Phytoplankton & Primary Production

December 6, 2022

Phytoplankton & Primary Production

Agenda

9:00 AM	Vital sign
9:10 AM	Changing primary productivity in the Salish Sea. A geochemical perspective
9:40 AM	Remote sensing technology to monitor ocean conditions
10:00 AM	Analyzing historical primary production data
10:05 AM	Bottom-up drivers of zooplankton food web structure and function
10:15 AM	Tools for sub-basin and inlet nutrient budgets
10:25 AM	Quantifying estuarine advective exchange with the Salish Sea Model
10:35 AM	Q&A
10:55 AM	Wrap-up

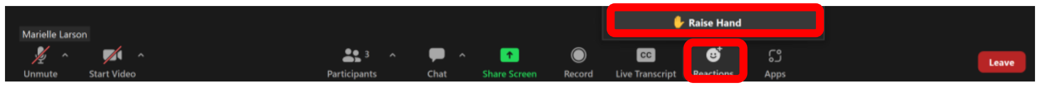
Navigating the Workshop

Welcome! While we wait, please:

- Update your name to include your pronouns and organization
- Message Marielle with any access needs
- Introduce yourself in the chat. We've muted participants and turned off your videos to minimize technical issues, so we encourage you to use the chat to say hello instead

Questions or Comments?

- Add them to the chat
- Raise your hand and we'll unmute you

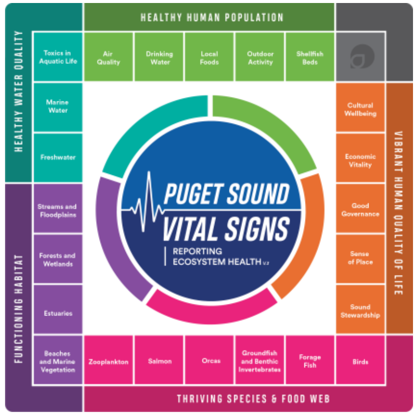


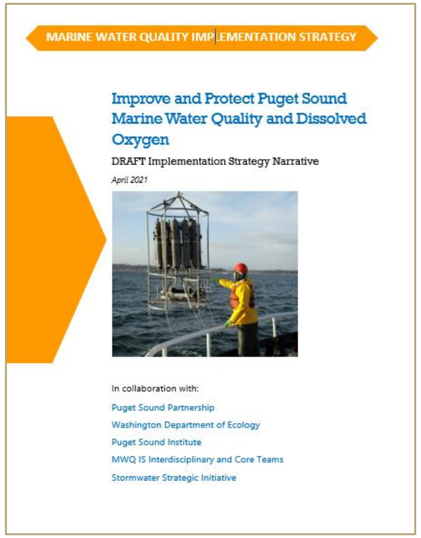
The slides, recording, and summary will be available on [Puget Sound Institute's website]


Land Acknowledgement

University of Washington Puget Sound Institute’s Role

Puget Sound Partnerships’ Marine Water Quality Implementation Strategy





MARINE WATER QUALITY IMPLEMENTATION STRATEGY

Improve and Protect Puget Sound Marine Water Quality and Dissolved Oxygen

DRAFT Implementation Strategy Narrative

April 2021

In collaboration with:

Puget Sound Partnership
Washington Department of Ecology
Puget Sound Institute
MWQ IS Interdisciplinary and Core Teams
Stormwater Strategic Initiative

Technical Uncertainties

Research, Modeling, and Monitoring to Reduce Uncertainties

Nutrient Science Community in Puget Sound

PUGET SOUND INSTITUTE
UNIVERSITY of WASHINGTON | TACOMA

SALISH SEA MODELING CENTER
UNIVERSITY of WASHINGTON

Help address technical uncertainties and advance modeling tools to assist decision-making.

- Facilitate scientific workshops and regional collaboration
- Convene Model Evaluation Group
- Lead complementary model runs
- Expand access to models, outputs, tools, and scientific knowledge

Refine Research Actions

Targeted Technical Uncertainties

- Improve confidence in modeling of the Salish Sea and share findings
- Kickoff (7/26)
- Tools to Evaluate Water Quality (9/29)
- Biological integrity of key habitats and species (10/6)
- Sediment exchange (10/19)
- Phytoplankton and primary production (12/6)

Upcoming Workshops

- **Watershed modeling (12/12)**
- **Interannual variability (week of 1/23)**

Improved Confidence in Actions

Driving Scientific Question

Considering future climate change, how do changes in density structure in response to the relative timing of coastal upwelling and earlier river discharge alter growth conditions for phytoplankton productivity?

Phytoplankton & Primary Production Vital Sign Development Workshops

Core Team

- Jude Apple, Dept. of Ecology at Padilla Bay
- Cheryl Greengrove, UW Tacoma
- Julia Bos, King County
- Ashley Bagley, Long Live the Kings

Phytoplankton Science Advisory Team

- Kim Stark & Gabriela Hannach, King County
- Teri King, Washington Sea Grant
- Jan Newton, NANOOS/UW
- Julie Keister & Evelyn Lessard, UW
- Julie Masura, UW Tacoma
- Neil Harrington, Jamestown S'Klallam Tribe
- Sylvia Yang, Dept. of Ecology at Padilla Bay

Funded by

PUGETSOUND PARTNERSHIP

EPA

Image Source: Sailors for the Sea

How are these workshops related?

UW Puget Sound Institute Workshops - help **address technical uncertainties and advance modeling tools** to improve confidence in modeling of the Salish Sea, share findings and assist with decision-making.

Phytoplankton & Primary Production Vital Sign Development Workshops – Bring together a community of experts and stakeholders to gather information on phytoplankton and primary production in Puget Sound and lay the foundational framework needed to integrate these critical components of the estuarine ecosystem into the Puget Sound Partnership’s Vital Sign Indicator matrix.

Phytoplankton & Primary Production Vital Sign

Phase I

June 17 2022

Phytoplankton & PP Data Inventory

Create inventory
Identify gaps

Full day, Hybrid

August 18 2022

Phytoplankton & PP Data Connectivity

Connect to other indicators & ecosystem recovery goals

½ day, Zoom

October 2022
January 2023

Existing Monitoring Programs & Indicators, Pts 1 and 2

Other estuaries: Monitoring programs & experts

2 x ½ day, Zoom

March 2023

Framework & Plan for Indicator Development

Brainstorm potential indicators
Groundwork for QAPP

Full day, Hybrid

Final Report:
Foundation for
VS & QAPP

Phase II
(not yet funded)

2023-2024

Develop Vital Signs and regional QAPP

PUGET SOUND PARTNERSHIP

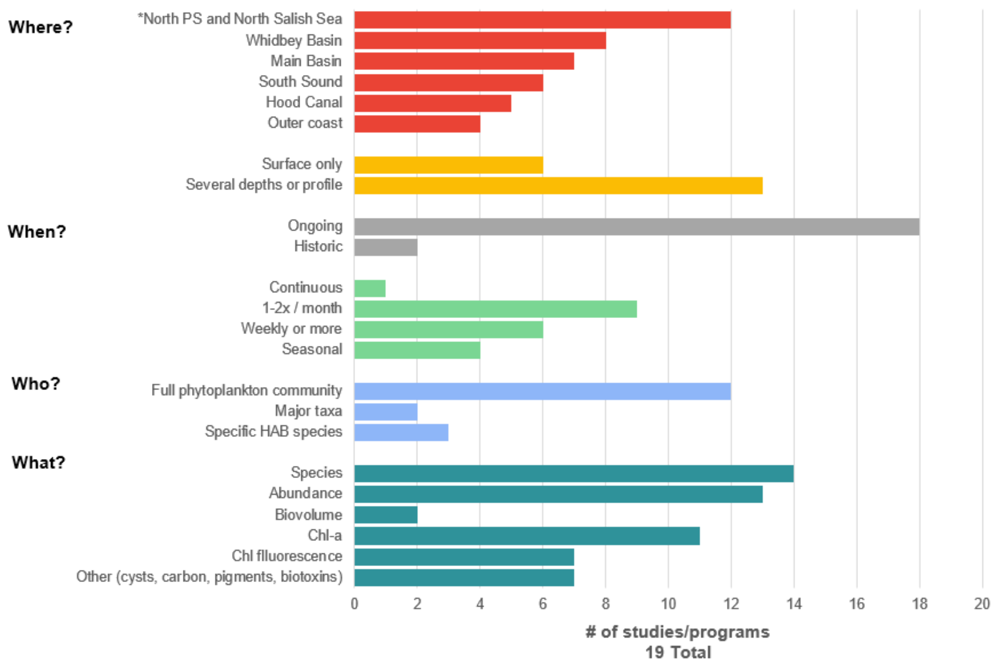
Vital Sign Workshop Highlights

#1
- **Got phytoplankton community and stakeholders together to brainstorm and share information**
- **Defined terms and definitions (i.e., rate vs. concentration)**
- **Developed monitoring inventory – still in process**

#2
- **Connected with other related Vital Sign Indicator developers**

#3
- **Shared a preliminary review of phytoplankton-based indicators in other estuaries**
  - Primary indicator: Chlorophyll a
  - Supporting lines of evidence: primary production, water clarity, chlorophyll fluorescence, pigments, community structure/composition, etc.
- **Highlighted the potential to combine satellite and in situ data**
- **Noted opportunity to analyze community compositing with Suzanne Strom's size fractionation**

Monitoring Inventory Survey Results



**Admiralty Inlet, Bellingham Bay, San Juan Islands, Strait of Juan de Fuca, and Strait of Georgia*

Vital Sign | Additional Workshop Information

Workshop #1 – Inventory
https://drive.google.com/drive/folders/1HZs9S6eg28gDhXt0qFVCbXEhd14tjnDZ?usp=share_link

Workshop #2 – Vital Signs
https://drive.google.com/drive/folders/1TyABEfY7n0ml7ehzCOS-XJLkVQIJbI41?usp=share_link

Workshop #3 – Other Estuary Experts
https://drive.google.com/drive/folders/1BY6G9IUM4jRzNhSXGrbQINSONPHgHrB6?usp=share_link

To get on the email list or if you have questions contact:

Ashley Bagley abagley@lltk.org

Changing primary productivity in the Salish Sea

A geochemical perspective

Sophia Johannessen
DFO Institute of Ocean Sciences

Total productivity vs. type of productivity

Controversy over 1970s primary productivity

(Strait of Georgia)

Parsons, 1970: 120 gC m^{-2} yr^{-1}

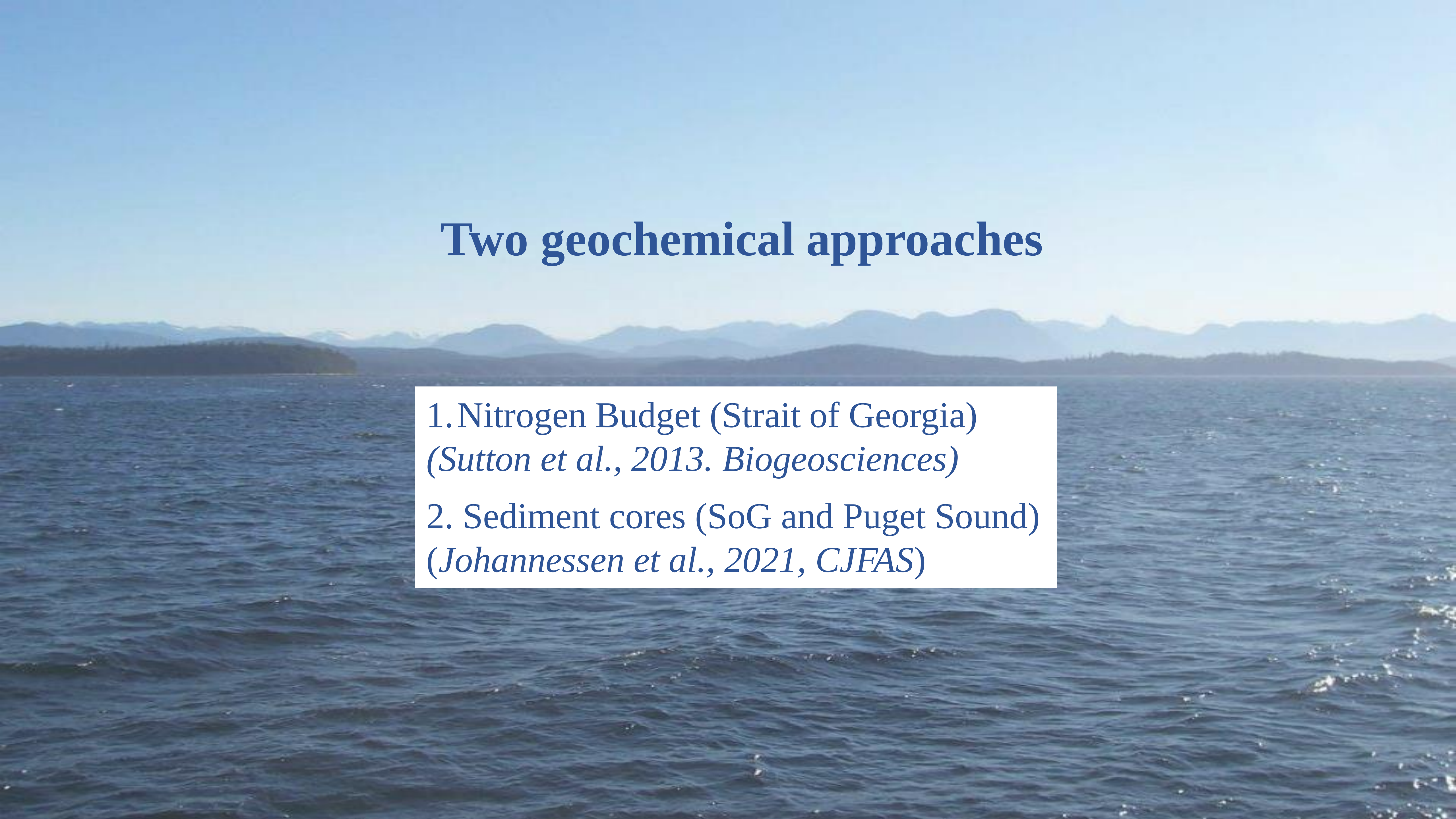
Stockner, 1979: 345 gC m^{-2} yr^{-1}

Eutrophication?

Harrison et al., 1983: 280 gC m^{-2} yr^{-1}
Can. J. Fish. Sci.

QUESTION 1: Has total primary productivity in the Salish Sea declined… or increased… since the 1970s?

- Fisheries models assumed 30% decrease
- Declining oxygen implied 250% increase



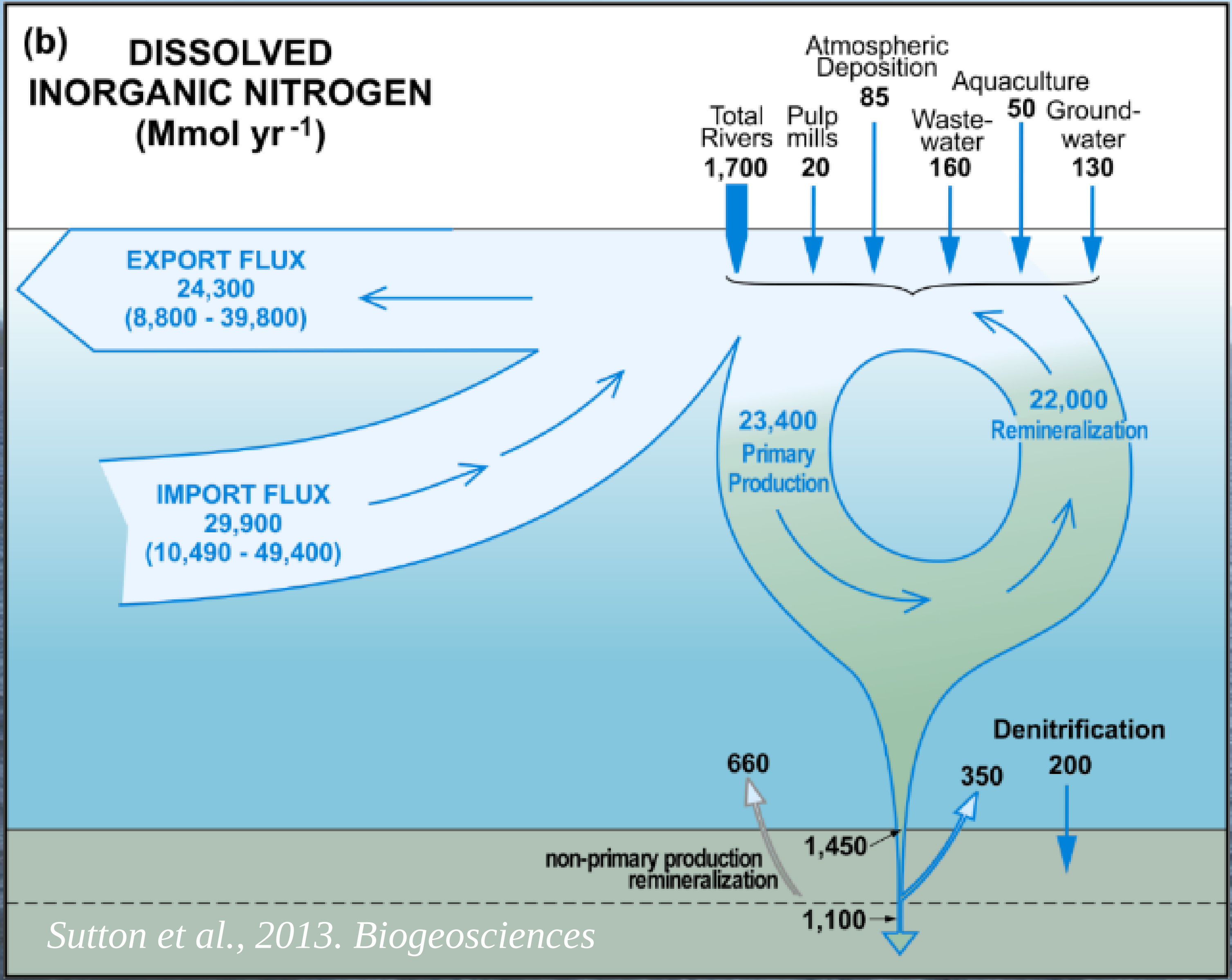
Two geochemical approaches

1. Nitrogen Budget (Strait of Georgia)
(Sutton et al., 2013. Biogeosciences)

2. Sediment cores (SoG and Puget Sound)
(*Johannessen et al., 2021, CJFAS*)

Nitrogen Budgets

Particulate and dissolved nitrogen, incl. stable isotopes



Sutton et al., 2013. Biogeosciences

Nitrogen budget result
(Strait of Georgia)

1970s (Harrison et al., 1983): **280** gC m^{-2} yr^{-1}

2000s (Sutton et al., 2013): **280 ± 20** gC m^{-2} yr^{-1}

Productivity has neither increased nor decreased since the 1970s.

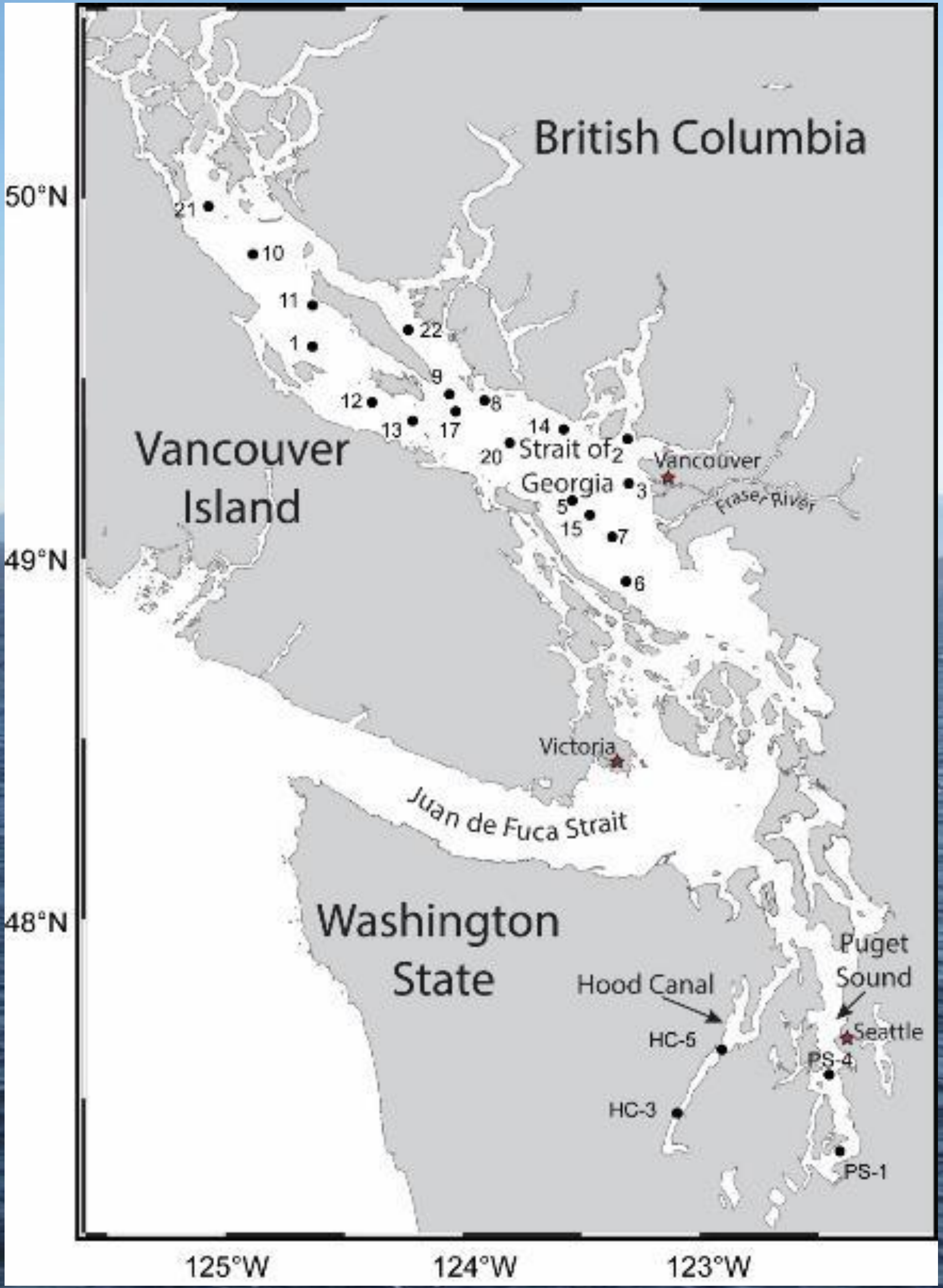
Longer term? Puget Sound?

Recent and long-term sediment records

Puget Sound sediments suggested decline in productivity
(Brandenberger, 2011. Aquatic Geochemistry)

Compare Strait of Georgia Cores…

Salish Sea Sediment Cores



Stable isotopes of C and N:
Has sedimented marine organic matter declined?

$\delta^{13}C$

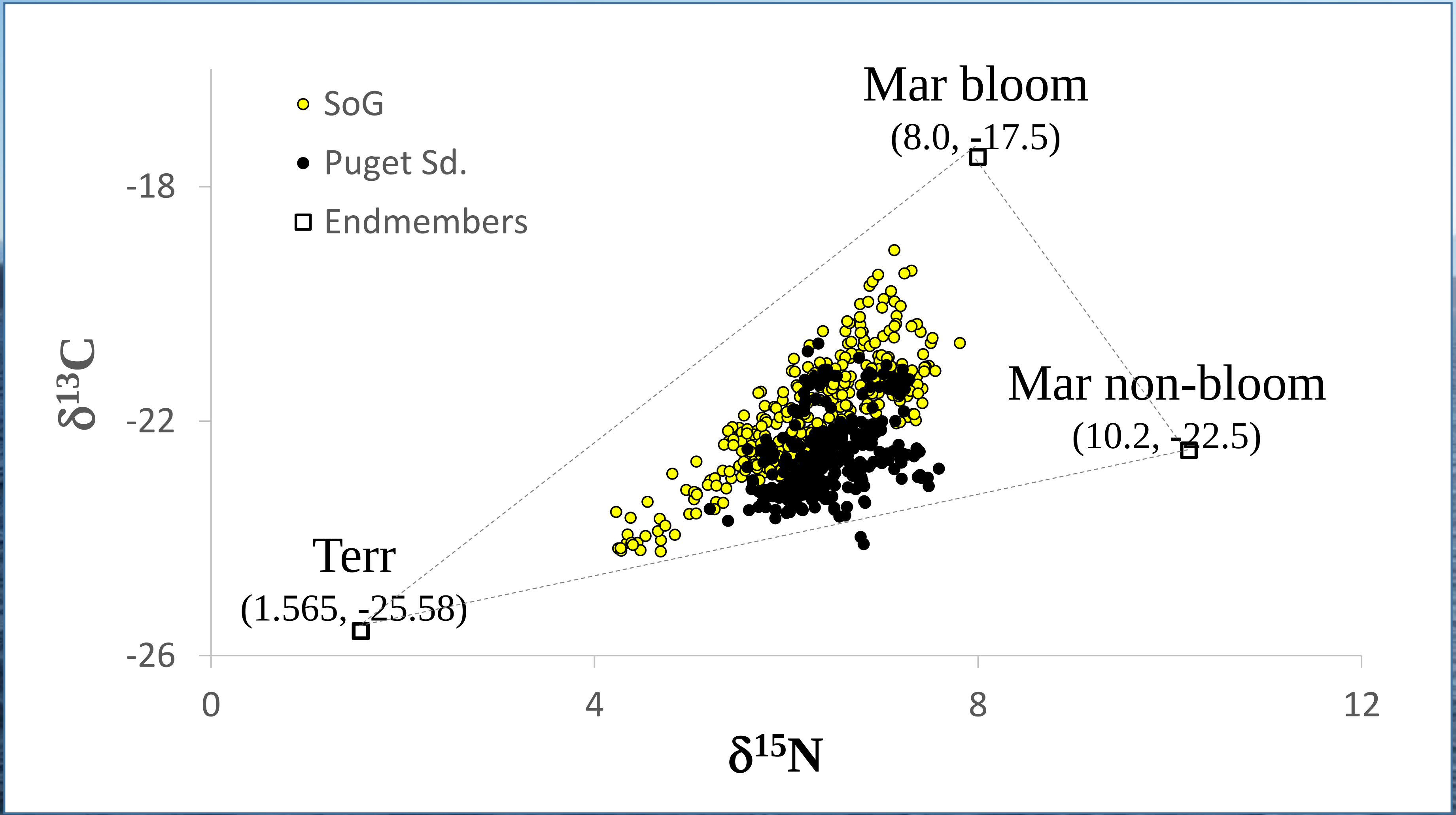
- marine / terrigenous source
- productivity

$\delta^{15}N$

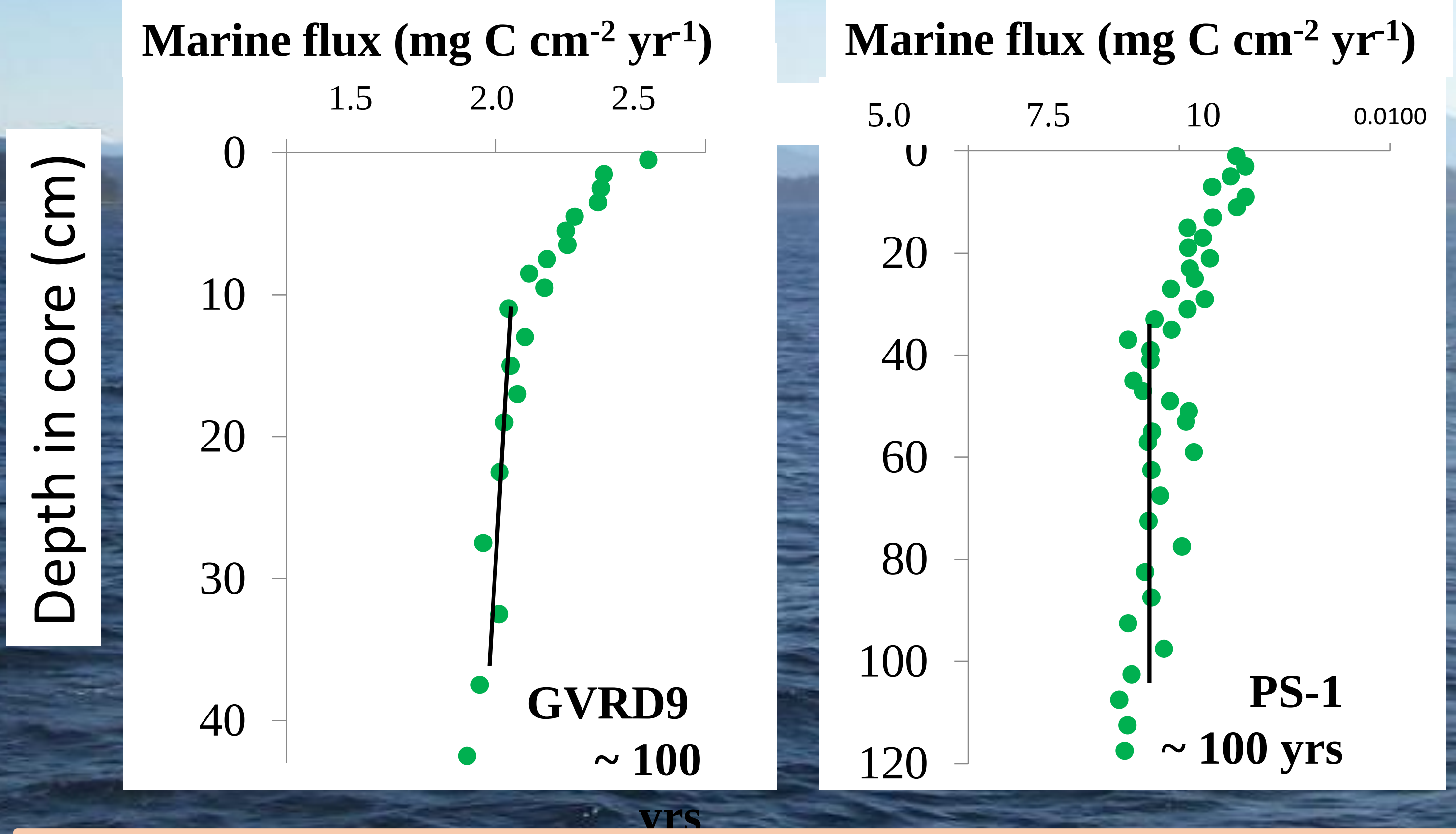
- marine / terrigenous source
- length of food chain

Difficult to interpret isotopes individually, but we can interpret them together.

