Reservoir Management Strategies to Reduce Fish Mercury Levels

California Statewide Mercury Control Program for Reservoirs

NALMS Symposium

Nov. 1, 2013

Multi-Region Team

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

California Statewide Mercury Control Program for Reservoirs

See Fact Sheet:

Statew... ervoirs

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).

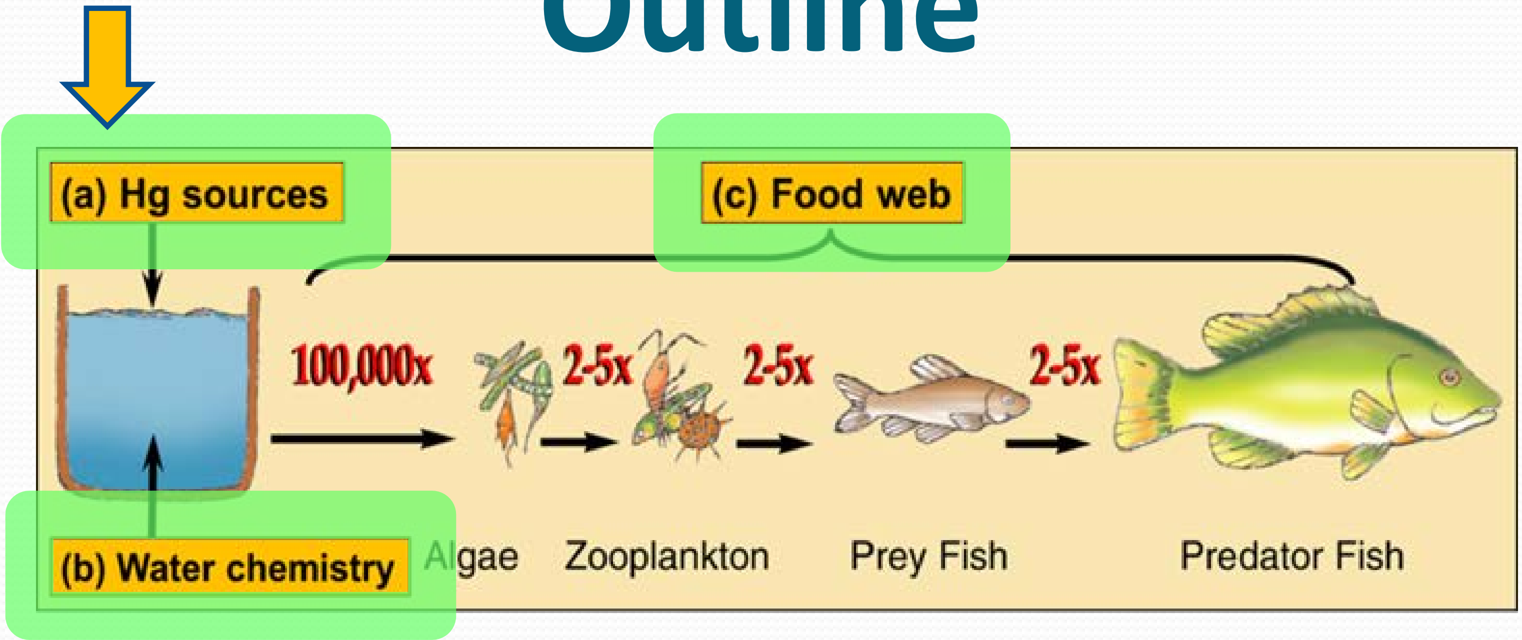
Goal:

Quickly, measurably reduce fish MeHg

Website with fact sheets & updates

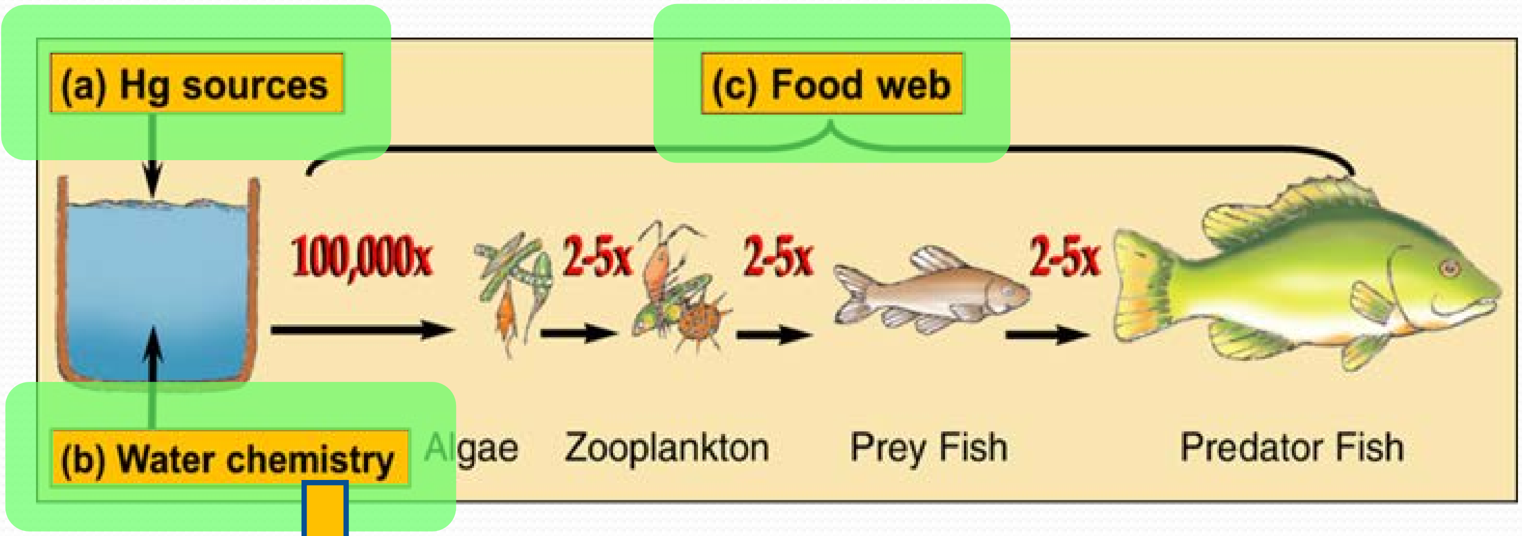
www.waterboards.ca.gov/water_issues/programs/mercury

Outline



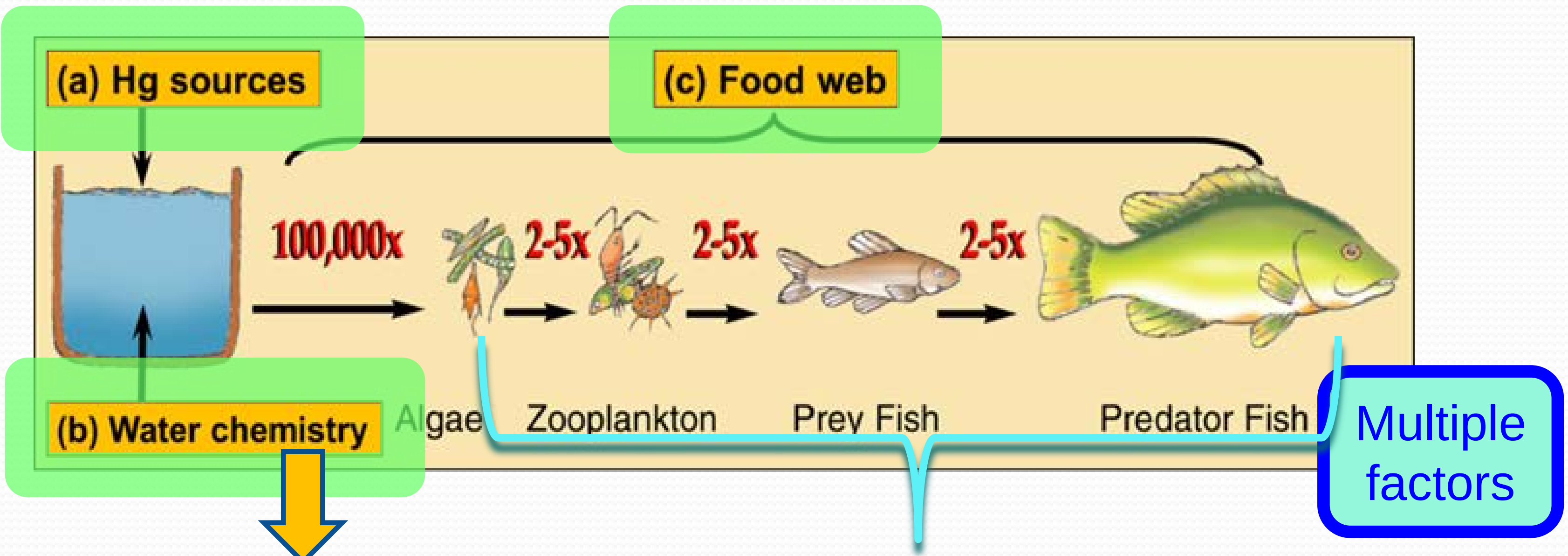
(a) Hg sources
(c) Food web
100,000x
2-5x
2-5x
2-5x
(b) Water chemistry
Algae
Zooplankton
Prey Fish
Predator Fish

