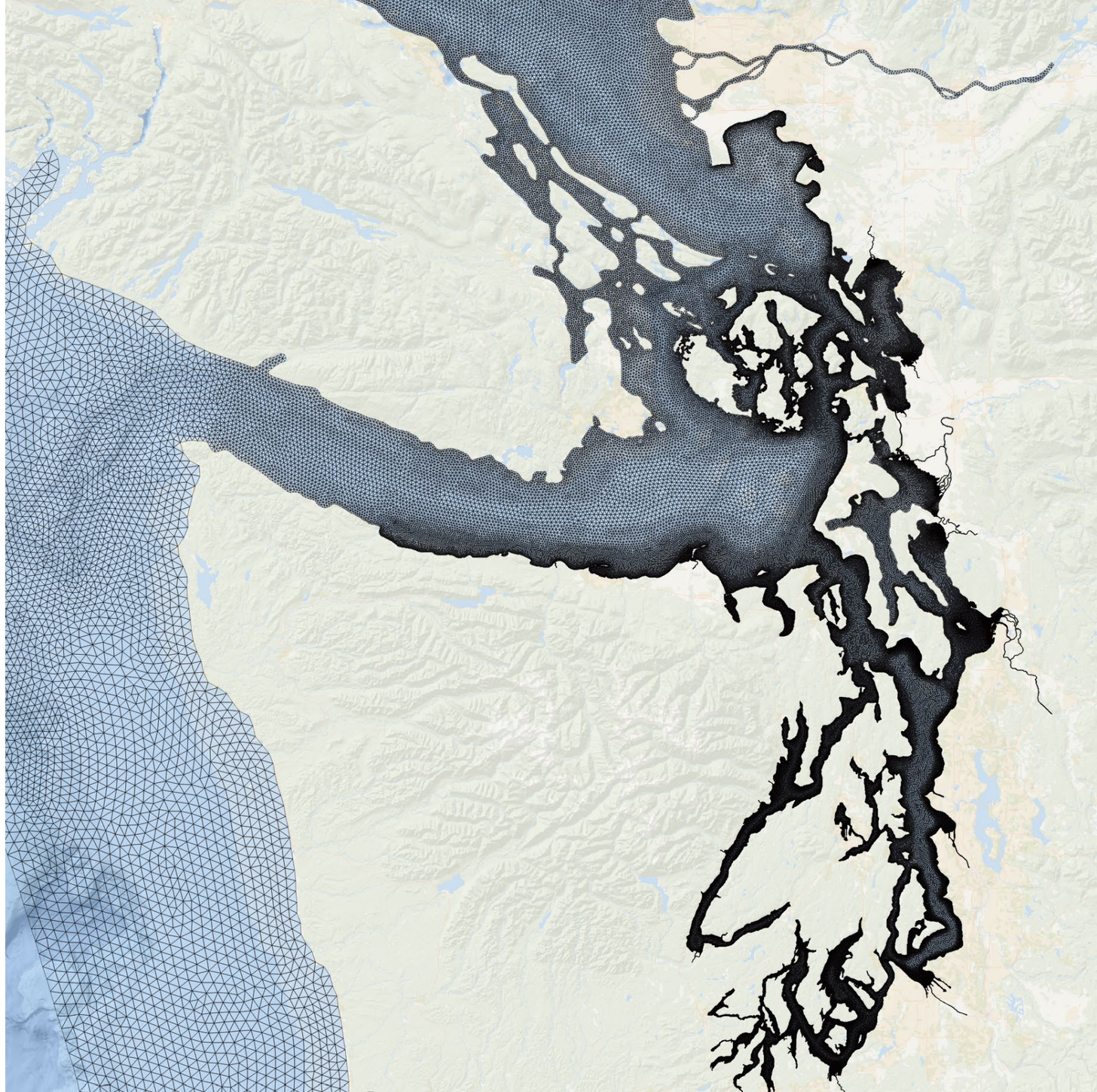
Nutrient pollution impact reduction assessment - *Hypothetical euphotic zone avoidance/bypass considerations*

TARANG KHANGAONKAR[1,2]
SU KYONG YUN[1]

[1]Pacific Northwest National Laboratory
[2]University of Washington, Tacoma

South Sound Science Symposium
Shelton, Washington
October 16, 2024



PNNL is operated by Battelle for the U.S. Department of Energy

What is nutrient pollution?

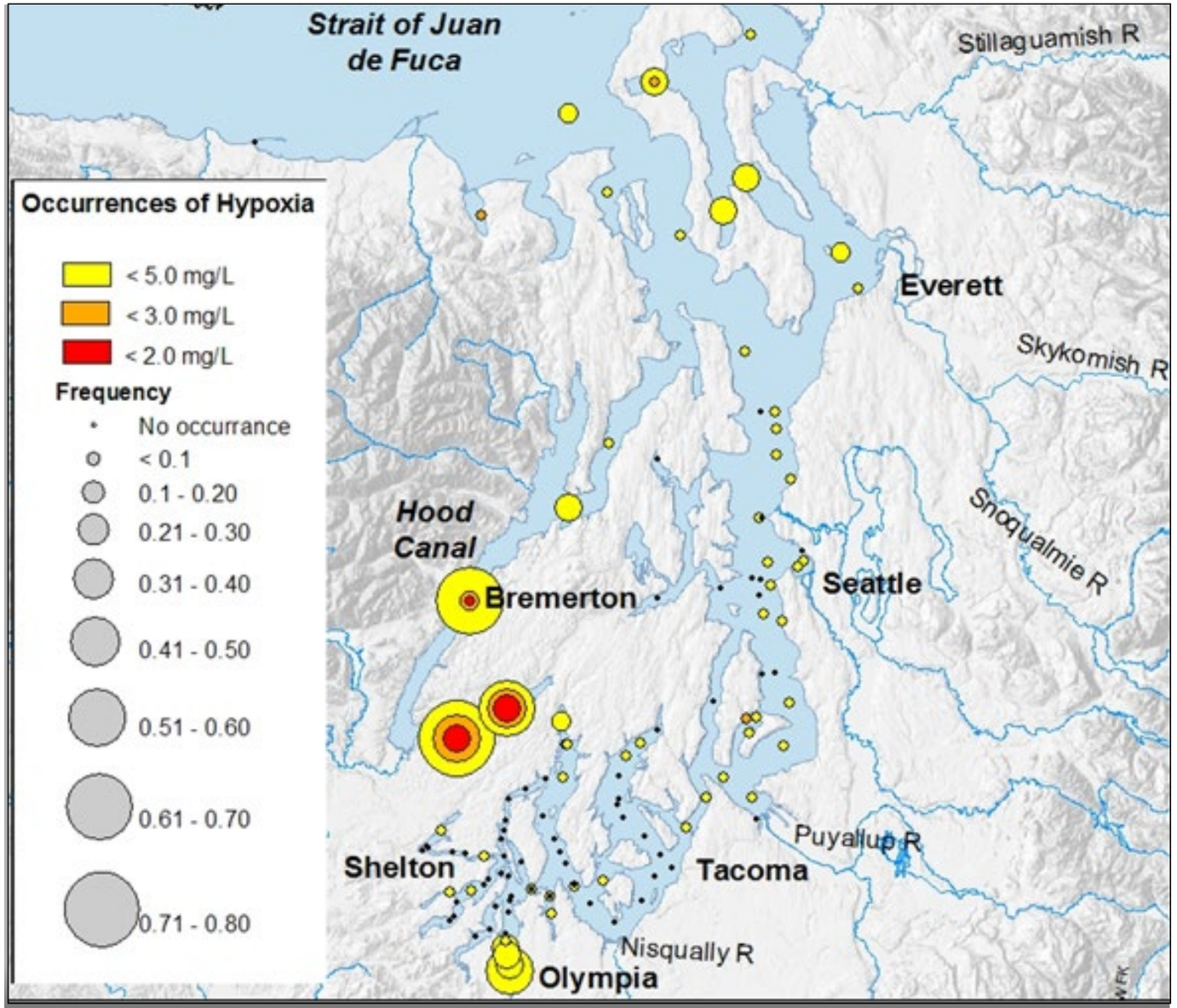
(Nutrient loads > natural)

↓

($DIN - NO_3 + NH_4$)

Impact?