Marine and terrigenous endmembers

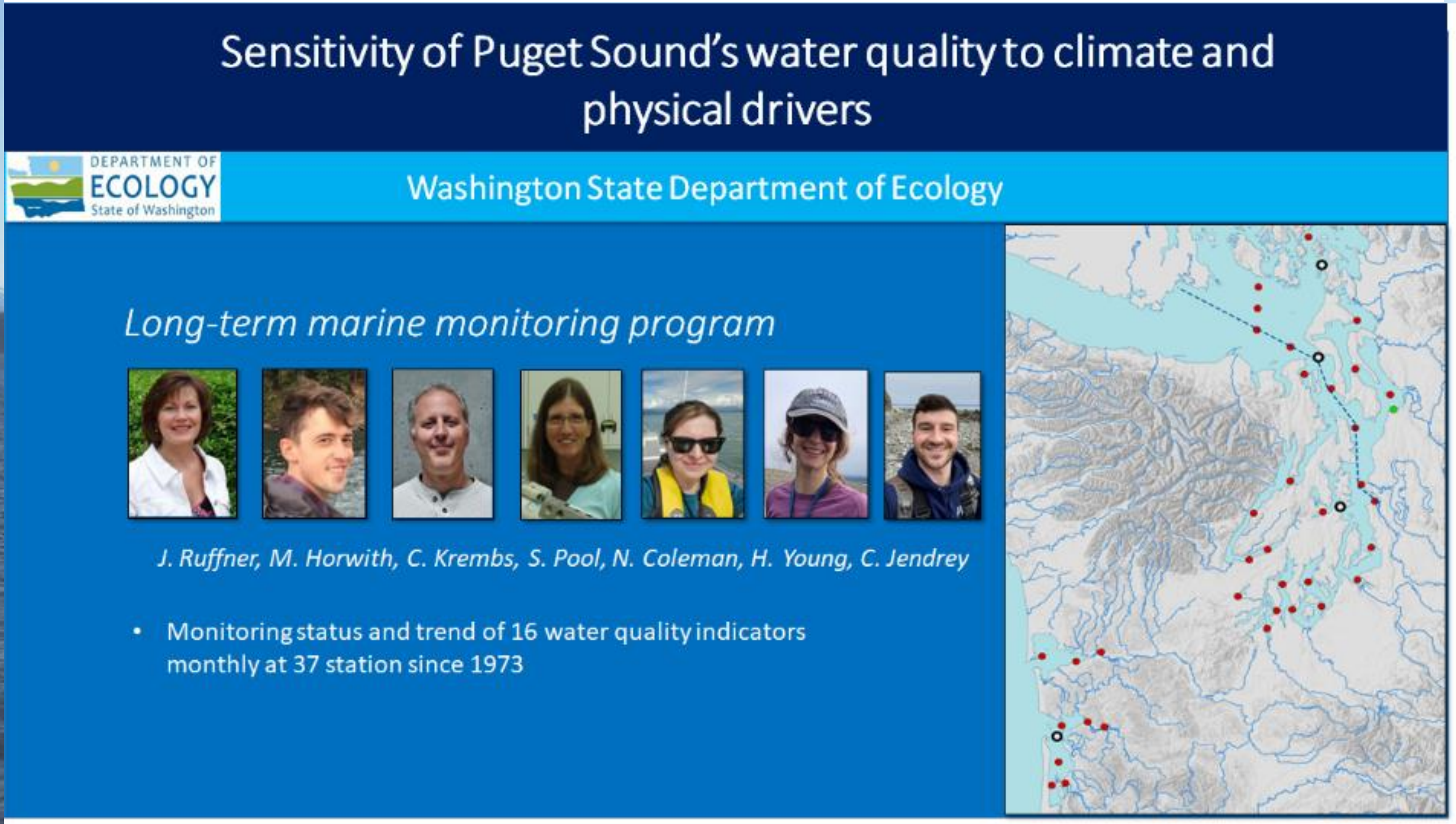


FLUX of marine-derived organic matter has not declined in the last 100 years (Check for increase…)



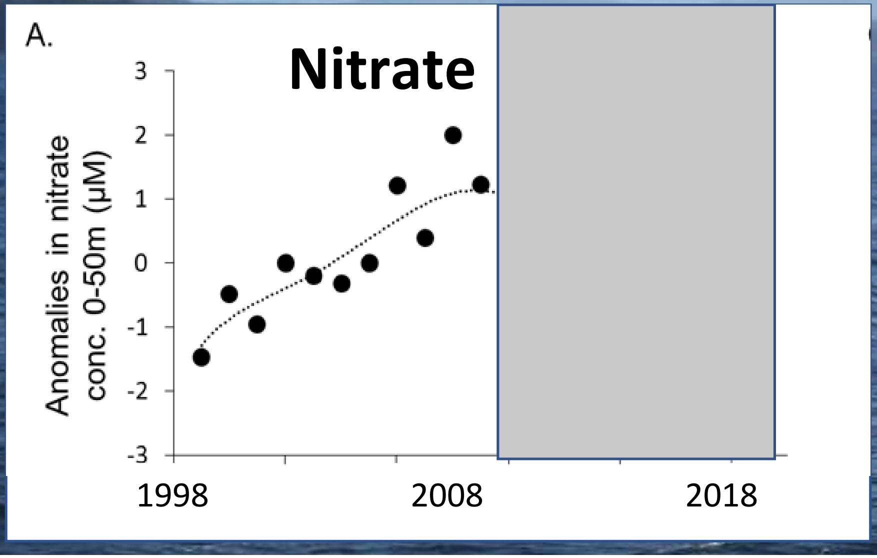
Answer: Terrigenous flux has increased. Marine flux constant.

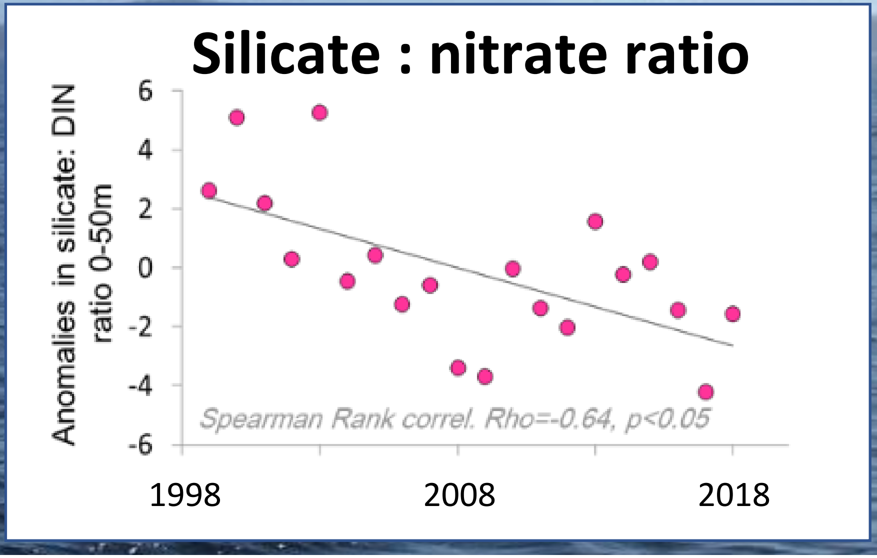
QUESTION 2: **Has the type of primary productivity in the Salish Sea changed?**



Has the type of productivity changed?

Eyes over Puget Sound
(Updated by Christopher Krembs, Jan 2020 pers. comm.)





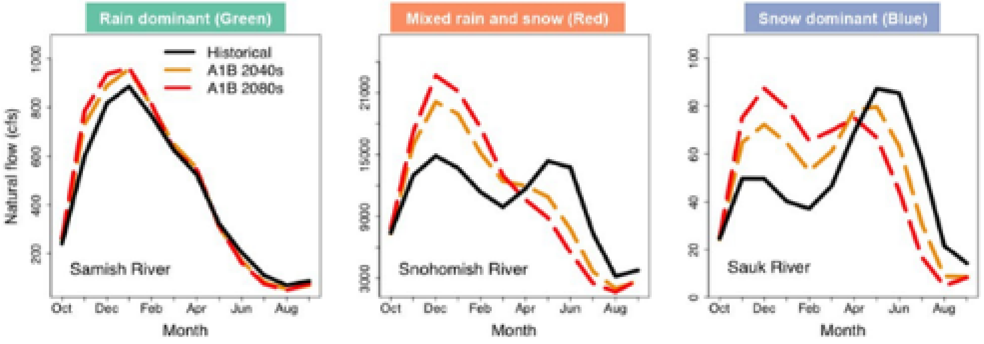
Puget sound annual average anomaly, top 30 m; regional anomalies calc. separately

Hypothesis…

Climate

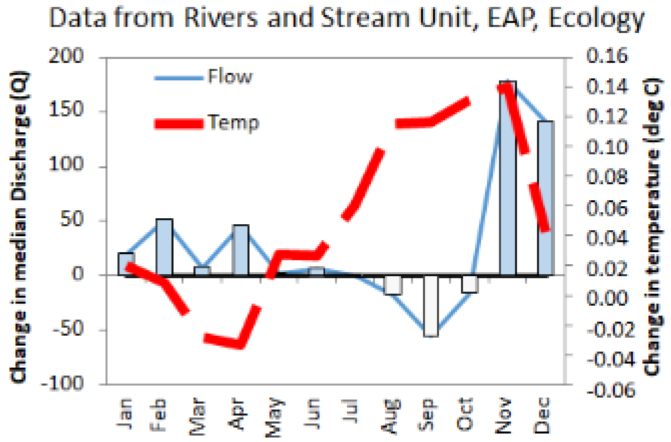
Predicted and observed freshwater response to climate

2014 Climate Impact Report, predictions western Washington



- **Increase in rain-dominated systems in winter**

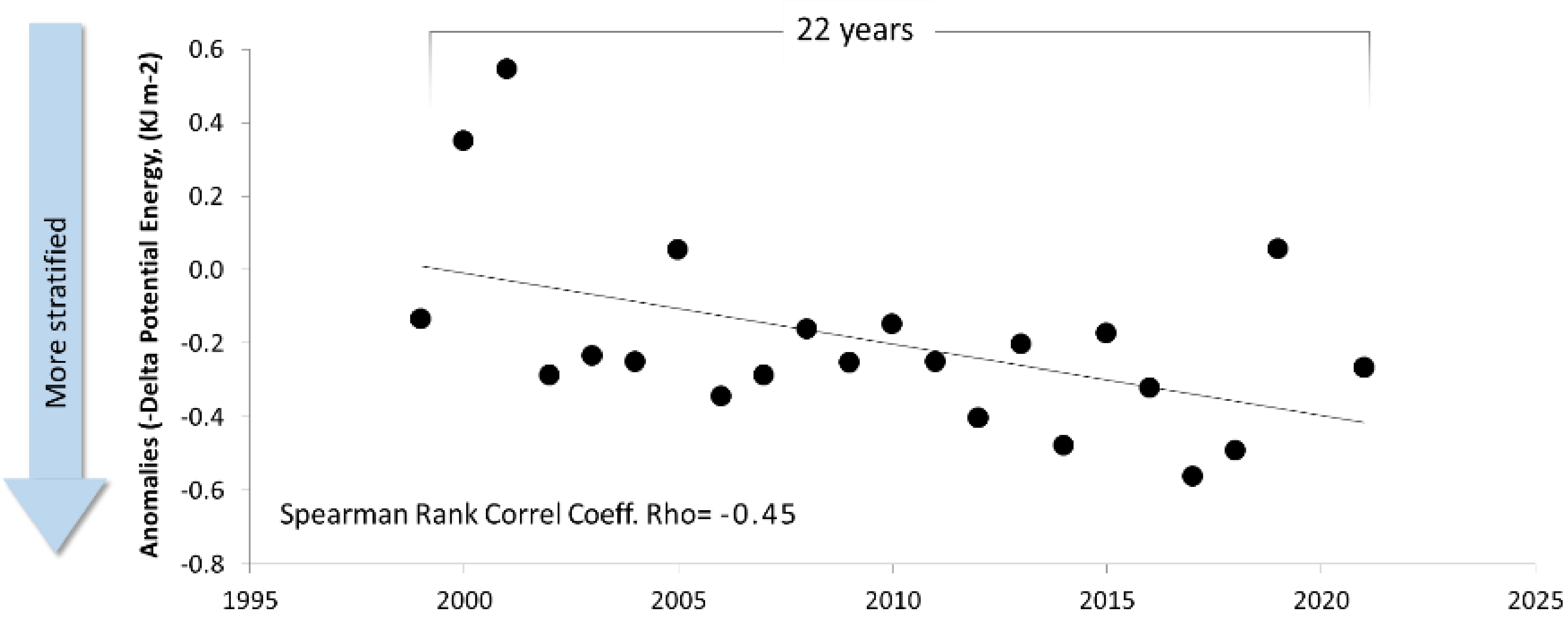
Ecology's 20-year river flow and temperature trends



- **20 years of monitoring confirms increase in rain-dominated systems**

Christopher Krembs slides previously presented at the annual water year update for Washington and Oregon in Oct 2022

Climate change drives increased stratification (particularly in late winter)

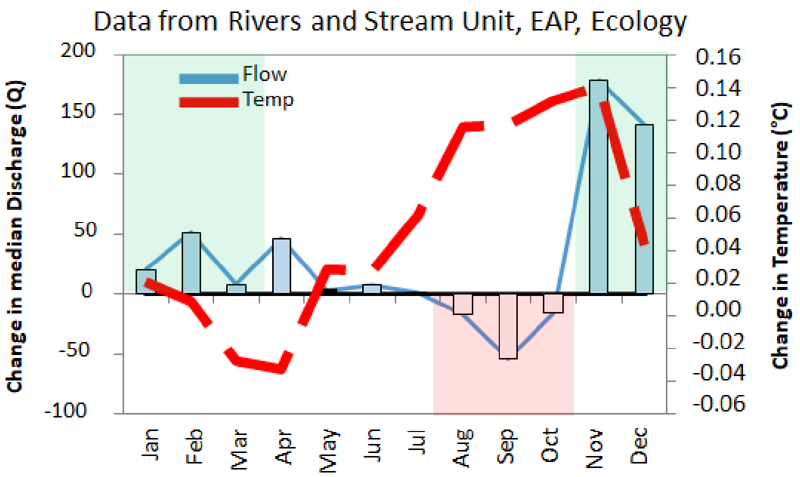


Stratification in Puget Sound increasing

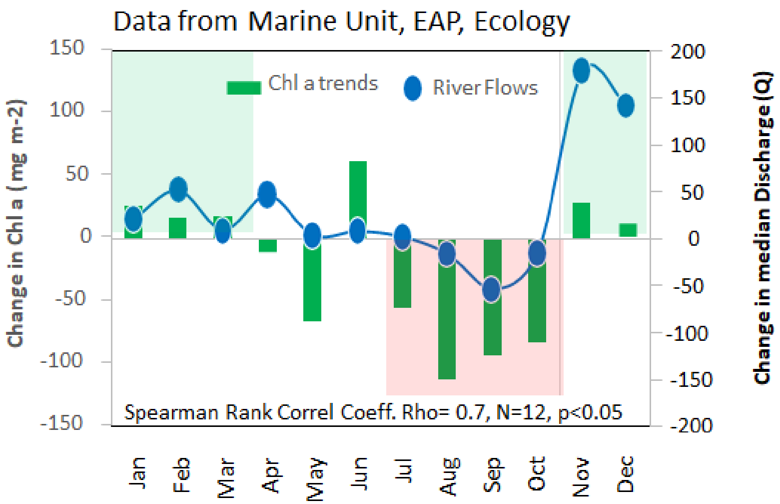
Implications of changing river flows for PS Phytoplankton Biomass

- **HS: Stratification in winter could promote winter-time phytoplankton blooms**

Ecology's 20-year river flow and temperature trends



Ecology's 20-year river flow and PS phytoplankton trends

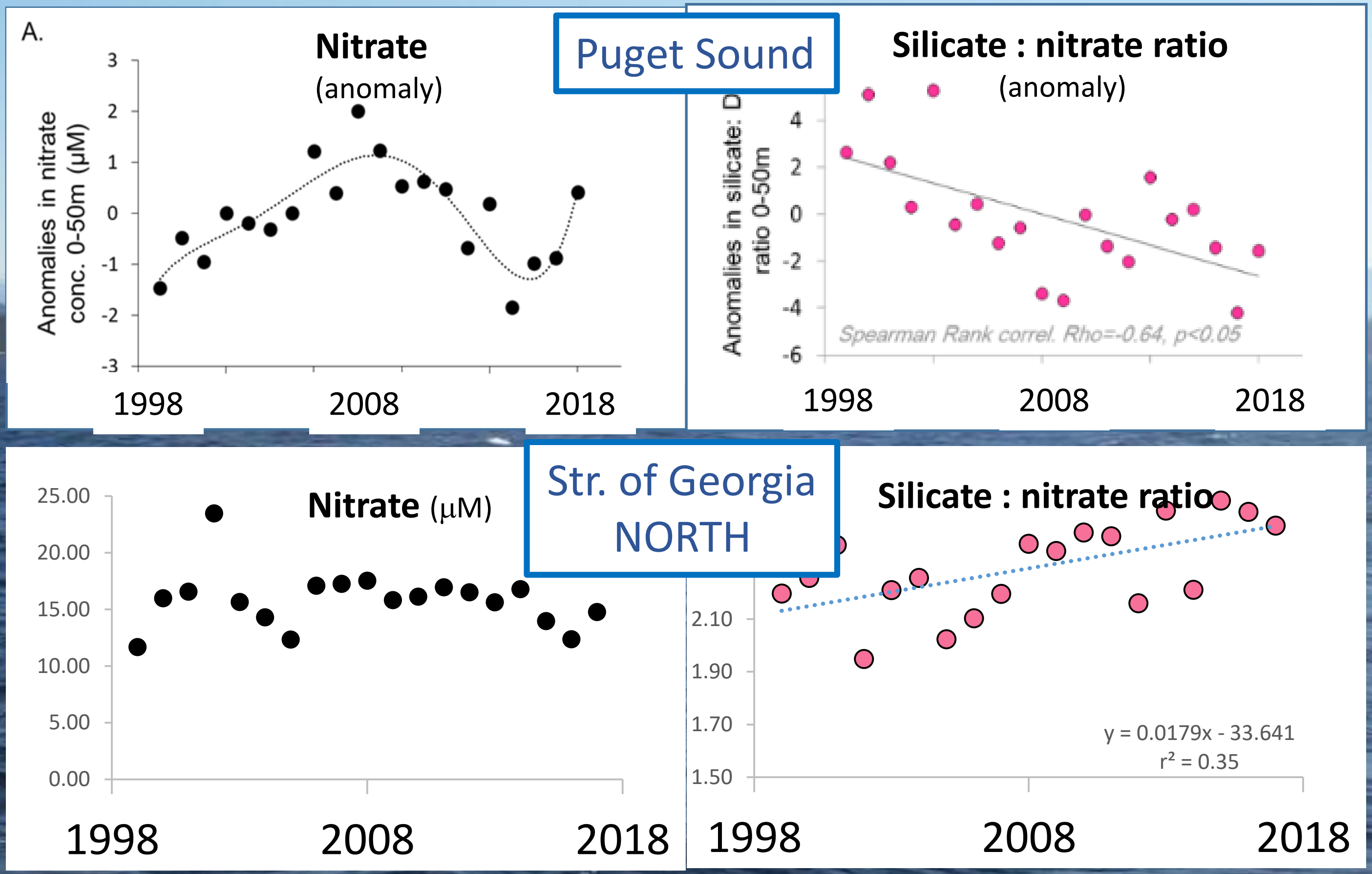


- **HS: Low river flows in summer negatively affect phytoplankton biomass**

Puget Sound ≠ Strait of Georgia

Different areas in Puget Sound may be responding differently…

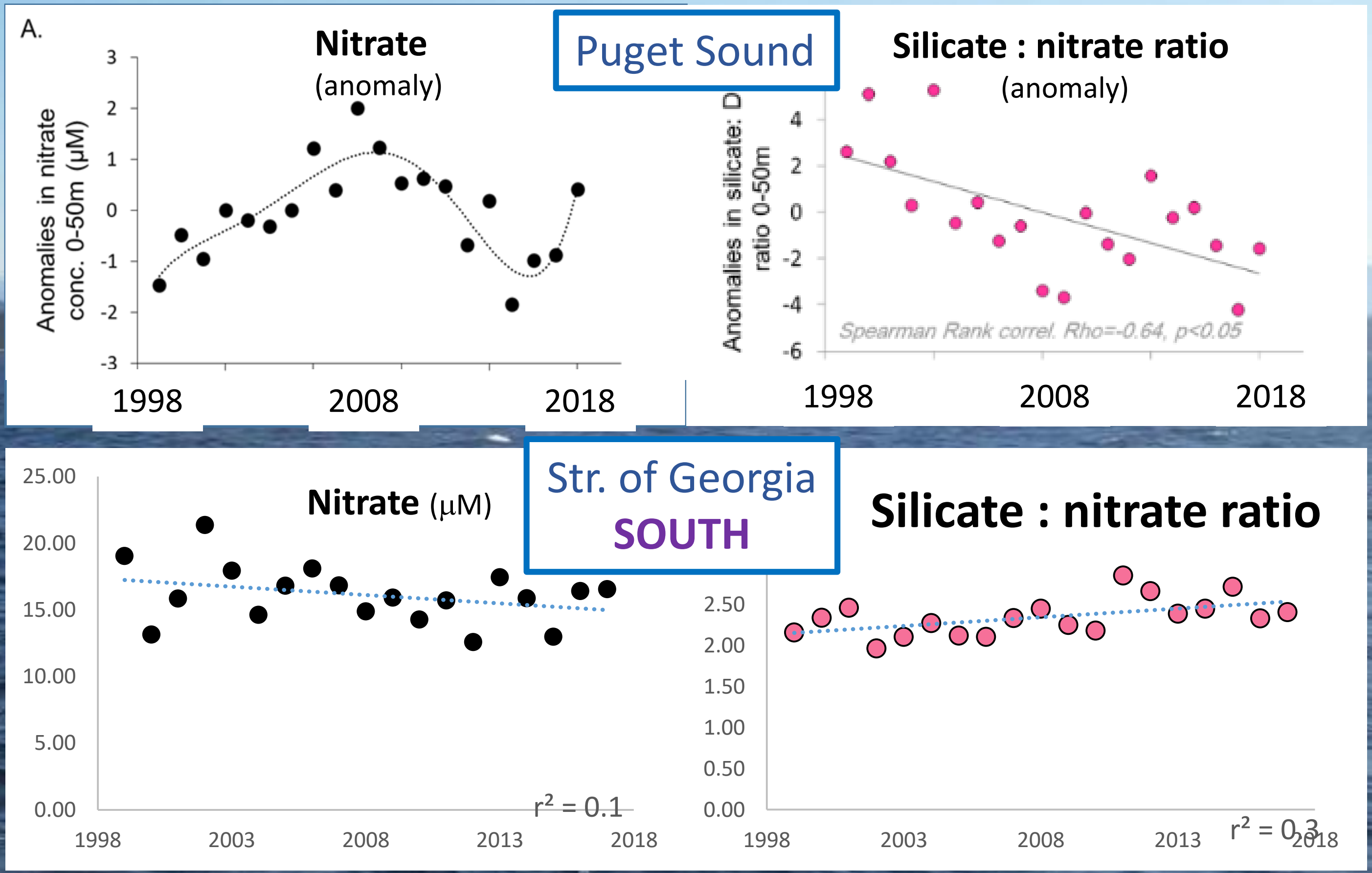
Puget Sound ≠ Strait of Georgia NORTH



Annual average, top 30 m

Puget Sound anomalies; Strait of Georgia absolute values.

