Kickoff: The Science of Puget Sound Water Quality

July 26, 2022

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Agenda

8:00 AM	Intro
8:10 AM	Role of the University of Washington Puget Sound Institute
8:20 AM	Dr. Martha Sutula's Keynote
8:50 AM	Q&A
9:10 AM	Breakout Discussions
9:55 AM	Next Steps

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

- During the breakout sessions, you can also *Ask for Help* to call the host to your breakout room

The slides, recording, and synthesis will be available on Puget Sound Institute's website

Land
Acknowledgement

Introduction

University of Washington's Puget Sound Institute provides analysis, research, and communication to inform and connect the science of ecosystem protection.

Implementation Strategy Analyses

- Shoreline Armoring

- Benthic Index of Biotic Integrity (B-IBI)

- Land Development and Cover

- Toxics in Fish

- Marine Water Quality (in progress)

https://www.pugetsoundinstitute.org/about/document-library/

Topics We'll Cover in this Section

- Driving scientific questions and the role of iterative modeling and monitoring

- Marine Water Quality Implementation Strategy and this work

- Additional activities: addressing targeted uncertainties

- Purpose of this particular workshop and breakout groups
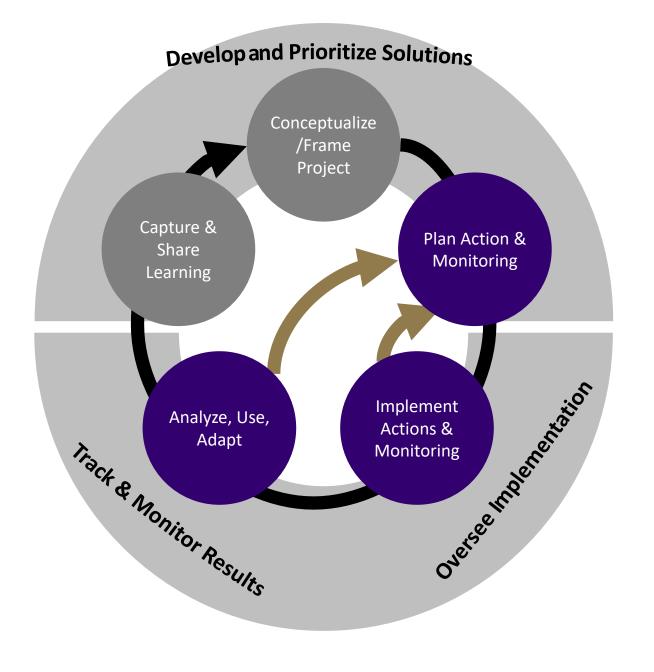
Background: Driving Scientific Questions

- What are the natural and anthropogenic nutrient loadings to Puget Sound?

- What are the ecosystem impacts of the current nutrient loads?

- How confident are we in modeling the consequences of changing these nutrient loads?

Instead of getting stuck on these technical uncertainties, we can move forward to reduce uncertainties that can support action now, and inform future modeling and monitoring
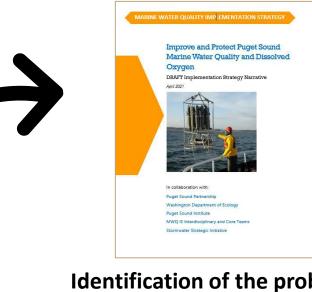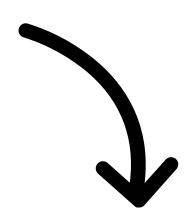
Approach: Adaptive Science Management

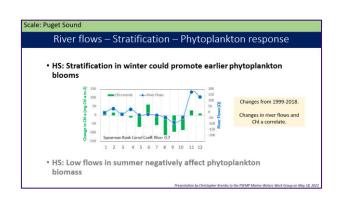Adapted from *Puget Sound Partnership Adaptive Management Framework*

Adaptive Science Management: Modeling/Monitoring

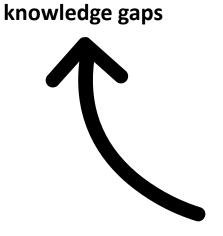**Identification of the problem and uncertainties**

Address further monitoring & knowledge gaps
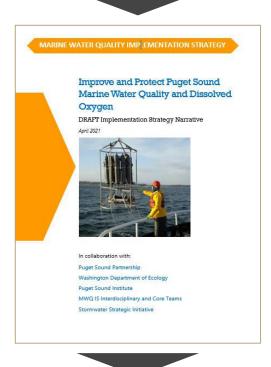
Hypothesis from monitoring

Modeling to test hypothesis

Marine Water Quality Technical Uncertainties

Puget Sound Partnerships' Marine Water Quality Implementation Strategy
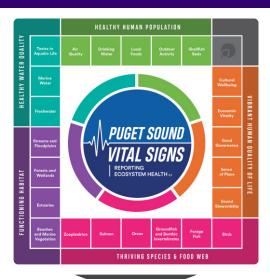
Technical Uncertainties

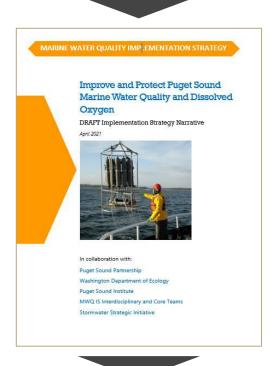**Expectations/outcomes- consensus on uncertainties to move forward with:**

- Improved level of confidence in model application

- System science: gaps and priorities for longer-term modeling & monitoring

- Transparent and available access to models and analysis

Marine Water Quality Technical Uncertainties

Puget Sound Partnerships' Marine Water Quality Implementation Strategy

Technical Uncertainties

Research, Modeling, and Monitoring to Reduce Uncertainties

Nutrient Science Community in Puget Sound

PUGET SOUND INSTITUTE
W 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 communicate findings

Fall Workshops

- **Dissolved oxygen impacts on the biological integrity of key habitats and species** *(week of 9/26)*

- **Change in interannual variability of rivers and ocean impact** *(week of 10/17)*

- **Phytoplankton and primary production** *(week of 10/24)*

- **Sediment exchange** *(week of 11/14)*

- **Improve watershed modeling to evaluate source reduction strategies to adaptively manage strategies** *(week of 12/12)*

Improved Confidence in Actions

Additional Activities: Addressing Targeted Uncertainties

Convene Model Evaluation Group

- Advise Puget Sound Institute and independently evaluate the application of the Salish Sea Model to support Puget Sound recovery goals on water quality
- **Not in initial scope:**
    - Evaluate regulatory standards
    - A full audit of the Salish Sea Model
- **For transparency:** Collaborate at fall workshop and share recommendations in technical memo and presentation

Lead Complementary Model Runs

- Targeted runs to increase our confidence in the application of the Salish Sea Model for nutrient reduction strategies
- Expand access to the model and modeling outputs

Expand Access to Scientific Knowledge

Articles, infographics, videos, webinars, and more to expand access to models, outputs, tools, and scientific knowledge

Meet the Members

Bill Dennison

Jacob Carstensen

Jeremy Testa

Kevin Farley

Peter Vanrolleghem

Feel free to share!

Dr. Martha Sutula

INGREDIENTS TO A SOLUTION: ADDRESSING CLIMATE CHANGE AND COASTAL EUTROPHICATION STRESS ON NEARSHORE ECOSYSTEMS IN THE SOUTHERN CALIFORNIA BIGHT

Martha Sutula
Biogeochemistry Department Head
Southern California Coastal Water Research Project Authority (SCCWRP)
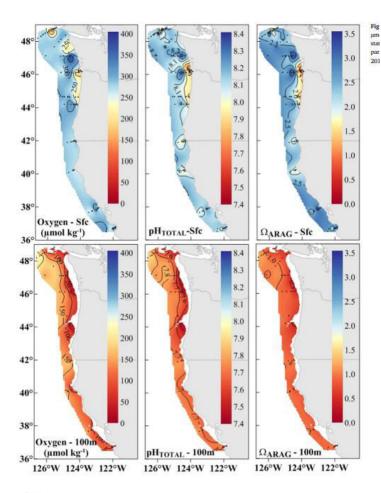
Puget Sound Institute
Workshop on "Science Supporting Nutrient Management"
Keynote Address
July 26, 2022

PACIFIC WEST COAST IS STRESSED OUT BY CLIMATE CHANGE
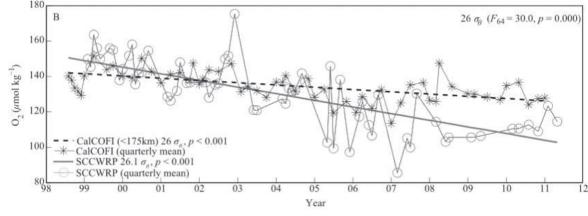## ACIDIFICATION & DEOXYGENATION (OAH), WARMING AND HARMFUL ALGAL BLOOMS (HABS) ARE HAVING SIGNIFICANT BIOLOGICAL IMPACTS

Feely et al. (2018) doi.org/10.1016/j.csr.2017.11.002

California Current: Corrosive water and hypoxic waters already being seen in shallow water close to shore

Why we are concerned: Declining DO (and pH) in the SCB, e.g. Booth et al. (2014)

Coastwide 2015 Pseudo-Nitschzia bloom caused $125 million coastwide in losses to Dungeness crab, rock crab, and razor clam harvesters, and caused deaths of many species of marine mammals.

2015	Shellfish Harvest and Fishery Closures with Maximum Domoic Acid Values
7-May	Quinault tribe razor clam harvest closure (WA)
8-May	Commercial, tribal & recreational razor clam harvest closure (WA)
9-May	Razor clam harvest closure (northern OR)
14-May	State wide razor clam harvest closure (OR)
15-May	Shellfish harvest closure (BC Canada)
29-May	Anchovy viscera maximum 1671 ppm (CA)
1-Jun	Anchovy, sardine fishery closure (CA)
3-Jun	Dungeness crab maximum 65 ppm (WA)
5-Jun	Dungeness crab fishery closure (WA)
3-Jul	Anchovy, sardine, mussel, & clam closures expanded to southern CA
11-Sep	Dungeness crab maximum 140 ppm (northern CA)
27-Oct	Razor clam maximum 170 ppm (southern OR)
3-Nov	Dungeness crab & rock crab warning for recreational harvest (CA)
6-Nov	Commercial rock crab fishery closed (CA)
8-Nov	Dungeness crab maximum 70 ppm (southern OR)
11-Nov	Dungeness crab & rock crab recreational & commercial fishery closure (CA)
22-Nov	Dungeness crab maximum 270 ppm (northern CA)
23-Nov	Rock crab maximum 1000 ppm (southern CA)
23-Nov	Delayed opening of commercial Dungeness crab fishery (WA, OR, CA)
9-Feb-2016	CA seeks federal disaster declaration for commercial crab fishery

WATER QUALITY MANAGERS ON OUR COAST SHARE MANY OF THE SAME CHALLENGES IN ADDRESSING THIS PROBLEM
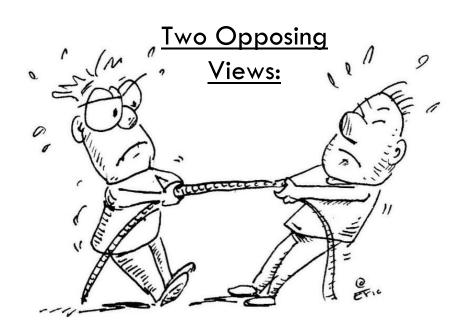
- Tremendous variability in pollution inputs, circulation, climate, biological communities
  - One size fits all solution will not work

- Limited long-term support for monitoring and modeling to inform management actions

- Limited knowledge about exact nature of biological impacts (where and when do you see the impacts?)

- Dated water quality goals that do not relate to biological effects

- Urgency to act quickly (short response time)

- Multiple jurisdictions (federal agencies, states, counties and/or municipalities)

- Lack of buy-in on vision for "solutions" and way forward

Ingredients to a Solution to Increase Coastal Resilience to Global and Local Stressors

#1 <u>Willing partners</u> to invest in solutions

#2 Sustained investment in <u>coastal numerical models</u>

#3 Identify solutions worth chasing

#4 <u>Modeling uncertainties</u> are understood

– stakeholder community engagement

– coastal monitoring/research to validate model and investigate causal mechanisms

#5 Scientific basis for thresholds of algal biomass, pH and DO impact marine biological resources, as the basis for new water quality goals

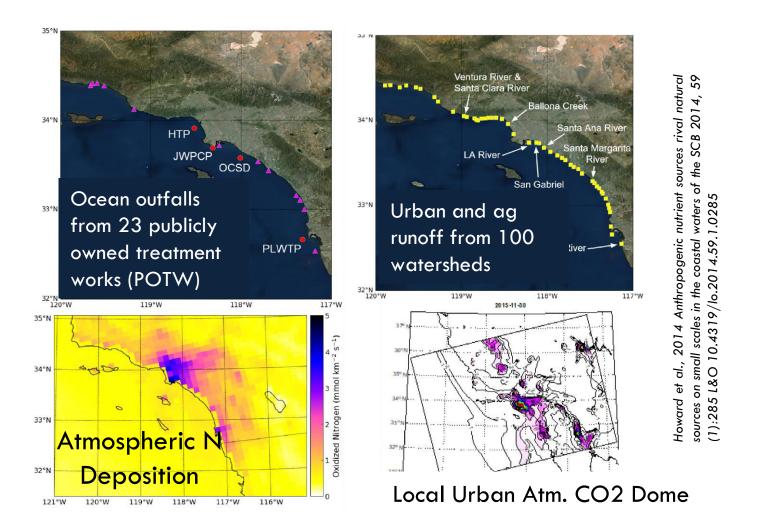#6 Flexibility on what a solution could look like

SOUTHERN CALIFORNIA BIGHT (SCB) IS A TEST CASE TO INVESTIGATE THE EFFECTS OF ANTHROPOGENIC INPUTS ON HABS, OAD AND CONSIDER POTENTIAL SOLUTIONS

California coastal waters are dominated by upwelling, therefore anthropogenic nutrients are not a primary driver

Anthropogenic Inputs from a Coastal Population of 20 Million Has Doubled N In the SCB Nearshore

THE SOLUTION: Nutrient Management Will Cost Tens of Billions of Dollars—is This Really Needed?

Two Opposing Views:

Local anthropogenic inputs can exacerbate global drivers, potentially pushing HABs, DO and pH to ecological tipping-points

Ocean outfalls from 23 publicly owned treatment works (POTW)

HTP
JWPCP
OCSD
PLWTP

Urban and ag runoff from 100 watersheds

Ventura River & Santa Clara River
Ballona Creek
Santa Ana River
LA River
Santa Margarita River
San Gabriel

Atmospheric N Deposition

Oxidized Nitrogen (mmol km⁻² s⁻¹)

Local Urban Atm. CO2 Dome

Howard et al., 2014 Anthropogenic nutrient sources rival natural sources on small scales in the coastal waters of the SCB 2014, 59 (1):285 L&O 10.4319//lo.2014.59.1.0285

WILLING PARTNERS AT FEDERAL, STATE AND REGIONAL LEVEL TO INVEST IN SCIENCE AND MANAGEMENT CONVERSATIONS TO EXPLORE SOLUTIONS

- California State policy and strategies to invest in SOLUTIONS
  - **Manage local pollution sources**
  - Sequester C through habitat restoration
  - **Create biologically relevant OA and DO water quality criteria**

- Clear directives on science and research from West Coast OAH Panel:
  - Invest in **numerical ocean modeling** to disentangle the contributions of climate change, natural variability and local pollution

- Sustained federal-state-local investments in science and management conversations
  - NOAA and OPC made strategic investments in coastal numerical models
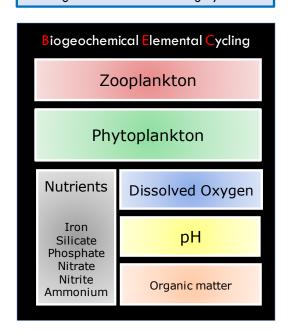
IN SOUTHERN CALIFORNIA, WE HAVE 50-YEAR PARTNERSHIP OF REGULATED WATER AGENCIES, REGULATORS (US EPA, CAL-EPA), CA OCEAN PROTECTION COUNCIL
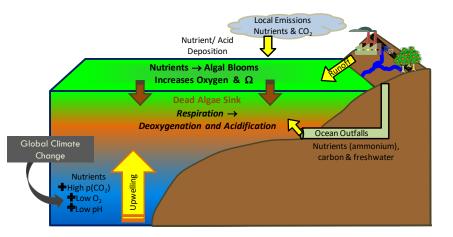
- Identify key regional science questions

- Cooperatively fund modeling, research and monitoring

- Get consensus on interpretation of that science

  - What is driving the problem
  - Agree on interpretation framework (a.k.a. water quality goals)
  - Solutions

- Managers use this science to support policy decisions

  - Informal mechanism to build trust and engage in policy discussions
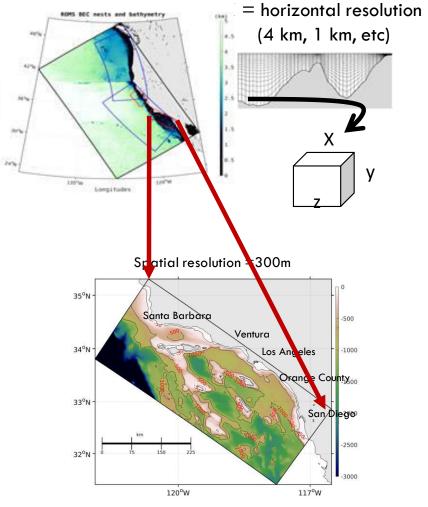
OCEAN NUMERICAL MODEL: MECHANISTIC 3-D REGIONAL OCEAN MODELING SYSTEM (ROMS), PLUS BIOGEOCHEMICAL ELEMENTAL CYCLING (BEC)

