California Statewide Mercury Control Program for Reservoirs

Part 1

California Lake Management Society
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Multi-Region Team
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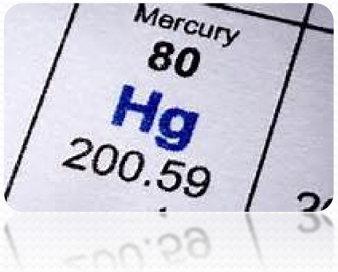
& many others

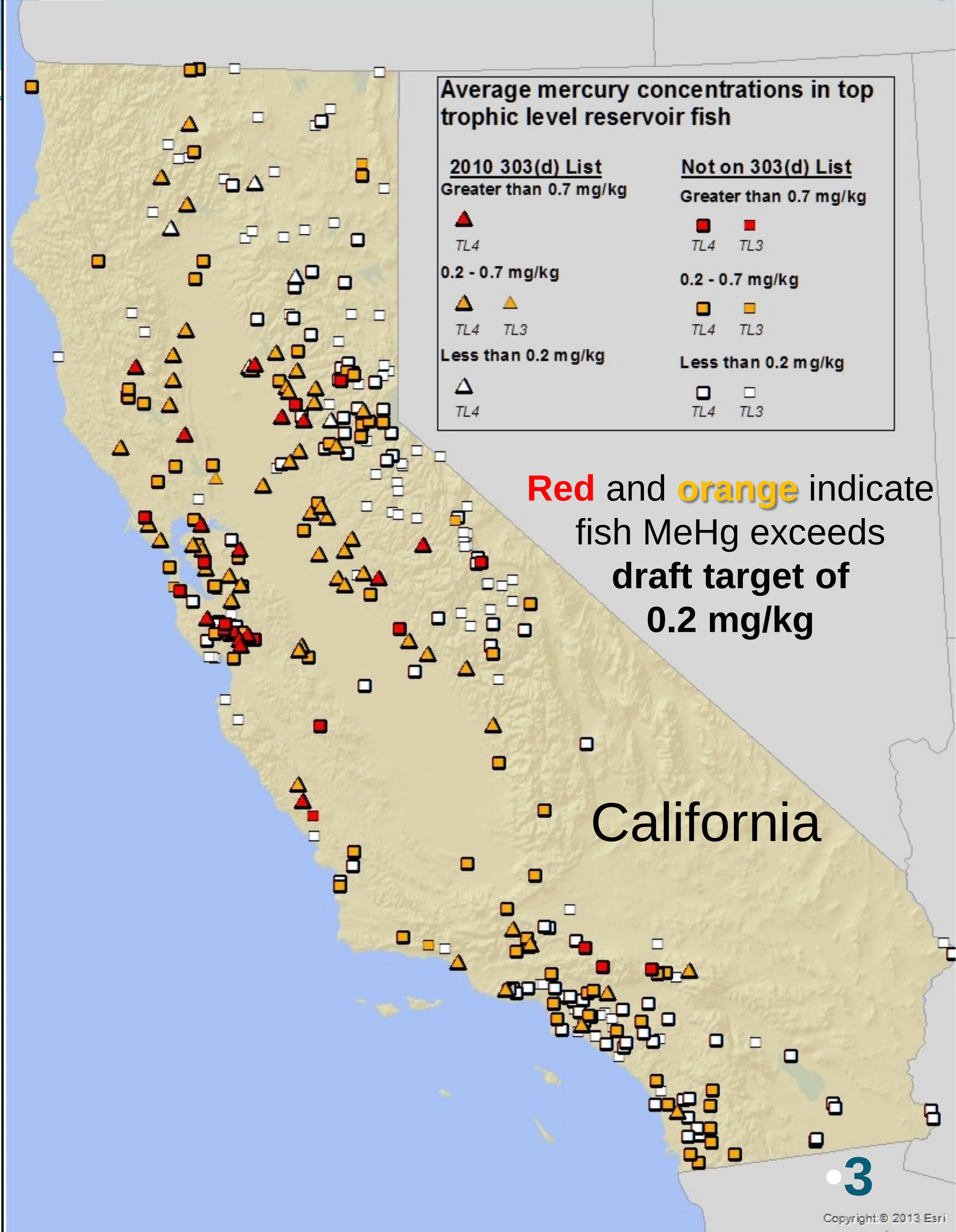
Outline



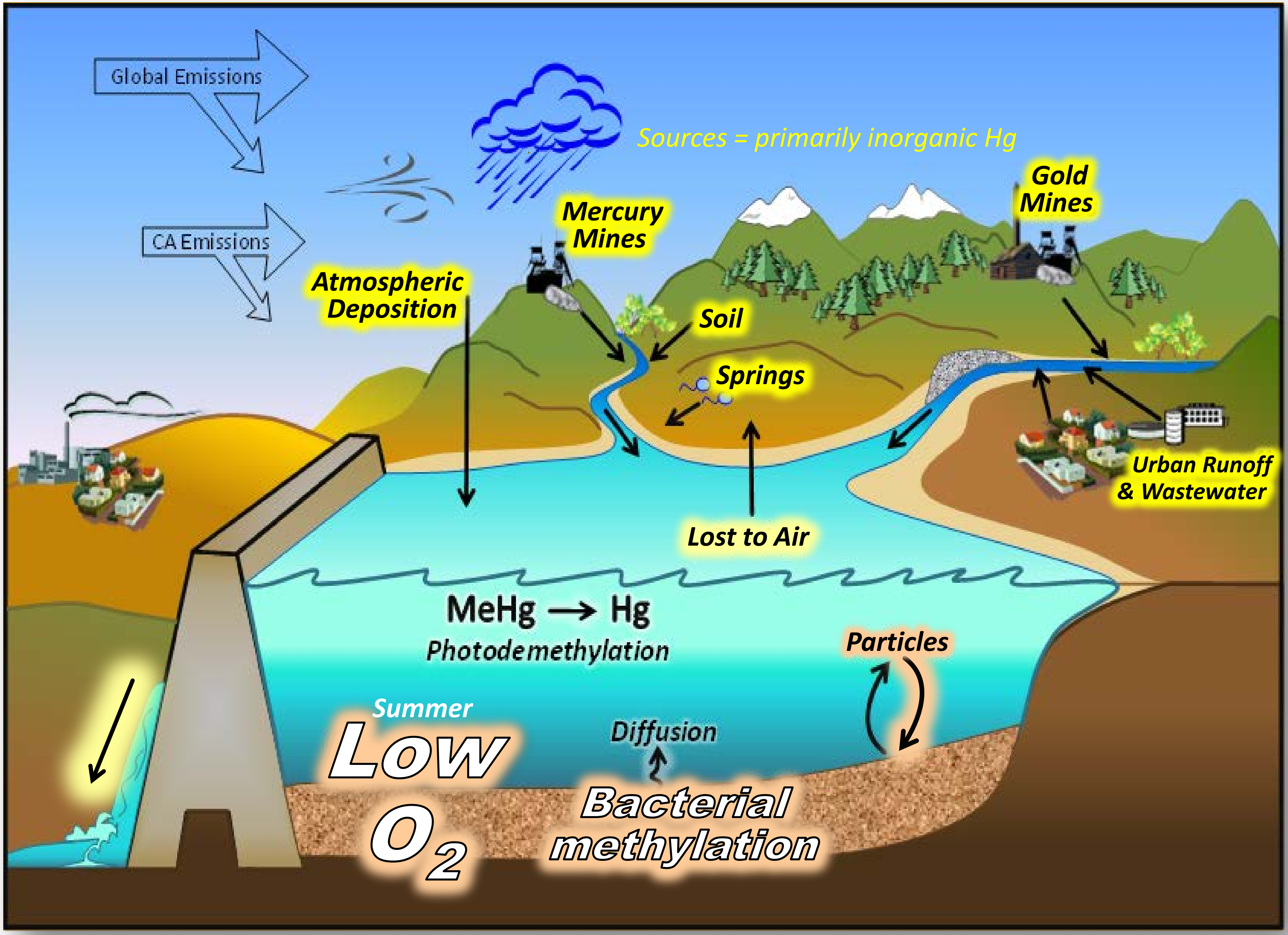
- Introduction to the California mercury problem
- Overview of mercury cycling in reservoirs
- Statistical model development
- Factors influencing reservoir fish mercury
- Summary

