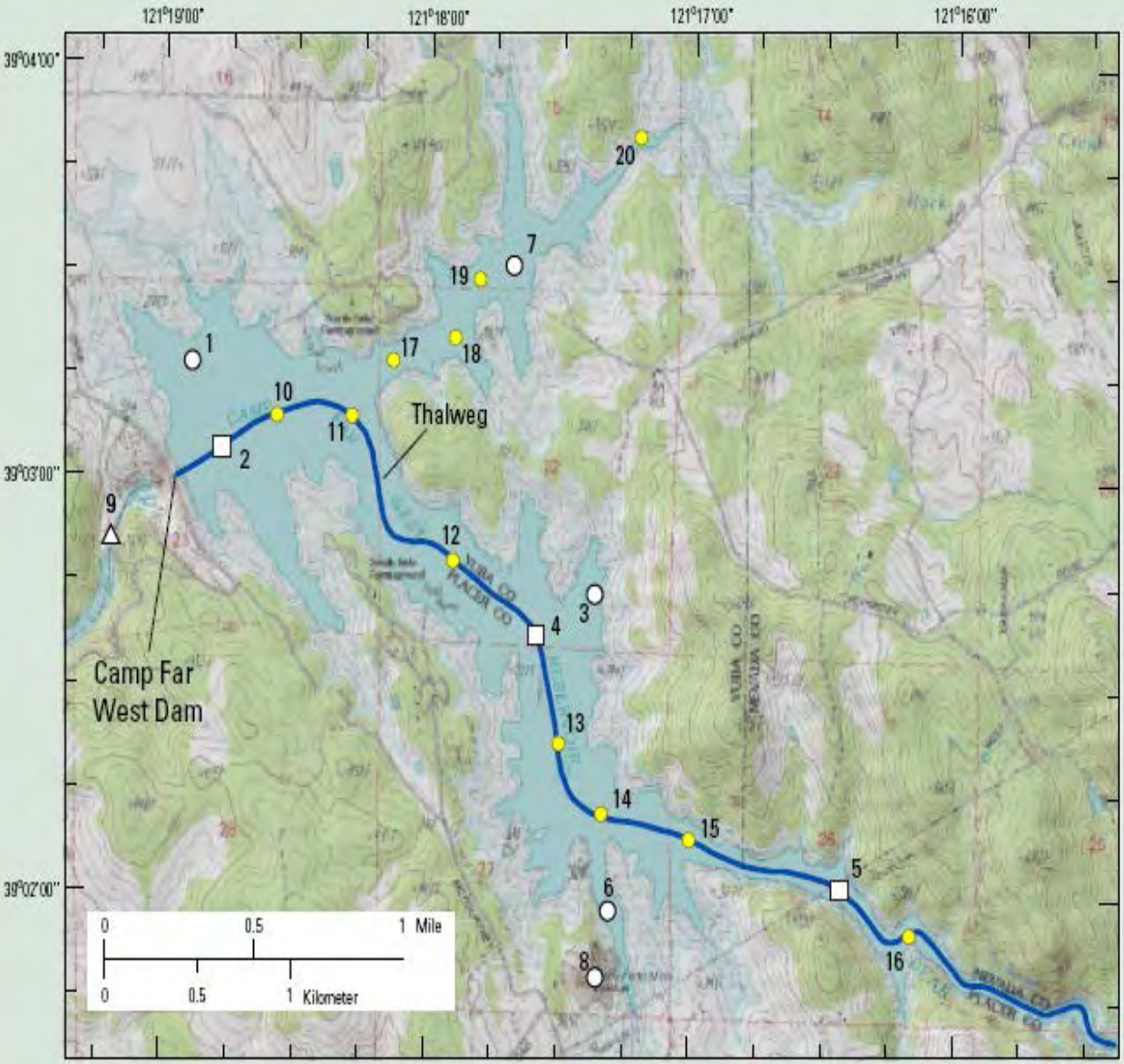
Food-web mercury bioaccumulation study Camp Far West Reservoir

Objectives:

- Determine spatial and temporal variations in physical, chemical, and biological characteristics of CFWR
- Assess environmental factors that affect Hg methylation and bioaccumulation

Approach:

- Vertical profiles of Temp., DO, SC, and pH
  - Quarterly with water samples plus additional measurements
- Water-quality and bed-sediment sampling
  - 6 to 9 locations, 8 occasions (quarterly, Fall 2001 through Summer 2003)
  - Water analyzed for THg, MeHg (Fil & Unf), DOC, nutrients, major cations and anions, trace metals, chl-a & pheo-a, stable isotopes (H, O, S)
  - Sediment analyzed for THg, MeHg, LOI, S and Fe species
- Biological sampling
  - Zooplankton taken at 3-4 locations, 8 occasions, concurrent with water
  - Invertebrates (3 taxa) and fish (3 species) taken at 3 locations, 2 occasions, summer 2002 and 2003, analyzed for Hg, MeHg, stable isotopes (C, N)
  - Gut contents and condition index of fish measured ~monthly