Atmospheric forcing
- **W**eather **R**esearch **F**orecast -

Ocean circulations
- **R**egional **O**ceanic **M**odeling **S**ystem -

Biogeochemical **E**lemental **C**ycling

Zooplankton

Phytoplankton

Nutrients | Dissolved Oxygen

Iron
Silicate
Phosphate
Nitrate
Nitrite
Ammonium | pH | Organic matter

Local Emissions
Nutrients & CO_2

Nutrient/ Acid
Deposition

Nutrients → Algal Blooms
Increases Oxygen & Ω

Runoff

Dead Algae Sink

*Respiration →
Deoxygenation and Acidification*

Ocean Outfalls

Nutrients (ammonium),
carbon & freshwater

Global Climate
Change

Nutrients
+High p(CO_2)
+Low O_2
+Low pH

Upwelling

Nested Grid: 4km resolution at
California Current Scale; 2 subdomains at
1 km resolution for CA, OR and WA

= horizontal resolution
(4 km, 1 km, etc)

X
y
z

Spatial resolution ~300m

Santa Barbara
Ventura
Los Angeles
Orange County
San Diego

**2 smaller subdomains at 300 m resolution
within the SCB an and SF/ Monterey Coast**
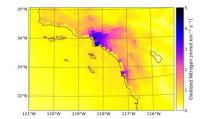
We force land & atmospheric
inputs to simulate effects of at
300-m within SCB

River runoff

100 watersheds
~ 40 rivers
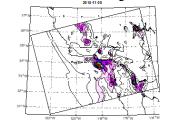
POTW ocean outfalls

18 POTW
outfalls

Modeled wet and dry deposition
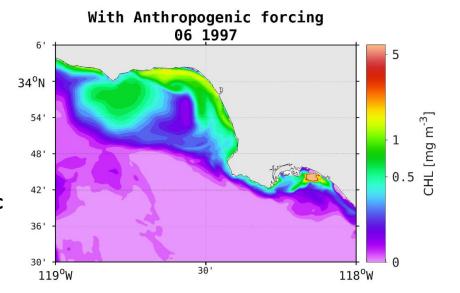
Modeled atm. CO_2 exchange

KESSOURI ET AL. (2021) DEMONSTRATED THAT ANTHROPOGENIC NUTRIENTS ARE AMPLIFYING PRIMARY PRODUCTION, ACIDIFICATION AND DEOXYGENATION IN THE SCB

Modeled surface chlorophyll concentration in June 1997

Chlorophyll concentration is increased by anthropogenic inputs

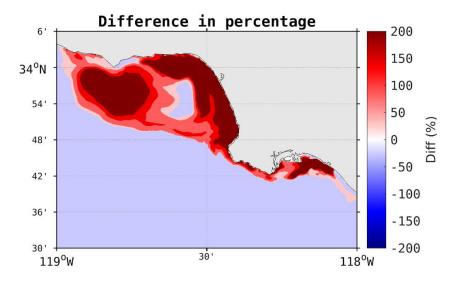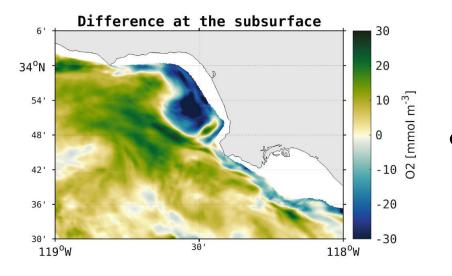Surface DO increases considerably driven by increased photosynthesis
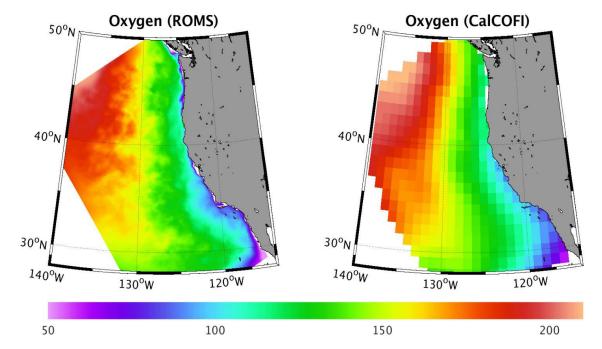
Percentage increase of surface chlorophyll-a

subsurface DO decreases, caused by increases respiration

FROM BIGHTWIDE TO PLUME SCALE WITHIN THE SCB, WE'VE DEMONSTRATED THAT MODEL IS REPRODUCING KEY SEASONAL, VERTICAL AND HORIZONTAL GRADIENTS AND CLIMATE EVENTS FOR MODEL PREDICTIONS
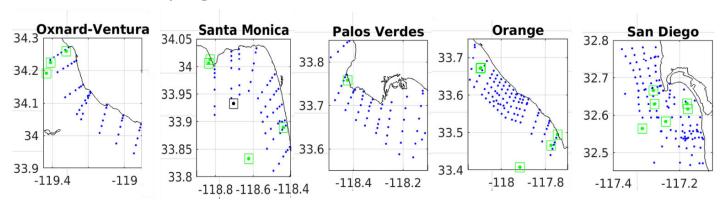
……at CCS-Wide Scale (Renault et al., 2021, Deutsch et al. 2021)

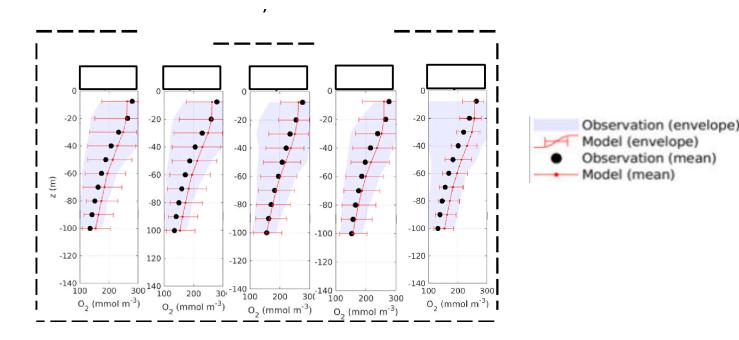*Depth averaged O2 concentrations in ROMS BEC (a) versus measured (CalCOFI (b) O2 in mM*

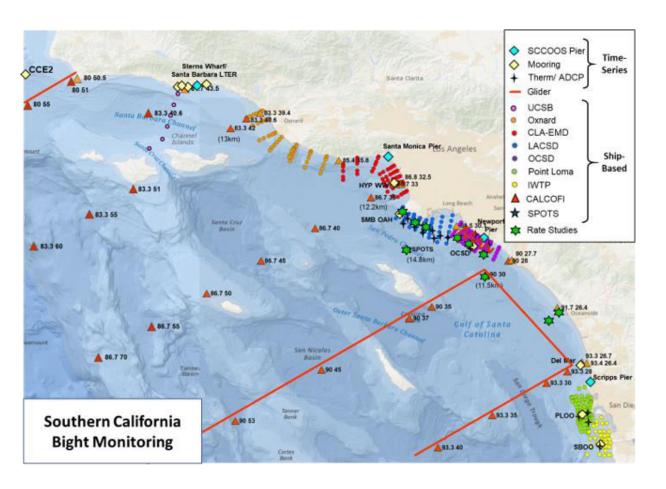*Surface averaged O2 concentrations in ROMS BEC (red line mean and variance) versus measured (CalCOFI) in grey*

….Within SCB, From Plume to Subregional Scale, Focusing on Anthropogenic Gradients (Kessouri et al., 2021)

ROMS-BEC reproduces seasonal (winter, summer) and annual mean and variability of chl-a, oxygen and pH and biogeochemical rates (McLaughlin et al., in prep)

WE WORKED WITH SCB STAKEHOLDERS TO COMPILE ANTHROPOGENIC INPUTS AND ON MODEL VALIDATION TO INCREASE MODEL CREDIBILITY FOR POLLUTION APPLICATIONS

- With SCB stakeholders (utilities, regulators, environmental NGOs) and scientists, we agreed on a relevant list of anthropogenic gradients, indicators and metrics for validation

- We got consensus on interpretation

- Invested in stakeholder education: Summer 2021 workshop on modeling uncertainty

Regional monitoring partnership provided wealth of data

- 50 years of wastewater and 20 years of stormwater data
- 22 years of quarterly data on ocean state and rates
- Multiple temporal and spatial scales

RECOMMENDATIONS FROM 2021 UNCERTAINTY WORKSHOP: HOW TO INCREASE MANAGEMENT CONFIDENCE IN MODELS

1. **Invest in and maintain an open dialogue**

2. **Invest in and maintain long-term chemical and biological monitoring**

3. **Assess the skill of the model, on an ongoing basis**

4. Make transparent the rational for model selection and parameterization

5. **Managers should provide guidance on the interpretation framework**

6. Utilize observations, experiments, and model simulations to synthesize and update conceptual model of coastal eutrophication drivers

7. Make model output, skill assessment metrics, and model code freely available

8. Develop ways to communicate uncertainty in scientific findings

9. Provide sustained funding for modeling program over the long term

EXISTING CALIFORNIA OCEAN WATER QUALITY OBJECTIVES (WQO) ARE NOT "PLUG AND PLAY" FOR THIS APPLICATION
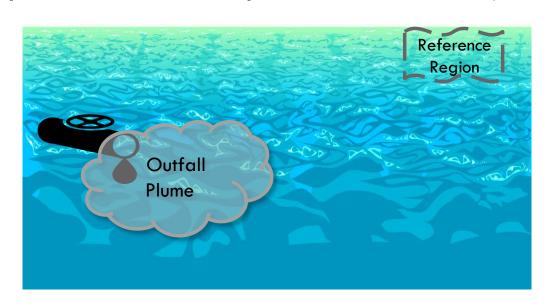
Biological integrity WQO are narrative

- Nutrient materials* shall not cause objectionable aquatic growths or degrade* indigenous biota.

- Biological characteristics: Marine communities…shall not be degraded.*

CALEPA: "I'd like to see us use biological effects (rather than existing numeric WQO)

Numeric pH and Dissolved oxygen (DO) WQO intended to be an "end of pipe" criteria

Can't apply as intended- since nutrients are dispersed regionally and "reference" doesn't exist

- – DO WQO ± 10% difference

- – pH WQO ± 0.2 pH unit difference)

Reference Region

Outfall Plume

SCIENCE TO ASSESS BIOLOGICAL EFFECTS
THIS WORK HAS THREE MAJOR COMPONENTS

Threshold and/or Index Development

Protocols to Apply Thresholds to Model Output or Observations

Validation of Thresholds with Chemical-Biological Effects Observations
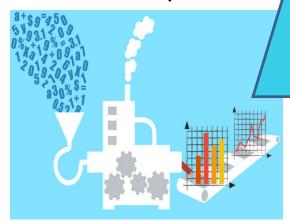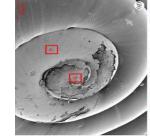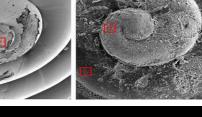
Laboratory Experiments

Field Observations

Data Synthesis & Expert Consensus
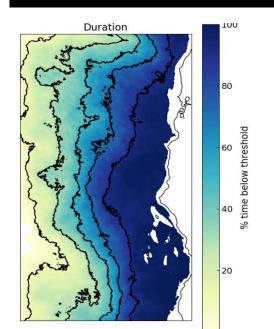
Multi-stressor Index Development
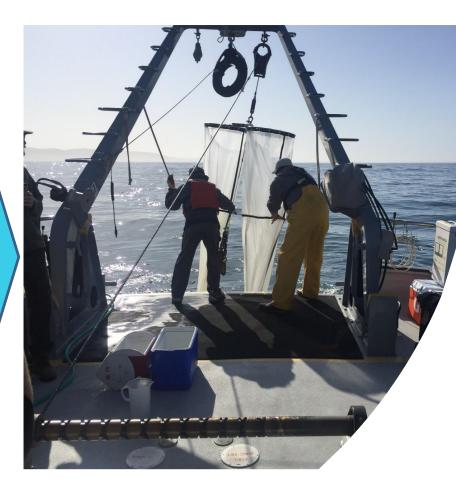
Interpretation of Modeled Effects on Biology: e.g. Pteropods

Duration

% time below threshold

ESTABLISH PROCESS AND CLEAR SET OF SCIENCE AND POLICY QUESTIONS TO GUIDE TARGET SETTING
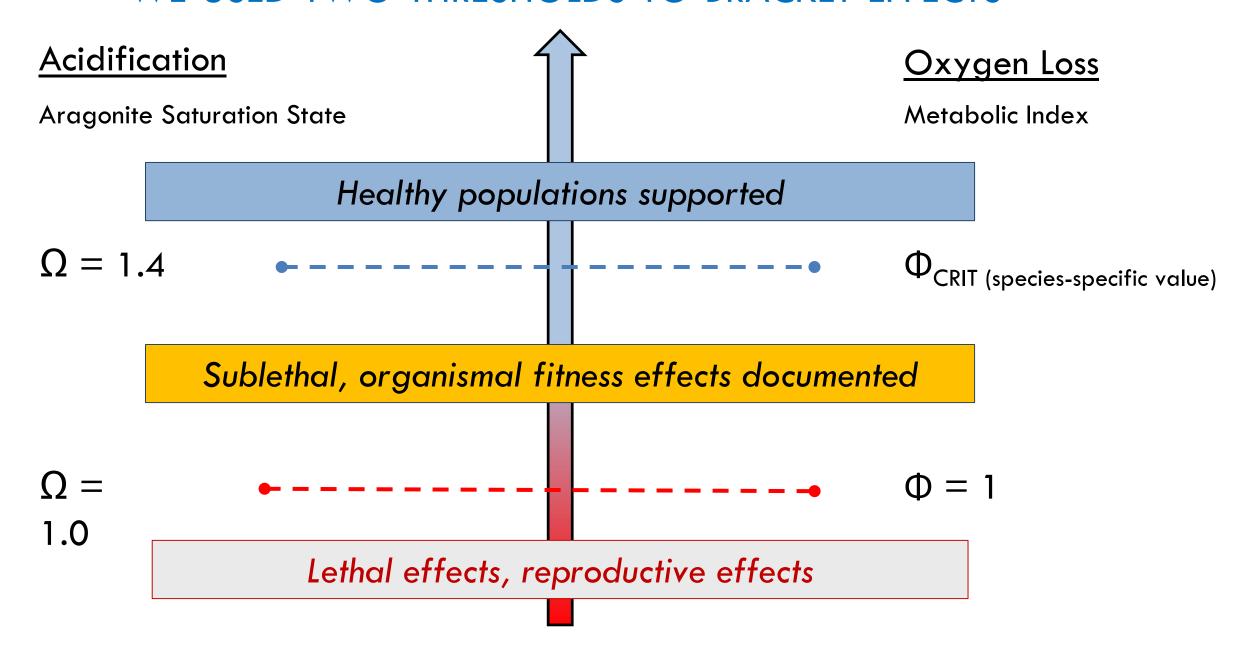
To choose Biologically-relevant Oxygen and pH Targets:

- What metric?
    - E.g. pH, pCo2, aragonite saturation state
- What about multiple stressors?
- What threshold?
    - Level of severity
    - Habitat, taxa, and data used to derive thresholds
- Duration required and spatial and temporal scales used to apply thresholds
- Acceptable frequency of deviation from thresholds

Clarify what technical issues or questions the scientists should weigh in on

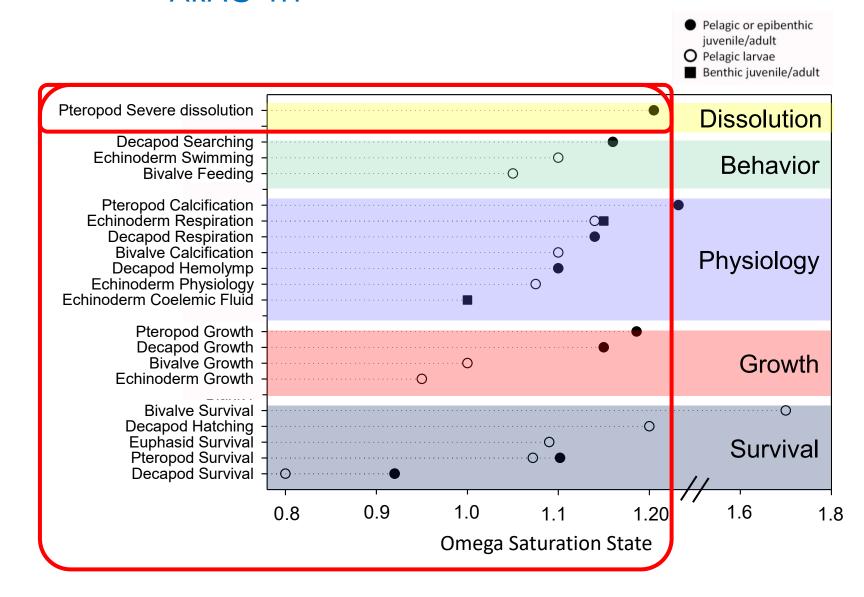*And what questions or issues are policy decisions*

To evaluate effects of anthropogenic inputs on pH and O_2, we used two thresholds to bracket effects

Acidification

Aragonite Saturation State

Oxygen Loss

Metabolic Index

Healthy populations supported

$\Omega = 1.4$

$\Phi_{\text{CRIT (species-specific value)}}$

Sublethal, organismal fitness effects documented

$\Omega = 1.0$

$\Phi = 1$

Lethal effects, reproductive effects

WHAT VALUE OF Ω?

OUR ANSWER IS $\Omega_{\text{ARAG-TH}} = 1.4$

Why?

