Important Factors Influencing Predatory Fish Mercury Concentrations in California Reservoirs: A Statistical Approach

North American Lake Management Society

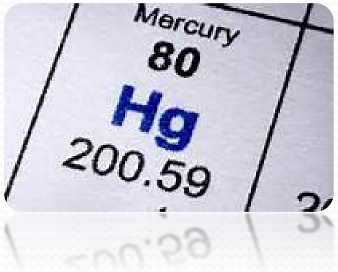
33rd International Symposium

November 1, 2013

California Water Boards
Multi-Region Team

Stephen Louie, Michelle Wood, Carrie Austin, & many others

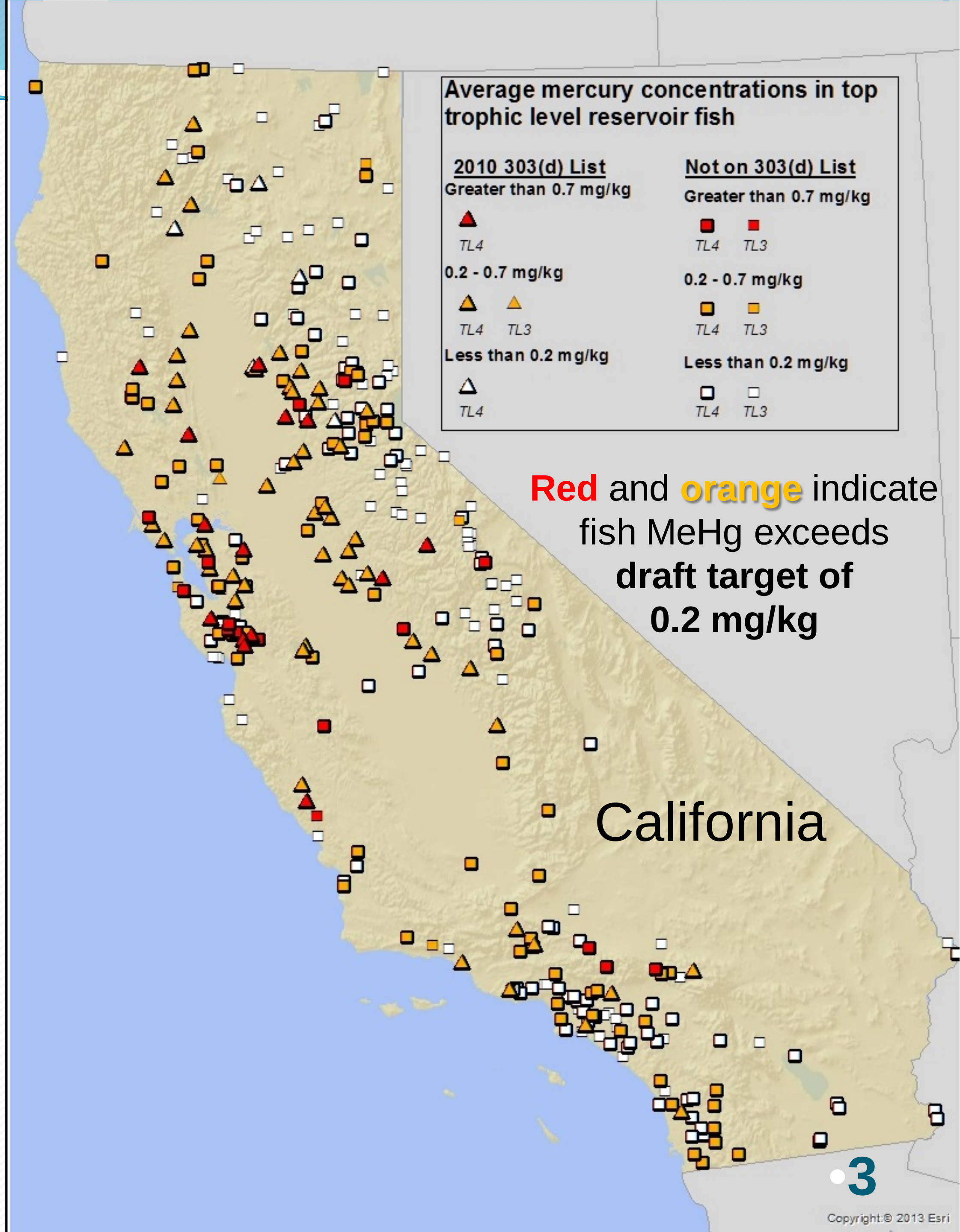
Outline



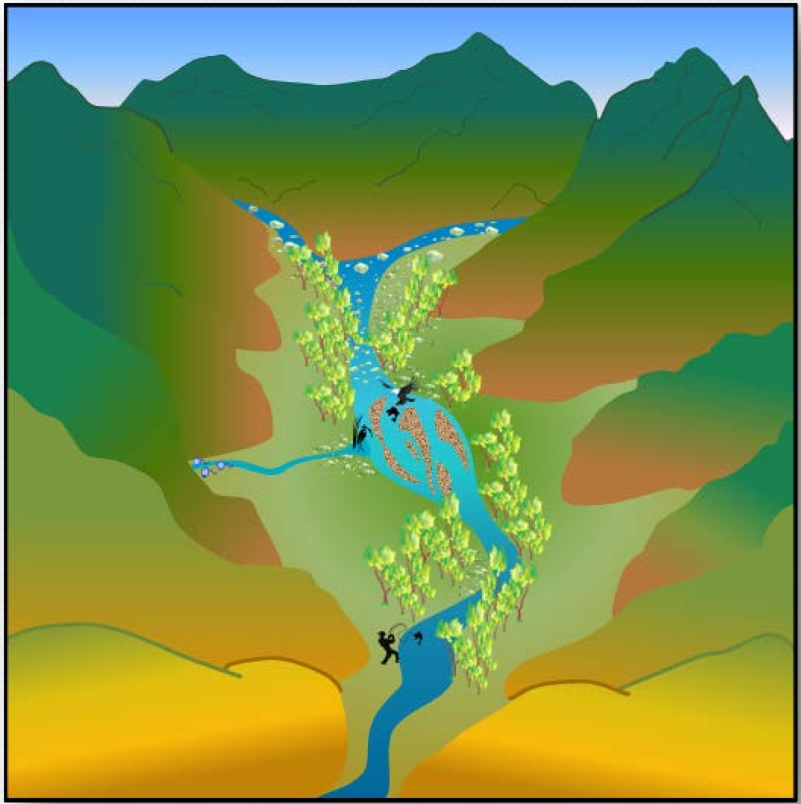
- Introduction to the California Mercury Problem
- Overview of Mercury Cycling
- Statistical Model Development
- Factors Influencing Fish Mercury
- Summary