- **Excessive primary production**
- **Eutrophic conditions**
- **Water quality impairment**
  - **Increase in exposure to hypoxic condition**
  - **Fish kills … etc.**

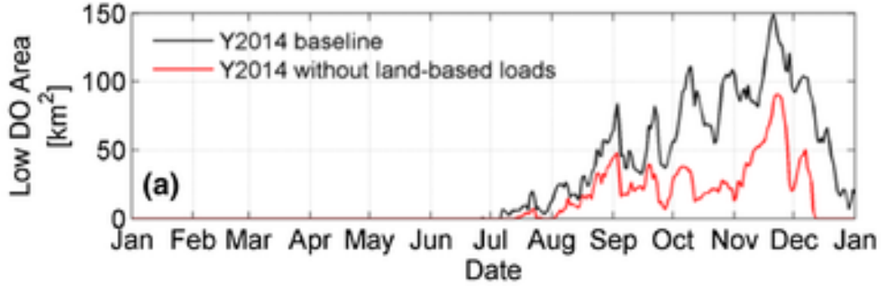


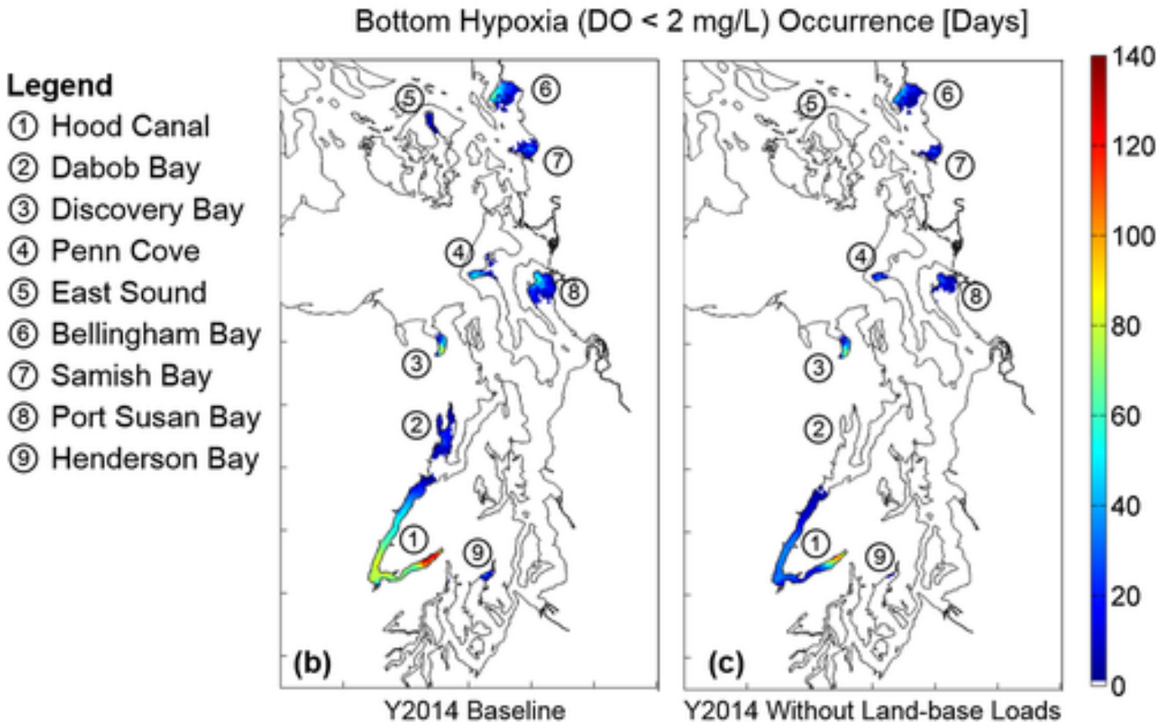
Source: Puget Sound Partnership 2009 State of the Sound

Need for regionwide management of nutrient pollution and hypoxia

- Development of a comprehensive predictive computational tool for the *Salish Sea* Ecosystem
  - Tidal hydrodynamics
  - Biogeochemistry
- Salish Sea Model (SSM)

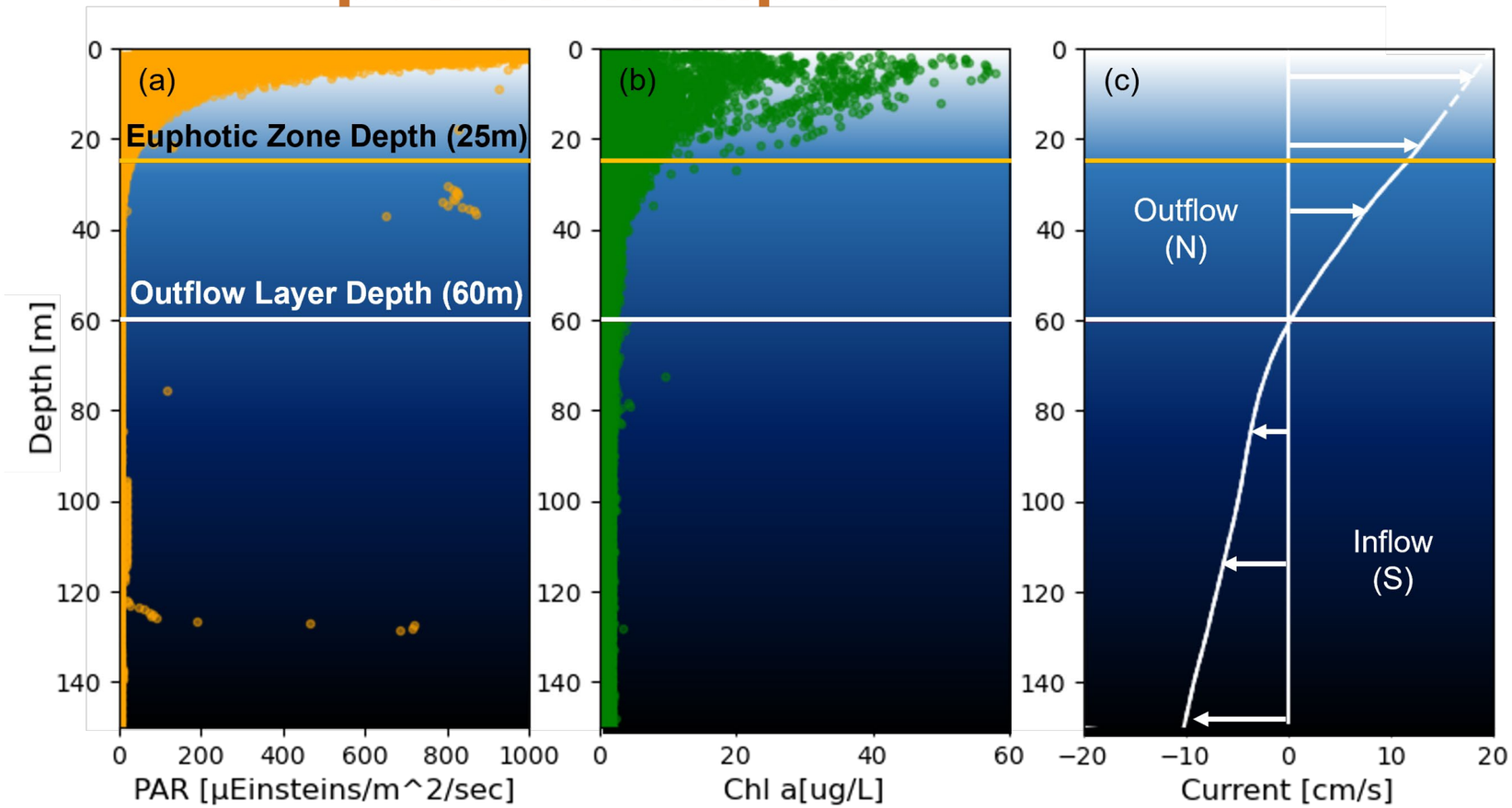
  (2010 – present)
  - U.S. EPA
  - Wa. Dept. Ecology





Khangaonkar T, A Nugraha, W Xu, W Long, L Bianucci, A Ahmed, T Mohamedali, and G Pelletier. 2018. Analysis of Hypoxia and Sensitivity to Nutrient Pollution in Salish Sea. *Journal of Geophysical Research – Oceans*, 123(7): 4735-4761. **doi: 10.1029/2017JC013650**

Potential opportunity to reduce the nutrient pollution impact



- PAR measurements from 7 stations in Puget Sound (2002 to 2003) by Washington State Department of Ecology (Ecology) and King County
- Chlorophyl data from Ecology's monthly marine monitoring program
- Tidally averaged current profile from ADCP data (NOAA-COOPs 2015)

