The Biogeochemical Cycling of Mercury within Lake Powell, Glen Canyon National Recreation Area, Utah-Arizona

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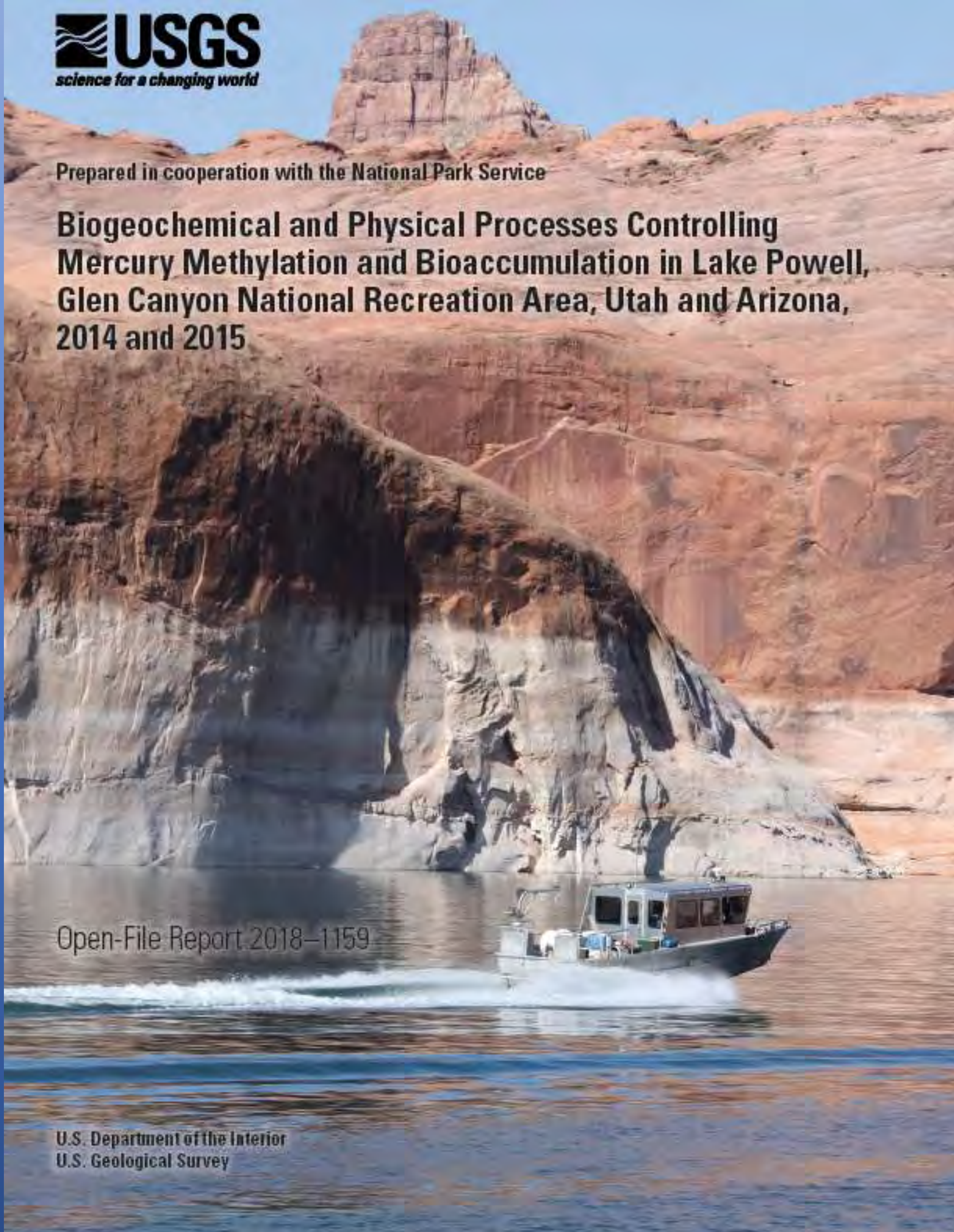
[4] U.S. Geological Survey, Boulder, CO, U.S.A.
[5] Montana State University, Bozeman, MT, U.S.A.
[6] National Park Service, Page, AZ, U.S.A.

Photo: M. Marvin-DiPasquale



Naftz, D.L., Marvin DiPasquale, M., Krabbenhoft, D.P., Aiken, G., Boyd, E.S., Conaway, C.H., Ogorek, J., and Anderson, G.M., 2019, Biogeochemical and physical processes controlling mercury methylation and bioaccumulation in Lake Powell, Glen Canyon National Recreation Area, Utah and Arizona, 2014 and 2015: U.S. Geological Survey, Open-File Report 2018–1159, 81 p.

Glen Canyon Dam

- completed 1966 (USBR)
- Height: 220 m (710 ft)
- hydro-electric: 4×10^9 kwh/yr

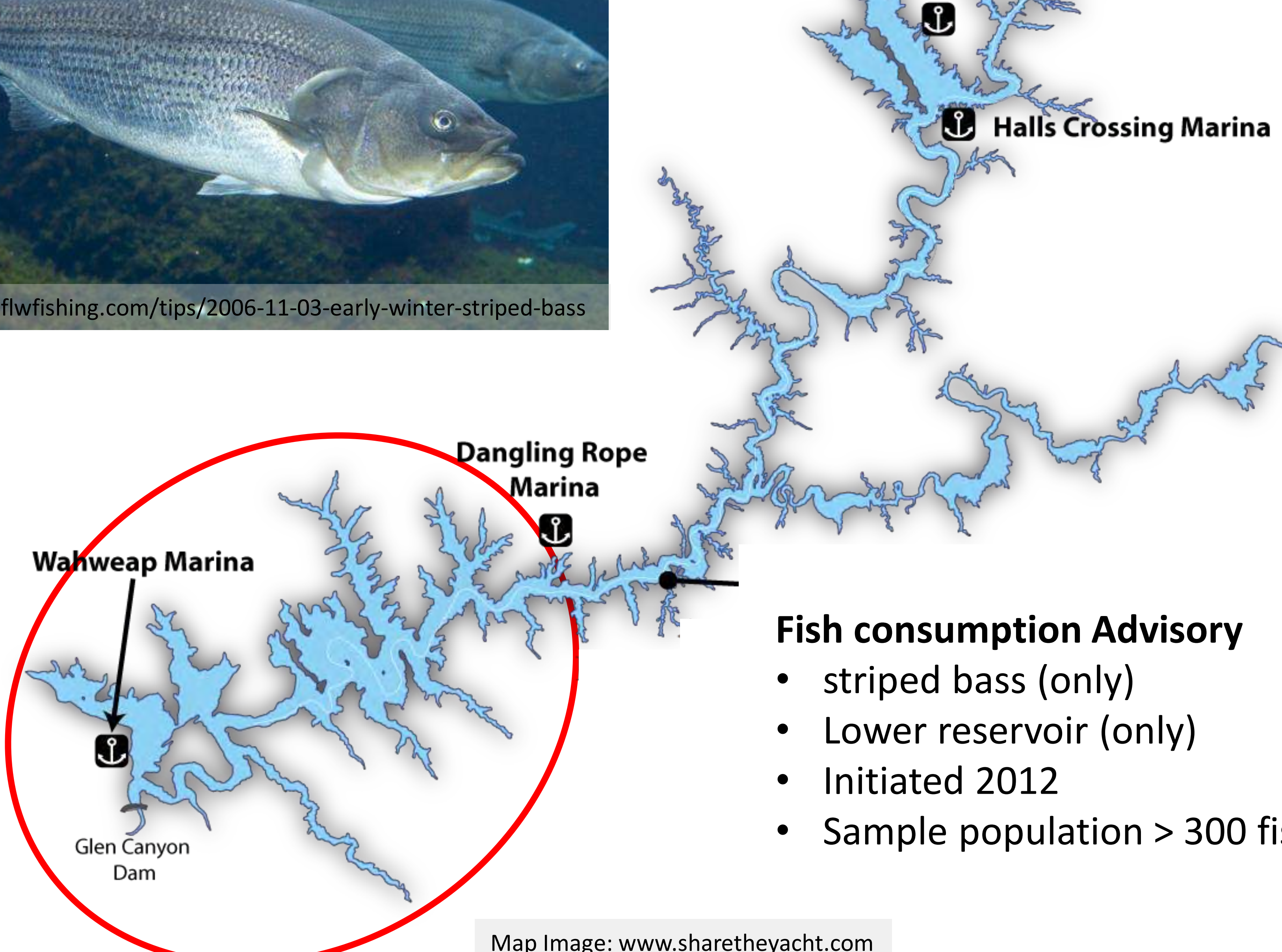
Lake Powell

- Volume: 27×10^6 acre*ft
- Length: 300 km

www.glencanyon.org/glen_canyon/why-glen-canyon

en.wikipedia.org/wiki/Glen_Canyon_Dam

Image: www.flwfishing.com/tips/2006-11-03-early-winter-striped-bass



Map Image: www.sharetheyacht.com

Fish consumption Advisory

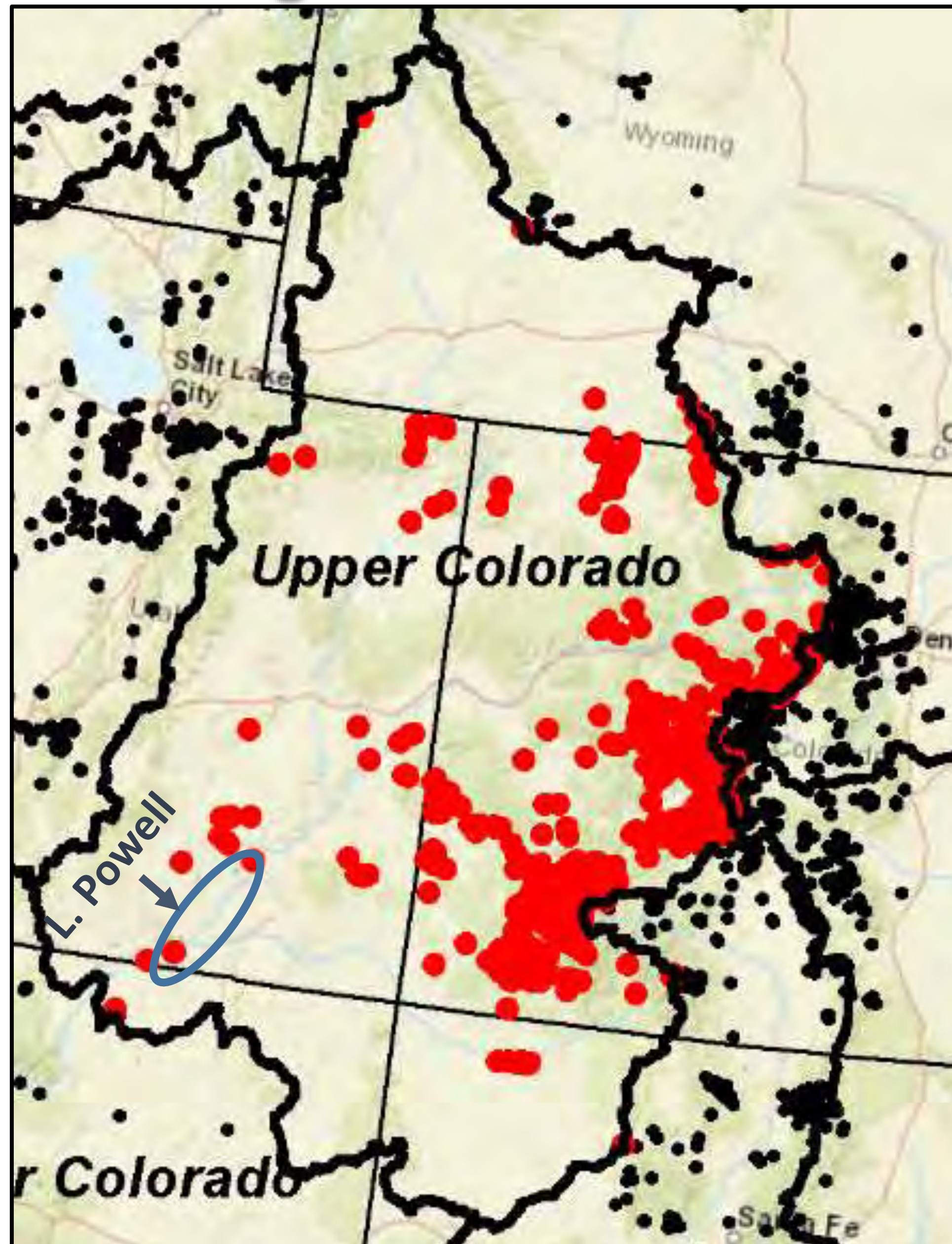
- striped bass (only)
- Lower reservoir (only)
- Initiated 2012
- Sample population > 300 fish

STUDY GOALS / OBJECTIVES

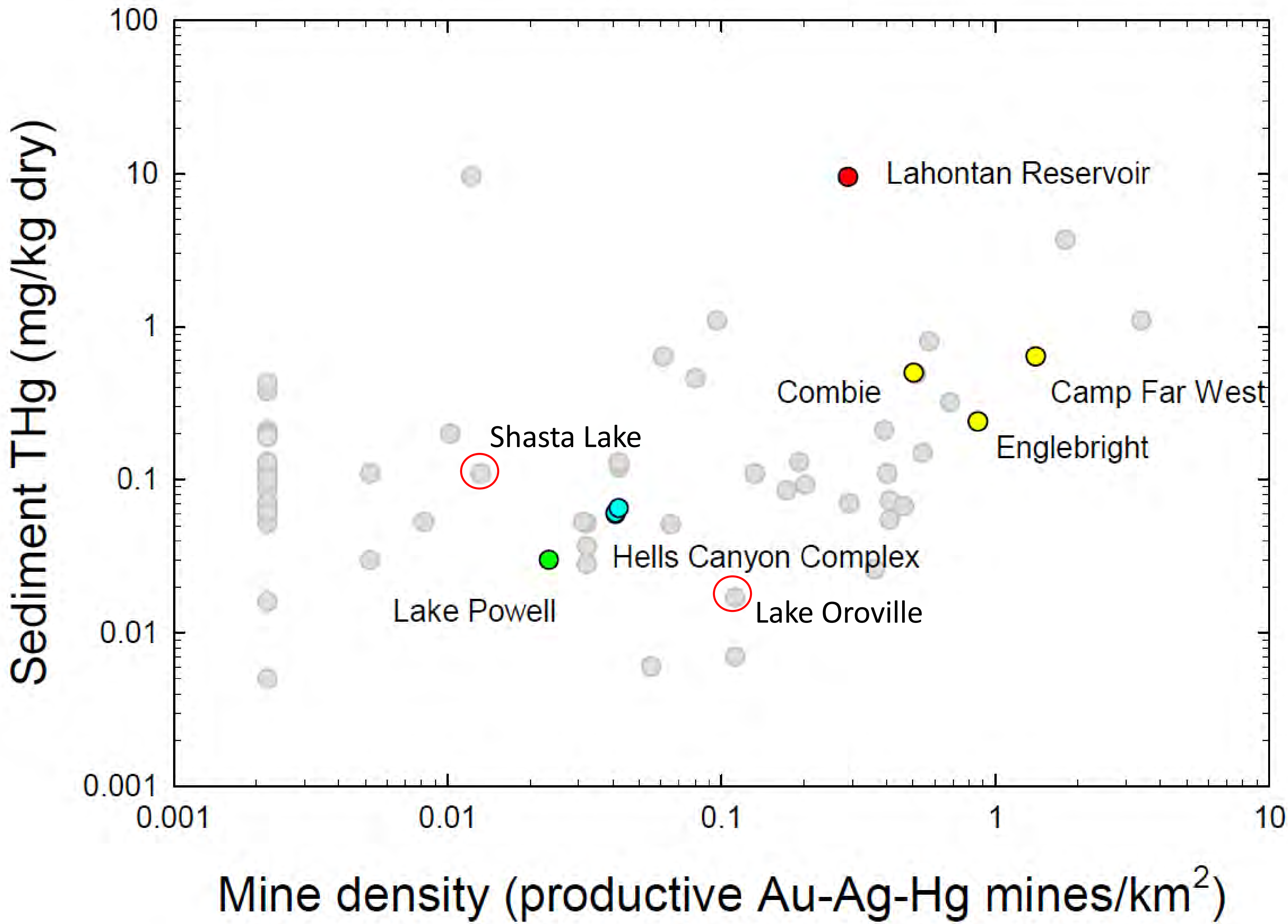
a) Determine underlying processes that lead to fish Hg spatial trends
b) Investigate spatial differences (upper vs lower reservoir / arms vs mainstem)
c) Investigate seasonal differences (high flow vs low flow)