Mercury Problem

- About ½ of the 350 reservoirs with data have elevated Hg
- >1000 reservoirs in CA



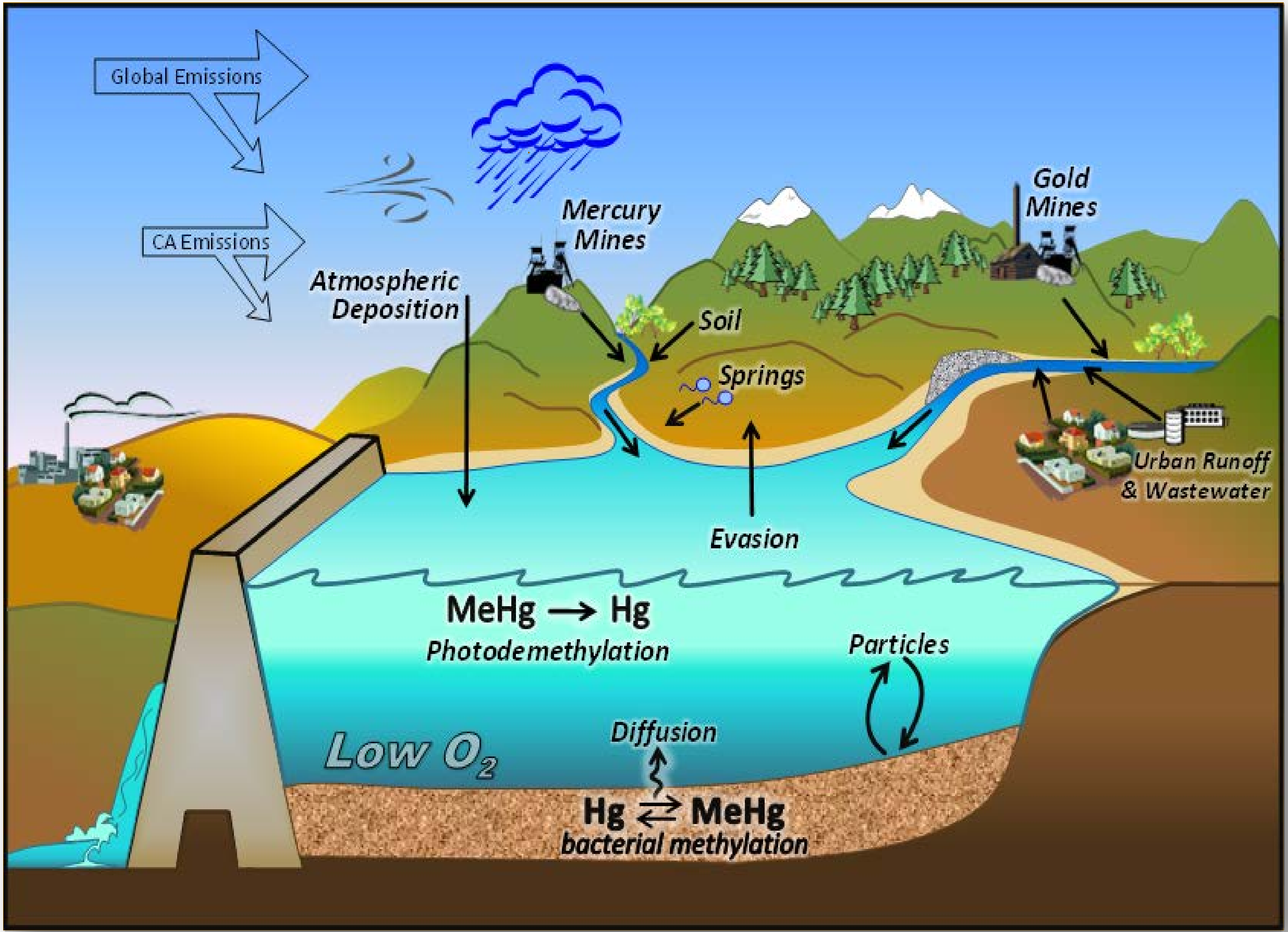
Dams Change Water Chemistry



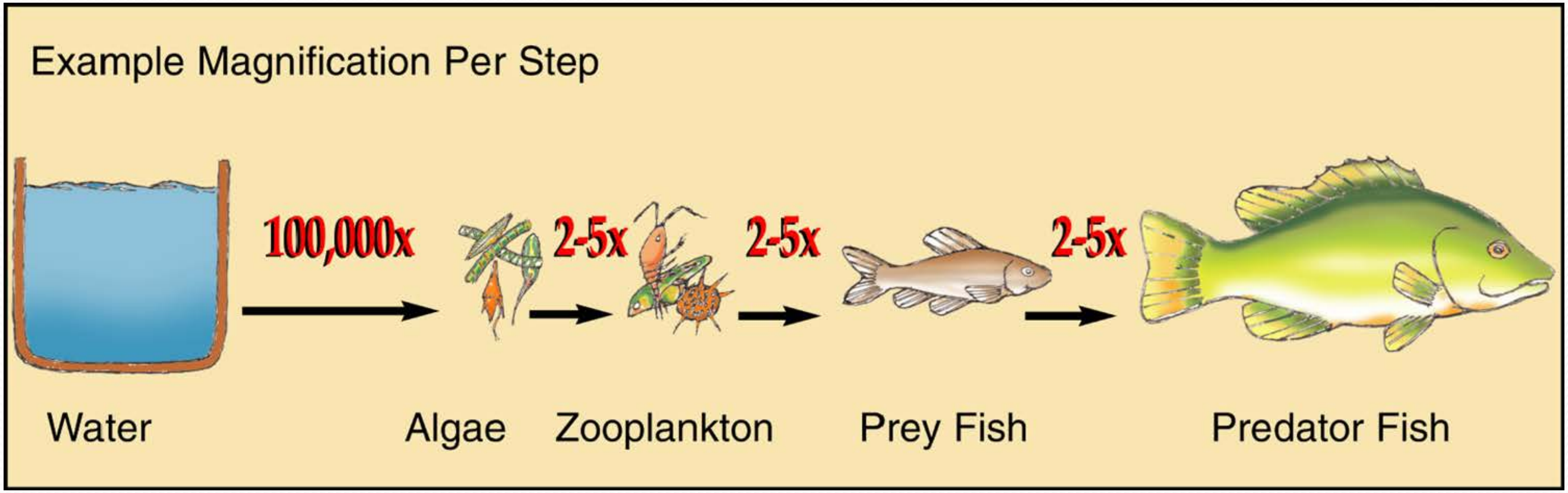
Before

After

Water Chemistry



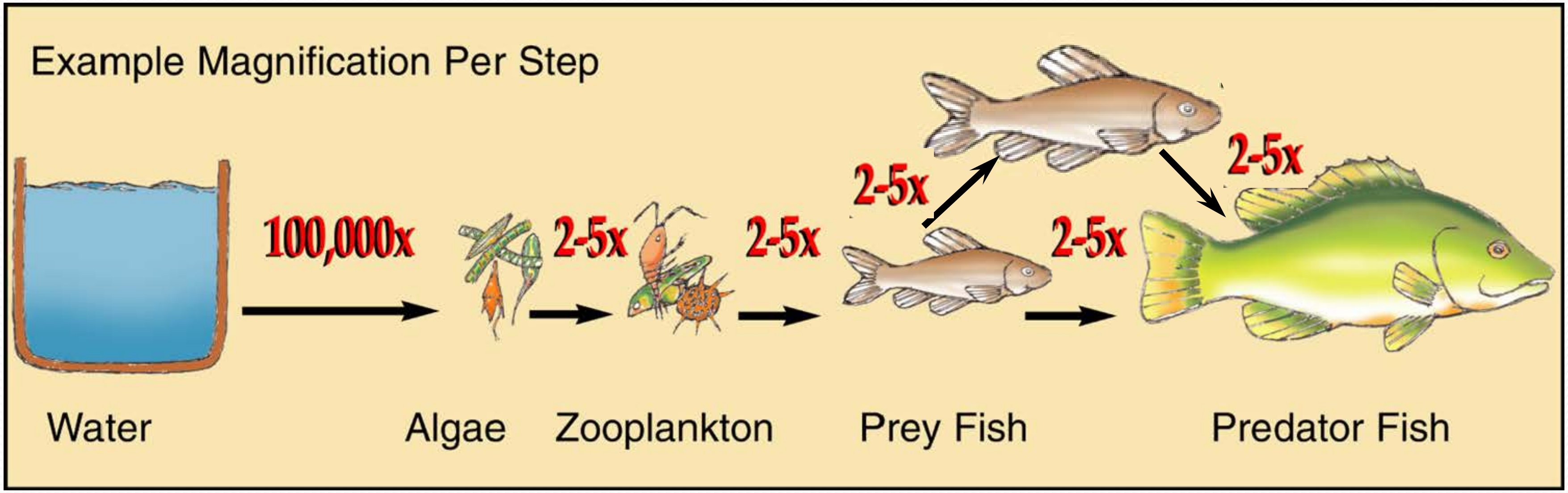
Methylmercury Biomagnification



Low levels of aqueous MeHg can result in high levels in fish

Highest MeHg is in top trophic level fish species

Methylmercury Biomagnification



Low levels of aqueous MeHg can result in high levels in fish

Highest MeHg is in top trophic level fish species

Statistical Model Development

>30 Factors Evaluated

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

Statistical Model Development

>30 Factors Evaluated

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

Little Data Available				
DOC	Food Chain Length	Degree of Anoxia	pH	others

Statistical Model Development

I. Data Compilation – readily available data

II. Fish Hg Concentrations – length standardized

III. Box-Cox Power Transformations

IV. Parametric and non-Parametric Correlations and Regressions

    I. 17 predictor variables for multiple regression development

    II. Predictor variables were z-score standardized

V. Best Subsets Regression

    I. Overall measures of quality

    II. 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] =

0.56 * [aqueous total Hg]

+ 0.34 * [aqueous MeHg] / [chlorophyll-*a*]

+ 0.39 * (annual water level fluctuation)

