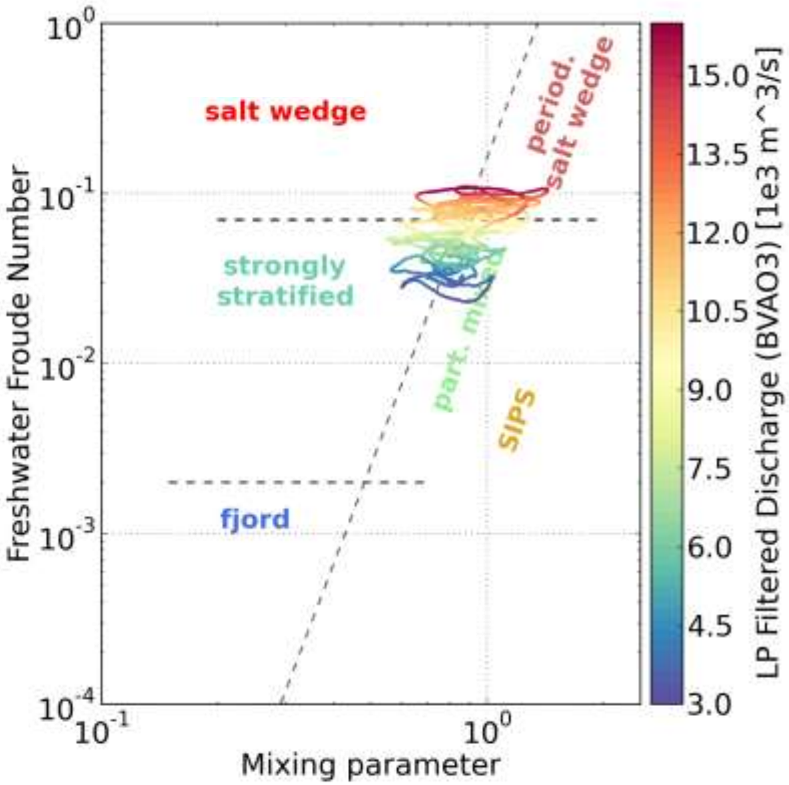
Fast prediction of river influences on the estuary, **and why it matters**



Estuarine classification scheme: R. Geyer and P. MacCready
Placement of Columbia River: T. Kärnä and A. Baptista

António M. Baptista, OHSU

Credit:

Kurt Fresh, NOAA

Dan Bottom, NOAA

Jessica Miller, OSU

Krista Jones, USGS

Hans Moritz, USACE

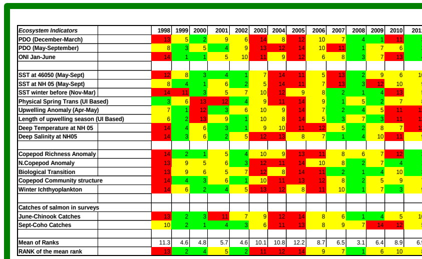
Cynthia Studebaker, USACE

Rob Lothrop, CRITFC

The CMOP (www.stccmop.org) team @ OHSU, OSU and UW

Acknowledgements and disclaimer

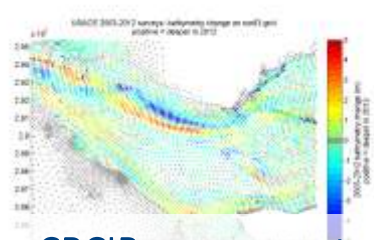
Various agencies have funded this work, and many collaborators have patiently taught each other the basics and tools of their disciplines, so that a shared understanding could be built. **However, opinions expressed are those of the presenter, and do not necessarily represent the opinion of collaborators or funding agencies.**