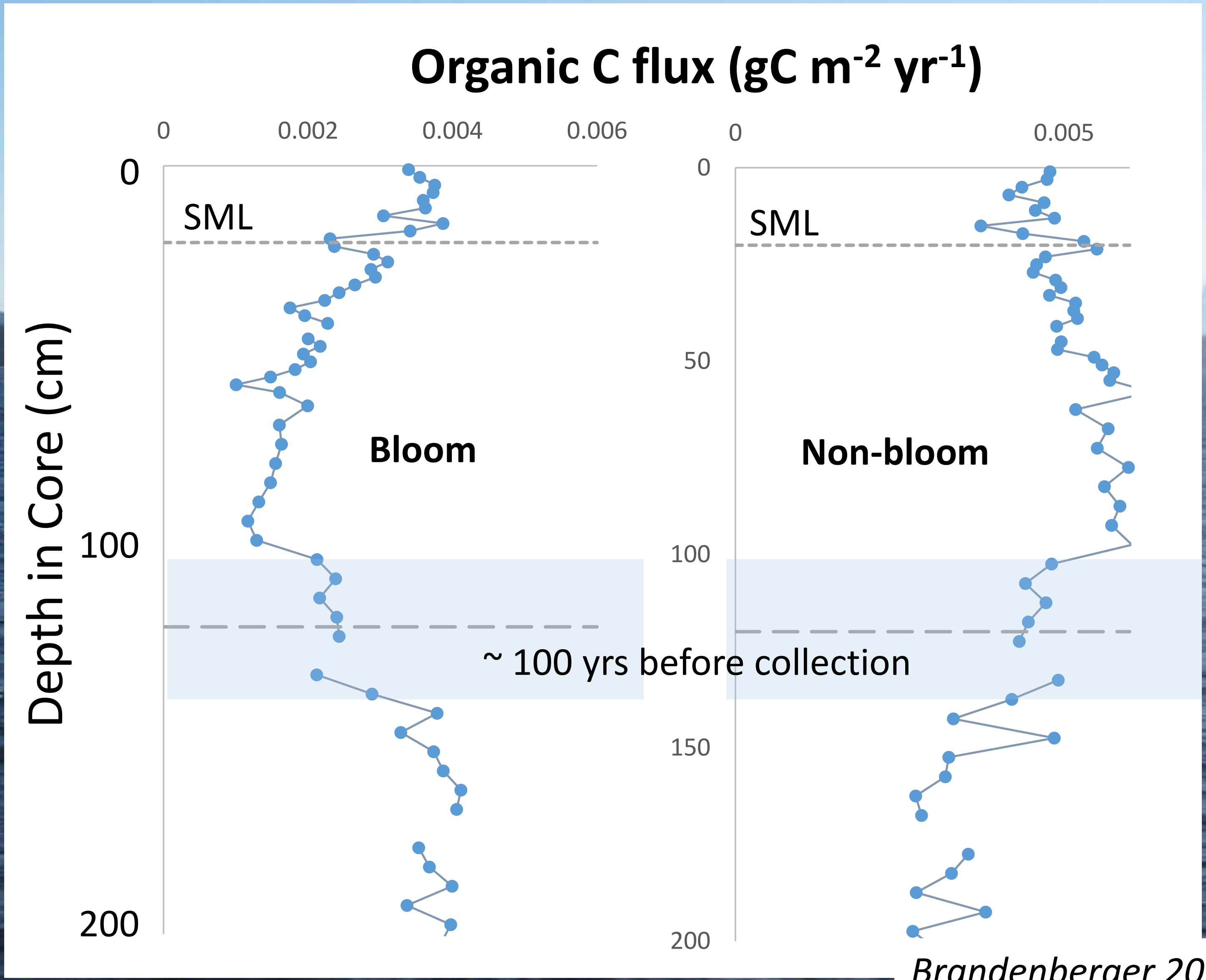
Puget Sound ≠ Strait of Georgia SOUTH



Annual average, top 30 m

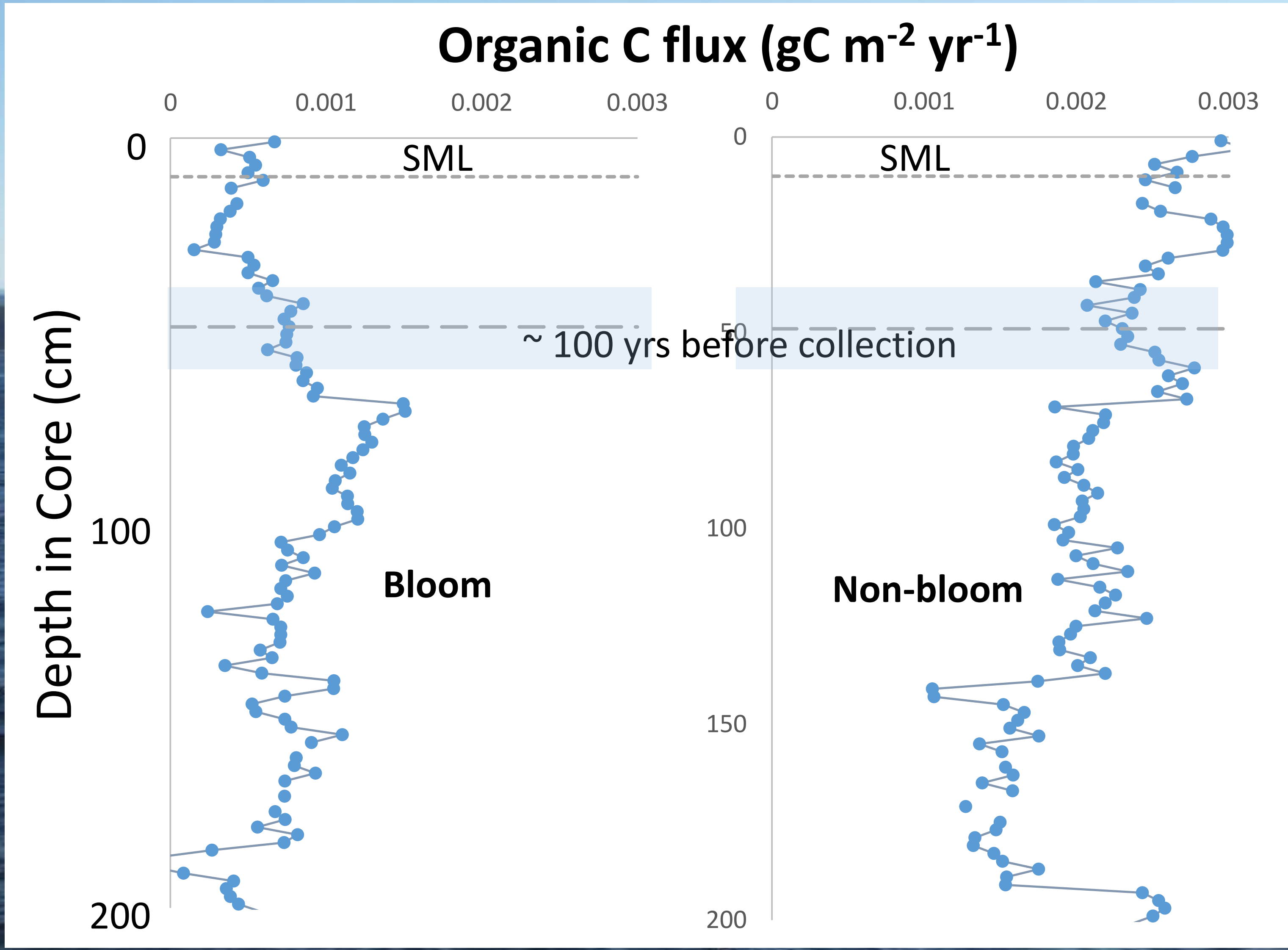
Different areas of Puget Sound not the same either…

Puget Sound Main Basin sediment



Brandenberger 2011, Core PS1

Puget Sound Hood Canal sediment



Conclusions

1. Total primary productivity in the Salish Sea is unchanged since 1970s (and for ≤ 100 years).

2. The type of productivity might have changed (diatom-dominated to small-phyto-dominated… but if so, not the same everywhere. To be continued…

3. Changes have yet to be linked to climate stressors.

4. Timing…?

Proposals / Future work

1. With Maycira Costa (UVic). Combine existing satellite and sediment trap data in SoG: How does surface ocean colour relate to exported organic matter?

2. (With Akash Sastri and Christopher Krembs). Combine nutrient, sediment core geochemistry and taxonomy: Has the type of productivity changed over time in the Salish Sea? If so, does the change relate to climate change stressors?

3. (Speculative). Collect new cores in Puget Sound and deploy sediment traps.

Thank you!

Sophia.Johannessen@dfo-mpo.gc.ca

Remote Sensing technology to monitor ocean conditions

Maycira Costa

University of Victoria

The Science of Puget Sound Water Quality, December 06, 2022

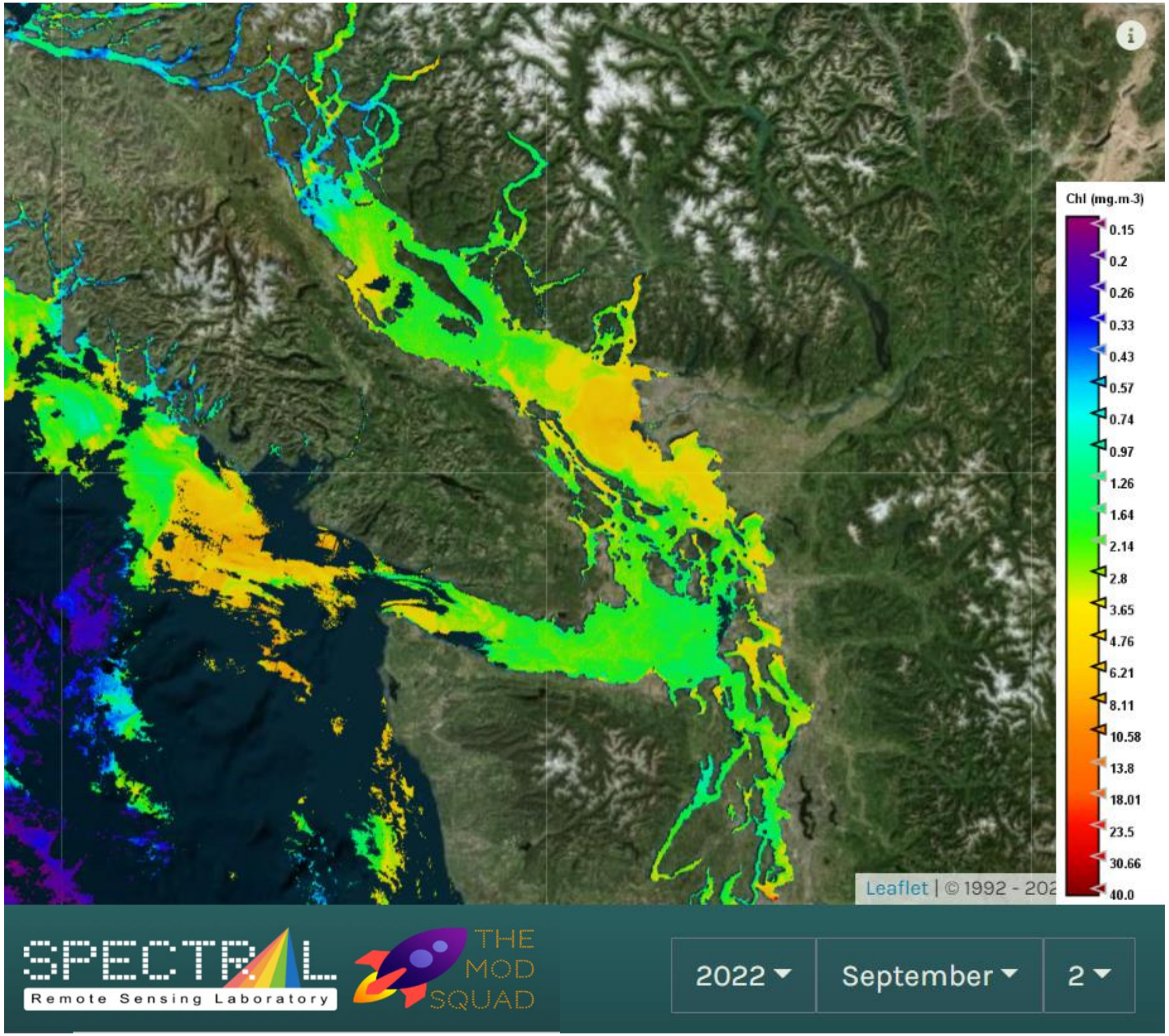
SPECTRAL Remote Sensing Laboratory

http://uvicspectral.com/
maycira@uvic.ca

University of Victoria

I acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory UVic stands

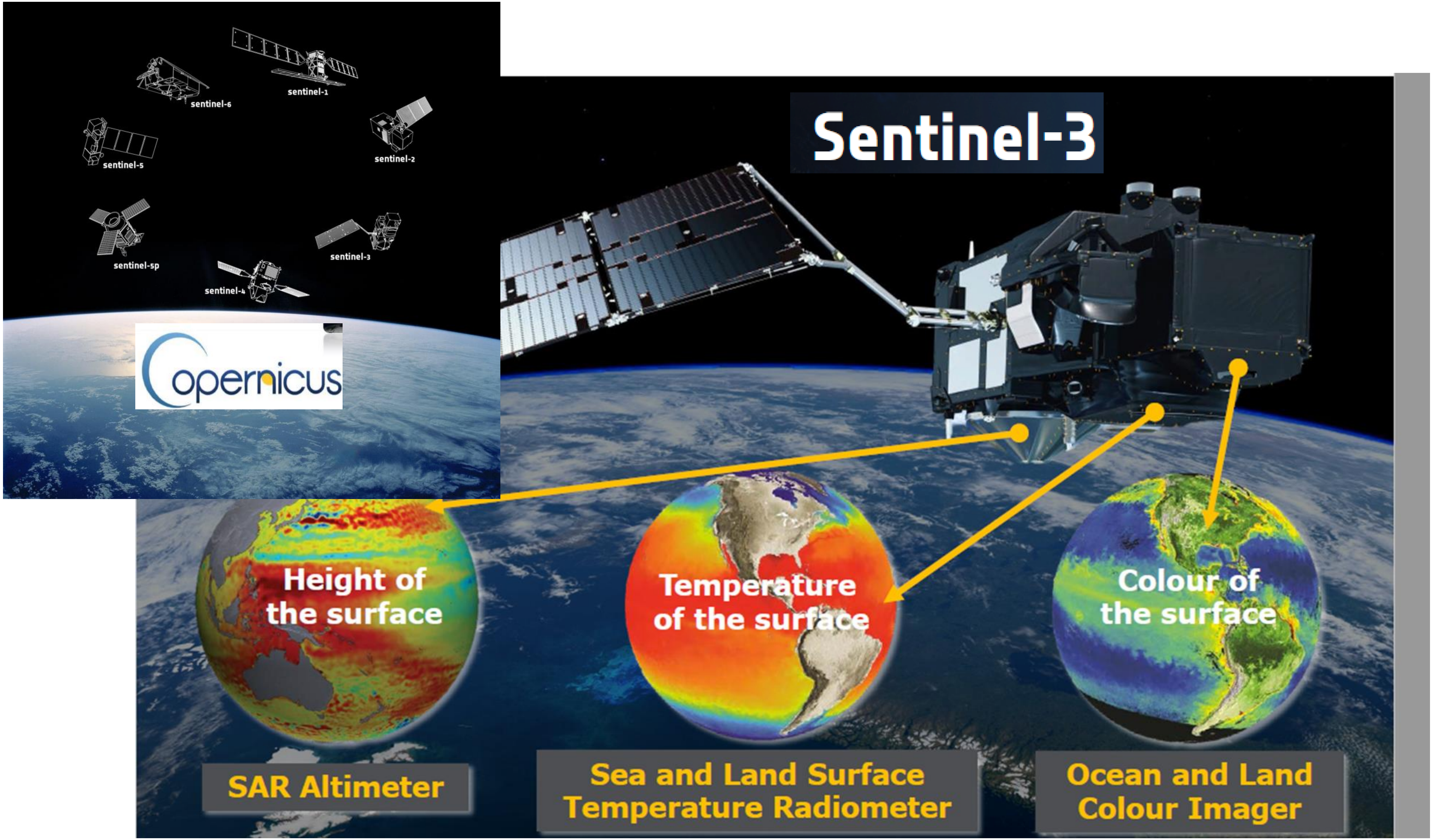
Sentinel 3 Chla surface chlorophyll September 02 2022



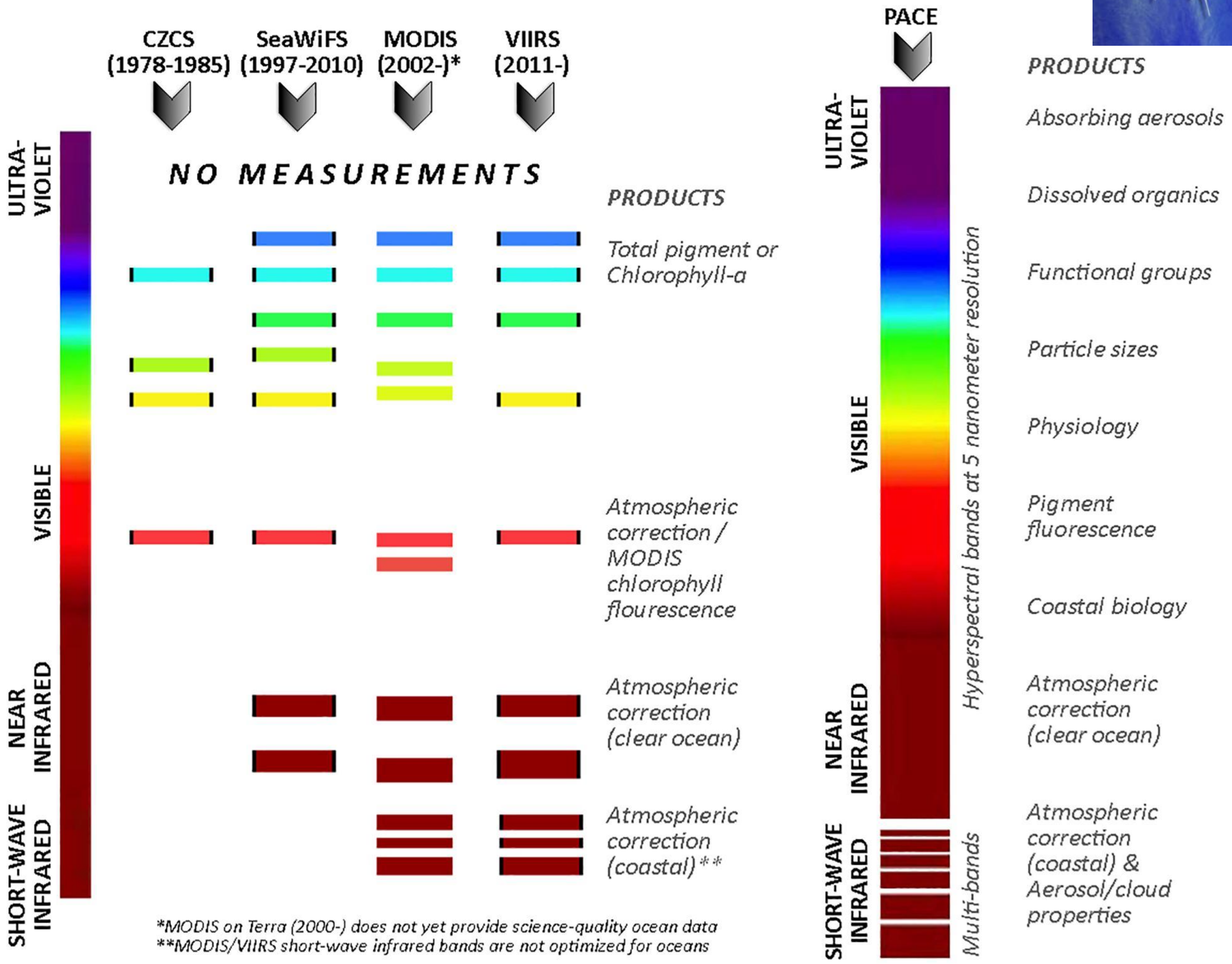
Hakai
Science on the Coastal Margin

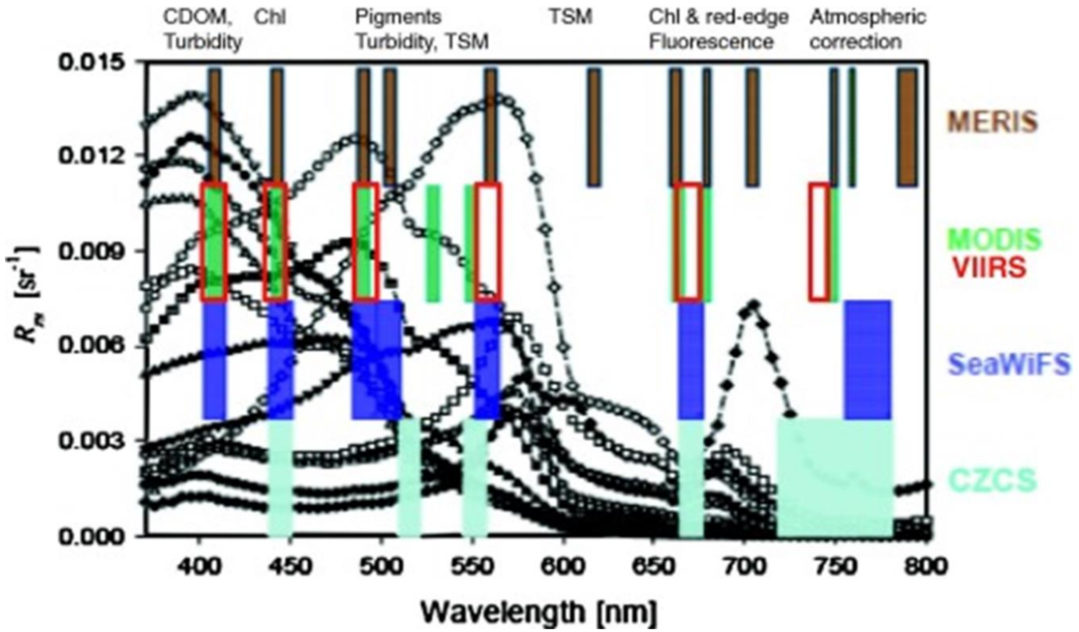
CIOOS
CANADIAN INTEGRATED OCEAN OBSERVING SYSTEM

algaeexplorer.ca


sentinel-1
sentinel-6
sentinel-5
sentinel-2
sentinel-5p
sentinel-3
sentinel-4
Copernicus
Sentinel-3
Height of the surface
Temperature of the surface
Colour of the surface
SAR Altimeter
Sea and Land Surface Temperature Radiometer
Ocean and Land Colour Imager

SPECTRAL COVERAGE
OCEAN COLOR HERITAGE SENSORS compared with PACE



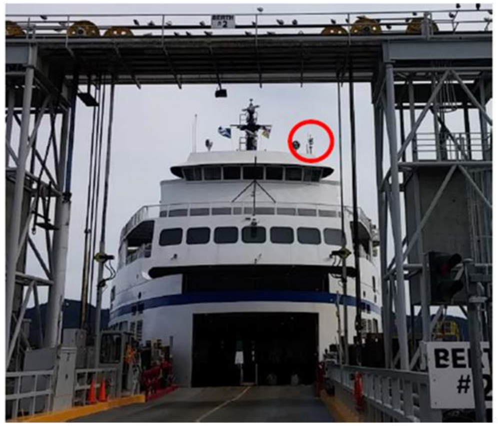


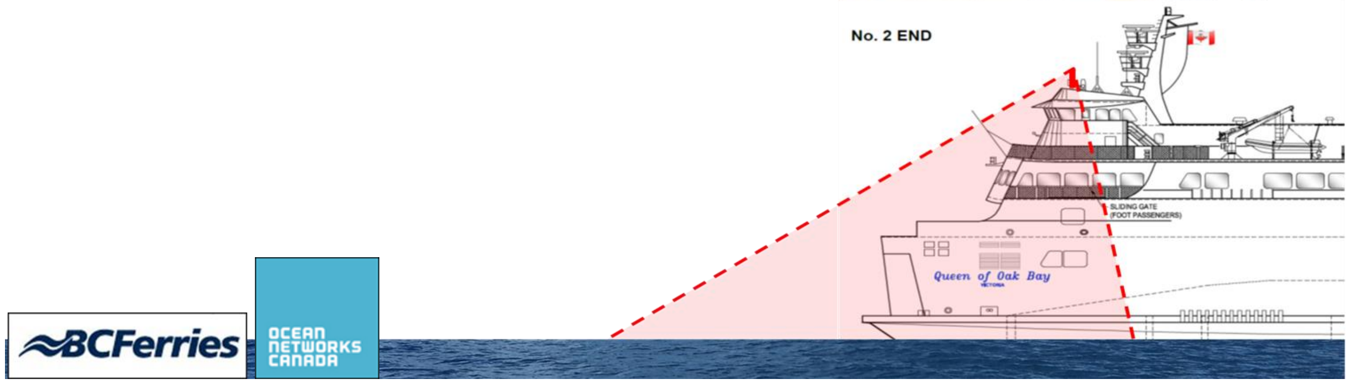
FOCOS

(Ferry Ocean Colour Observation System)

Our work in BC

- Radiometry – calibration
- Atmosphere
- Model development
  - Chlorophyll, turbidity, CDOM
  - Phytoplankton Groups (PFT)
- Bioregionalization