− 0.91

$R^2 = 0.83$

Adjusted $R^2 = 0.81$

Predicted $R^2 = 0.72$

n = 26 reservoirs, $P < 0.001$

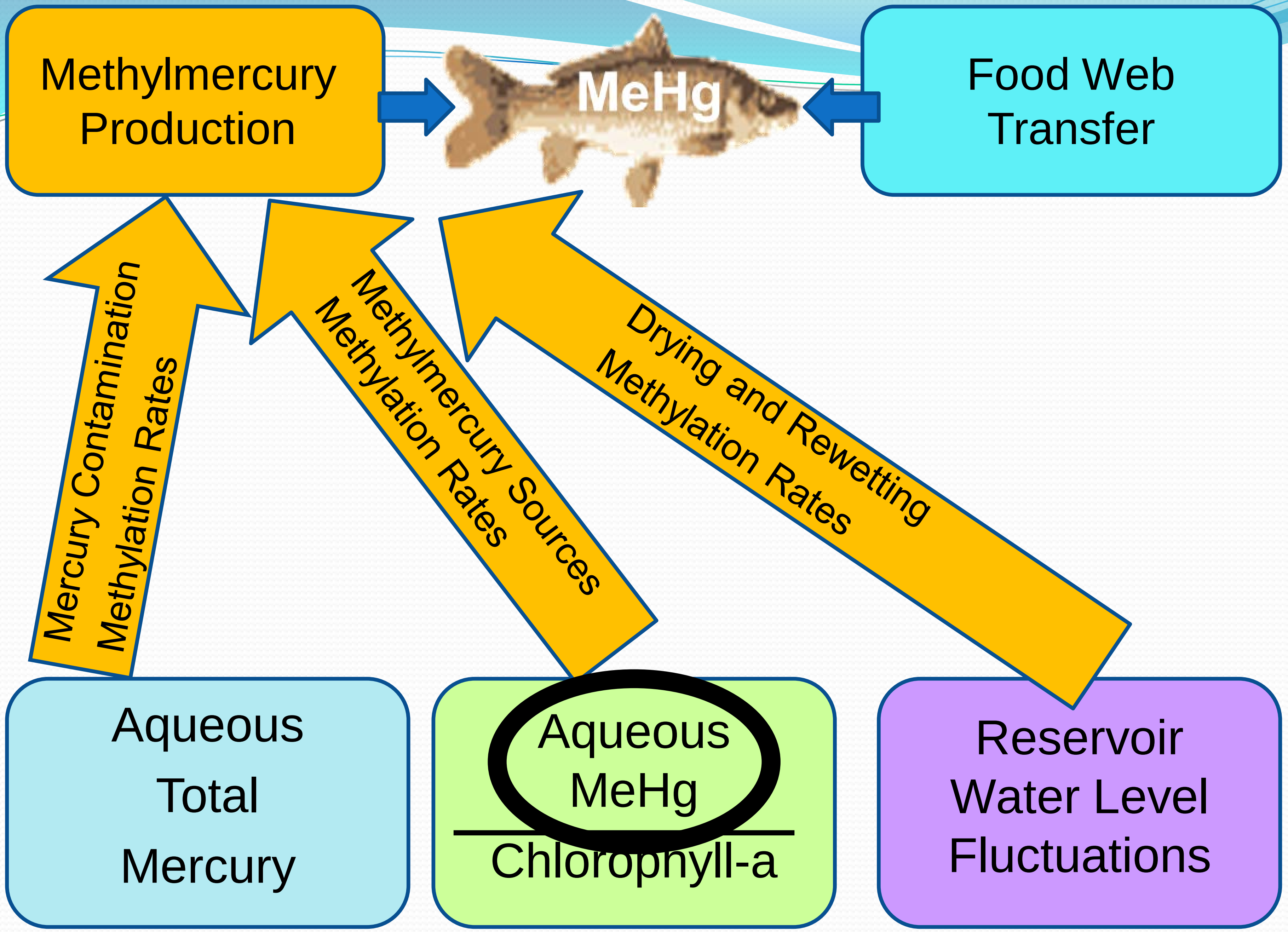
Methylmercury Production

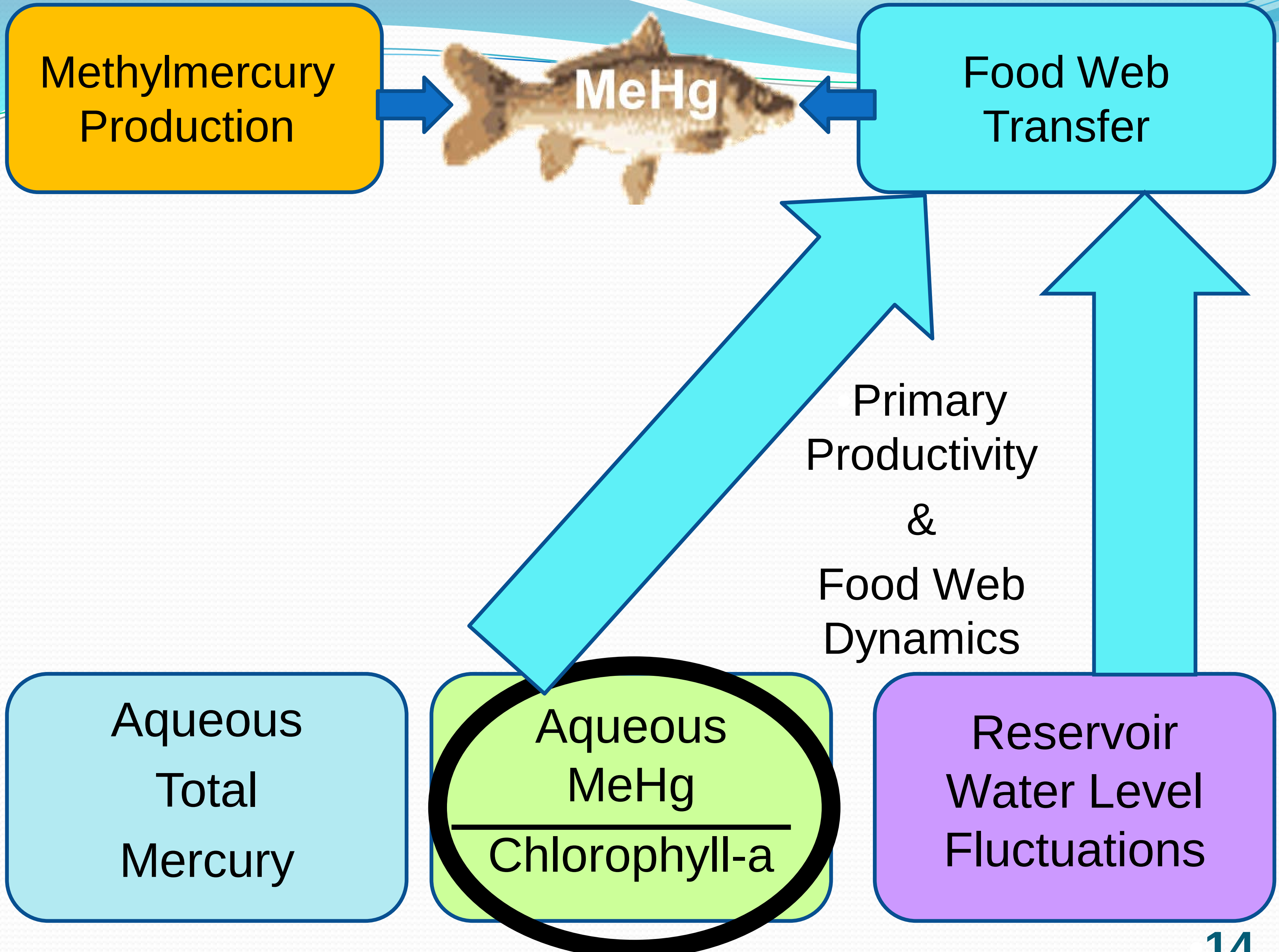
Food Web Transfer

Aqueous Total Mercury

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

Reservoir Water Level Fluctuations


Methylmercury Production
MeHg
Food Web Transfer
Mercury Contamination
Methylation Rates
Methylmercury Sources
Methylation Rates
Drying and Rewetting
Methylation Rates
Aqueous Total Mercury
Aqueous MeHg
Chlorophyll-a
Reservoir Water Level Fluctuations