1. Sensitive taxa approach:

   • For pteropods, severe dissolution occurs at $\Omega = 1.2$

   • Thresholds with highest confidence

2. Multi-taxa approach:

   • $\Omega = 1.2$ protects against physiological and growth threshold responses for multiple taxa: decapods (crabs + krill), echinoderms, urchins, bivalves

3. Protect with measurement error of ±0.2; Therefore, $\Omega_{\text{Arag-Th}} = 1.4$

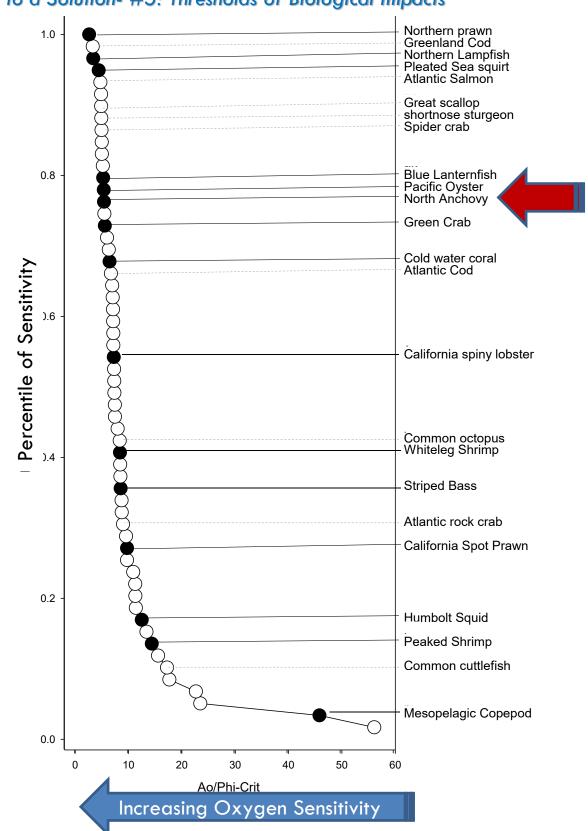# OXYGEN LOSS AND BIOLOGICAL EFFECTS:
WHY THE METABOLIC INDEX?

- Historical precedence is to use oxygen concentration (mg/L) to set biologically relevant thresholds

- However, the partial pressure of O_2, pO_2, is what is sensed by biology (drives gas exchange)

- Further, biological sensitivity to oxygen is temperature-dependent

    - Oxygen thresholds can vary 2-fold across temperature range

The Metabolic Index combines pO_2 with temperature-dependent biological responses to oxygen in order to define "aerobically available habitat"

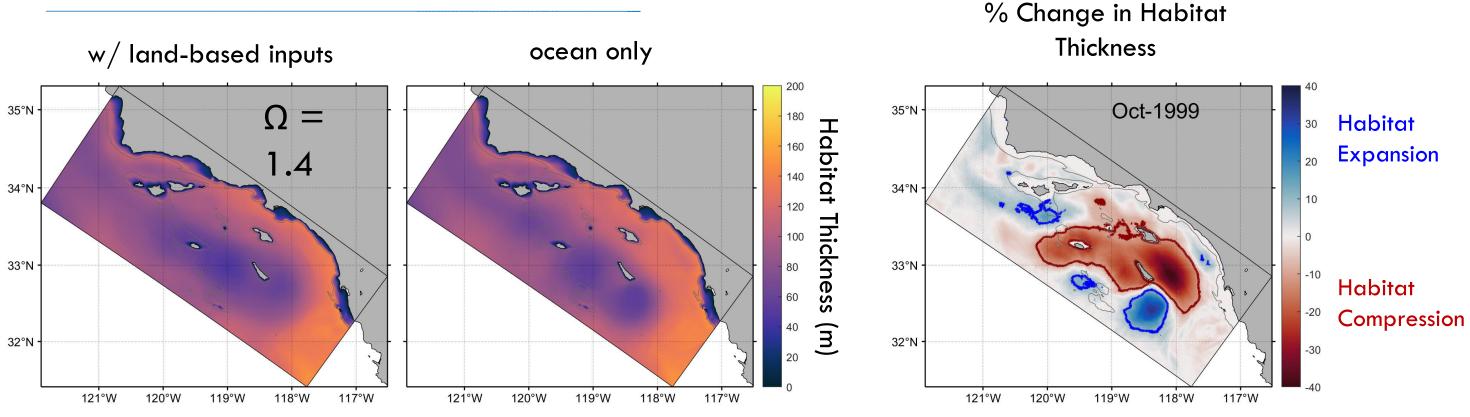# Metabolic Index –Which Value to Choose

Chose oxygen sensitivity representative of northern anchovy

- Epipelagic

- Represents 75th percentile of aerobic sensitivity across all taxa
  - Median of epipelagic taxa

- Commercially and ecologically important

- Validated for California Current with a published case study
  - Strong correspondence to observed abundance data

Percentile of Sensitivity vs Ao/Phi-Crit

Species labels (top to bottom):
Northern prawn
Greenland Cod
Northern Lampfish
Pleated Sea squirt
Atlantic Salmon
Great scallop
shortnose sturgeon
Spider crab
Blue Lanternfish
Pacific Oyster
North Anchovy
Green Crab
Cold water coral
Atlantic Cod
California spiny lobster
Common octopus
Whiteleg Shrimp
Striped Bass
Atlantic rock crab
California Spot Prawn
Humbolt Squid
Peaked Shrimp
Common cuttlefish
Mesopelagic Copepod

Increasing Oxygen Sensitivity

THRESHOLD APPLICATION IN MODEL-BASED ANTHROPOGENIC CHANGE ASSESSMENT

% Change in Habitat Thickness

w/ land-based inputs

ocean only

$\Omega = 1.4$

Habitat Thickness (m)

Oct-1999

Habitat Expansion
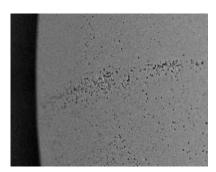
Habitat Compression

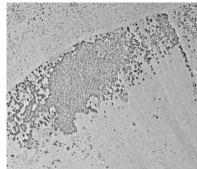*Note-- it is a longer road to develop biologically relevant water quality criteria*

CONSENSUS ON INDICATOR ORGANISMS AND METRICS HAVE SPURRED INVESTMENTS IN COUPLED CHEMICAL BIOLOGICAL MONITORING, LINKING REGIONAL PROGRAMS TO WEST COASTWIDE OBSERVATIONS
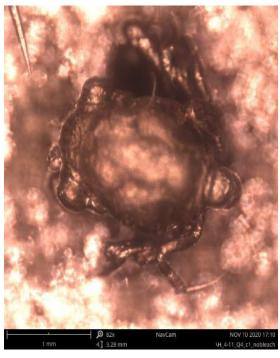
How do observed species distributions match model predictions based on temperature, dissolved oxygen and pH/carbonate saturation state?
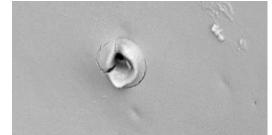

Heliconoidies

Limacina

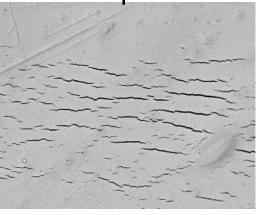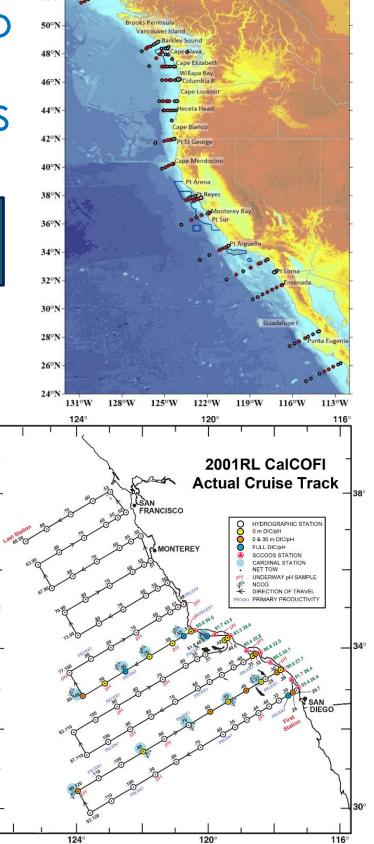Intensity and % Cover of Dissolution

Crab Larvae
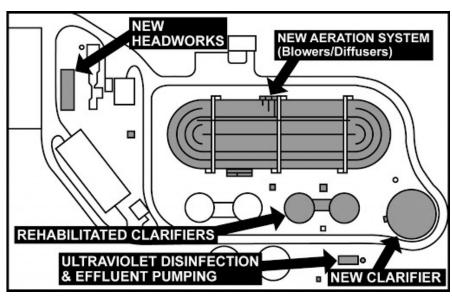
Dissolution of mechanoreceptors

Dissolution of carapace

Wastewater and Stormwater Recycling and Recovery

Engineering Solutions

Wastewater Upgrades (Nutrient Management)

Seagrass and Kelp

"Living" Solutions That Enhance Coastal Resiliency

Kelp Culture and Kelp/Oyster Co-Culture

INCENTIVIZE WATERSHED AND ESTUARINE RESTORATION, BECAUSE FACTORS OTHER THAN NUTRIENTS (E.G. HYDROMODIFICATION, WARMING) CAN CAUSE EUTROPHICATION!

Addressing human impacts on Coastal Ecosystems

Shared Challenges

- Multiple stressors: hypoxia and low DO, sea level rise, and ocean acidification, food web shifts, increasing toxicity, etc.

- Tremendous variability in pollution inputs, circulation, climate, biological communities

- Limited knowledge about biological impacts (where and when do you see the impacts?)

- Urgency to act quickly (short response time)

- Scarcity of support for combined monitoring and modeling to inform management actions

- Multiple jurisdictions (federal agencies, states, counties and/or municipalities)

- Lack of buy-in to shared vision and way forward

Ingredients to a Solution
Southern California Case study

#1 Willing partners to invest in solutions

#2 Sustained investment in coastal numerical models

#3 Investments to identify solutions worth chasing

#4 Model uncertainties are constrained

- regulated community engagement

- sustained investment in coastal monitoring and research

#5 Scientific evidence for thresholds of algal biomass, pH and DO impact marine biological resources

#6 Flexibility on what a solution could look like

Questions? Thank You!

marthas@sccwrp.org

Breakout Discussions

Today's Breakout Sessions

The breakouts specifically are intended to:

- **Get people excited**

- Continue regional discussions like the Marine Water Quality Implementation Strategy and the Nutrient Forum **where technical uncertainties were identified**.

- Be **a teaser to jump-start conversations** for the workshops this fall where we'll spend a more time on each technical uncertainty.

The specific goals of each breakout today vary in **detail and depth** depending on the existing consensus and parallel efforts.

Breakouts

Dissolved oxygen impacts on the biological integrity of key habitats and species *(week of 9/26)*
> Martha Sutula, *Southern California Coastal Water Research Project*

Change in interannual variability of rivers and ocean impact *(week of 10/17)*
> Tarang Khangaonkar, *Salish Sea Modeling Center, University of Washington*
>
> Parker MacCready, *LiveOcean, University of Washington*

Phytoplankton and primary production *(week of 10/24)*
> Julia Bos, *Phytoplankton and Primary Production Vital Sign Co-lead*

Sediment exchange *(week of 11/14)*

Improve watershed modeling to evaluate source reduction strategies to adaptively manage strategies *(week of 12/12)*
> Bob McKane, *Environmental Protection Agency*

Wrap up

- We'll share the presentation materials, recording, and a synthesis 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) to connect directly
    - Join the workshops this fall to dig in further

Fall Workshops

Dissolved oxygen impacts on the biological integrity of key habitats and species *(week of 9/26)*

Change in interannual variability of rivers and ocean impact *(week of 10/17)*

Phytoplankton and primary production *(week of 10/24)*

Sediment exchange *(week of 11/14)*

Improve watershed modeling to evaluate source reduction strategies to adaptively manage strategies *(week of 12/12)*

Dissolved Oxygen Impacts on the Biological Integrity of Key Habitats and Species

Breakout: Dissolved Oxygen Impacts on the Biological Integrity of Key Habitats and Species

Targeted Technical Uncertainties examples
- What are the DO requirements for the most sensitive species, including an adequate margin of safety?
- How should the duration and spatial extent of lower DO events be considered relative to the needs of the most sensitive species?
- What is the best method to estimate the uncertainty in these DO benchmarks?

Research Action: Dissolved Oxygen threshold values for Puget Sound species (MWQ RC5.1.1 & 5.1.2)
1. Identify species that may be at the highest risk for exposure to anthropogenic-related DO depletion.

2. Perform a **literature review** focusing on the sensitivity of the species of interest to low DO.

3. Utilize **model output** data to produce spatially explicit exposure maps that identify areas of greatest species-risk, and includes a description of which species are at risk in each area.

Discussion Questions

1. Which **species and habitats should be prioritized** for consideration in the next year?
   For example: shallow vs. deep water, benthic vs. pelagic, commercial importance, species and lifecycle stage

2. How should we **consider sensitivity** of these species to stressors?
   For example: severity (above sub lethal) vs. acute (some data available now) sensitivity

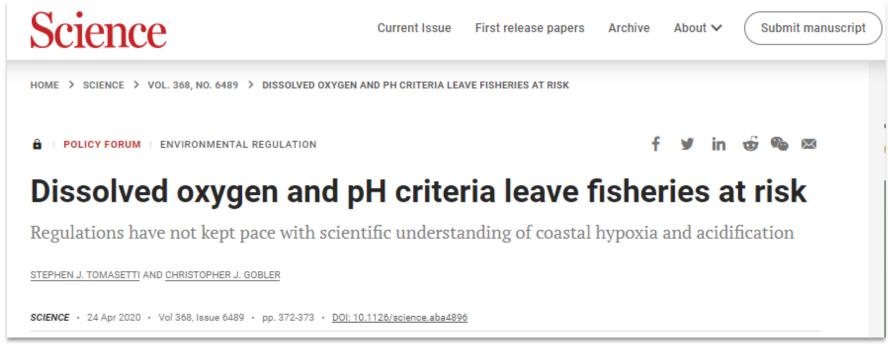3. What **existing literature and monitoring data** can be included in an initial desktop study?

Existing Ocean and Estuarine Water Quality Criteria for Oxygen and pH are not Biologically Relevant

- Criteria that are expressed as deviation from natural are problematic to interpret
  1. We almost always have insufficient temporal baseline of data to clearly define
  2. Attempt to compare with minimally disturbed "reference" are confounded by shifting baselines of anthropogenic effects

- Baseline of "natural variability" is shifting due to climate change
  - e.g Increased water temperatures lower oxygen solubility, increased stratification

Science

HOME > SCIENCE > VOL. 368, NO. 6489 > DISSOLVED OXYGEN AND PH CRITERIA LEAVE FISHERIES AT RISK

POLICY FORUM | ENVIRONMENTAL REGULATION

Dissolved oxygen and pH criteria leave fisheries at risk

Regulations have not kept pace with scientific understanding of coastal hypoxia and acidification

STEPHEN J. TOMASETTI AND CHRISTOPHER J. GOBLER

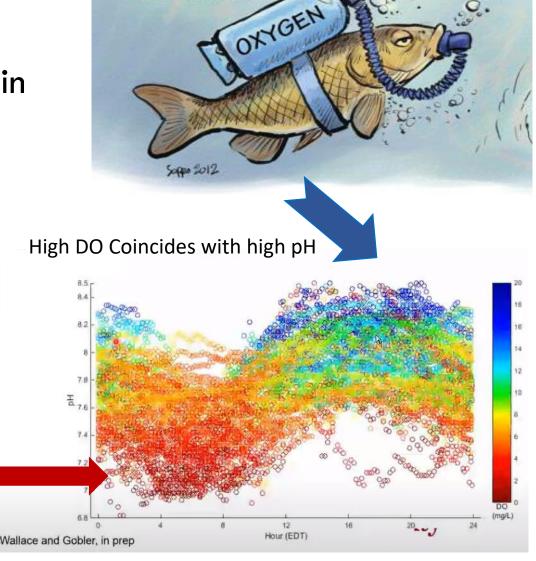SCIENCE · 24 Apr 2020 · Vol 368, Issue 6489 · pp. 372-373 · DOI: 10.1126/science.aba4896

Common Method for Developing Site Specific Dissolved Oxygen Criteria: Virginia Province Approach (VPA: EPA 2000)

- Identify fish and invertebrate indicator species

- Review existing data on tolerance of organisms to low DO:

  - Juvenile and adult survival (acute)

  - Growth, reproduction (chronic)

- Identify most sensitive endpoints with respect to individual species

  - In absence of data, consider "nearest relative"

- If appropriate, calculate numeric criteria for consideration/discussion

Scientific Challenges of VPA Approach

- Very little data to define sublethal endpoints for Pacific West Coast species
  - Most data are sourced from EPA experiments conducted decades ago to support DO objectives in Chesapeake Bay

- Does not consider multiple stressors
  - Typically ignores temperature effects on physiological tolerance
  - EPA experiments kept pH artificially high, while in nature they covary, adding an additional, unaccounted for stress

High DO Coincides with high pH

Low DO Coincides with low pH

Wallace and Gobler, in prep

Recommendations

- Identify key data gaps through literature review first

- Invest in coupled chemical and biological monitoring
  - Characterize DO regime
  - Compare chemistry (and physics) with species abundance

- Collect experimental datasets of physiological tolerances for most sensitive species
  - Focus on sublethal endpoints (e.g. growth, reproduction)

- Consider comparative approaches to setting DO criteria
  - Metabolic index is an example

OXYGEN LOSS AND BIOLOGICAL EFFECTS:
WHY THE METABOLIC INDEX?

- Historical precedence is to use oxygen concentration (mg/L) to set biologically relevant thresholds

- However, the partial pressure of O_2, pO_2, is what is sensed by biology (drives gas exchange)

- Further, biological sensitivity to oxygen is temperature-dependent

  – Oxygen thresholds can vary 2-fold across temperature range

The Metabolic Index combines pO_2 with temperature-dependent biological responses to oxygen in order to define "aerobically available habitat"

Metabolic Index –Which Value to Choose

Chose oxygen sensitivity representative of northern anchovy

- Epipelagic

- Represents 75th percentile of aerobic sensitivity across all taxa
  - Median of epipelagic taxa

- Commercially and ecologically important

- Validated for California Current with a published case study
  - Strong correspondence to observed abundance data

QUESTIONS?