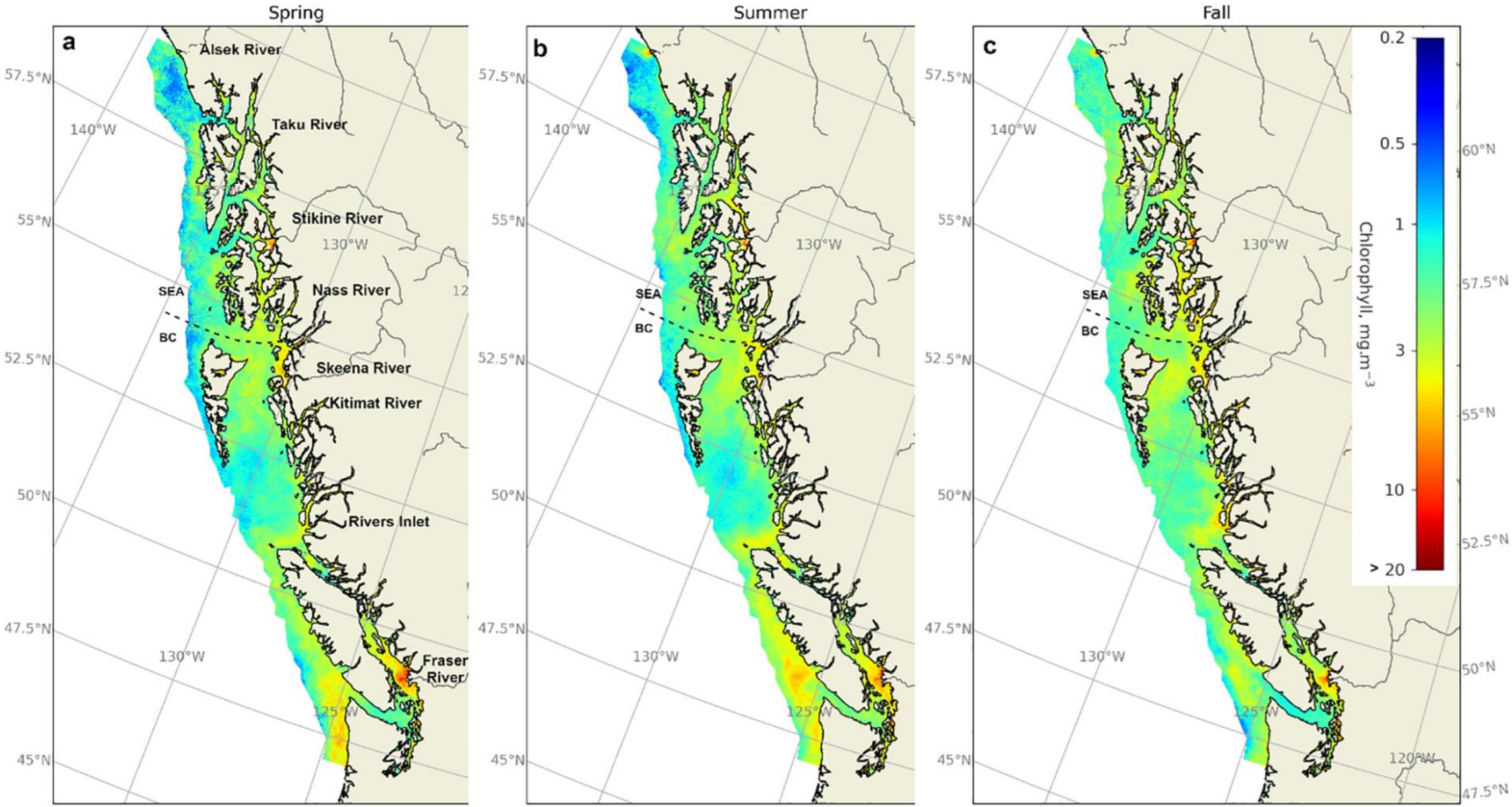




Wang and Costa, 2022
Juhirhussain et al., 2022

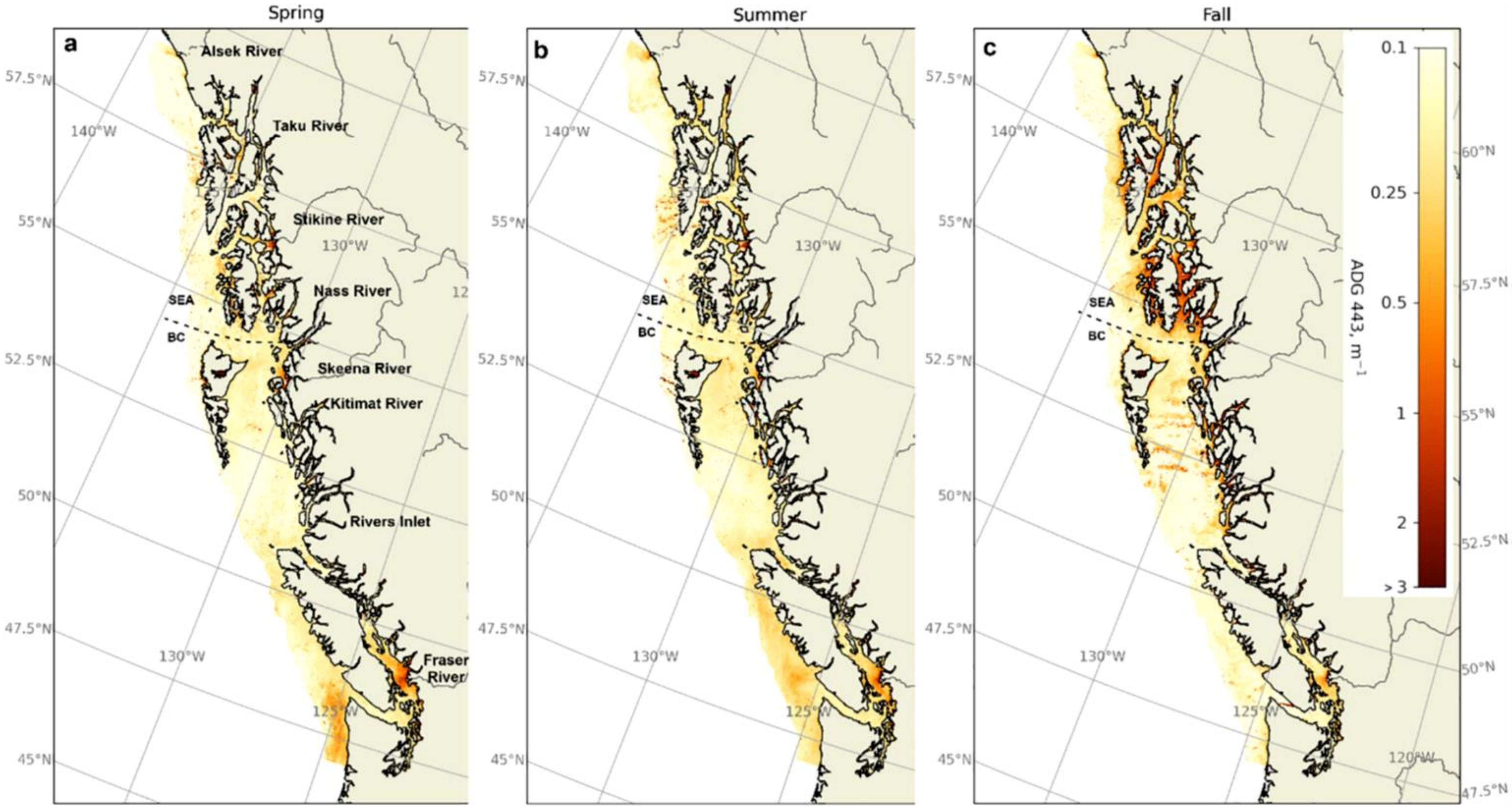
Sentinel-3

Atmosphere and Model development: Chla product at 300m



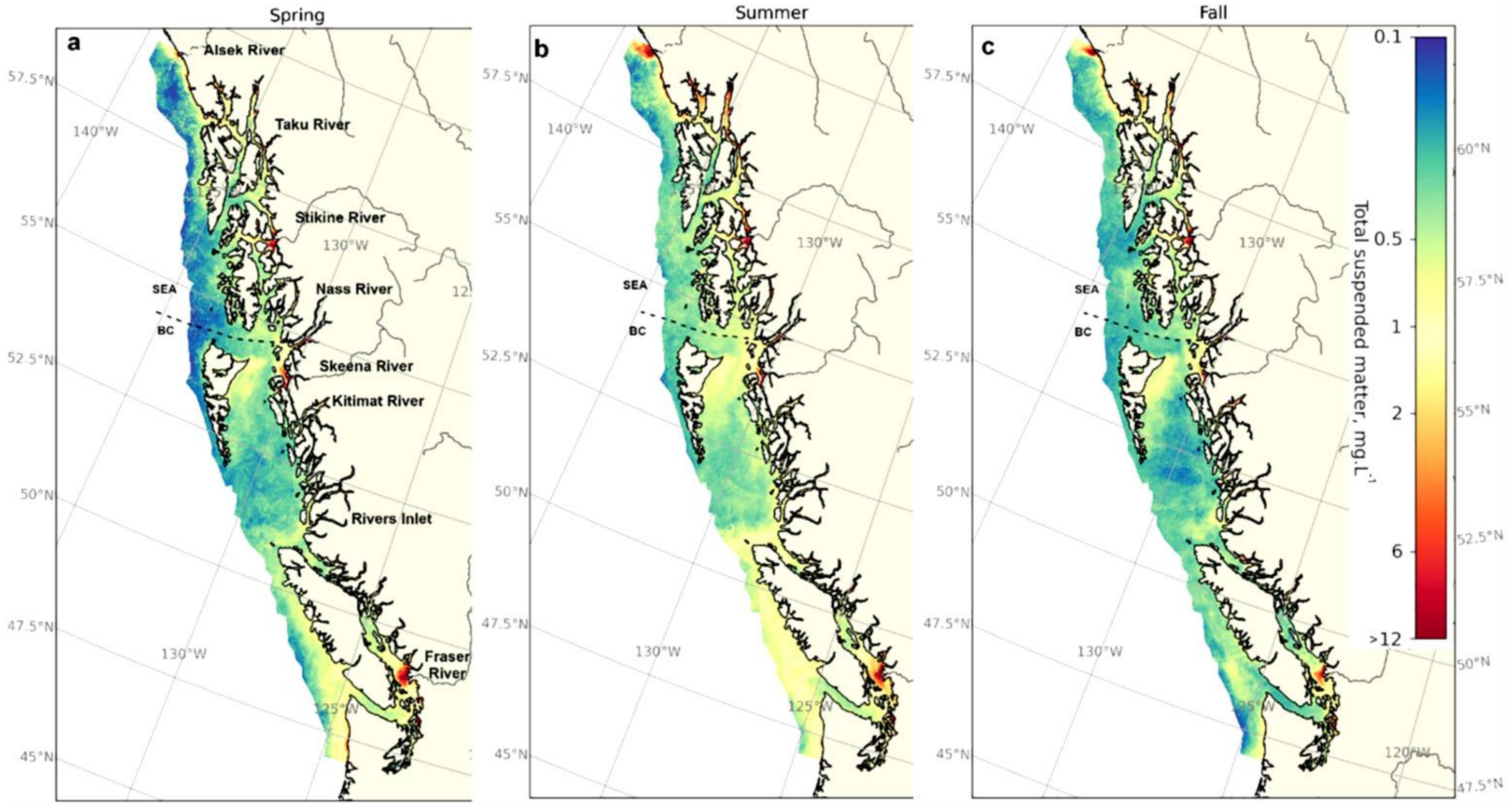
Giannini et al., 2021

Atmosphere and Model development: Dissolved Organic Matter



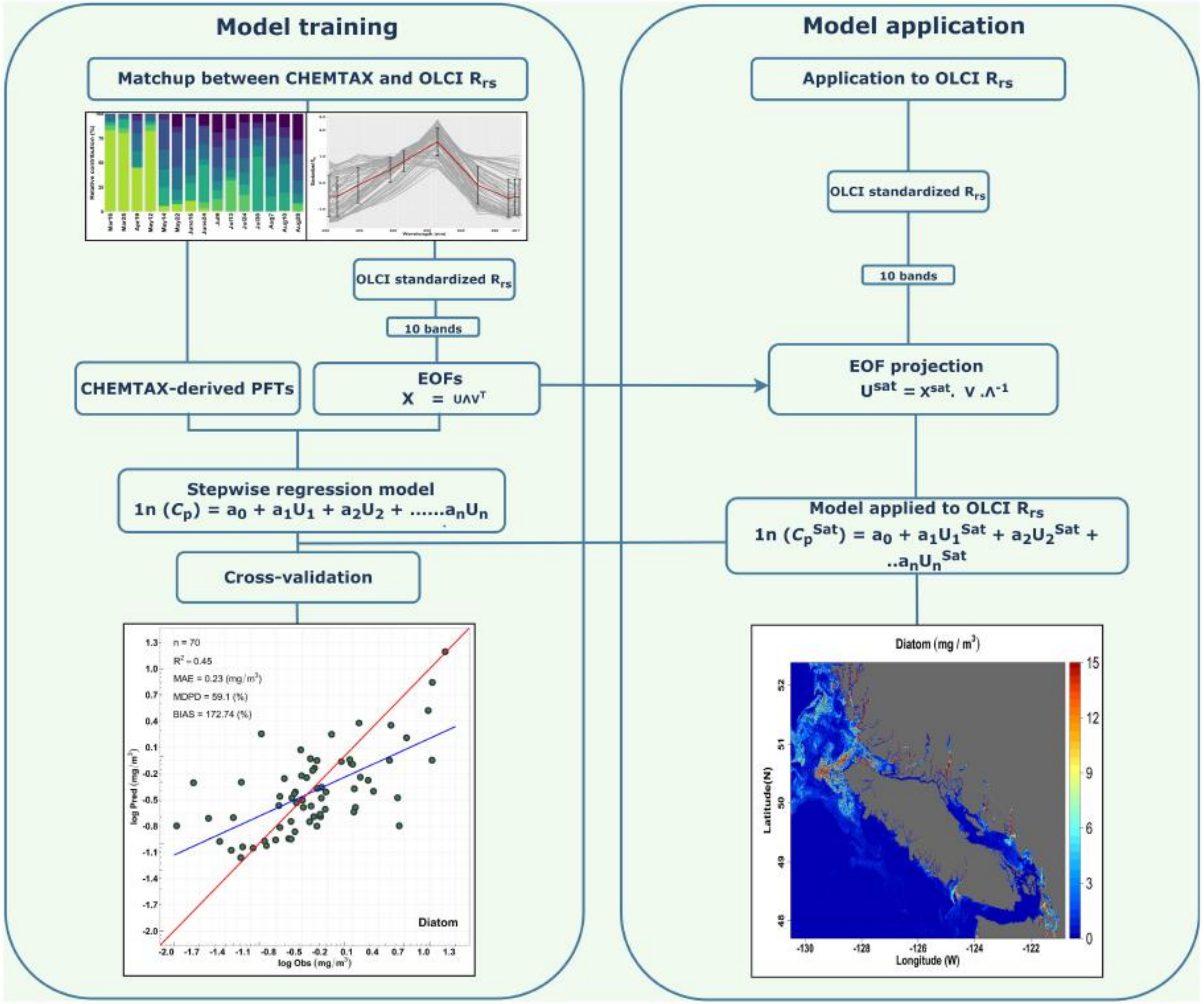
Giannini et al., 2021

Atmosphere and Model development: Turbidity



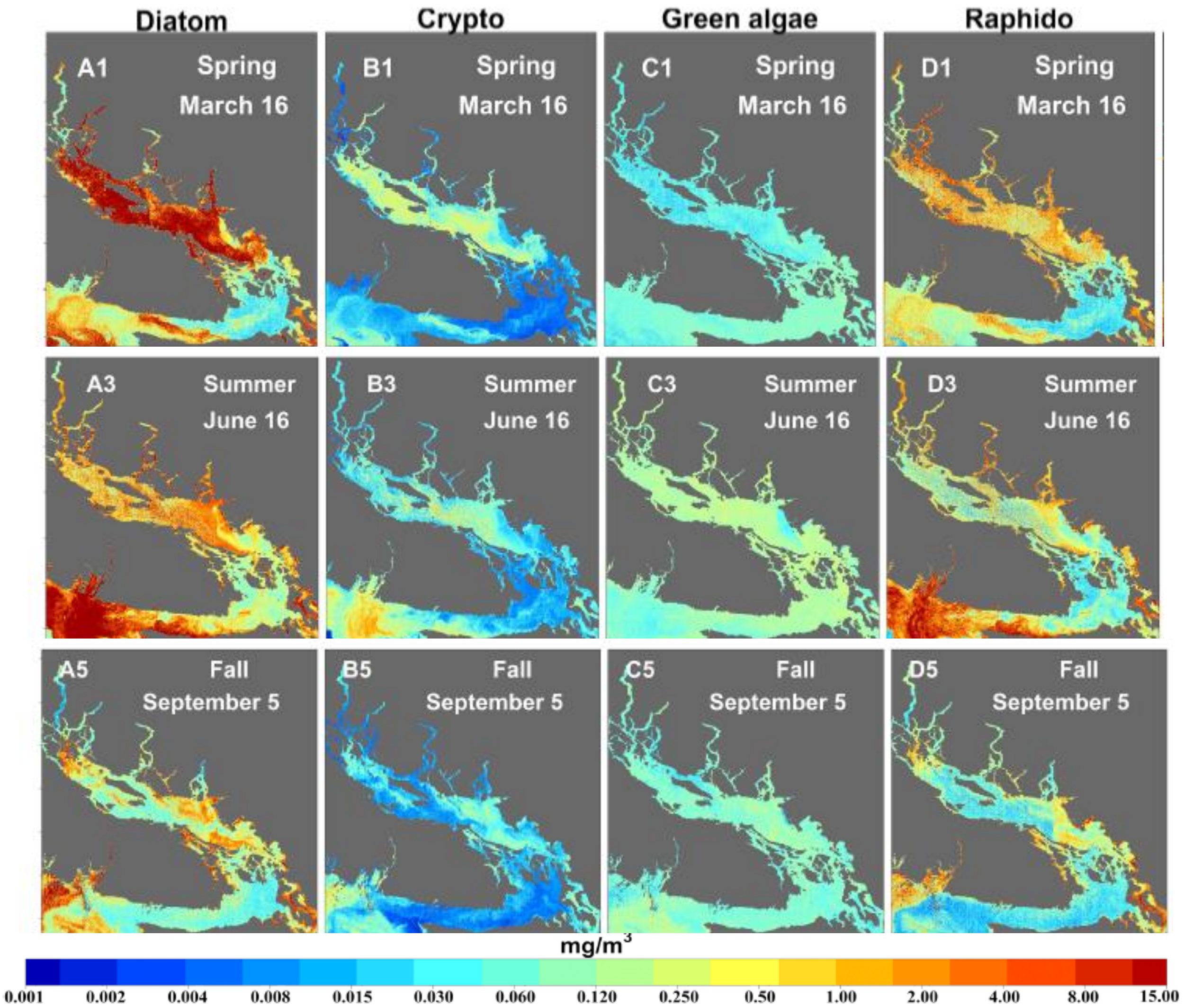
Giannini, Costa, et al., 2021

Sentinel 3 - Phytoplankton Groups

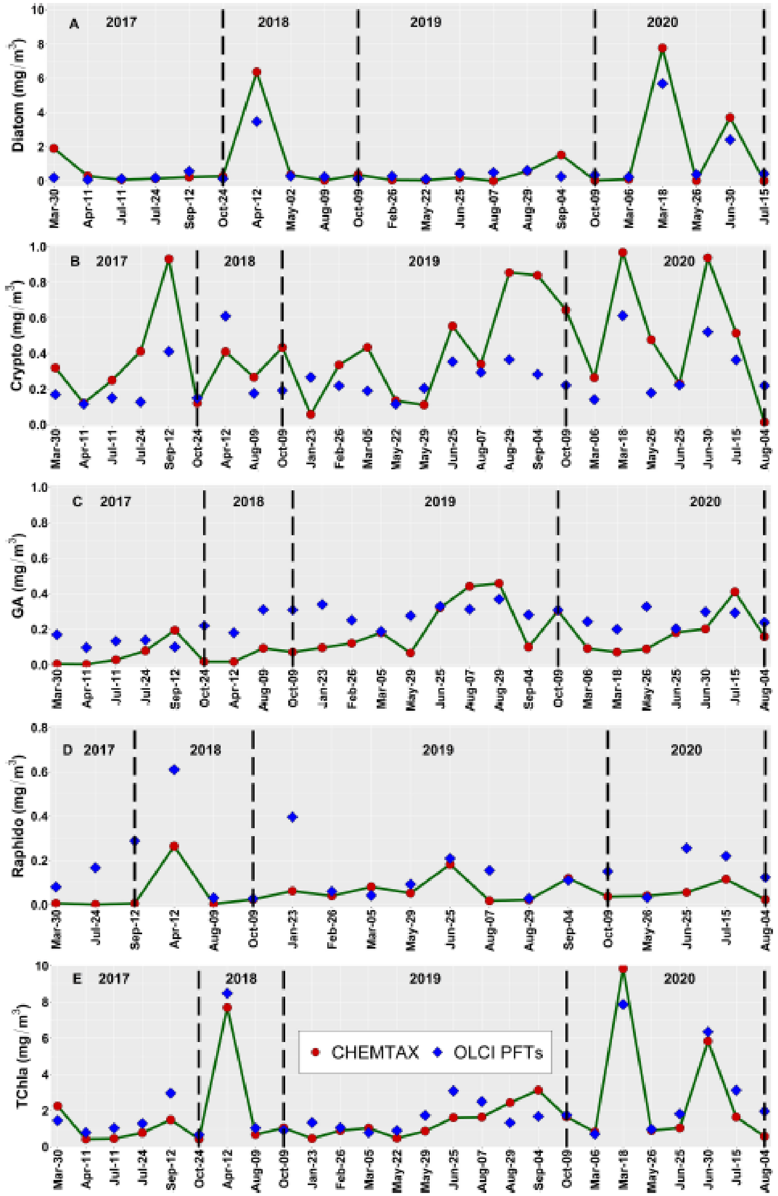


Vishnu, Costa et al., 2022

Sentinel 3 - Phytoplankton Groups, 2018



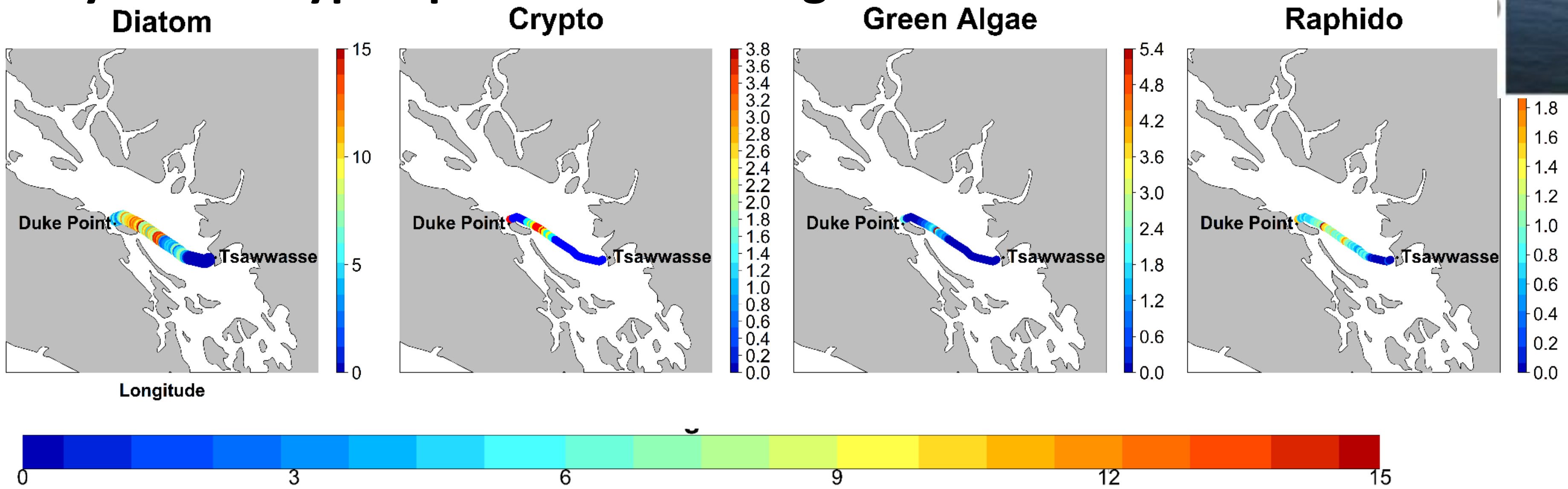
Independent validation dataset



Vishnu, Costa et al., 2022

Sentinel 3 - Phytoplankton Groups, 2018

Ferry-based Hyperspectral → leading to PACE!

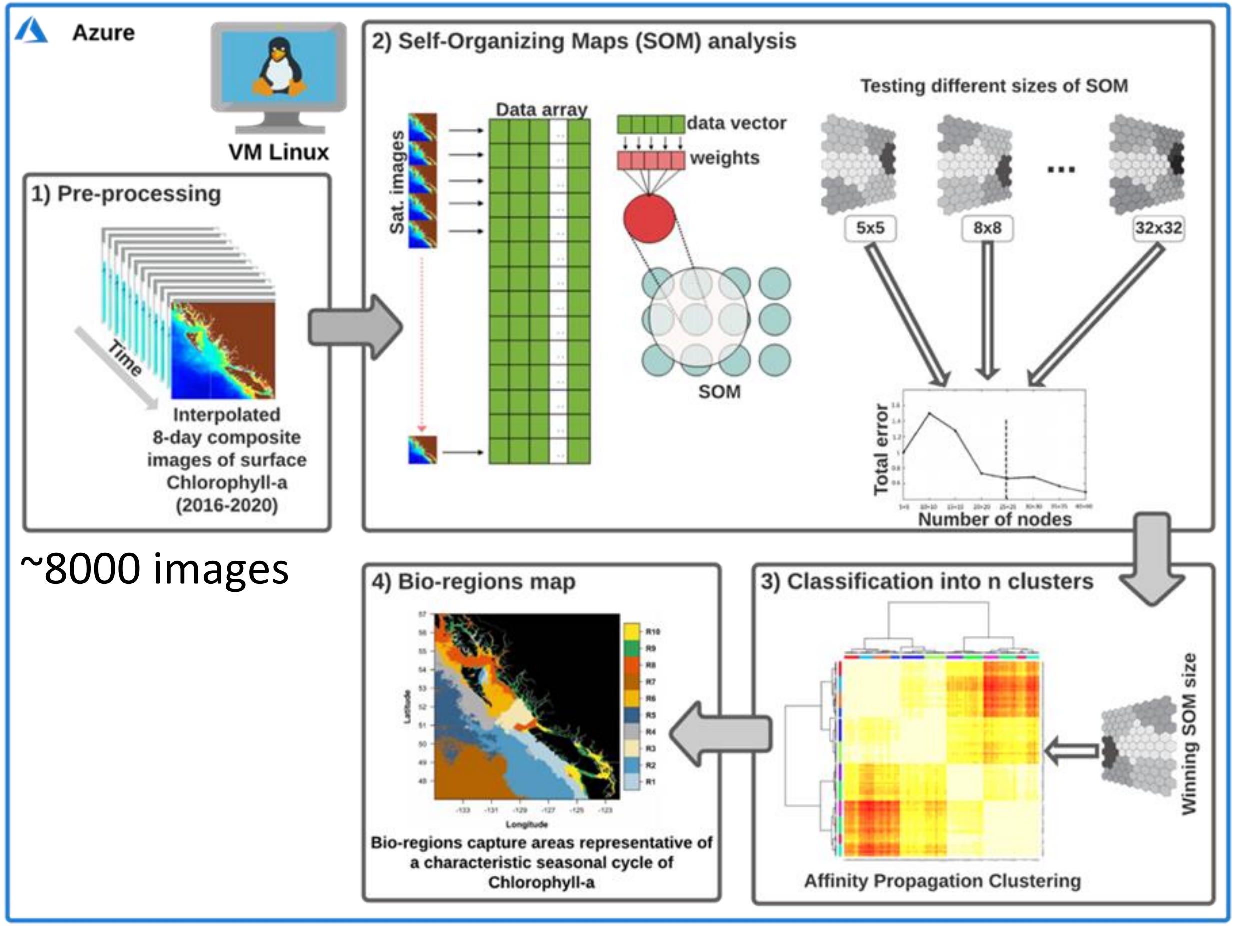


Vishnu, Costa, et al., (in prep)

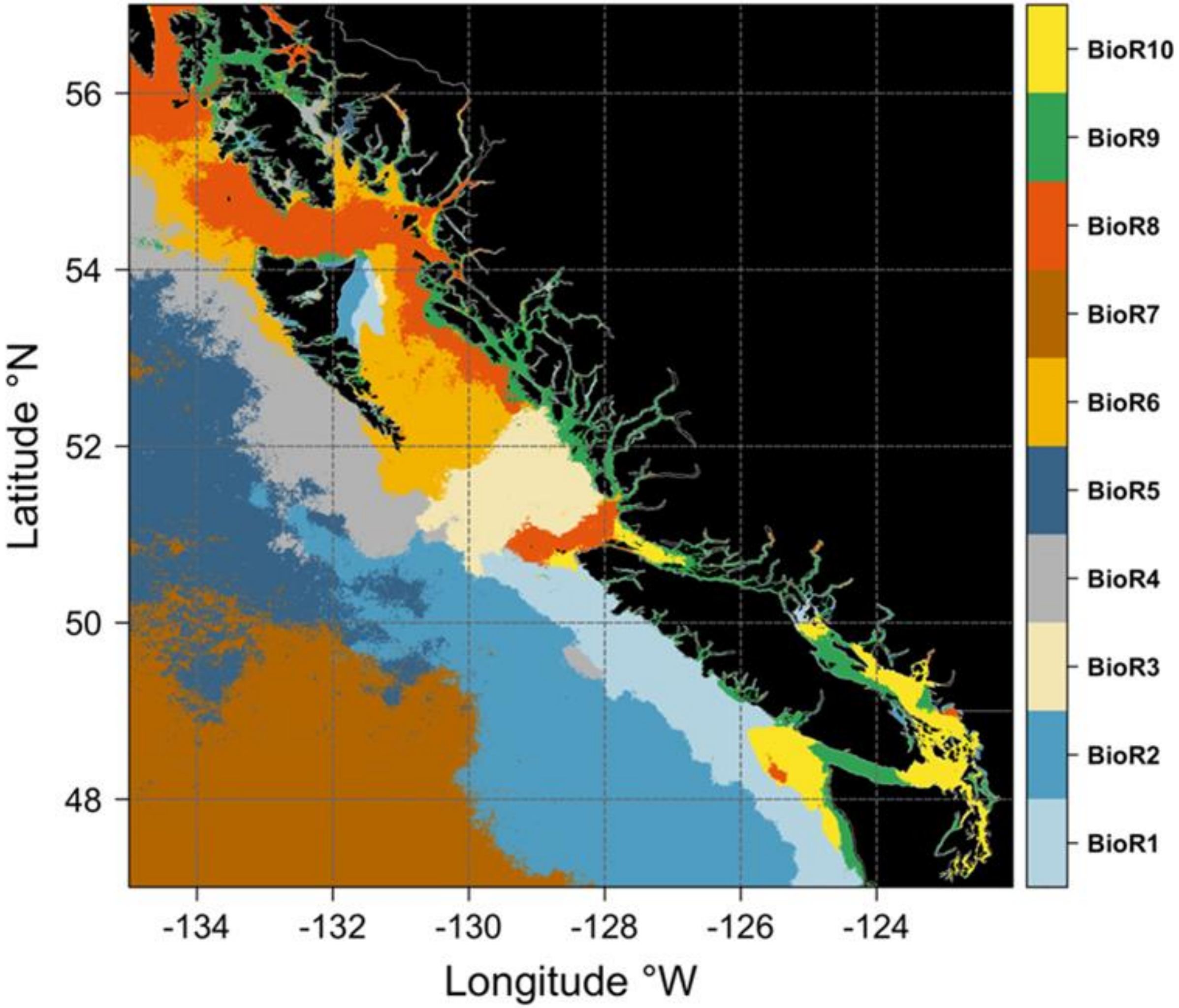
Bioregionalization: Juvenile salmon migration route