Photo: www.nps.gov/glca/index.htm

Mining UPSTEAM of Lake Powell

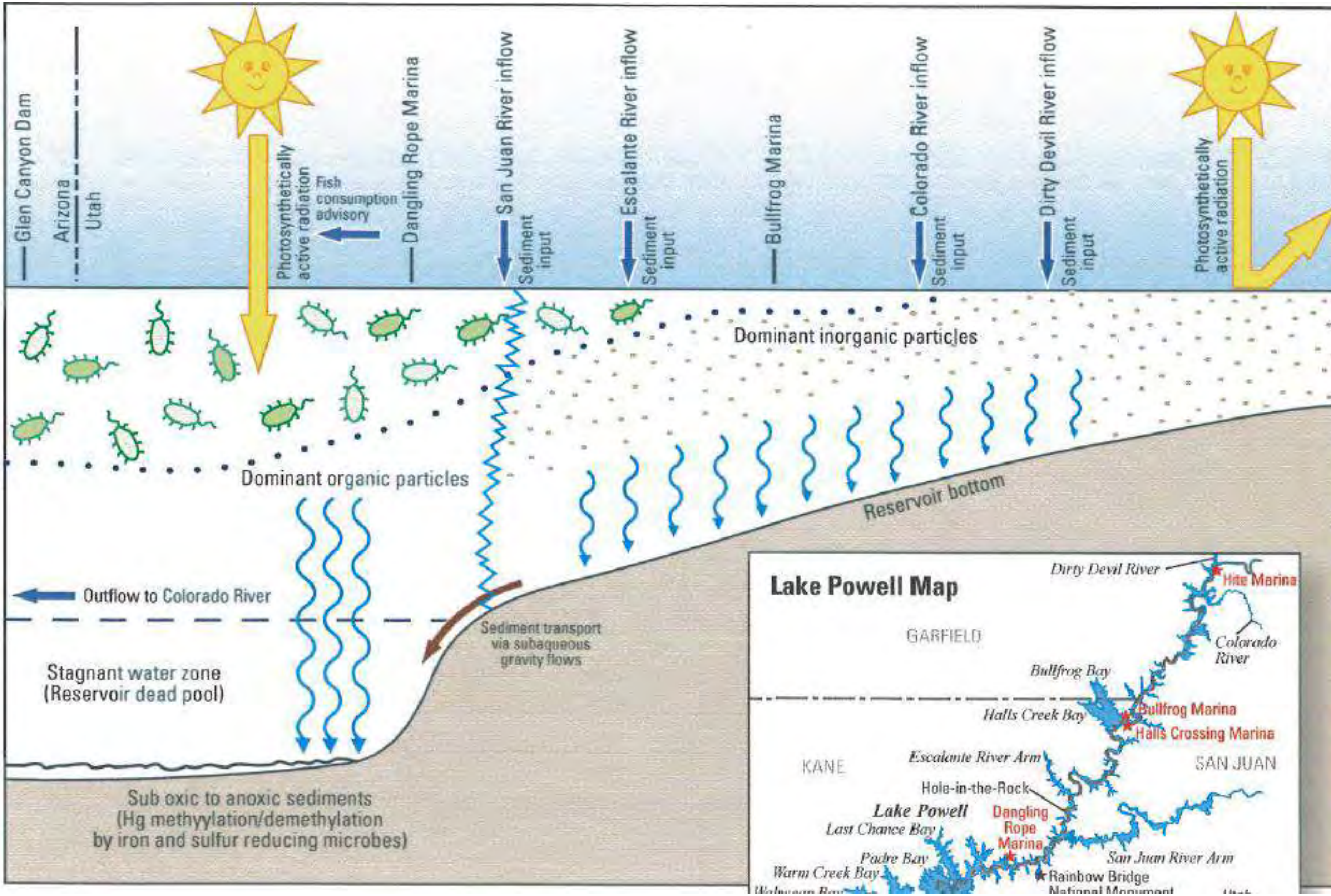


- Mineral Resources Data Systems database
- Upper Colorado drainage basin
- 113,347 square miles
- 2650 Mines: mercury / gold / silver
- Mine Density = 0.023 mines / sq. mile (u/s of Lake Powell)
- Distance from Lake Powell = 350 miles (mean geometric center of the mines)



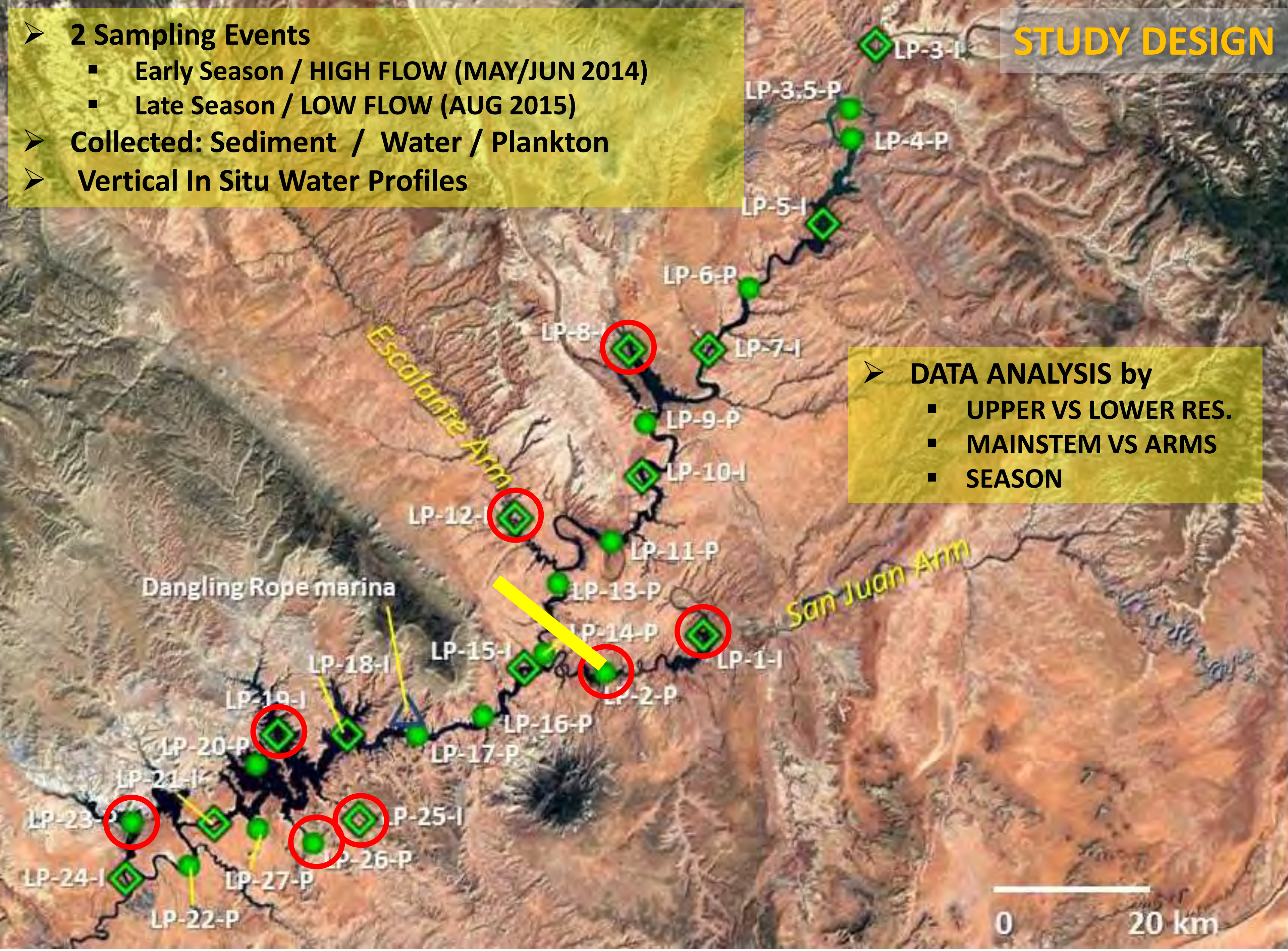
Data from SWRCB, Reservoir TMDL draft staff report (2017), Table B-1
plus unpublished USGS data

Conceptual Model



STUDY DESIGN

- 2 Sampling Events
  - Early Season / HIGH FLOW (MAY/JUN 2014)
  - Late Season / LOW FLOW (AUG 2015)
- Collected: Sediment / Water / Plankton
- Vertical In Situ Water Profiles



- DATA ANALYSIS by
  - UPPER VS LOWER RES.
  - MAINSTEM VS ARMS
  - SEASON

The Analytical Toolbox

Water Column: In Situ Metrics
- temperature
- dissolved O_2
- pH
- specific conduct.
- fDOM
- algal pigments (chl.a)
- turbidity

Water Column: Intensive (≤ 5 depths)
- Total Hg (THg)
- Methylmercury (MeHg)
- nutrients
- DOC and SUVA
- particulate C and N (isotopes)
- total suspended solids (TSS)
- microbial 16S-rRNA
- major anions & cations
- alkalinity

Plankton: vertical tows (20 m)
- size fractioned plankton biomass
- THg & MeHg

Surface Sediment (0-2 cm)
- THg & MeHg
- reactive inorganic Hg(II)
- MeHg production potential rates
- MeHg degradation potential rates
- microbial 16S-rRNA
- organic content
- total reduced sulfur
- iron chemistry
- grain size
- redox
- pH

Least Squares Mean Statistical Models

For Water Parameters:

$Y = TYPE.1 + TYPE.2 + SEASON + DEPTH + [SITE]_{random}$

where: TYPE.1 (upper / lower)

TYPE.2 (mainstem / arm)

SEASON (early / late)

DEPTH (surf / epi + therm / hyp + b2)

For Plankton Parameters:

$Y = TYPE.1 + TYPE.2 + SEASON + FRAC + [SITE]_{random}$

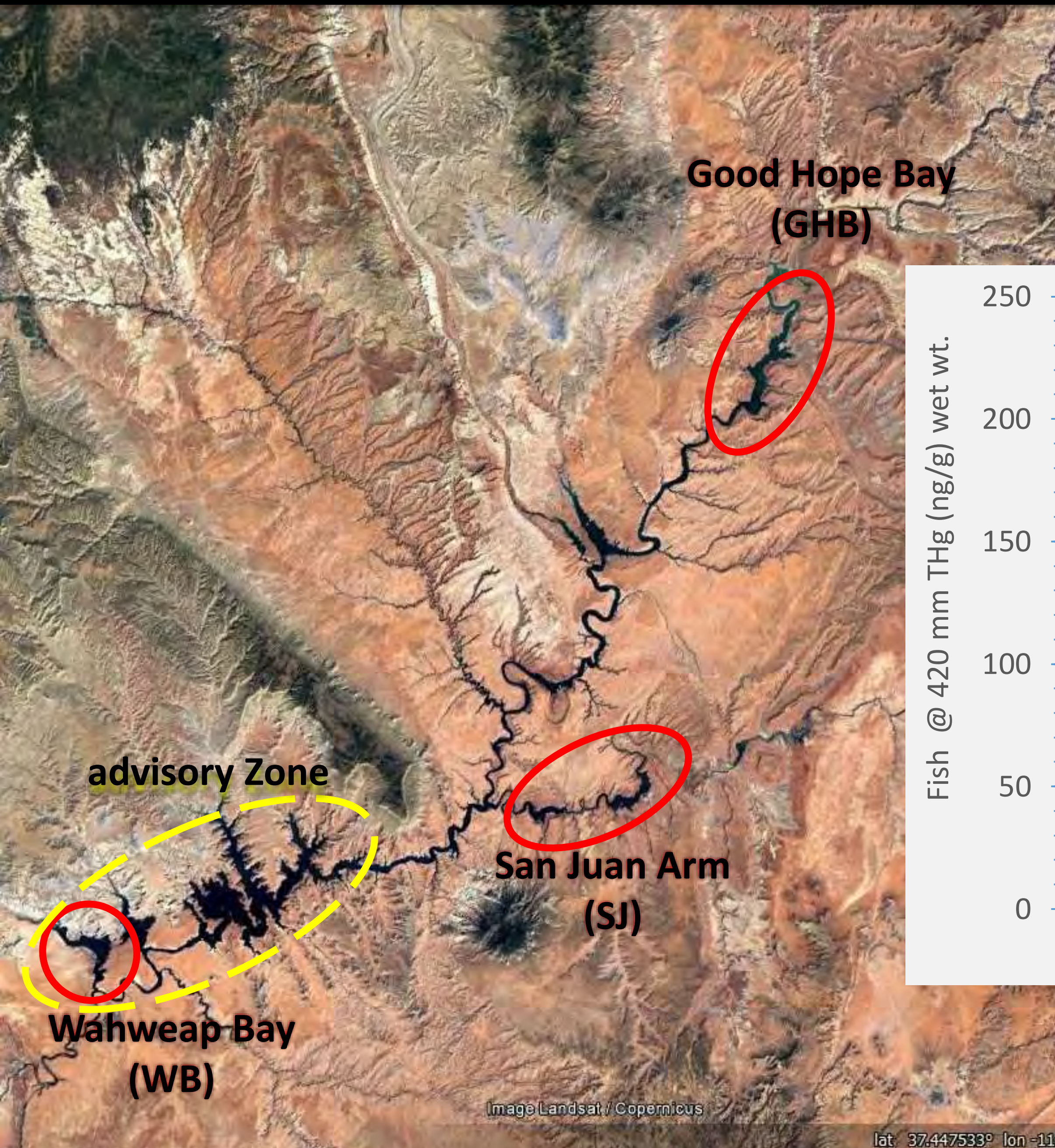
where: FRAC (63-118 / 118-243 / 243-500 / > 500 µm)

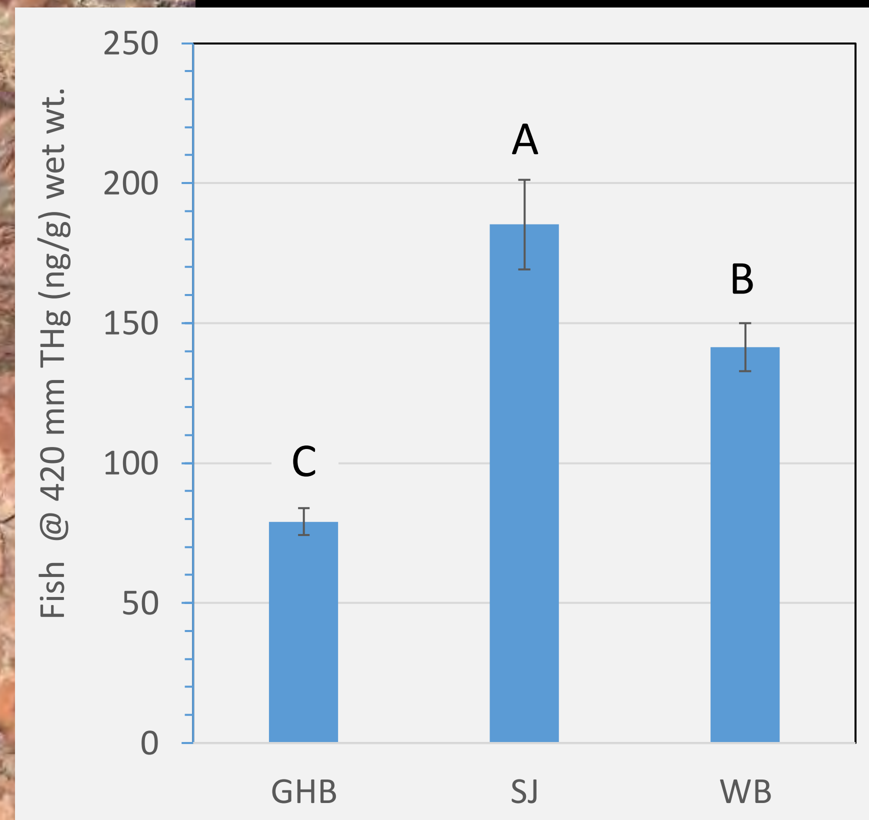
For Sediment Parameters:

$Y = TYPE.1 + TYPE.2 + SEASON + [SITE]_{random}$

Striped Bass THg

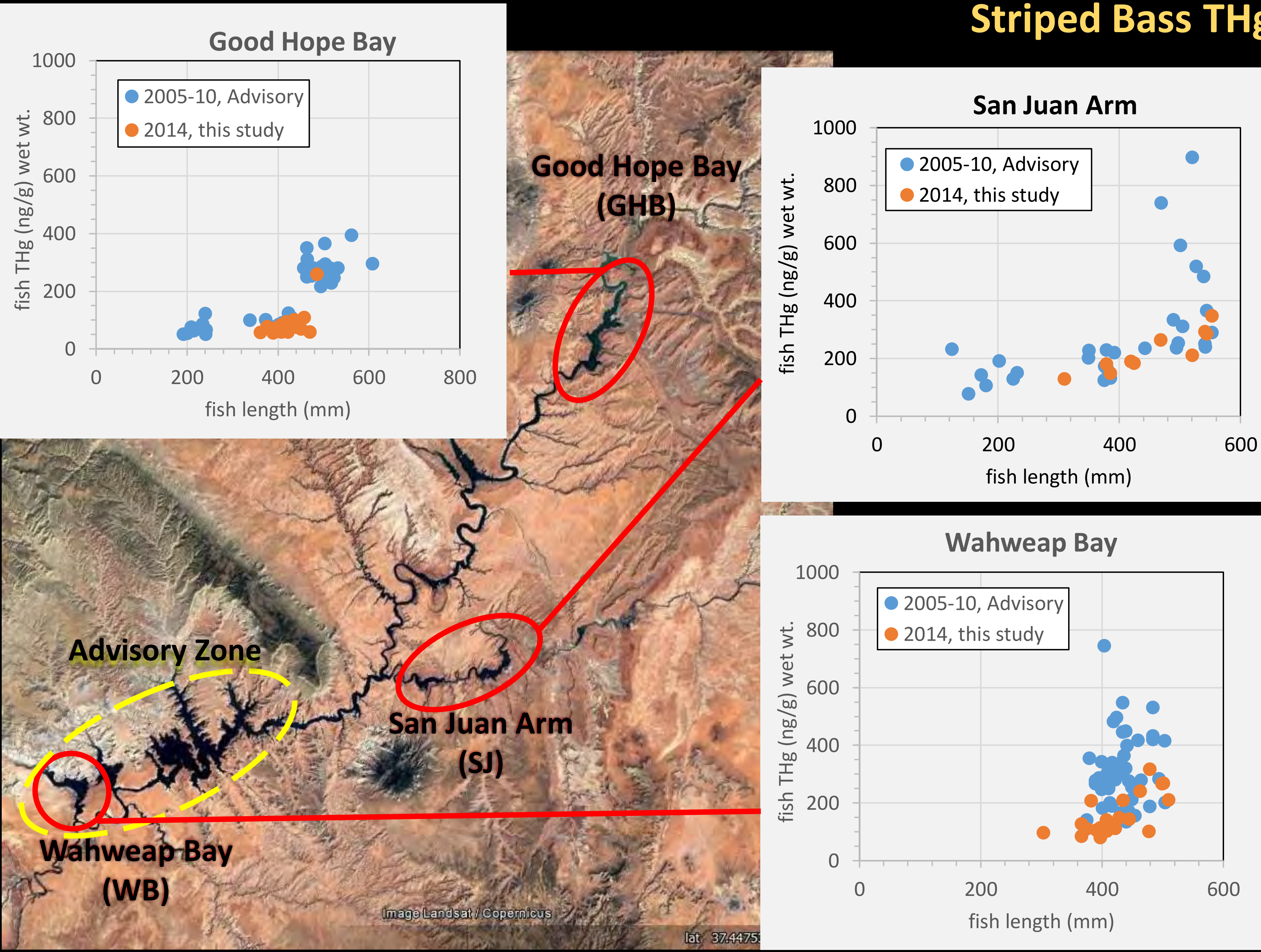
- Sampled: Nov. 2014
- N = 50
- Data standardized (420 mm)