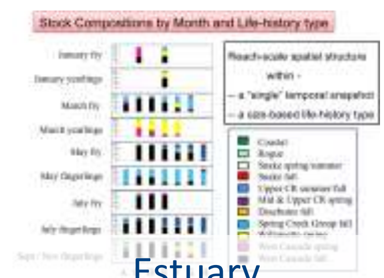
Plume

Lead PI: Kym Jacobson, NOAA

Lead PI: António Baptista, OHSU



CRCIP assessment

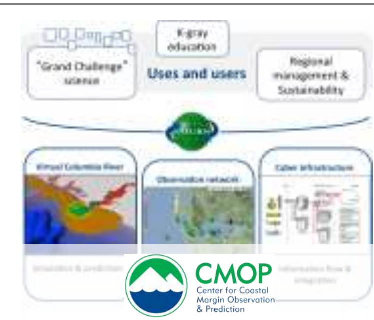


Estuary

Lead PI: Dan Bottom, NOAA

Lead PI: Krista Jones, USGS

CR Treaty Review



Lead PI: António Baptista, OHSU

Take-home message

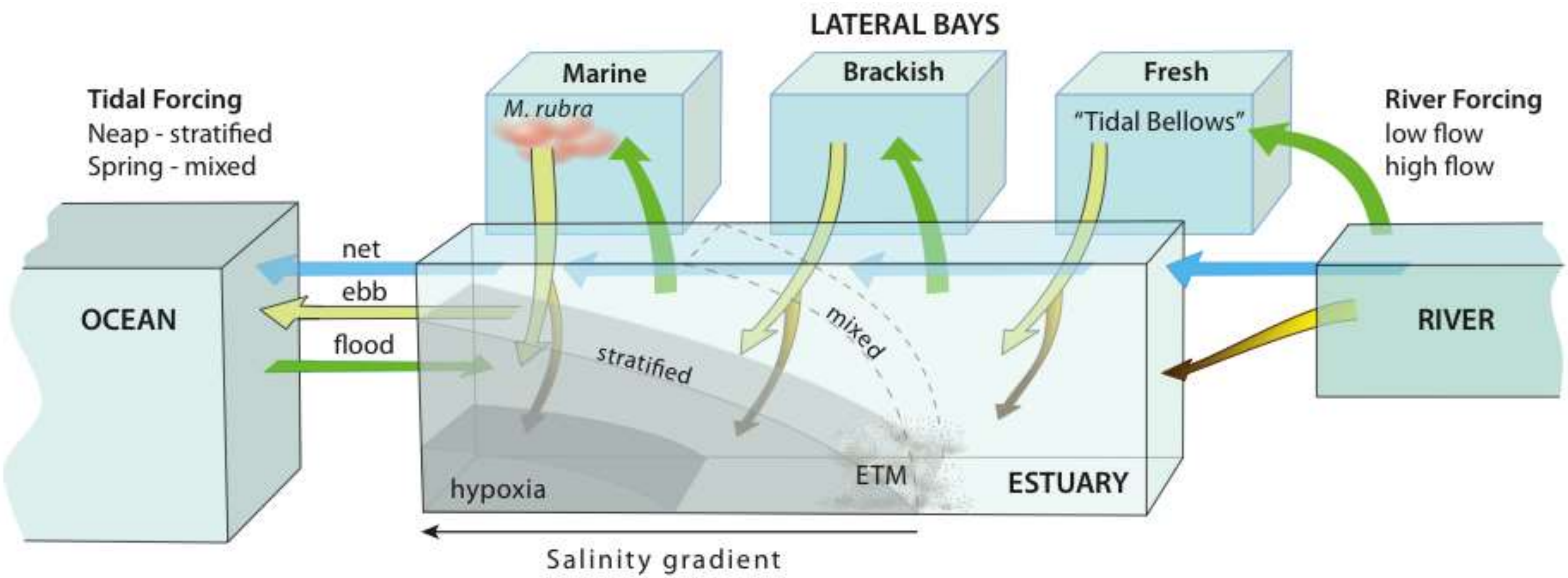
- The estuary—defined across the river-to-ocean continuum—is an essential, complex and scarce regional resource
- The FCRPS controls estuarine physics, and thus key ecosystem services (bioreactor, salmon) of the estuary
- We can predict estuarine physics—and beyond—at different temporal scales and in excruciating spatial detail*
- Motivated by the CRTR, we now have fast predictors for salmon- and bioreactor-relevant physical metrics as a function of flows
- We thus have potentially transformative tools to guide daily, in-season and long-term adjustments of FCRPS flows, should these adjustments be beneficial to manage ecosystem services
- **Is it time for managers, operators, regulators and scientists, to work together to take advantage of this opportunity?**

As you listen, please focus on the concepts and possibilities, not on technical details

*** Caution: detail ≠ accuracy**

The Columbia River as an estuarine bioreactor

In spite of very low water residence times, the estuary functions at times as a "bioreactor" by processing and altering land and ocean inputs via active biological "hotspots"

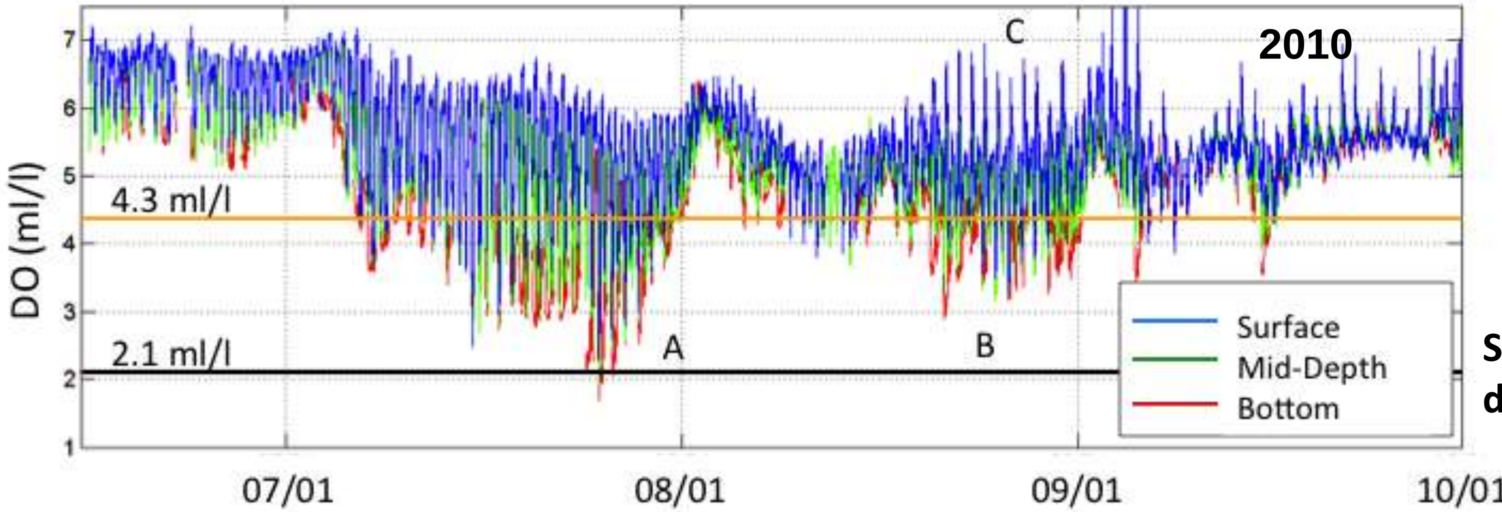


Look for a major synthesis of CMOP science in an upcoming thematic issue of L&O:F&E (2015)

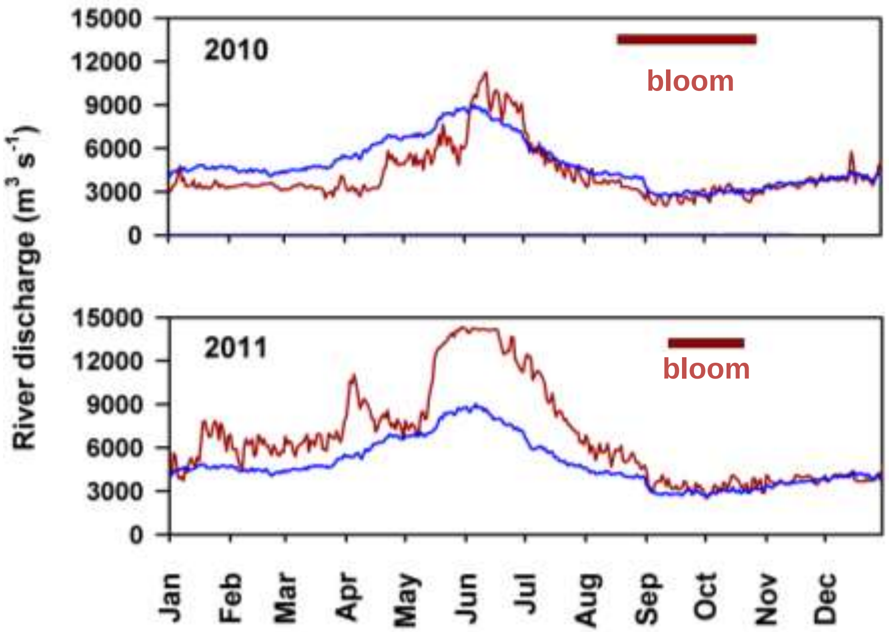
CMOP Center for Coastal Margin Observation & Prediction