Outline



Methylmercury Production

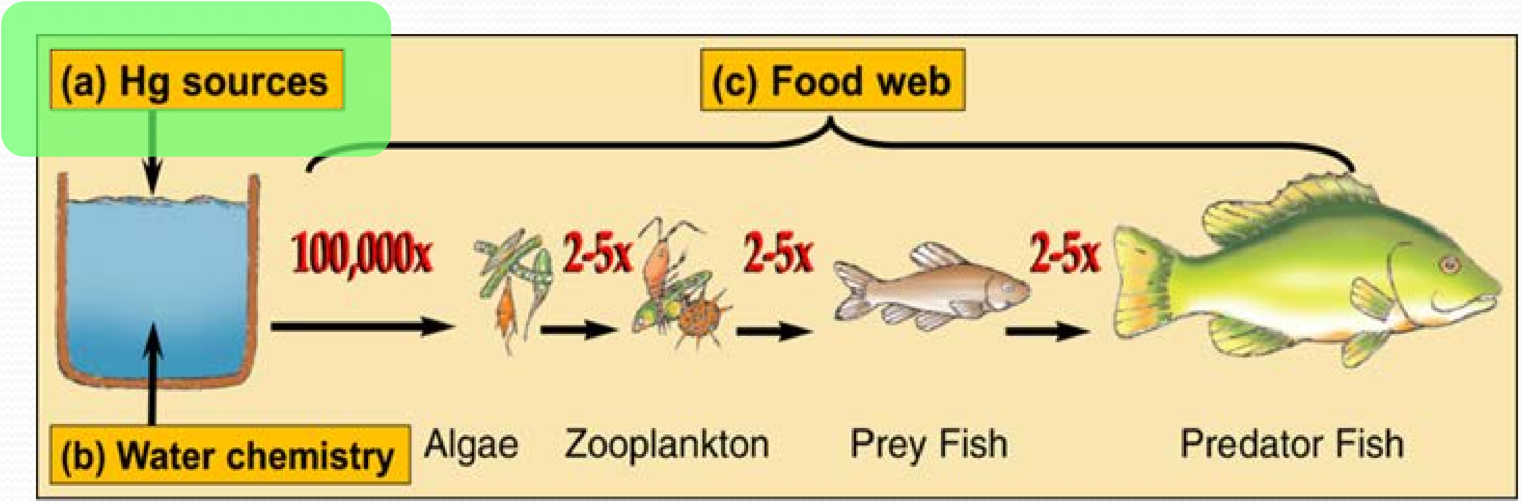
Outline



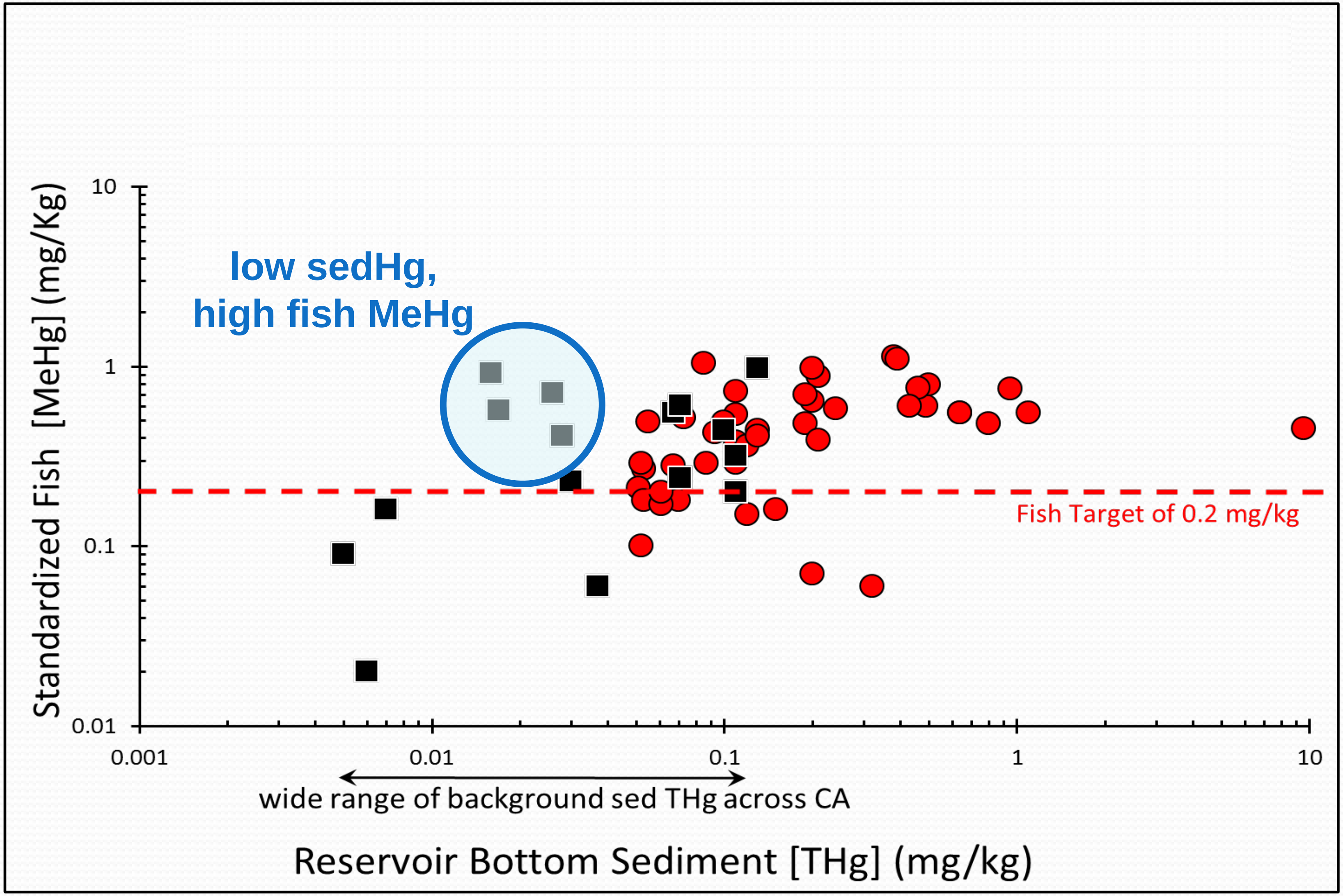
Methylmercury Production

Food Web Transfer

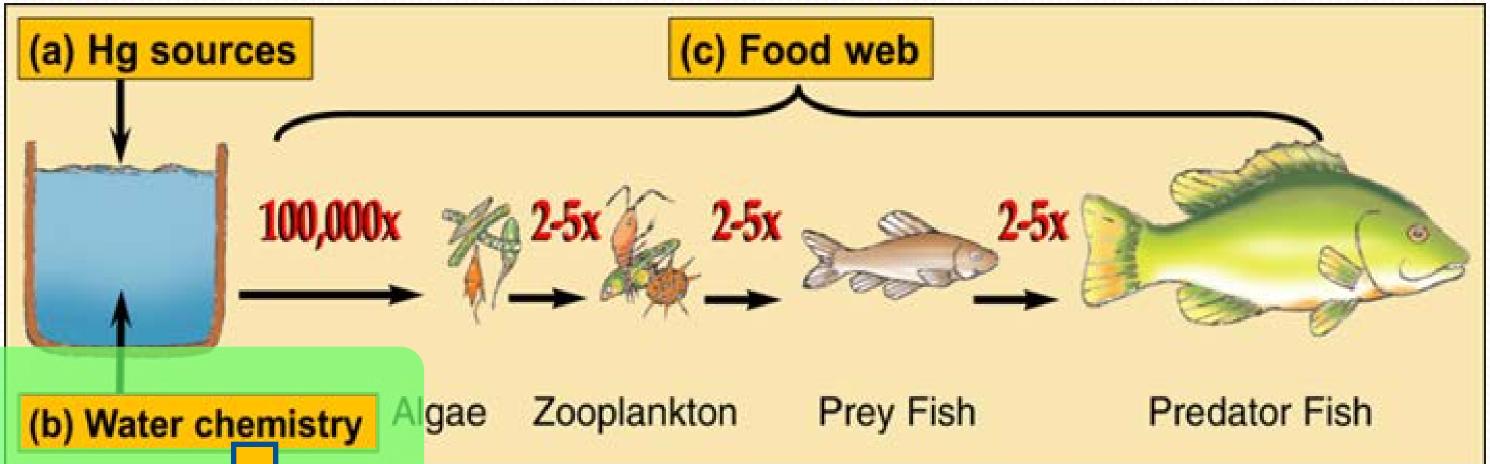
Limited benefits from source control



Limited benefits from source control



Manage redox conditions



Methylmercury Production

Redox sequence:

- O_2 aerobic heterotrophs
- NO_3^- denitrifiers
- MnO_2(s) fermenters
- $Fe(OH_3)$(s) fermenters
- SO_4^{2-} sulfate reducers
- H^+ methane producers

Desirable (O_2 aerobic heterotrophs, NO_3^- denitrifiers)

Avoid (SO_4^{2-} sulfate reducers)

Oxygenation: Session F2 Mercury Management 1

Hypolimnetic Oxygenation to Reduce Bioavailable Mercury in Santa Clara Valley Water Supply Reservoirs

The Effect of Oxygen, Nitrate and Aluminum Hydroxide on Methylmercury Efflux from Contaminated Profundal Lake Sediments

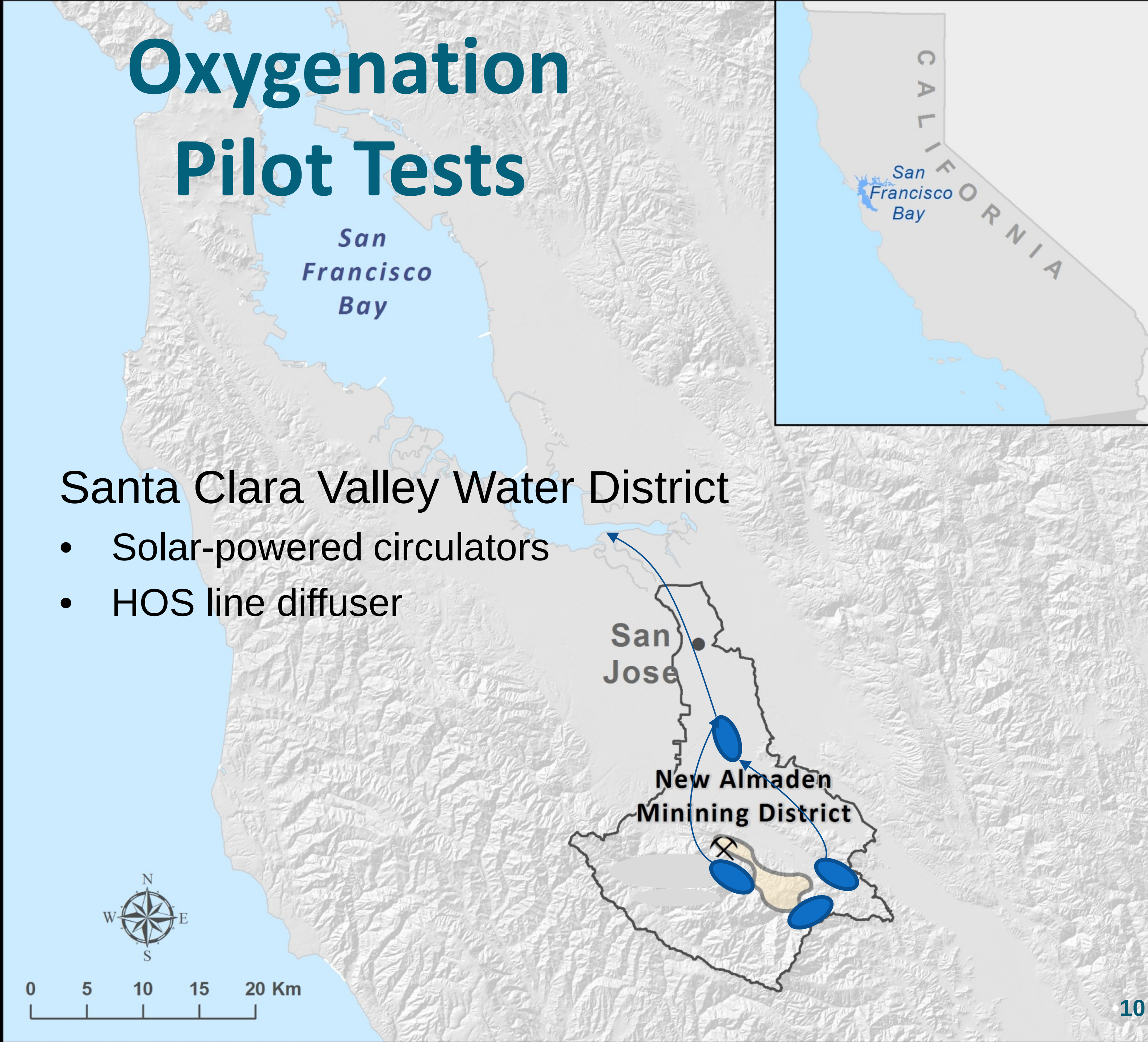
Efficacy of Hypolimnetic Oxygenation on Managing the Accumulation of Mercury in Lakes