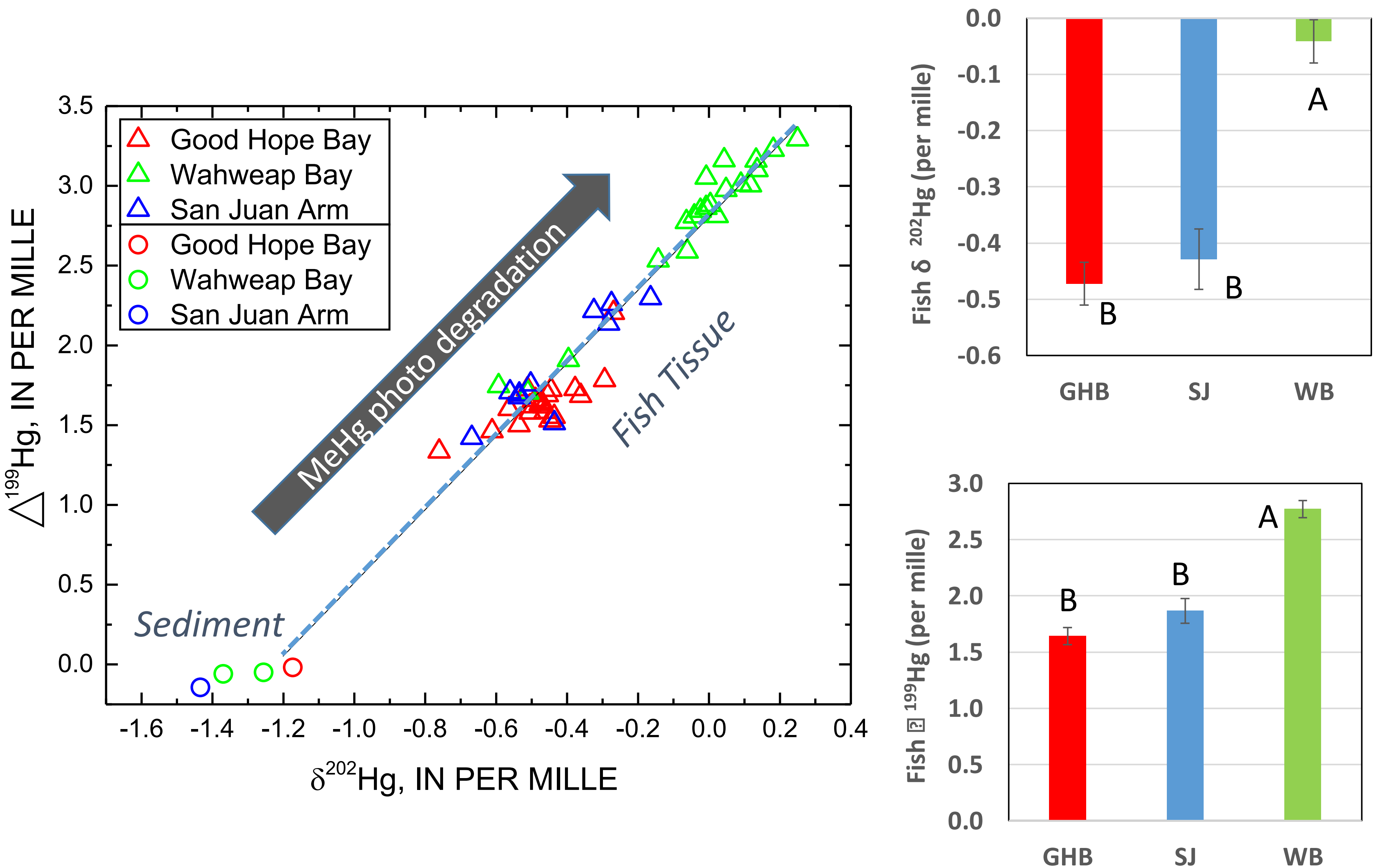


Fish Collection by: Utah Division of Wildlife Resources

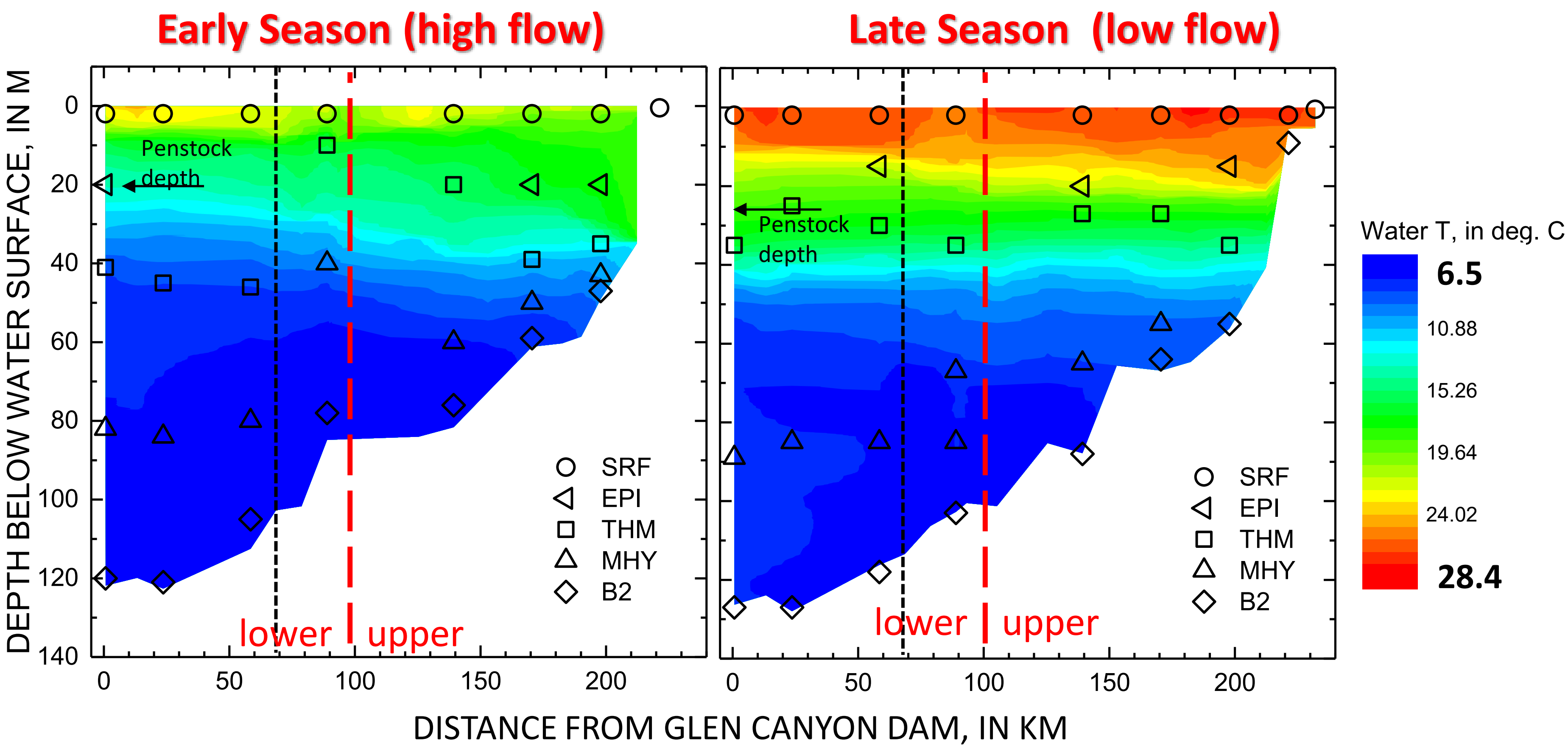
Striped Bass THg



Striped Bass and Sediment Hg Isotope Data



WATER COLUMN: Temperature

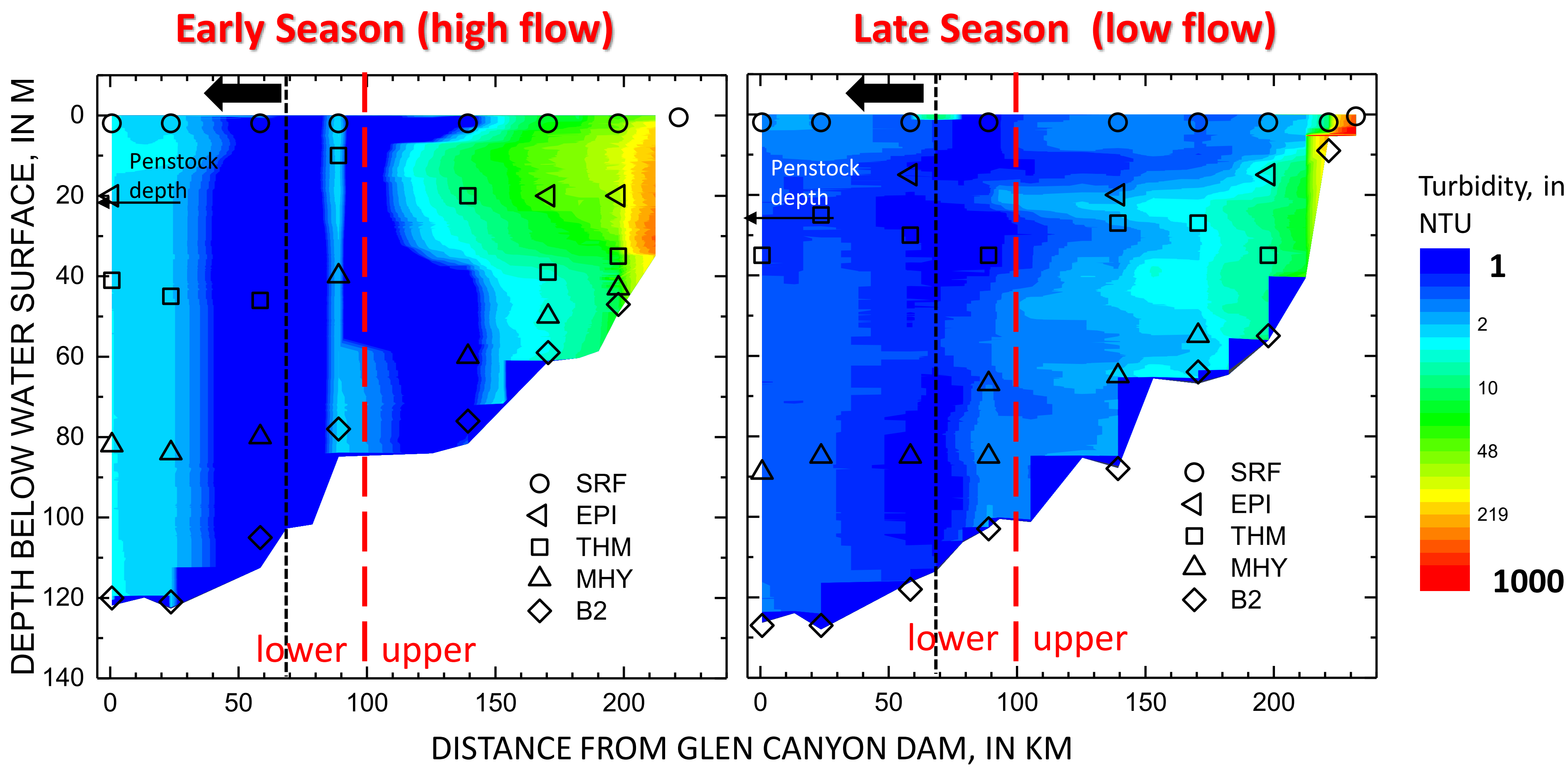


Lower | < | Upper

Main | < | Arm

Early | < | Late

WATER COLUMN: Turbidity

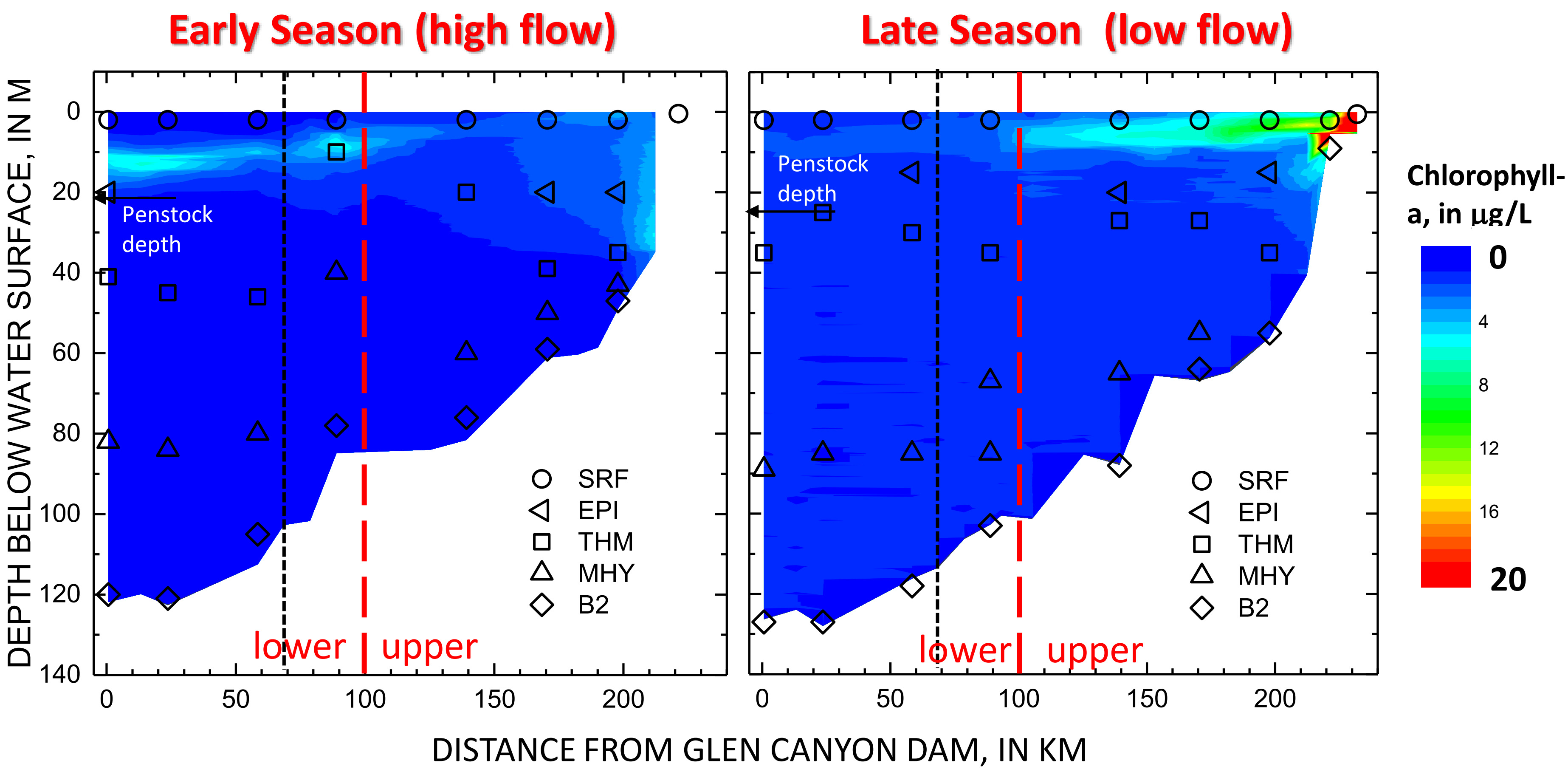


Lower	<	Upper

Main	=	Arm

Early	=	Late

WATER COLUMN: Chlorophyll-a