Mercury Problem

- About ½ of the 350 reservoirs with fish data have elevated methylmercury (MeHg)
- Widespread problem → Statewide mercury control program

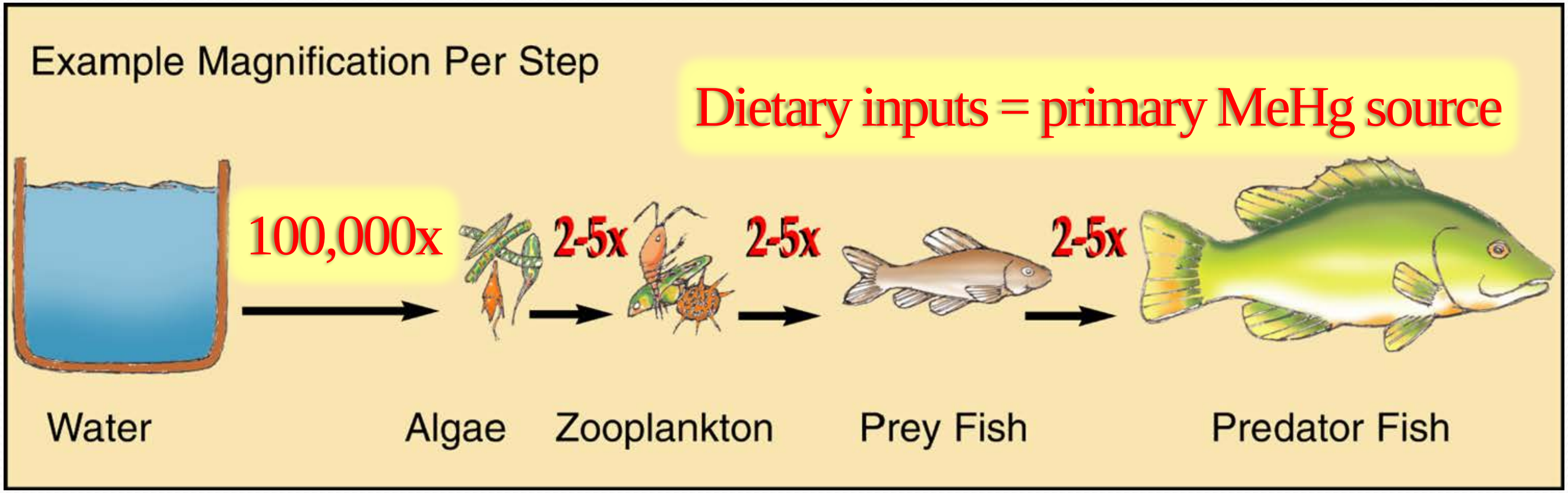


Water Chemistry



Methylmercury Biomagnification

Repeated MeHg consumption & accumulation → ↑MeHg in each food chain level



Low levels of aqueous MeHg can result in high fish MeHg	Highest MeHg is in top trophic level fish species

Statistical Model Development

Goal: Identify driving factors for Hg bioaccumulation in CA reservoirs

Evaluated >70 Factors & >90 Reservoirs

Chemical	Reservoir Characteristics	Mercury Source Types/Rates	Land Use
Aqueous [MeHg]	WY water level fluctuation	Atm Dep to reservoir	Latitude
Sediment [THg]	Reservoir surface area	Wet Atm Dep to reservoir	Longitude
Aqueous [THg]	Watershed surface area	Atm Dep to watershed	% Wetland
[Chlorophyll-a]	Ratio of reservoir surface area to watershed surface area	Atm Dep to reservoir from CA sources	% Forests
Upland soil [THg]	Year dam built (age)	Wet Atm Dep to watershed	% Vegetation
[Aq MeHg]:[Chl-a]	Reservoir Elevation	Atm Dep to watershed from CA sources	% Open Water
	Mean storage	# of Mines	% Agriculture
	Maximum reservoir capacity	Mine Density	% Urban
			# U/S Dams
			NPDES WWTP