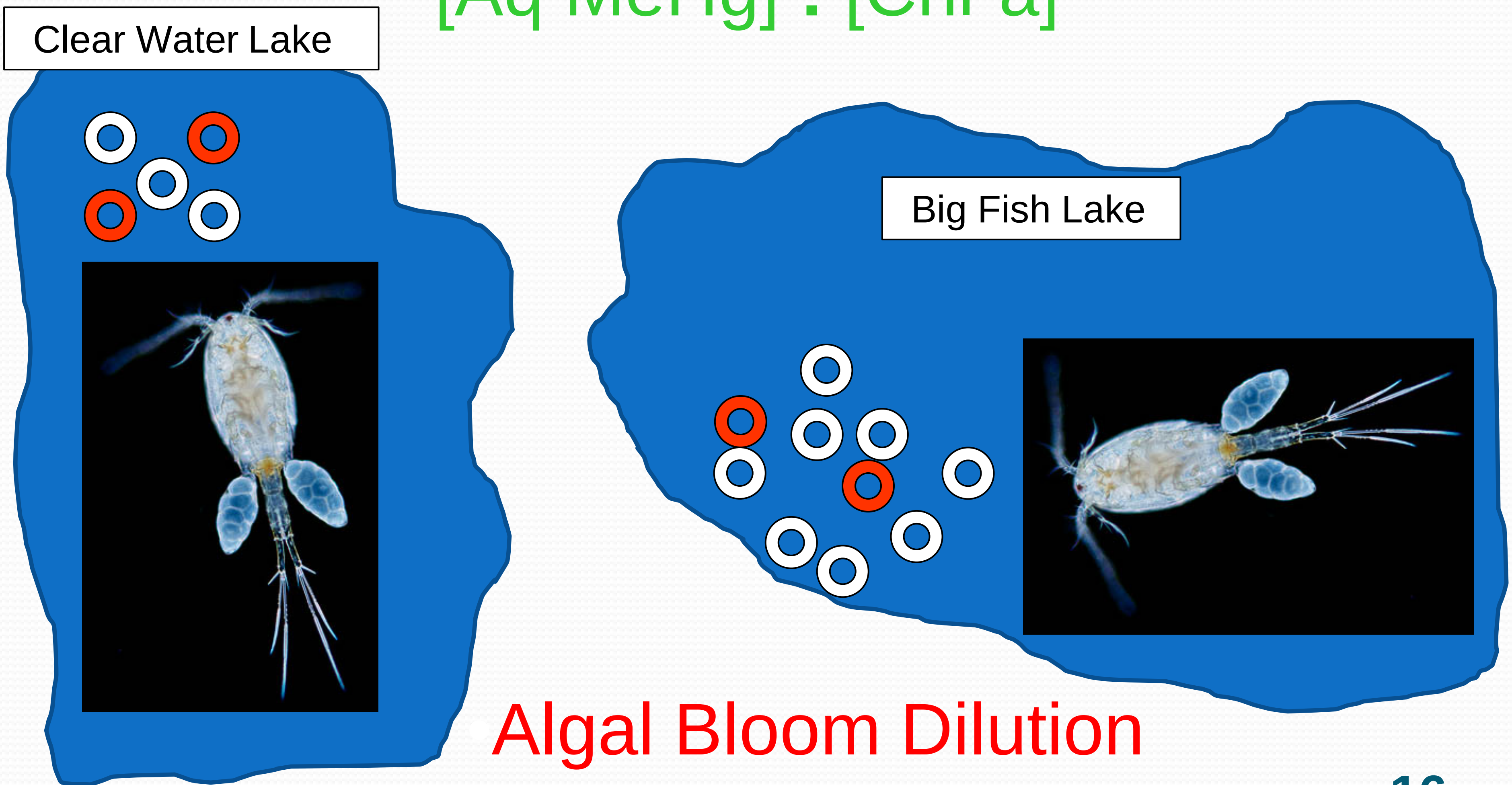

Methylmercury Production
MeHg
Food Web Transfer
Primary Productivity
&
Food Web Dynamics
Aqueous Total Mercury
Aqueous MeHg
Chlorophyll-a
Reservoir Water Level Fluctuations

Food Web Transfer

[Aq MeHg] : [Chl-a]

Food Web Transfer

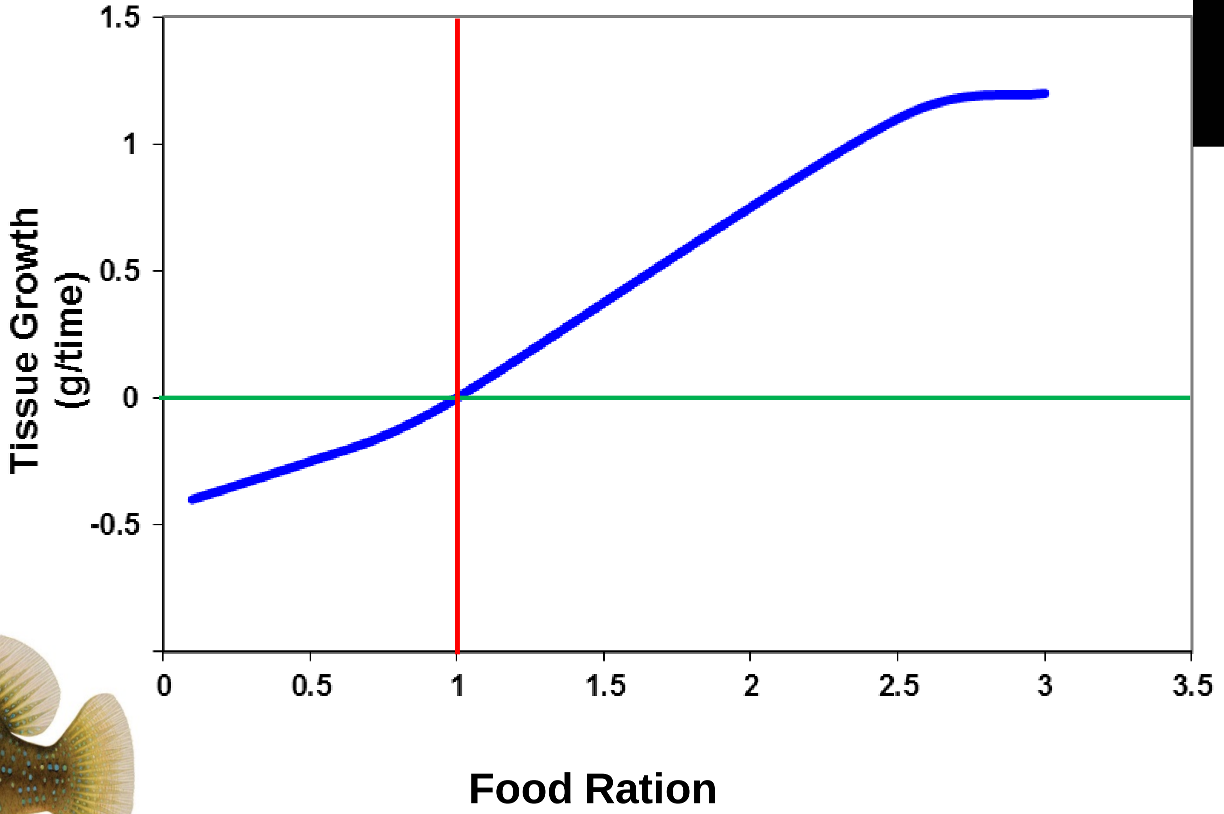
[Aq MeHg] : [Chl-a]