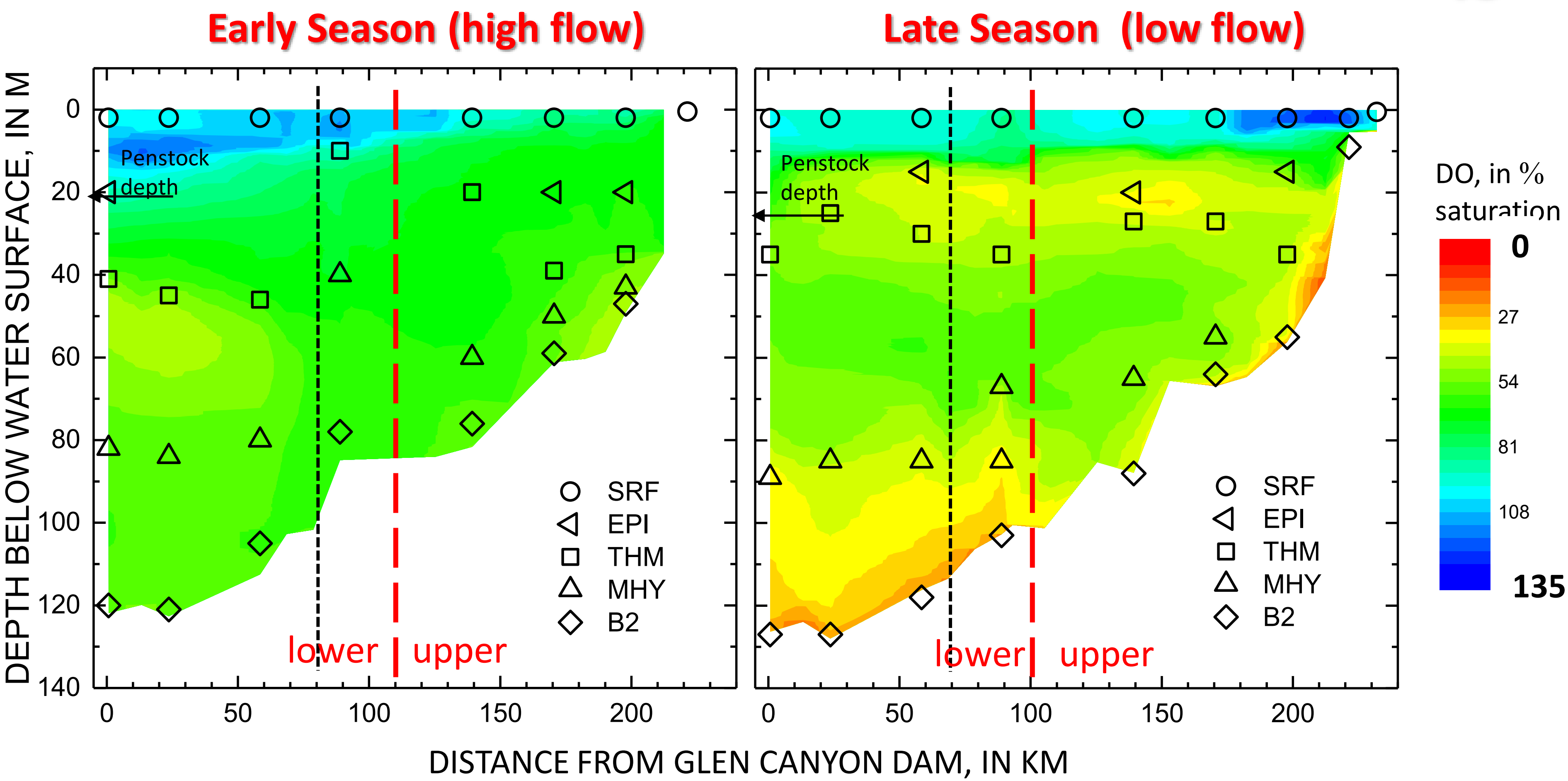


Lower | **<** | **Upper**

Main | **=** | **Arm**

Early | **<** | **Late**

WATER COLUMN: Dissolved Oxygen

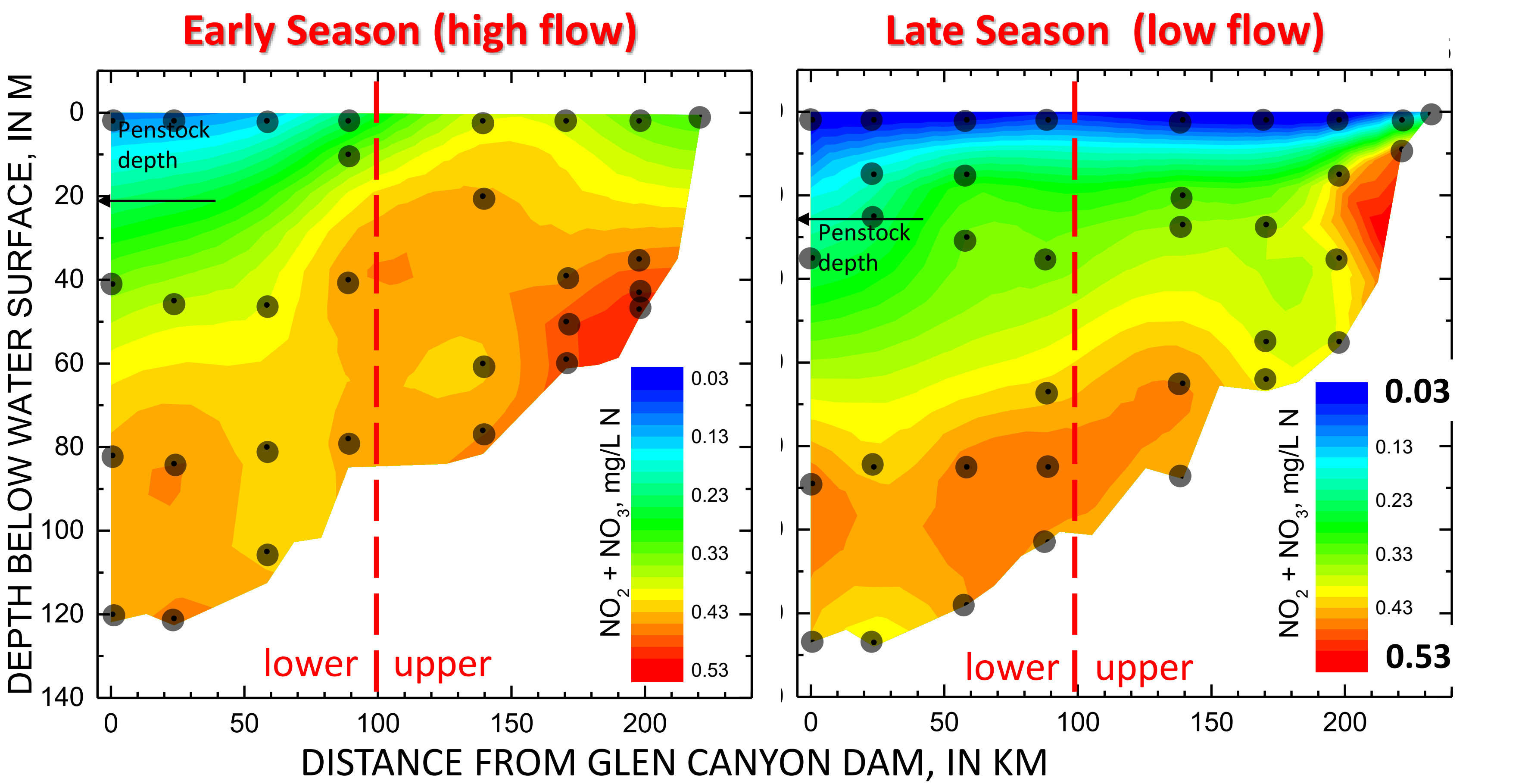


Lower	=	Upper

Main	=	Arm

Early	>	Late

WATER COLUMN: Nitrate + Nitrite

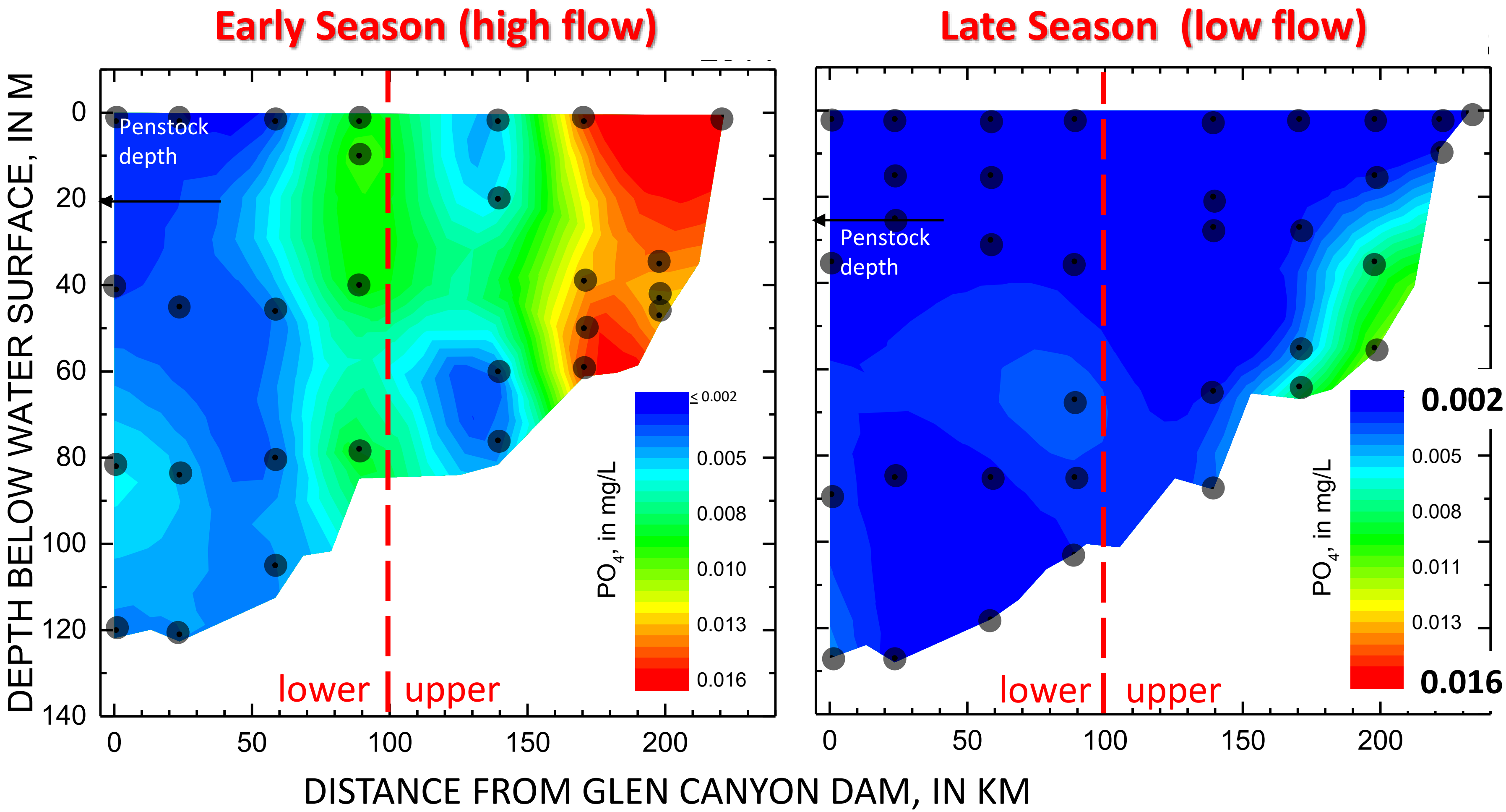


Lower	=	Upper

Main	>	Arm

Early	>	Late

Water Column: Phosphate



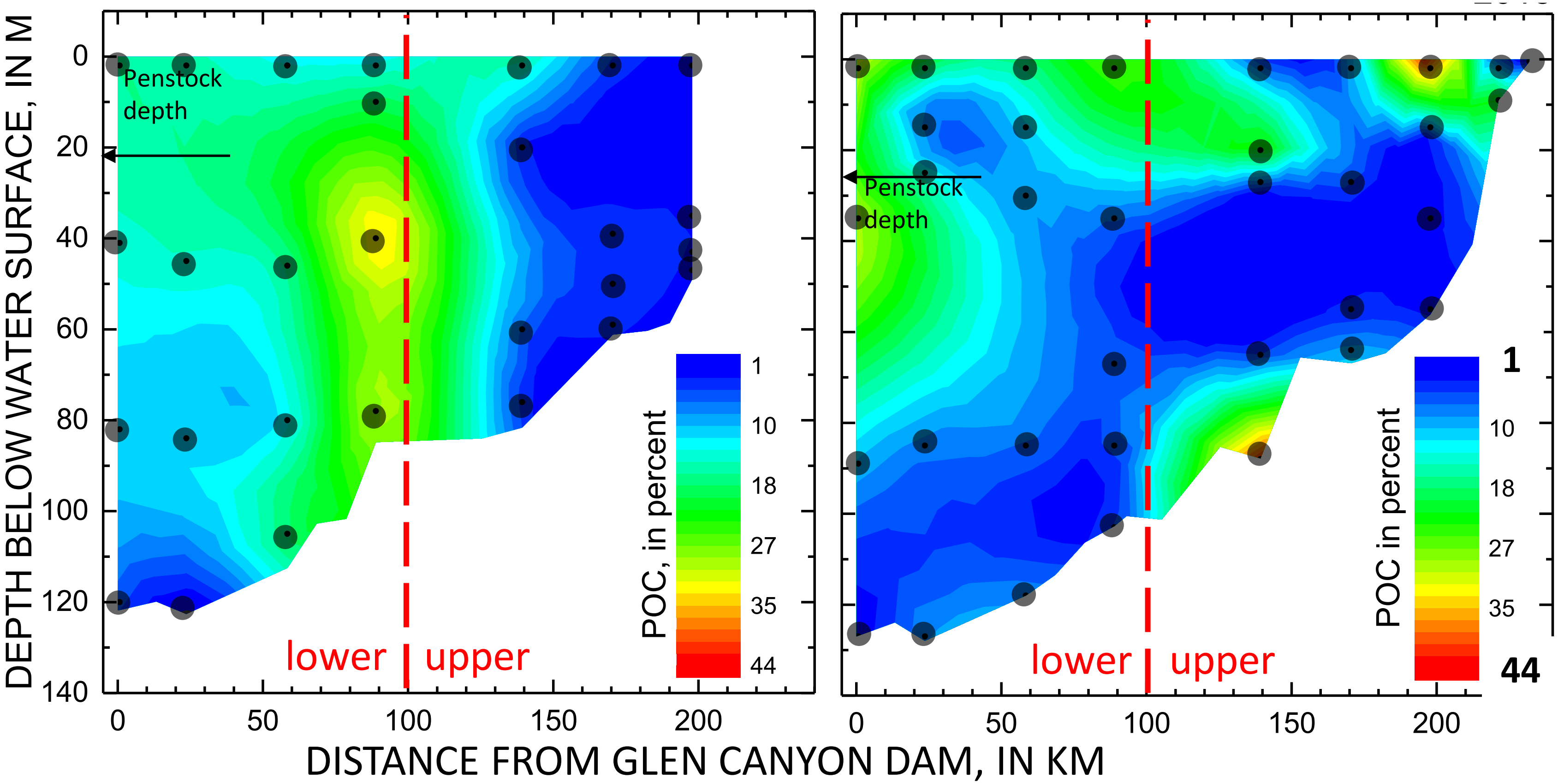
Lower	<	Upper

Main	=	Arm

Early	>	Late

WATER COLUMN: Particulate Organic Carbon (%)