Integrated Research Plan 2011

Example of biological mediation of ocean influences



SATURN-03 data



River threshold for the blooms: ~3,000-4,000m^3/s

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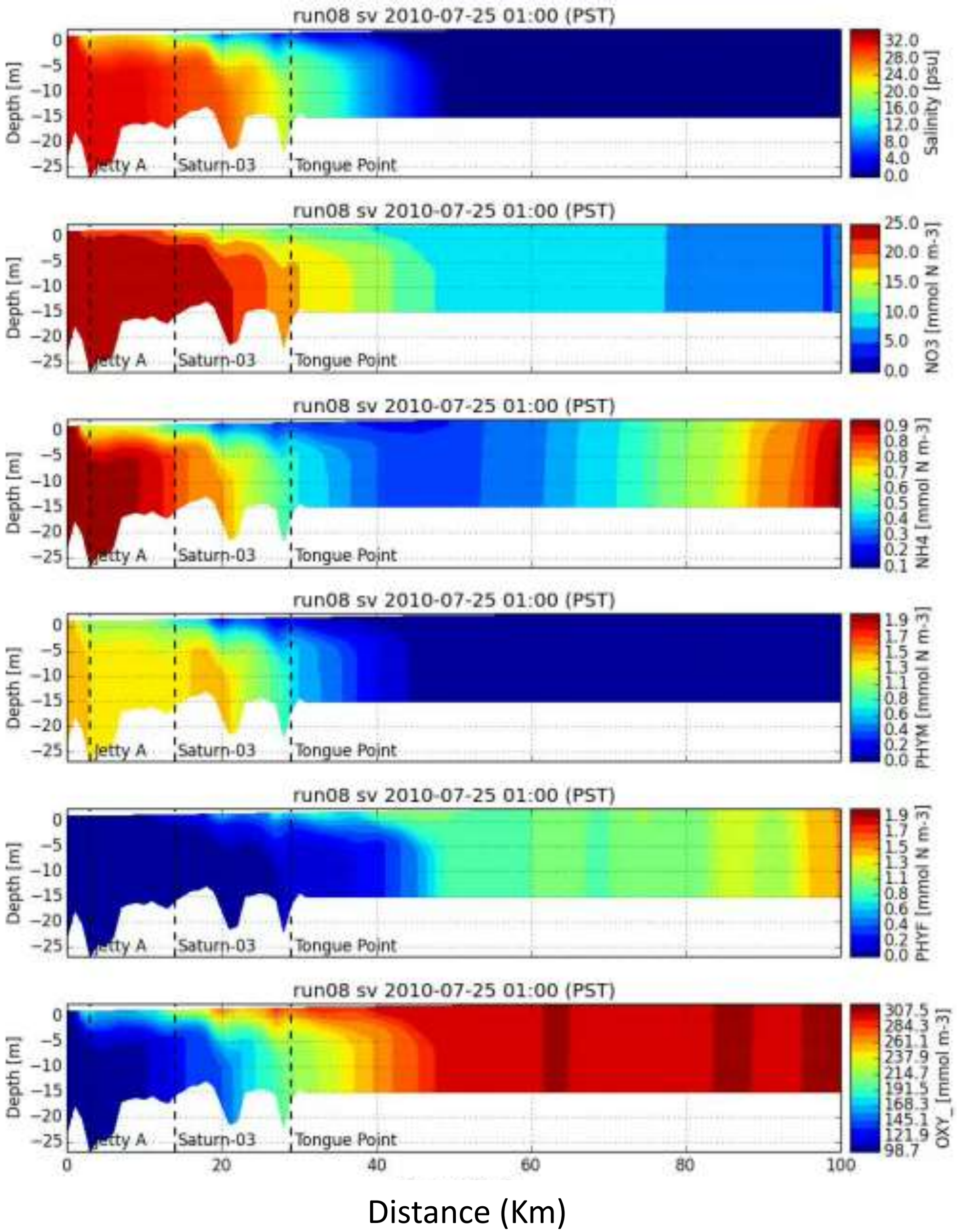
Salinity as an indicator of ocean influences



Salinity

Nitrate

Ammonium

Marine Phytoplankton

Freshwater Phytoplankton

Oxygen

Llebot et al., in prep.