Monitoring Effects of Hypolimnetic Oxygenation on Methyl Mercury in Fish in Water Supply Reservoirs

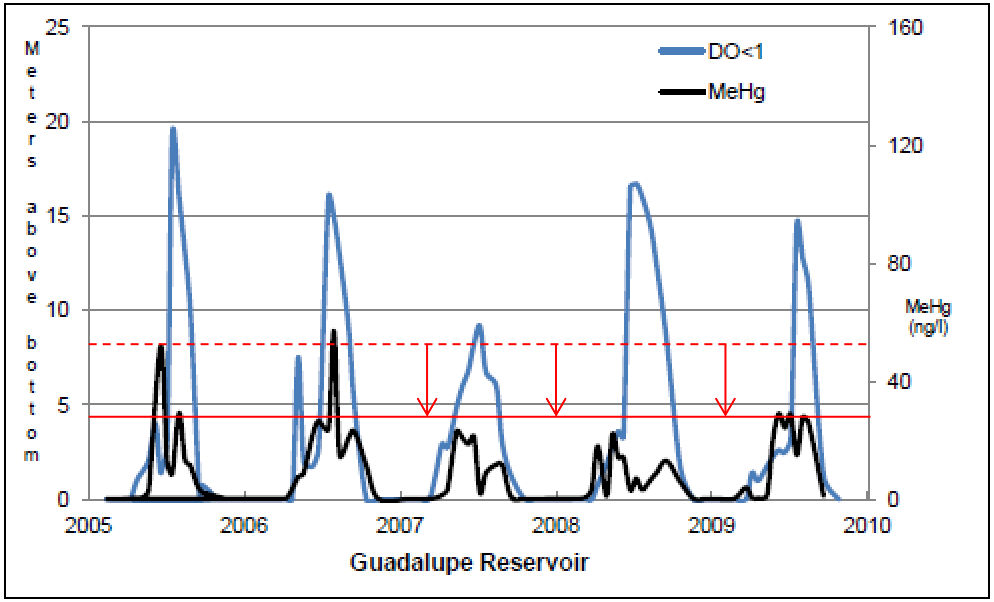
Oxygenation Pilot Tests

Santa Clara Valley Water District

- Solar-powered circulators
- HOS line diffuser



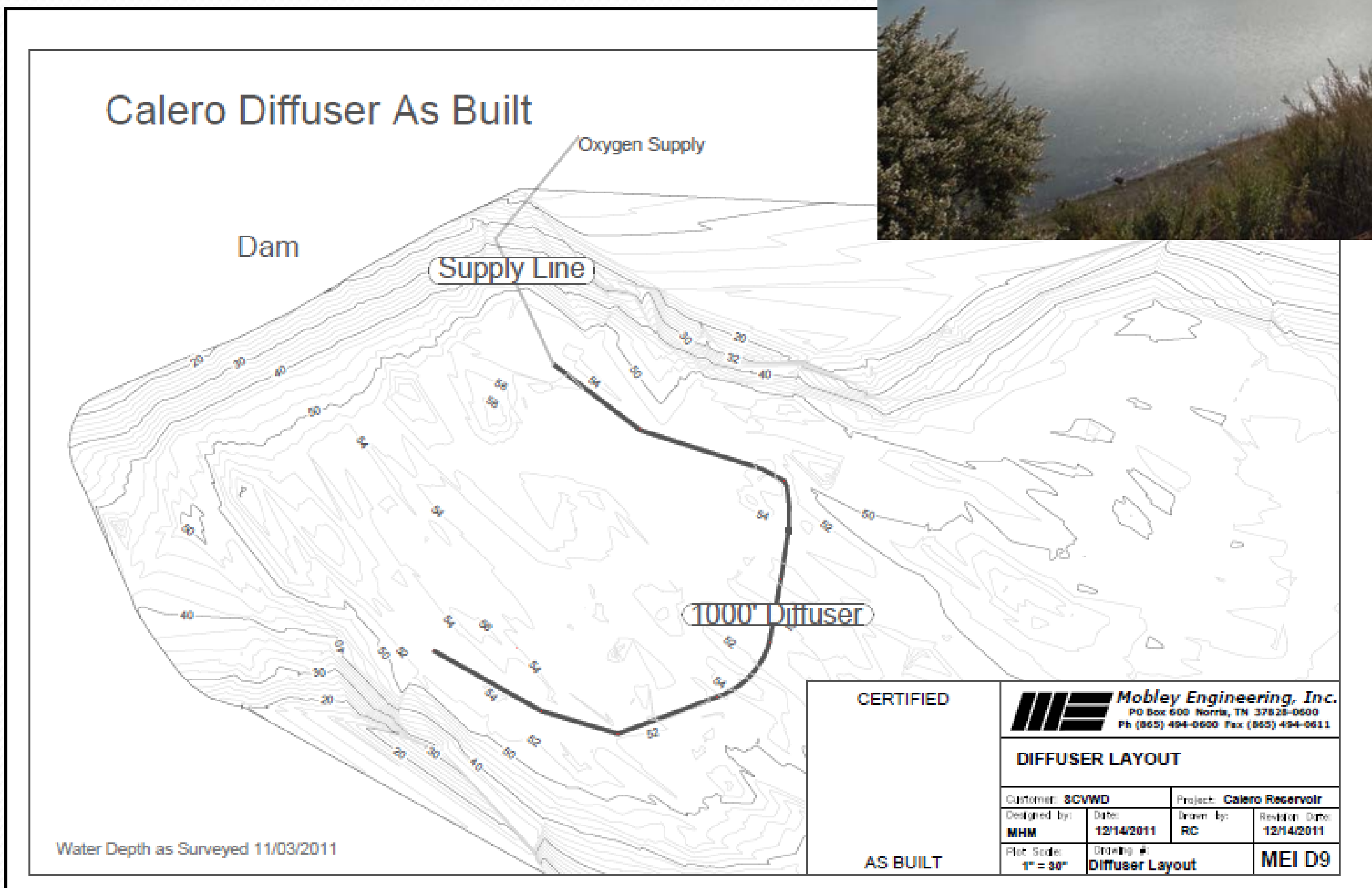
Solar-powered circulator↓MeHg



Annual coincidence: MeHg & seasonal anoxia

Citation: Santa Clara Valley Water District

Santa Clara Valley Water District

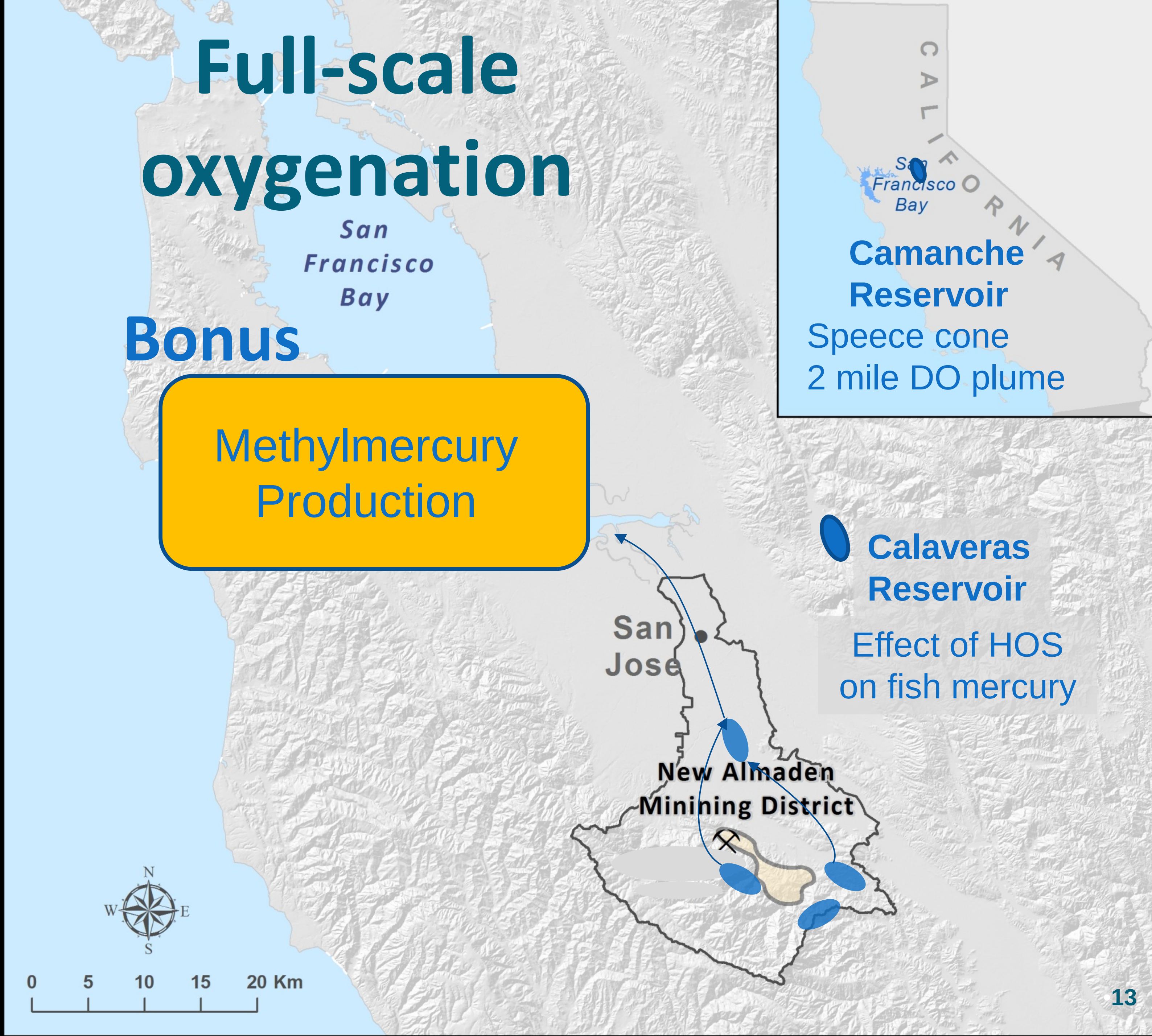


HOS:

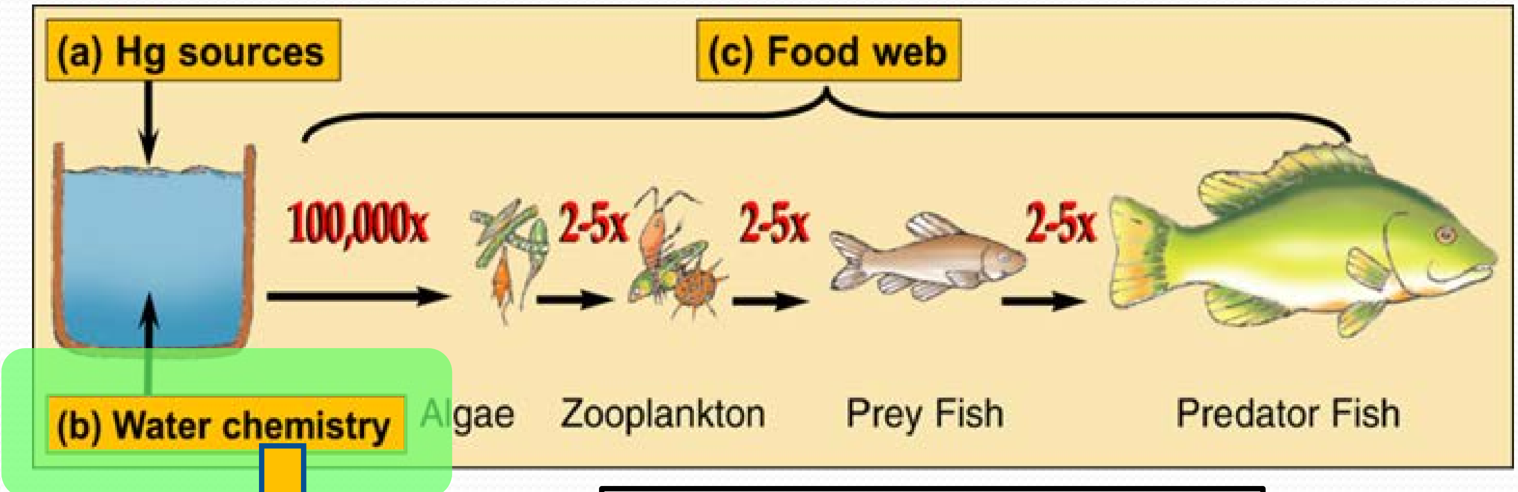
Hypolimnetic Oxygenation System

Citation:

Dave Drury SCVWD


Full-scale oxygenation
San Francisco Bay
Bonus
Methylmercury Production
CALIFORNIA
San Francisco Bay
Camanche Reservoir
Speece cone
2 mile DO plume
Calaveras Reservoir
Effect of HOS on fish mercury
San Jose
New Almaden Mining District
N
W
E
S
0 5 10 15 20 Km

Manage redox conditions



Methylmercury Production

Redox sequence:

O_2 aerobic heterotrophs
NO_3^- denitrifiers
MnO_2(s) fermenters
$Fe(OH_3)$(s) fermenters
SO_4^{2-} sulfate reducers
H^+ methane producers

Desirable

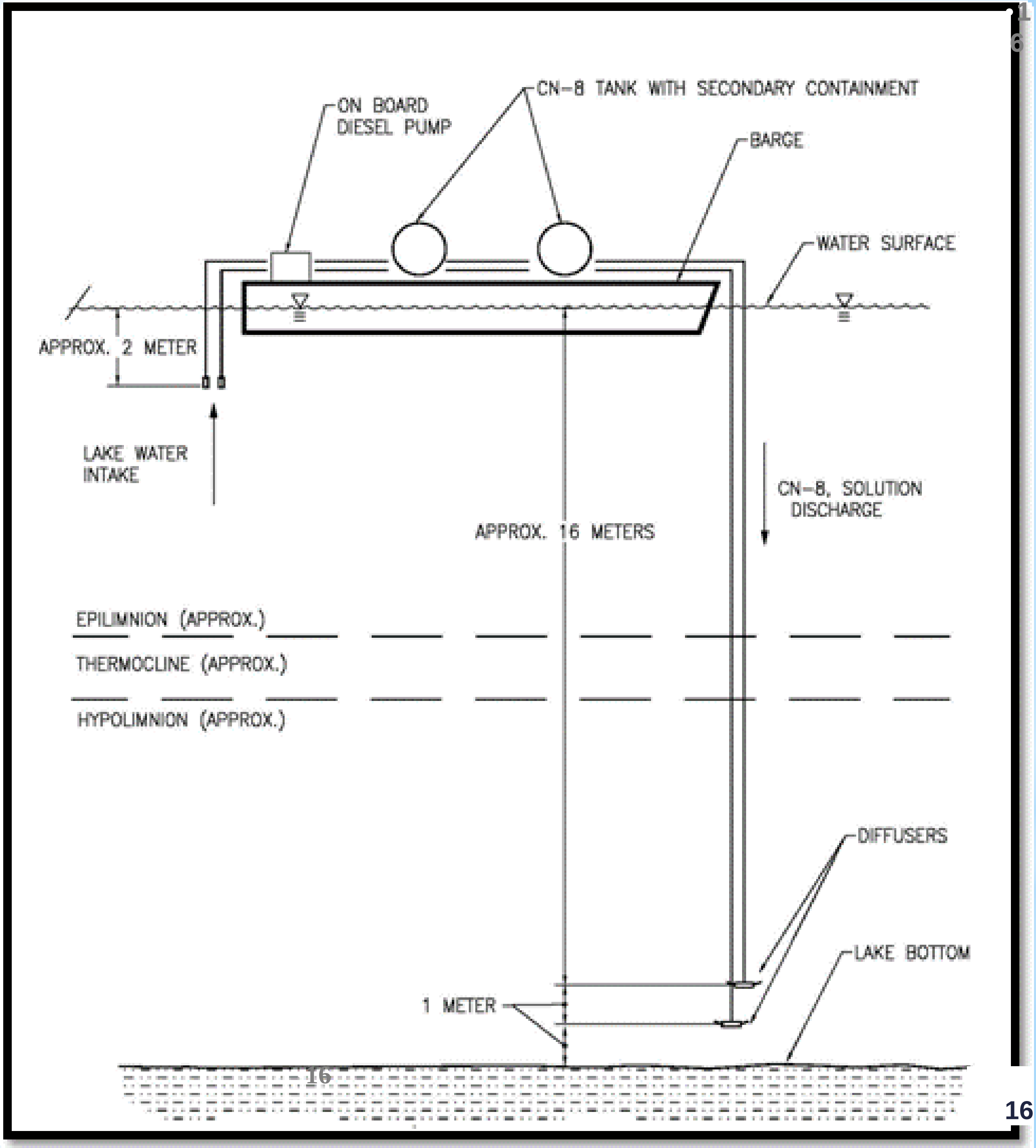
Avoid

Source Removal and Nitrate Addition
Onondaga Lake, New York

Citation:

Charles T. Driscoll
Syracuse University

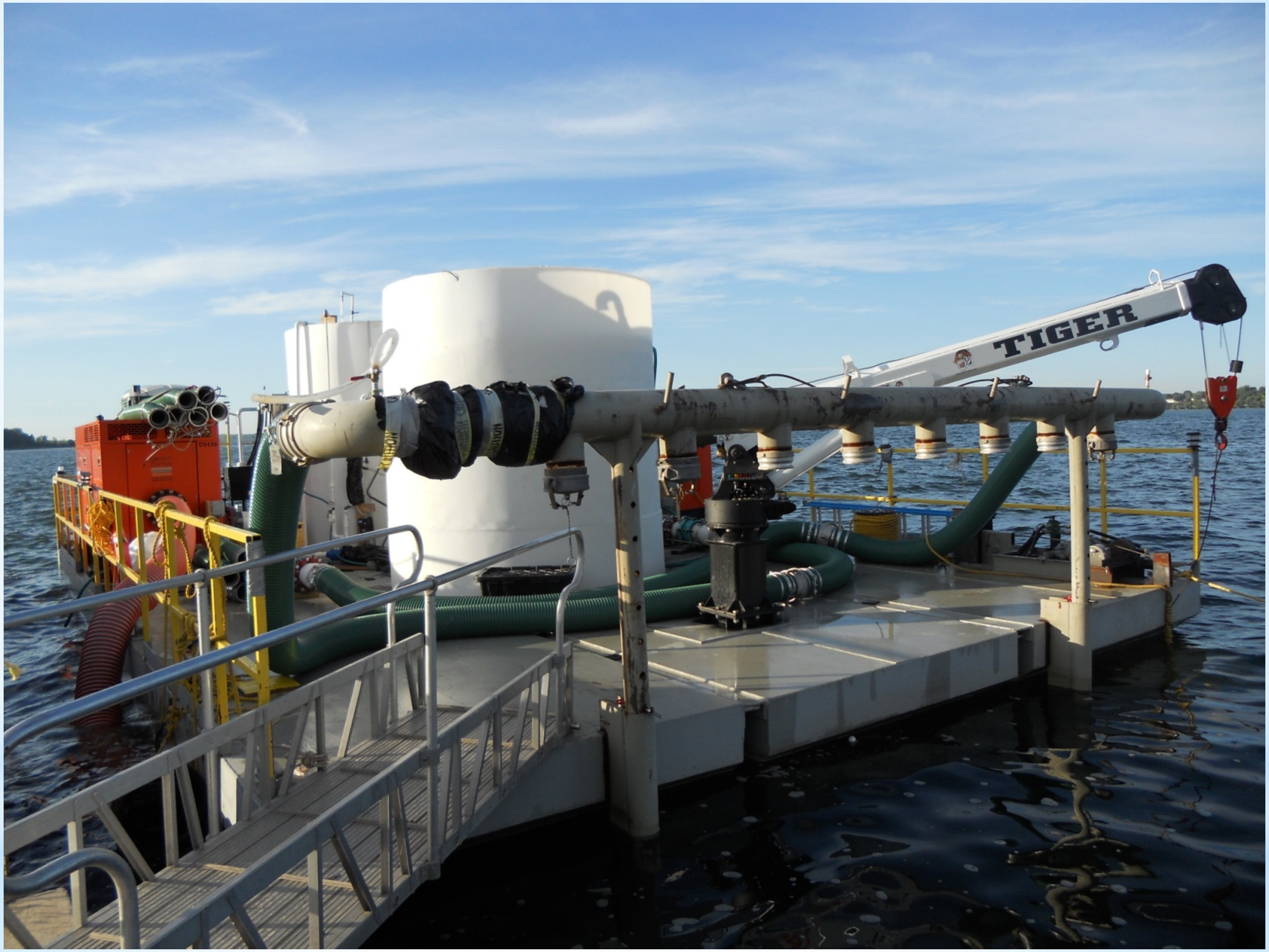
Manage redox with NO_3^-



Citation:

Charles T. Driscoll
Syracuse University

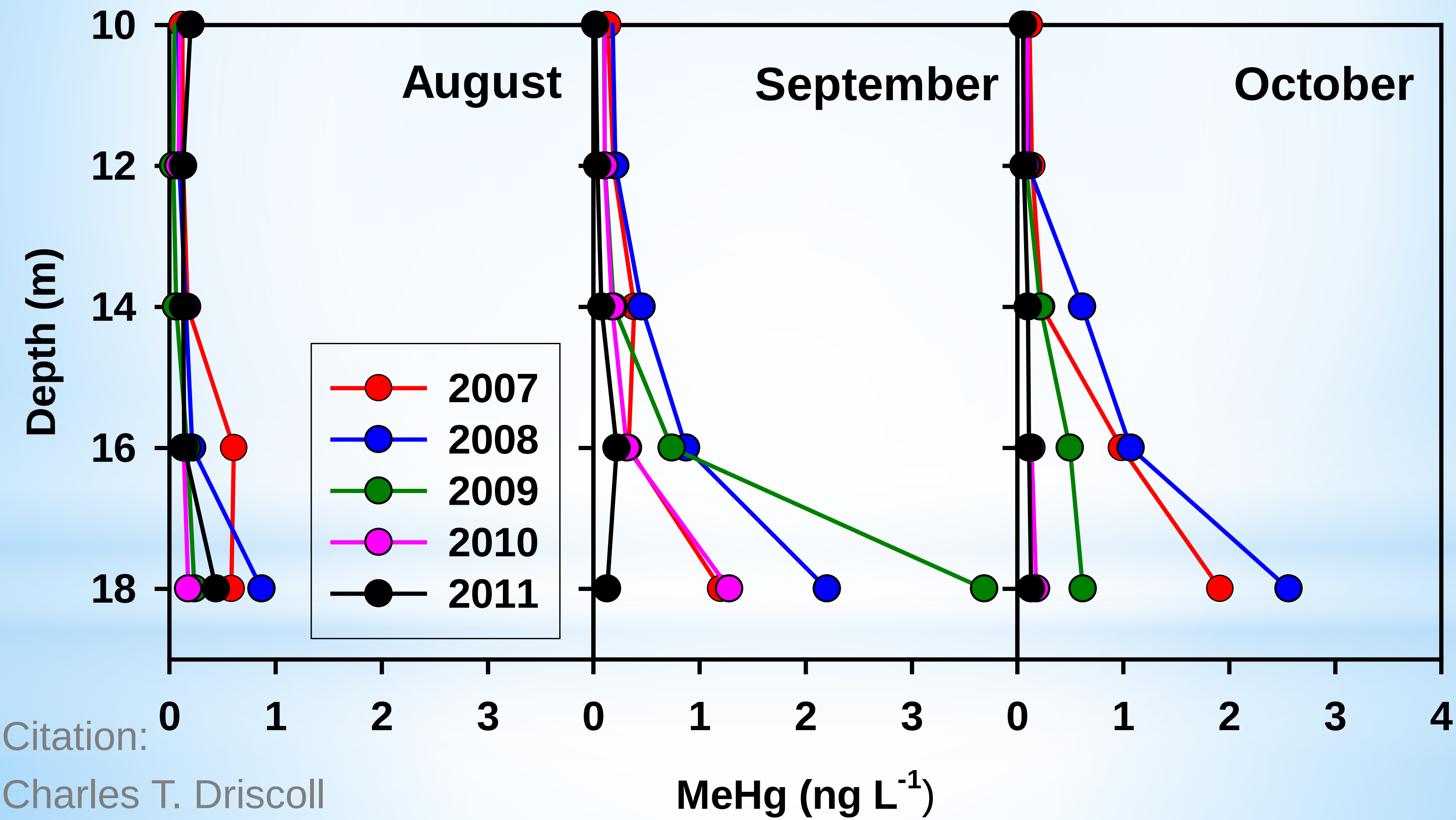
Manage redox with NO_3^-



Citation:

Charles T. Driscoll
Syracuse University

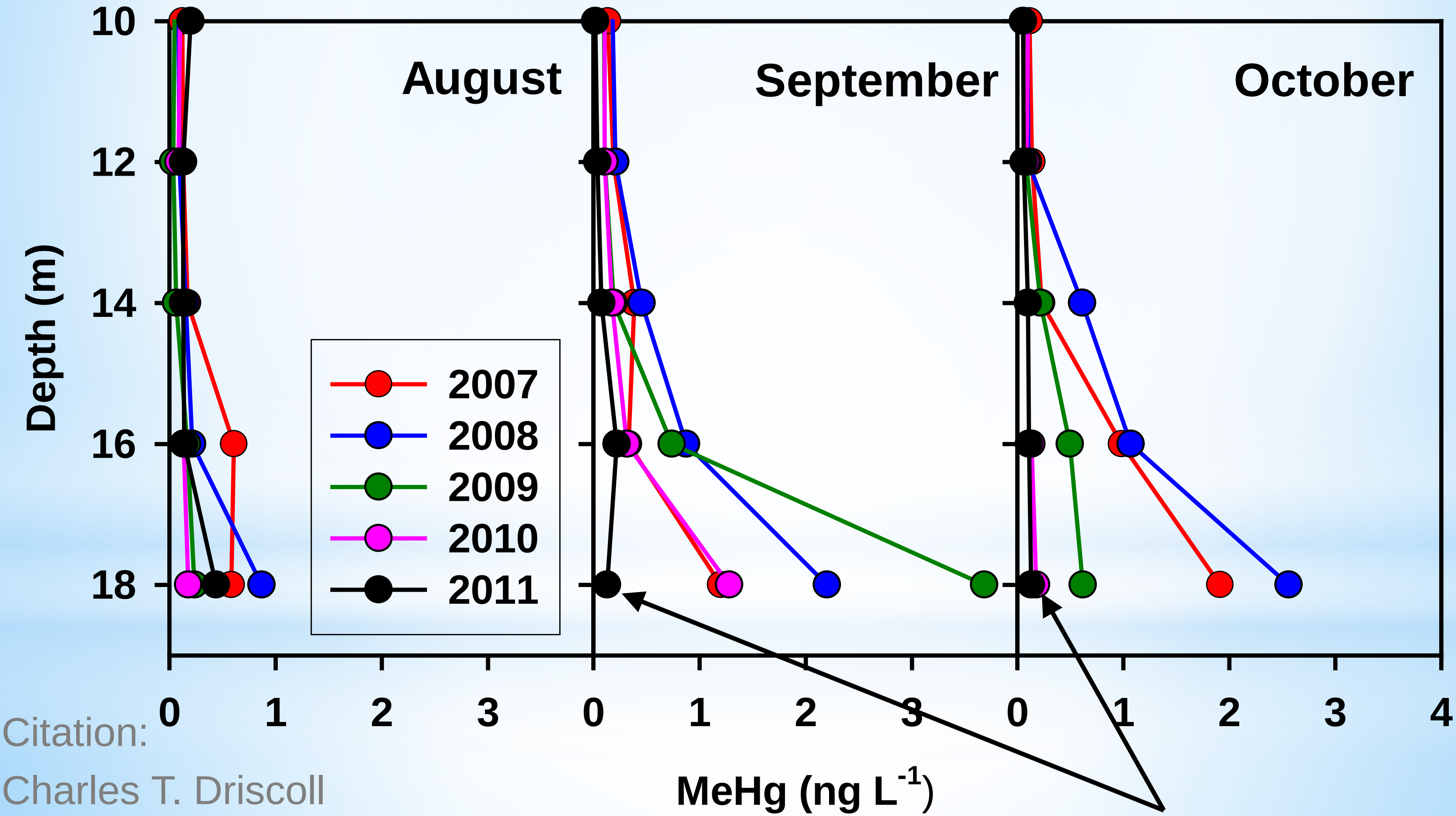
Vertical Profiles of MeHg: 2007-2011



Citation:

Charles T. Driscoll
Syracuse University

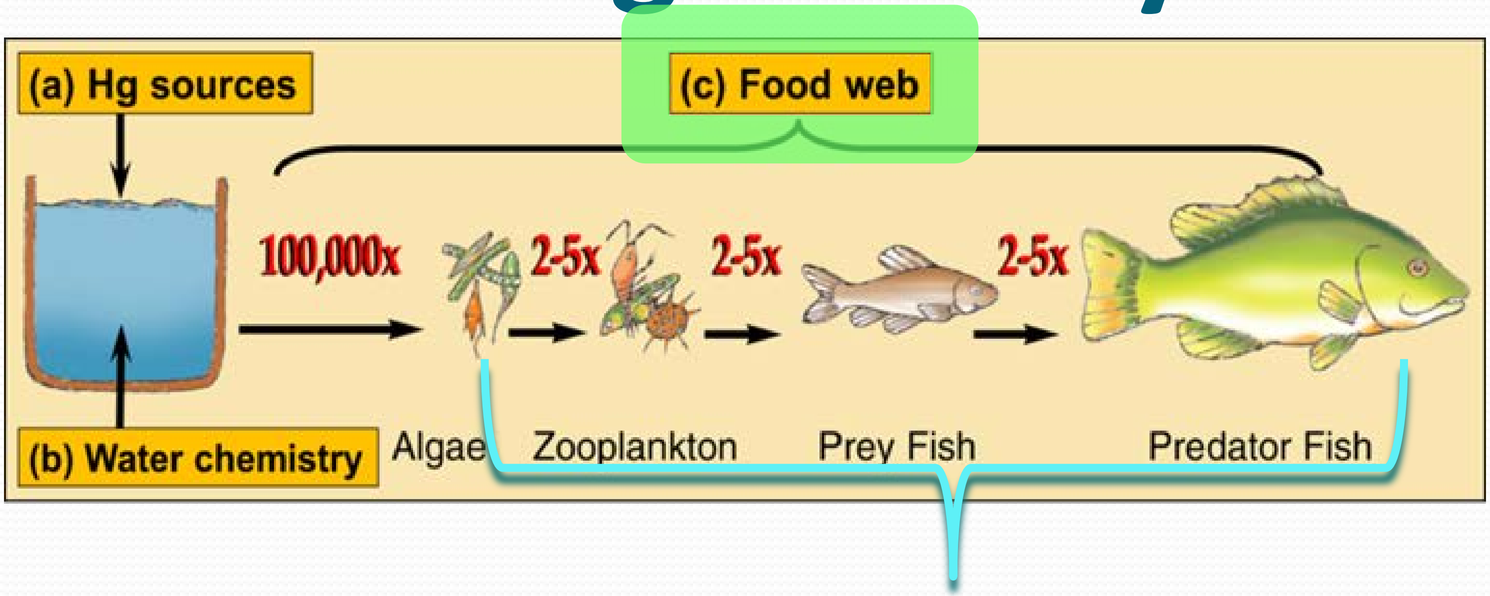
Vertical Profiles of MeHg: 2007-2011



Citation:

Charles T. Driscoll
Syracuse University

Manage fishery



Food lower in MeHg

Cull fish

Select species

Food Web Transfer

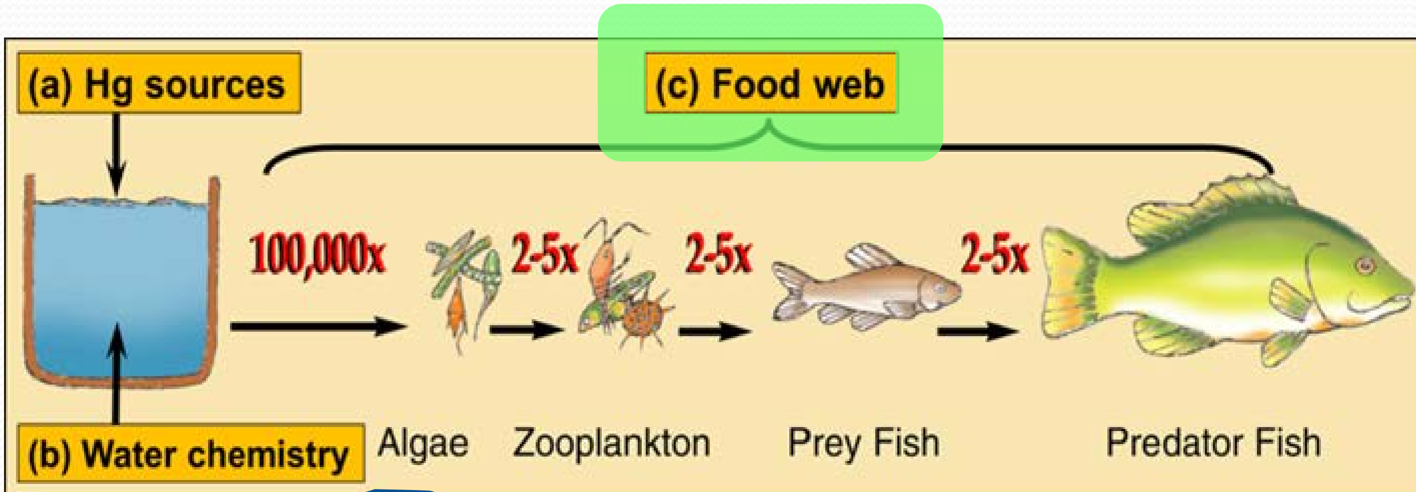
Food lower in MeHg

1

Fertilize

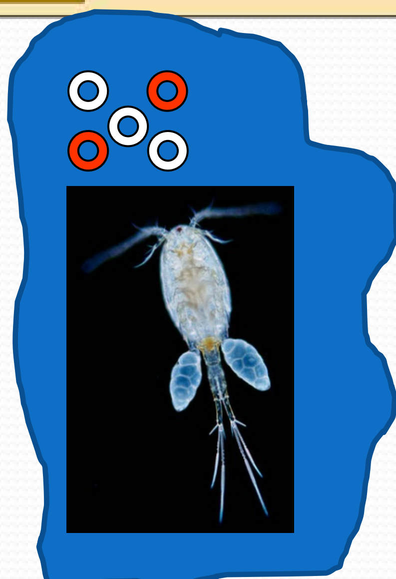
↑ Algae

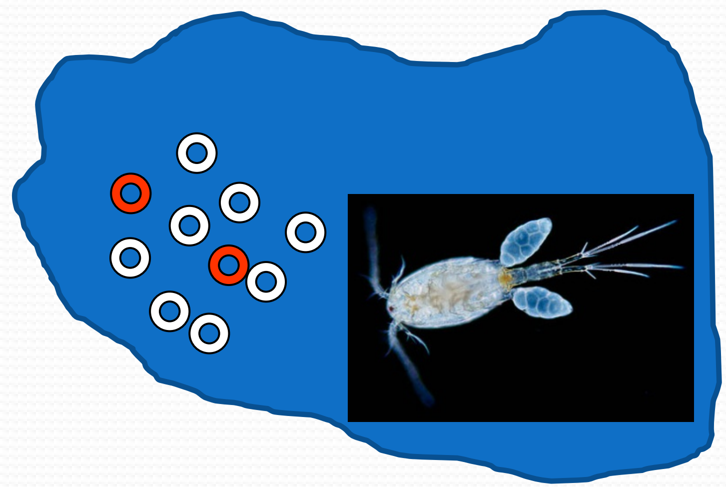
= MeHg



No more than 2x Chl-*a* and Chl-*a* ≤5 ug/L

Algal Bloom Dilution





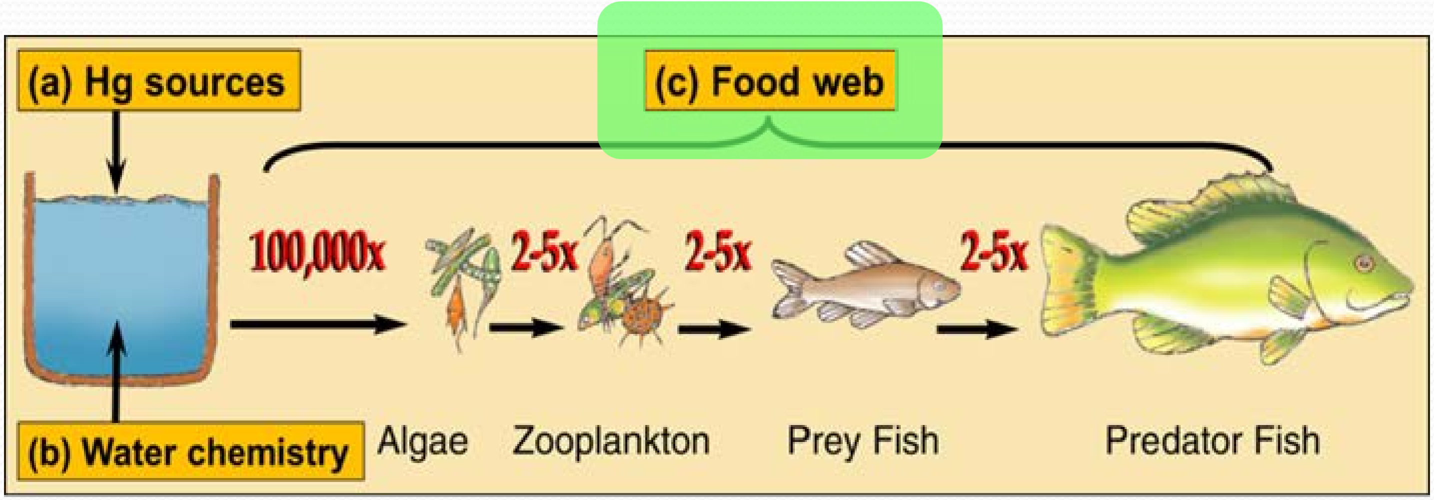
Food lower in MeHg

1

Fertilize

↑ Algae

= MeHg