Reservoir Sites

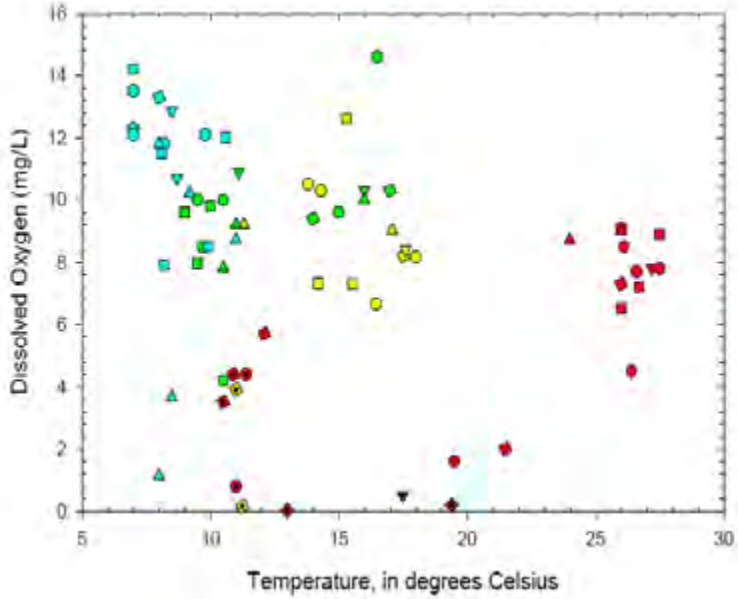
- □ 2 Lower Reservoir, Thalweg
- □ 4 Mid-Reservoir, Thalweg
- □ 5 Bear River Arm
- ○ 1 Lower Reservoir, Shallow
- ○ 3 Mid-Reservoir, Shallow
- ○ 6 Dairy Farm Arm
- ○ 7 Rock Creek Arm
- ○ 8 Dairy Farm Mine Pit
- ● 10–20 Water-column depth profile locations

River Site

- △ 9 Bear River below Camp Far West Reservoir

Alpers et al. (2008) SIR 2006-5008

Temperature vs. Dissolved O_2



EXPLANATION

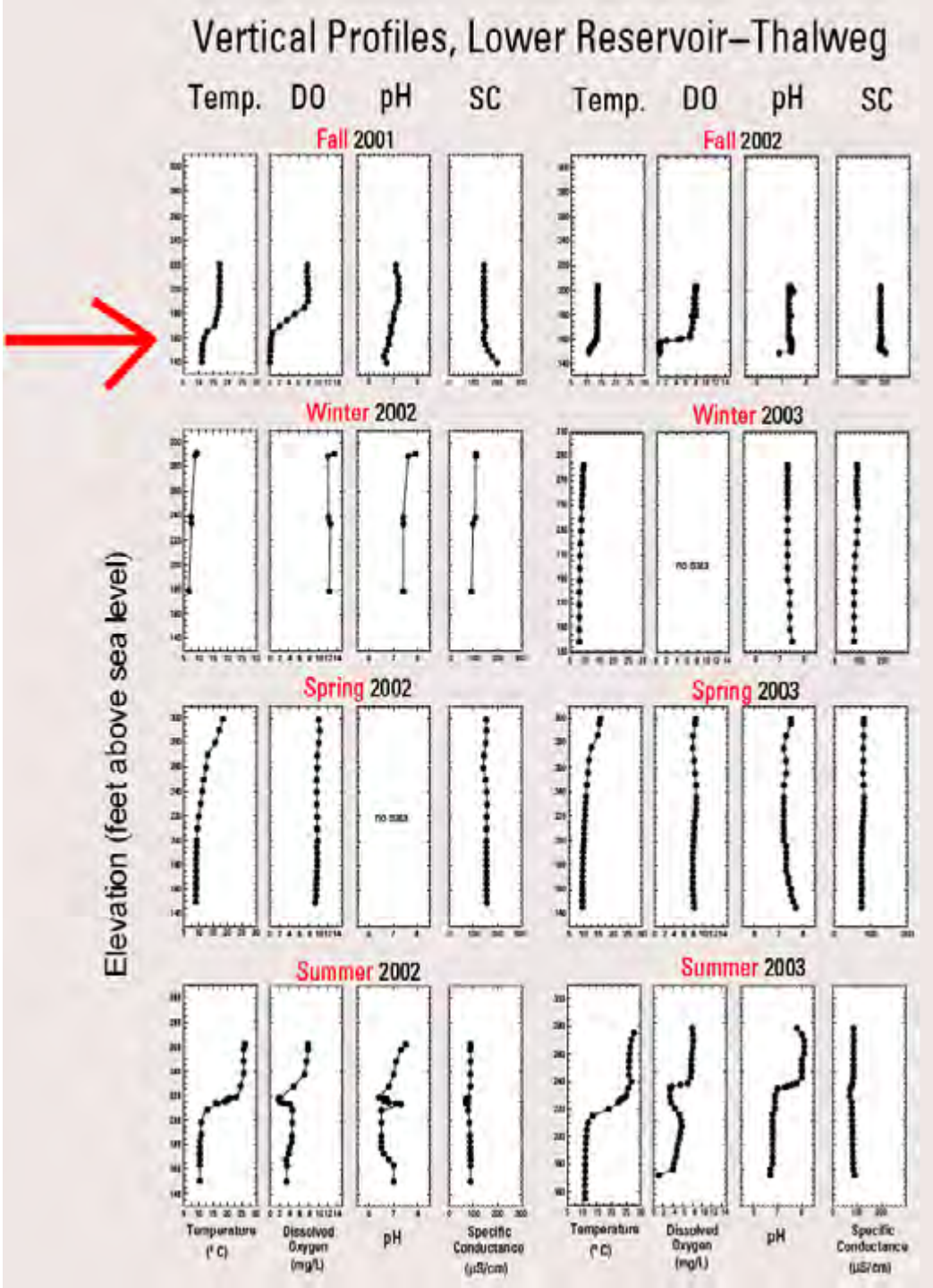
	Site Number	Fall	Winter	Spring	Summer
Lower reservoir	1, 2	□	□	■	■
Mid-reservoir	3, 4	○	○	●	●
Bear River arm	5	◇	◇	◆	◆
Dairy Farm arm	6	▽	▽	▼	▼
Rock Creek arm	7	○	○	●	●
Dairy Farm Mine pit lake and impoundments	8, 9	△	△	▲	▲