Breakout: Dissolved Oxygen Impacts on the Biological Integrity of Key Habitats and Species

Targeted Technical Uncertainties examples
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   For example: severity (above sub lethal) vs. acute (some data available now) sensitivity

3. What **existing literature and monitoring data** can be included in an initial desktop study?

Fish and invertebrate spatial distributions to inform the Atlantis model for Puget Sound

Hem Nalini Morzaria–Luna[1]

Isaac Kaplan[2], Raphael Girardin[3], Chris Harvey[2], Michael Schmidt[1], Elizabeth A. Fulton[4], and Parker MacCready[5]
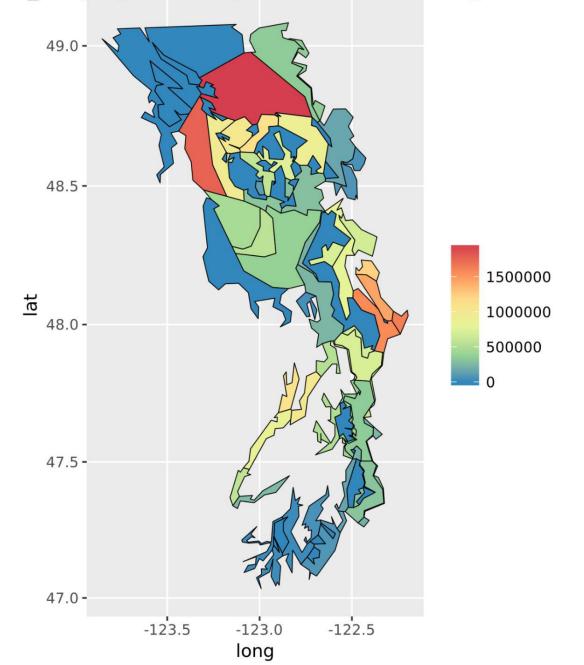
1. Long Live the Kings; 2. NOAA Northwest Fisheries Science Center; 3. IFREMER, Boulogne–sur–mer, France. 4. CSIRO Marine and Atmospheric Research. 5. University of Washington
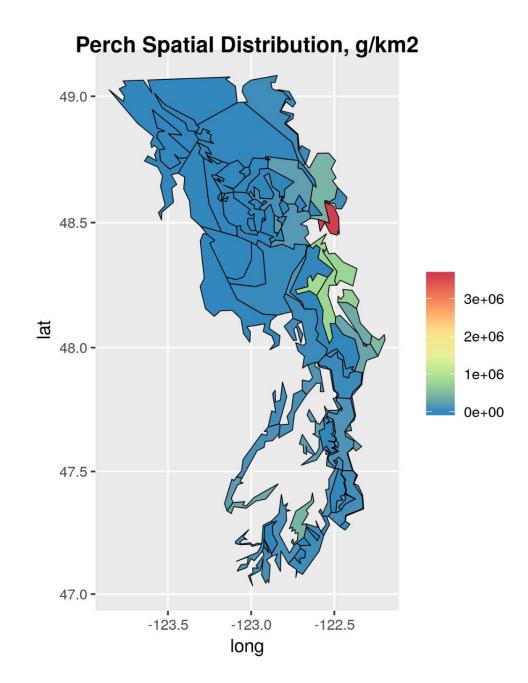
Fish
- Herring
- Salmon
- Surfperch
- Hake & large gadoids
- Large demersal predators
- Demersal rockfish
- Midwater rockfish
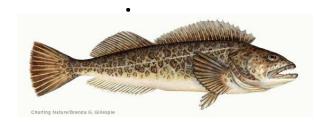
- Small demersal fish
- Small-mouthed flatfish
- Piscivorous flatfish
- Spiny dogfish
- Skates
- Ratfish

Hake_Large gadoids Spatial Distribution, g/km2

Perch Spatial Distribution, g/km2
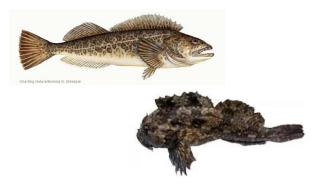
Survey data
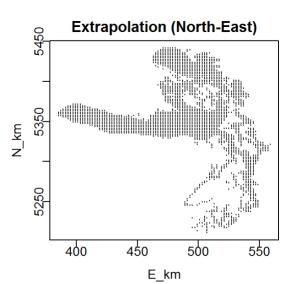
Estimate catch rate by
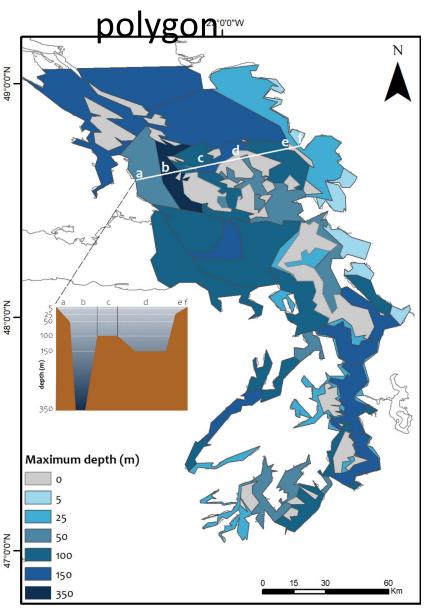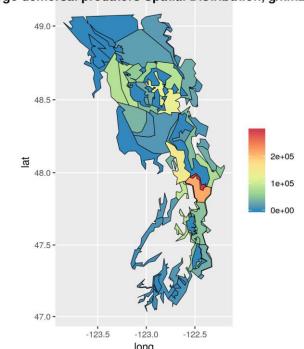
Average catch rate per AMPS polygon

Biomass per functional group

Extrapolation (North-East)

Maximum depth (m)

0
5
25
50
100
150
350

Large demersal predators Spatial Distribution, g/km2

Change in interannual variability of rivers and ocean impact

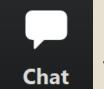# Upcoming Workshop: Change in interannual variability of rivers and ocean impact

Research Action: Uncertainties around oceanic and river loadings

Several areas of research have been identified depending on a better understanding of interannual variability related to future scenarios and nutrient management both short term and long term. These include:

- Natural variability: e.g. What is the variability and how does this impact nutrient availability year to year?
  Longer-term follow-up
- Climate change: e.g. What are the future conditions of the oceanic load?
- Increasing population impacts considering Climate Change and Canadian and other sources
- How do these processes drive variability?

Short-term actions to better constrain uncertainty: physical controls of natural interannual variability

- Timing and magnitude of **ocean influences** on the Salish Sea?
- Timing and magnitude of the **freshet and riverine influence**?
- Accordingly,
  - The availability of nutrients to the **euphotic zone**, first considering the role of temperature and salinity on **stratification**
  - Influence on residence time and flushing time of shallow embayments where low DO is observed (**Ocean exchange** and **riverine flushing**)
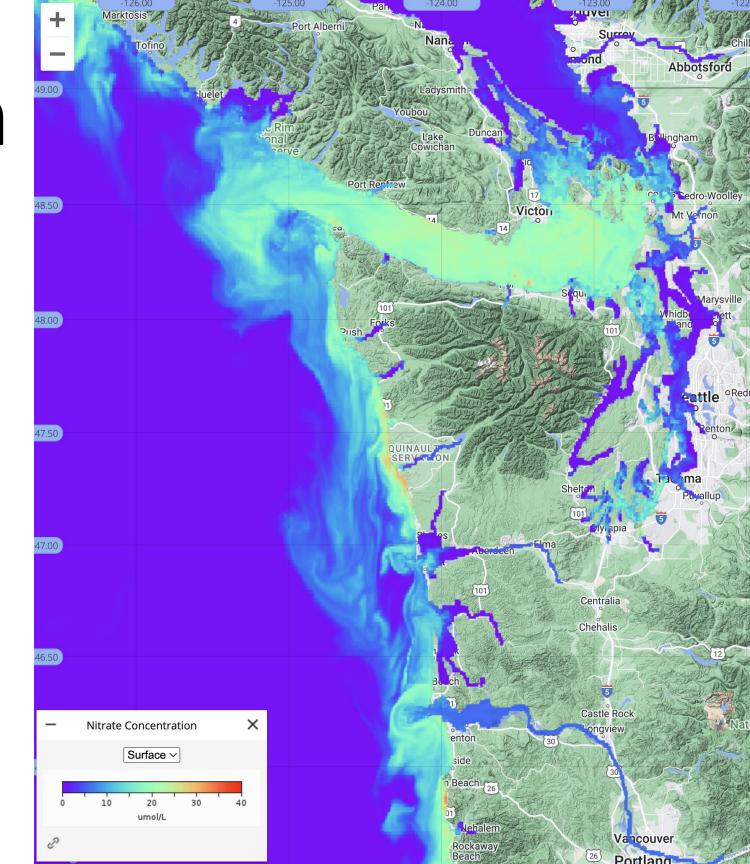
> Chat
>
> In the Chat: Who else should we engage in the next interannual variability workshop either as participants or presenters?

Nutrient Loading in the Salish Sea

Parker MacCready

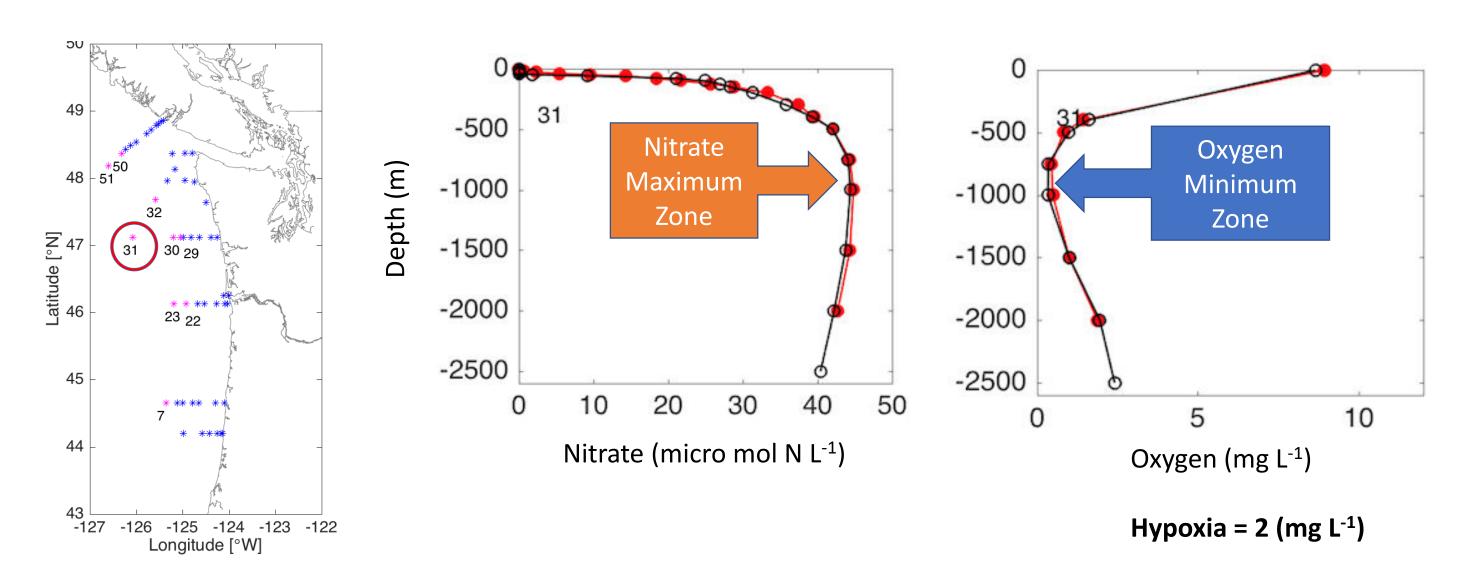Leo Maddox Endowed Professor of Oceanography

University of Washington

School of Oceanography

Overview and Questions

- Dissolved Inorganic Nitrogen (DIN) in the Salish Sea comes from rivers and human sources like WWTP's, and mostly from the ocean via the estuarine exchange flow.

- How much do these sources change on monthly, annual, and longer time scales?

- How do the size and the variability of these sources affect our ability to predict consequences of actions we might take?
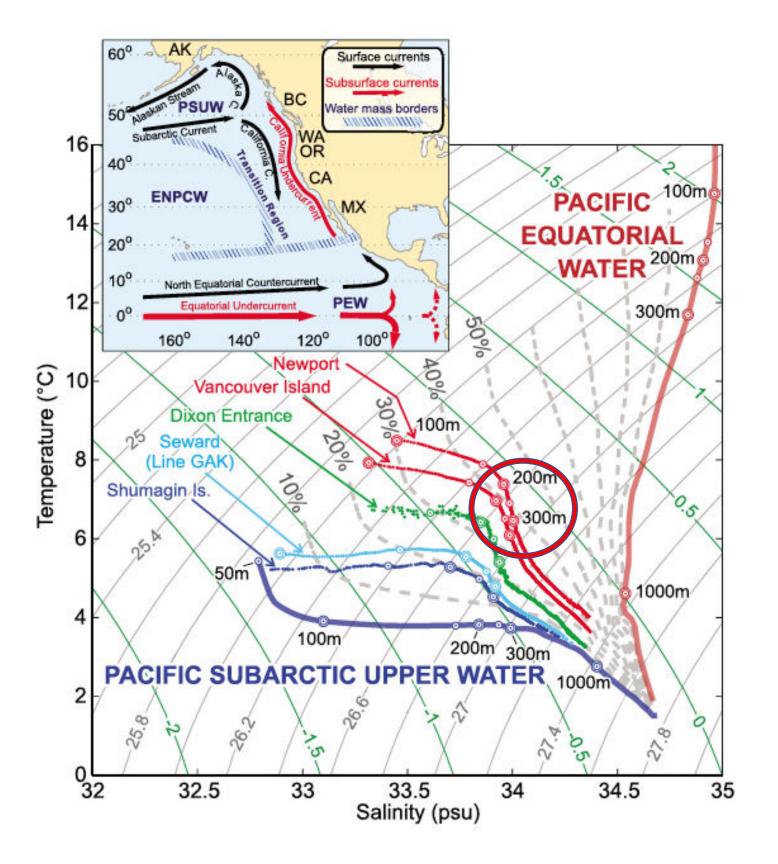
There is a lot of High-Nitrate, Nearly-Anoxic water offshore below the shelf break (NOAA Casts 2016)
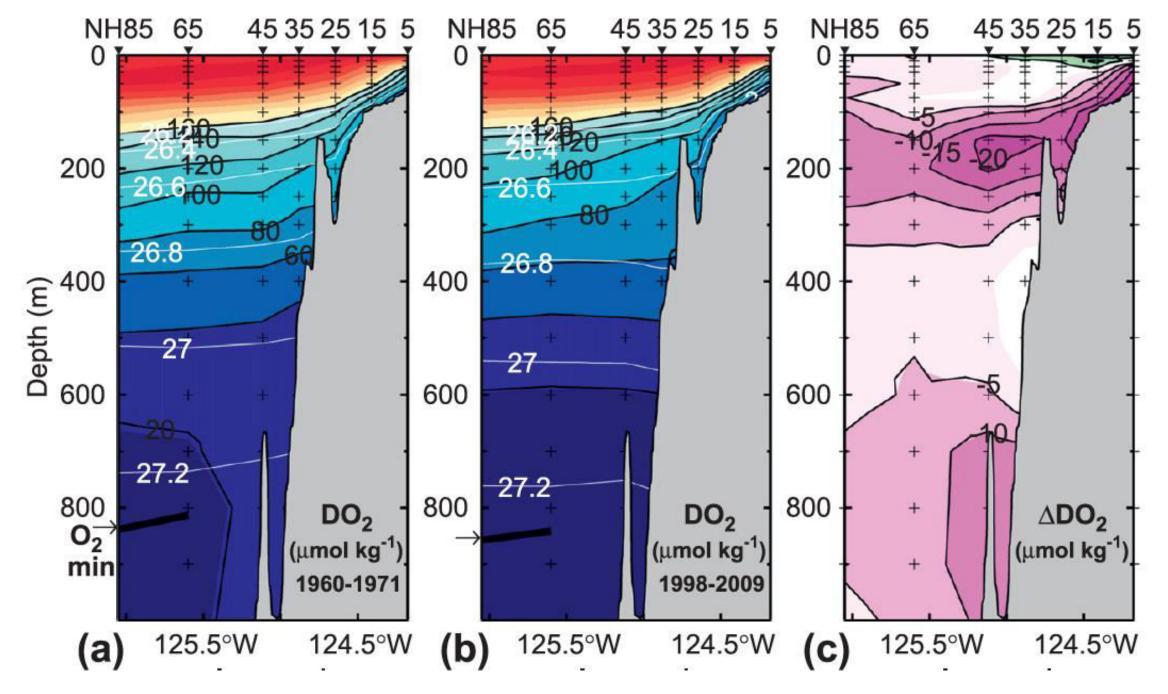

Reflects the accumulated remineralization of organic matter in the global ocean circulation

The incoming water at the mouth of Juan de Fuca is a 40:60 mixture of Pacific Equatorial Water coming north in the California Undercurrent, and Pacific Subarctic Upper Water from the NW Pacific

Thomson & Krassovski (2010 JGR) Poleward reach of the California Undercurrent extension

DO decreased by about 20% at the depth of the shelf break over 40 years.