Sentinel 3 - Chla product 300m

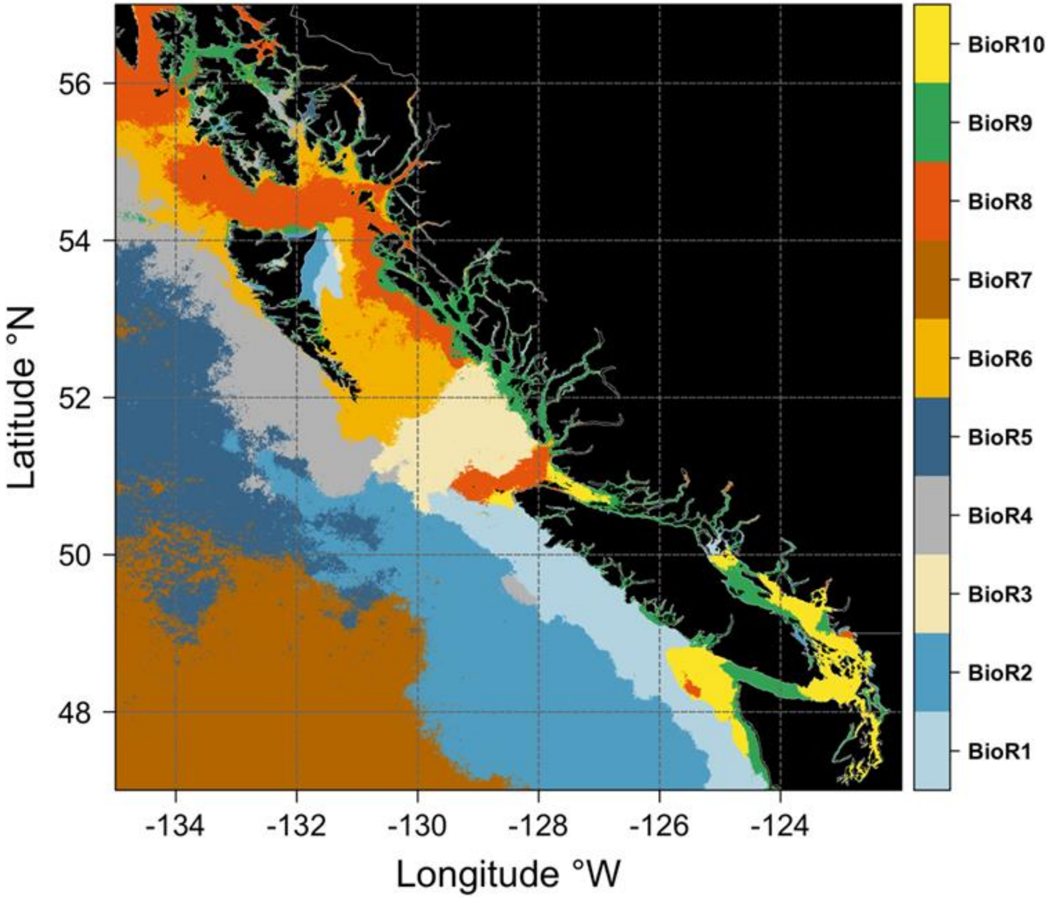
Neural Network - SOM



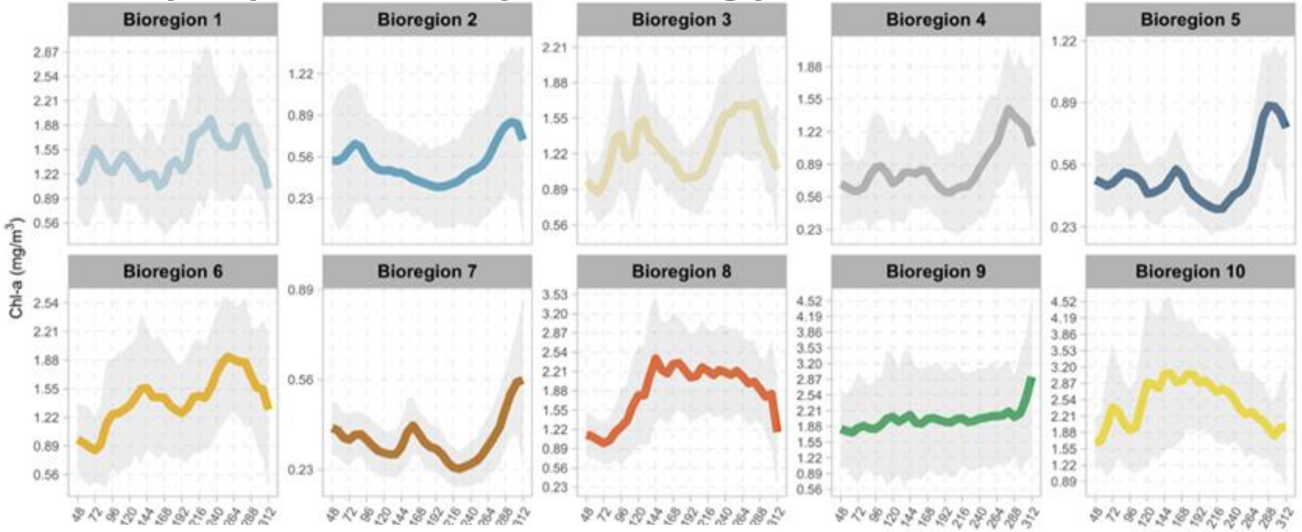
~8000 images



Marchese, Costa et al., 2022

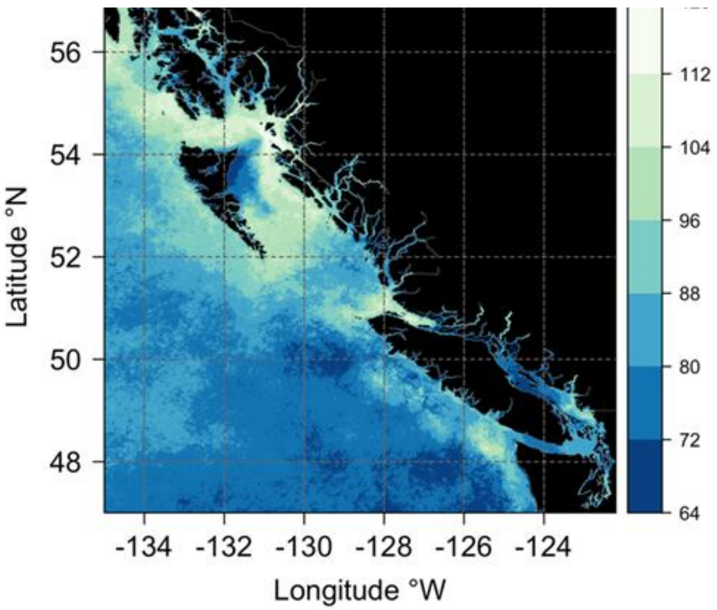


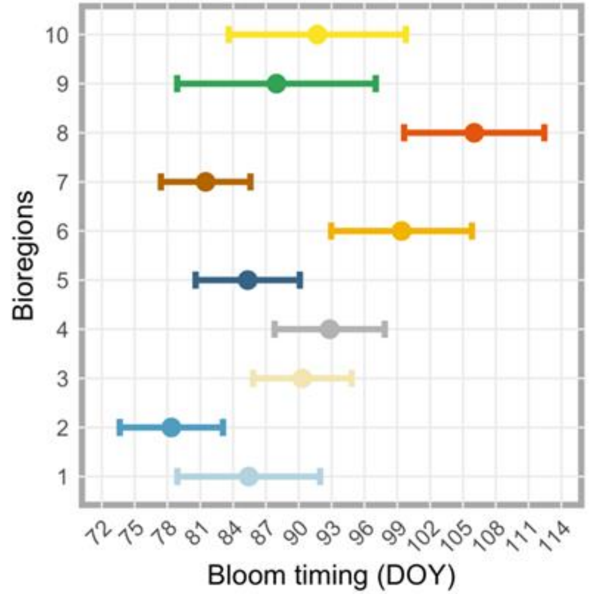
Phytoplankton phenology



A)

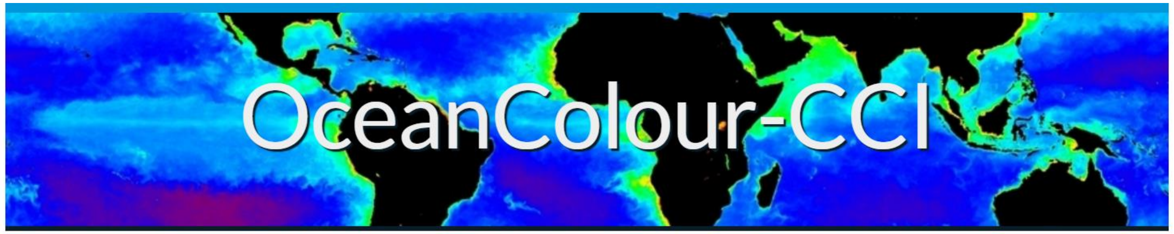
Phytoplankton Bloom Initiation



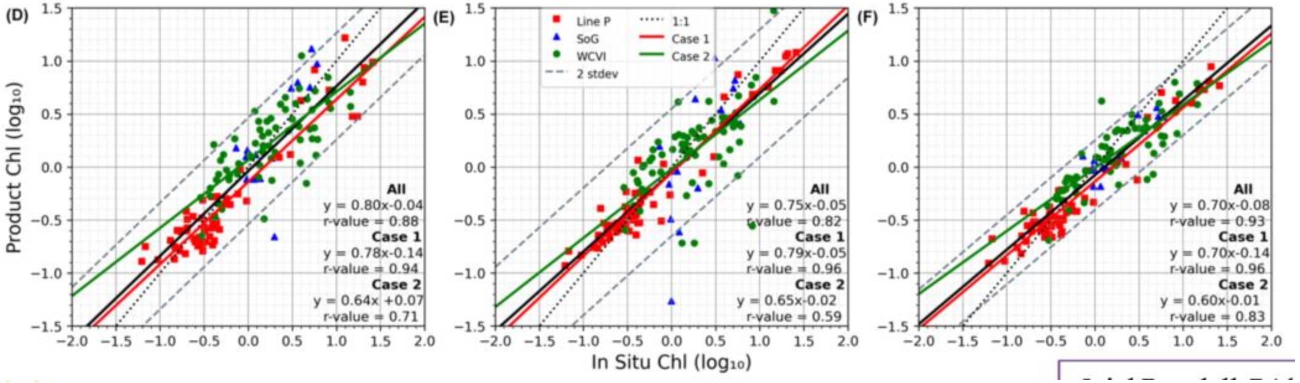


Marchese, Costa et al., 2022

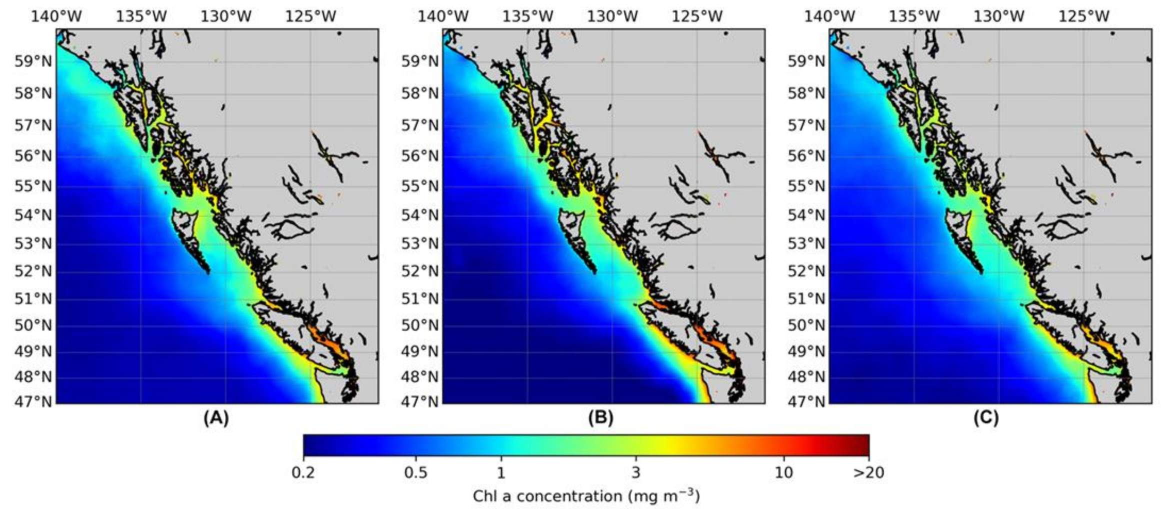
Merged OC data: solution for clouds and long Time series analysis (1997 – present)



GlobColour Interpolated OC-CCI GlobColour

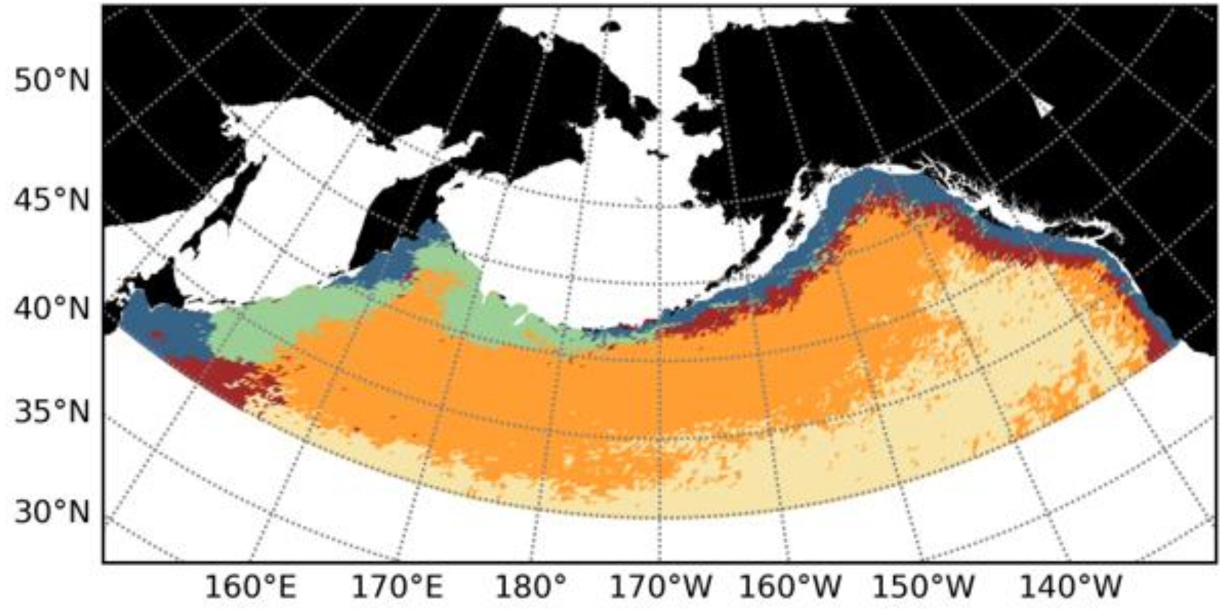


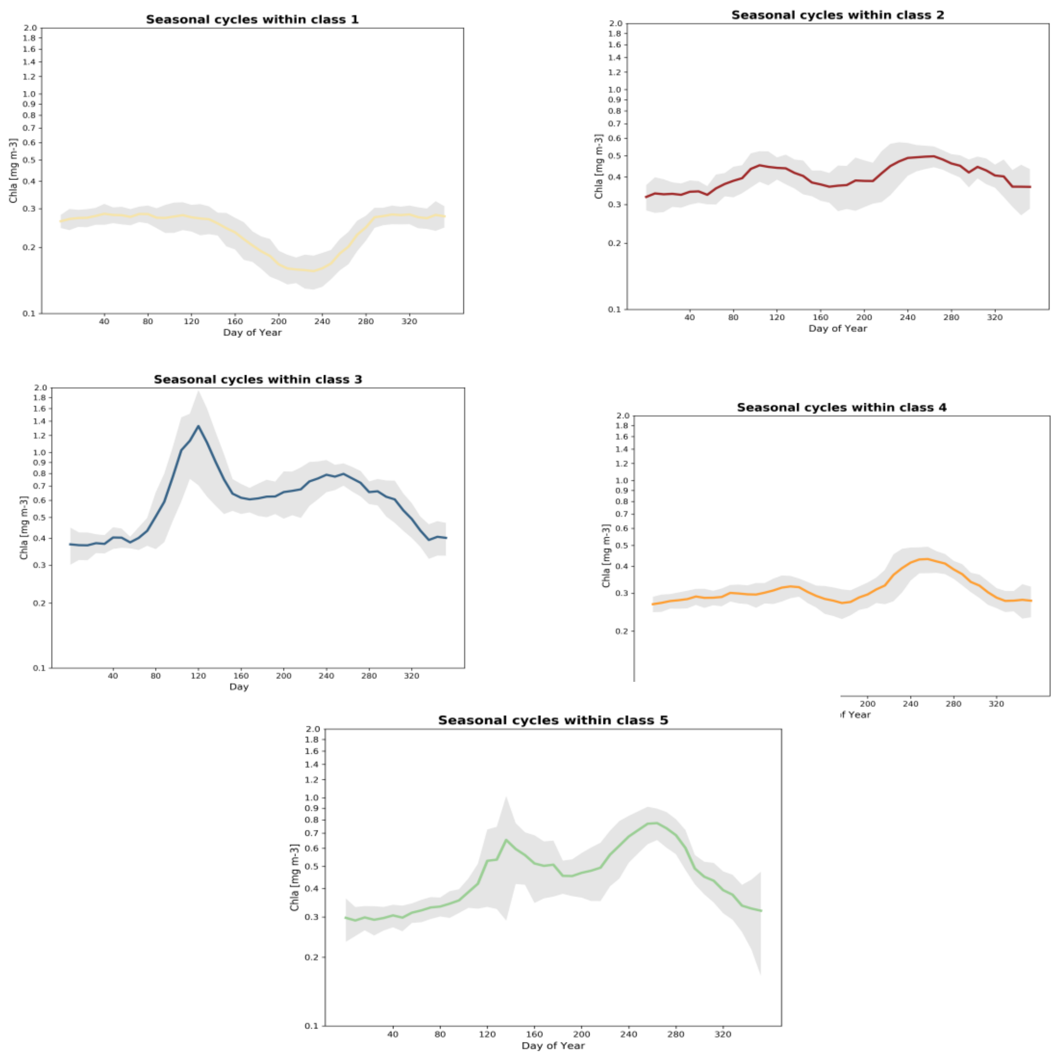
1998-2021 SPRING SUMMER FALL



(Pramlall et al., under review

North Pacific: Salmon Habitat Bioregionalization: GlobColour (1998-2021) – Chla phenology and PFTs

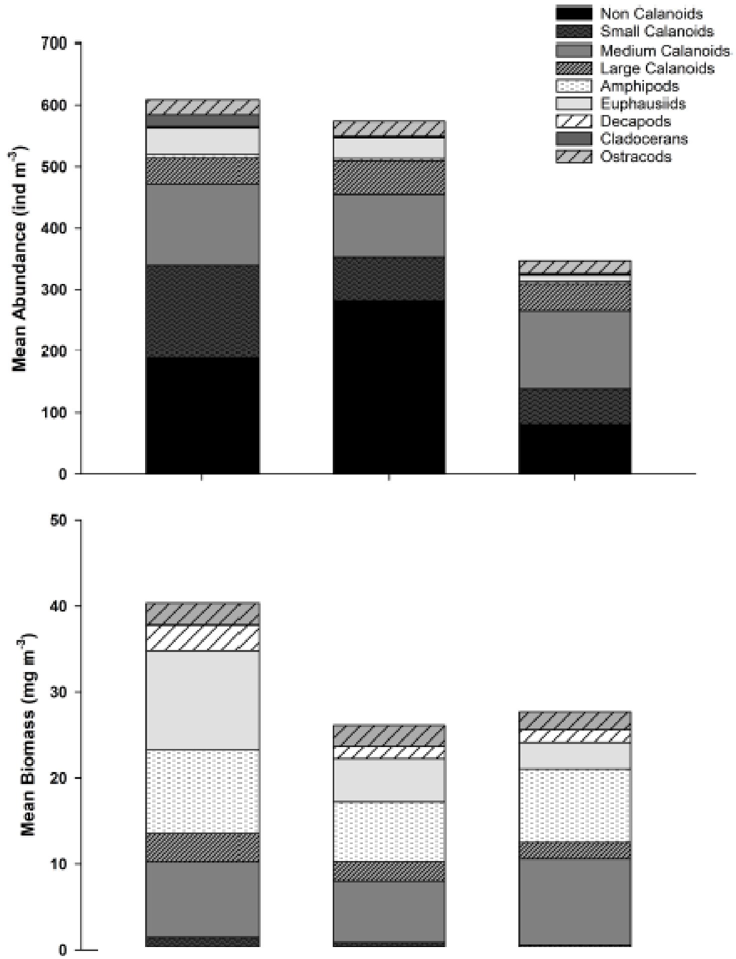




(Konick, Costa et al., in prep)

From satellite to salmon… phytoplankton/zooplankton match/mismatch

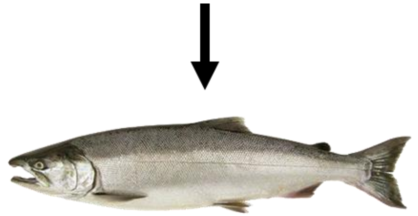
Strait of Georgia time series: Satellite-Phyto phenology and DFO Zoop abundance



Average **Early** **Late** **Chla bloom initiation**

Early phyto bloom→Mismatch: high abundance of small zooplankton and of lower food quality

Poor condition for salmon???



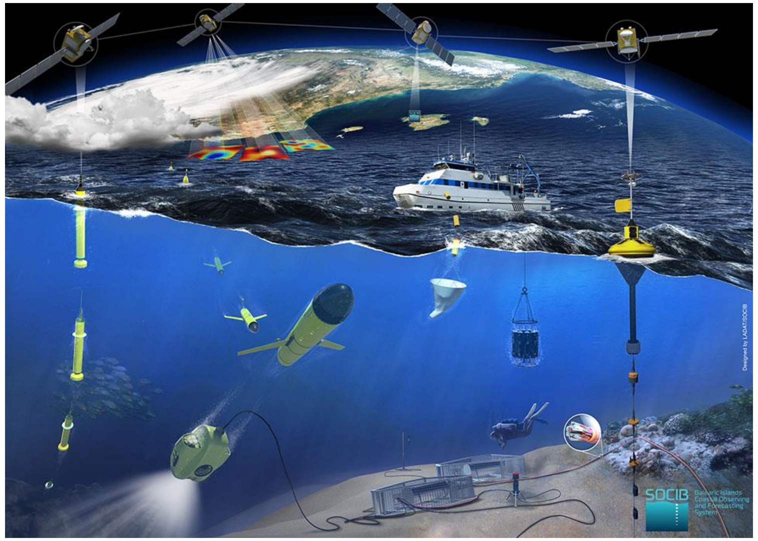
Average/late phyto→Match: higher biomass of zoop

Good conditions for salmon???

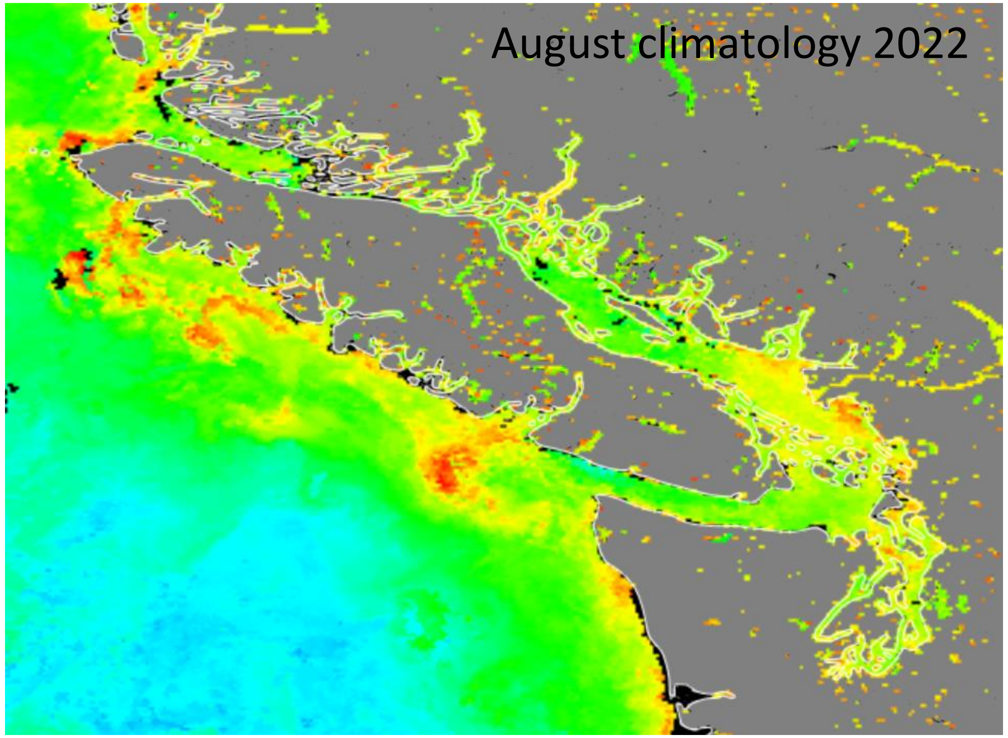
Suchy, Costa et al., 2019
Suchy, Costa et al., 2022

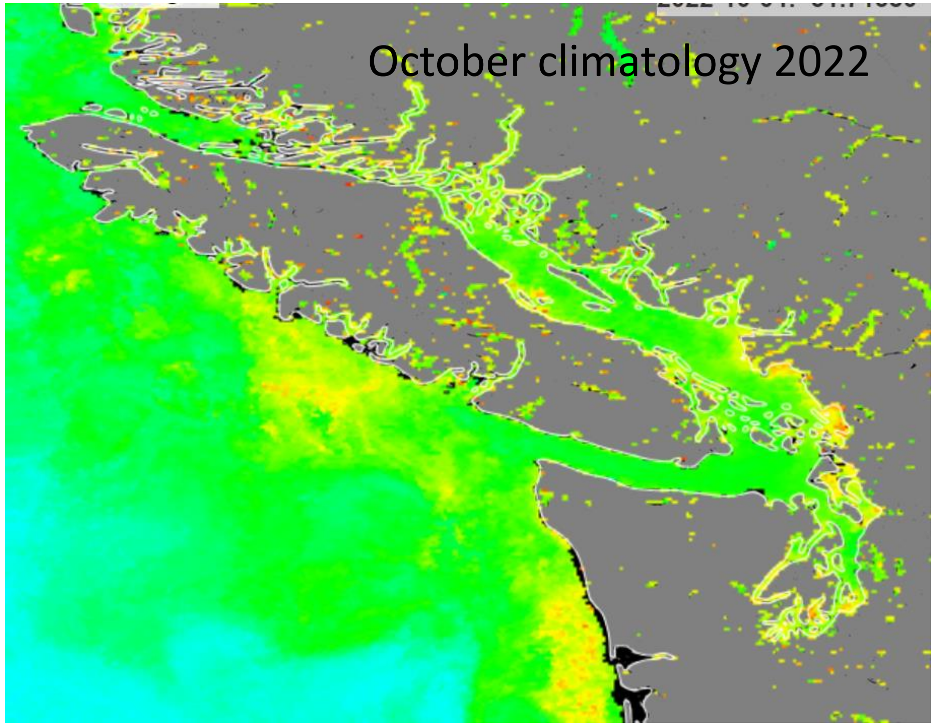
Yes, there are challenges – validation of products!
(as there are challenges with any data collection system!)
But there are many opportunities

Satellite derived data is just one piece of the puzzle!!!



Sentinel 3a - climatology





Thank you (maycira@uvic.ca)

Compile and Analyze Historical Primary Production Data

- Reveal spatial patterns and variation
  - Primary production
  - Production:Biomass (P:B) ratio using C-14 uptake over chlorophyll
- Assess comparability to chlorophyll and phytoplankton counts
- Provide input for model parameterization

C-14 Uptake Data

- 1999 – 2014 (seasonal or monthly)
- Sound-wide or regionally
- PRISM, SPASM, HCDOP, LOTT, King County, etc.

Ask: Support for an oceanography senior or master student for a summer or ideally a year

6 December 2022

Bottom up drivers of zooplankton food web structure and function

Dr. Brian Hunt

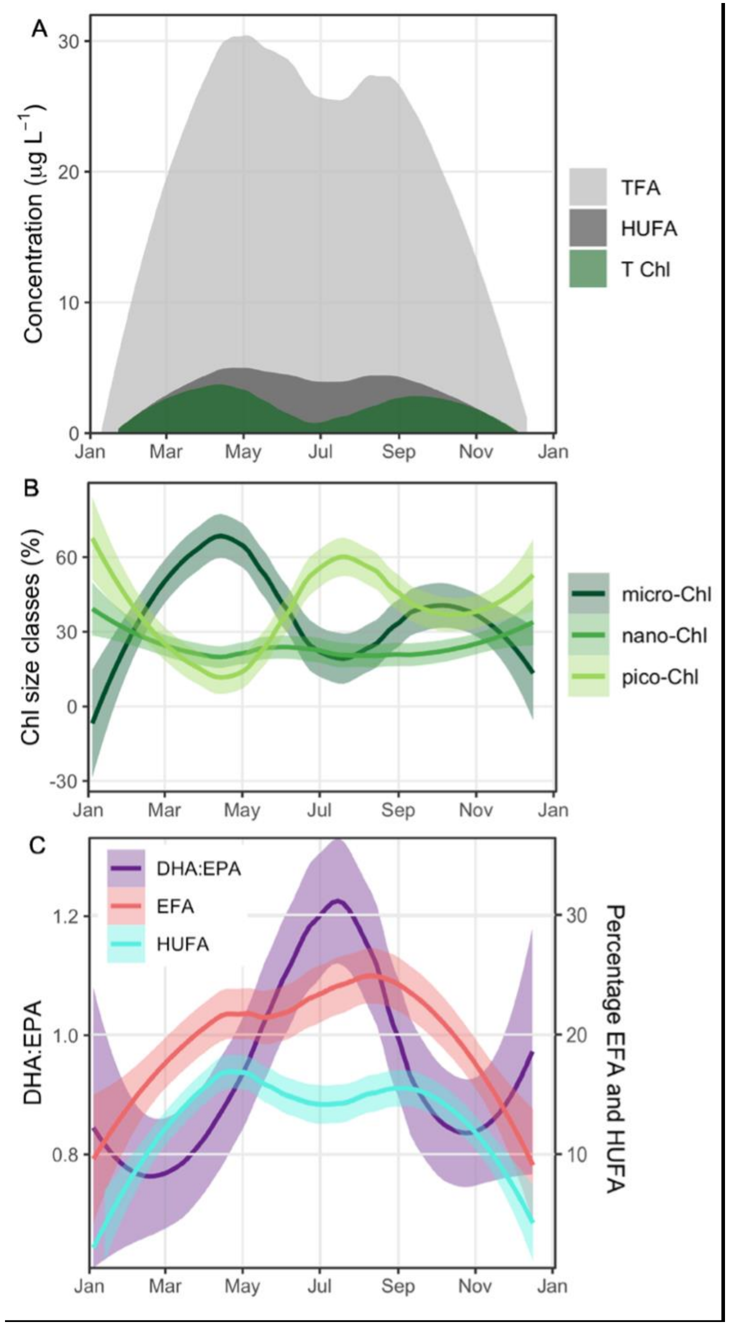
Institute for the Oceans and Fisheries, University of British Columbia

Phytoplankton & Particulate matter variation relevant to zooplankton nutrition

Northern Salish Sea

- Phytoplankton size structure matters to zooplankton → changes seasonally
- Phytoplankton composition affects nutrients available to zooplankton
- 18C PUFAs abundant in pico-phytoplankton → can be converted to DHA & EPA by microzooplankton
- Pico-phyto. can support a varied and nutritious prey field.