Early Season (high flow) **Late Season (low flow)**

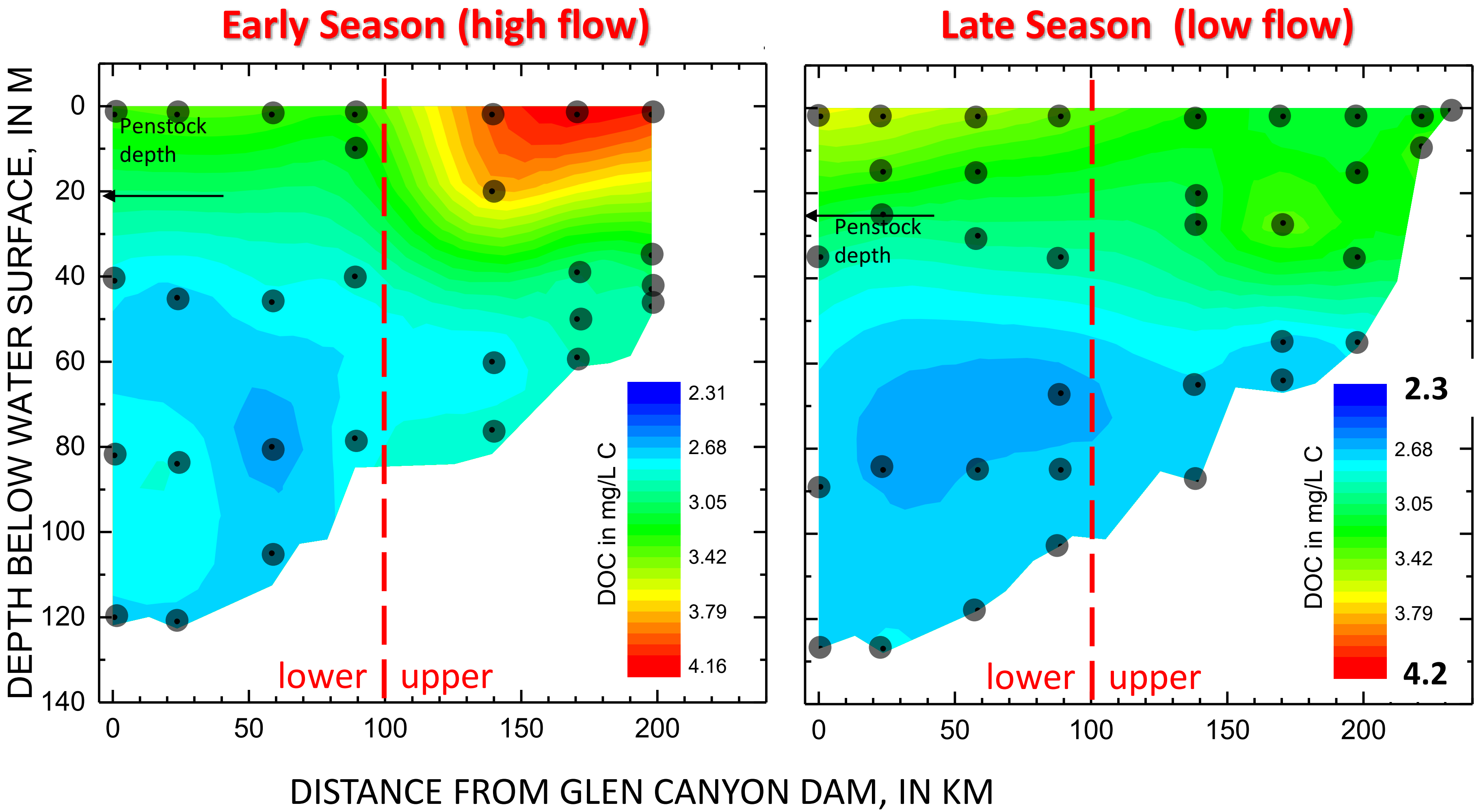


Lower	>	Upper

Main	=	Arm

Early	=	Late

WATER COLUMN: Dissolved Organic Carbon

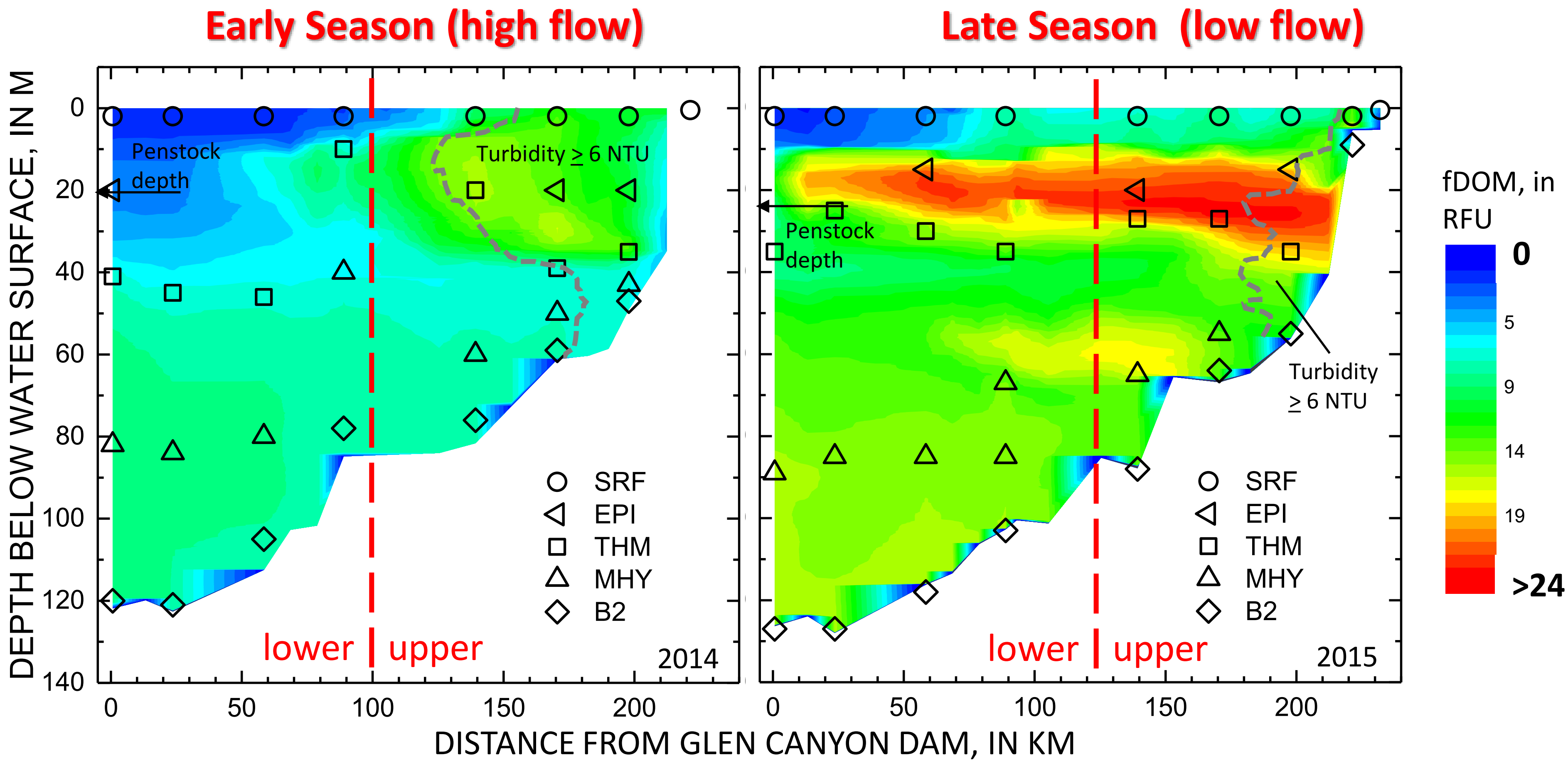


Lower	<	Upper

Main	=	Arm

Early	=	Late

WATER COLUMN: Fluorescent Dissolved Organic Matter

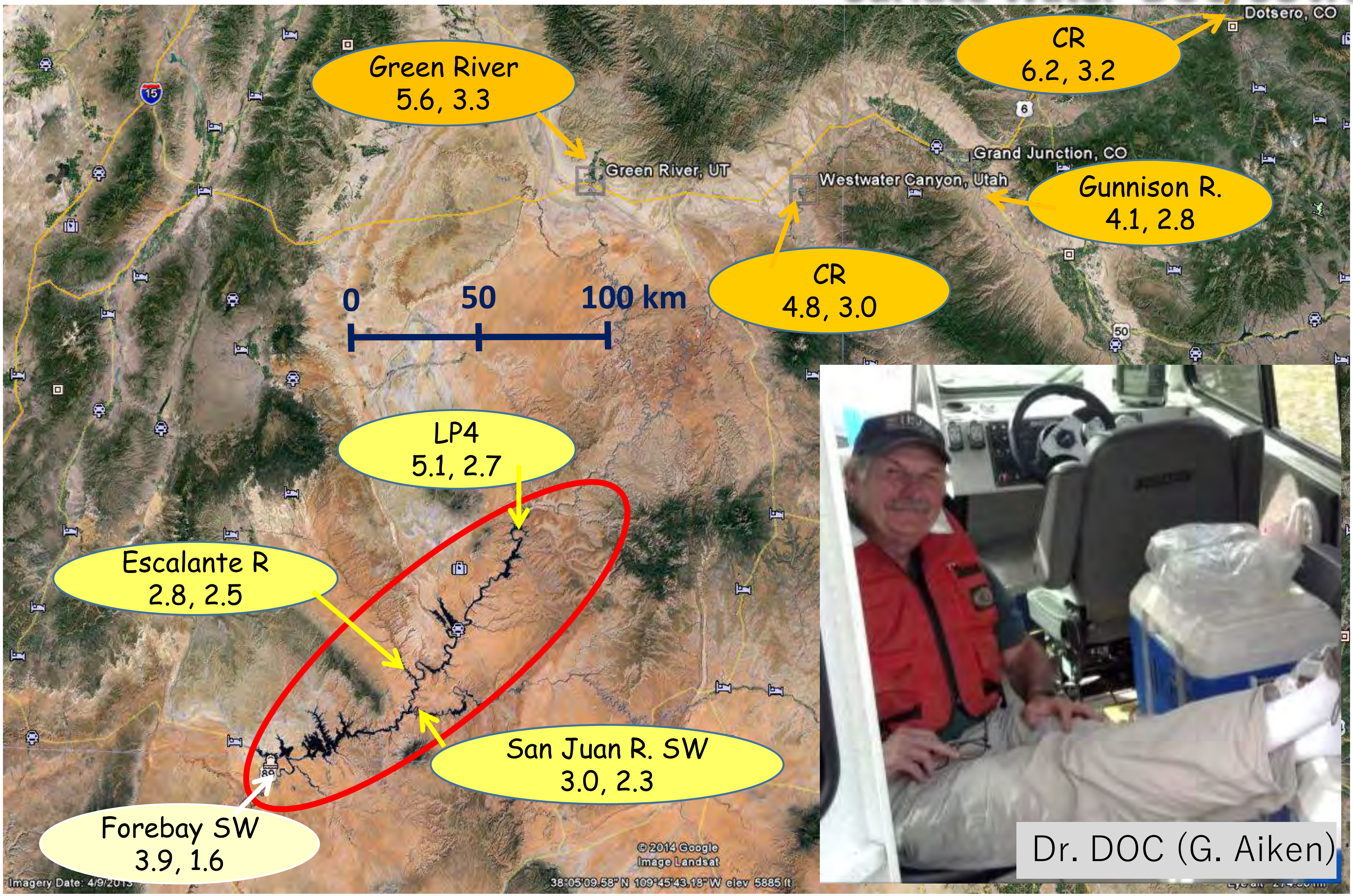


Lower	<	Upper

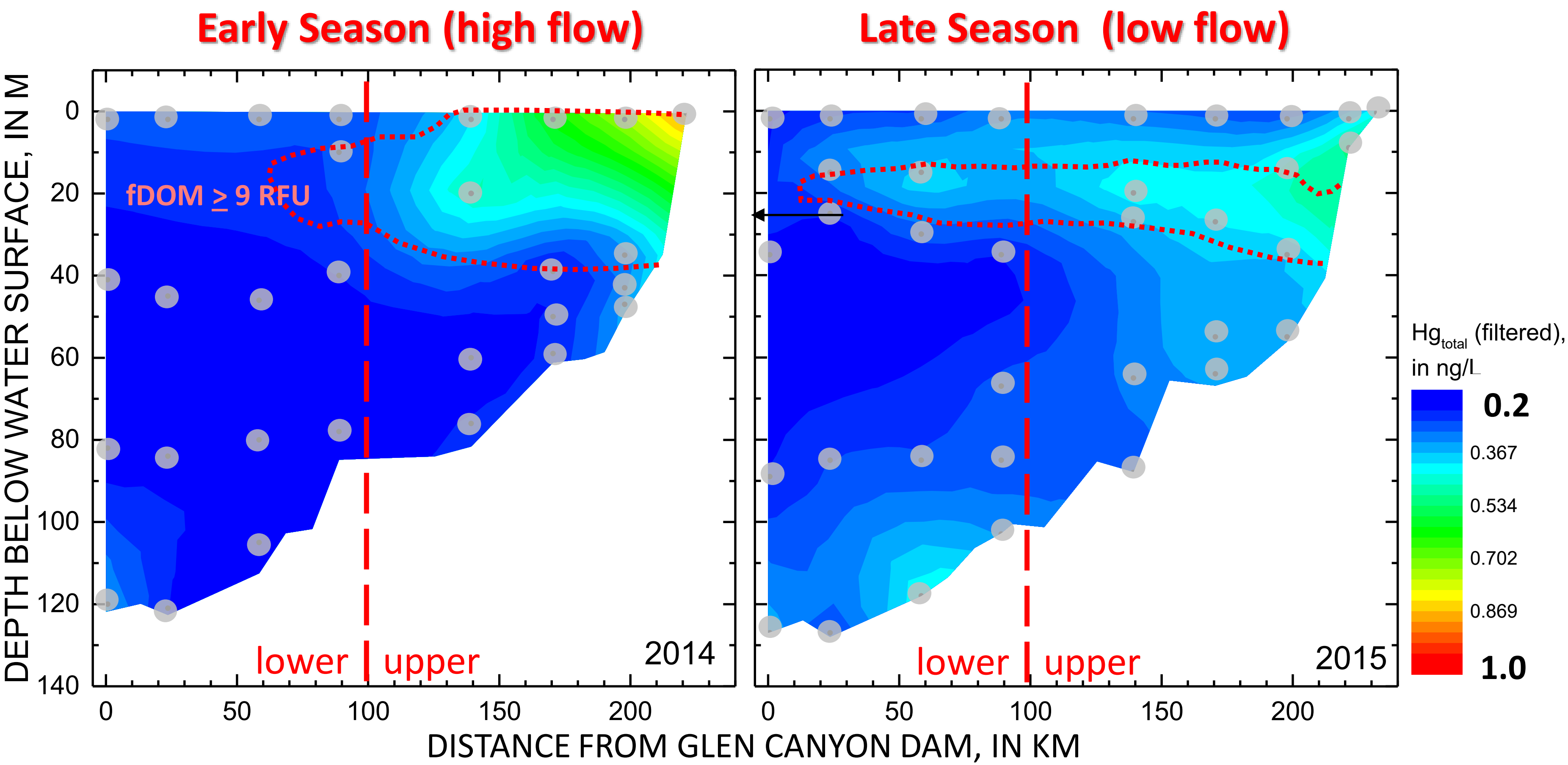
Main	=	Arm

Early	<	Late

Surface Water DOC, SUVA



WATER COLUMN: Filter Passing Total Hg



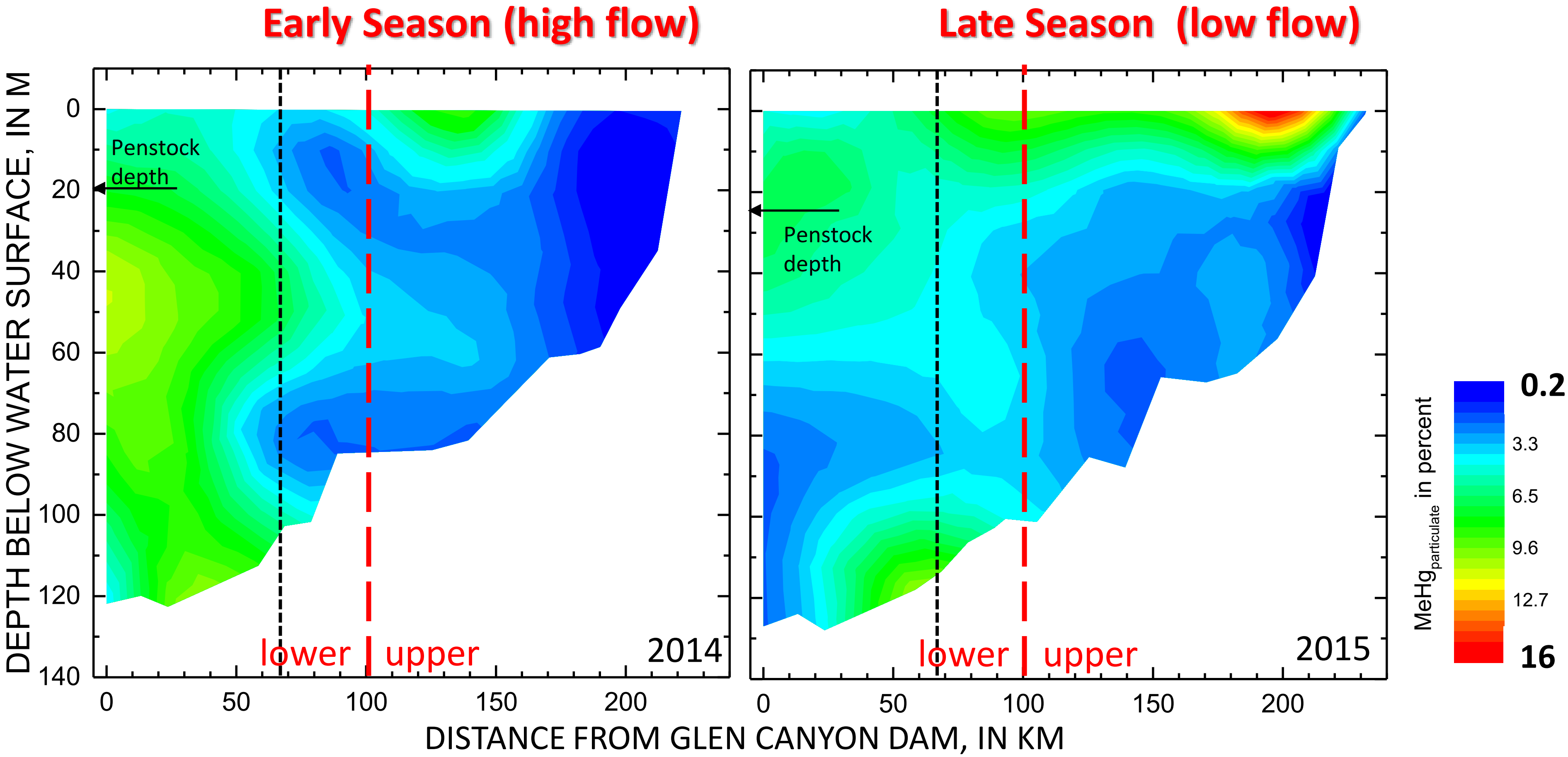
Lower	<	Upper

Main	=	Arm

Early	<	Late

STATISTICS trends for f.THg match those for fDOM

WATER COLUMN: Particulate %.MeHg (% of THg)