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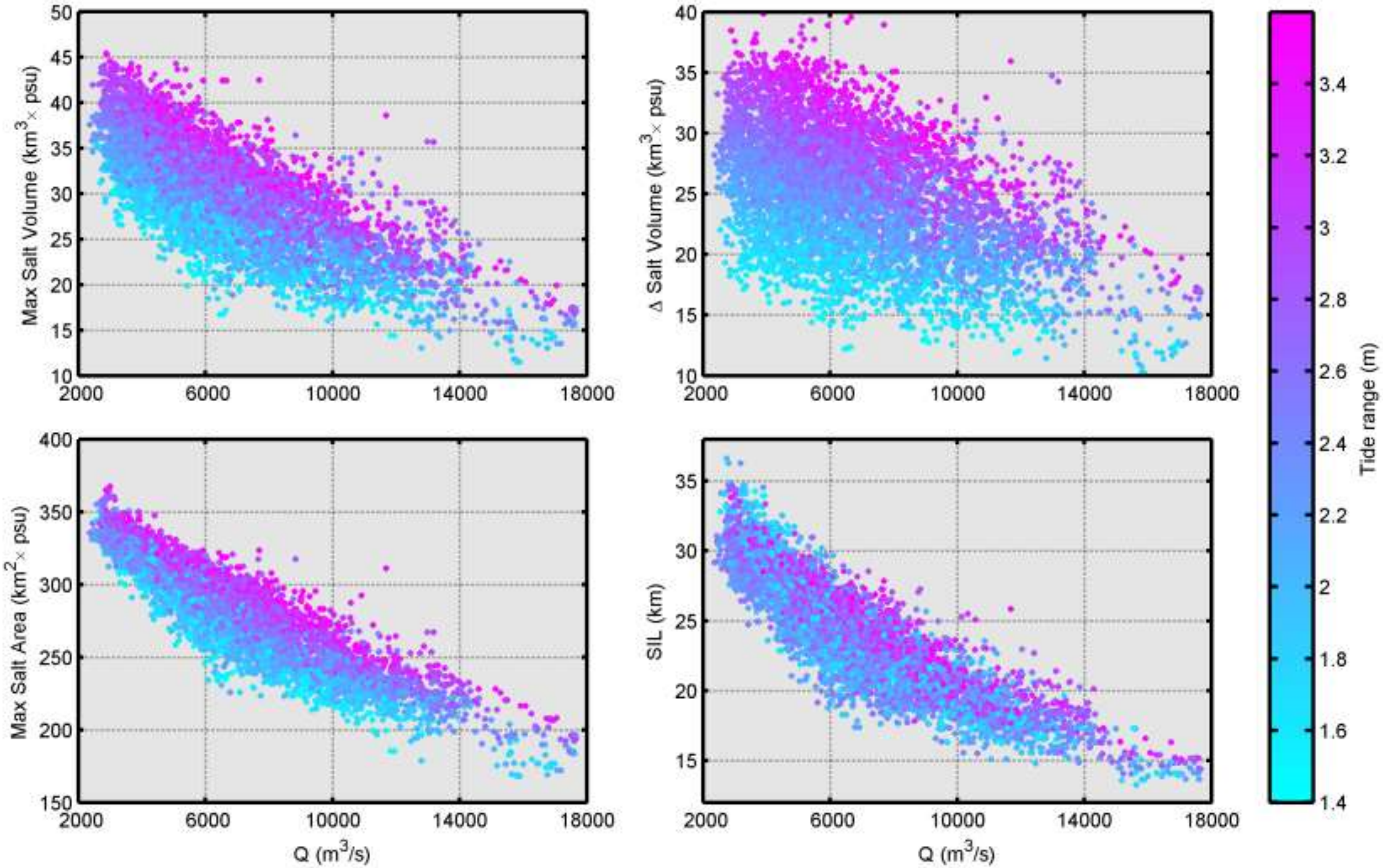