Algal Bloom Dilution

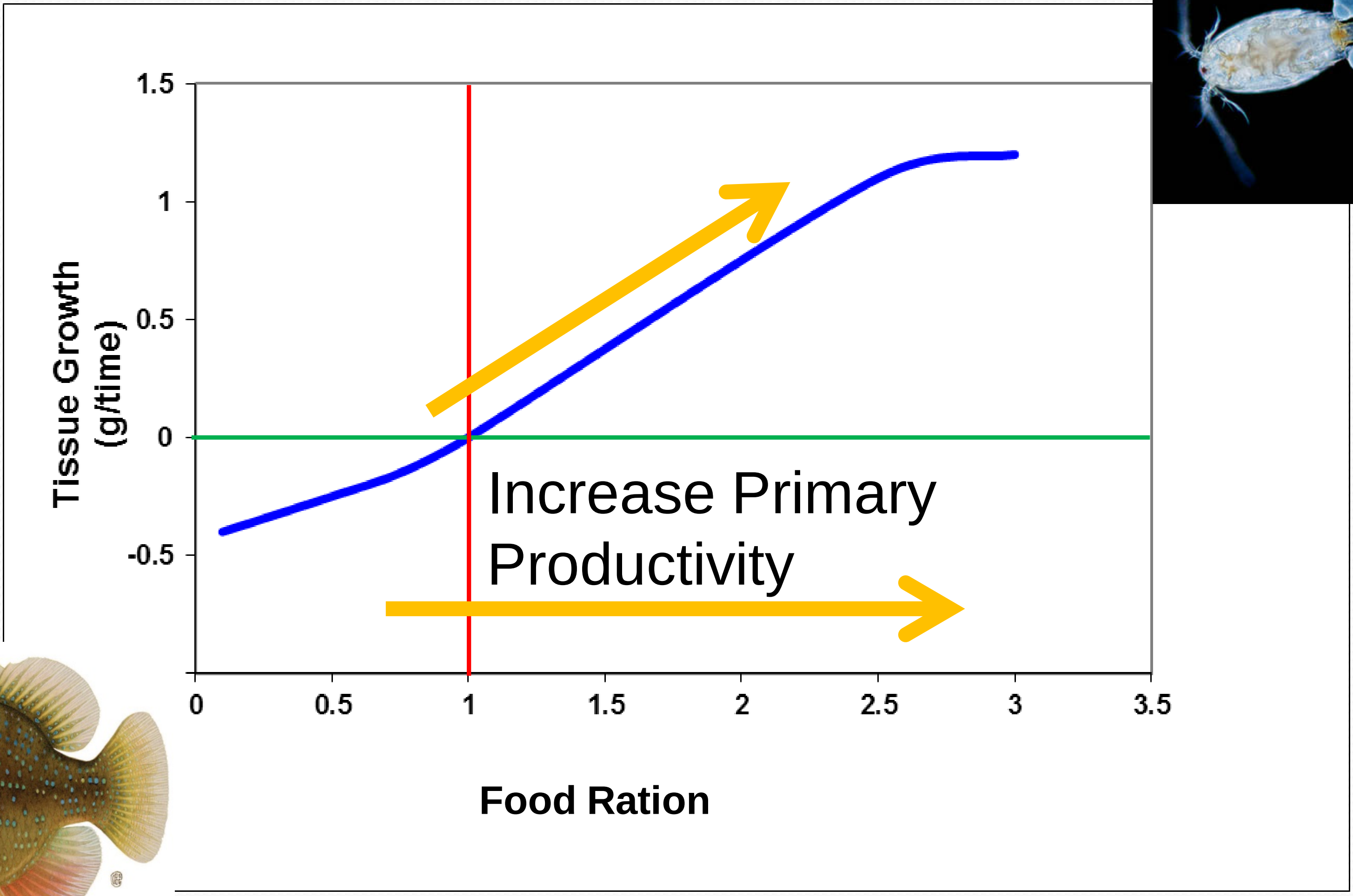
Food Web Transfer

Somatic Growth Dilution



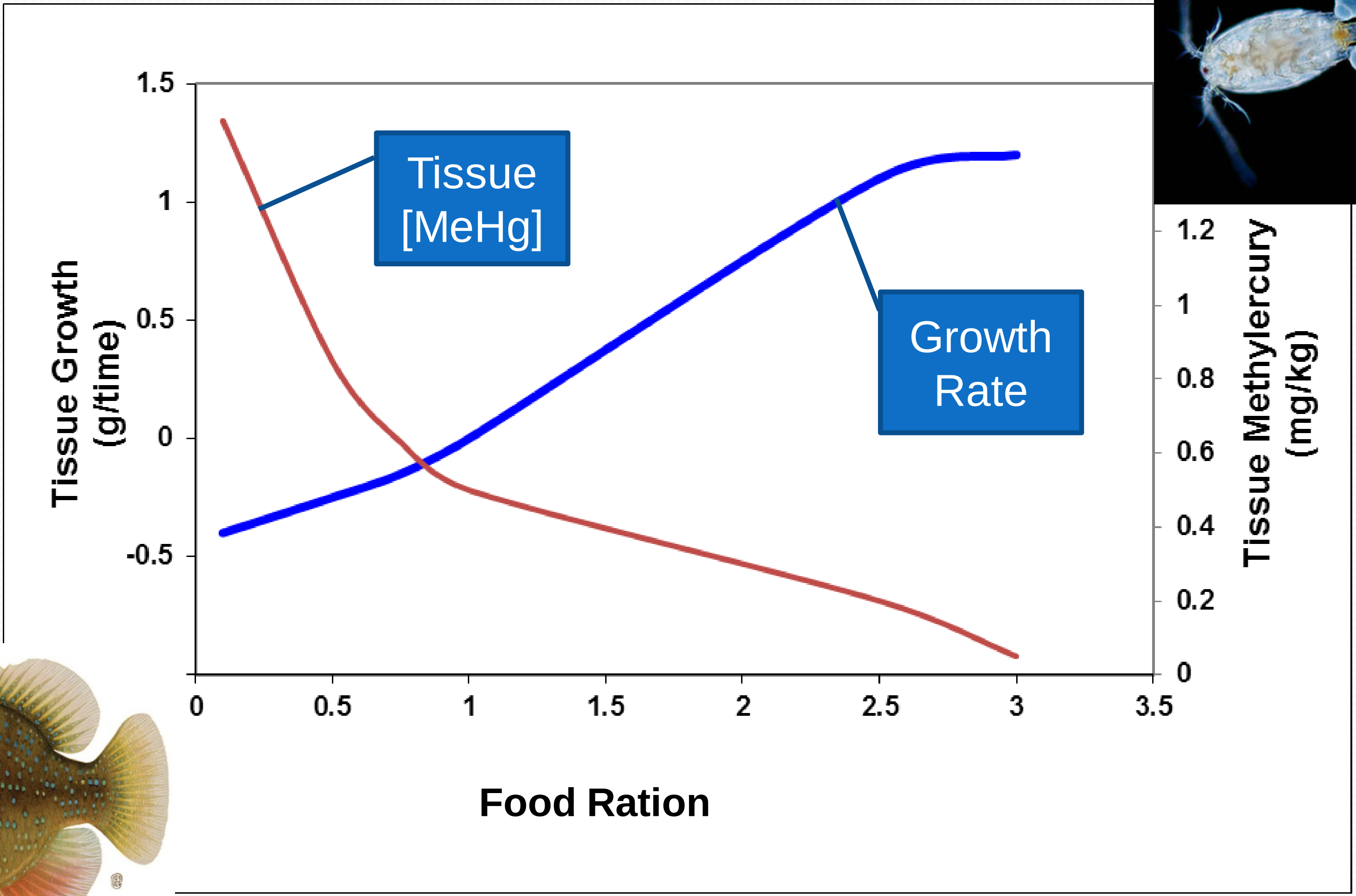
Food Web Transfer

Somatic Growth Dilution



Food Web Transfer

Somatic Growth Dilution



Reservoir Water Level Fluctuations