Limited Data Available			
DOC	Food Chain Length	Degree of Anoxia	pH

Statistical Model Development

1. Data compilation – readily available data
2. Fish Hg concentrations – length standardized (350mm LMB)
3. Box-Cox power transformations
4. Parametric and non-parametric correlations and regressions
   - 17 predictor variables for multiple regression development
   - Predictor variables were z-score standardized
5. Best Subsets Regression
   - >100,000 variable combinations
   - Overall measures of quality
   - Adj-R^2, Mallows C_p, PRESS

See Fact Sheet:

Statewide Mercury Control Program for Reservoirs

Linkage analysis

Water Board staff conducted a statistical analysis to identify the most important factors that control methylation and bioaccumulation. Overall, the analysis assessed the influence of almost 40 factors on predatory fish methylmercury concentrations "[MeHg]" in California reservoirs (Table 1). More than 90 reservoirs had a variety of data that were used in different components of the analysis. The environmental factors were initially screened using correlation coefficients similar to Table 1, and important factors were included in the multivariable model development. All data were Box-Cox power transformed to aid in the parametric statistical analyses.

Model equation:

LN [Fish methylmercury] = 0.56 x [aqueous total mercury]
+ 0.34 x ratio [aqueous methylmercury] / [chlorophyll-a]
+ 0.39 x (average water level fluctuation) - 0.91

$R^2 = 0.83$, Adjusted $R^2 = 0.81$, Predicted $R^2 = 0.72$,
$n = 26$ reservoirs, $P < 0.001$

These three factors together explained the greatest amount of variability in fish methylmercury levels in California reservoirs. This model equation is supported by scientific literature and the Conceptual Model in the following ways:

- **[aqueous total mercury]** in reservoir water likely reflects the overall magnitude of mercury sources to the reservoir, and higher aqueous total mercury likely results in higher aqueous methylmercury
- The **ratio [aqueous methylmercury] / [chlorophyll-a]** represents the magnitude of methylmercury entering the food chain
- The magnitude of **water level fluctuation** may act upon multiple pathways of mercury cycling (methylation and bioaccumulation)

All individual coefficients were statistically significant at $P<0.05$, and the variables showed minimal multicollinearity (VIF<2). The model was cross-validated using PRESS to prevent over-fitting the model. Predictor variables were z-score standardized to give them equal weights.

Table 1: Correlation coefficients for 350 mm standardized predatory fish [MeHg] versus reservoir and watershed factors