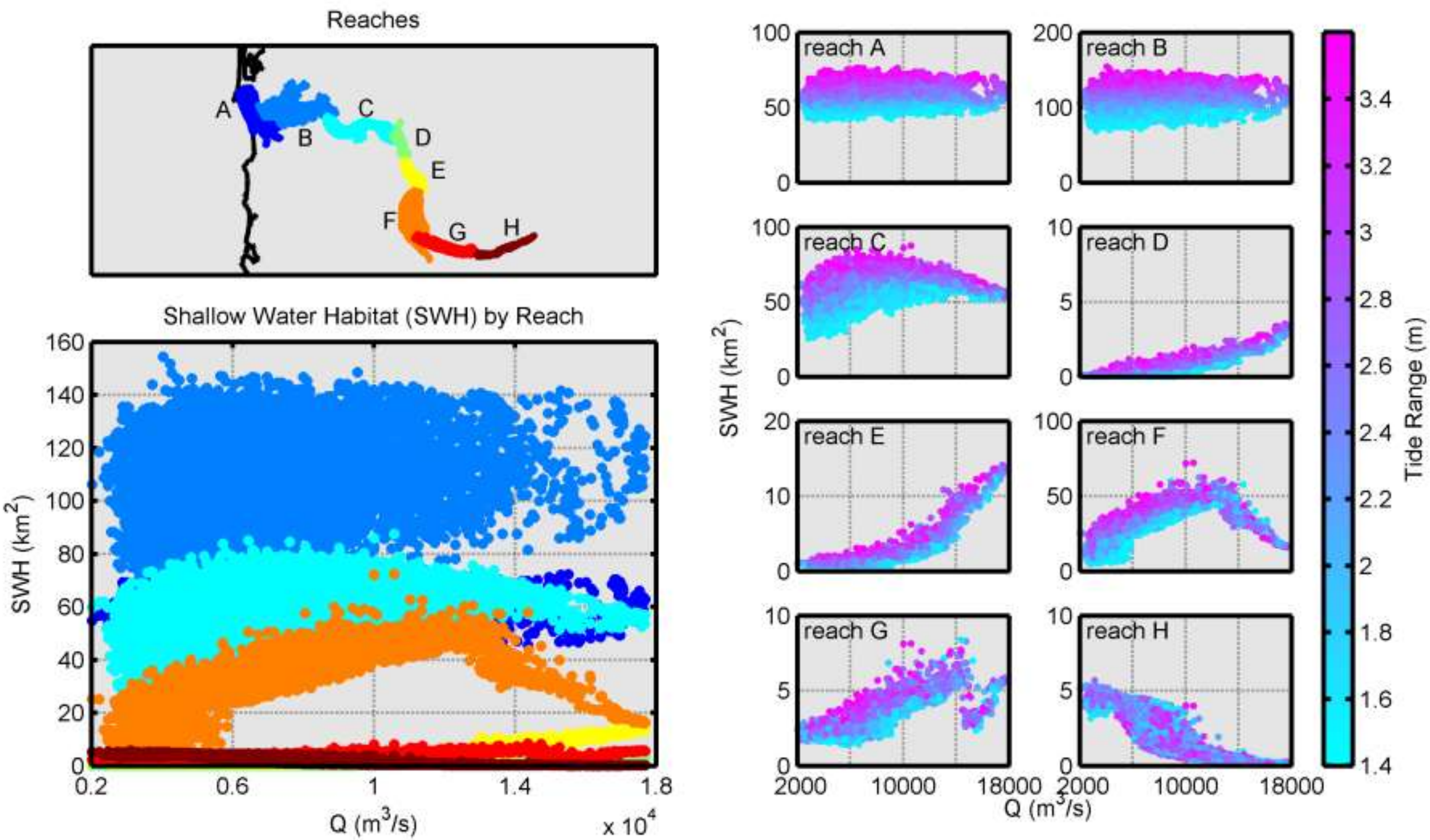
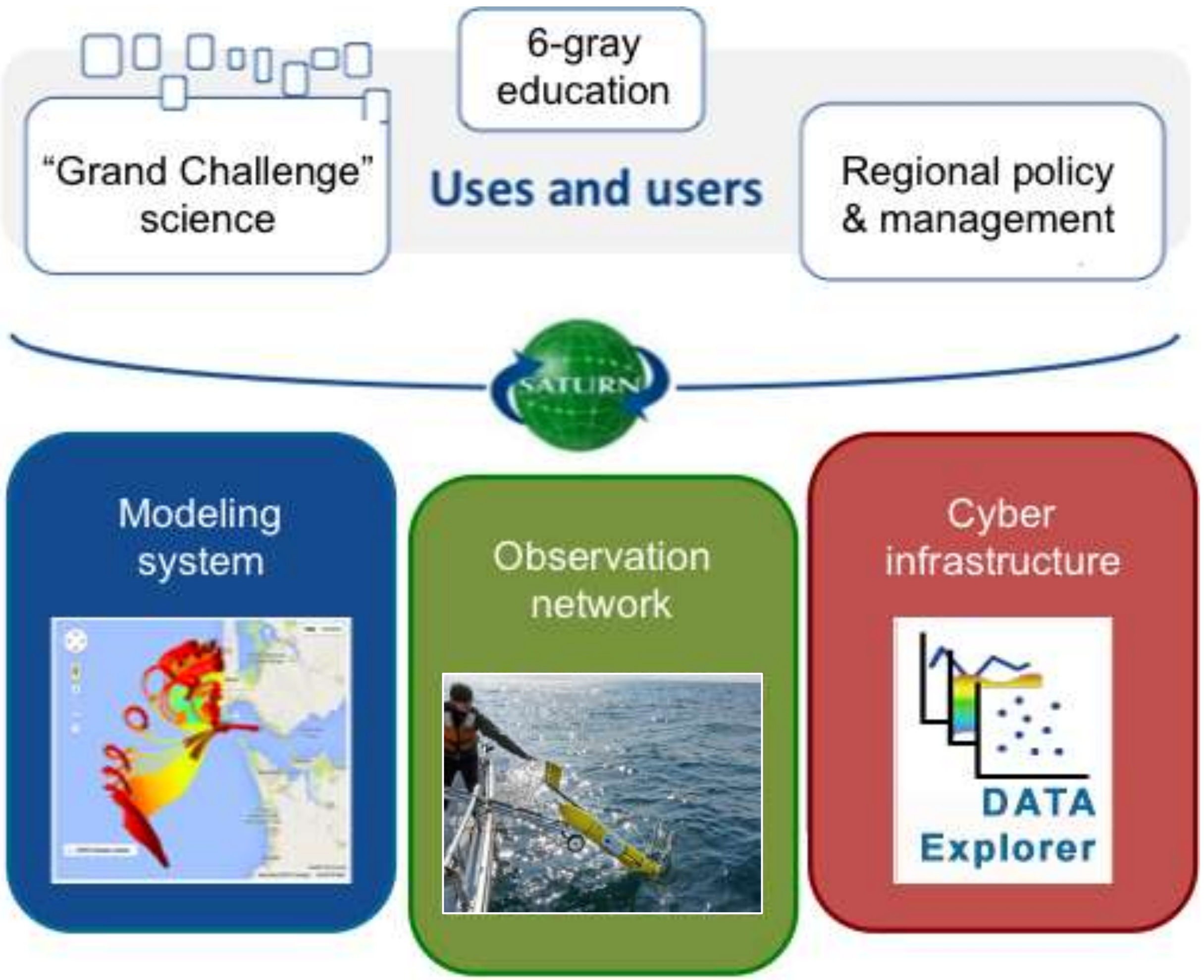
Response of salinity intrusion to river flows