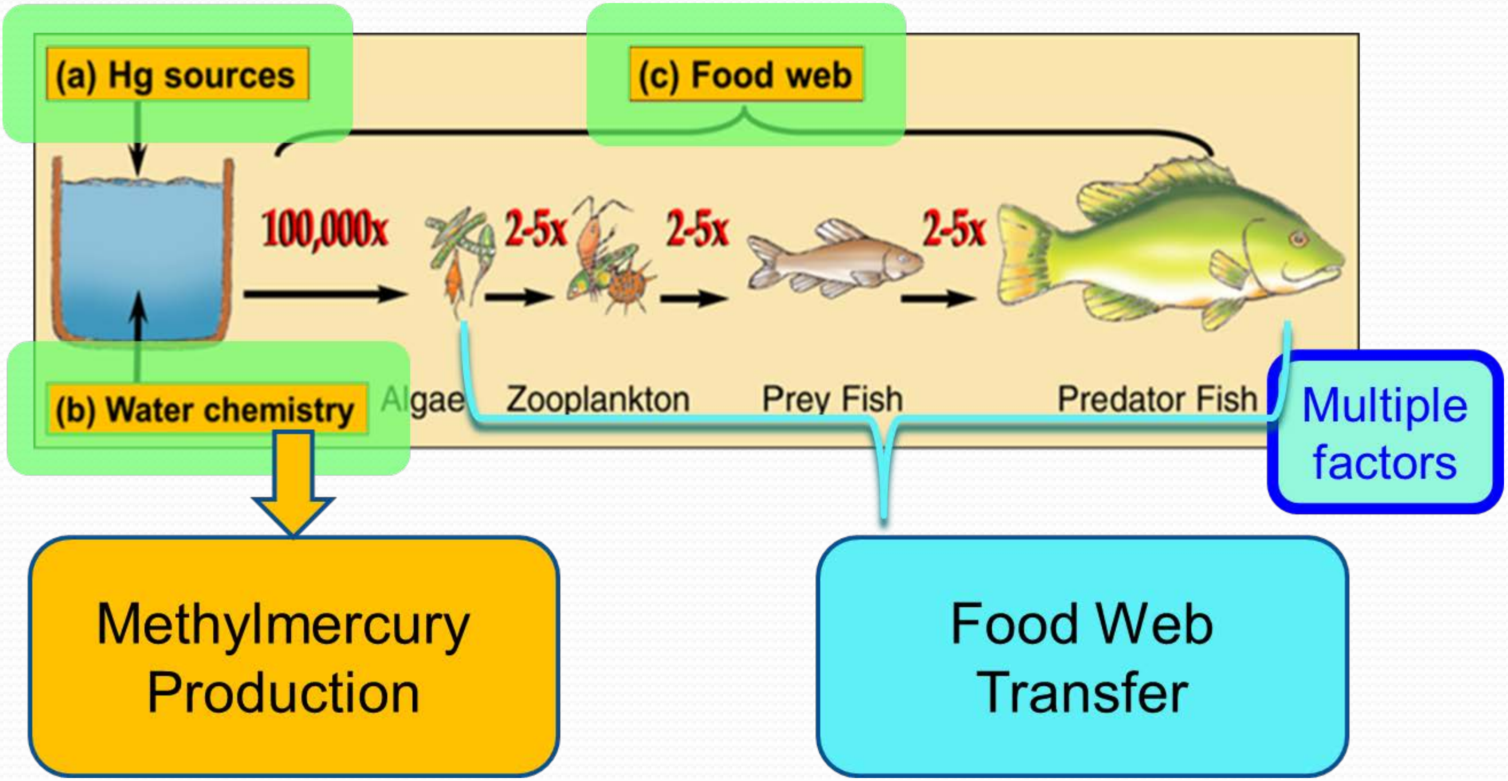
Res. Fluctuations =
WY Max Elevation –
WY Min Elevation

Large fluctuations erode fine sediment and nutrients

Reduces <u>benthic</u> primary productivity

Decreases fish and invertebrate growth rates

Summary



- **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