Estuarine outflow depth > Euphotic zone depth

Passive export of anthropogenic nutrients out of Puget Sound

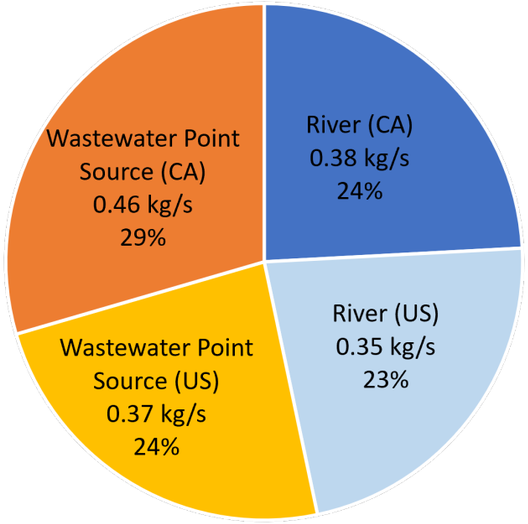
Reduction in total primary production

Characterization of nutrient loads to Puget Sound

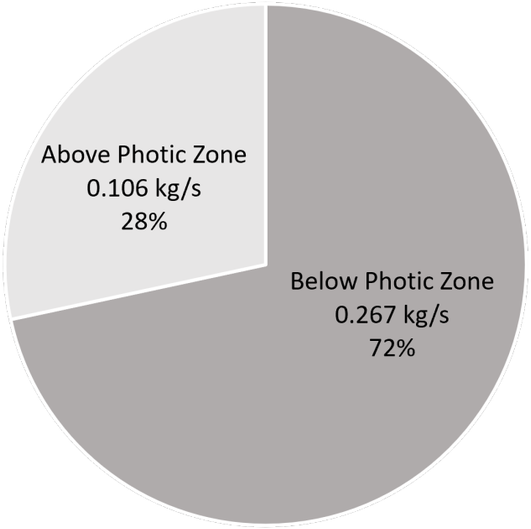
99 WWTP outfalls, 161 River inflows

Daily 48hr forecast of surface salinity produced by SSCOFS at SSMC

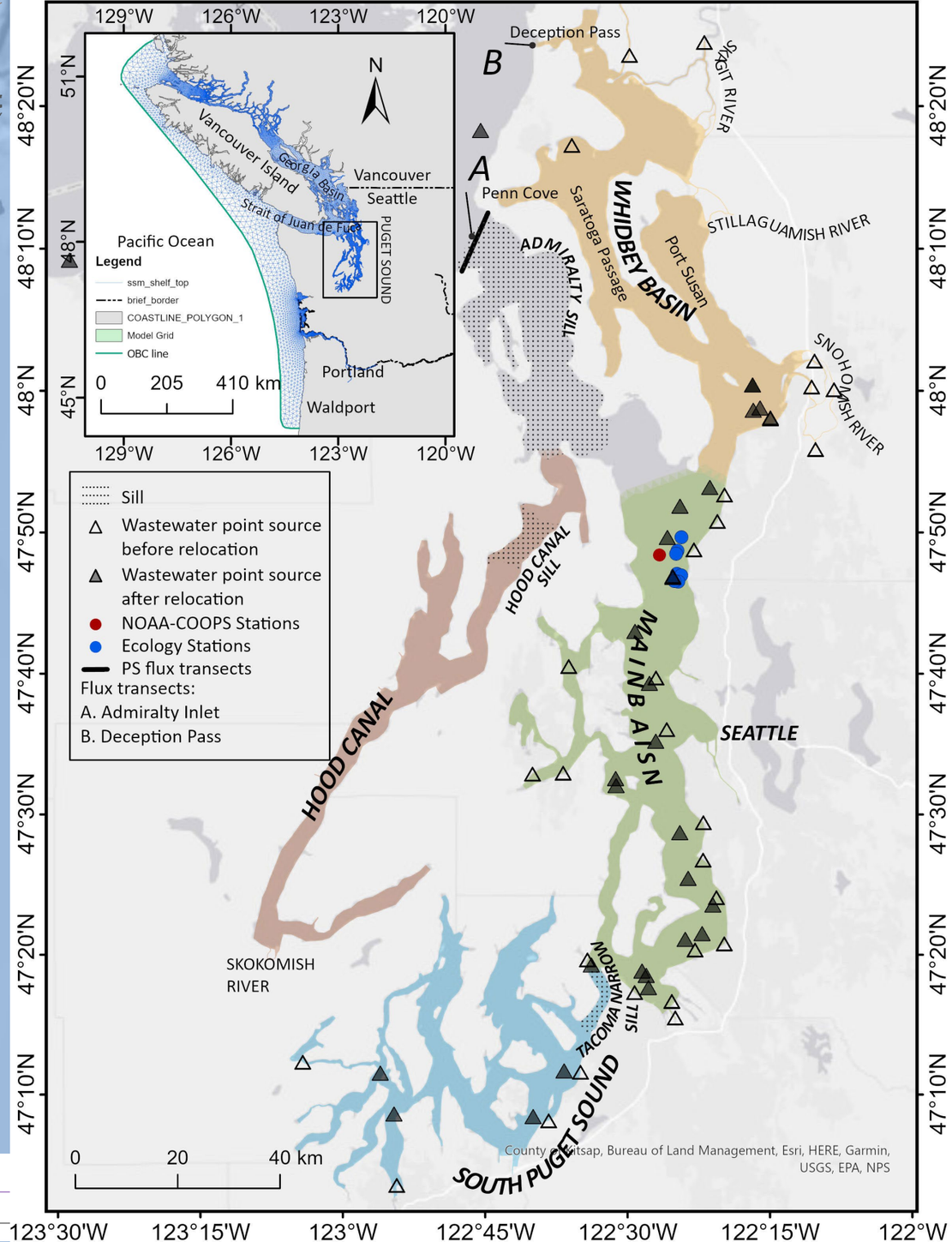
(a) Average DIN Loading [kg/s] of Salish Sea

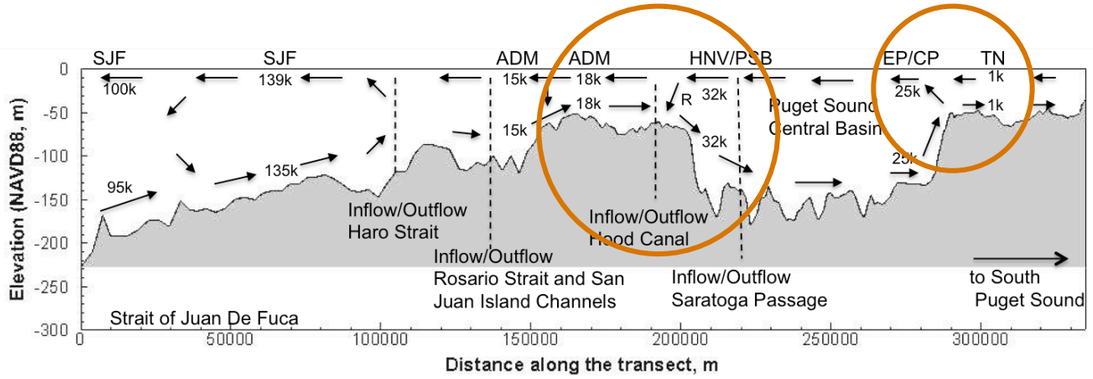


(b) Average DIN Loading [kg/s] of Point Source (US)

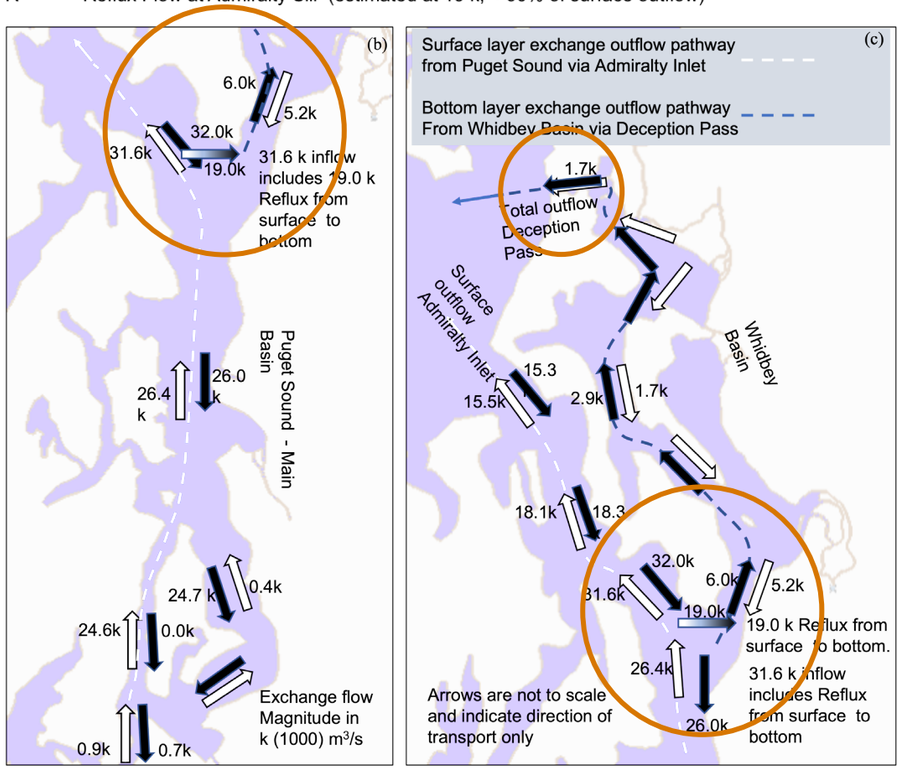


The loading value % are presented relative to the total average DIN loading (1.44kg/s) to the Salish Sea, including Canadian and U.S. regions





SJF = Strait of Juan De Fuca
ADM = Admiralty Inlet
HARO = Haro Strait
R = Reflux Flow at Admiralty Sill (estimated at 19 k, ≈ 60% of surface outflow)
HNV/PSB = Hansville, Puget Sound
EP/CP = East Passage / Colvos Passage
TN = Tacoma Narrows