□ ○ ◇ ▽ Solid symbol indicates epilimnion

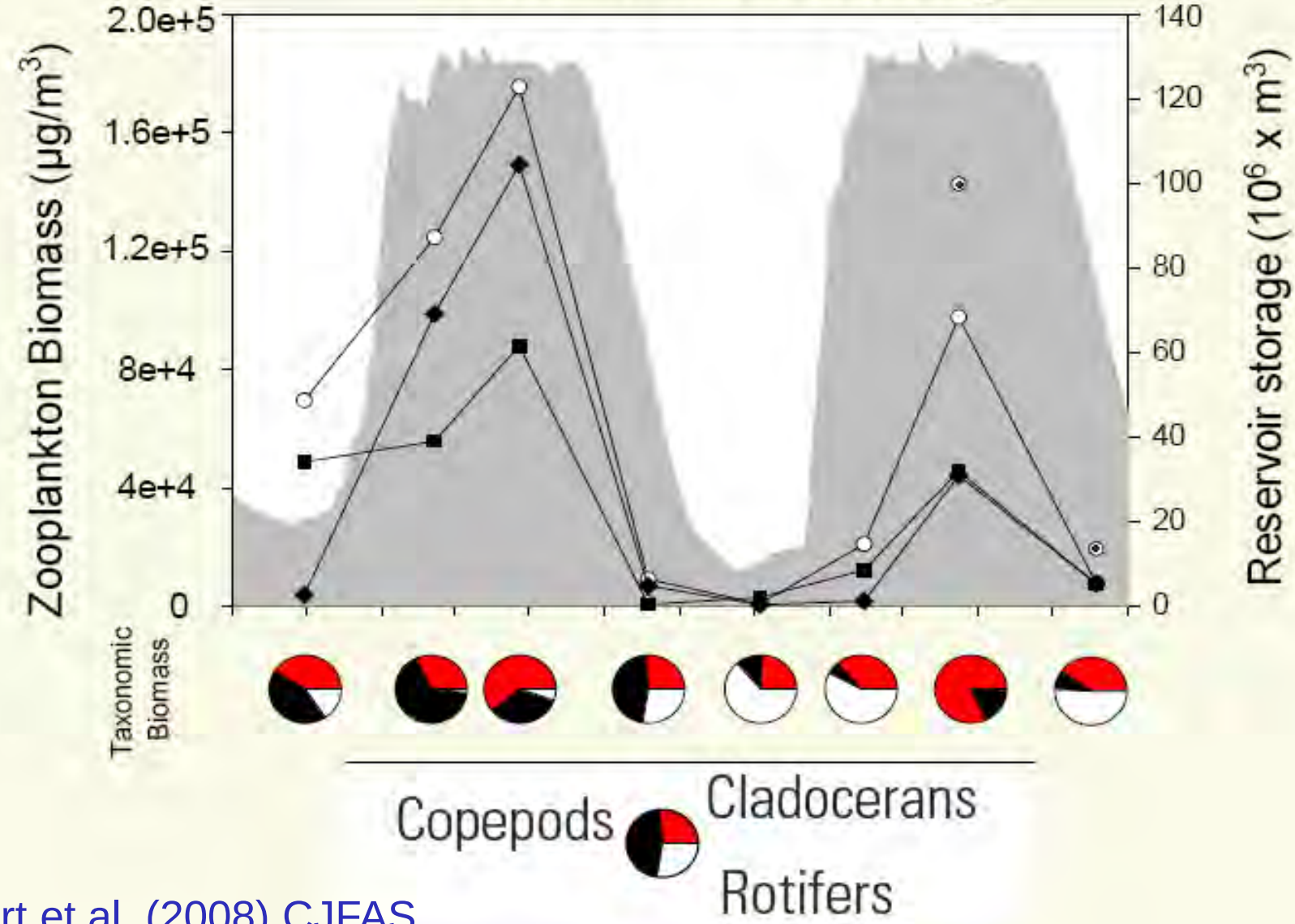
⊡ ⊙ Dot indicates metalimnion

⊠ ⊙ ◈ ▽ Cross indicates hypolimnion

Alpers et al. (2008) SIR 2006-5008

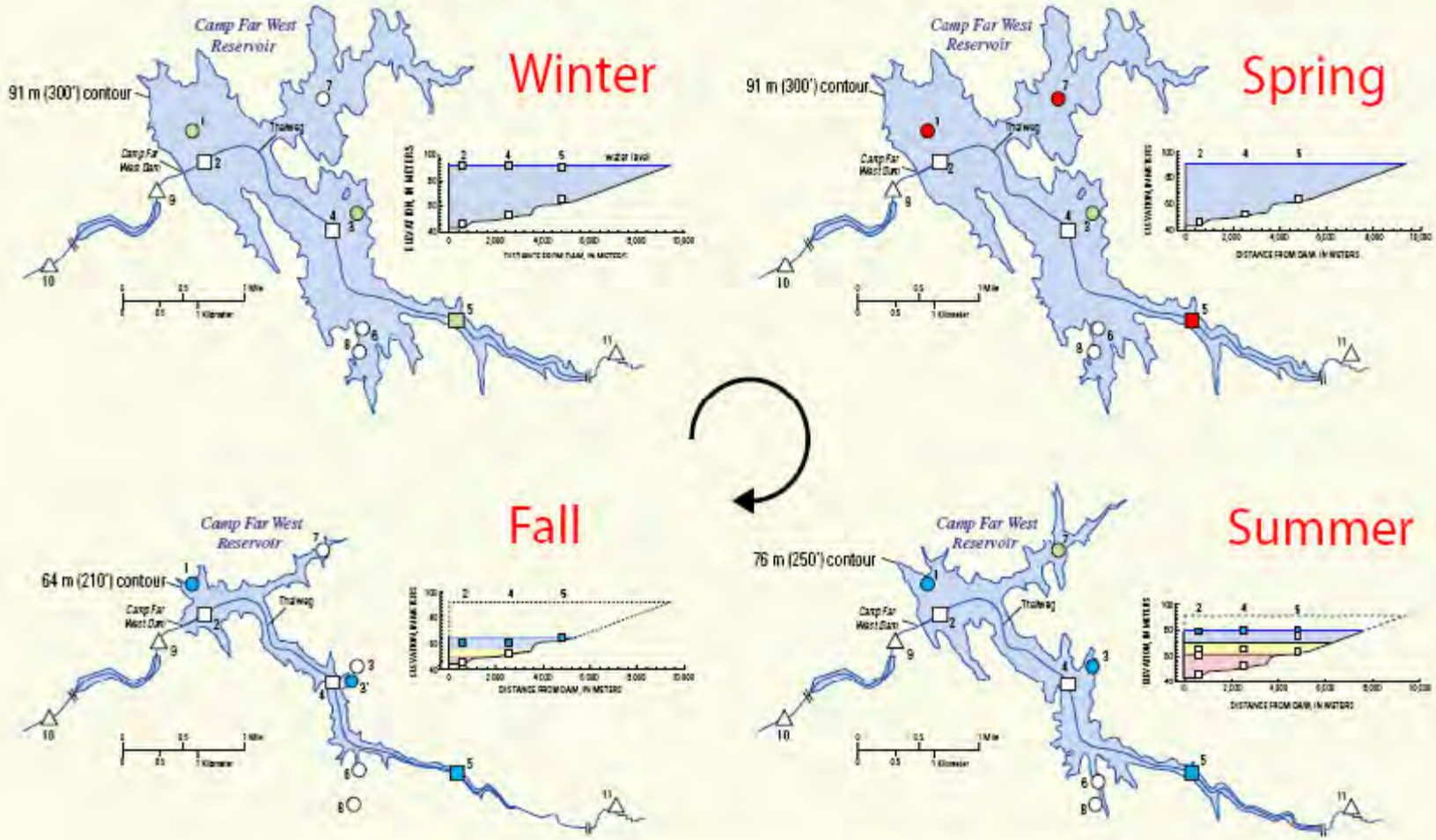