Environmental Factors*	Lambda Trans-formation	Pearson's r	Spearman's Rho
		Correlation Coefficient	
[aq MeHg] Geomean / [Chl-a] Geomean	0	0.67	0.70
Reservoir Sediment [THg] Geomean	0	0.50	0.47
Watershed Soil [THg] Geomean	0	0.40	0.44
Reservoir Longitude	5	0.39	0.40
Reservoir [Chl-a] Geomean	-0.22	0.34	0.27
Average Water Level Fluctuation	0	0.33	0.35
Watershed Percent Vegetation	3	0.32	0.29
[aq MeHg] Geomean	-0.5	-0.31	-0.38
[aq THg] Geomean	0	0.30	0.25
Watershed Percent Open Water	0	-0.27	-0.30
Reservoir Dam Height	0.5	0.25	0.34
Reservoir Elevation	0.21	-0.22	-0.27
Watershed Percent Forests	2	0.22	0.12
CA Hg Atm Dep Rate to the Watershed	0	0.19	0.17
Watershed Productive Mines per Mile	-3.77	-0.17	-0.05
Number of Mines in Watershed (PAMP)	-0.5	-0.15	-0.17
Year Dam Built	5	0.15	0.19
Watershed Mines per Mile	-2	-0.14	-0.01
Number of Dams Upstream of Reservoir	-0.22	-0.13	-0.06
Reservoir Maximum Capacity	0	0.10	0.17
Watershed Area/Reservoir Surface Area	-0.11	-0.09	-0.19
CA Hg Atm Dep Rate to the Reservoir Surface	0	0.08	0.12
Reservoir Latitude	5	0.08	0.04
Watershed Surface Area	0	-0.05	0.13
All Hg Atm Dep Rate to the Watershed	-1	-0.03	-0.02
All Hg Wet Atm Dep Rate to the Reservoir Surface	0	-0.03	0.03
Number of Productive Mines in Watershed	-0.13	-0.03	-0.002
Watershed Percent Wetlands	-5	0.02	0.002
All Hg Atm Dep Rate to the Reservoir Surface	-1	0.02	-0.05
All Hg Wet Atm Dep Rate to the Watershed	0	0.01	-0.04
Watershed Percent Agriculture	-5	0.01	0.08
Reservoir Surface Area	0	0.01	0.05
Number of Mines in Watershed (MRDS)	0	-0.002	-0.03

* Highlighted environmental factors indicate statstically signficant correlations with fish tissue mercury concentrations for the parametric, non-parametric, or both analyses (using their respective two-sided tests of signficance, P < 0.05).

September 2013 4

Best Fit Model Equation

LN [fish methylmercury] =

0.36 * [aqueous total Hg]

+ 0.48 * [aqueous MeHg] / [chlorophyll-*a*]

+ 0.35 * (annual water level fluctuation)