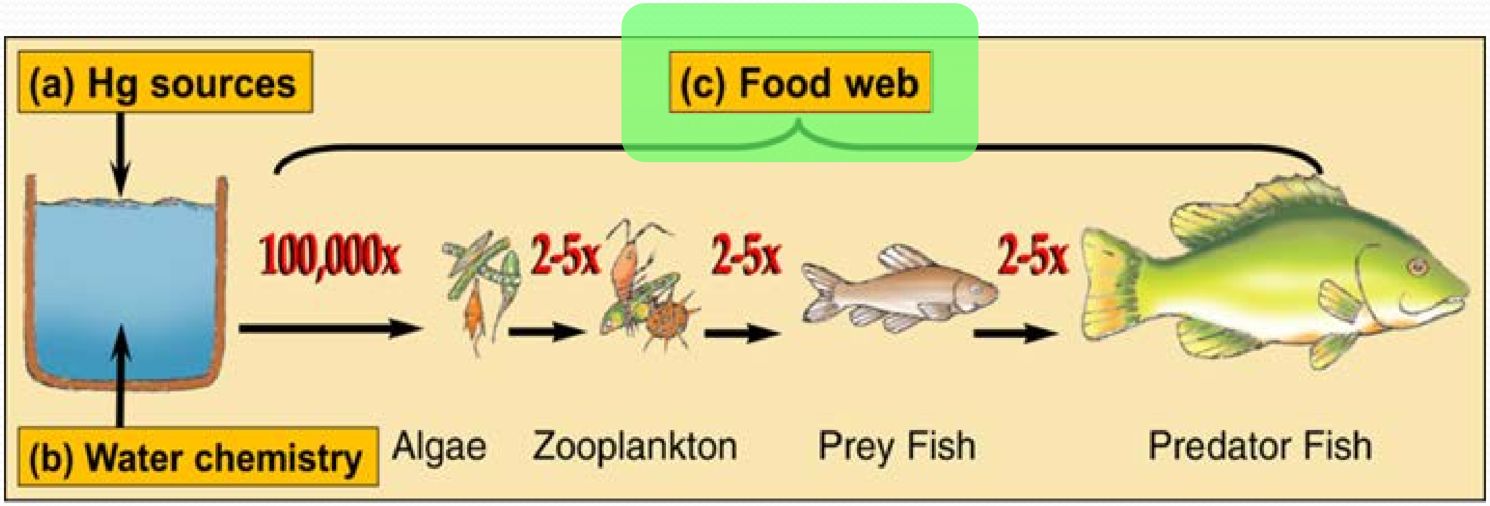


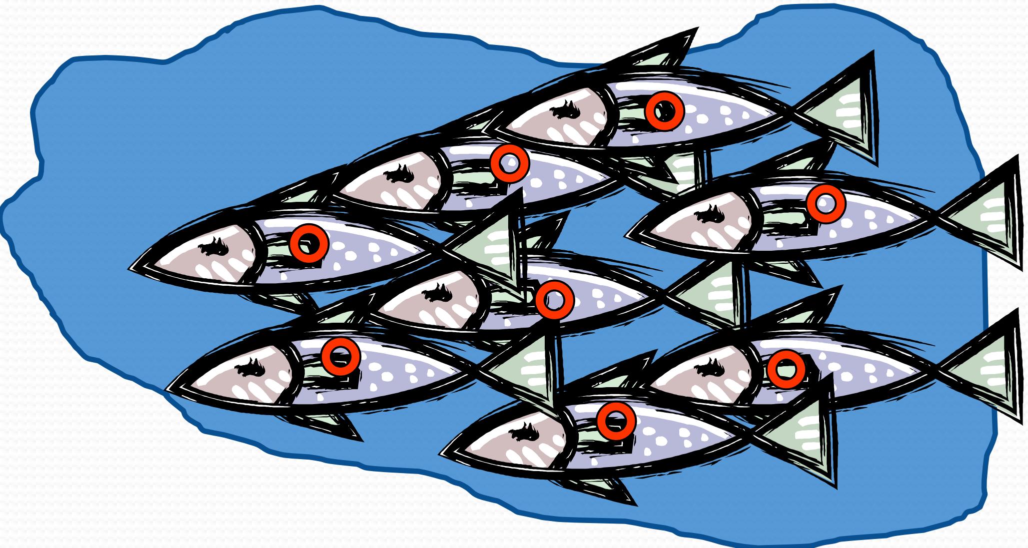
2 **Stock prey with low MeHg**

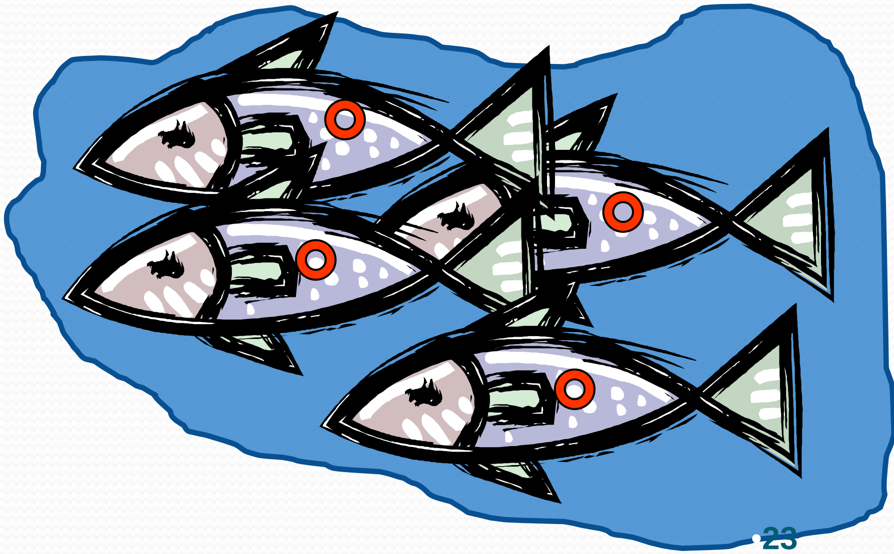
e.g., Rainbow trout

Citation:
Jesse Lepak

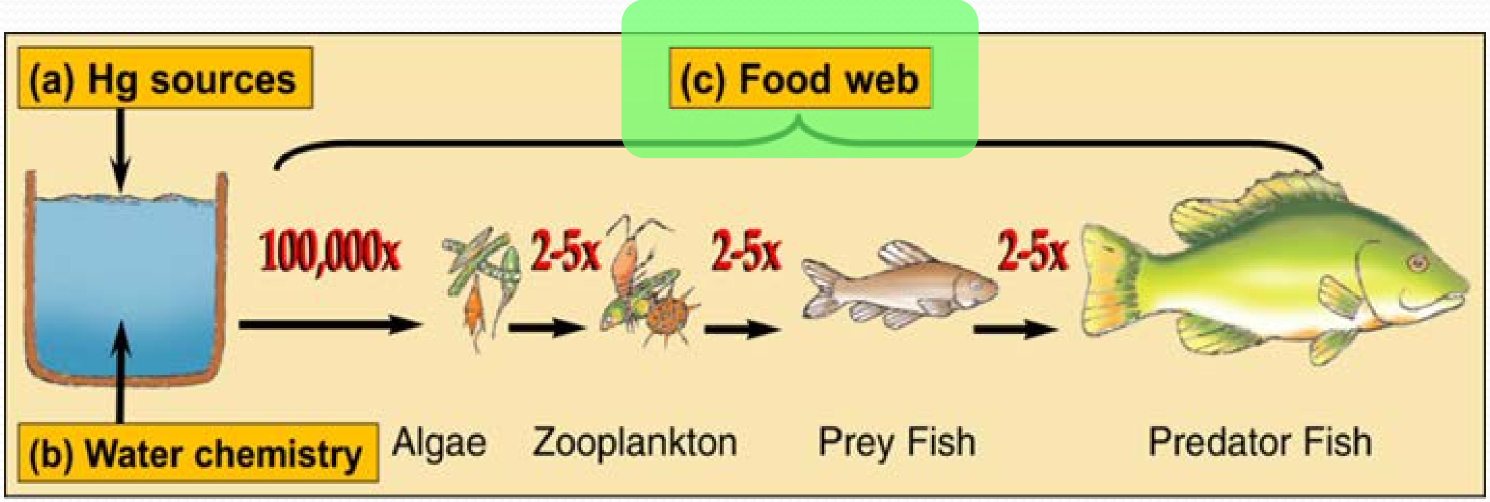
Cull or "intensive fishing"



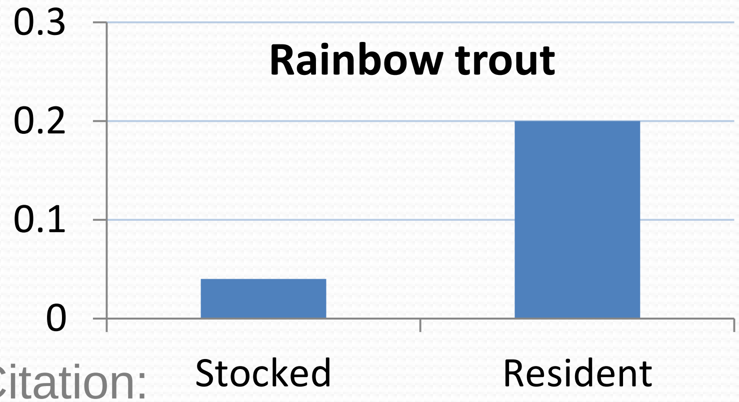




Select species



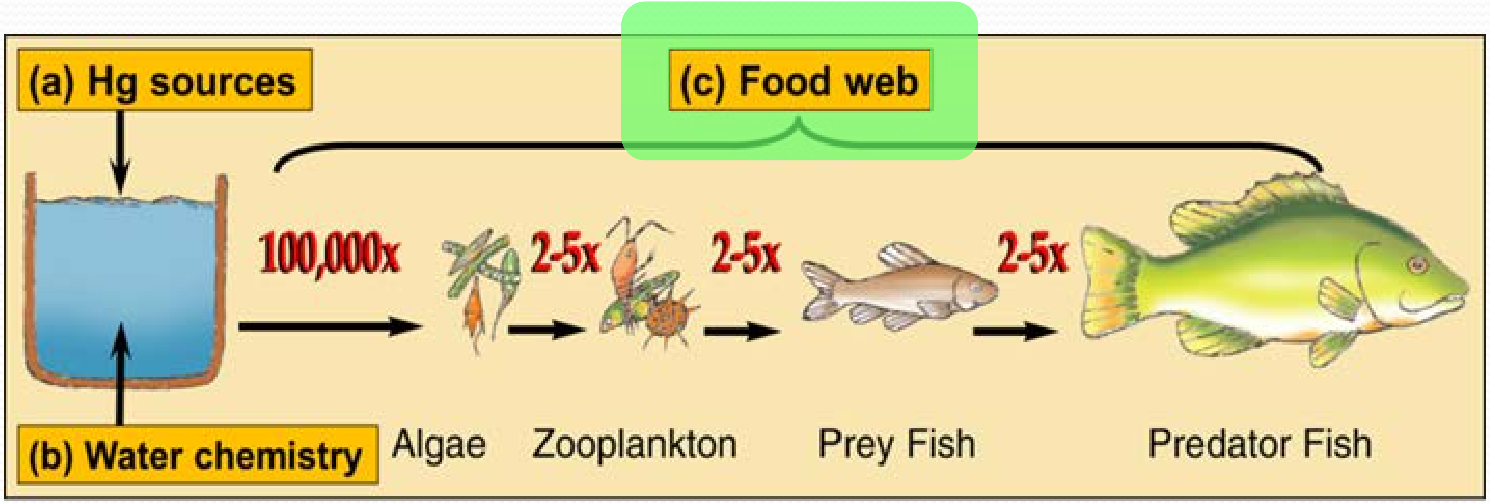
Stock – hatchery diets low in MeHg



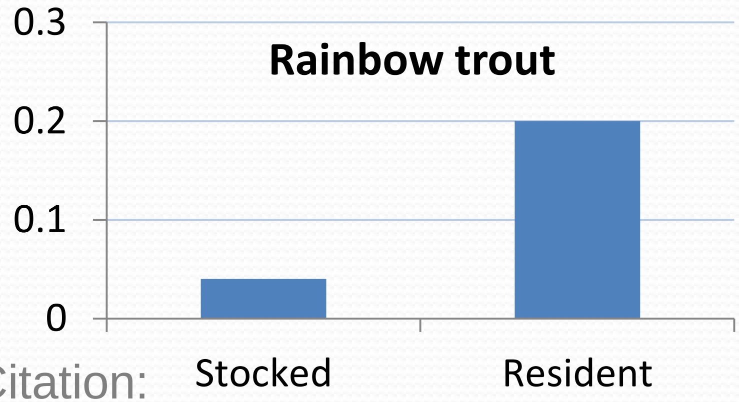
Citation:

Mike Horvath, SFPUC

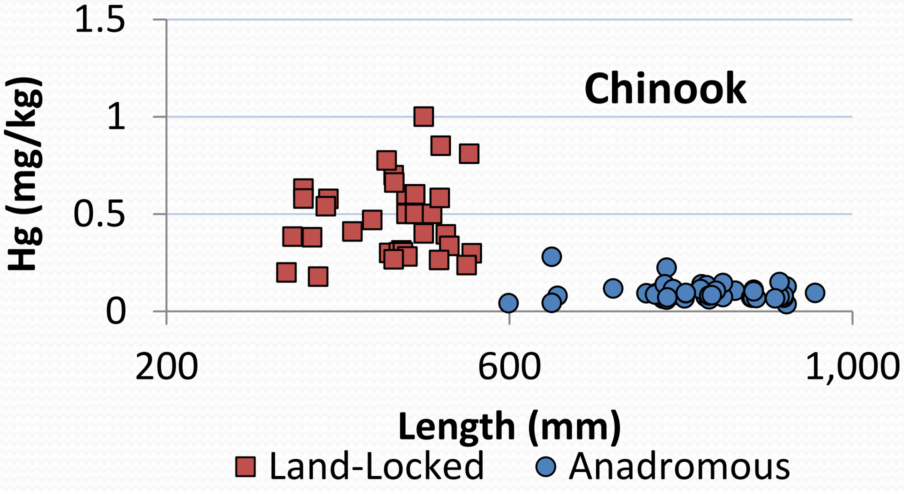
Select species



Stock – hatchery diets low in MeHg

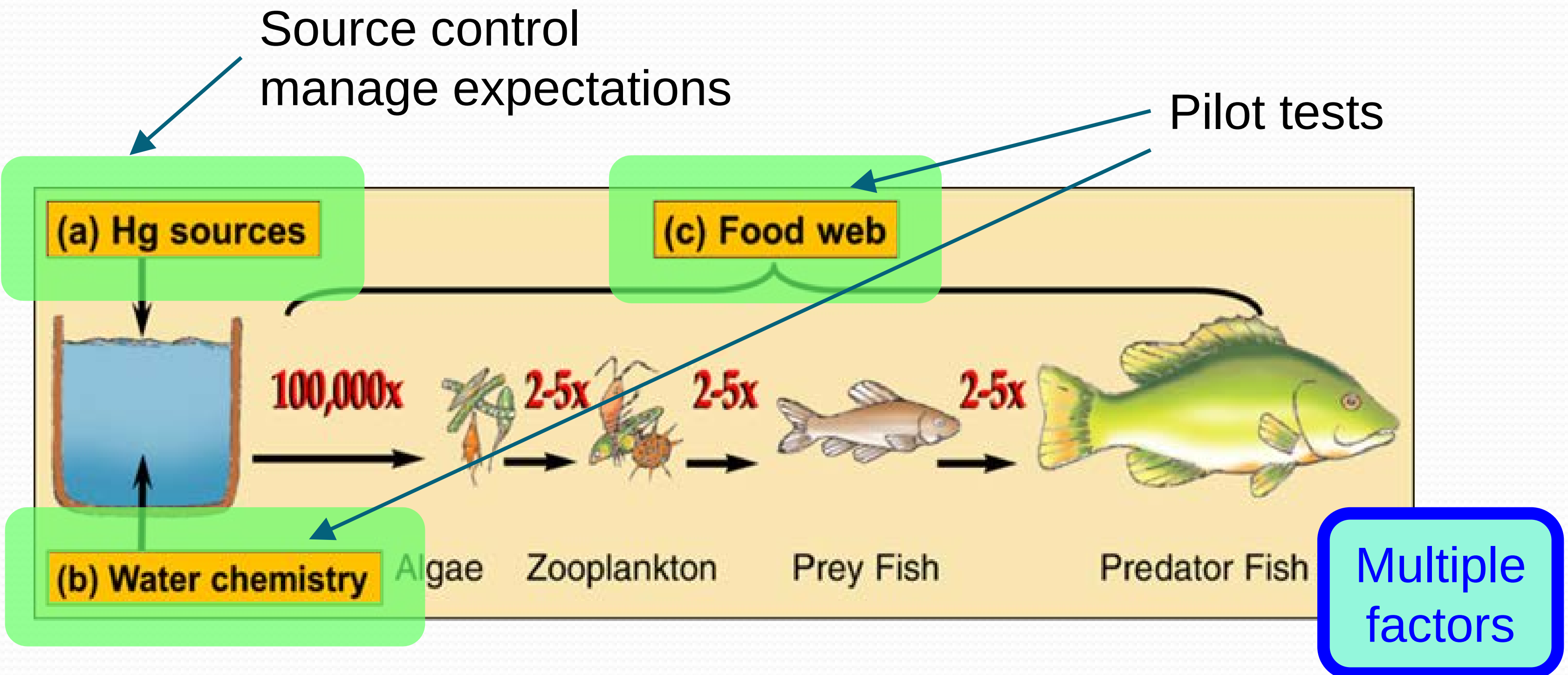


Restore native anadromous fish



Citation:
Mike Horvath, SFPUC

California Statewide Mercury Control Program for Reservoirs



Website with fact sheets & updates

www.waterboards.ca.gov/water_issues/programs/mercury

Upland and in-lake remediation areas

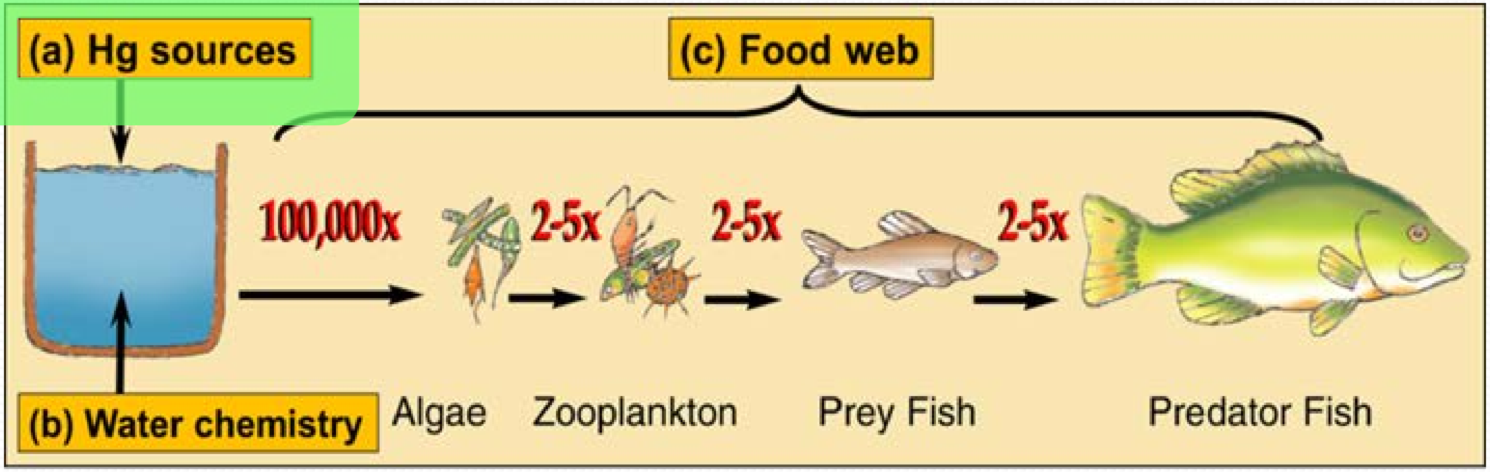
Isolation cap 172 ha

Thin layer cap 11ha

Citation:

Charles T. Driscoll
Syracuse University

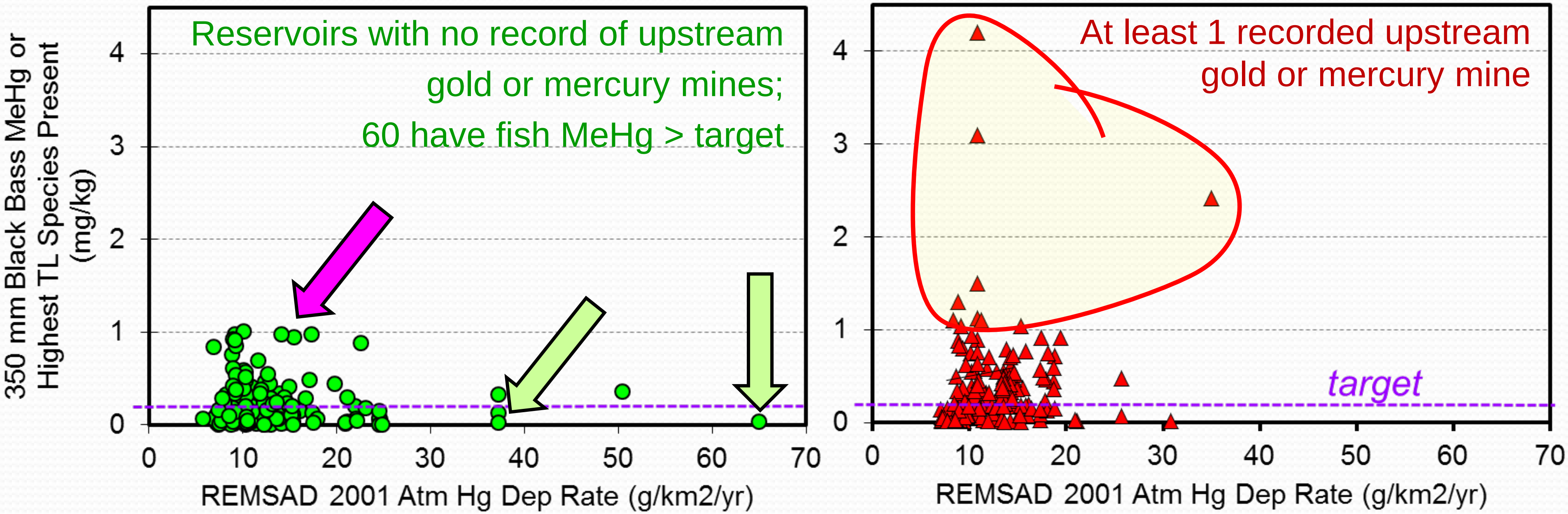
↓ Hg → reservoir (source control)



Mines
mercury and gold

Atmospheric Deposition

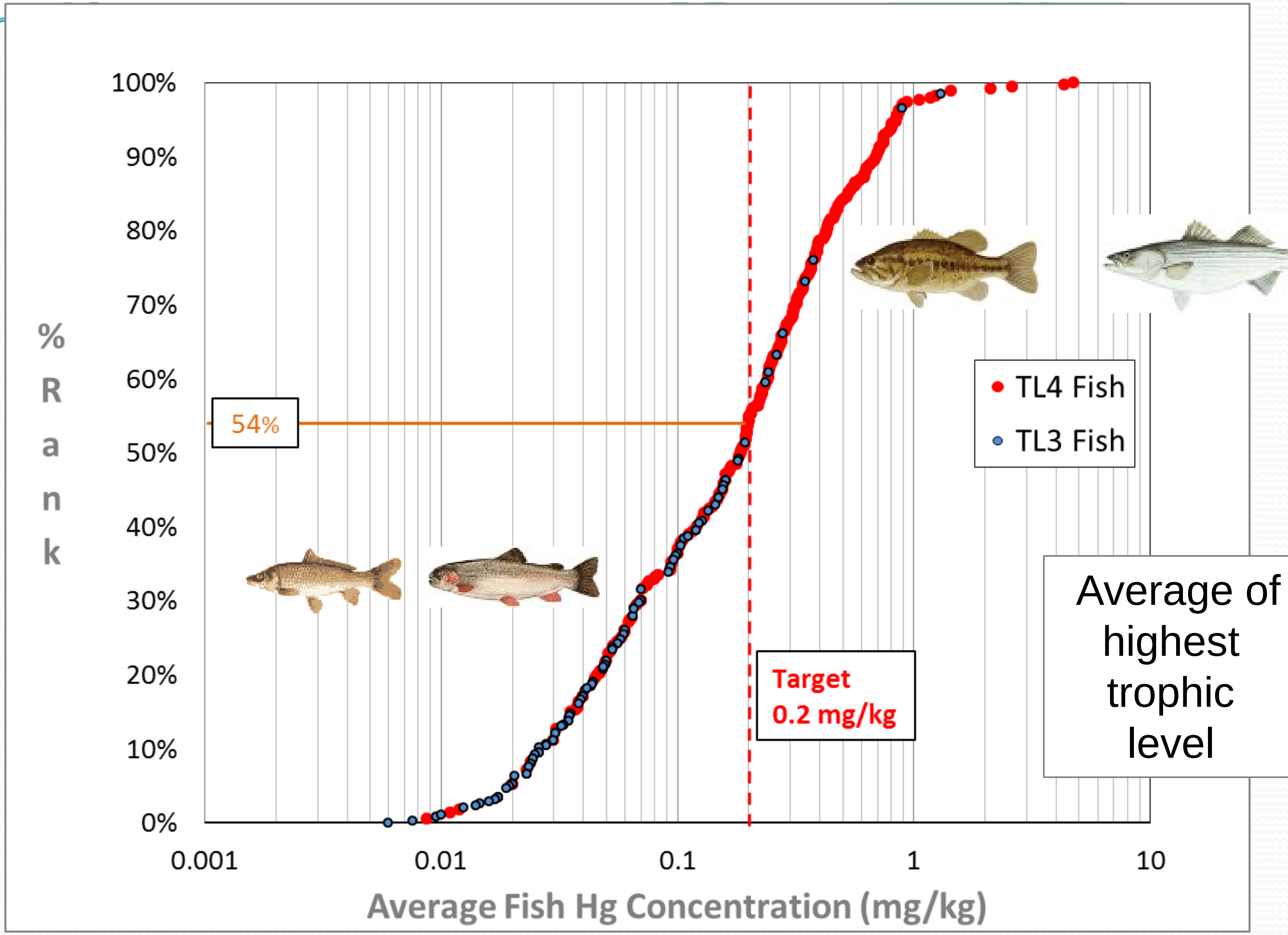
Mercury from atmospheric deposition and mines



Multiple Factors

- Can have high fish MeHg but low atm dep and no mines
- Can have low fish MeHg but very high atm Hg dep
- Very highest fish MeHg associated with extensive Hg mining

Multiple factors: fish species



California: 350 reservoirs and lakes

SF Bay Region: hotspot for high fish mercury levels