Because the vertical gradients are strong, any change in the depth of the ocean source of the exchange flow could also be very important.
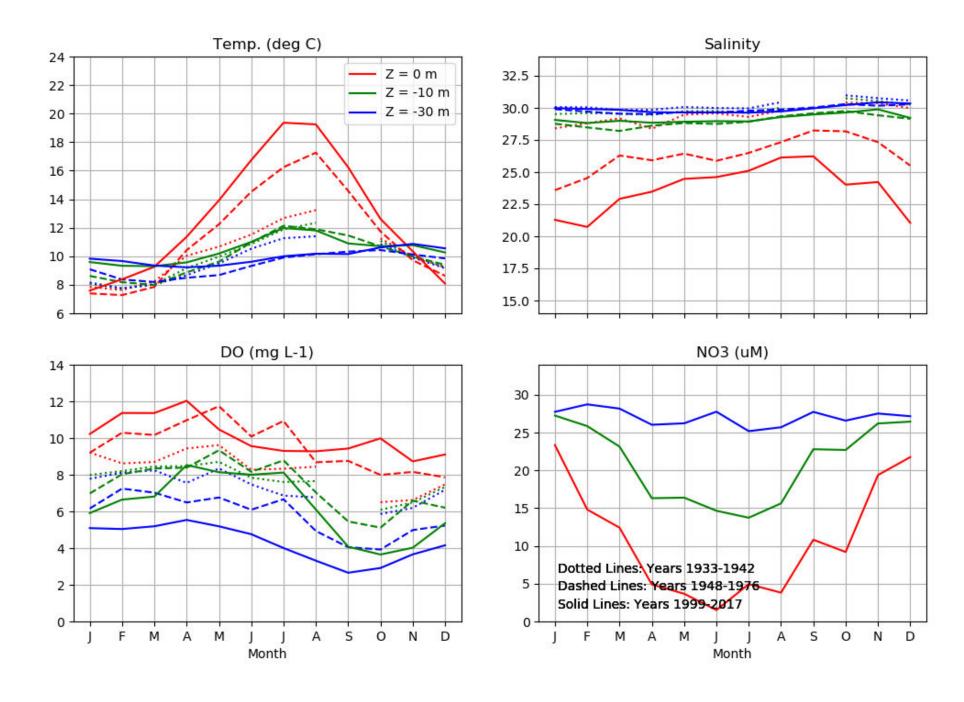
There are also long-term changes in Puget Sound

Using Collias CTD data from 1932-1975, and Ecology data for recent decades, we find that Hood Canal surface water has gotten warmer and fresher, and the deeper water has less DO.

The largest signal in Main Basin is that it is warmer by about 1 °C (top to bottom, all seasons).
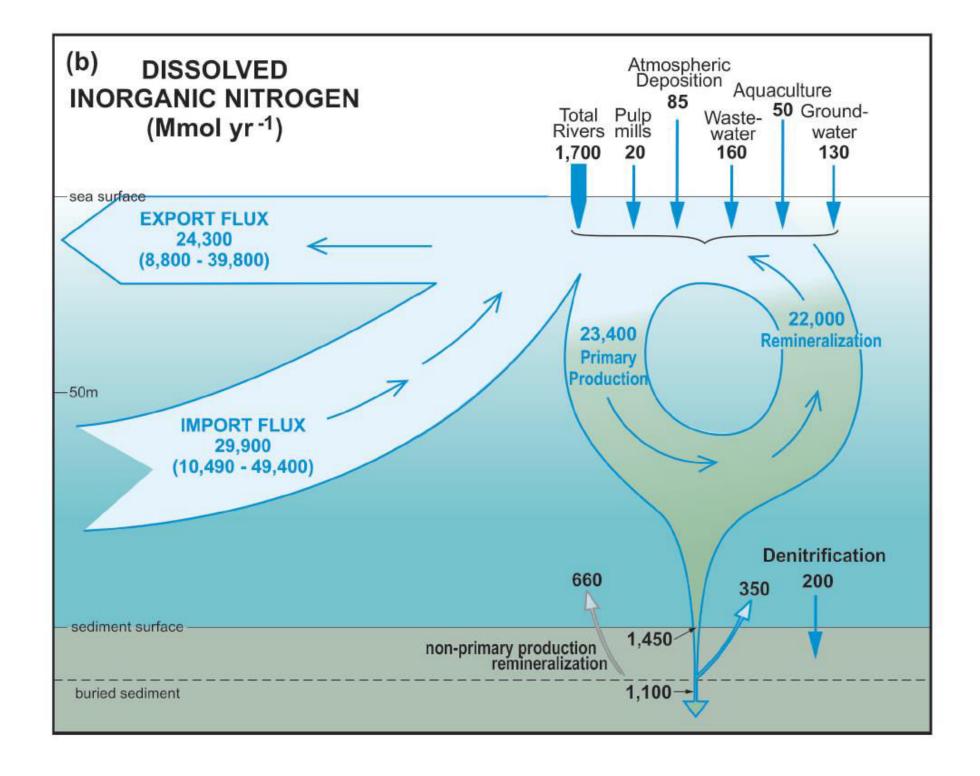

Hood Canal

Strait of Georgia DIN Budget

The estuarine exchange flow is the biggest DIN source and sink, and the net ocean source is about 60% of the total sources.

Import – Export = 5000 Mmol/yr

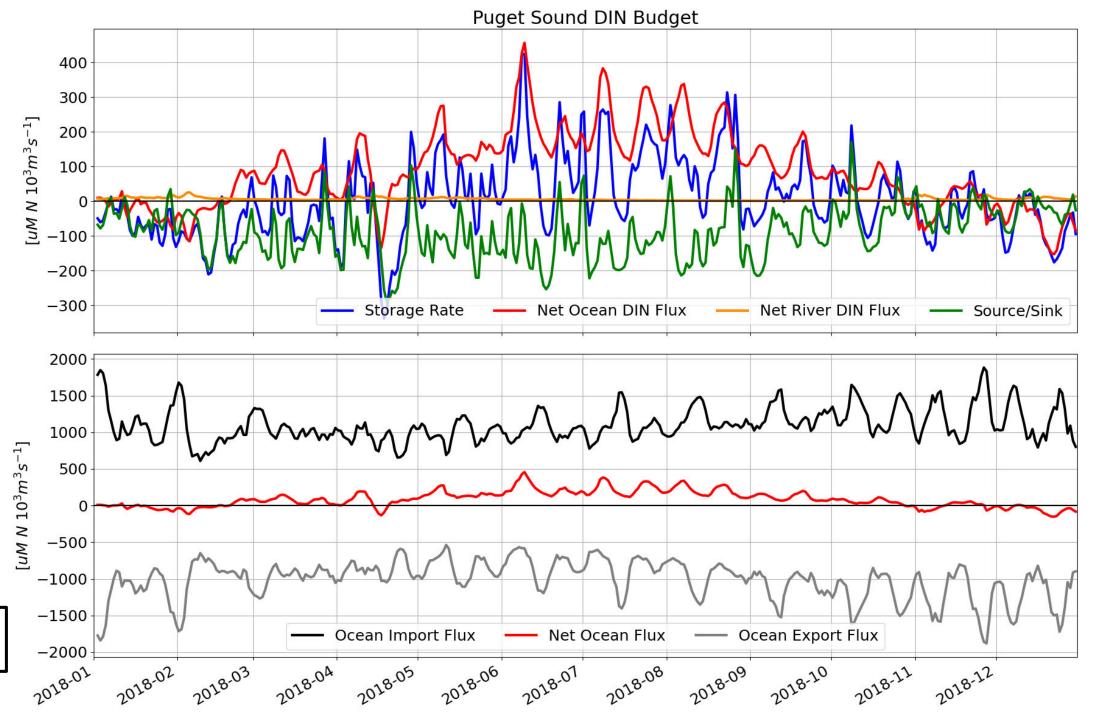Note the large variability of the ocean exchange.

(b) DISSOLVED INORGANIC NITROGEN (Mmol yr^{-1})

Atmospheric Deposition 85 — Aquaculture 50

Total Rivers	Pulp mills		Waste-water		Ground-water
1,700	20		160		130

sea surface

EXPORT FLUX 24,300 (8,800 - 39,800)

50m

IMPORT FLUX 29,900 (10,490 - 49,400)

23,400 Primary Production

22,000 Remineralization

Denitrification

660   350   200

sediment surface

non-primary production remineralization   1,450

buried sediment   1,100→

Model DIN Budget of Puget Sound

Puget Sound DIN Budget

Legend (top panel): Storage Rate, Net Ocean DIN Flux, Net River DIN Flux, Source/Sink

Legend (bottom panel): Ocean Import Flux, Net Ocean Flux, Ocean Export Flux

y-axis: $[uM \ N \ 10^3 m^3 s^{-1}]$

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

Net = Import - Export

Why the Size of the Ocean DIN Import Flux Matters

- In the Mohamedali et al. (2011) Report the Net DIN Loading from Rivers+WWTP's is estimated to be about 50% of the Net from the ocean. Thus, we expect that changing human loading may matter.

- However, the River+WWTP load is only 4% of the Ocean Import, and WWTP's are only 2.5%.

- Using the Ocean Import a more meaningful measure of the ocean influence on the system.
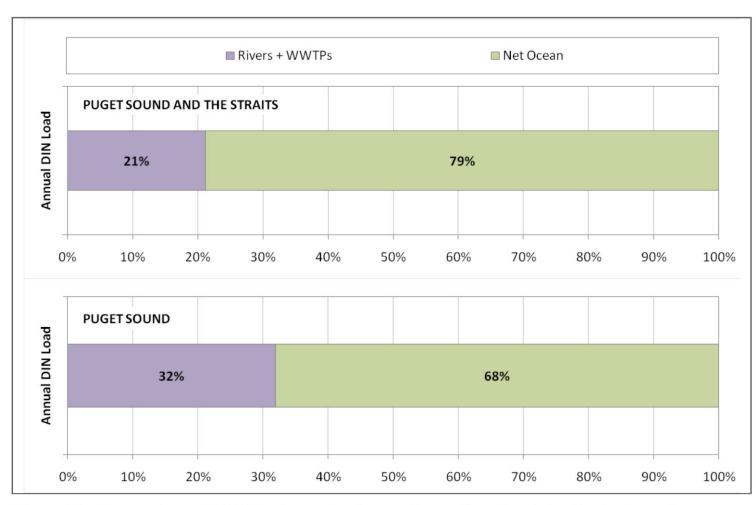

Figure 31. Comparison of DIN load contributions to Puget Sound and the Straits from rivers, WWTPs, and the oceanic loads from Mackas and Harrison (1997).

Puget Sound Dissolved Oxygen Model Nutrient Load Summary for 1999-2008, T. Mohamedali, M. Roberts, B. Sackmann and A. Kolosseus, 2011 Report Number: 8778336341

Important Hypotheses and Research Directions

- Variability of Ocean Source water is likely to be very important to the ecosystem.

- Is Variability of Ocean Source water important for uncertainty estimates?

- For Biogeochemical Modeling we would greatly benefit from more observations of:
  - Phytoplankton growth rates
  - Zooplankton grazing rates
  - PAR (Photosynthetically active radiation)
  - Organic Particle Fluxes
  - Benthic Fluxes

Salish Sea response to interannual variations during the marine heat wave years (2013-2017)

Tarang Khangaonkar[1,2]
Adi Nugraha[1]
Su Kyong Yun[1]
Lakshitha Premathilake[1,2]
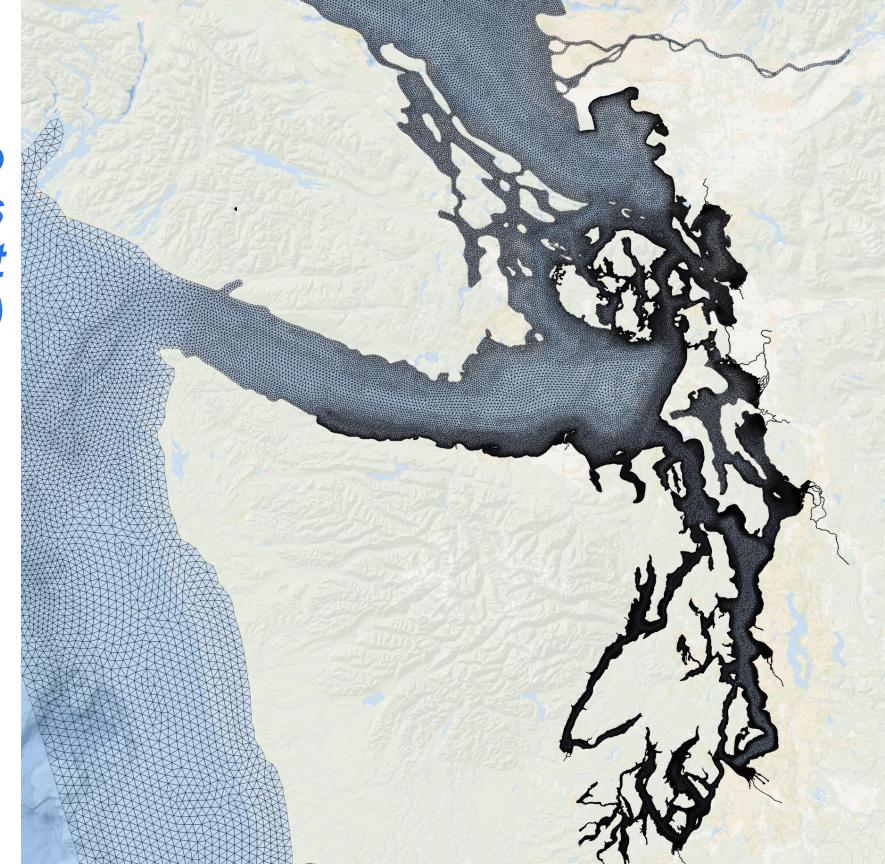Julie E. Keister[3]
Julia Bos[4]

[1]Salish Sea Modeling Center (SSMC) at UW Tacoma
[2]Pacific Northwest National Laboratory (PNNL)
[3]University of Washington (UW) - Oceanography
[4]Washington State Department of Ecology

Kickoff: Science supporting decision-making workshop
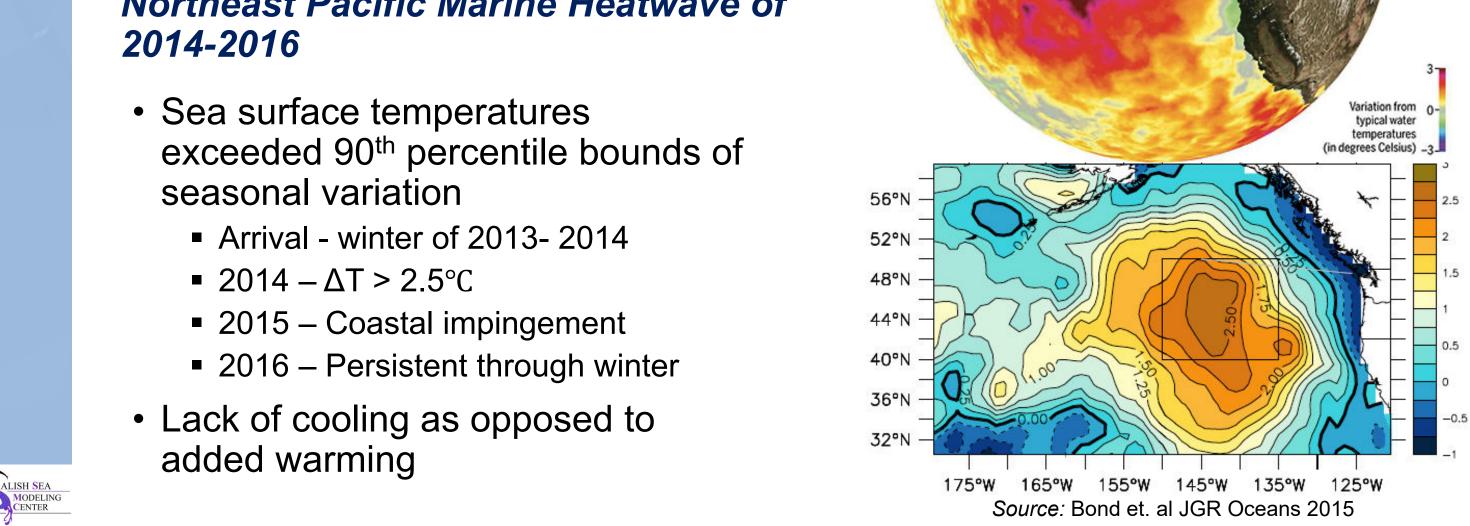**UW Puget Sound Institute**

July 26, 2022

Background/Motivation
Concern over climate change impacts
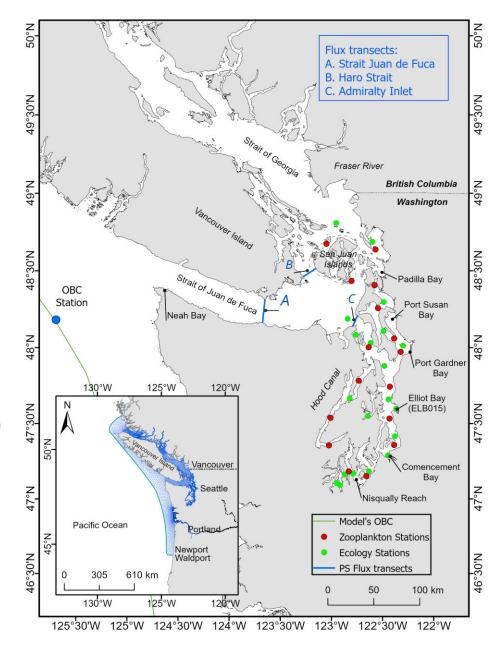
Northeast Pacific Marine Heatwave of 2014-2016

- Sea surface temperatures exceeded 90th percentile bounds of seasonal variation
  - Arrival - winter of 2013- 2014
  - 2014 – ΔT > 2.5℃
  - 2015 – Coastal impingement
  - 2016 – Persistent through winter
- Lack of cooling as opposed to added warming

Variation from typical water temperatures (in degrees Celsius)

Objective: Characterize and quantify impacts

Focus on inner estuarine waters of the Salish Sea

- Coastal impact documented based on field studies
  - Nearshore SST – ΔT as high as 6.2℃ (Southern California) (Gentemann et al. 2017)
  - Decrease in phytoplankton biomass - *induced by anomalous winds* (Whitney et al. 2015)
  - Coastwide Pseudo-nitzschia bloom in spring 2015 - *due to warmer waters* (McCabe et al. 2016)
  - Overall drop in copepod biomass - *potential collapse of the food chain* (Peterson et al. 2017)
  - Massive mortality of planktivorous seabirds (Jones et al. 2018)
- Any inner estuarine impacts? Impacts to the *Salish Sea?*
  - Noted increase in primary production (monitoring data)
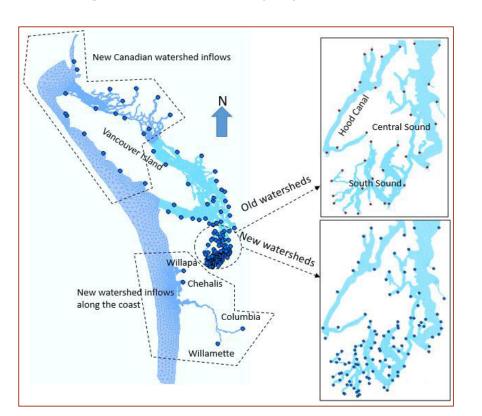 - Impacts - Largely unquantified, inconclusive, and somewhat speculative …