Response of shallow water habitat to river flows

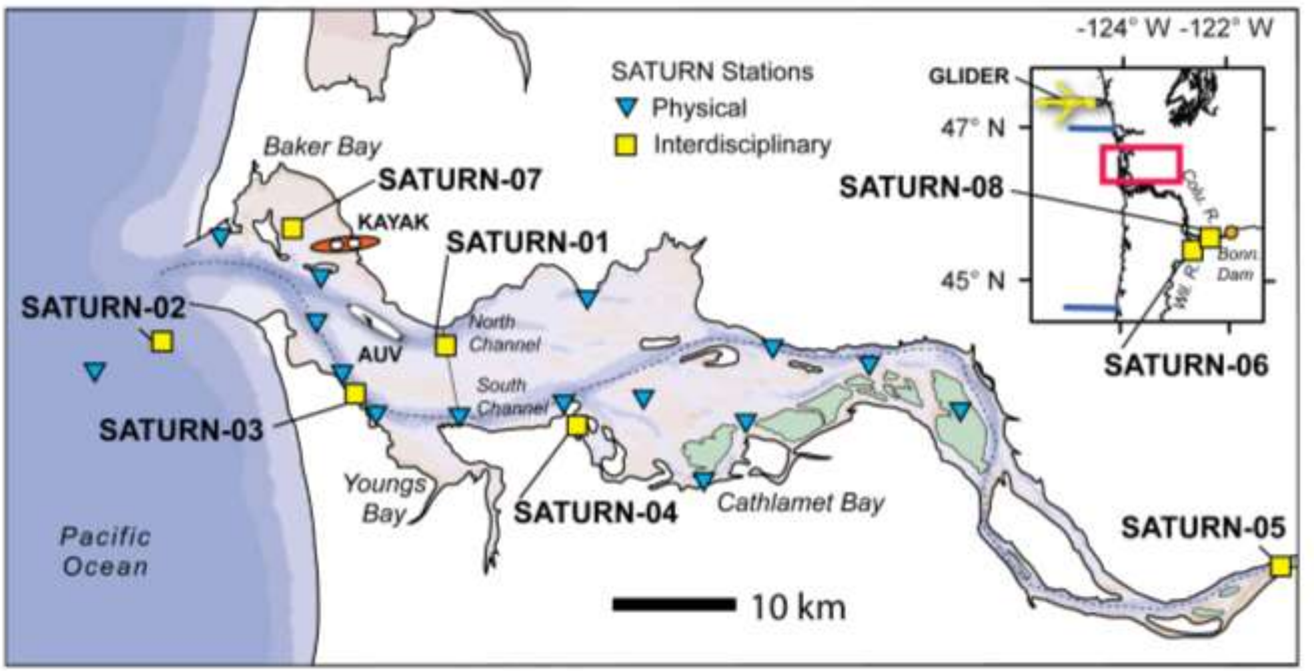


The SATURN *collaboratory*



http://www.stccmop.org/saturn

The SATURN observation network



http://www.stccmop.org/datamart/observation_network

Endurance stations

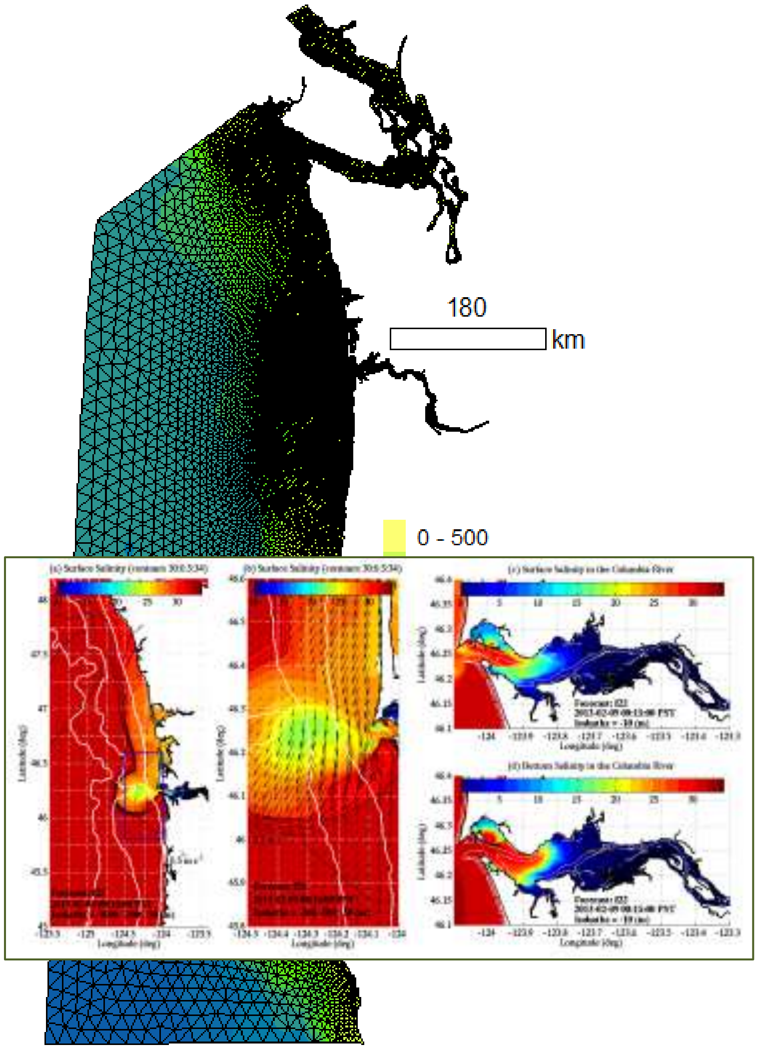
- Interdisciplinary stations (SATURN-01 through 08)
  - Profiler (01)
  - Dock-access stations (03, 04)
- Physical stations

Pioneer array

- Glider (Sloccum; WA shelf)
- 2 AUVs (Remus-100; plume and North channel)
- Bottom nodes
- Kayak (Baker Bay)
- Cruises

SATURN modeling system (the *Virtual Columbia River*)

- River-to-ocean domain
- Unstructured horizontal grids of O(100,000) nodes, with highest resolution in the estuary
- O(50) vertical layers
- Realistic bathymetry and river, ocean and atmospheric forcing
- Circulation modeling: operational products include daily forecasts, **15y simulation databases**, climatology
- Modeling of sediments and biogeochemistry: current focus on development and process studies
- Computationally demanding



- The CRTR required the calculation of salmon-relevant ecosystem metrics from high-resolution simulations of 3D circulation conducted with a finite element model.
- Straightforward, right? After all, we have the advantage of a powerful observation and prediction system built with this type of requirements in mind!
- Except that …

  … the metrics needed to be computed over 70 years, for 11 alternative scenarios, in a grid with over 4M nodes

  … and the results were needed approximately a month after the management scenarios became available

The challenge

To extract useful and scientifically defensible results from a complex numerical circulation model taken far outside of its computational comfort zone

	Run time	Storage
1 year of simulation*:	**2.5 weeks** (0.6x)	**5 TB**
x 70 years:	**175** (44x)	**350**
x 11 scenarios	**1925** (481x)	**3850**
/ 4 clusters	**481**** (120x)	
Time available	4 weeks	
Storage available	100 free out of 500 TB total	

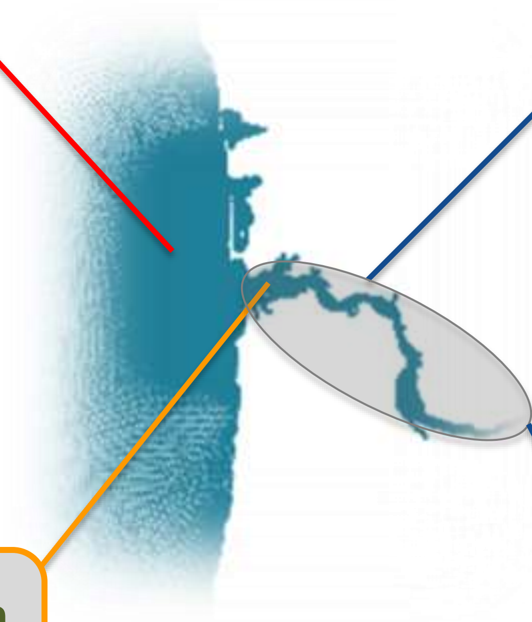
* On a CMOP cluster with 64 computing cores