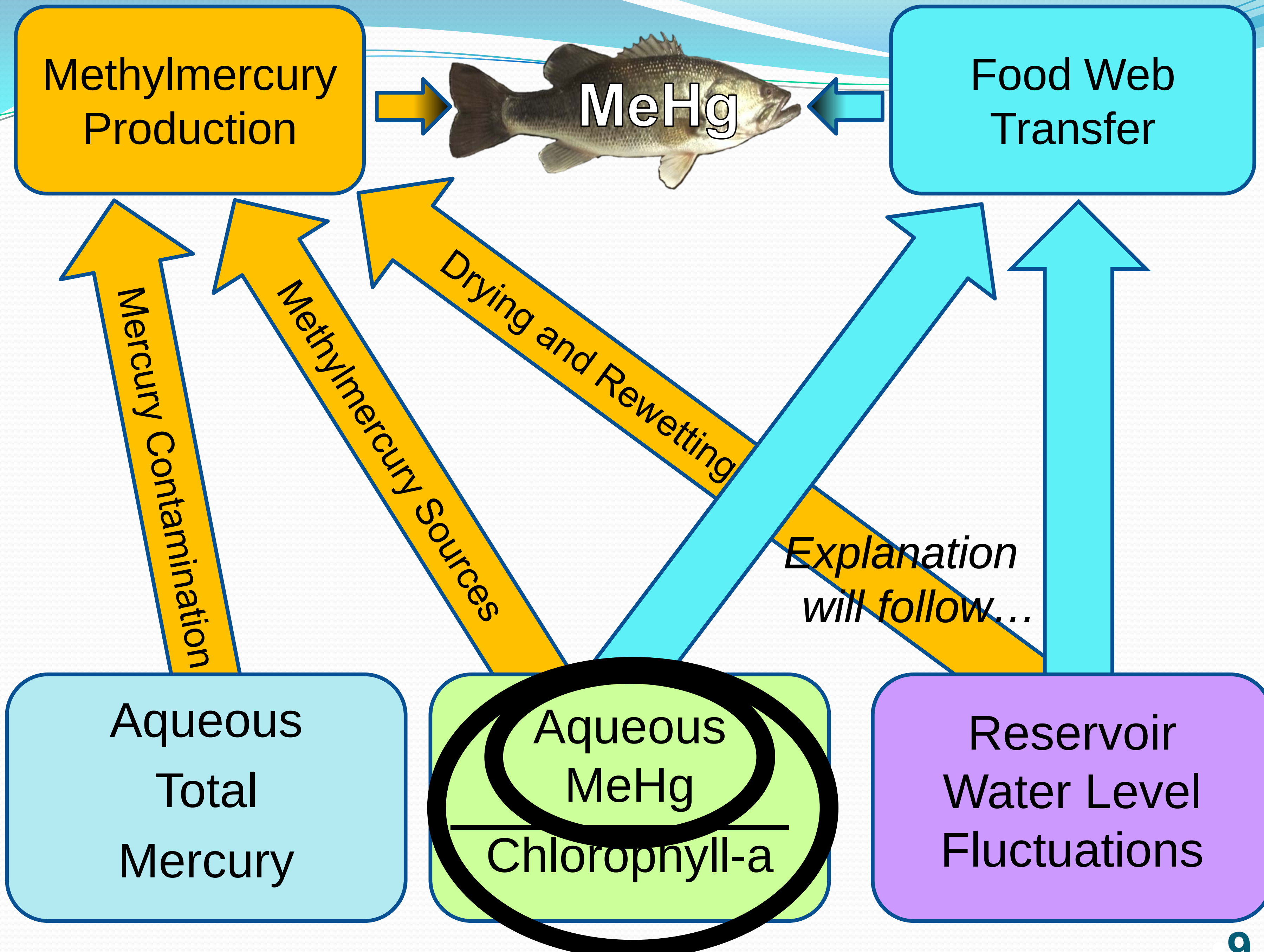
− 0.95

$R^2 = 0.85$

Adjusted $R^2 = 0.83$

Predicted $R^2 = 0.80$

n = 26 reservoirs, $P < 0.001$


Methylmercury Production
MeHg
Food Web Transfer
Mercury Contamination
Methylmercury Sources
Drying and Rewetting
Explanation will follow…
Aqueous Total Mercury
Aqueous MeHg
Chlorophyll-a
Reservoir Water Level Fluctuations

Fish MeHg concentration =

$$\frac{\textbf{mg methylmercury}}{\textbf{kg tissue weight}}$$

Methylmercury Production

Food Web Transfer

Food Web Transfer

Food Web Transfer

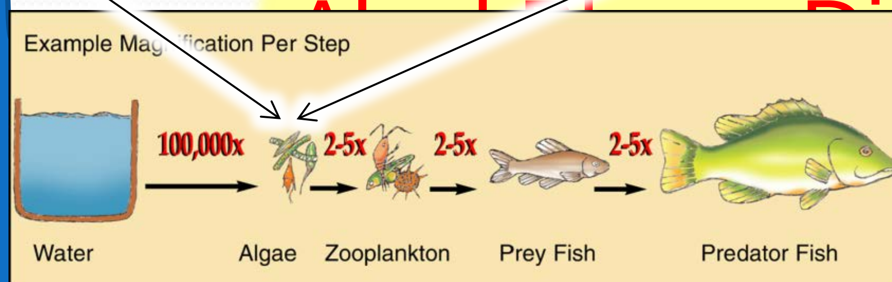
$$\frac{\text{Aqueous MeHg}}{\text{Chlorophyll-a}}$$