Circulation cells in Puget Sound separated by sills (Khangaonkar et al., 2017. *Ocean Modeling)*

Sensitivity tests using SSM

(a) River based nutrient loads
(b) Wastewater based nutrient loads
(c) Outfall location

- Su Kyong Yun

Nutrient reduction scenarios and outfall relocation scenarios

Nutrient reduction scenarios

(2) Reference

Ant. River Loads = 0
Point Source Loads =0

(3) pnt_to_ref

Point Source Loads =0

(4) riv_to_ref

Ant. River Loads = 0

Outfall relocation scenarios

(5) pnt_to_bot

Point Source Loads = Bottom

(6) pnt_to_surf

Point Source Loads = Surface

(7) 99%_pnt_reloc

99% of point source loads=Bottom

Direct impact of nutrient reduction on DO improvement

Nutrient reduction scenarios

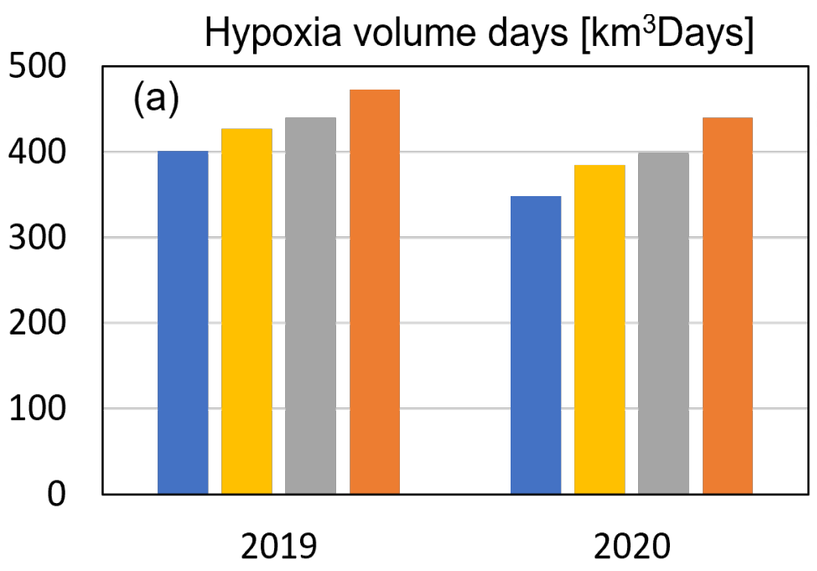
(2) Reference	(3) pnt_to_ref	(4) riv_to_ref
Ant. River Loads = 0 Point Source Loads =0	Point Source Loads =0	Ant. River Loads = 0

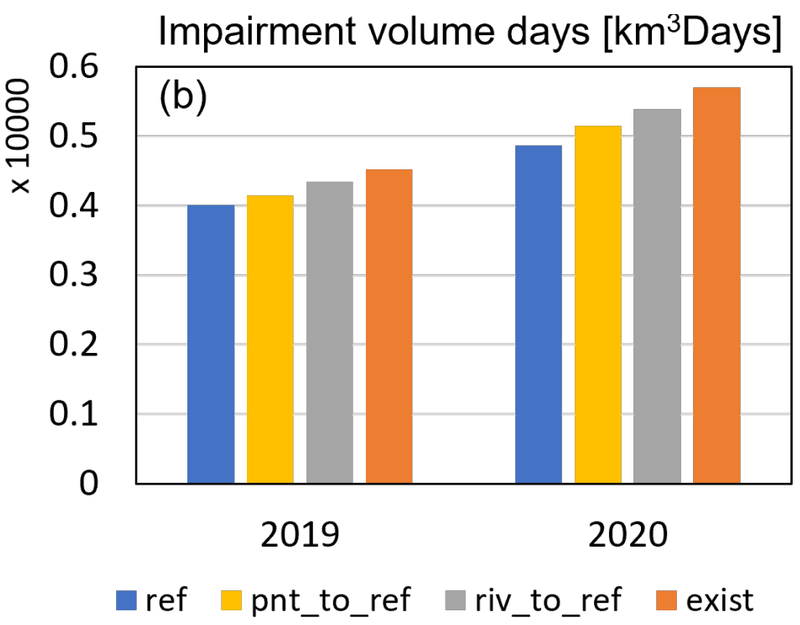
Hypoxia

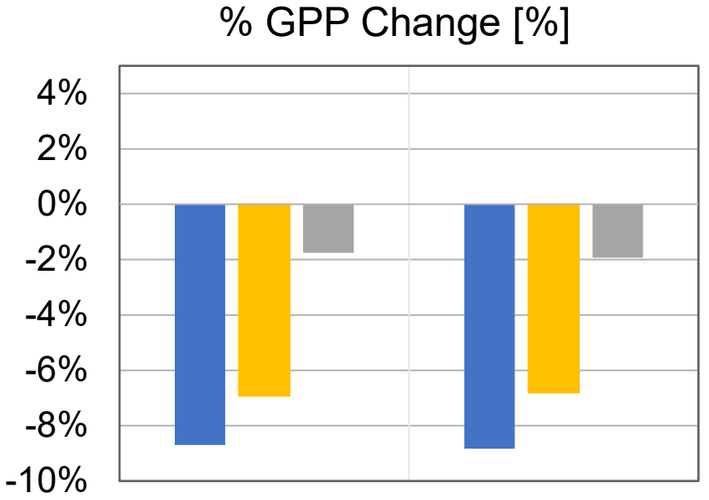
- Dissolved Oxygen < 2mg/L

Impairment

- Dissolved Oxygen < 5mg/L



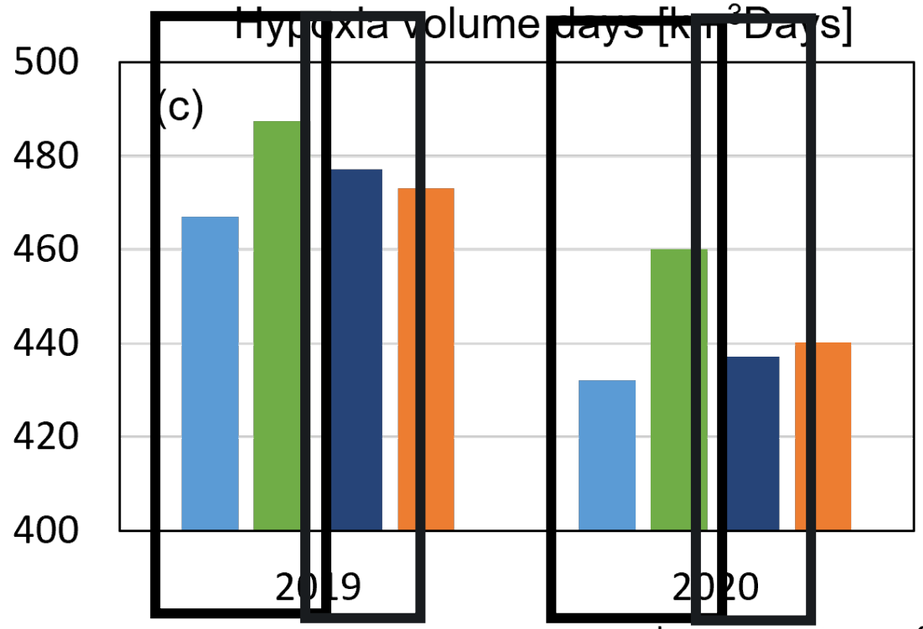


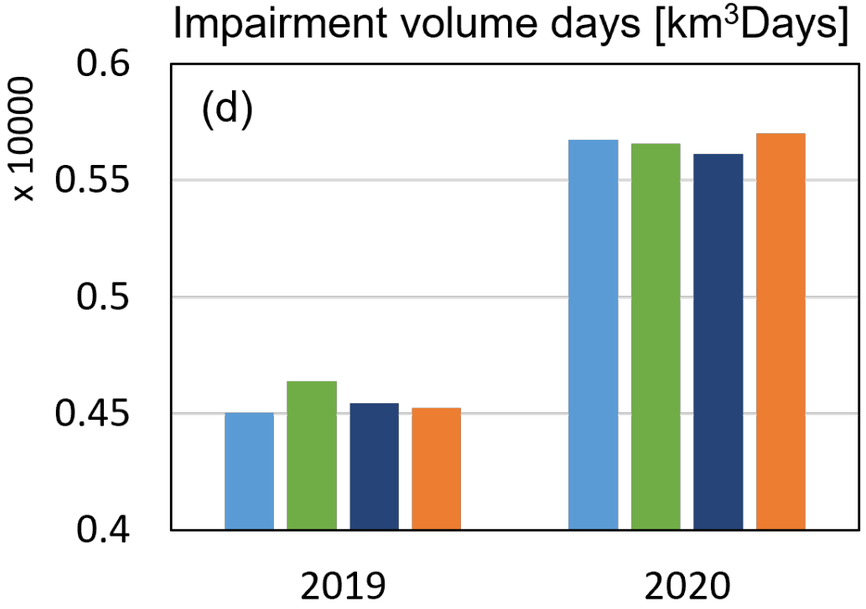


Varying Impacts of Outfall Relocation Scenarios on DO Improvement

Outfall relocation scenarios

(5) pnt_to_bot	(6) pnt_to_surf	(7) 99%_pnt_reloc
Point Source Loads = Bottom	Point Source Loads = Surface	99% of point source loads=Bottom