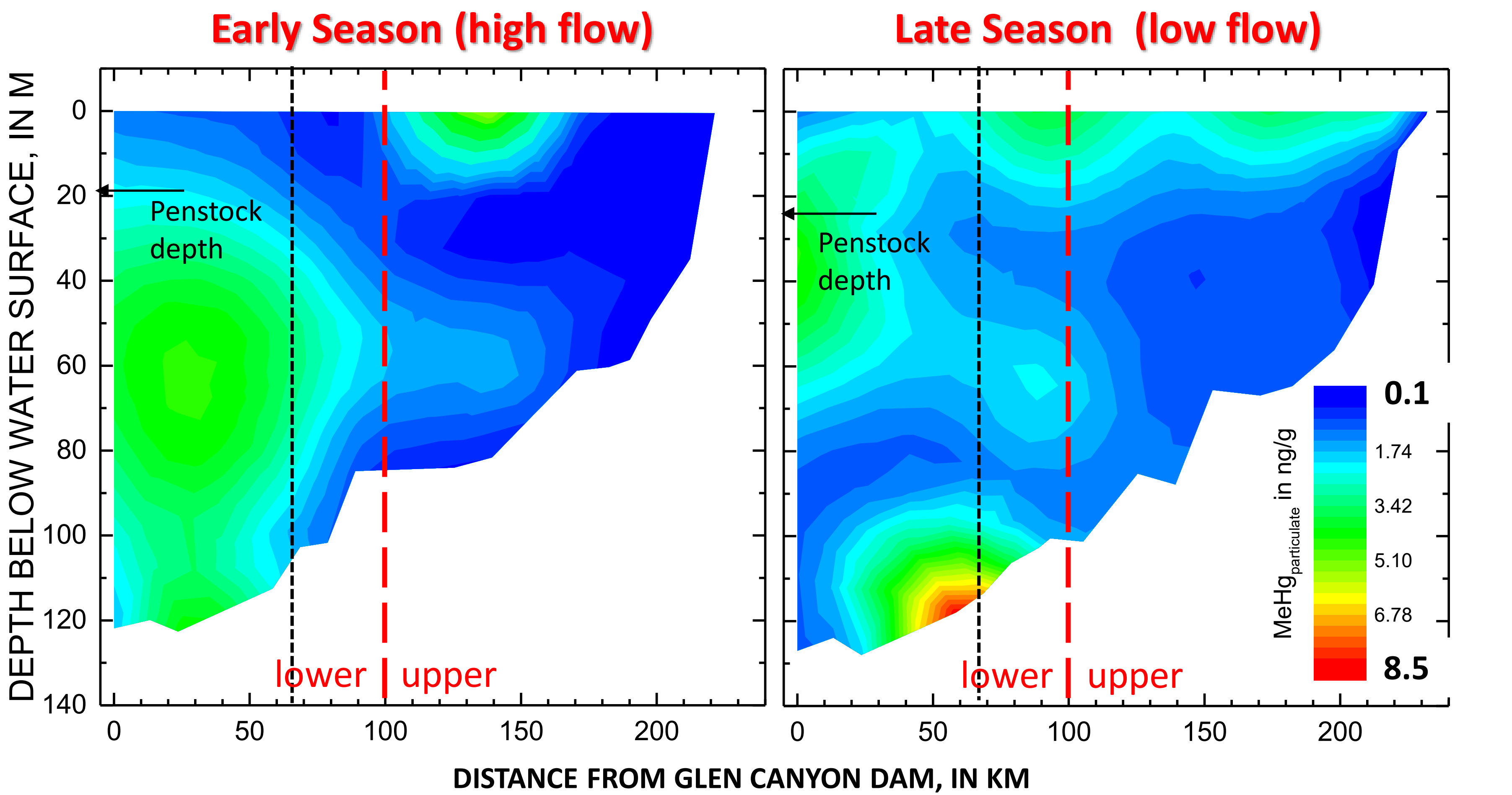


Lower | > | Upper

Main | < | Arm

Early | < | Late

WATER COLUMN: Particulate MeHg (by mass, ng/g)

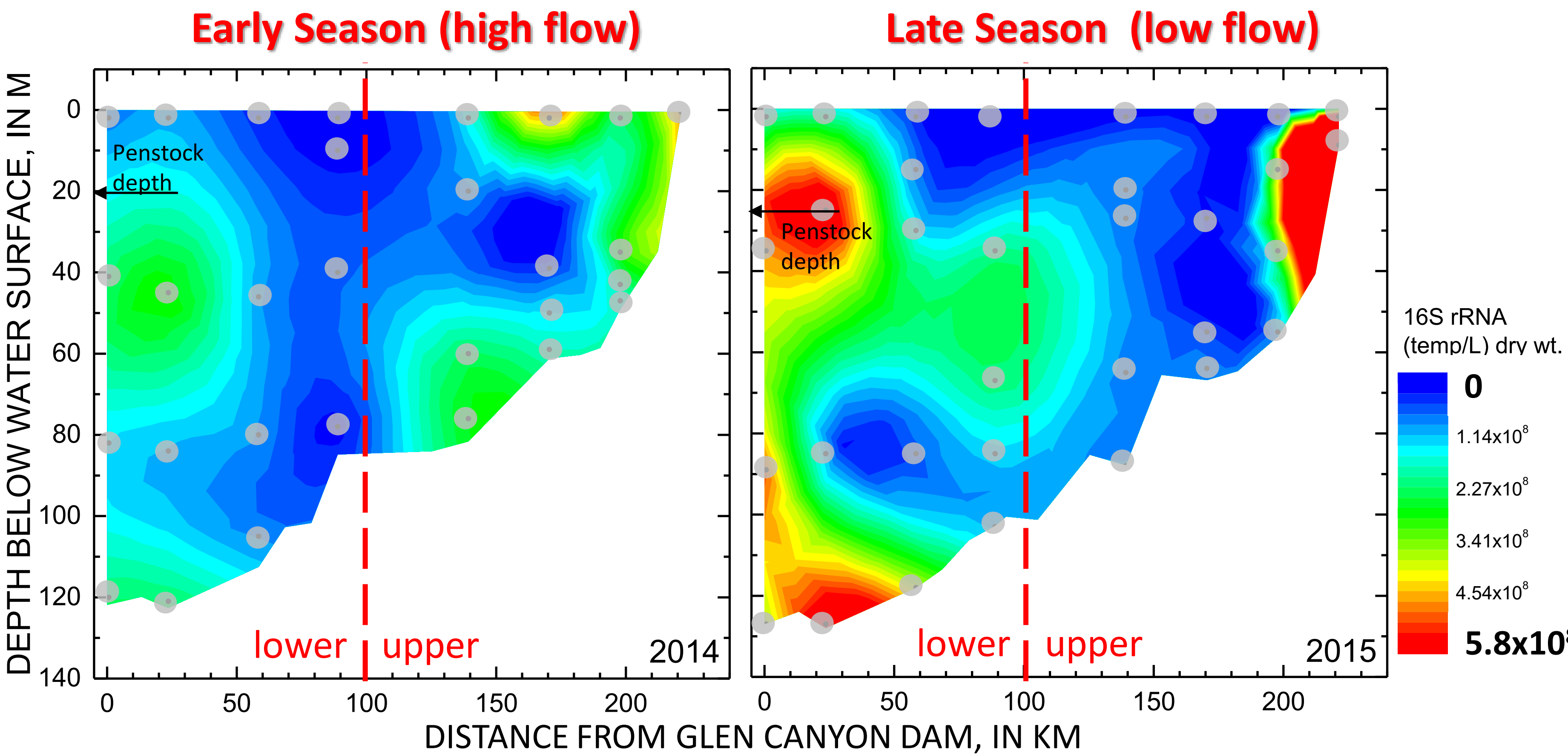


Lower > Upper

Main < Arm

Early < Late

WATER COLUMN: Total microbial 16S rRNA

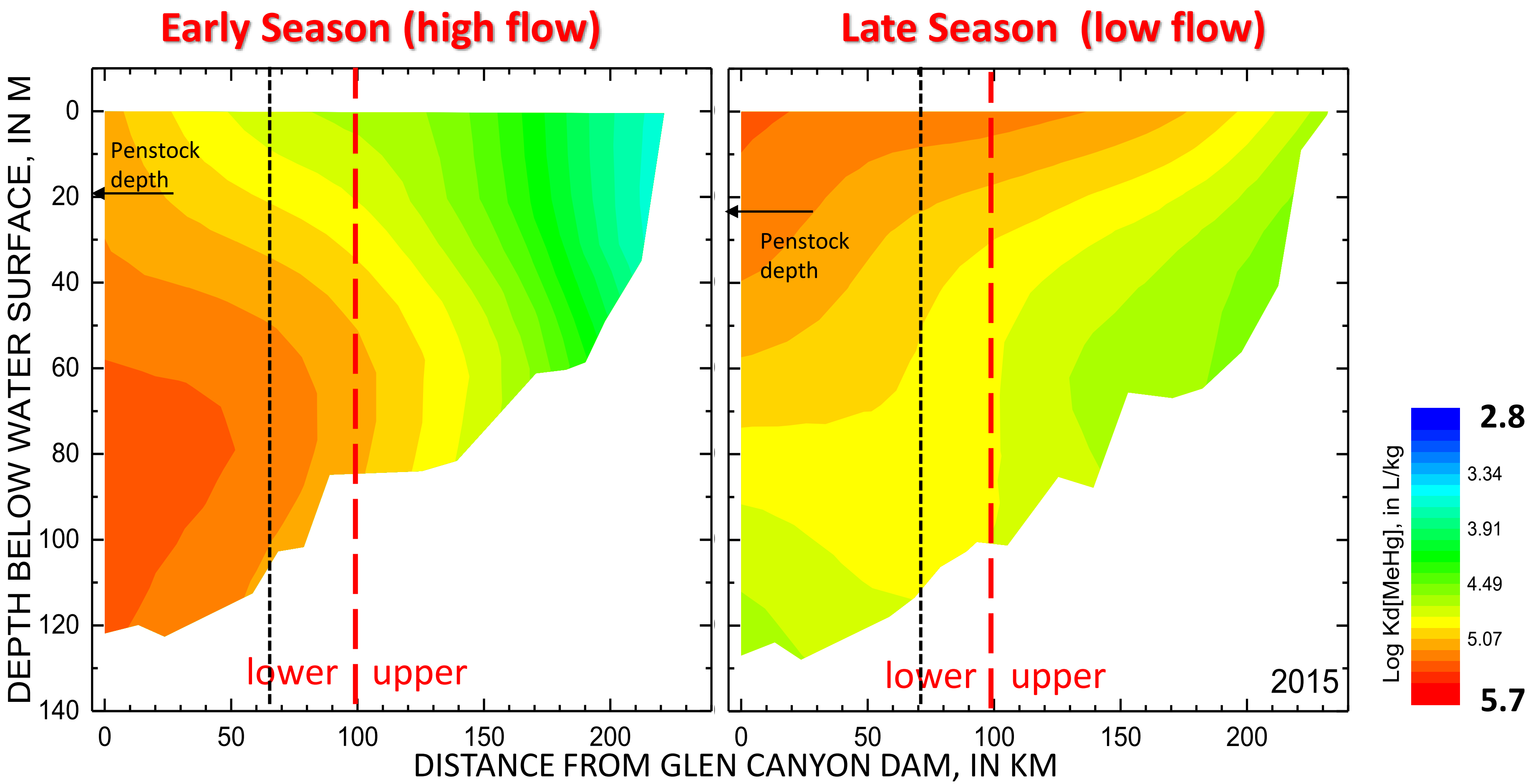


Lower	=	Upper

Main	=	Arm

Early	<	Late

WATER COLUMN: MeHg Partitioning (particulate/aqueous)