Amount of MeHg entering food web base

Proxy for how much algae is present & amount of pelagic primary productivity

Clear Water Lake

...ution



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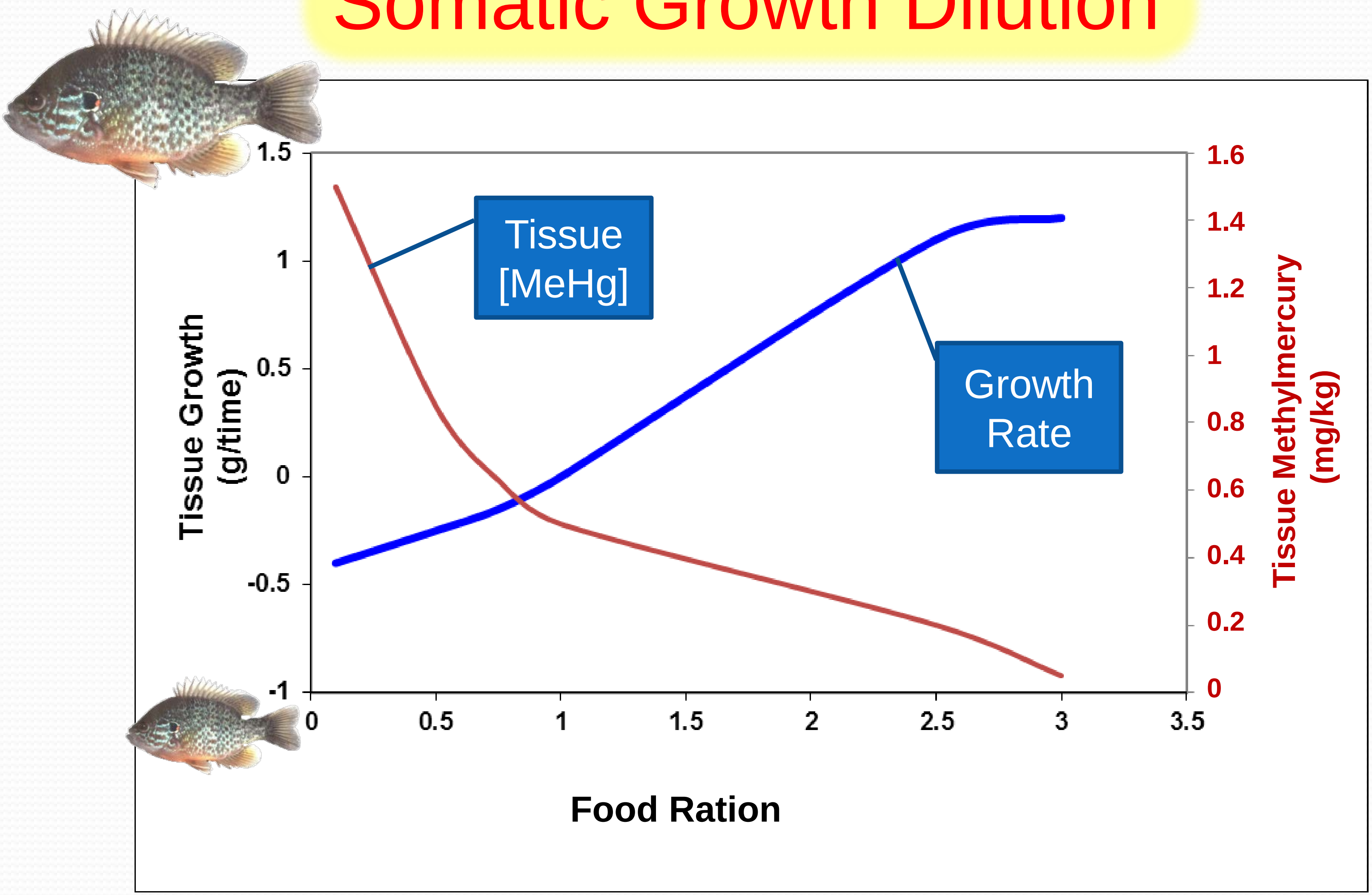
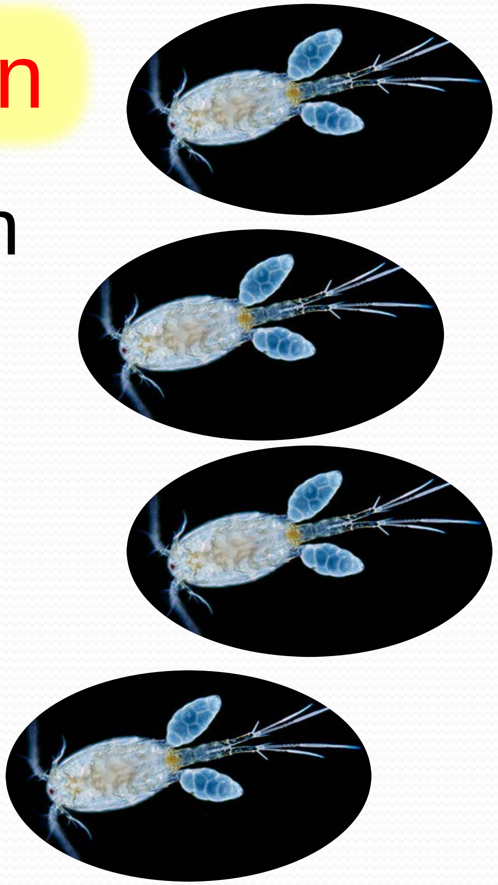
Food Web Transfer