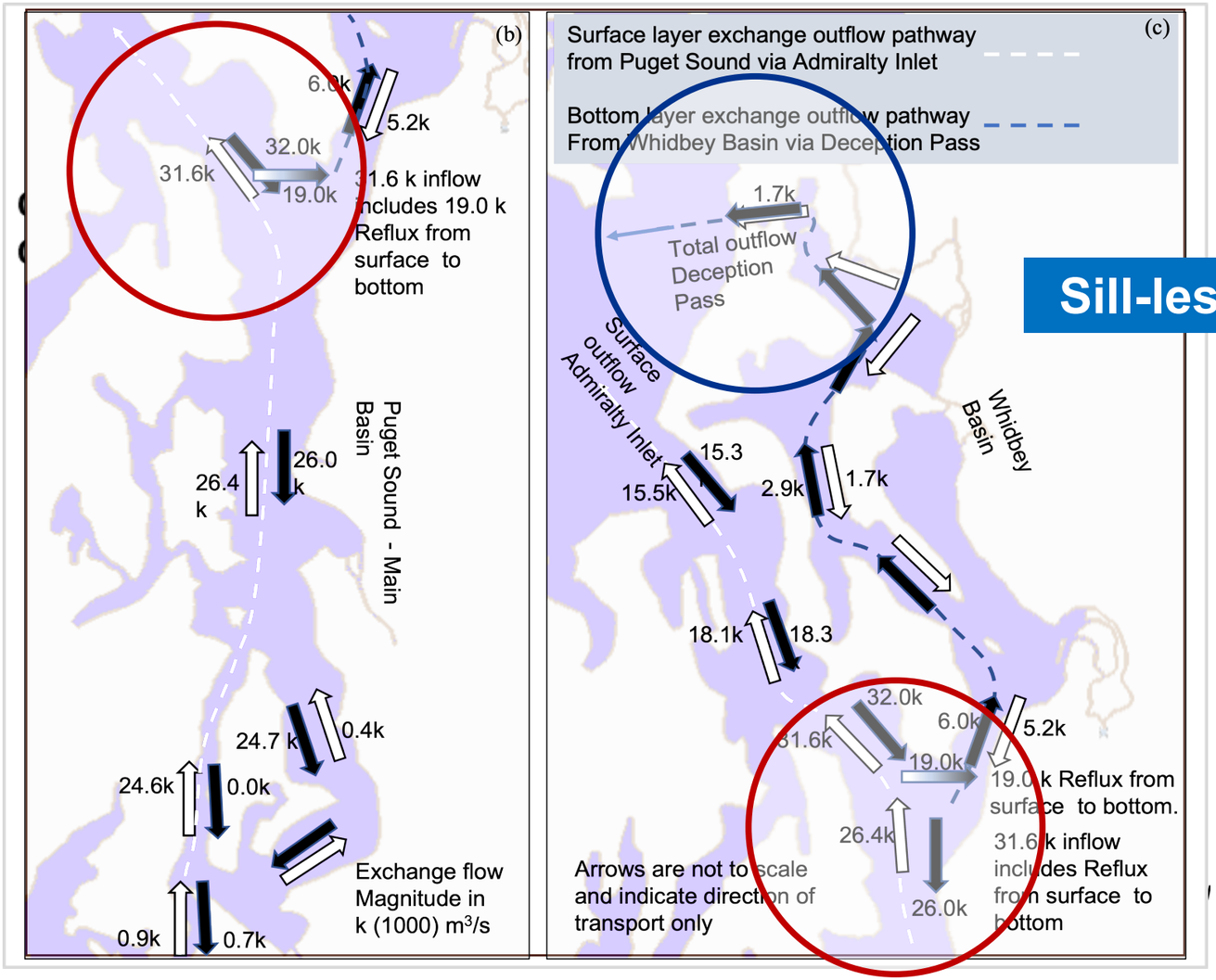
pnt_to_bot pnt_to_surf 99%_pnt_reloc exist

Estuarine outflow depth > Euphotic zone depth

Passive export of anthropogenic nutrients out of Puget Sound

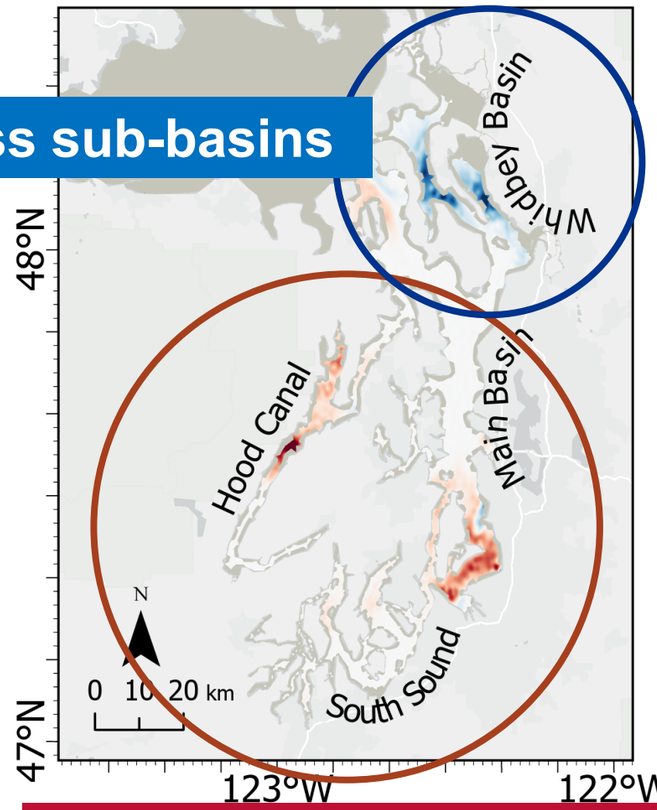
Reduction in total primary production

Regional Variability in Response to Outfall Relocation

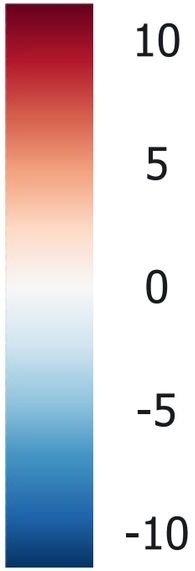


99%_pnt_reloc
(YR2019)

Sill-less sub-basins

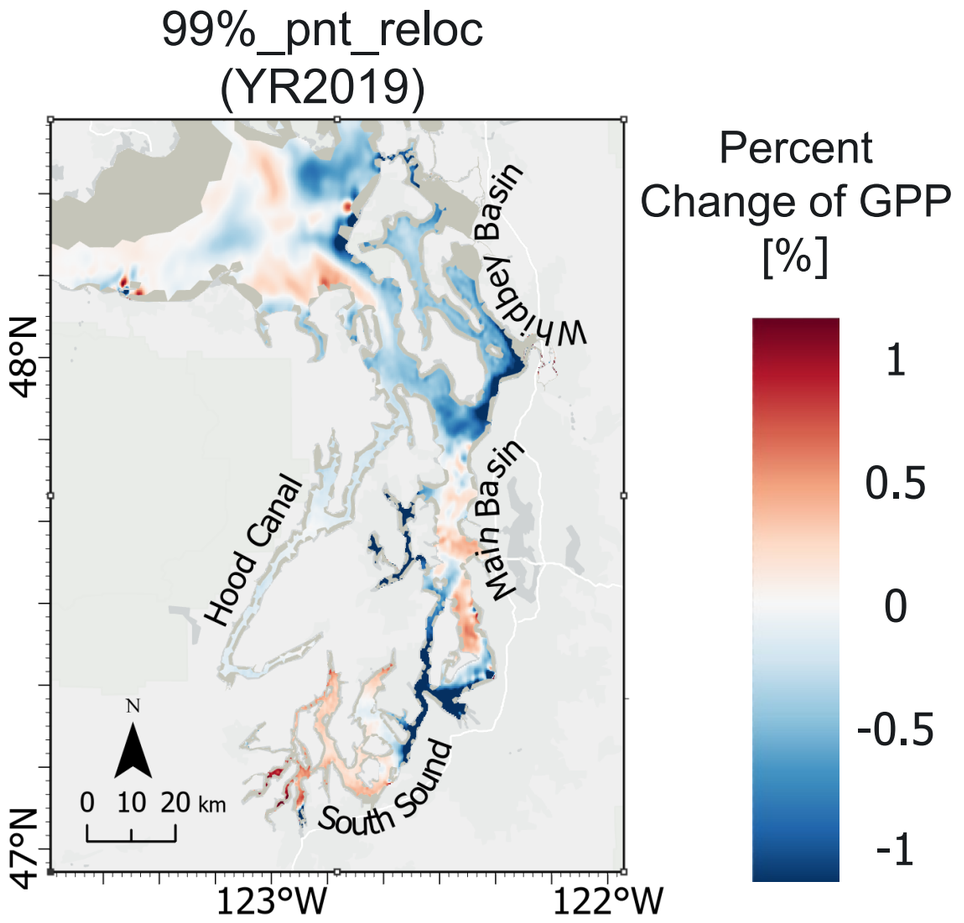


ΔImpairment Volume Days [km³Days]