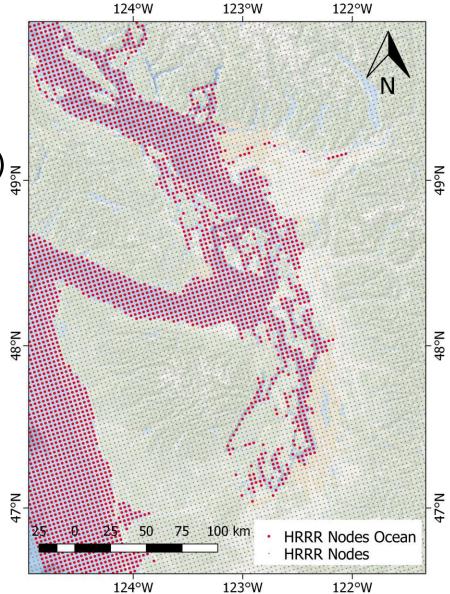# Approach: modeling-based quantification
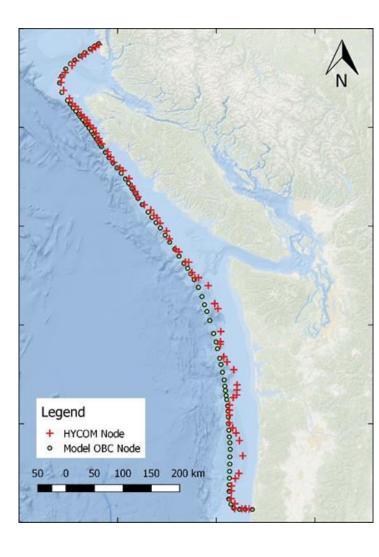## Multi-year validation & sensitivity test

- ***Salish Sea Model*** Setup and validation 2013 - 2017
  - Hydrodynamics (FVCOM)
  - Biogeochemistry (FVCOM-ICM)
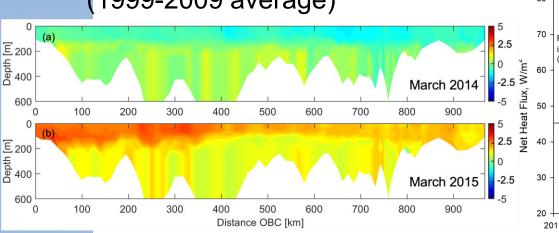

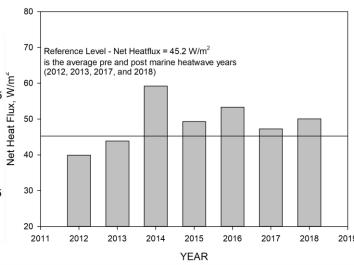[Khangaonkar et al. 2018, 2019, 2021]

Approach: modeling-based quantification (2 scenarios)

(a) Existing condition - validation
(Marine heatwave included)

(b) Reference condition - no warming

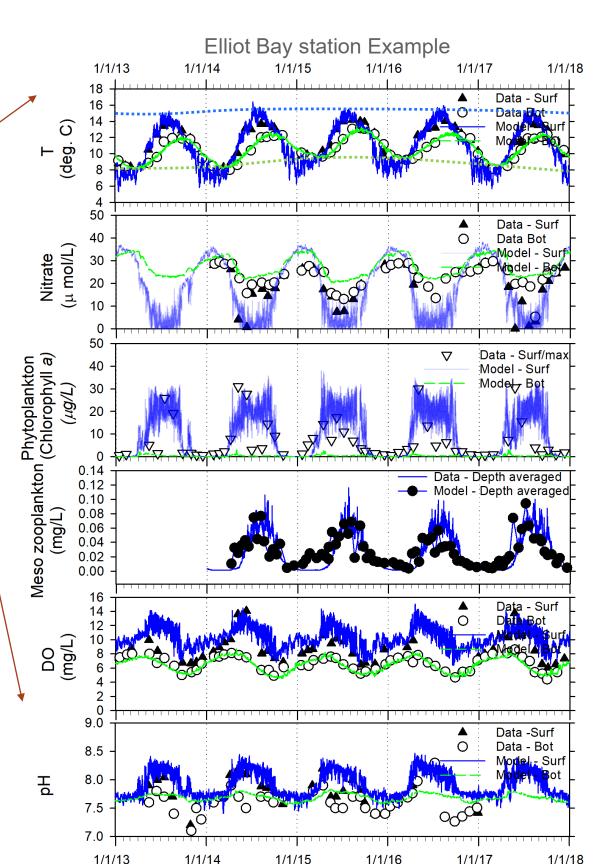Climatological ocean boundary
(1999-2009 average)

Average net heatflux

Average atmospheric net heat flux during the marine heatwave years (2014–2016) was (≈+19%)

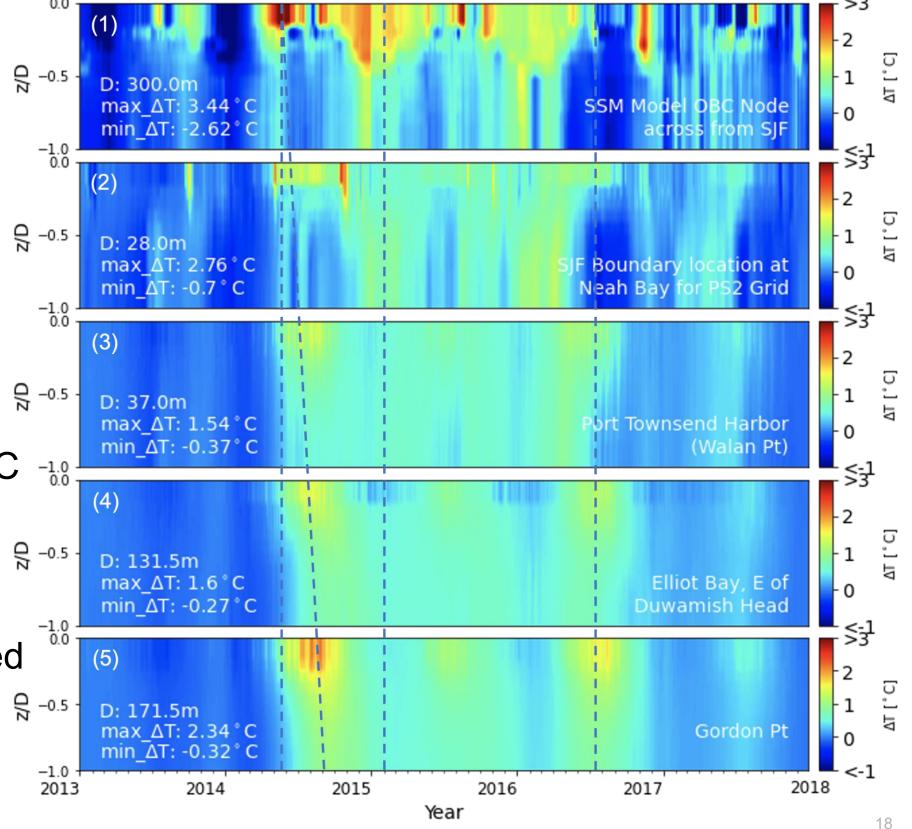Elliot Bay station Example

Results: Propagation of the MHW into Salish Sea

- Maximum ΔT 3-4 ℃ at OBC

- Inner Salish Sea
  - Max ΔT 2-3 ℃ at surface during impingement period

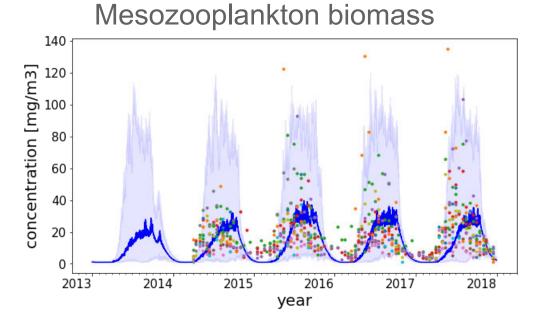- Sustained average elevated temperatures 2015-2016
  - ΔT ≈ 0.4-0.6 ℃
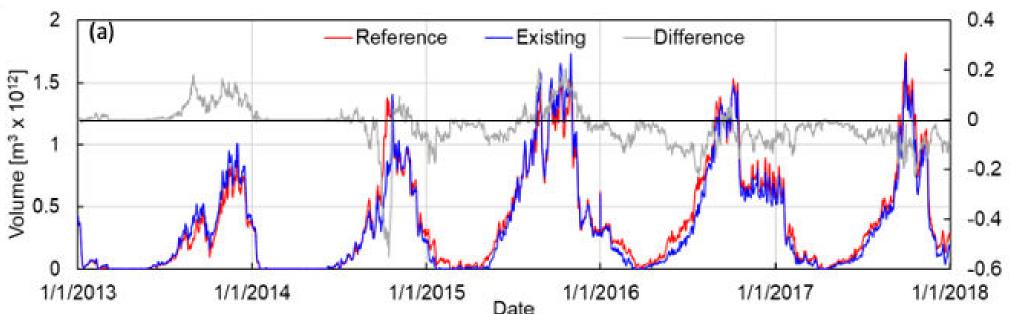
Salish Sea Monitoring Data 2014-2017
Primary production increased during the heatwave

Mesozooplankton biomass

- Increase in 2015 and 2016 relative to 2014
  - +9%, and 2% Δ phytoplankton biomass
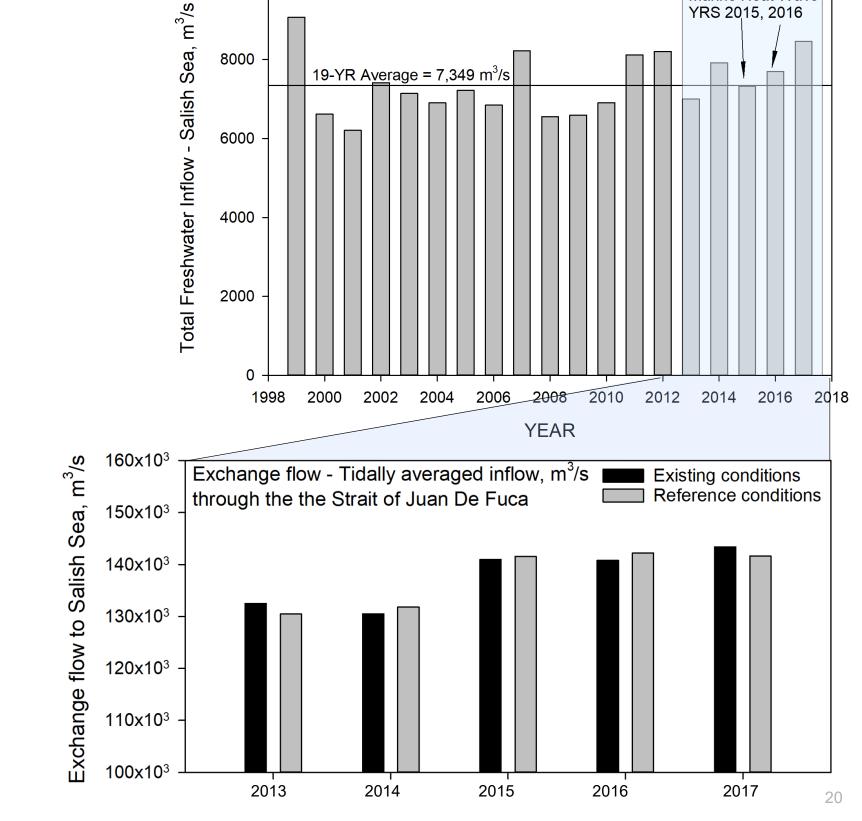 - + 10%, + 8% Δ zooplankton biomass

Hypoxic volume

Hypoxic volume – with marine heatwave (Existing) and without (Reference)

Influence of interannual variability in freshwater loading

- Affects salinity gradients
  - Impacts annual exchange with the Pacific Ocean
  - Indirect influence on oceanic nutrients availability to the photic zone
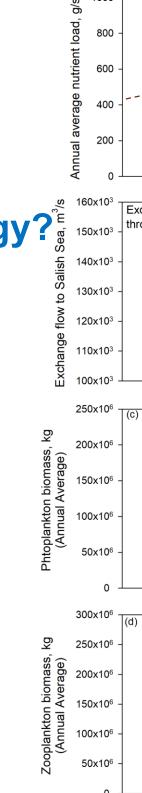- Direct influence on nutrient loads to the photic zone
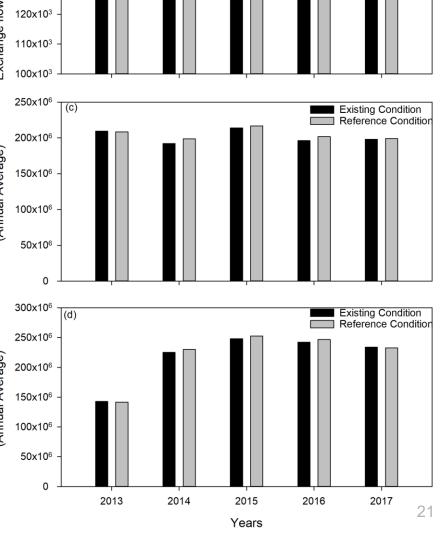
Summary / Discussion

Observed interannual variation (2013-2017)

- **Impact of the marine heatwave? Or**
- **Marine heatwave effect on hydrology? Or**
- **Interannual variability - meteorology & hydrology?**

- Concurrent with the marine heatwave
  - Fresh water inflow/loads increased from 2013 by ≈ 7%
  - Net heat flux increased by ≈ 19%
  - Exchange flow strength increased ≈ 8%

- Overall higher biomass ≈ + 10% (2015-2107)
  - *Likely unrelated to marine heatwave*
  - Attributed primarily to interannual variability

- Relative to conditions without marine heatwave
  - Reduced estuarine exchange (<1%)
  - Reduced primary production was (<4%)

Model limitations and uncertainties

- Definition of **reference conditions**
  - Pre-Marine heatwave vs long-term average

- Assumption that MHW did not affect hydrology and loading to SSM

- Accuracy of global models HYCOM and WRF in capturing MHW

- Model parameters and constituents based on limited years of calibration
  - Required an adjustment / relaxation of prior calibration parameter values

- Improvement needed in some of the sub-basins
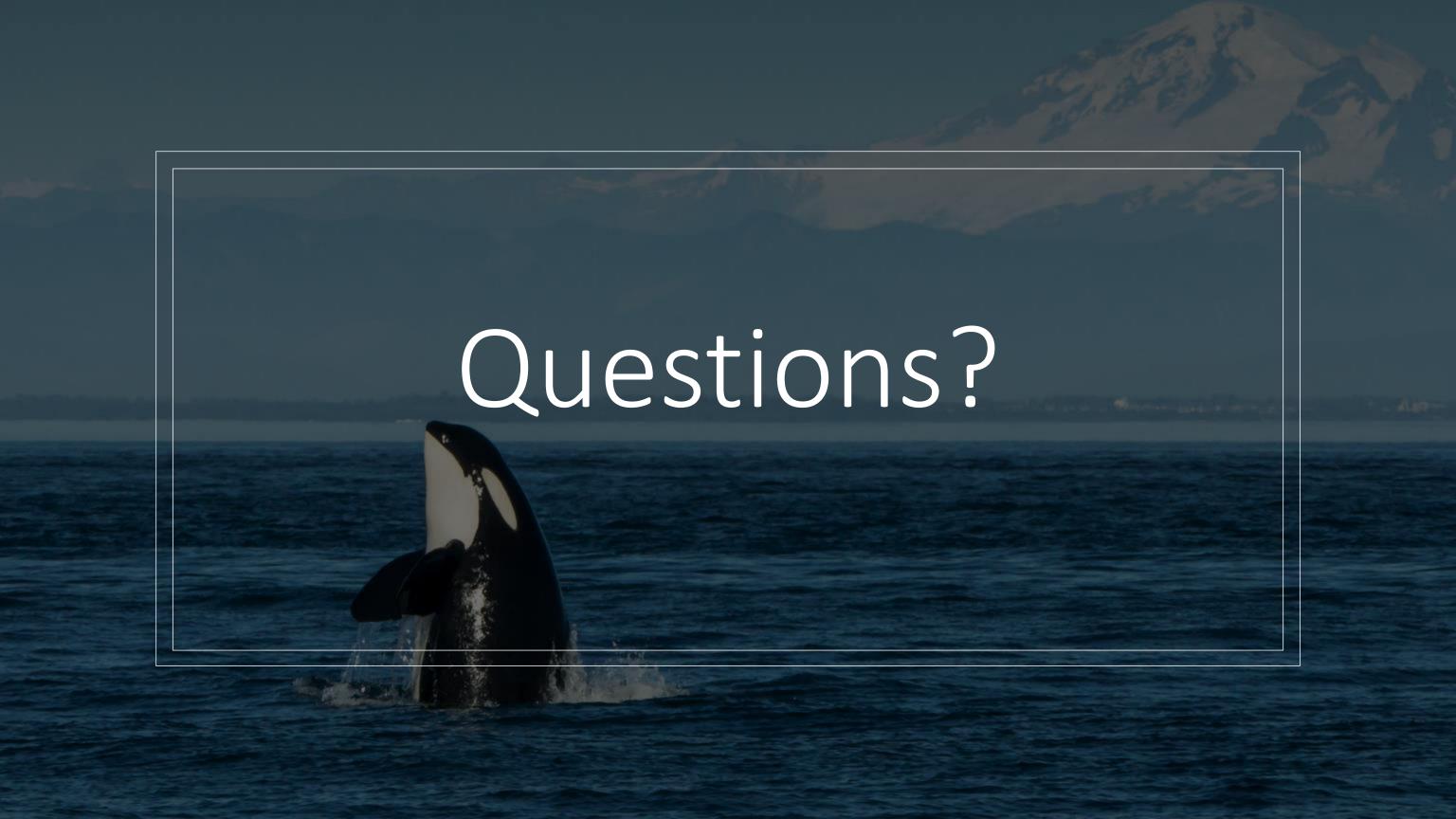 - Increase in resolution
  - Improve wind-effects on mixing

https://ssmc-uw.org//
https://salish-sea.pnnl.gov

Questions?