Zooplankton Biomass (>75 µm) and Taxonomy

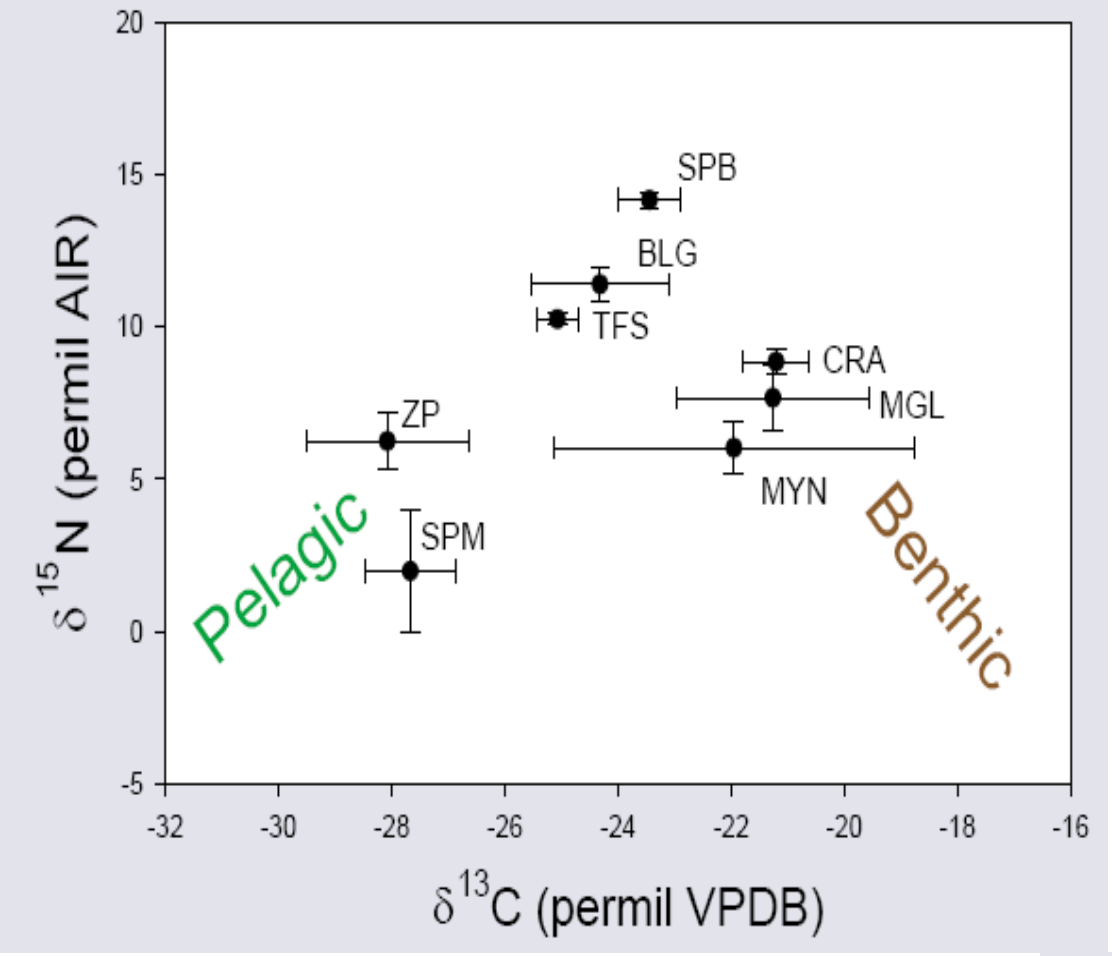


Stewart et al. (2008) CJFAS

MeHg in Zooplankton



	ng/g dry wt.	(percentile)
Epilimnion	> 68.8	(75th)
Metalimnion	20.7 - 68.8	(25th - 75th)
Hypolimnion	< 20.7	(25th)
	no data	