McLaskey et al., Progress in Oceanography (2022); https://doi.org/10.1016/j.pocean.2022.102843



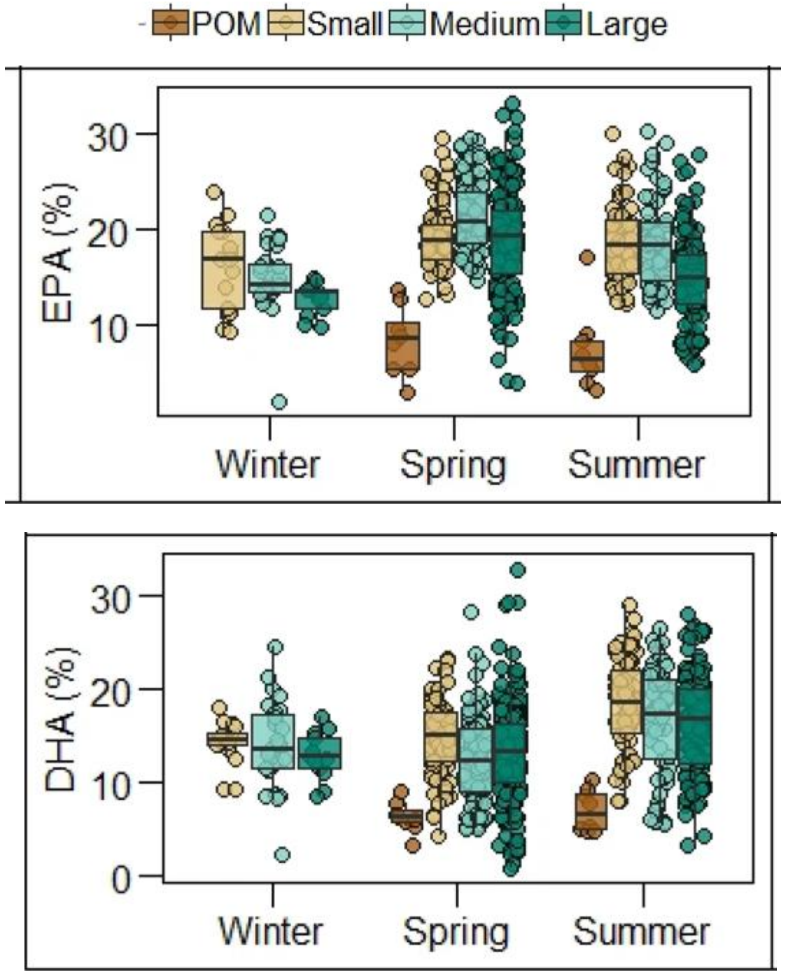
Zooplankton food web pathways

Fatty acid trophic markers

Support seasonal shift in trophic pathways

- Diatom dominated in spring
- Flagellate dominated in summer

Zooplankton size classes



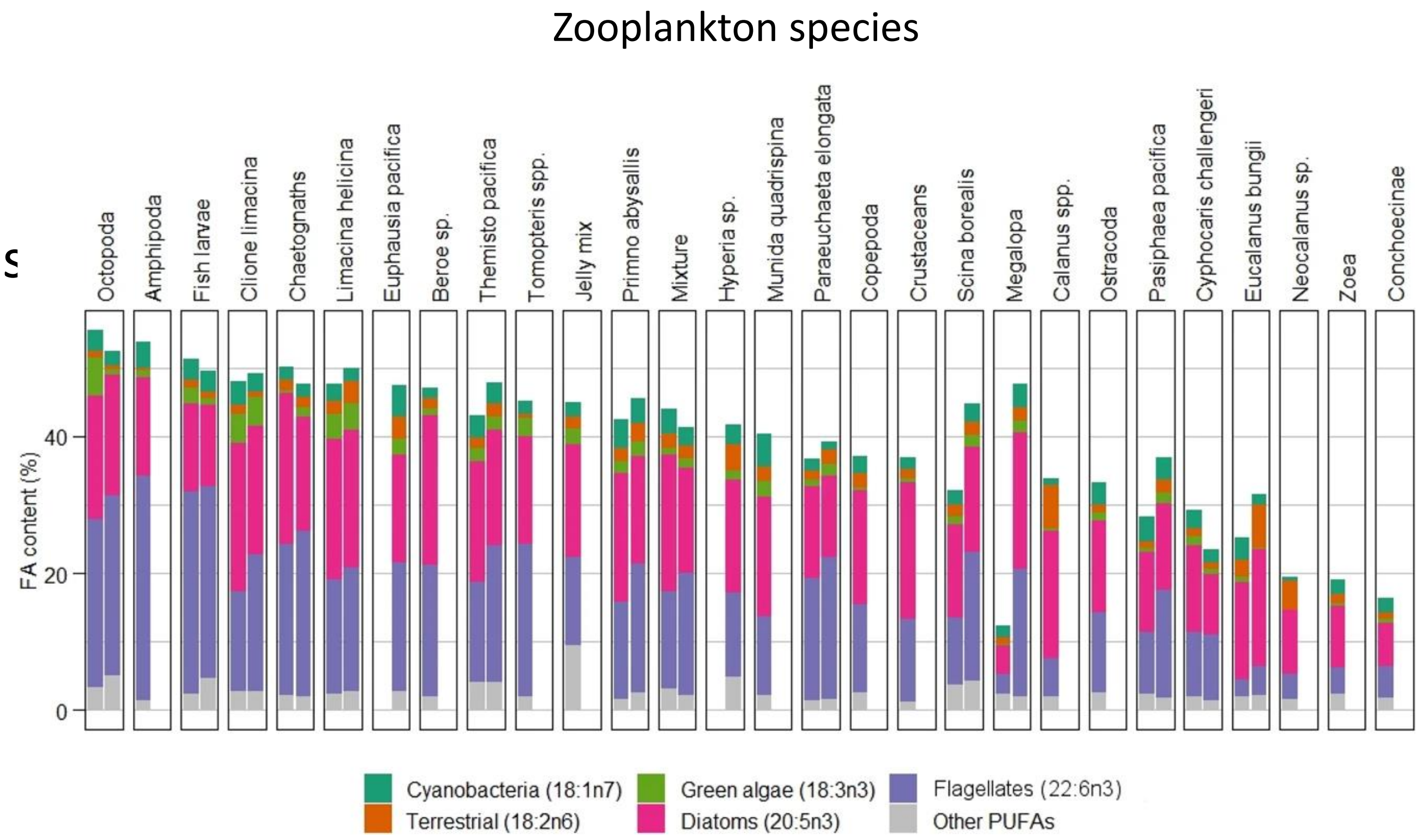
Costalago et al., Scientific Reports (2020); https://www.nature.com/articles/s41598-020-65557-1

Zooplankton food web pathways

Fatty acid trophic markers

Suggest diatoms & flagellates dominate BUT can also be sourced through microzoo.

Cyanobacteria, Green Algae and Terrestrial material also contribute



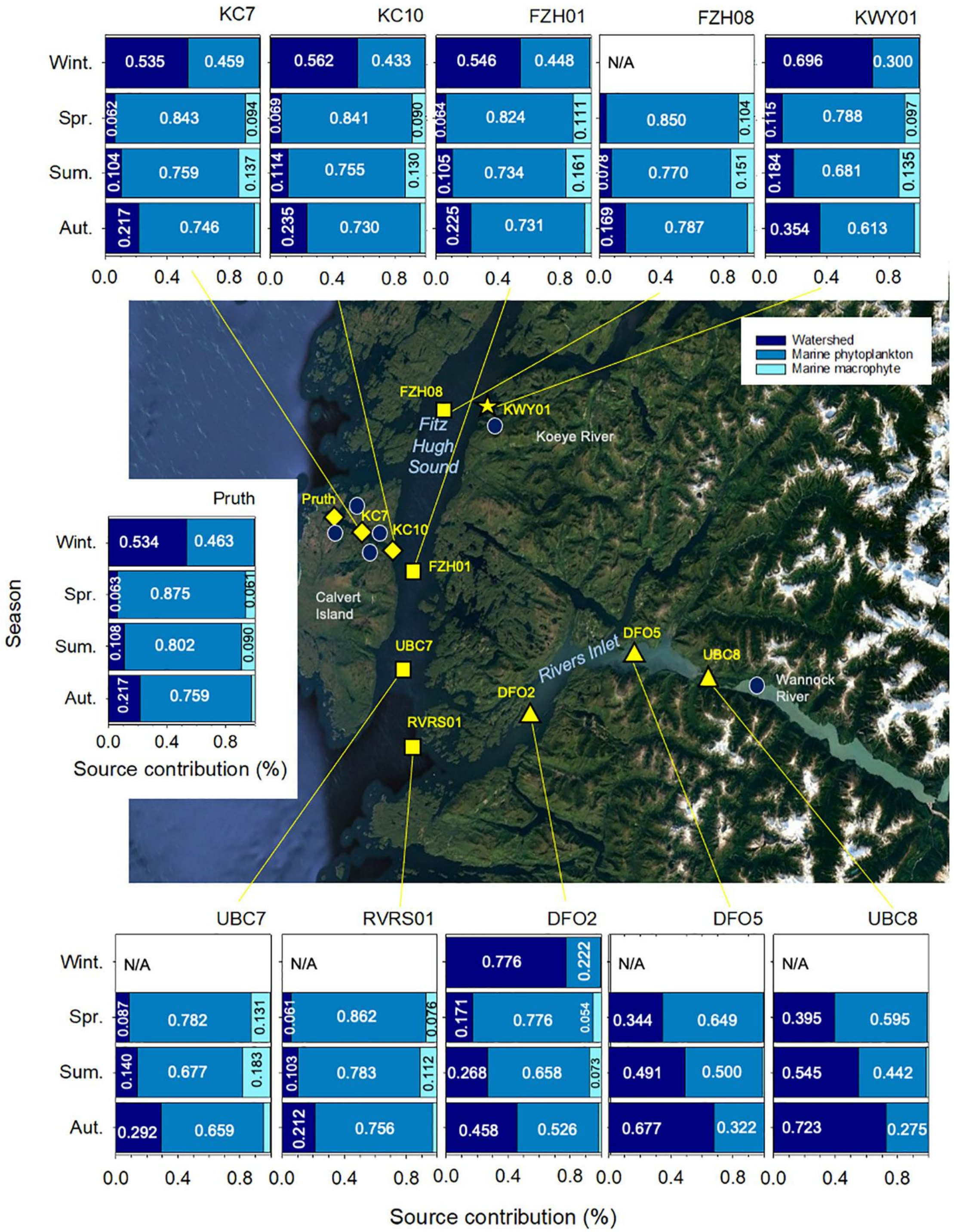
Costalago et al., Scientific Reports (2020); https://www.nature.com/articles/s41598-020-65557-1

Organic matter sources in the nearshore and coastal ocean

Central coast of BC

- Phytoplankton are not the only organic matter sources available to zooplankton
- Terrestrial material inputs scale with proximity to watersheds
- Macrophytes can contribute up to ~20% of POM biomass

St. Pierre et al., Frontiers in Marine Science (2022); https://doi.org/10.3389/fmars.2022.863209



Future work

- Characterization of additional organic matter sources to coastal ocean (e.g., Urban Environs)

- Understanding food web pathways - application of multiple trophic markers (FAs and Isotopes) in addition to zooplankton stomach DNA to resolve zooplankton diets

- Resource as drivers of zooplankton food web structure - fine scale characterization of nearshore zooplankton communities using eDNA to identify community response to resource gradients

Brian Hunt contact details: b.hunt@oceans.ubc.ca; http://pelagicecosystems.oceans.ubc.ca/

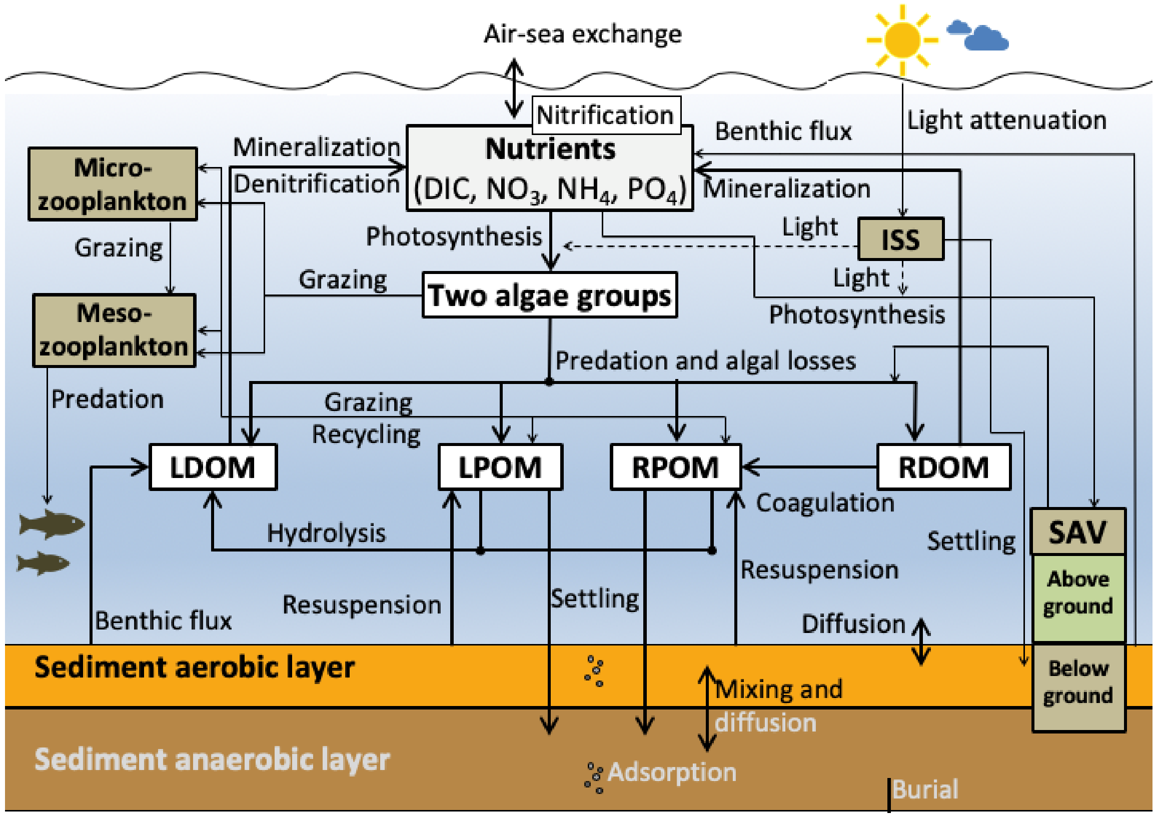
Driving Scientific Question

Considering future climate change, how do changes in density structure in response to the relative timing of coastal upwelling and earlier river discharge alter growth conditions for phytoplankton productivity?

Salish Sea Model

- Two representative phytoplankton algal groups
  - Growth and loss parameters (e.g., basal metabolic rate)
  - Does not account for competition
  - Two groups, broadly capturing diatoms vs dinoflagellates (parameterization for each based on widely accepted lit. values e.g. EPA)
- Accounts for algae's role in the biogeochemistry (i.e., nitrogen, carbon, and phosphorous cycles)
- Phytoplankton forced by parameters related to light and nutrient availability

Appendix E1/H, Ahmed et al. (2019)



Updates Since Puget Sound Nutrient Reduction Project Application

+ Change from constant predation term → simulate zooplankton explicitly
+ Inorganic suspended solids, turbidity, zooplankton, and submerged aquatic vegetation including the "associated nutrient and carbon source and sink mechanisms" (Khangaonkar et al., 2021a)

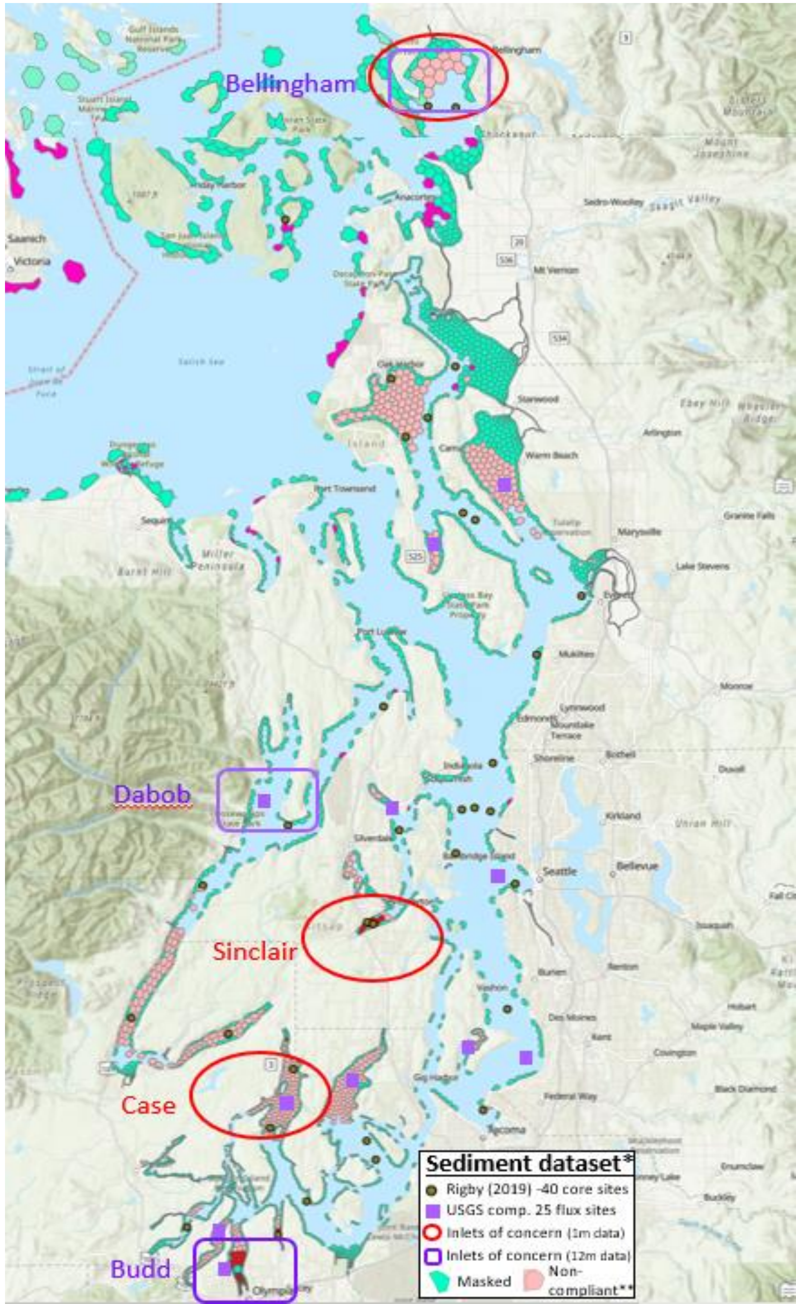
Khangaonkar et al. (2018, 2021a, 2021b, 2022)

Phytoplankton Primary Productivity | Salish Sea Model

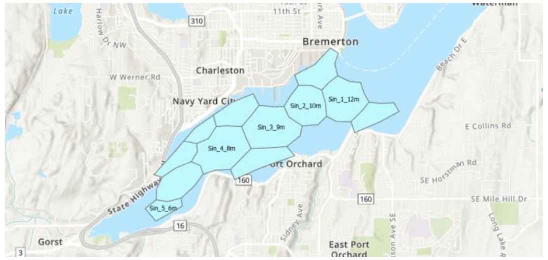
Expanding on sediment module validation in embayments that was proposed at the earlier [Sediment Exchange workshop](#).

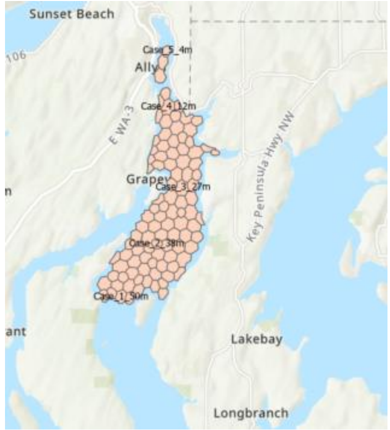
Examine phytoplankton primary productivity outputs of the Salish Sea Model at:

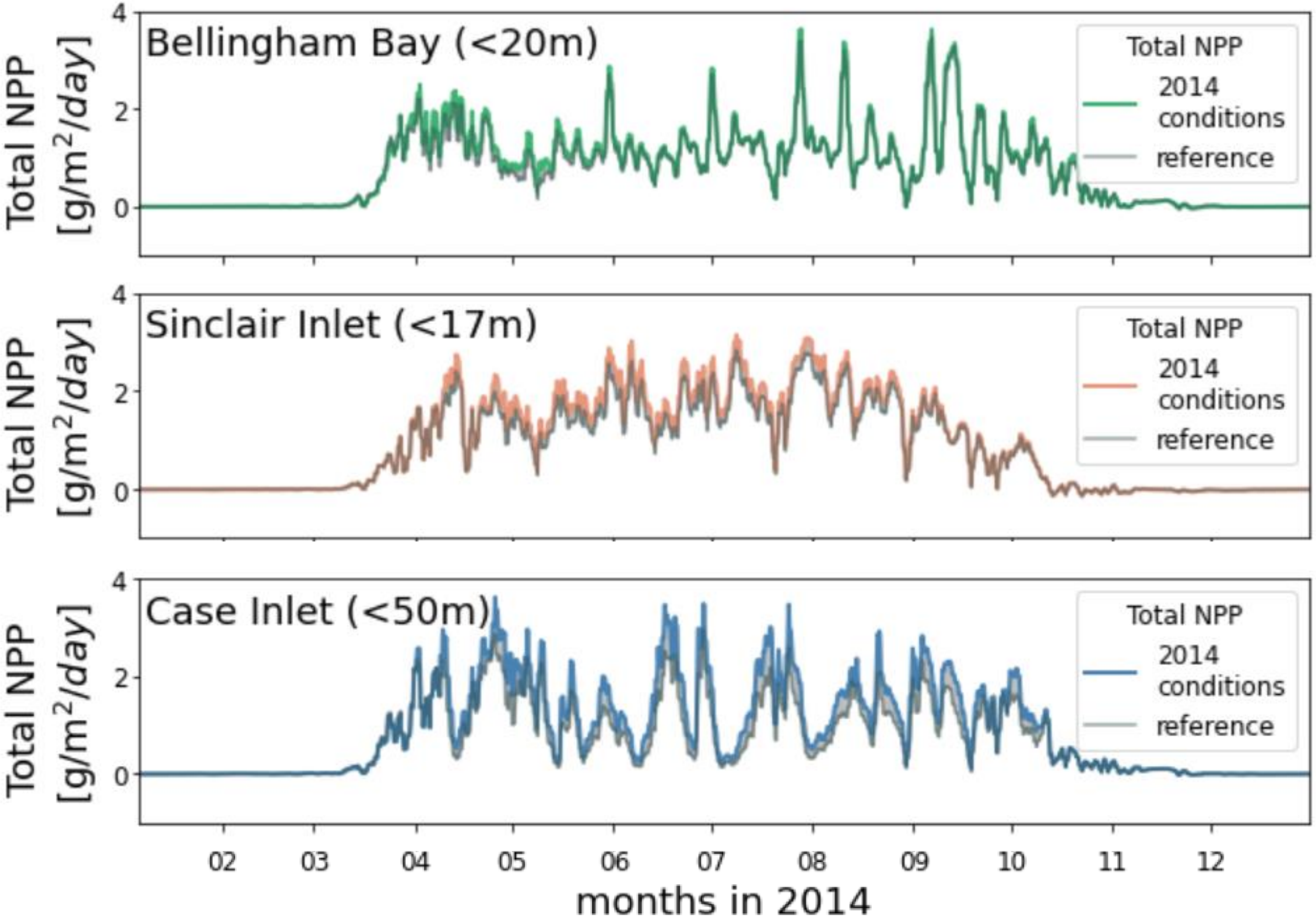
- Bellingham Bay (< 20m)
- Sinclair (<17m)
- Case inlet (<50m)



Phytoplankton Primary Productivity | Salish Sea Model

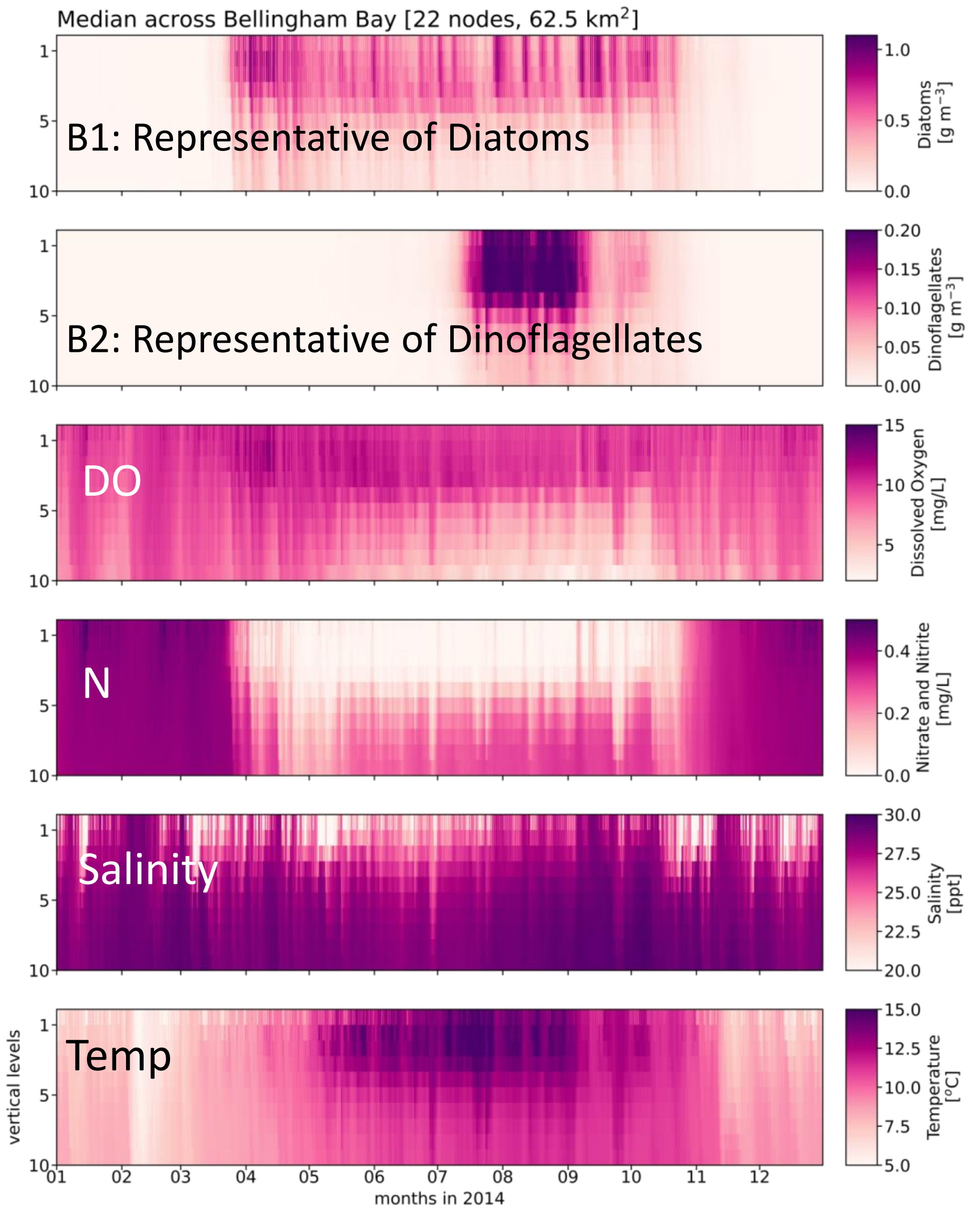


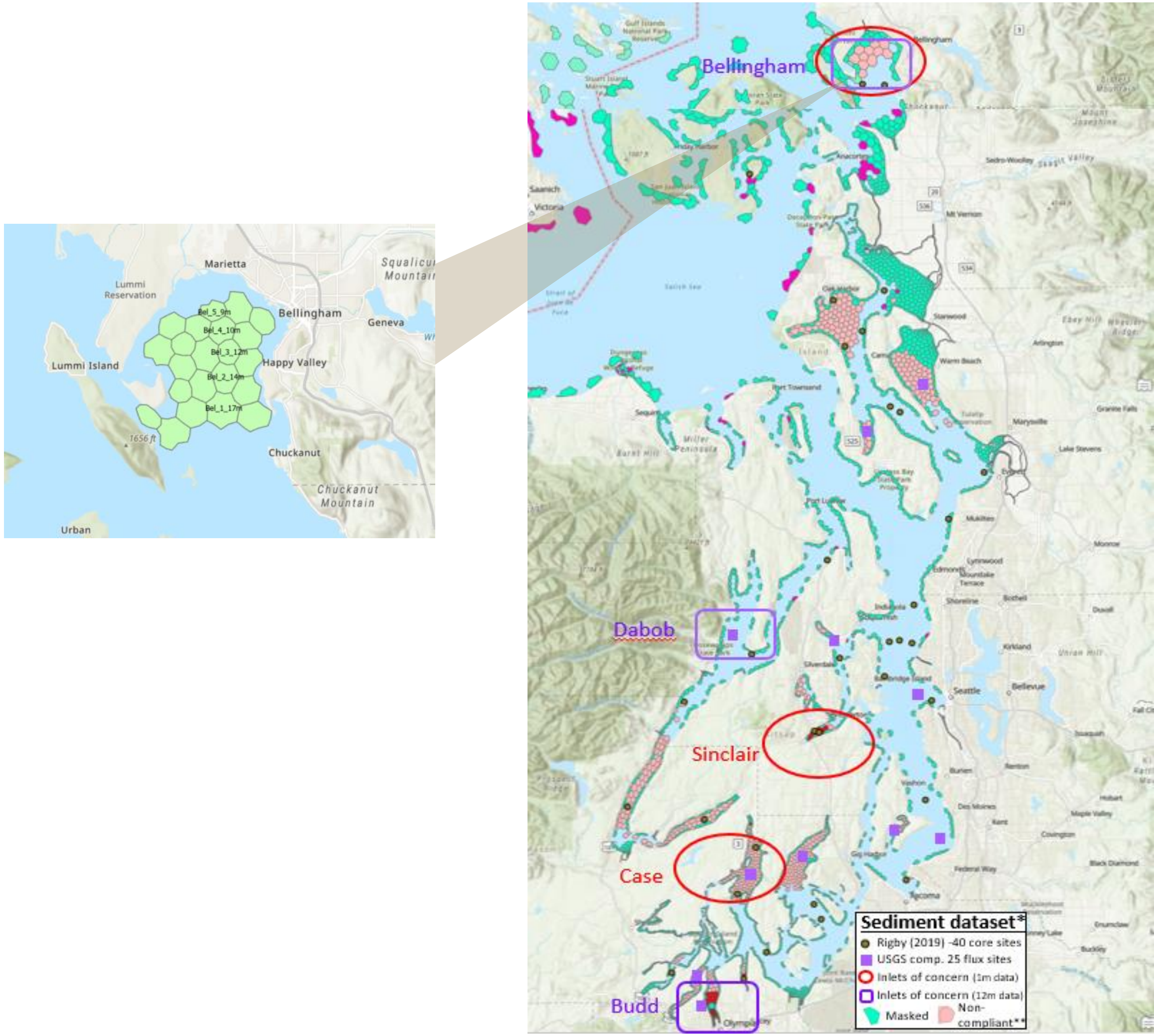




An Overview of Three Bays

Bellingham (22 nodes, 63 km2)