Multiple sills and circulation cells

Regional Variability in Response to Outfall Relocation: Percent Change of GPP

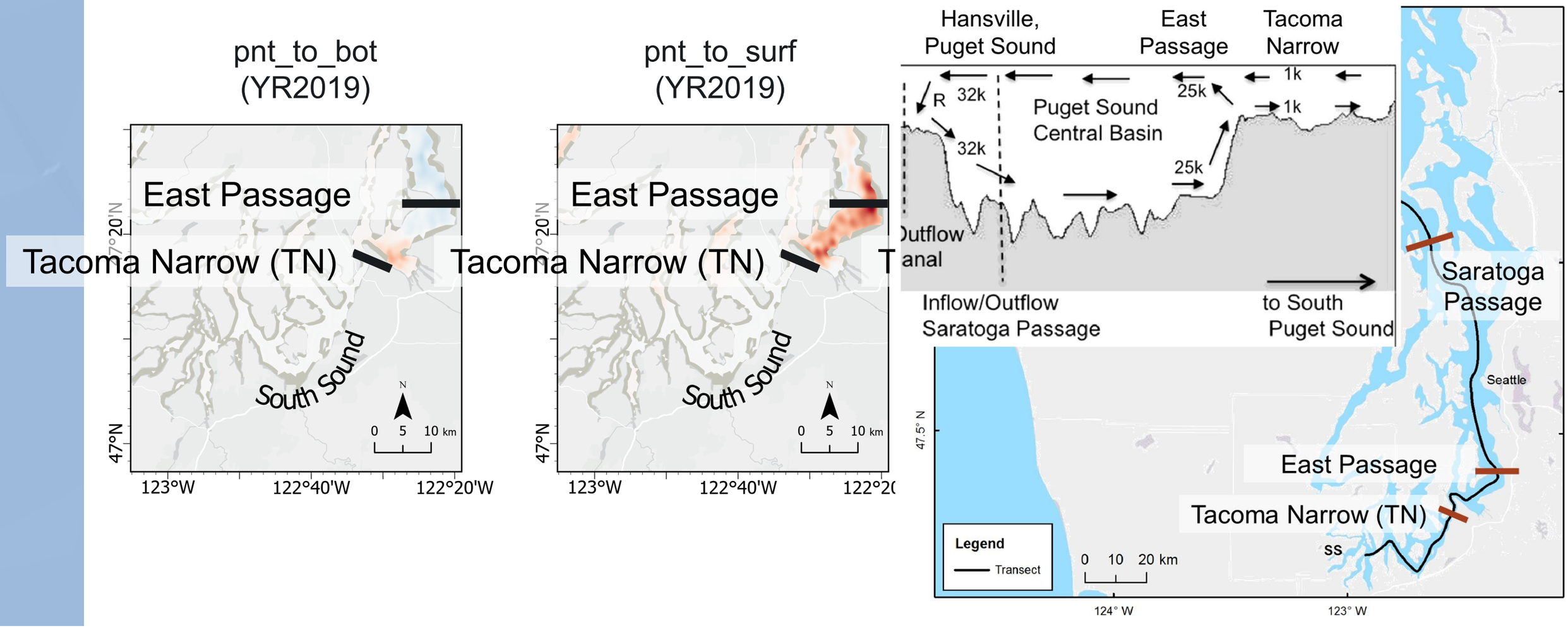


Estuarine outflow depth > Euphotic zone depth

Passive export of anthropogenic nutrients out of Puget Sound

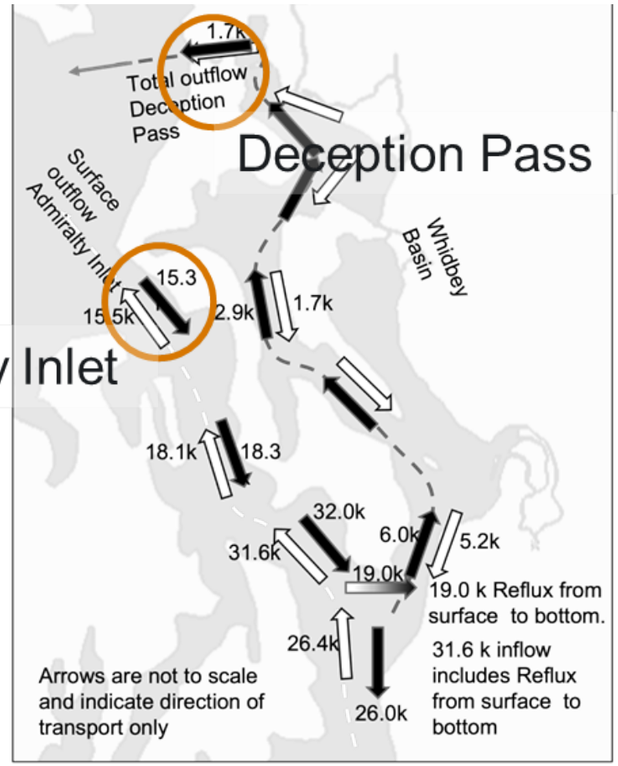
Partially successful in reducing primary production

Outfall Relocation Impacts on South Sound



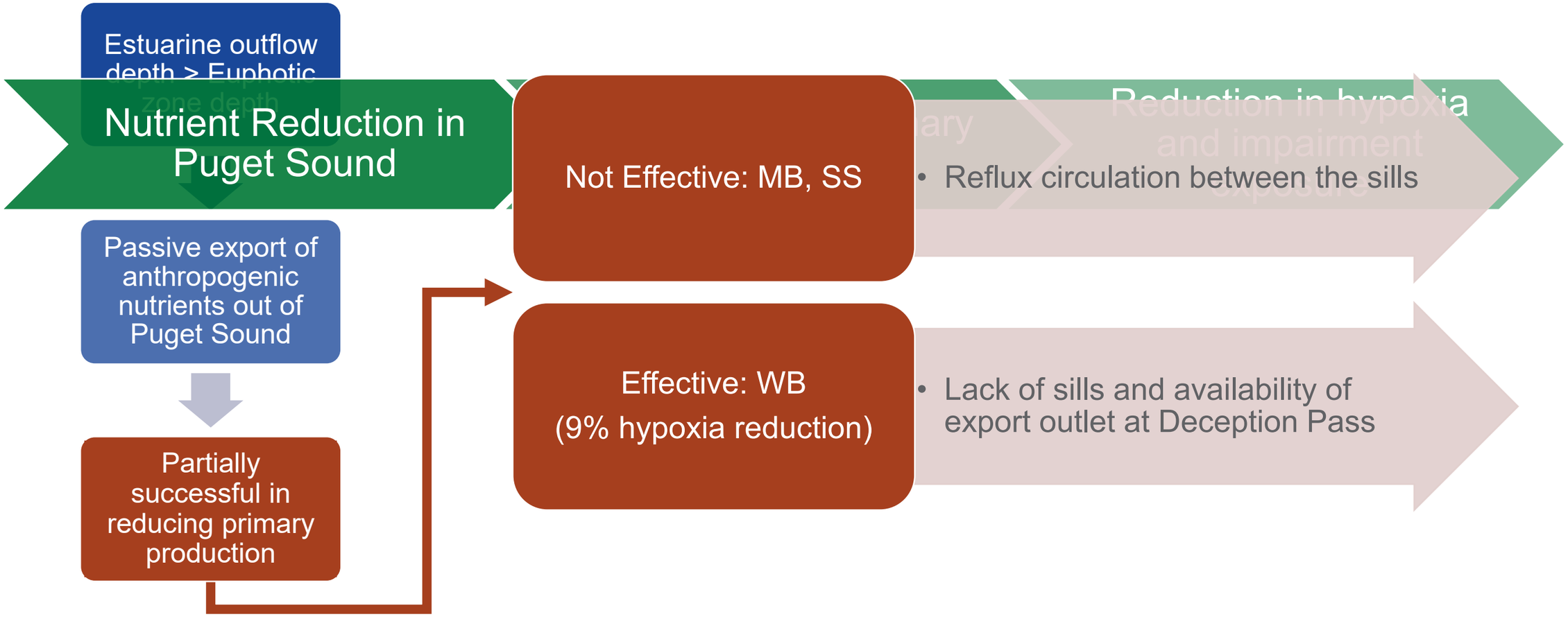
Effects of Outfall Relocation on Exchange Flow Dynamics in Puget Sound