Somatic Growth Dilution



Food Web Transfer

Somatic Growth Dilution



- Increased primary productivity can support:
  - Higher growth rates for individuals
  - Larger abundance of organisms
- Somatic growth dilution can occur at <u>all food web levels</u>

Food Web Transfer

Reservoir Water Level Fluctuations*

- Large fluctuations erode fine sediment and nutrients
- Reduces <u>benthic</u> primary productivity
- Decreases fish and invertebrate growth rates
- Opposite of somatic growth dilution

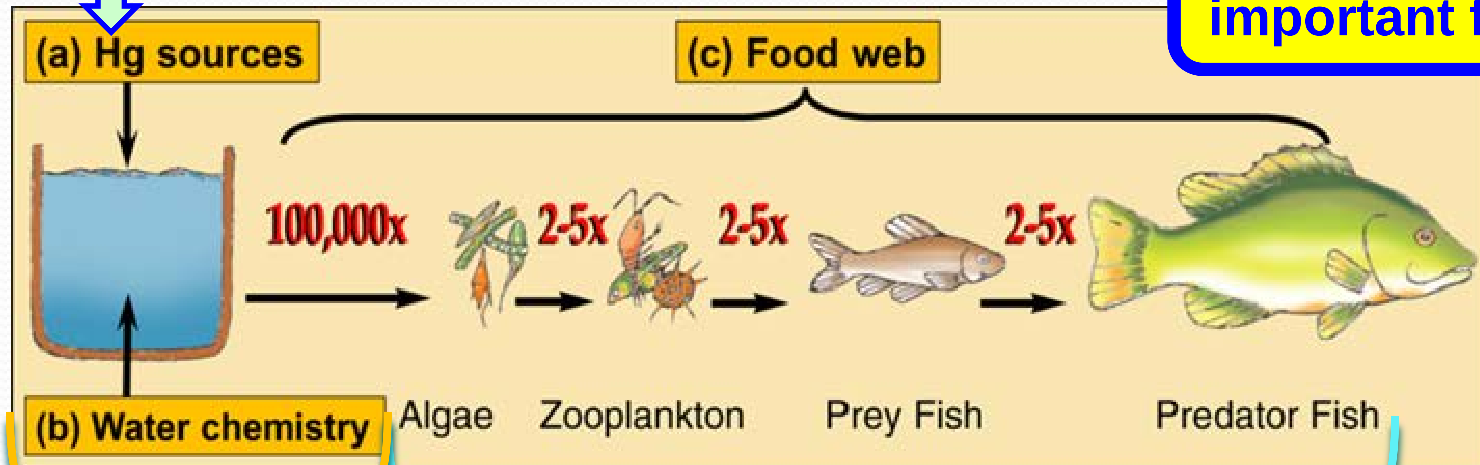
Folsom Lake, CA

* Reservoir Water Level Fluctuations = WY Max Elevation – WY Min Elevation

Summary

Mercury Sources

Three equally important factors



Methylmercury Production

Food Web Transfer

Website with fact sheets & updates
www.waterboards.ca.gov/water_issues/programs/mercury

Sign up for email notices at:
www.waterboards.ca.gov/resources/email_subscriptions/swrcb_subscribe.shtml#quality

Acknowledgements

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