Phytoplankton and Primary Production

Breakout: Phytoplankton and Primary Production

Navigating the Workshop
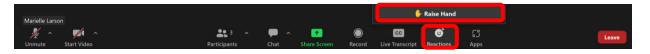
Welcome! While we wait, please:
- Introduce yourself in the chat.
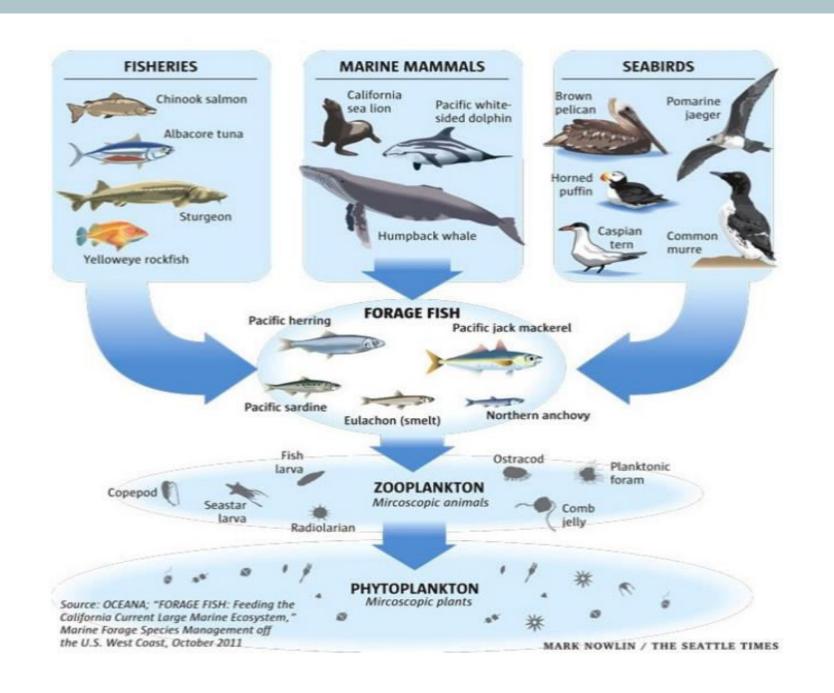
During discussion:
- Add your questions to the chat
- Raise your hand and we'll unmute you

- Discussion is focusing on the driving questions and associated scientific uncertainties. However, please feel to put in the chat any of the following towards brainstorming the future workshop discussion:
  - Who else should be in the room?
  - The "how" of addressing questions raised using modeling

The slides, recording, and synthesis will be available on Puget Sound Institute's website

Primary Production & Phytoplankton Breakout

FISHERIES
- Chinook salmon
- Albacore tuna
- Sturgeon
- Yelloweye rockfish

MARINE MAMMALS
- California sea lion
- Pacific white-sided dolphin
- Humpback whale

SEABIRDS
- Brown pelican
- Pomarine jaeger
- Horned puffin
- Caspian tern
- Common murre

FORAGE FISH
- Pacific herring
- Pacific jack mackerel
- Pacific sardine
- Eulachon (smelt)
- Northern anchovy

ZOOPLANKTON
Mircoscopic animals
- Fish larva
- Ostracod
- Planktonic foram
- Copepod
- Seastar larva
- Radiolarian
- Comb jelly

PHYTOPLANKTON
Mircoscopic plants

Source: OCEANA; "FORAGE FISH: Feeding the California Current Large Marine Ecosystem," Marine Forage Species Management off the U.S. West Coast, October 2011

MARK NOWLIN / THE SEATTLE TIMES

2013, 2016 PSEMP Monitoring Gaps Work

QUESTION 10: <u>**Is the ecology of phytoplankton, including nuisance and harmful algal bloom (HAB) species, in Puget Sound well understood?**</u>
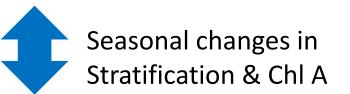
- **BIG GAP: Spatial and temporal resolution of phytoplankton species and abundance**.

- The time-scale for changes in phytoplankton abundance is short and spatially variable, requiring more frequent monitoring and in more areas. This applies to both HAB and non-HAB species. *For example, shifting between a diatom-dominated food web to microbial-dominated food web (e.g., Noctiluca) has large consequences in reducing the amount of carbon (food) available to higher trophic levels, such as fish and benthic biota.*

- Only chlorophyll is monitored regularly for most programs, but conversion to C is too variable to be meaningful for most applications.

- **BIG GAP: No phytoplankton rates are being monitored (production, respiration, and sinking)***
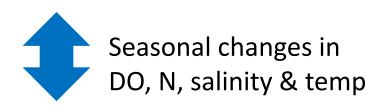
Setting the stage: addressing observed changes at the bottom of the food web

Long term changes observed (Ecology's 27 Stations≈1999 to 2018):

⬇ Silicate:DIN & near-bottom: surface Chl A

⬍ Seasonal changes in Stratification & Chl A

⬍ Seasonal changes in DO, N, salinity & temp

Source: See presentations by Christopher Krembs at Puget Sound General Nutrient Forum, July 19, 2017 and PSEMP phytoplankton group, May 18, 2022 for data plots
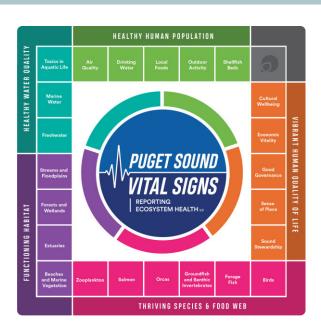
What are the impacts and why it matters to marine life and nutrient cycling? -focus of this presentation?

⬇

Hypothesis of change under discussion in regional monitoring forums

Vulnerability is largely impacted by ocean and river impacts on physics – a focus of other breakout group today
Opportunity for Modeling<>Modeling

Current Efforts: Complementary Monitoring & Modeling

Primary Productivity & Phytoplankton Indicator Workshop Series

PSEMP Marine Waters Work Group

5 workshops 2022-2023 to develop:
- State of Knowledge
- Existing Data
- Framework for developing monitoring & future indicators

Improved Monitoring

Research, Modeling, and Monitoring to Reduce Uncertainties

Address technical uncertainties & advance modeling tools for decision-making.

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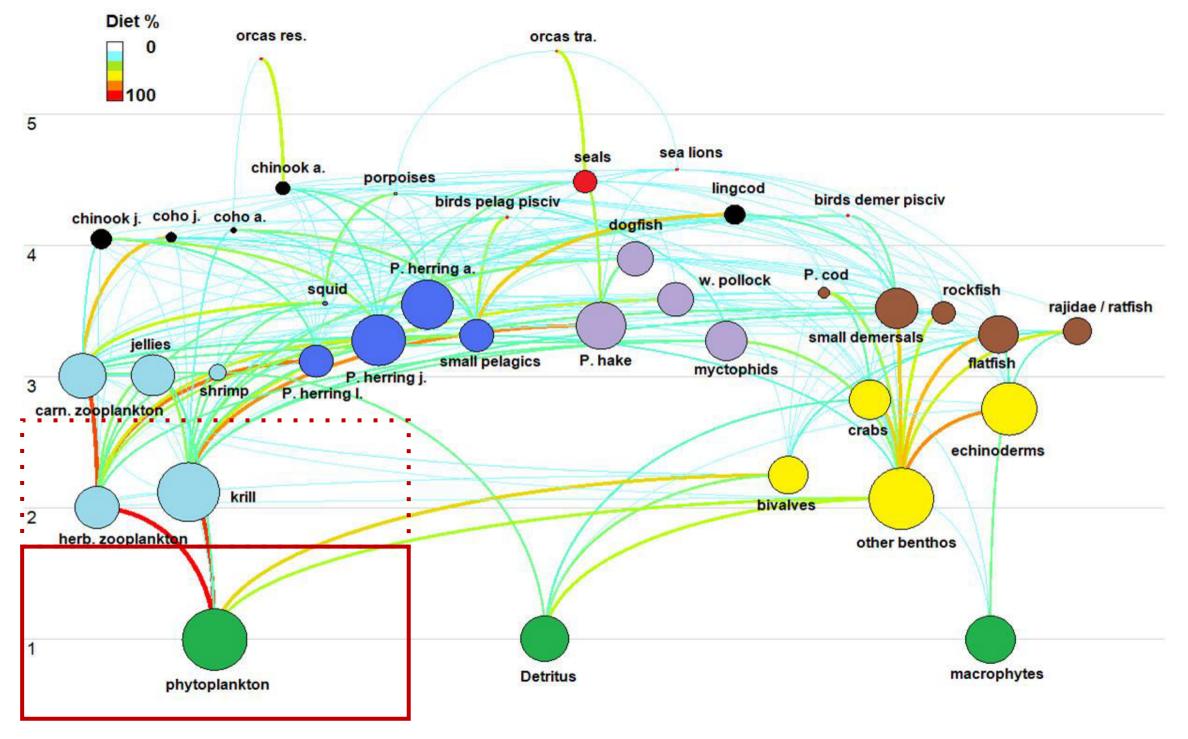- Expand access to models, outputs, tools, and scientific knowledge

Refine Research Actions

Terms & Definitions

|	Standard Definition	Other Definitions	Typical Units
Phytoplankton	Loose term, includes unicellular autotrophs, mixotrophs and heterotrophs	Only photosynthetic cells (auto/mixotrophs)	
Bloom	Loose term, large increase in cell density (Smayda paper)	Density above certain threshold (e.g., Chl >30 $\mu g/L$)	
HAB species	Any species that can have a toxic or harmful effect on other organisms (usually above a certain density)	Any species that can negatively affect the environment (e.g., hypoxia) Only toxigenic species	
Biomass	Total dry weight	Carbon content	mg C/m^3, pg C/cell
Primary Production	Rate of carbon assimilation (gross and net) –big discussion - agreed a rate		mg C/m^2/yr, mg C/m^3/yr
Chlorophyll-a	Cell-bound, measured in the lab following some extraction protocol, usually by collecting cells on a filter - discrete water samples - extraction	Proxy for biomass or PP	mg/m^2, mg/m^3 or μ/L
Chlorophyll Fluorescence	In vivo chlorophyll fluorescence, usually measured in situ		RFU (relative units), mg/m^3

Rate vs. Concentration!
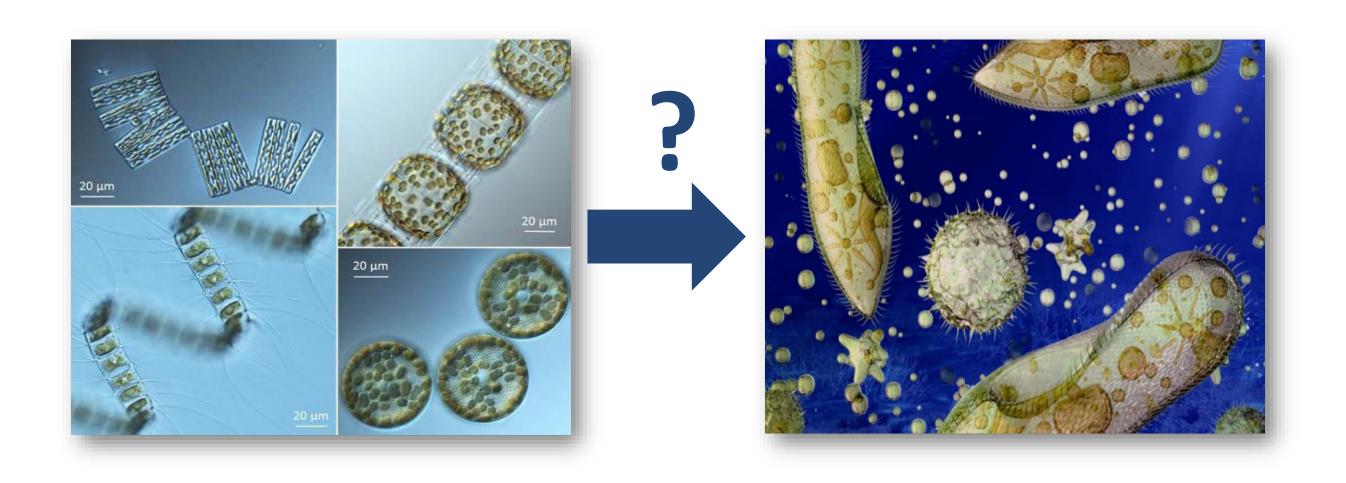
Developed and refined at the first Vital Sign workshop. Available here.

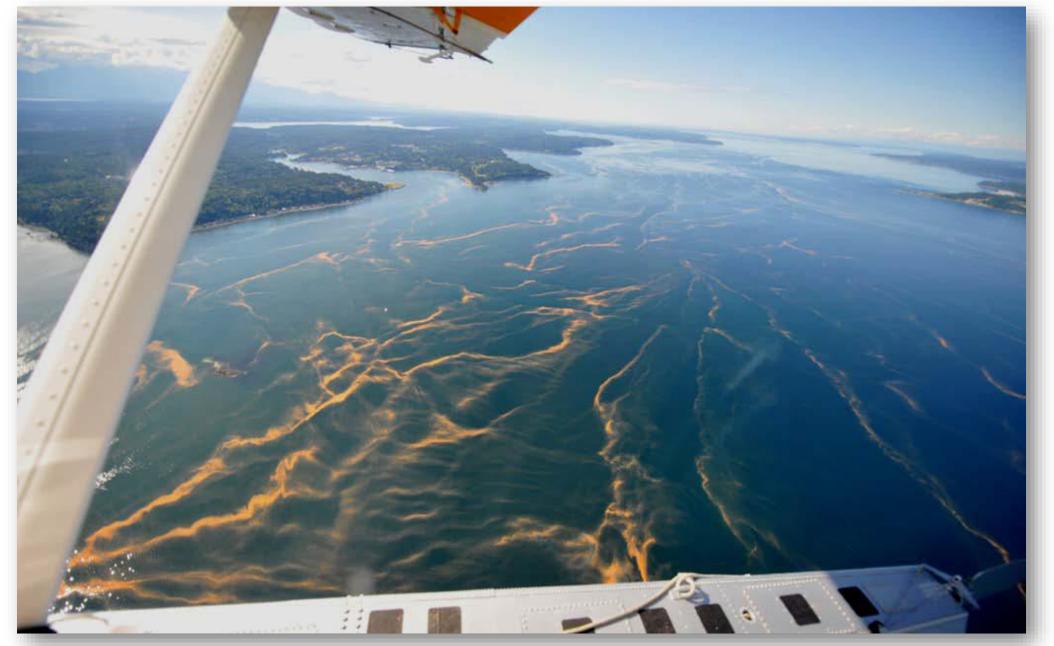# Phytoplankton Role & Function in Salish Sea Food Web