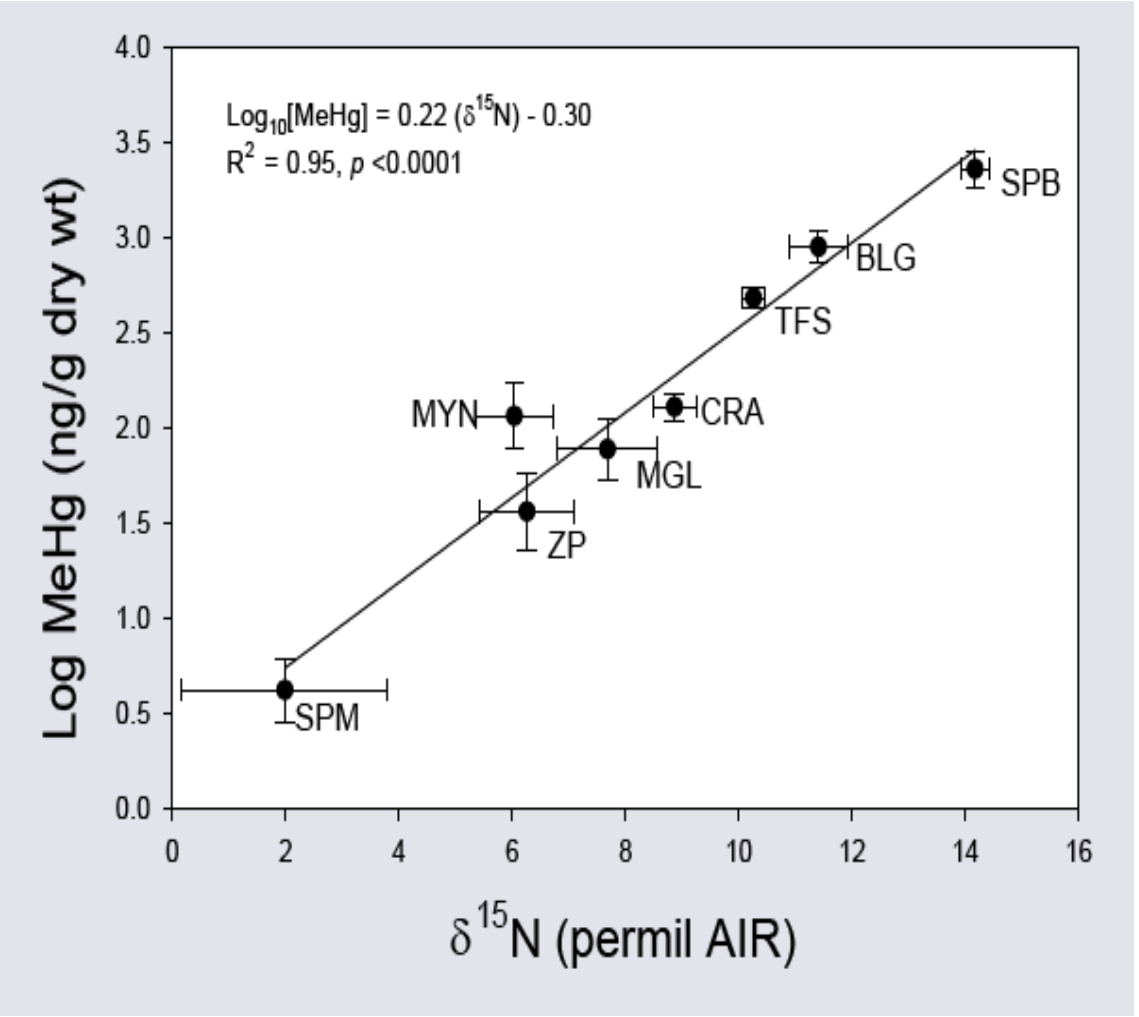


Food web stable isotopes (C, N) indicate pelagic and benthic food webs have a common top predator (spotted bass).

SPB - Spotted bass (*Micropterus punctatus*)
BLG - Bluegill (*Lepomis macrochirus*)
TFS - Threadfin shad (*Dorosoma petenense*)
CRA - Crayfish (*Orconectes virilis*)
MGL - Midge larvae (Chironomidae)
MYN - Mayfly nymphs (Baetidae)