Relocation of outfalls (99%_pnt_reloc) → 22% increase in freshwater released to the bottom → Affecting reducing the salinity gradients → Reducing the strength of exchange flow and circulation in Puget Sound → 4% reduction in the strength of exchange flow



Average YR19-20	Admiralty Inlet (outflow)			
Scenario	**Volume Flux, m3/s**	**Δ Volume Flux %**	**DIN Flux, kg/s**	**Δ DIN Flux %**
(1) Existing	15,757		-5.24	
(7) 99%_pnt_reloc	15,196	-4%	-5.04	-4%
Average YR19-20	Deception Pass (outflow)			
Scenario	**Volume Flux, m3/s**	**Δ Volume Flux %**	**DIN Flux, kg/s**	**Δ DIN Flux %**
(1) Existing	1,561.4		0.543	
(7) 99%_pnt_reloc	1,546.7	-0.9%	0.538	-0.9%

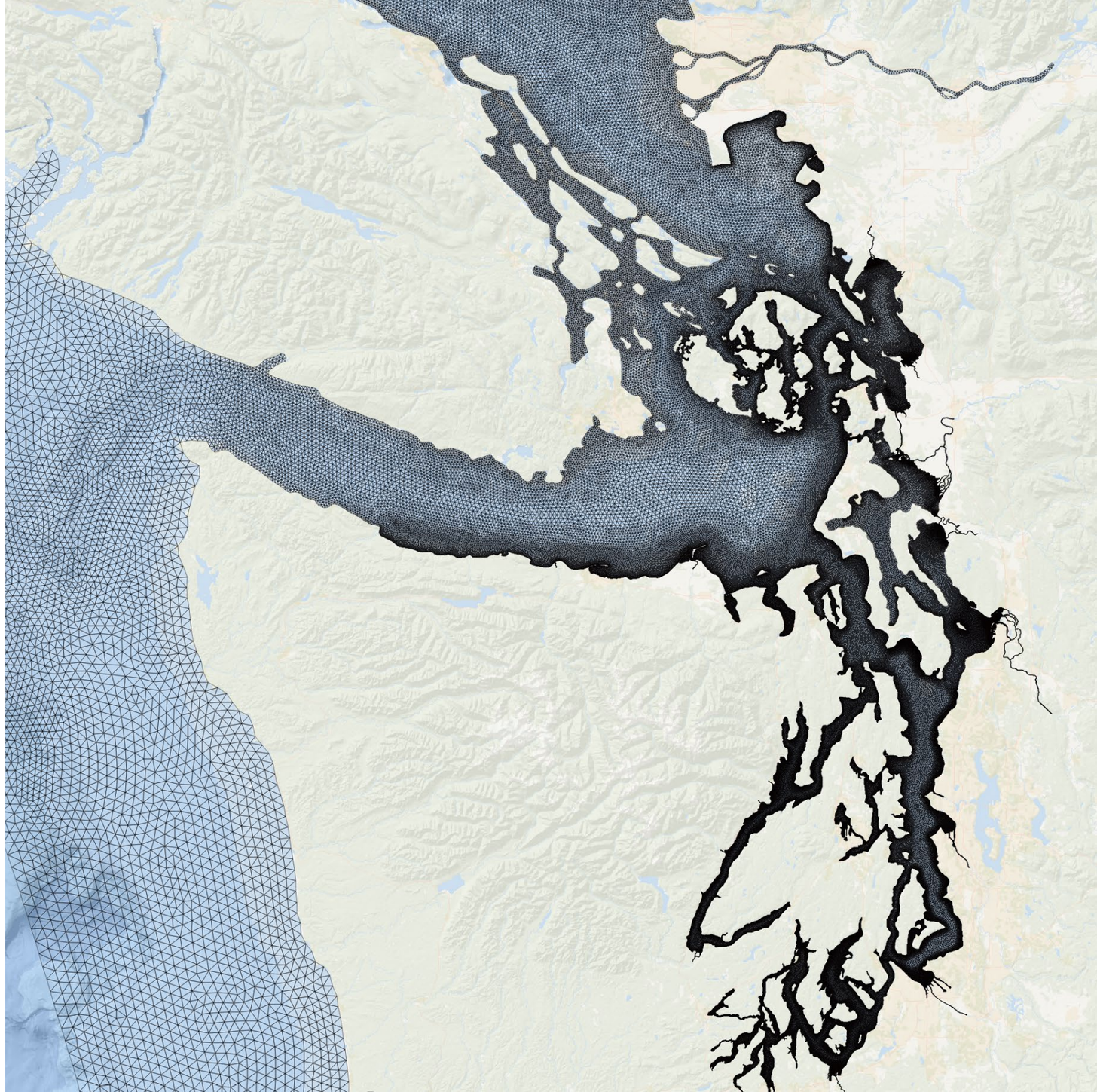
Conclusion


Estuarine outflow depth > Euphotic zone depth
Nutrient Reduction in Puget Sound
Passive export of anthropogenic nutrients out of Puget Sound
Partially successful in reducing primary production
Not Effective: MB, SS
Reflux circulation between the sills
Effective: WB
(9% hypoxia reduction)
Lack of sills and availability of export outlet at Deception Pass

Questions

Su KyongYun
sukyong.yun@pnl.gov

SSMC



U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

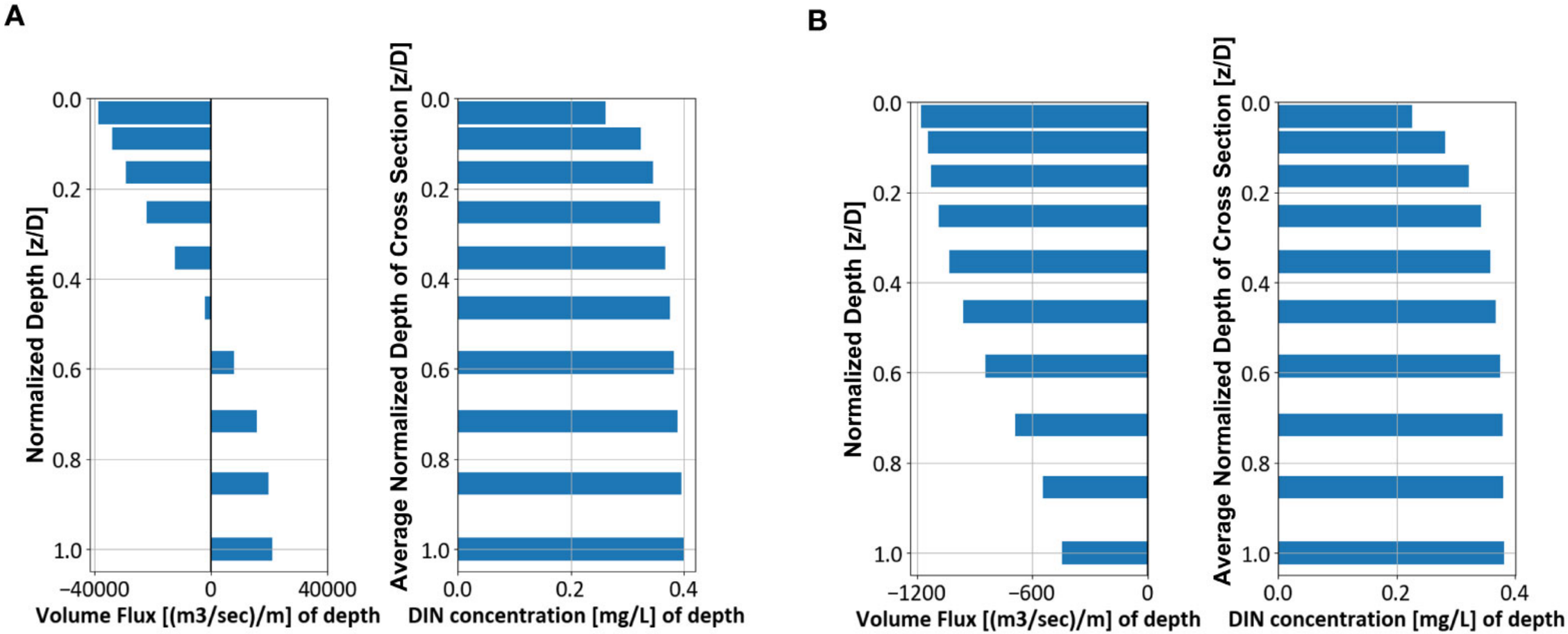
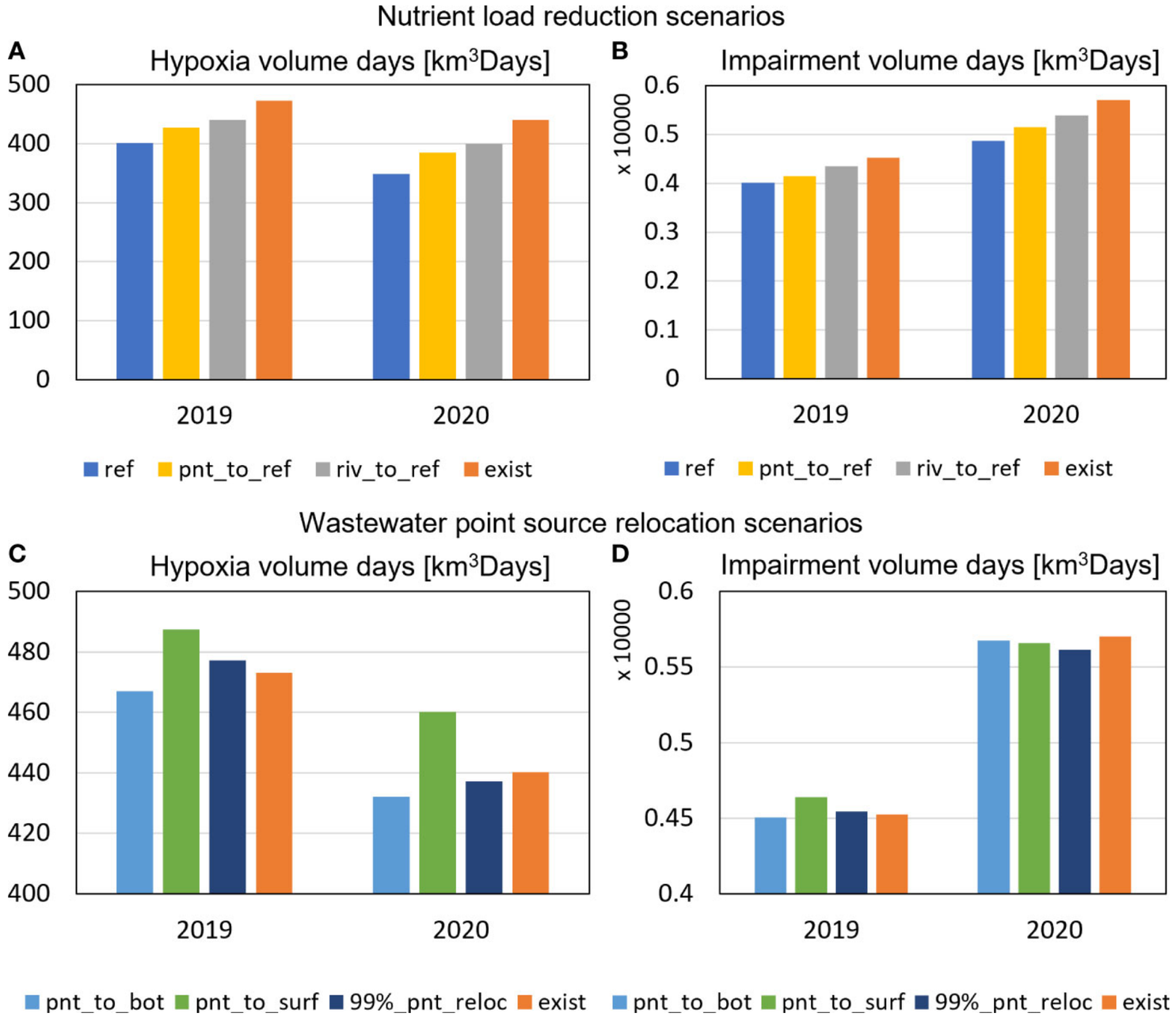