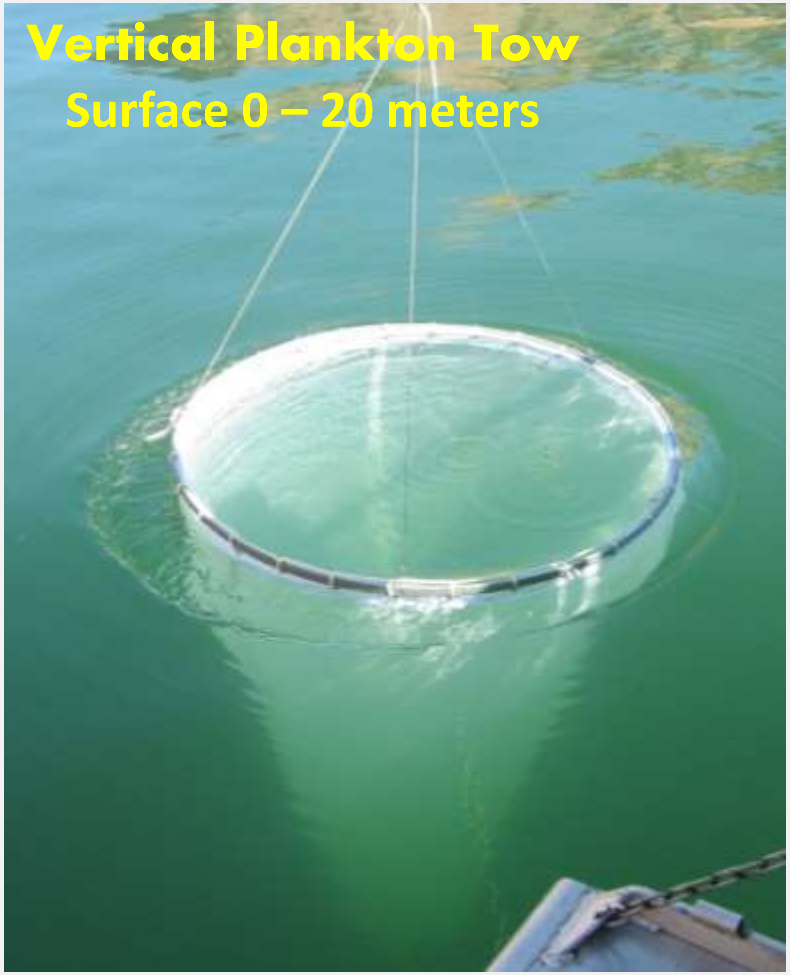


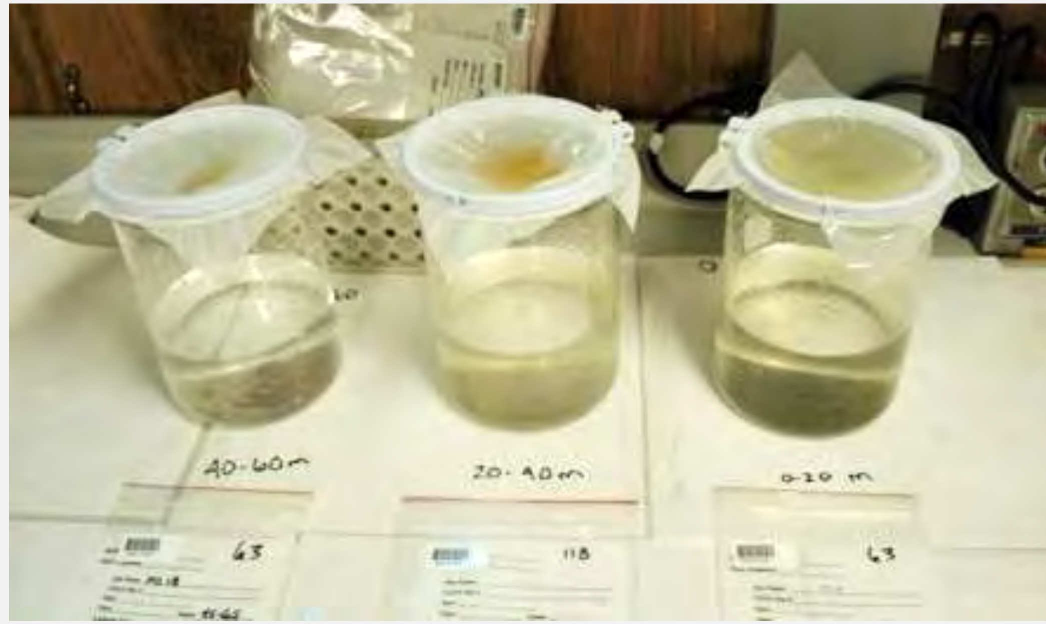
Lower > Upper

Main = Arm

Early = Late

Plankton Sampling

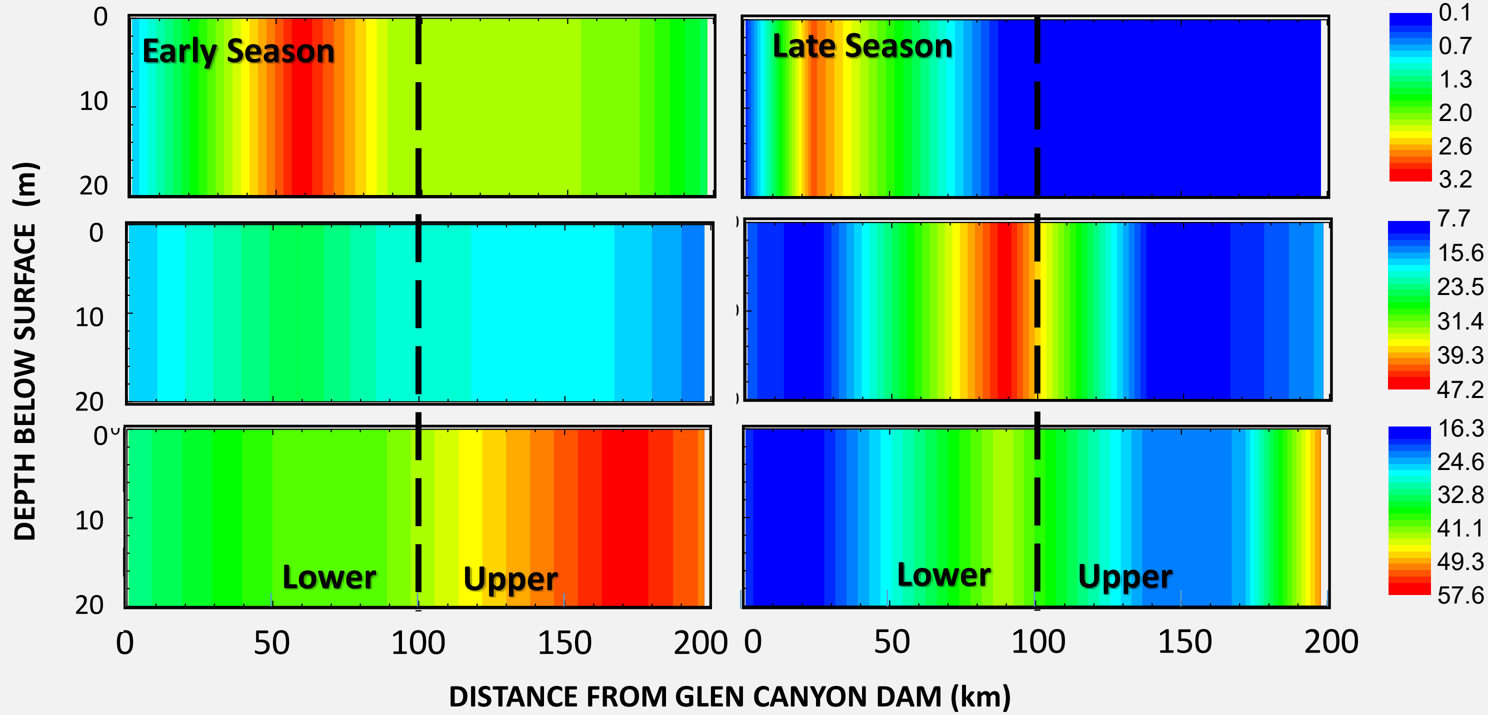




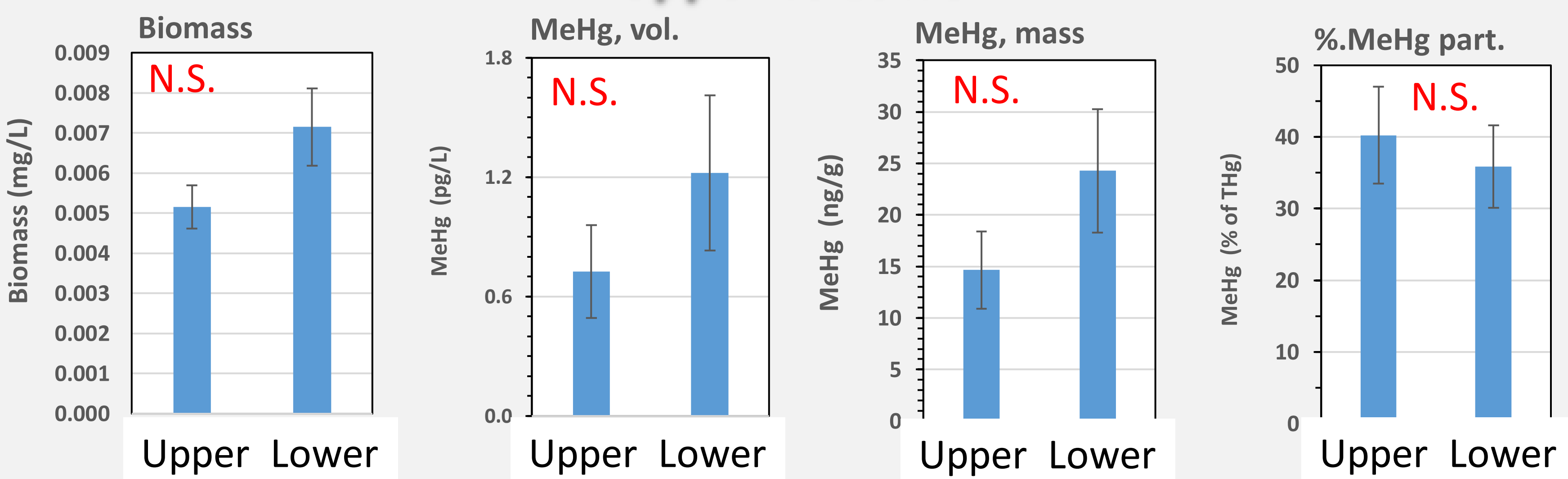
Size Fractions:

- 63-118 µm (phyto & zooplankton)
- 118-243 µm (phyto & zooplankton)
- 243-500 µm (zooplankton)
- > 500 µm (zooplankton)
- BULK (63 to > 500); reconstructed

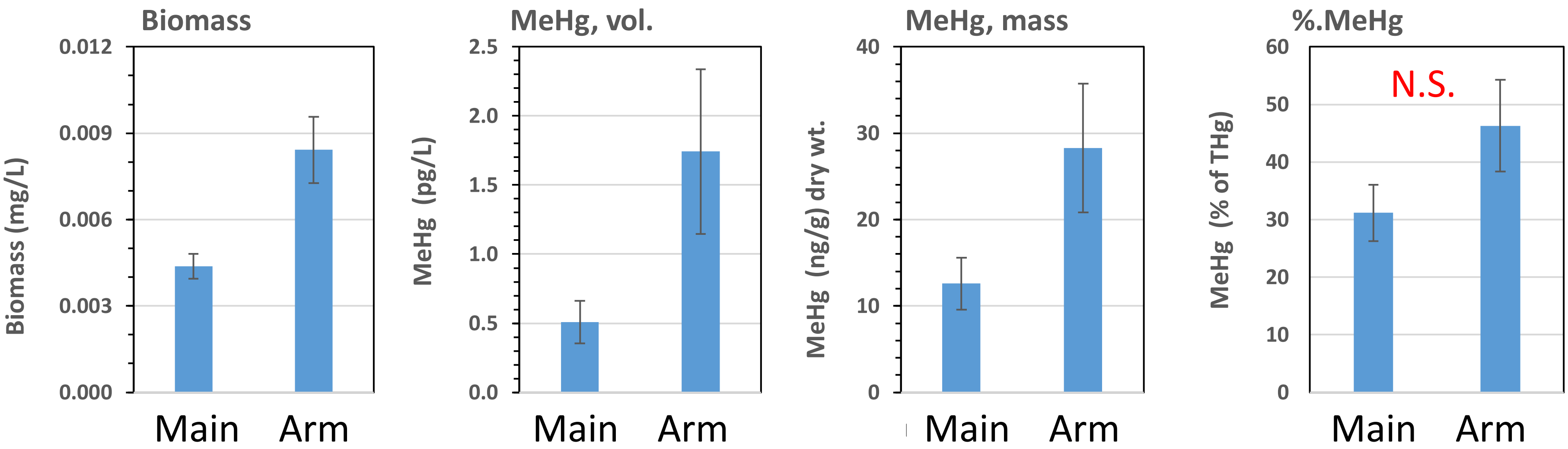
BULK Plankton (63 to > 500 µm)