ZP - Zooplankton (various)
SPM - Suspended particulate matter

Stewart et al. (2008) CJFAS

Nitrogen isotope ($\delta^{15}N$) – MeHg relation at CFWR has slope similar to that found in other studies, indicating similar rate of biomagnification of MeHg with increasing trophic level.



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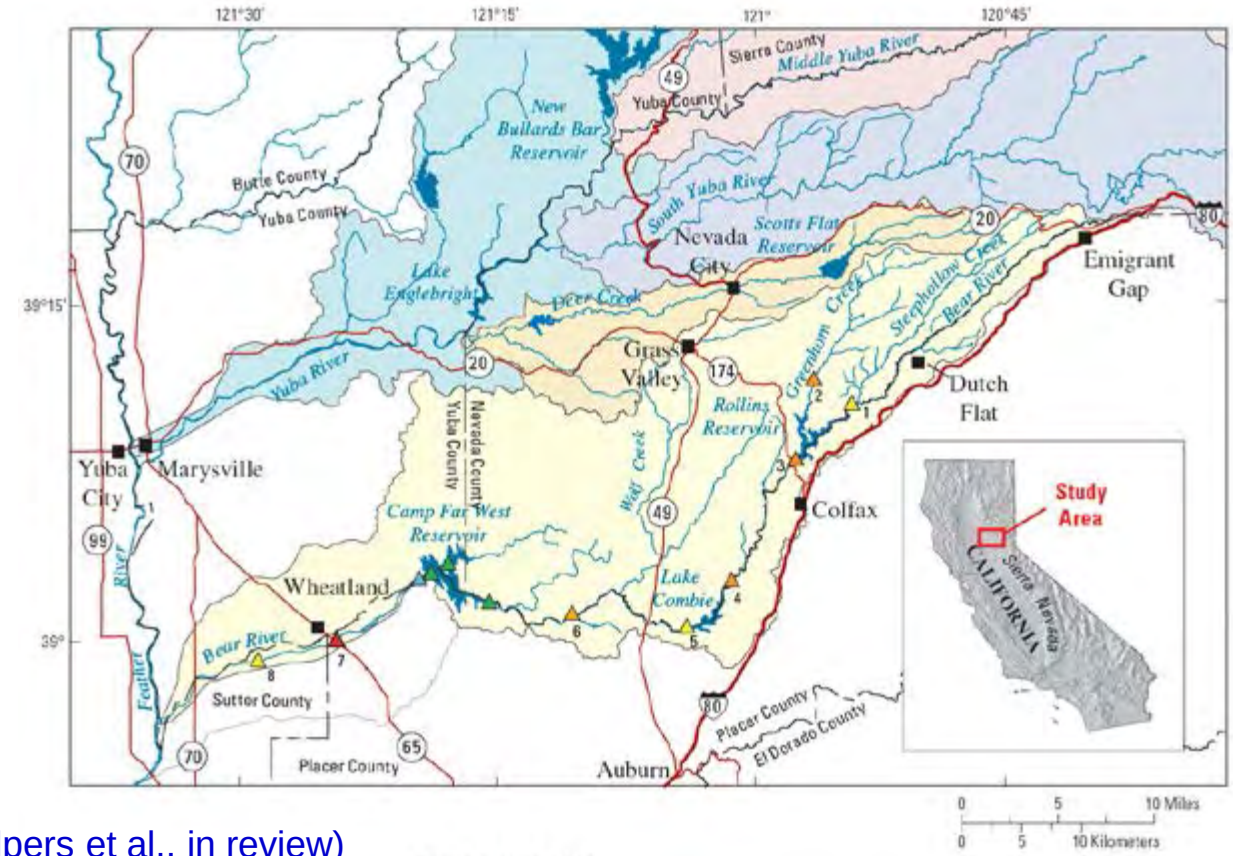
Stewart et al. (2008) CJFAS