LLTK - Strait of Georgia ecosystem model – D. Preikshot & I. Perry, Fisheries and Oceans Canada
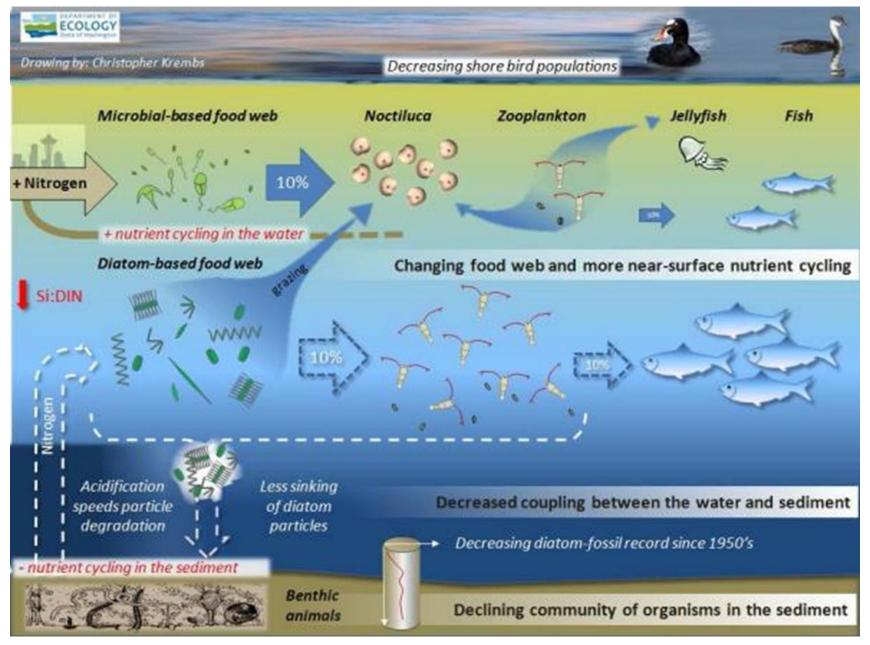
Observed Changes & Hypotheses of Drivers
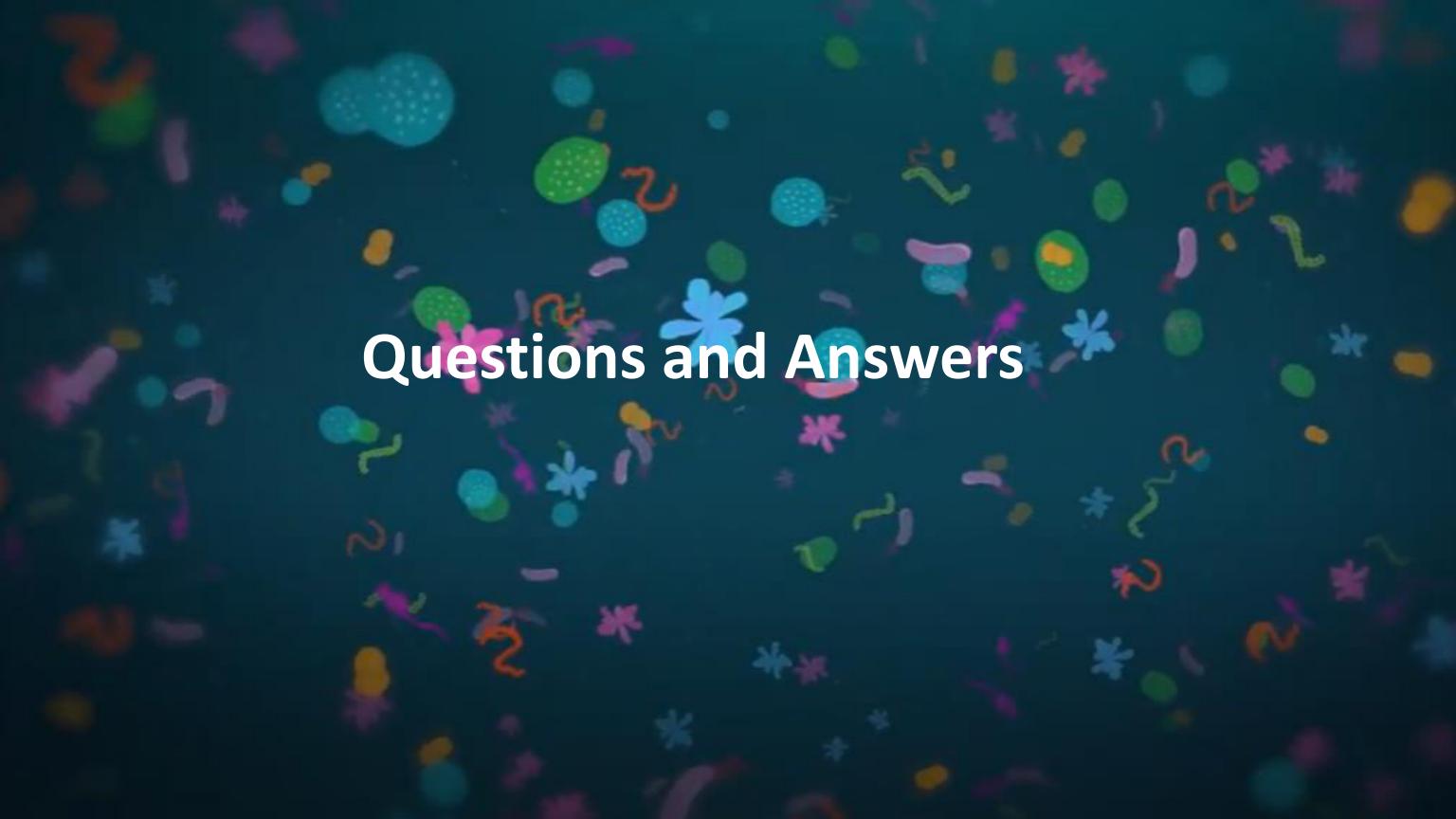
Observed Changes & Hypotheses of Drivers

Christopher Krembs. Eyes Over Puget Sound. Publication No. 13-03-075. Washington Dept. of Ecology, June 2013

Observed Changes & Hypotheses of Drivers

Christopher Krembs, Washington Dept. of Ecology

Questions and Answers

Discussion: Check on priorities moving forward

Next steps at these workshops:

1. Dive deeper on addressing uncertainties in changes observed, and hypothesis identified

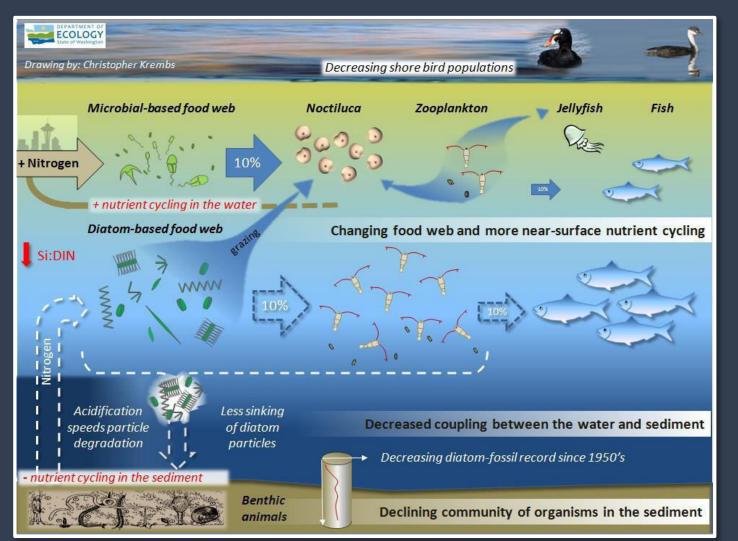**Hypothesis of change under discussion in regional monitoring forums, e.g.:**

- Climate change and local human contribution to change in physics/euphotic nutrient availability
- Nutrient balance > lower level food webs
- Diatom > microbial food web

What prioritization of different parts of the physics of the system on the availability of nutrients of the euphotic zone would to address some of these hypothesis

Hypothesis: Changes in the lower food web

"Supporting science varies in strength. See last slide for details on each topic".

HS-1: Climate change has the effect of magnifying human nutrient contribution to Puget Sound and shifts the food web in the summer months.

HS-2: Changes in the nutrient balance affect the growth conditions of the lower levels of the marine food web.

HS-3: In summer, the microbial food web has gained importance relative to the productive, diatom-based food chain.

HS-4: The organic particle export to deeper water changed in response to shifts in the lower-trophic levels of the food web.

DEPARTMENT OF ECOLOGY
State of Washington

Drawing by: Christopher Krembs

Decreasing shore bird populations

Microbial-based food web   Noctiluca   Zooplankton   Jellyfish   Fish

+ Nitrogen   10%

+ nutrient cycling in the water

Diatom-based food web   grazing   Changing food web and more near-surface nutrient cycling

Si:DIN

10%   10%

Nitrogen

Acidification speeds particle degradation   Less sinking of diatom particles   Decreased coupling between the water and sediment

Decreasing diatom-fossil record since 1950's

- nutrient cycling in the sediment

Benthic animals   Declining community of organisms in the sediment

Source: See presentations by Christopher Krembs at Puget Sound General Nutrient Forum, July 19, 2017

Watershed Modeling Breakout

Presenter:

Bob McKane

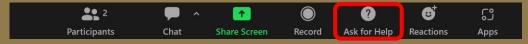U.S. Environmental Protection Agency

Facilitators:

Caitlin Magel & Rachael Mueller

Puget Sound Institute, UW Tacoma

Welcome! Please feel free to use your video.

Questions or Comments?
- Type them in the Zoom Chat
- Raise your hand

Click *Ask for Help* to call the event host to the breakout room

Breakout: Watershed Modeling

Targeted Technical Uncertainties:

- Advance beyond current watershed regression inputs to understand:
  - what is going on in the watershed (spatially),
  - what are the drivers of watershed loading (e.g., land-use and land cover),
  - and what is the effectiveness of proposed policy and program changes for receiving waters?
- Reduce uncertainties associated with watershed scenarios and level of confidence in model application

Proposed Research Actions:

Compare loading inputs and estimates from different model sources

Regression approach (2022 – 2024): Ecology/USGS update to SPARROW to include all Puget Sound watersheds and estimate seasonal nutrient loads. Coordinate with local implementation groups and local/state agencies to update datasets on water quality, land use, and implementation activity.

Lead: D. Bilhimer, WA Department of Ecology

Strategies for reducing uncertainties in modeled urban stormwater runoff and contaminant loads in Puget Sound nearshore streams

Bob McKane[1], Jonathan Halama[1], Brad Barnhart[1], Paul Pettus[1], Allen Brookes[1], Kevin Djang[2], Vivian Phan[1]
Ed Kolodziej[3], Kathy Peter[3], Zhenyu Tian[3,4], Stefano Mazilli[3], Marielle Larson[3], Tessa Francis[3]

[1]*U.S. Environmental Protection Agency, Corvallis;* [2]*CSRA, Corvallis, OR*
[3]*University of Washington Tacoma, Puget Sound Institute;* [4]*Northeastern University, Boston, MA*

Presented July 26, 2022 – Puget Sound Marine Water Quality Workshop

Office of Research and Development
Center for Public Health and Environmental Assessment - Pacific Ecological Systems Division, Corvallis, OR

Longfellow Creek watershed, West Seattle, WA

Surface

Soils

Surface 6PPD-Q

VELMA Simulated 6PPD-Q
Longfellow Creek Watershed
West Seattle, WA.

6PPD-Q
(g/m²)

5e-06

5e-03

0.0

N

Stream flow
& 6PPD-Q

Graph Visualization

50   Precipitation

0

Jan 26, 2020   Mar 16, 2020   May 05, 2020   Jun 24, 2020   Aug 13, 2020   Oct 02, 2020   Nov 21, 2020

January 01, 2020   January 01, 2020   December 31, 2020

6PPD-Q_LFtoGrabSample_2020_v2

Longfellow Creek Observed vs Modeled 6PPD-Quinone

Sources of uncertainty in modeled stormwater runoff and contaminant loads

Sources of Uncertainty	Key Questions
1) Model equations and parameters	Does the model adequately represent the processes controlling the outputs of interest? *For example, runoff via natural (soil matrix) and engineered (stormwater infrastructure) flow paths.*
2) Data for model implementation	Do the data accurately represent the system at the scales required to model the outputs of interest?
3) Calibration methods	Has the problem of equifinality been minimized? *Can we systematically disqualify solutions for which calibrated parameters provide the right answers for the wrong reasons?*
4) Propagation of uncertainty among submodels	Has model calibration reduced model uncertainty and its propagation among submodel components? *What model performance tests can help address these questions?*

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1) Model equations and parameters	Does the model adequately represent the processes controlling the outputs of interest? *For example, runoff via natural (soil matrix) and engineered (stormwater infrastructure) flow paths.*

Roadway daily additions of 6PPD-Q (g m^{-2} d^{-1})

| Parameters used to calculate roadway tire wear particle (TWP) deposition and 6PPD-Q daily loads	Low Range	High Range	Longfellow watershed value	References
TWP mg/km per vehicle counted	100 (cars)	600 (trucks)	Function of car/truck traffic count data	• TWP deposition per Kole et al. 2017 • Traffic count data per City of Seattle & WSDOT
6PPD g / tire rubber g	0.004	0.02	0.02	Tian et al., 2021
6PPD-Q yield g / 6PPD g	0.01	0.75	0.38	Tian et al., 2021
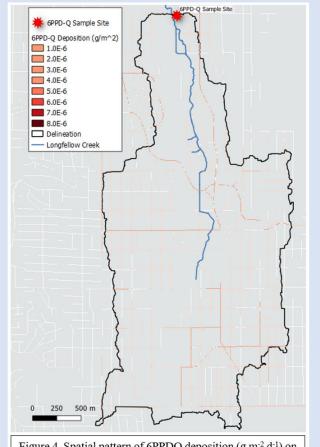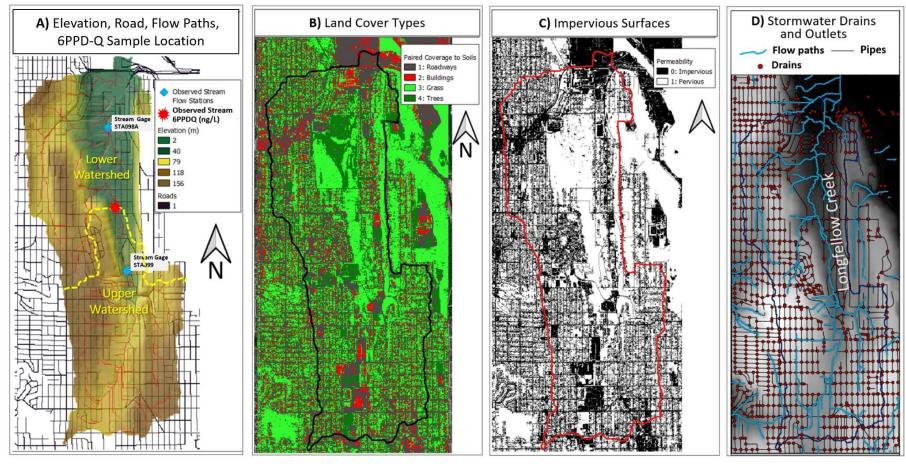
Figure 4. Spatial pattern of 6PPDQ deposition (g m^{-2} d^{-1}) on roads within the Longfellow Creek upper watershed, based on methods described in section 2.3.2.

Sources of Uncertainty	Key Questions
2) Data for model implementation	Do the data accurately represent the system at the scales required to model the outputs of interest?

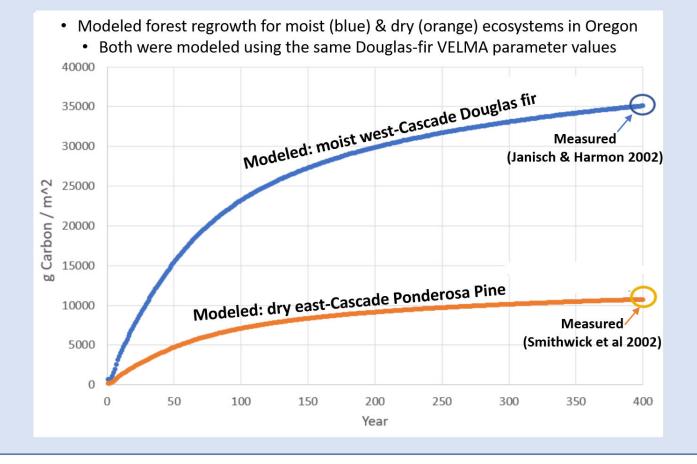# VELMA Urban Spatial Data Layers (5-meter Grid)

Halama et al., In review. Improved urban runoff prediction using high-resolution land-use, imperviousness, and stormwater infrastructure data applied to a process-based ecohydrological model.

Sources of Uncertainty	Key Questions
3) Calibration methods	Has the problem of equifinality been minimized? *Systematically disqualify solutions for which calibrated parameters provide the right answers for the wrong reasons.*

VELMA is calibrated using a Multi-Objective Evolutionary Algorithm (MOEA) that optimizes overall model performance for multiple outputs, e.g., runoff, soil moisture, decomposition, plant growth…..

Sources of Uncertainty	Key Questions
4) Propagation of uncertainty among submodels	Has model calibration reduced model uncertainty and its propagation among submodel components? *What model performance tests can help address these questions?*

Severe performance test: Are parameters calibrated for one location transferable to other locations?

- Modeled forest regrowth for moist (blue) & dry (orange) ecosystems in Oregon
  - Both were modeled using the same Douglas-fir VELMA parameter values

VELMA model parameters calibrated for a single forest calibration site (HJ Andrews ★) accurately predict, with minimal adjustment, forest ecohydrological processes at other sites (★) located across steep regional climate and soil nutrient gradients
*Possible exception, currently under study

Reference: U.S. EPA. Comparative Assessment of the Impacts of Prescribed Fire Versus Wildfire (CAIF): A Case Study in the Western U.S. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-21/197, 2021.

Sources of Uncertainty	Key Questions
4) Propagation of uncertainty among submodels **and to linked external models**	Has model calibration reduced model uncertainty and its propagation among submodel components? *What model performance tests can help address these questions?*

Modified from Darryl Marois

Integrated terrestrial-marine models are needed to
- Synthesize decades of terrestrial & marine data
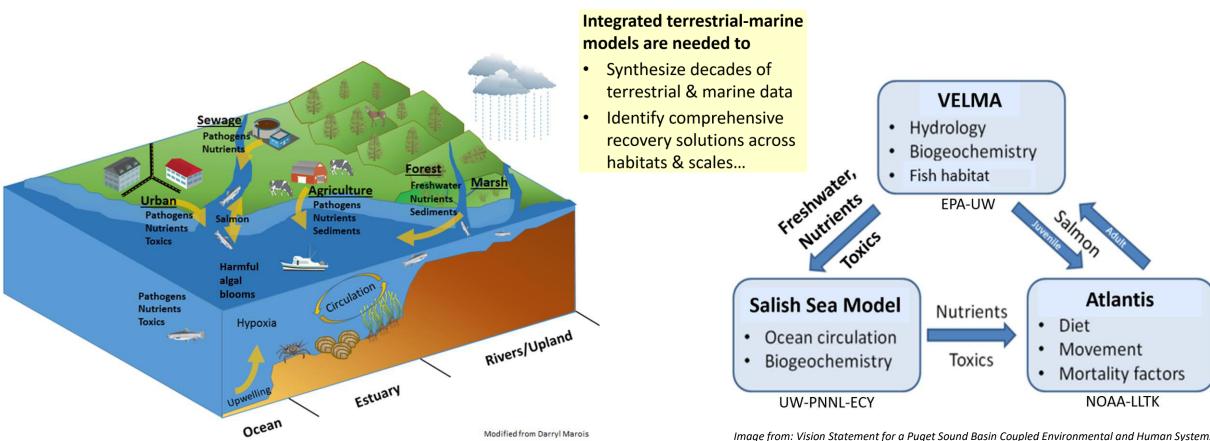- Identify comprehensive recovery solutions across habitats & scales...

Image from: Vision Statement for a Puget Sound Basin Coupled Environmental and Human Systems Modeling Framework (2018 unpublished). Bob McKane, Tarang Khangaonkar, Isaac Kaplan, Chris Harvey, Hem Nalini Morzaria Luna, Tessa Francis, Phillip Levin, Emily Howe, Jesse Israel, Michael Schmidt, Jonathan Halama, Allen Brookes, Kevin Djang

Breakout: Watershed Modeling

General Q&A for Bob (5-10 minutes)

Open Discussion (15-20 minutes)
What watershed uncertainties are shared across different modeling efforts?

Chat In the Chat: Who else should we engage in the next watershed modeling workshop either as participants or presenters?