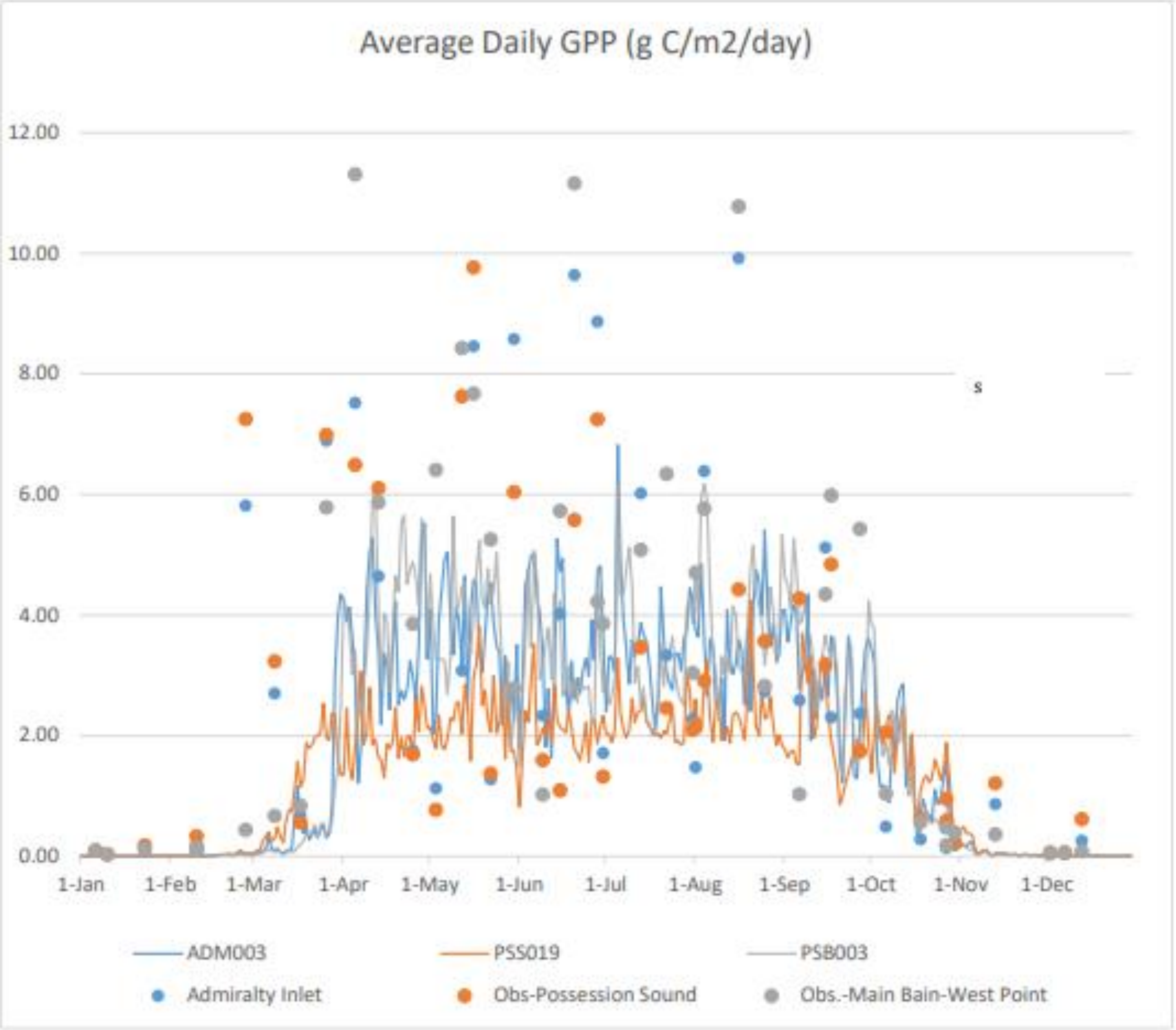




Phytoplankton Primary Productivity

Comparison of Observed and Predicted Annual Average Daily Gross Primary Production (mg C/m2/day) at Central Puget Sound Sites

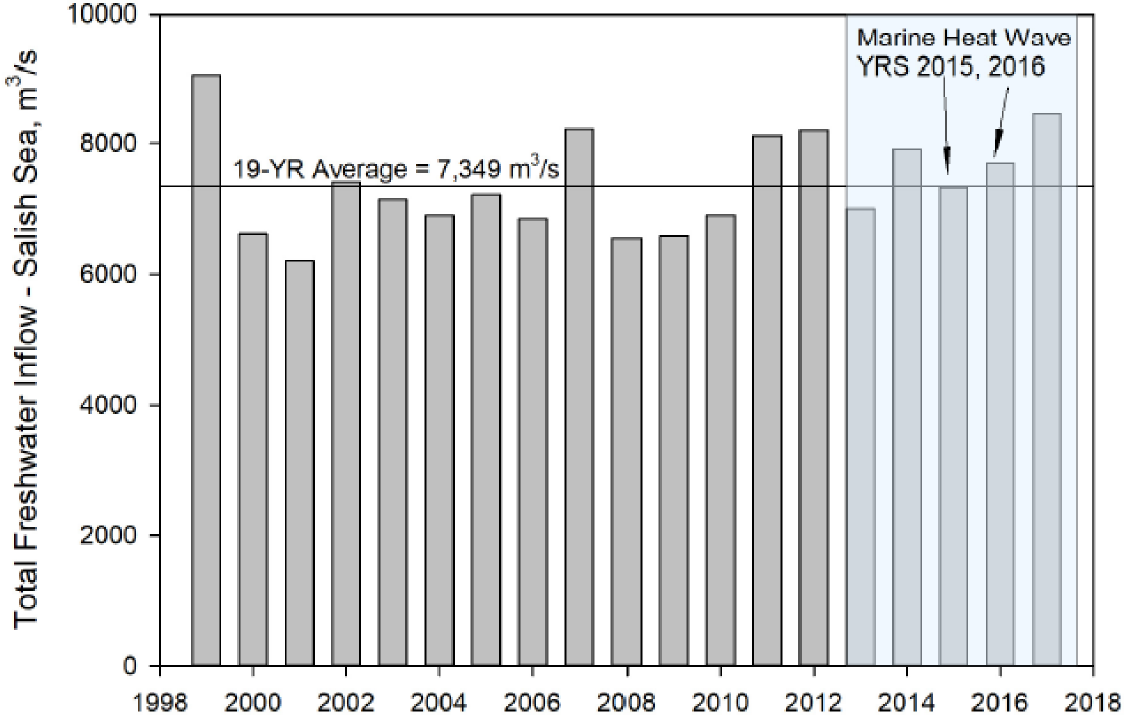
- Measured 11.3 g C/m2 /day (*[Newton and Van Voorhis (2002)]*) compared to 6.8 g C/m2 /day modeled
- Prior historical studies: range of spring peaks from 4.8-10 g C/m2/day (1968-1998; Ahmed et al, 2019)

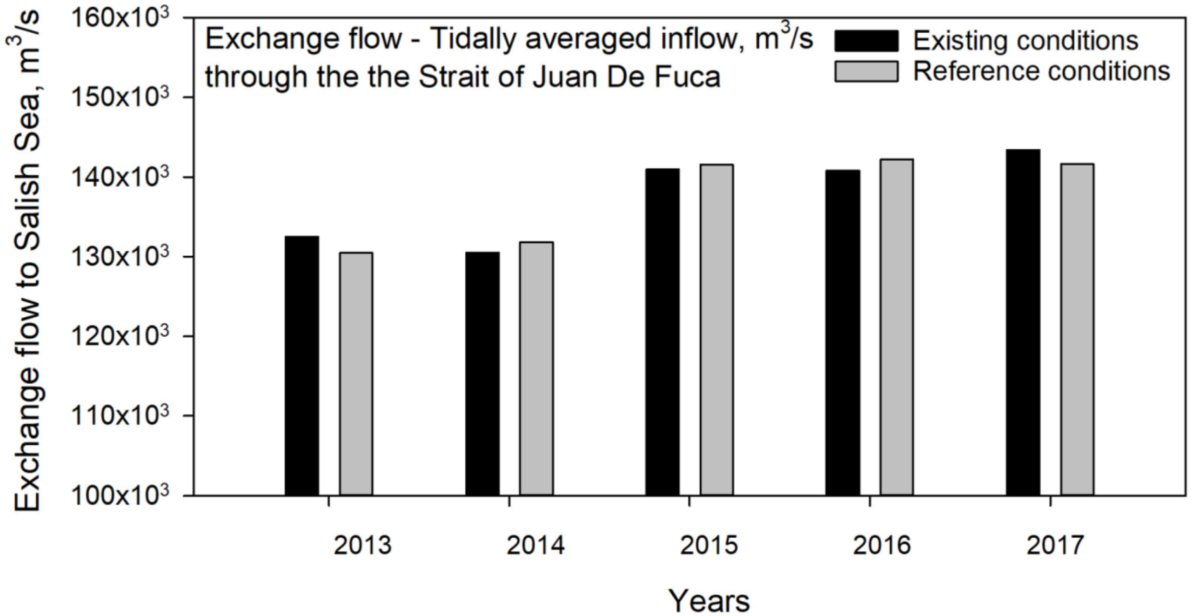


[Appendix H, Ahmed et al. (2019)]
[Newton and Van Voorhis (2002)]

Connection Between River & Exchange Flow > Primarv Production

↑ River Flow ▶ ↑ Exchange Flow





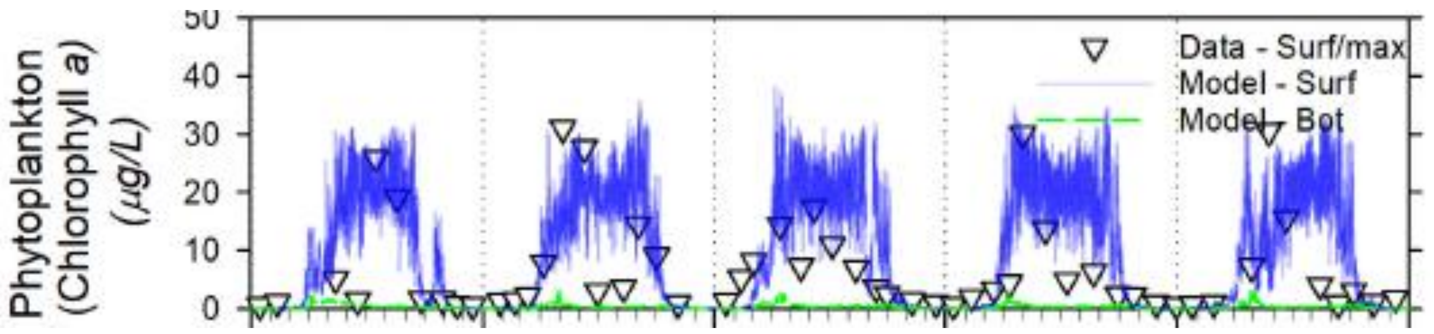
(Khangaonkar et al. 2021b)

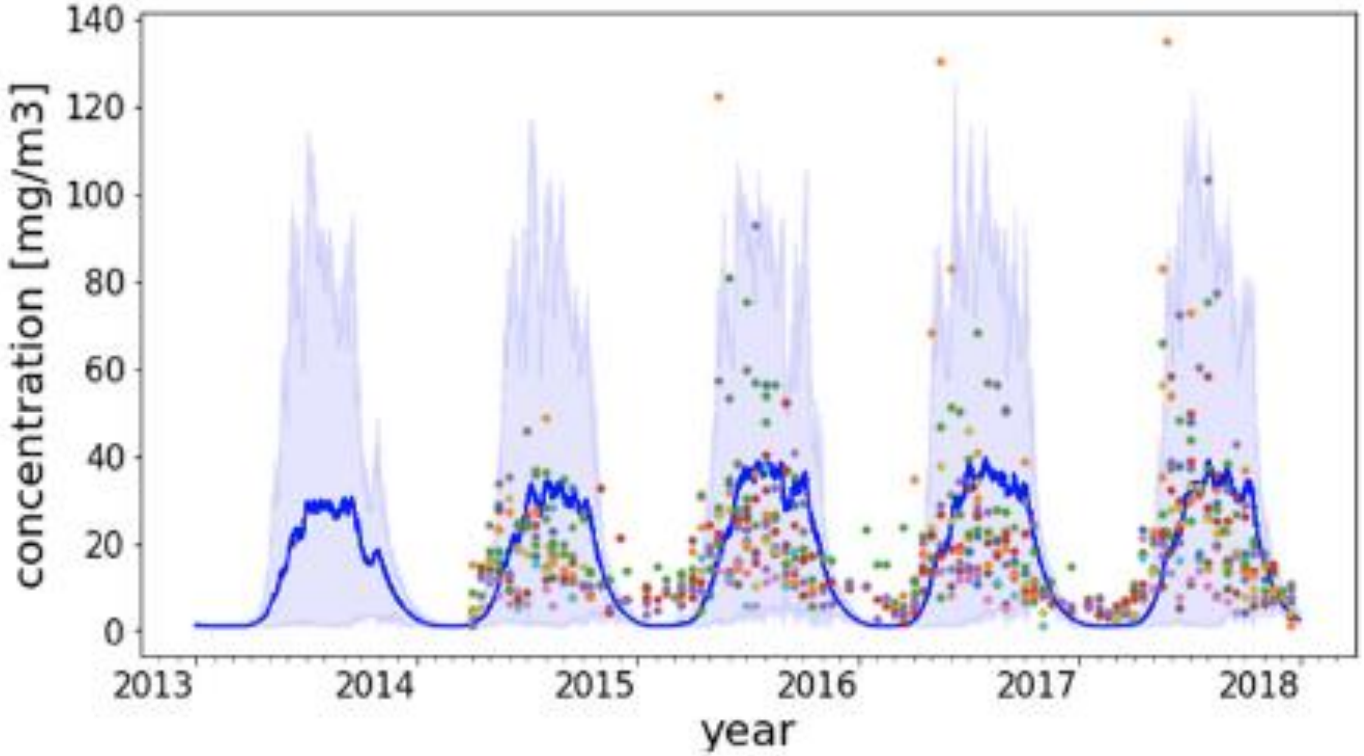
Connection Between River & Exchange Flow > Primary Production

↑ River Flow ▶ ↑ Exchange Flow

↑ Nutrients ▶ ↑ Primary Productivity

↑ Primary Productivity ▶ ↑ Zooplankton Biomass

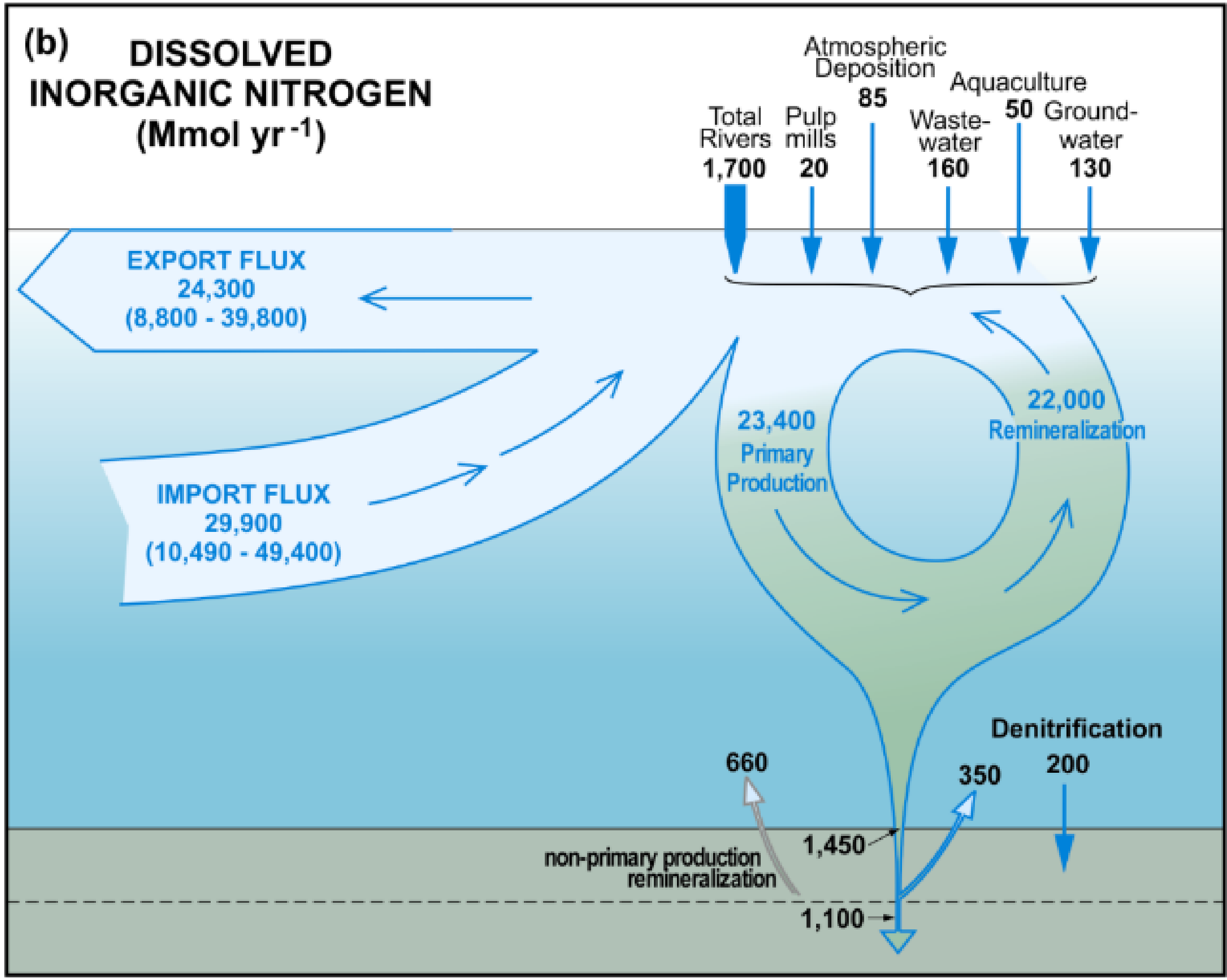




(Khangaonkar et al. [2021b](#))

Tools for sub-basin and inlet nutrient budgets

Changes to the salinity gradient and exchange flow influence the availability of nutrients to the euphotic zone



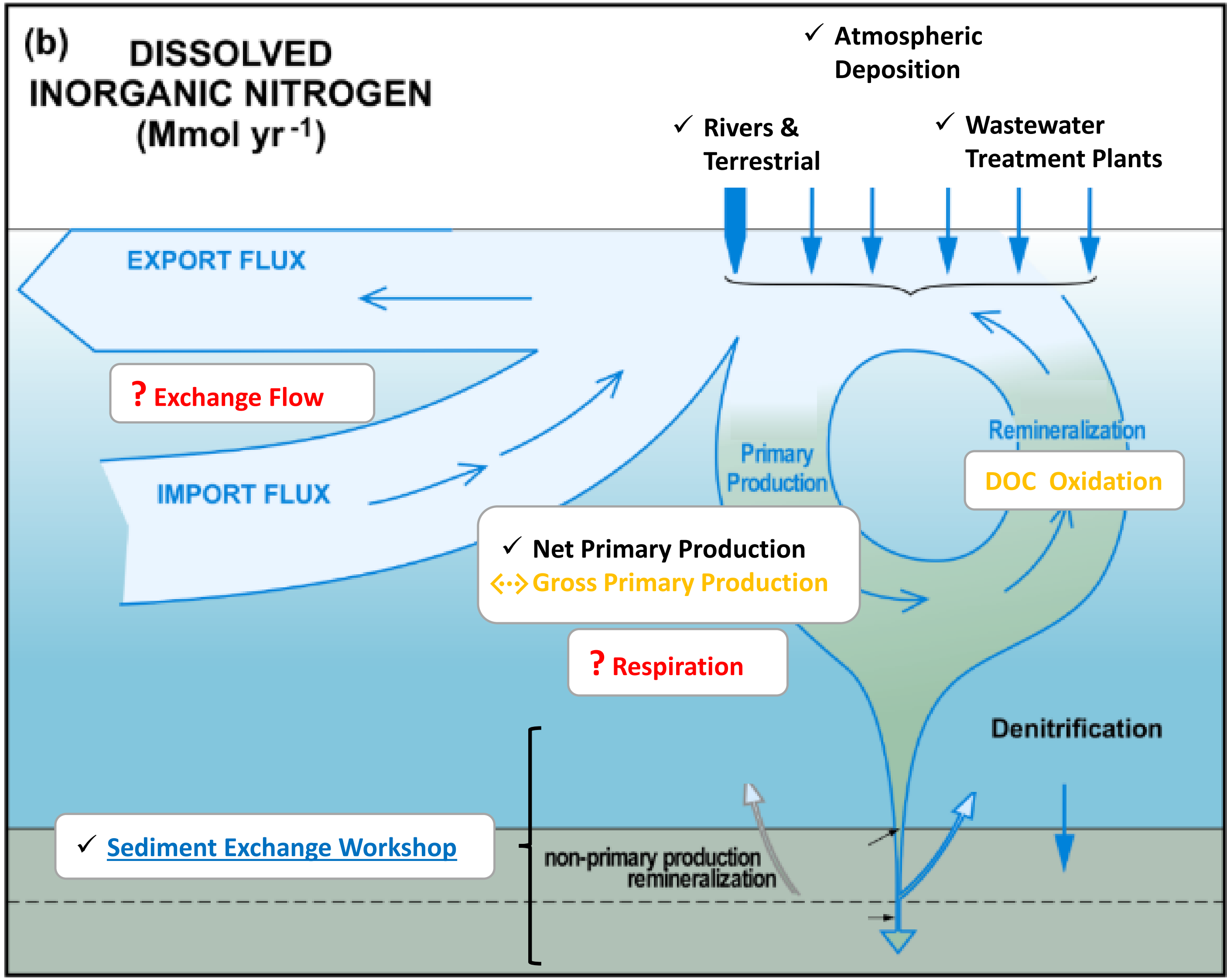
Sutton et al. (2013)

Tools for sub-basin and inlet nutrient budgets

Changes to the salinity gradient and exchange flow influence the availability of nutrients to the euphotic zone

Potential Next Steps to consider

- Re-run the model to extract and validate Gross Primary Production
- Align on a method to calculate respiration
- Analyze exchange flow
  - **Pre-processing*:** Direct tidally averaged mass flux ([Khangaonkar et al., 2017]())
  - **Post-processing:** Indirect salinity-based mass flux (Ben Roberts)



* Will be presented at the interannual variability workshop

Quantifying Estuarine Advective Exchange with the Salish Sea Model

Ben Roberts
University of Washington (Civil & Env Eng)

Background

- Strong ocean influence on DO/nutrients
  - Large fluxes both in and out
  - Dependent on **estuarine exchange**
- Goal: measure advective fluxes from model output in control volumes:
  - Large basins
  - Small inlets

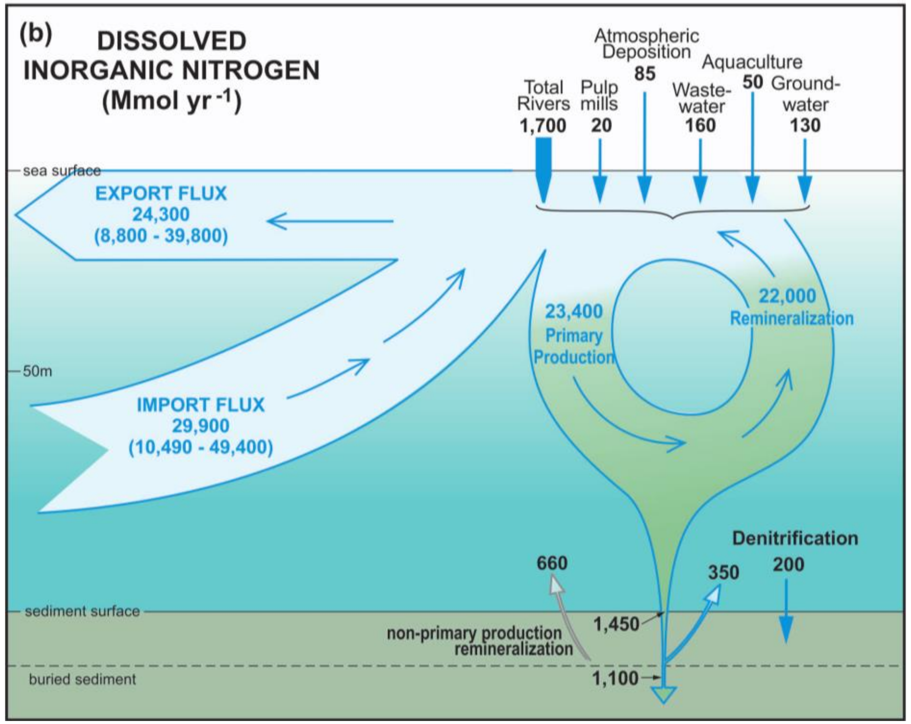
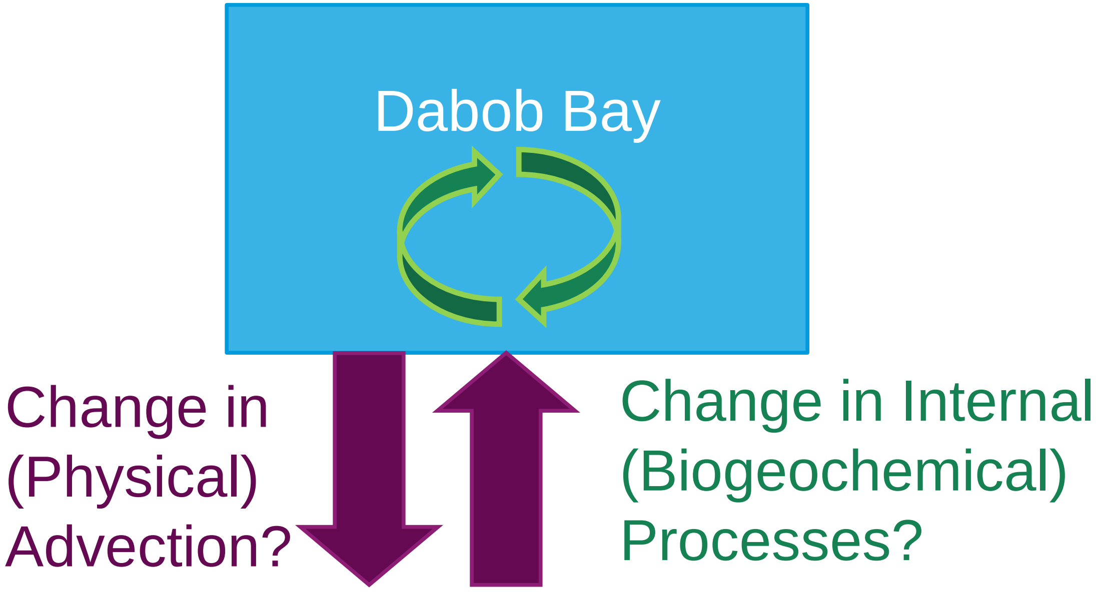


Fig 4b from Sutton et al, 2013

Conceptually:

- What mechanisms within the model led to different results?