** If the lead investigator were to retire in 10 years, he would see the results just a few months before retirement

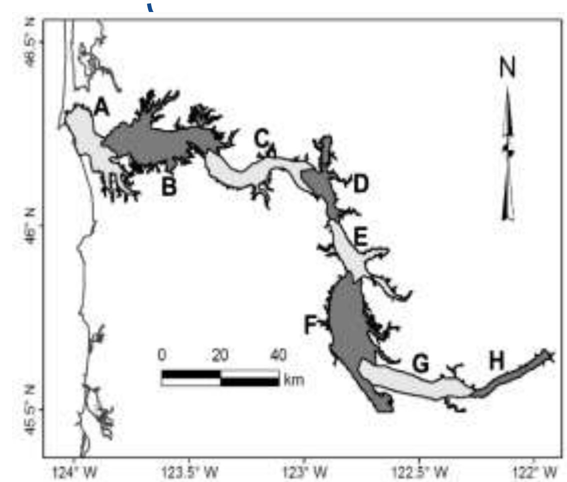
The solution: focus directly on the metrics

Target ecosystem metrics

Plume volume (PV)



Salmon Habitat Opportunity (SHO)

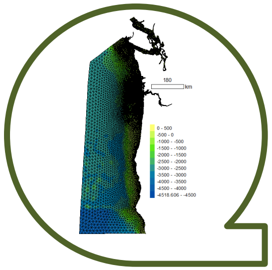


Salinity Intrusion Length (SIL)

Shallow Water Habitat (SWH)

All metrics are computable from η, $\vec{U}$, S, T

What we would normally do …



SIL time series

PV time series

SWH time series

SHO time series

Virtual Columbia River

- **70 years x 11 scenarios**
- **η, $\vec{U}$, S, T**

… is computationally unfeasible (run time, storage)

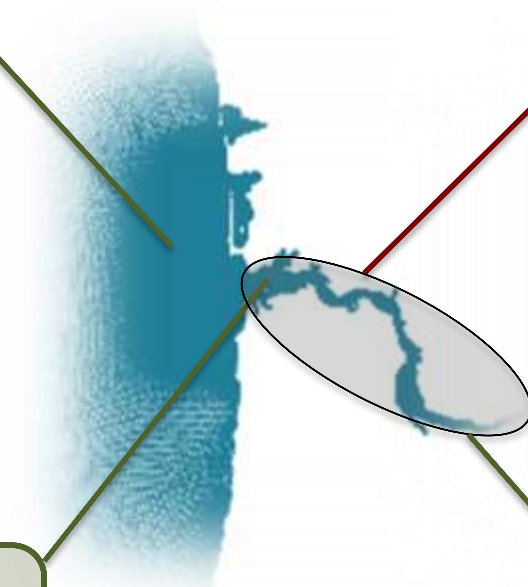
Alternatives:

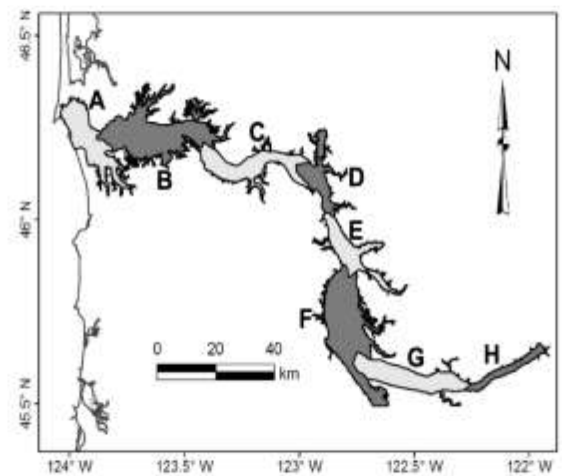
- Can we **train** multivariate regressions of the metrics relative to Q and other key forcing, that are adequately predictive?
- When regressions are not satisfactory, can we **train** machine-learning based fast model surrogates (van der Merwe et al. 2007; Frolov et al. 2009; Frolov et al. 2012) to predict η, $\vec{U}$, S, T "accurately enough" and then compute metrics from these approximate fields?

Correlation analysis: r^2 for the various metrics

Plume volume
(r^2=0.70)

Salmon Habitat Opportunity
(not significant)

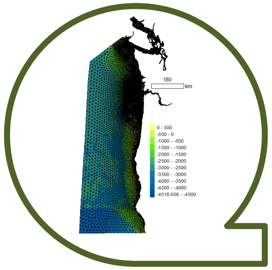




Salinity Intrusion Length (r^2=0.88)

Shallow Water Habitat (r^2=0.90)

Run times for Correlation Analysis



Virtual Columbia River

- **DB31 (1999, 2001, 2011, 2012)**
- **η, $\vec{U}$, S, T**

SIL time series 4y — O (1h) → SIL regression factors — O (s)

PV time series 4y — O (1h) → PV regression factors — O (s)

SWH time series 4y — O (5h) → SWH regression factors — O (s)

SHO time series 4y → SHO regression factors

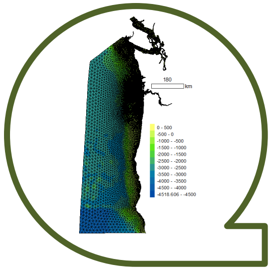
SIL time series (70 y x 11 scenarios) — O (s)

PV time series (70 y x 11 scenarios) — O (s)

SWH time series (70 y x 11 scenarios) — O (s)

SHO time series (70 y x 11 scenarios)

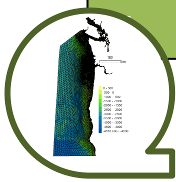
Run times for Surrogate Analysis



Virtual Columbia River

- DB31 (1999, 2001, 2011, 2012)
- η, $\vec{U}$, S, T

Training of surrogates



Hours

Prediction of EOFs (11x70y)

O(0.5d)
- O (1h/y/processor)
- 256 processors

Loop on 11 scenarios
- Loop on 70 years

Time series of SIL, PV, SWH and SHO

Time series of η, U, S, T

O(4.5d)
- O(9h/y/processor)
- 256 processors

By-passes the 3850 TB requirement

Synthesis and inferences

- A combination of strategies (correlations and surrogates, trained on pre-existing, extensive simulation databases of circulation) allowed the calculations of salmon-relevant metrics for 77 CRTR scenario x years of river flow in less than a month – with "enough accuracy" (Baptista et al., in prep.; Frolov et al., in prep.)
- With lessons learned, this translates into seconds of simulation for O(weeklong) predictions—the type of computational speed that is needed for real-time operational decisions and that has not been available till now
- The same or similar metrics and calculations are also useful to anticipate key responses of the bioreactor to river flows
- **While many scientific challenges remain in understanding and modeling estuarine services (salmon, bioreactor)**, the toolset now available is already potentially transformative in practice—if its incorporation in FCRPS management and operation is desired