Figure 11 (A) Exchange flow (m^3/s) at the entrance to Puget Sound at the Admiralty Inlet north boundary, and DIN concentration (mg/L) profile, and **(B)** exchange flow (m^3/s) at the Deception Pass connection of Puget Sound to the Strait of Juan de Fuca and DIN concentration (mg/L) profile.

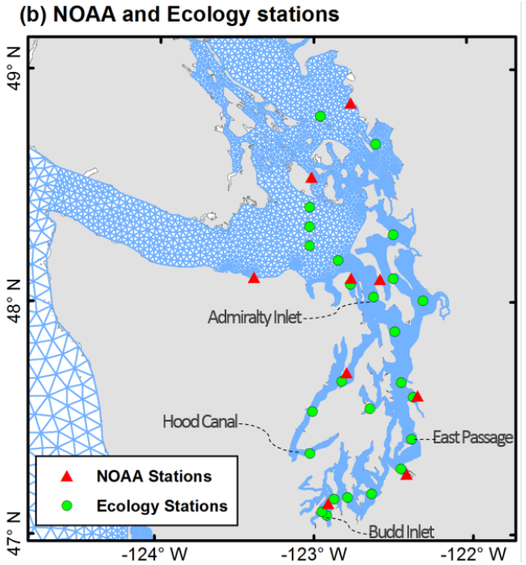


The Salish Sea model – hydrodynamics and biogeochemistry (2013-2020)

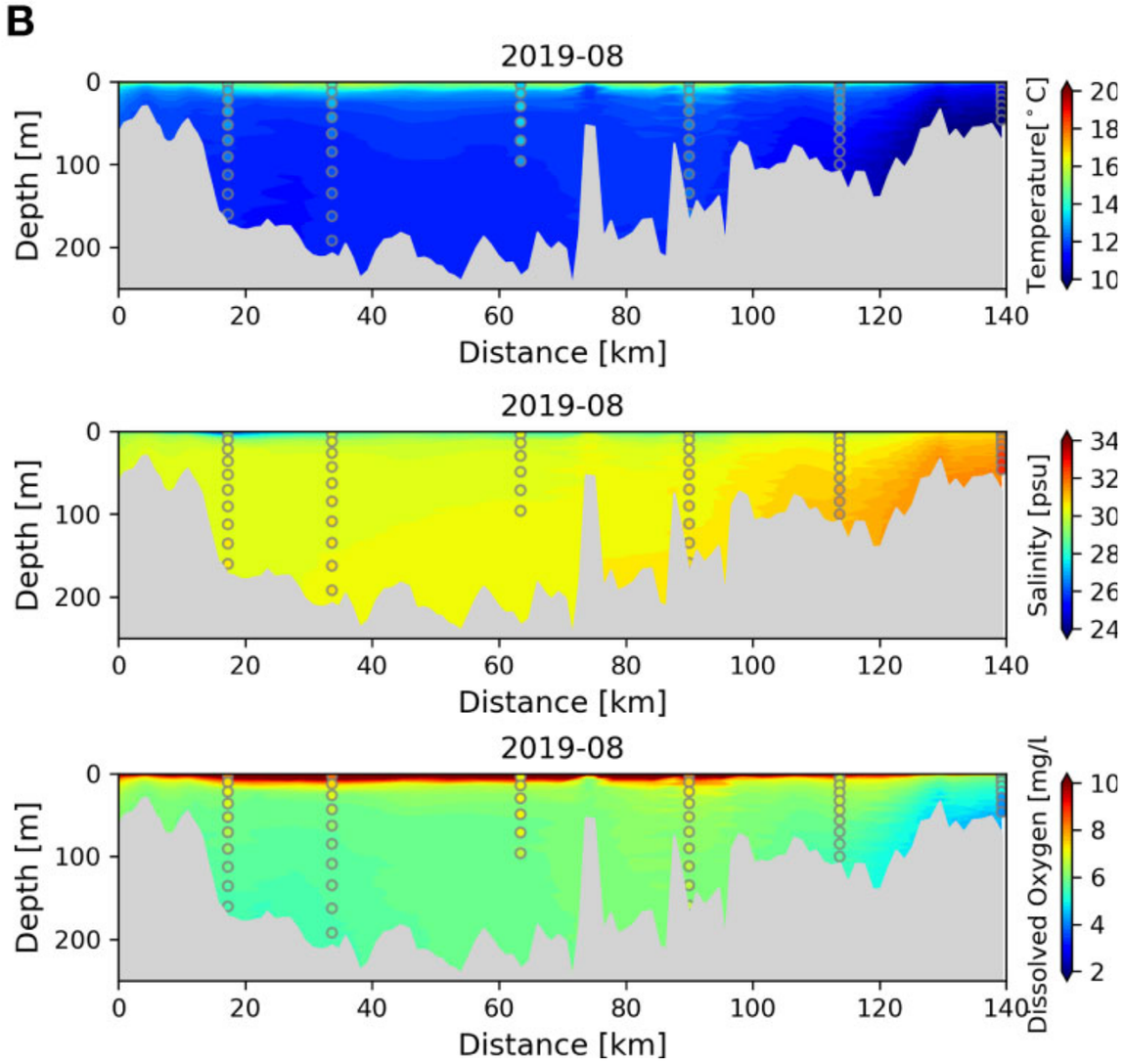
Salish Sea Model

FVCOM (HYD)

FVCOM-ICM (WQM)



	Average 2013-2020 RMSE
T [°C]	0.62
S [ppt]	0.95
DO [mg/L]	0.95
pH	0.26



Hypoxia

- Dissolved Oxygen < 2mg/L

Impairment

- Dissolved Oxygen < 5mg/L