Bear River Hg Bioaccumulation Factor Study



(Alpers et al., in review)

EXPLANATION

Watersheds

- Bear River
- Deer Creek
- South Yuba River
- Middle Yuba River
- Yuba River

- Sampling station and number–fish and water, this study
- Sampling station and number–invertebrates and water, this study
- Sampling station and number–fish, invertebrates, and water, this study
- Sampling station–fish and water, other USGS studies
- Sampling station–water only, other USGS studies

Bear River sites:
12 fish species
(2002-06)

- 194 fillets
- 60 whole body

177 water samples
(1999–2007)
(Alpers et al., in review)

CFWR (2002–03):
3 fish species

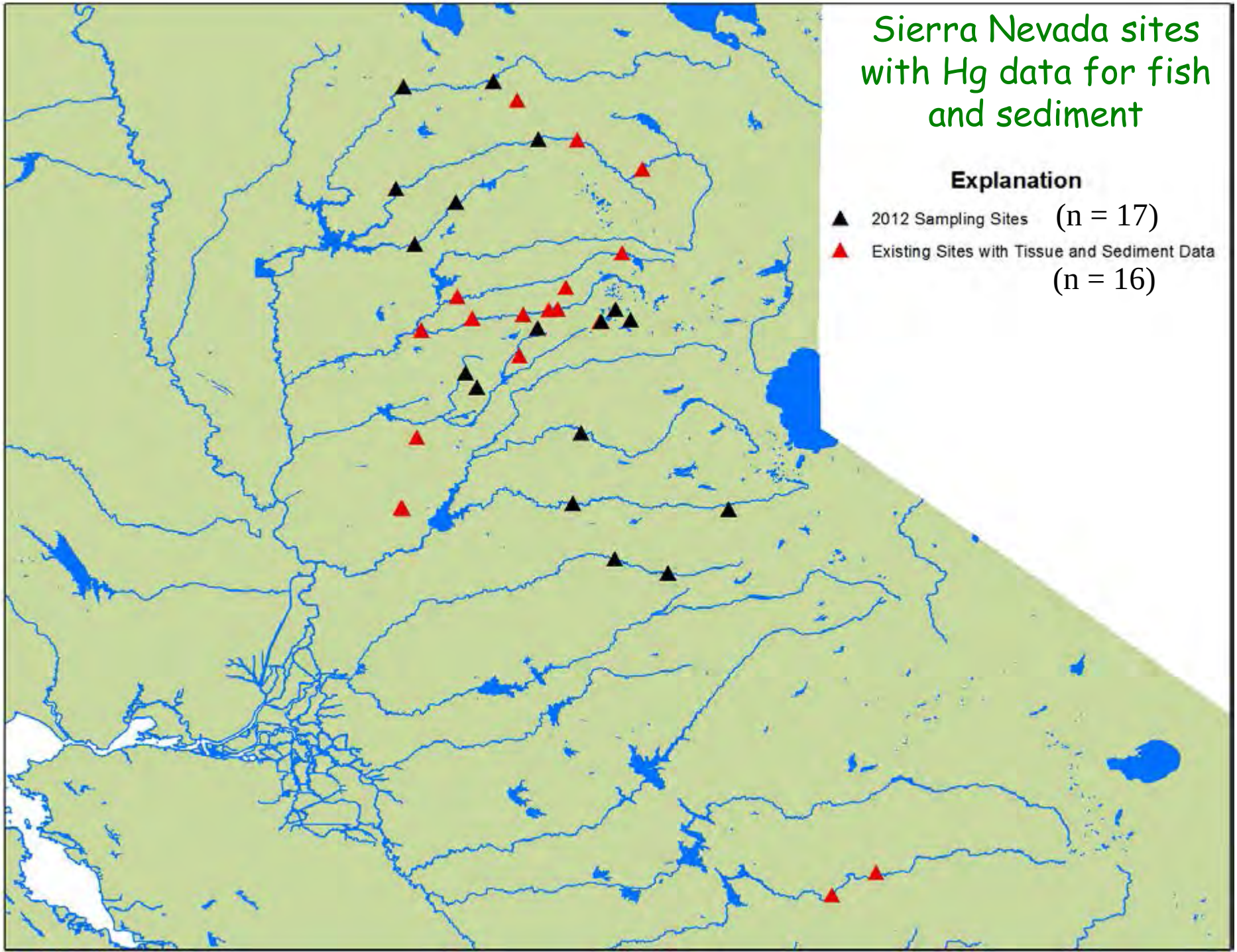
- 240 fillets
- 404 whole body

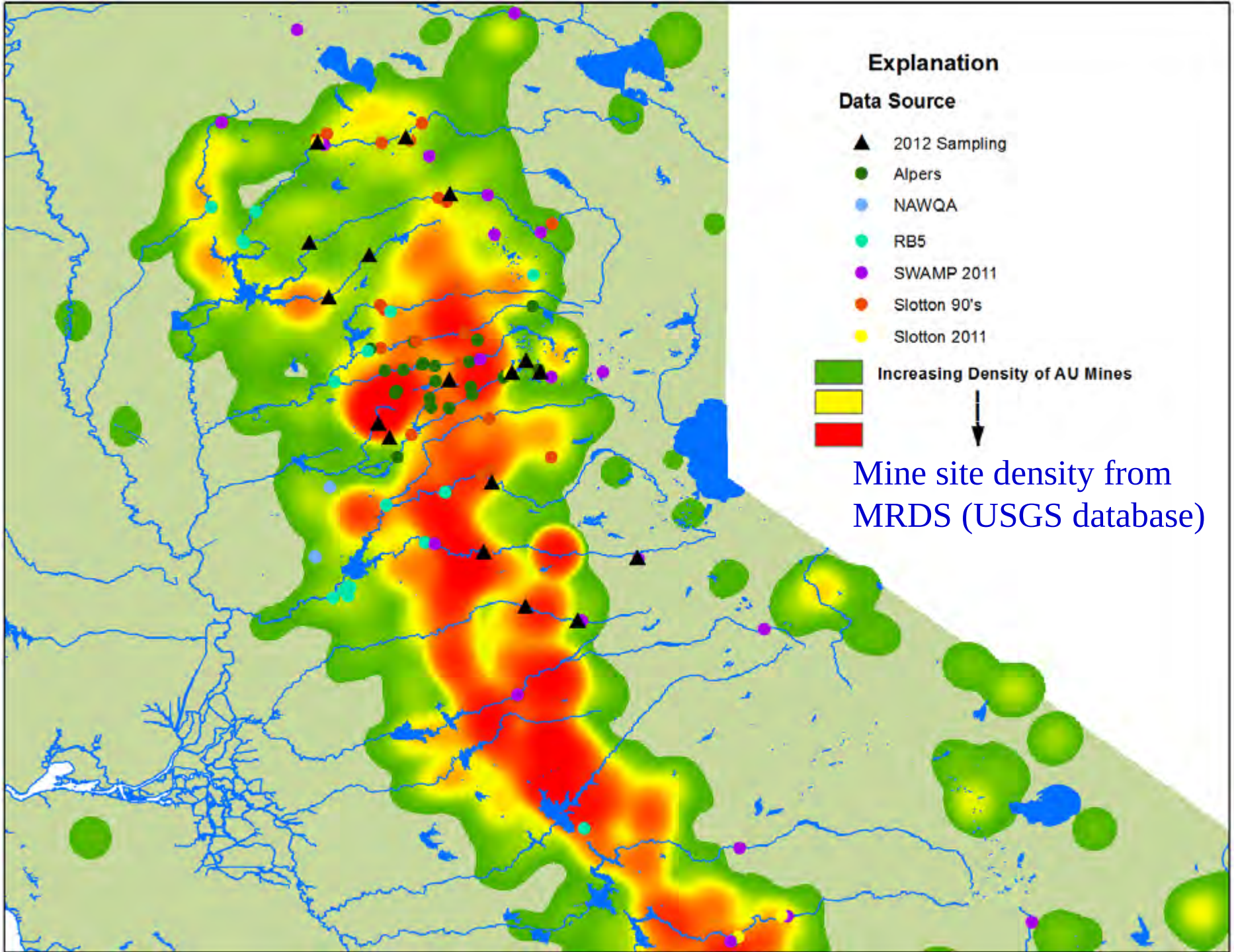
77 water samples

(Saiki et al., 2008)

Sierra Nevada Mercury Impairment Project

- **Goals:**
  - Investigate correlations between Hg in fish, Hg and MeHg in sediment and water, and historical mining intensity in Sierra Nevada watersheds
- **Approach:**
  - Compile and analyze available data on Hg and ancillary constituents (DOC in water; LOI, Fe, S in sediment)
  - Collect water, sediment, and biota at ~25 stream sites (2011–12)
    - Several 2011 sites in cooperation with SWAMP-BOG
  - Analyze data, write reports (2013–14)


Sierra Nevada sites with Hg data for fish and sediment
Explanation
2012 Sampling Sites (n = 17)
Existing Sites with Tissue and Sediment Data (n = 16)



Mine site density from MRDS (USGS database)

Summary and Conclusions

- Mercury contamination from historical gold mining is widespread in northern California
- Water, sediment, and biota are effective monitoring tools for finding Hg and MeHg “hot spots” associated with abandoned mine lands
- Large temporal (seasonal) variability in Hg methylation and bioaccumulation
  - seasonal sampling (4x/yr) is minimum frequency for water and zooplankton sampling in food web studies
- More data needed to determine processes affecting MeHg BAF’s
  - lotic (rivers, streams) vs. lentic (reservoirs, lakes)
  - other factors: T, DOC, land cover (% wetlands), Hg speciation
- Ongoing studies may determine whether Hg in sediment (from historical gold mining) is predictive of MeHg bioaccumulation

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