Could FCRPS flows be used to proactively steer the bioreactor and salmon habitat towards desirable targets? Examples:

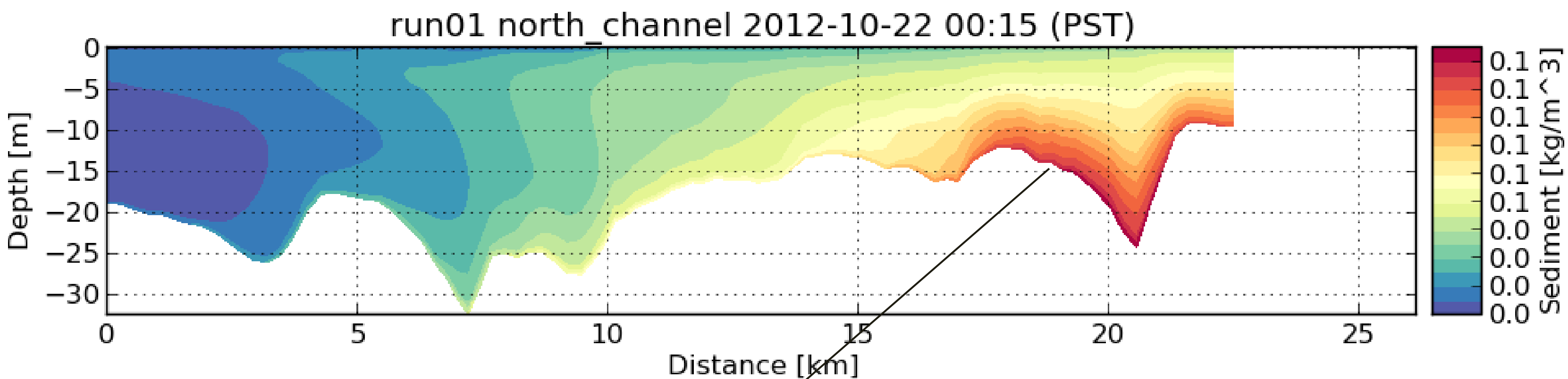
1. Mitigation of estuarine hypoxia/acidification through short-term increases (to reduce salinity intrusion length) or decreases (to promote *Mesodinium* blooms) in flows at Bonneville Dam

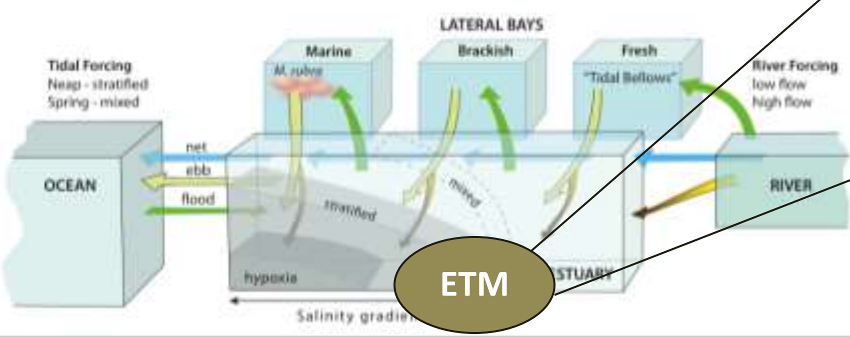
2. Selective amelioration, through limited water releases, of the habitat and ocean-entry conditions for specific salmon stocks, as they use specific regions of the estuary for rearing or migration;

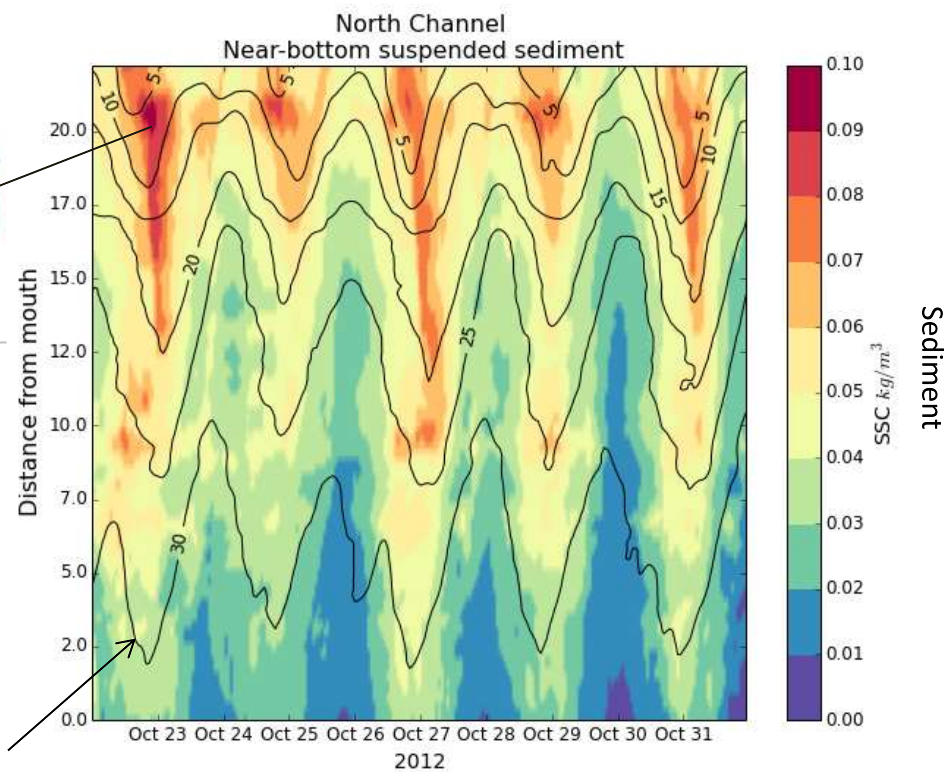
3. Operation of the FCRPS as a tool for adaptive management of the estuary, as the estuary responds to climate change and as the TBD terms of a revised Columbia River Treaty are implemented

CMOP is available to host a regional workshop to explore this opportunity and foster associated dialogue

Happy to entertain any questions







Salinity

Reminder: *M. Major* blooms are only one of the biological hotspots that enable the bioreactor, and that are controllable via the FCRPS

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Lopez et al., in prep.