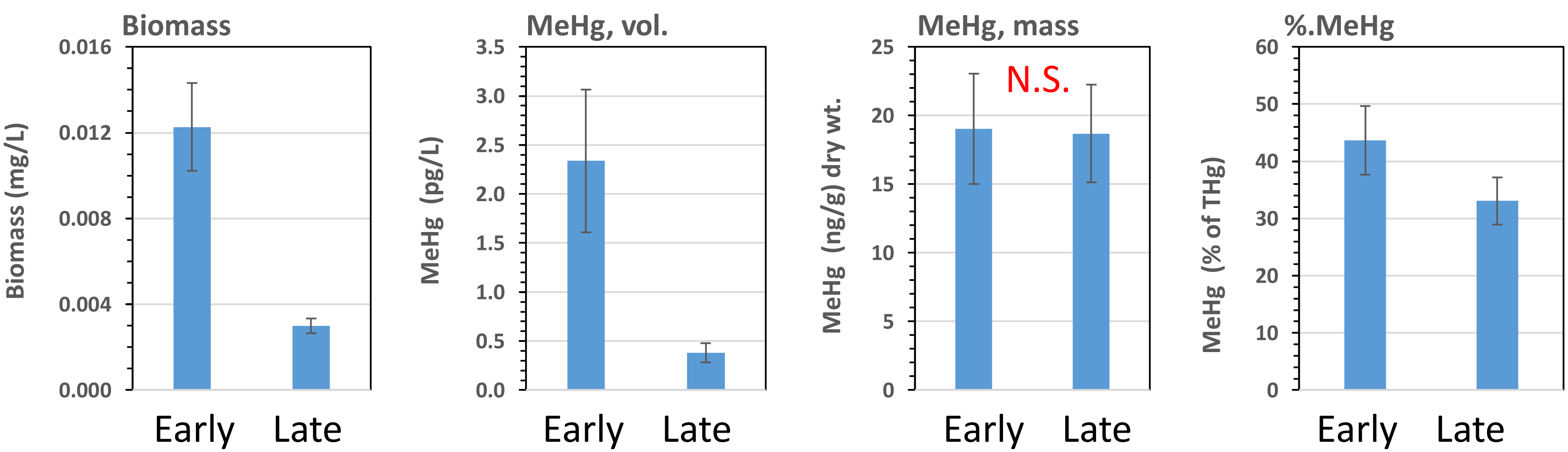
Upper vs Lower



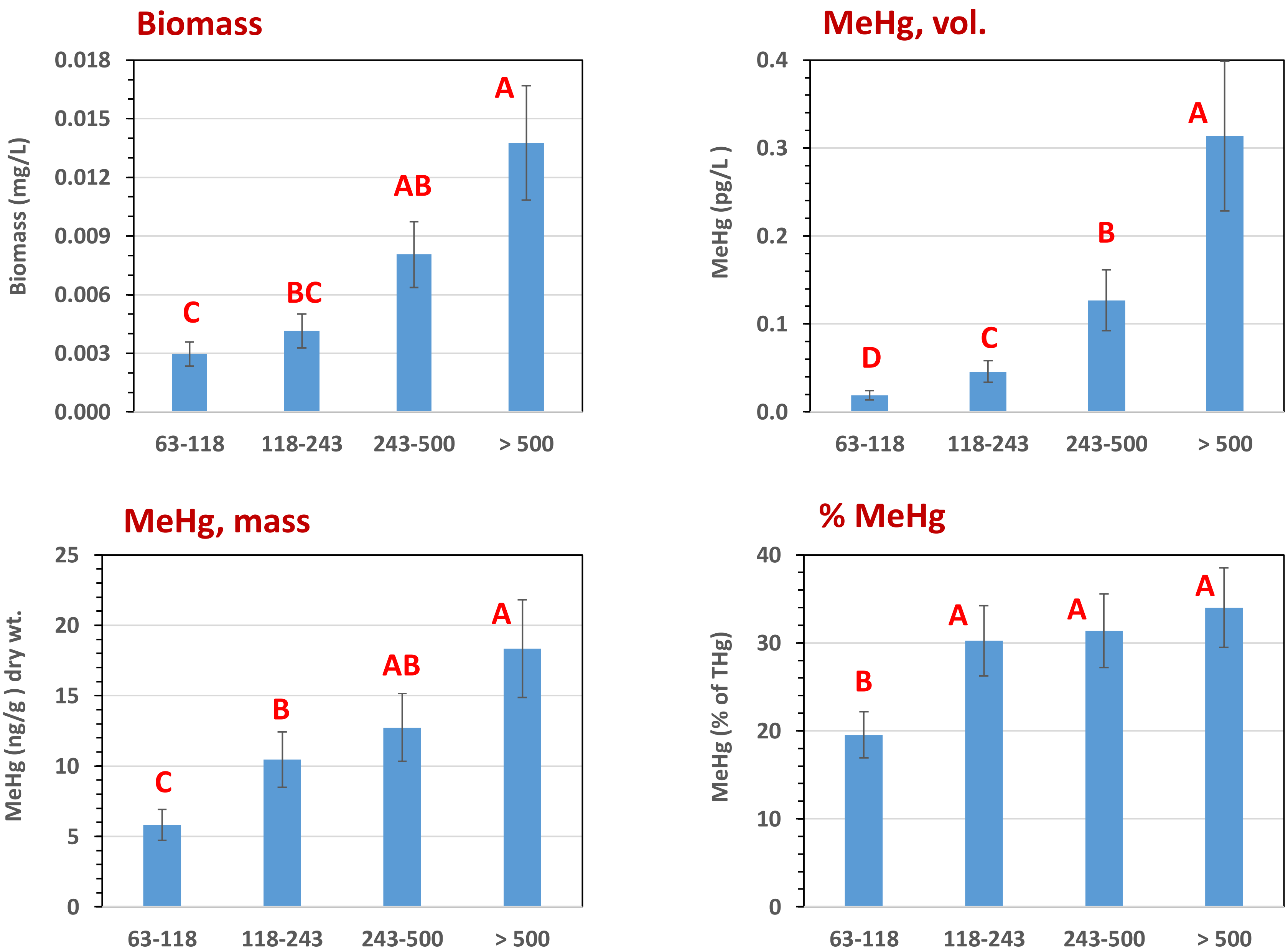
BULK Plankton: Mainstem vs Arms



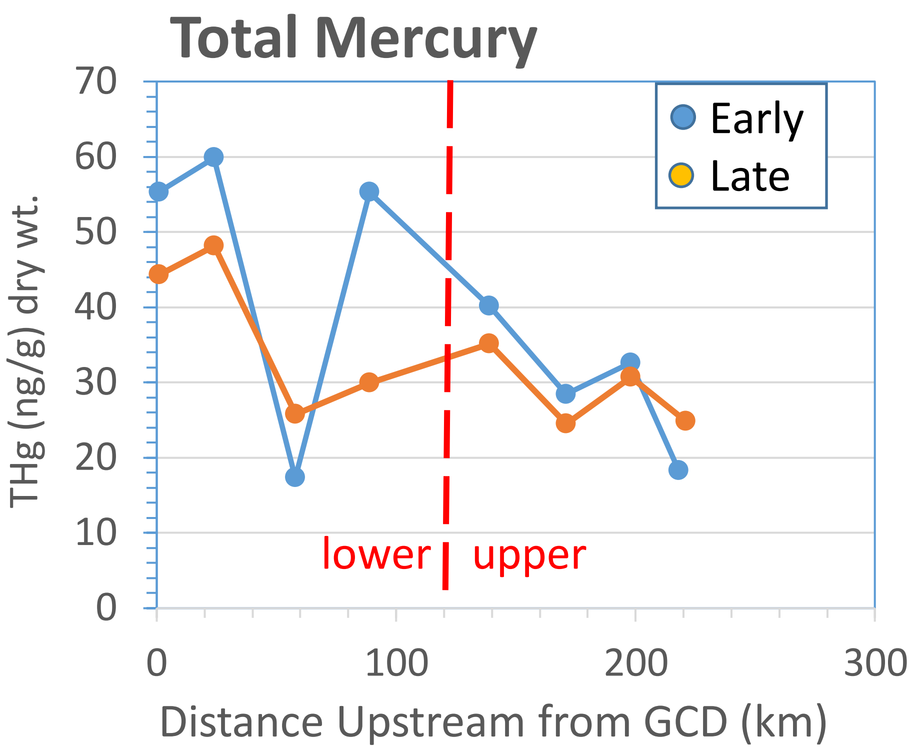
BULK Plankton: By SEASON

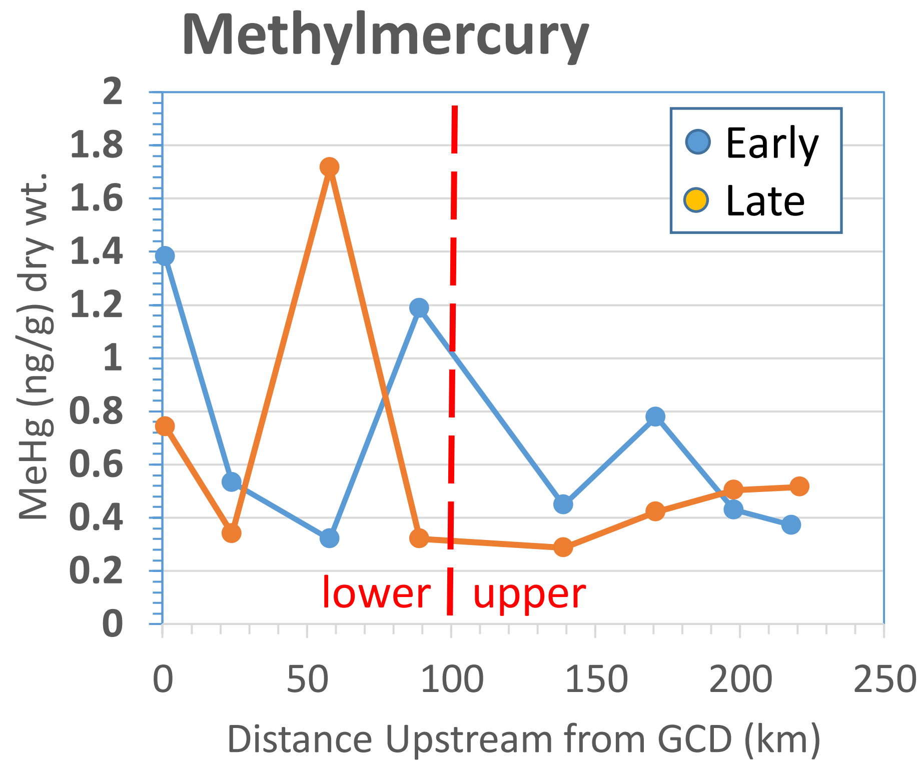


Plankton: By Size Fraction



SEDIMENT: Total-Hg and Methyl-Hg





Lower > Upper

Main = Arm

Early = Late

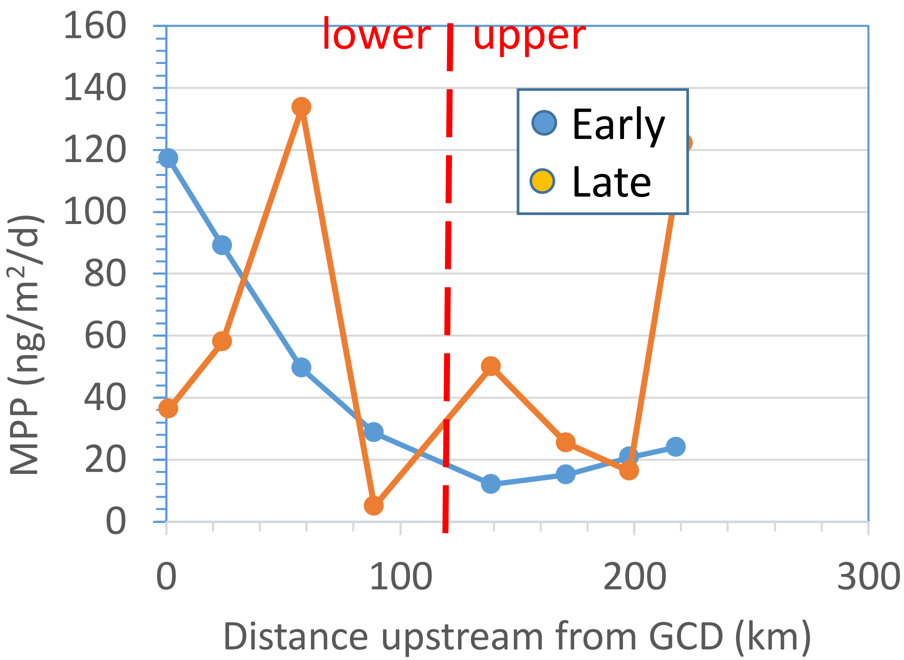
Lower = Upper

Main = Arm

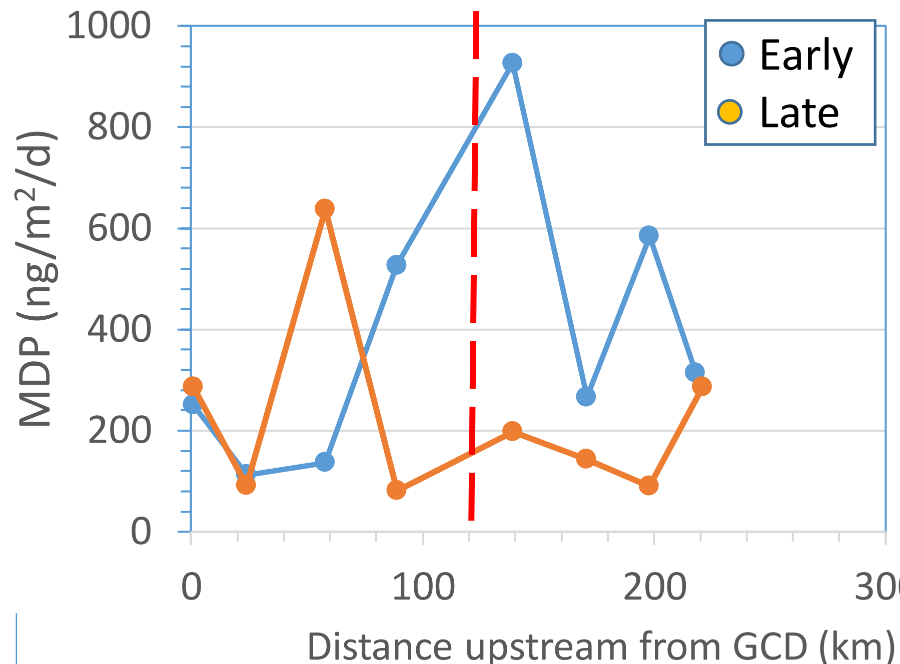
Early = Late

SEDIMENT: Potential Rates of MeHg Production and Degradation

Me^{200}Hg Production Potential Rate



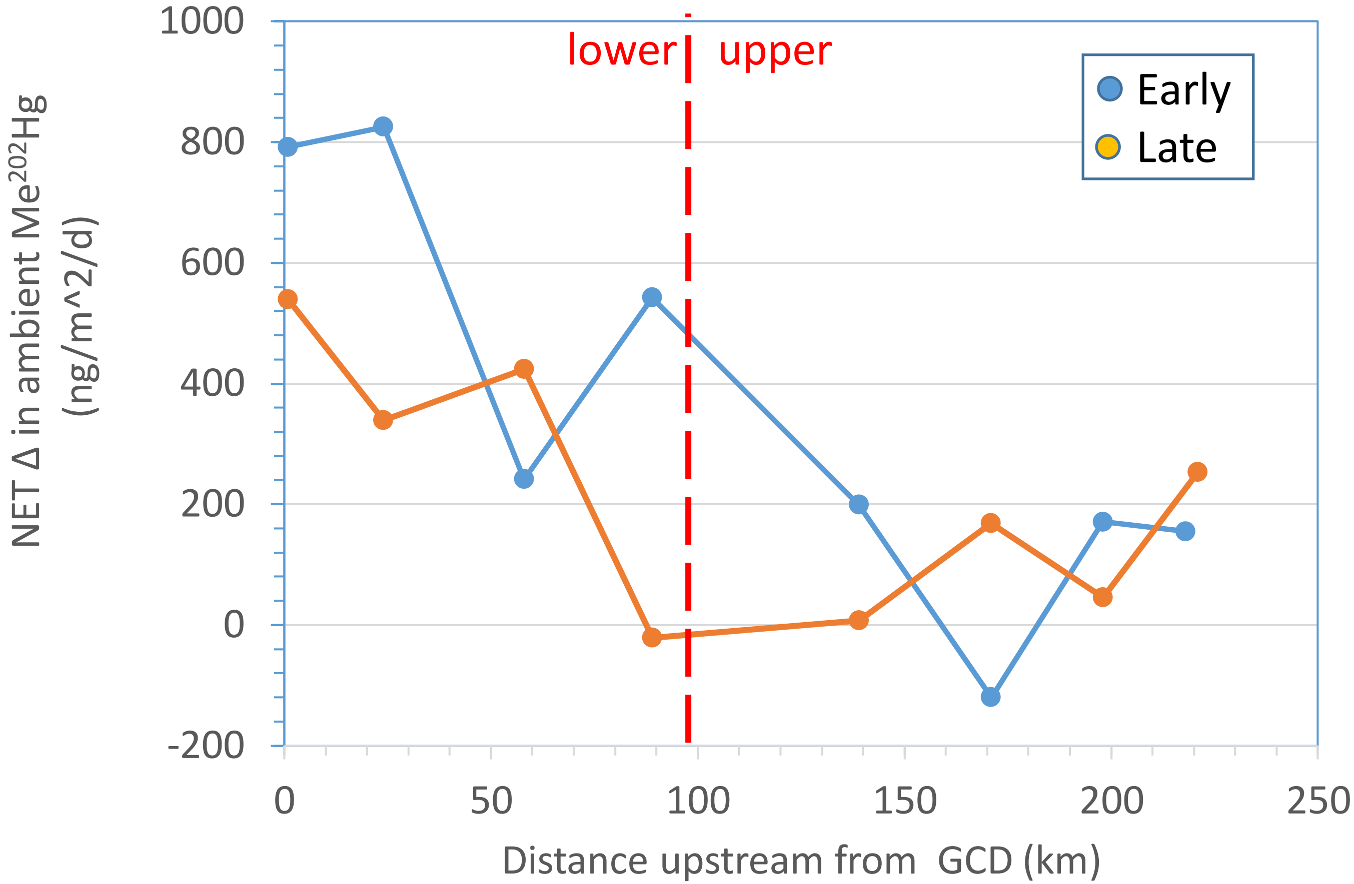
Me^{201}Hg Degradation Potential Rate



Lower	>	Upper
Main	>	Arm
Early	=	Late

Lower	=	Upper
Main	>	Arm
Early	=	Late

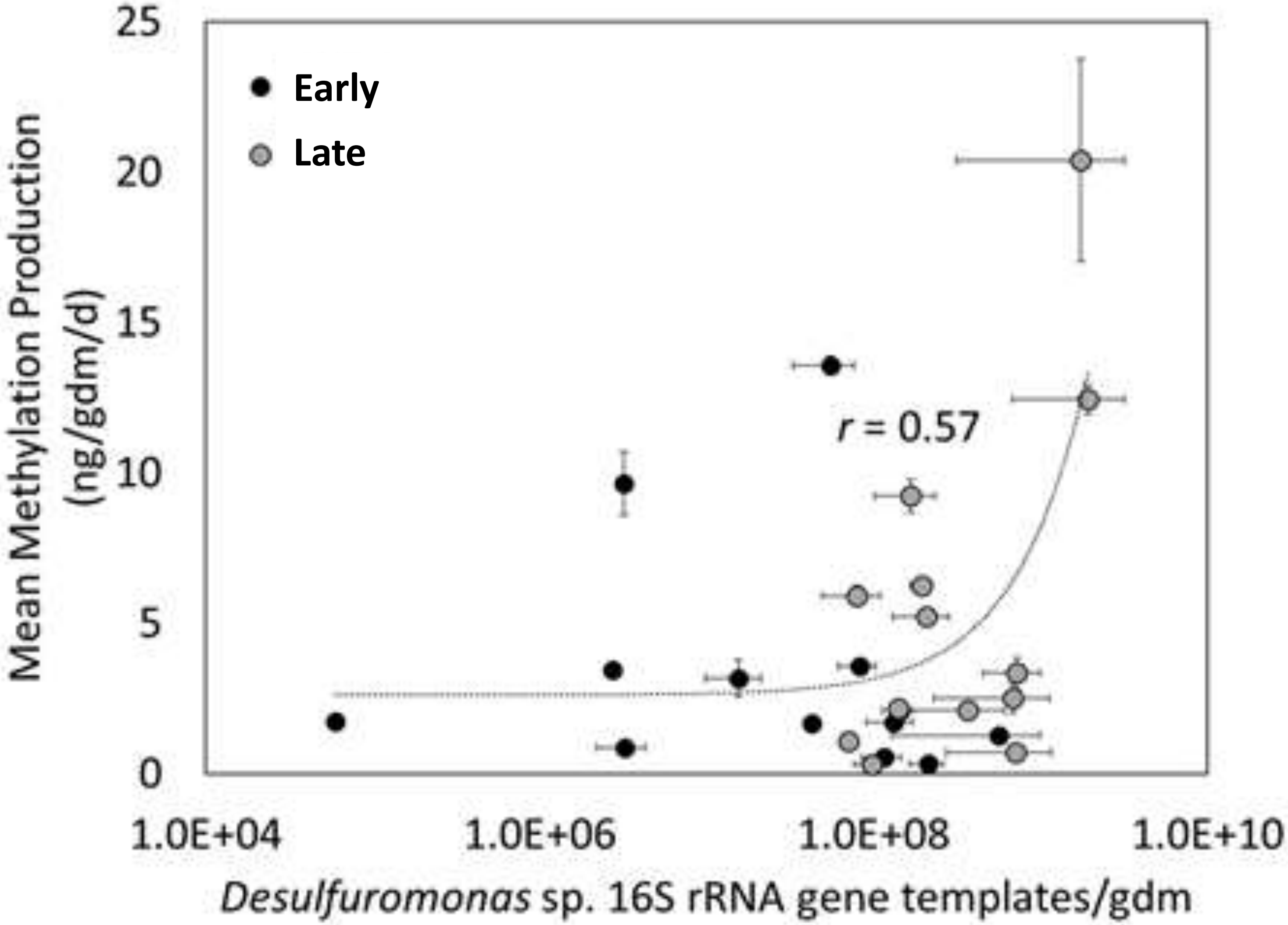
SEDIMENT: Net MeHg Production (ambient pool)



Lower	>	Upper

Main	=	Arm

Early	=	Late


Mean Methylation Production
(ng/gdm/d)
25
20
15
10
5
0
Early
Late
r = 0.57
1.0E+04
1.0E+06
1.0E+08
1.0E+10
Desulfuromonas sp. 16S rRNA gene templates/gdm

CONCLUSIONS

Why is striped bass Hg elevated in lower Lake Powell?

- Decreasing turbidity → higher %.POC / phytoplankton → higher MeHg production (benthos and water column (?)) → shift in MeHg partitioning towards particulates → enhanced uptake into plankton (base of foodweb)

- Verified: previously observed fish trend (upper vs lower)

- Demonstrated: The importance of tributaries / side canyons as important zones for elevated MeHg concentration in water, plankton and striped bass

- Demonstrated: Elevated water column MeHg during the low-flow late season (August) compared to the early season (May/June). BUT plankton MeHg is more elevated in the early season

en.wikipedia.org/wiki/Lake_Powell

What Made This Study Successful?

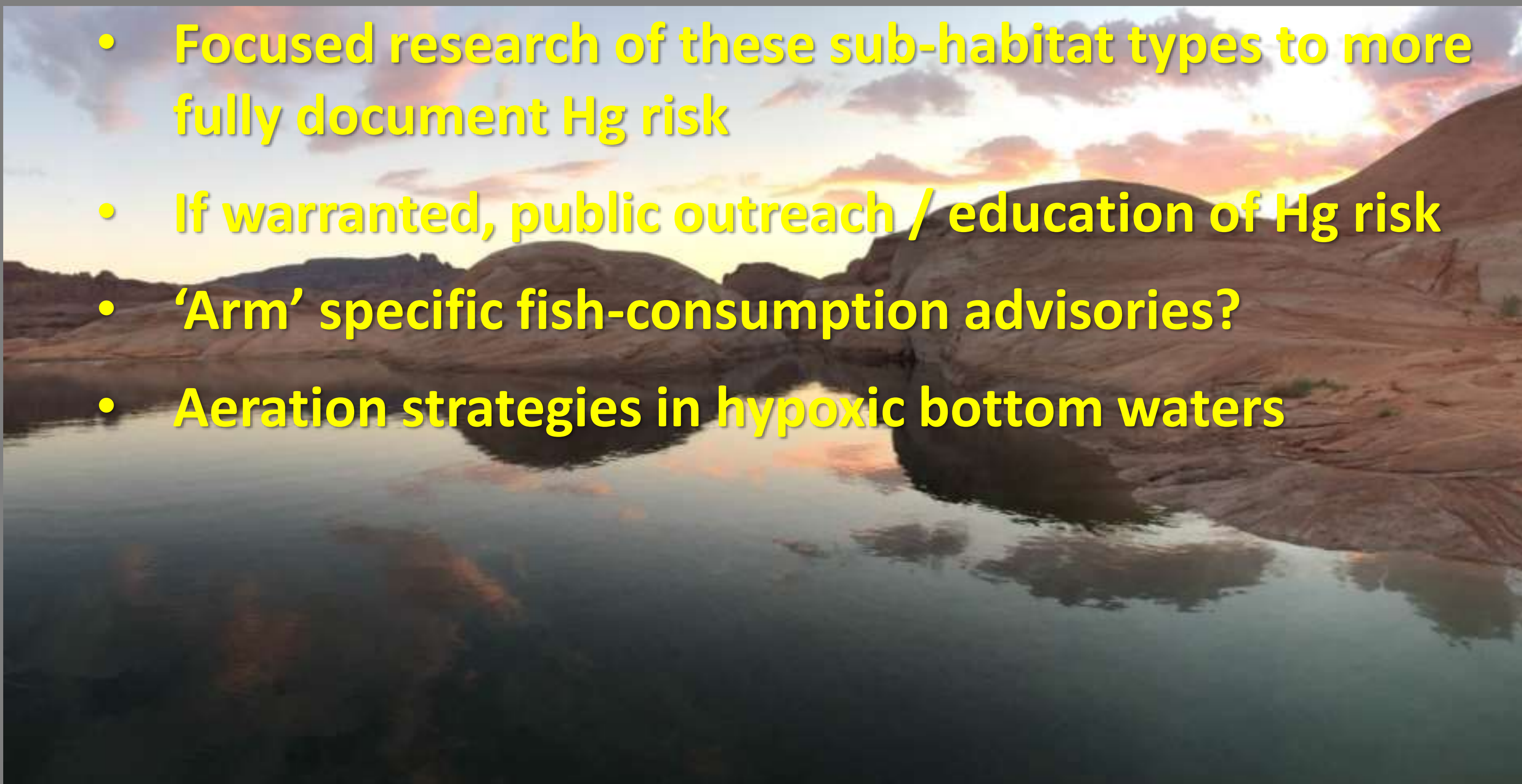
- Began with a conceptual model
- Designed with statistically testable hypotheses in mind
- Emphasis on processes (e.g. plankton dynamics),
  [not just Hg concentrations]
- Considered NON-Hg chemistry
- Considered seasonal dynamics
- The use of stable isotopes as a investigative tool
- High-resolution vertical profiles of water quality
- Studied the reservoir holistically
  - ► sediment, water, plankton, fish
  - ► drivers of Hg speciation (chemical form) and phase
  - ► spatial considerations (shallow / deep; upper / lower)

Study Limitations / Hindsight View

- Limited temporal sampling (and different years)
- No assessment of THg or MeHg load / flux / trapping
- No taxonomy on the plankton size fractions
- Initial under appreciation of the potential importance of 'arm' type sites
- Potentially important processes not assessed
  - photo-degradation of MeHg
  - water column MeHg production
- Not fully resolved: The relative importance of sediment vs the water column as zones of MeHg production

Next Steps / Mercury ‘Fixes’ for Lake Powell?

Side Canyons / Tributaries / Embayments



- Focused research of these sub-habitat types to more fully document Hg risk
- If warranted, public outreach / education of Hg risk
- ‘Arm’ specific fish-consumption advisories?
- Aeration strategies in hypoxic bottom waters