Total Exchange Flow

(MacCready, 2011)

- Can measure tidally averaged flows (Q_{in}, Q_{out}) and salinities (S_{in}, S_{out}) across a section
- Quantities satisfy an exact version of the 2-layer Knudsen relations
  - Even if bathymetry is complex, flow is more than 2-layer, etc

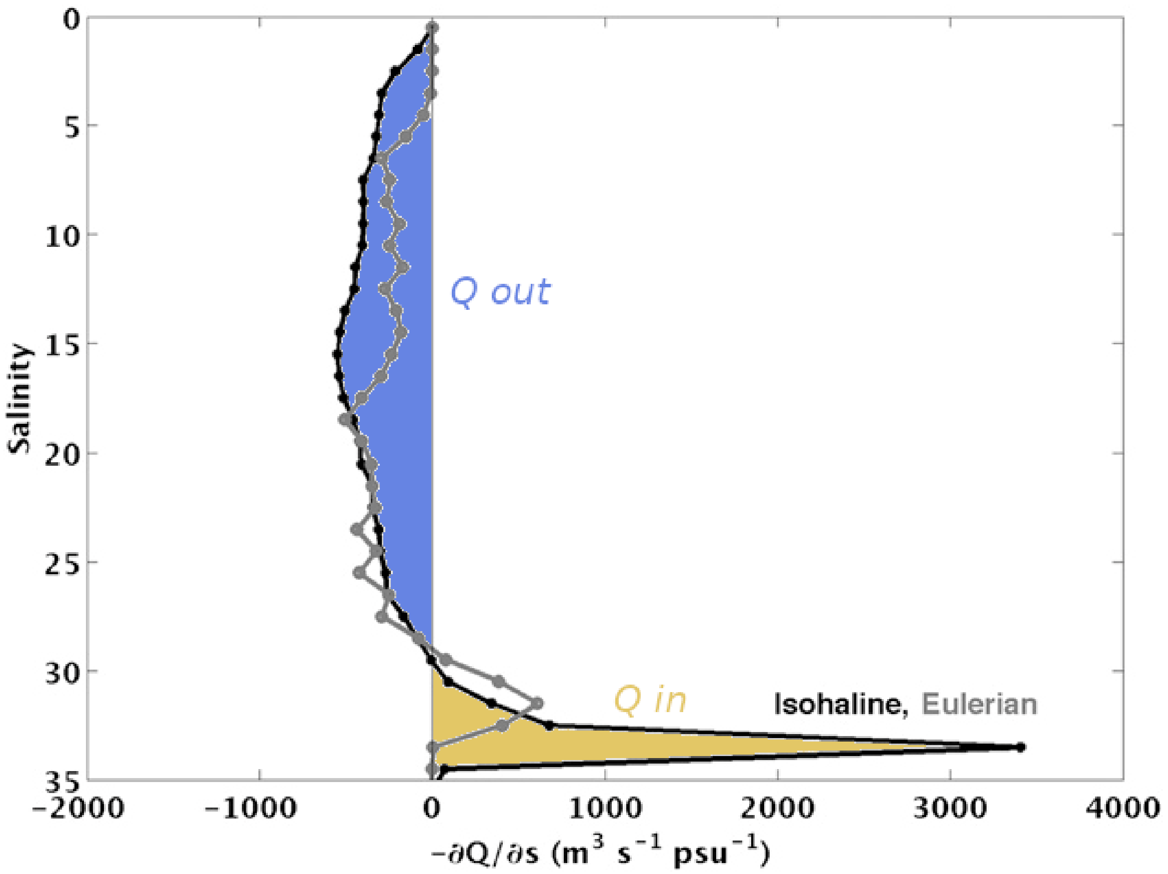


Fig 3 from MacCready, 2011

Total Exchange Flow: nonconservative tracers

- From model output:
  - Use Q_{in}, Q_{out} to measure advective flux of DO, nutrients across a section
  - Measure d(CV)/dt within control volume
  - Track freshwater inputs
- Perform mass balance $\frac{d(CV)}{dt} = Q_{in} C_{in} - Q_{out} C_{out} + FW_{in} - s$
- Remaining amount is total sources/sinks
  - Can collect certain fluxes (atmosphere, sediment) from model to refine

Applications to Puget Sound

(MacCready et al, 2021)

- In LiveOcean, grid is based on latitude & longitude
- E-W and N-S sections created
- Flow (velocity) across sections easy to get from output
- Processing code (Python) is public

https://github.com/parkermac/LiveOcean/tree/master/x_tef

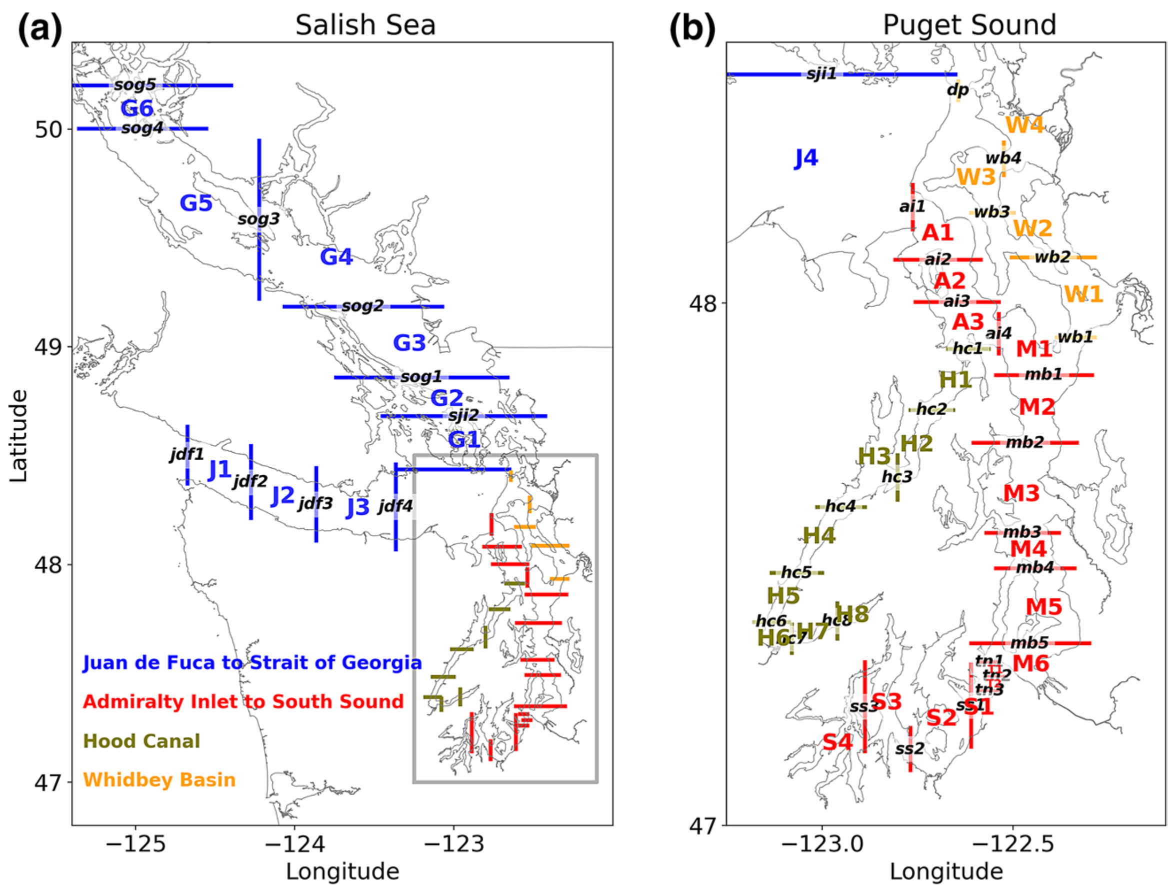
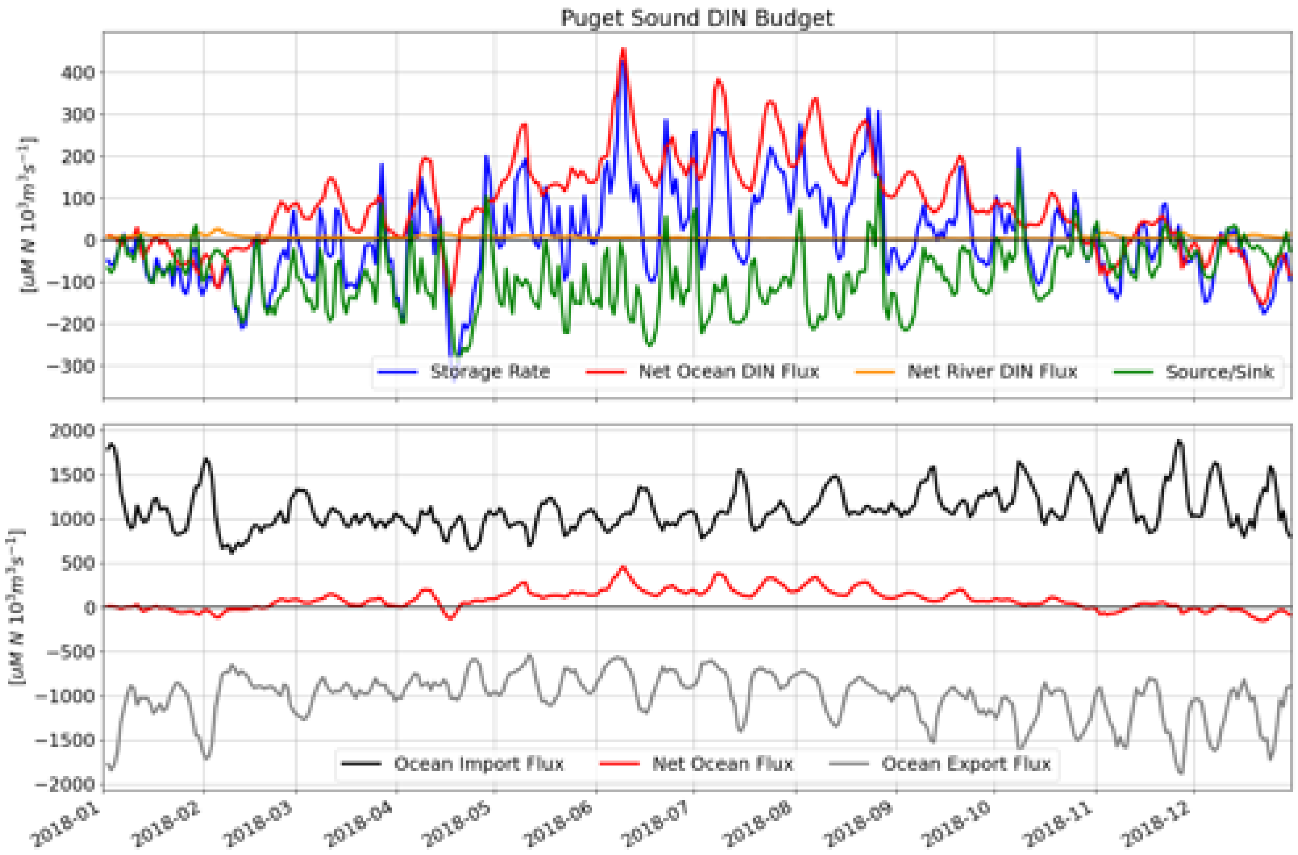


Fig 3 from MacCready et al, 2021

Nutrient and DO Budgets

Model DIN Budget of Puget Sound

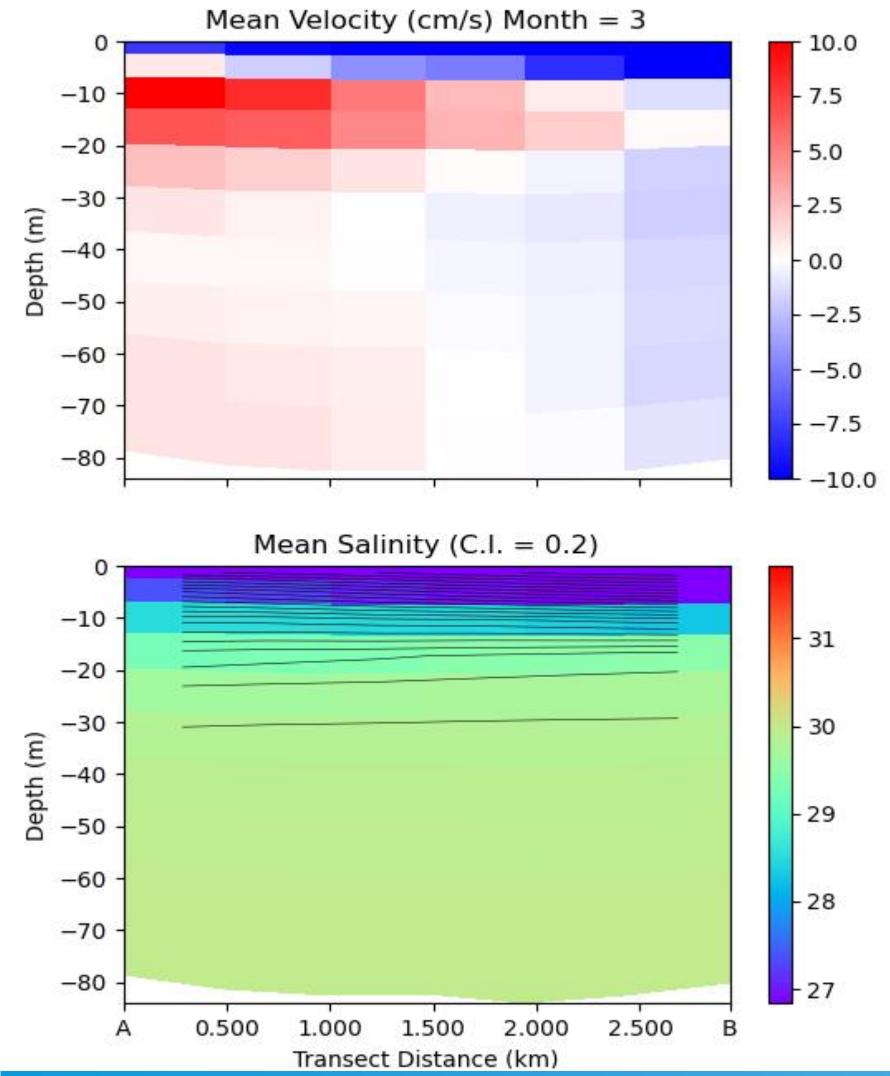


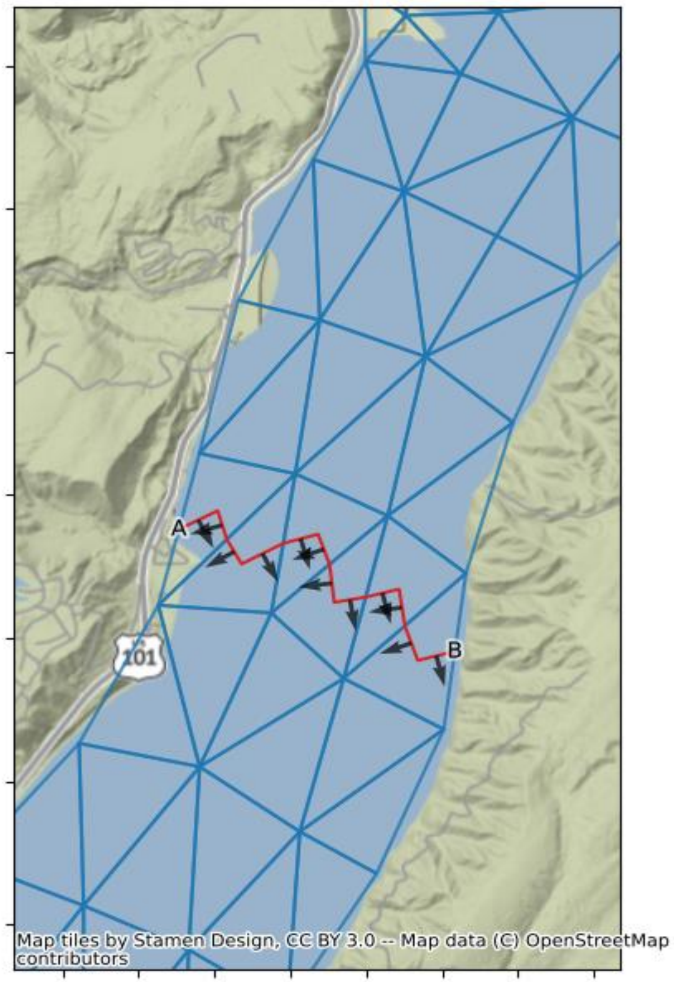
The Net Ocean DIN Flux through Admiralty Inlet and Deception Pass is the small difference of two large numbers.

Net = Import - Export

Estuarine Circulation, Mixing, and Residence Times in the Salish Sea, P. MacCready, R. M. McCabe, S. A. Siedlecki, M. Lorenz, S. N. Giddings, J. Bos, et al., Journal of Geophysical Research: Oceans 2021 Vol. 126 Issue 2 , DOI: 10.1029/2020jc016738

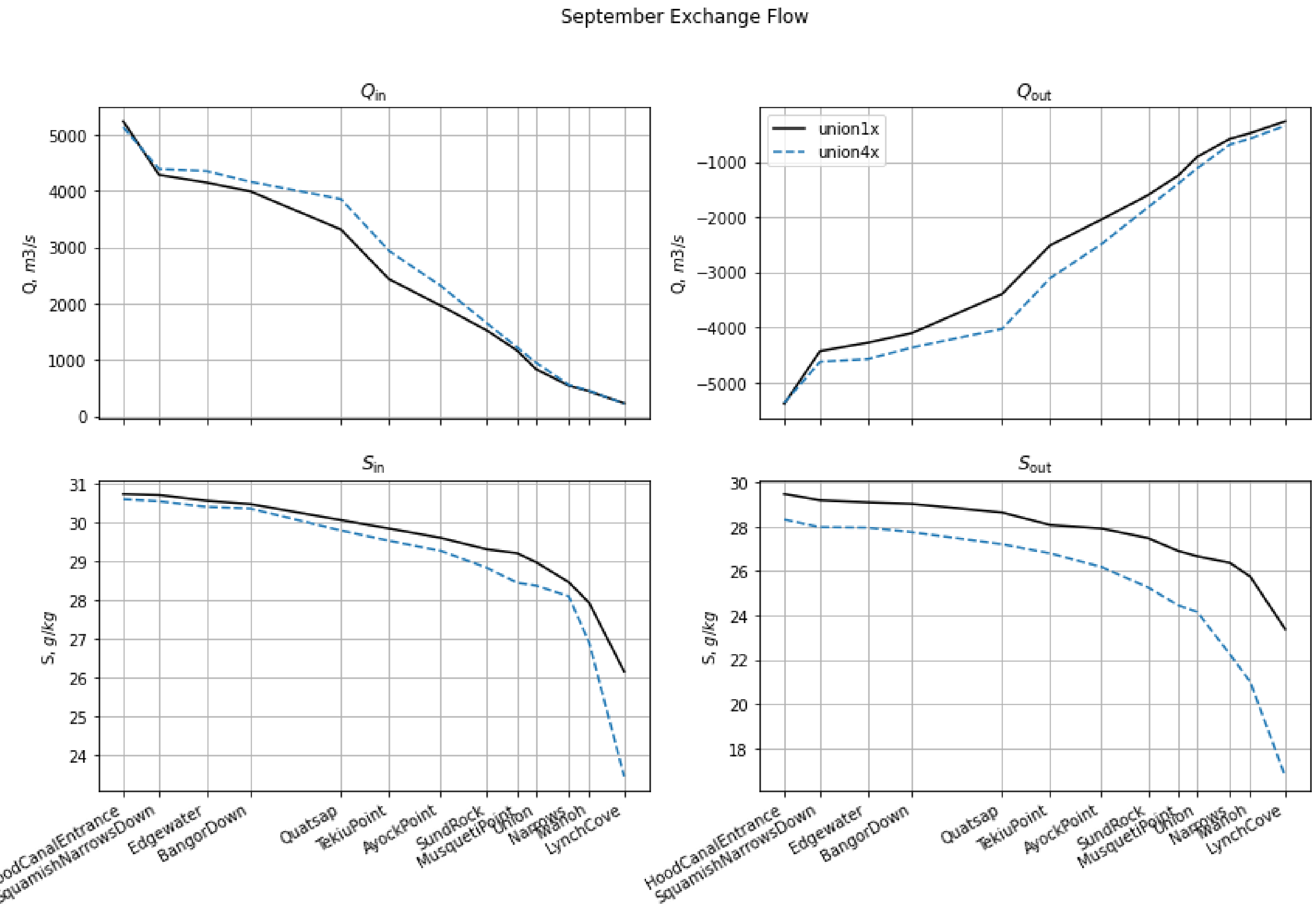
Adapting Methods for Salish Sea Model





- An example transect in Hood Canal
- Mean velocity/salinity for March 2014

TEF for Hood Canal, 2014

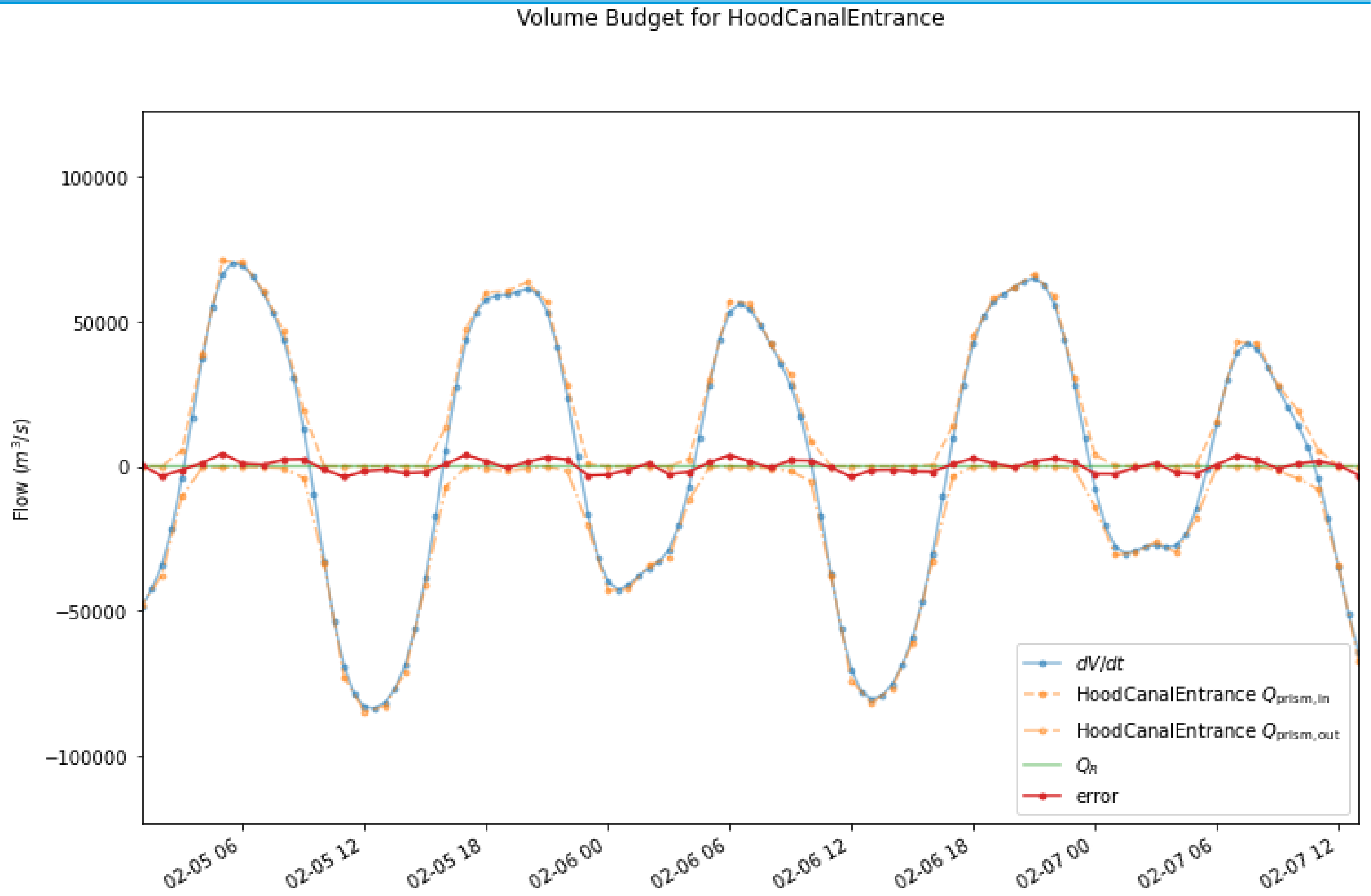


- Q_{in}, Q_{out} monotonic

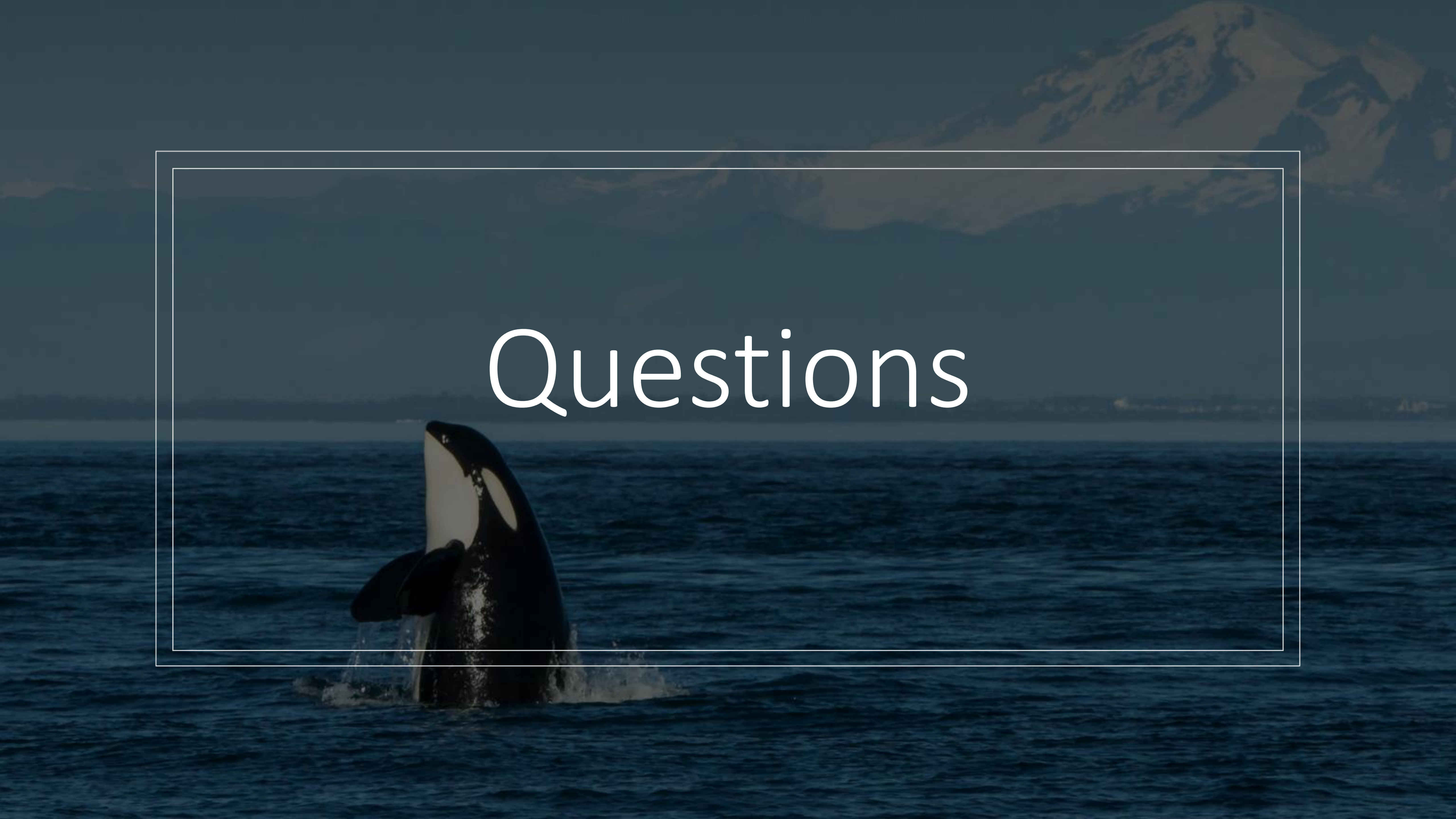
Budgets from the model extracts

- Mean volume error <0.5% of mean Q_R

  Sensitive to interpolation error on *dV/dt*
- Verifies section extractions
- Later calculations performed with Parker's scripts



Questions



Wrap up

- We'll share the presentation materials, recording, and a summary of the discussion
- Subscribe for updates at http://eepurl.com/h5nxsr
- Share any people, programs, or studies we should connect with
- Continue the discussion
    - Email Stefano Mazzilli (mazzilli@uw.edu) and Marielle Larson (marlars@uw.edu)
    - Join the upcoming workshops to dig in further

Upcoming Workshops

Watershed modeling *(12/2)*

Interannual variability *(January TBD)*