Modeled and historical monitoring insights on water quality differences throughout Puget Sound

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Overview

The Science of Puget Sound Water Quality workshop series explores emerging science and insights to help protect water quality in Puget Sound.

At the *Modeled and historical monitoring insights on water quality differences throughout Puget Sound* workshop, two University of Washington PhD students shared their research:

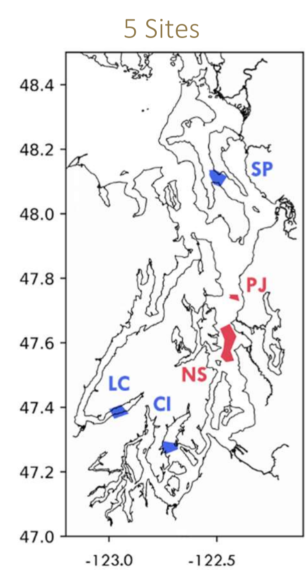
- Dakota Mascarenas wrangled 100 years of modern and historical monitoring data including datasets from the Department of Ecology, King County, NOAA NCEI, and earlier data collated collected by Dr. Eugene Collias (University of Washington). She synthesized this nuanced information to uncover trends in salinity, temperature, and dissolved oxygen, and explore how climate-driven warming influences these critical parameters.
- Aurora Leeson shared preliminary results from LiveOcean modeling, offering insights into the relative role of exchange flow and other processes causing low dissolved oxygen levels in hypoxia*-prone inlets like Penn Cove and Case Inlet.

Highlights

The slides and a recording are available on the *Science of Puget Sound Water Quality webpage*.

Dakota

To understand if dissolved oxygen is changing over time and why, Dakota identified 5 sites with sufficient data for century-scale trend analysis.

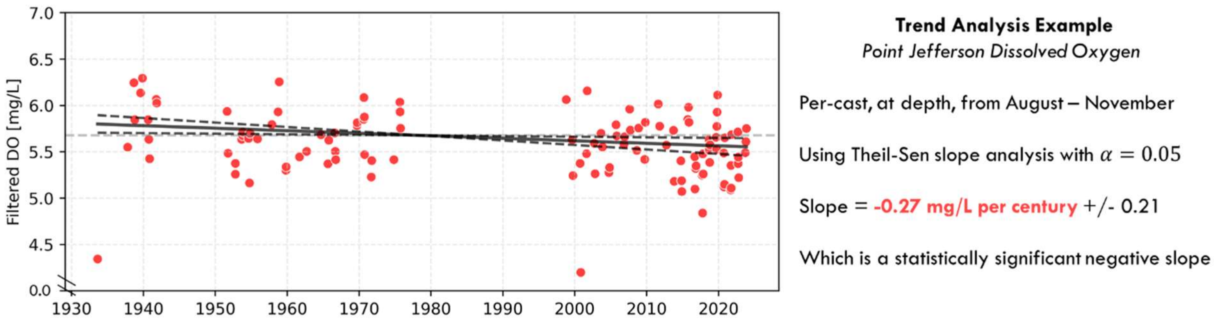


Point Jefferson, Near Seattle, Saratoga Passage, Carr Inlet, & Lynch Cove

Wrangling 100 Years of Data

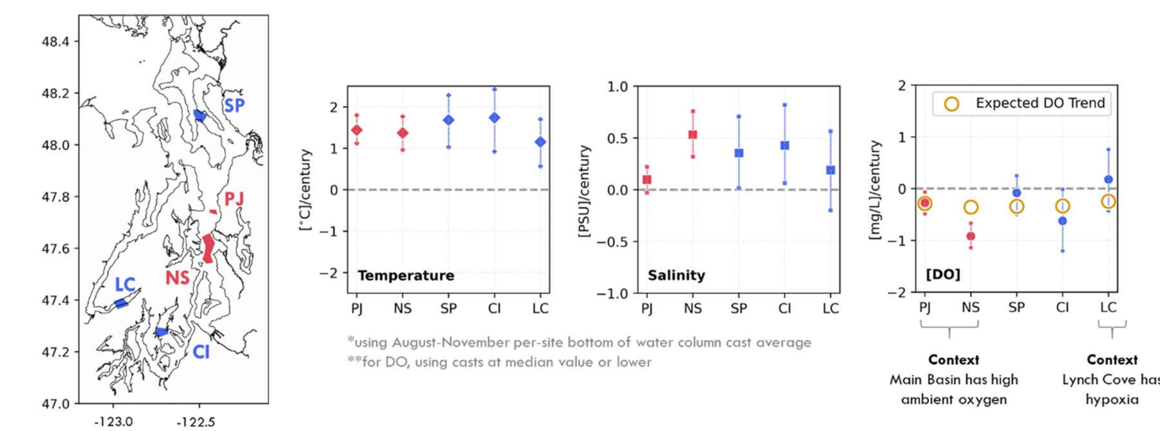
- Variation in dissolved oxygen occurs on shorter as well as decadal timescales. Therefore, the longest possible time series is desirable to understand secular, century-scale trends.
- Using 100 years of data from the Department of Ecology, King County, NOAA, and earlier data collated by Collias (University of Washington), identified and analyzed 5 sites that met the following criteria:
  - Consistent sampling location
  - Consistent sampling depth
  - At least 6 decades of data to control for decadal variation
- At the 5 sites, analyzed temperature, salinity, and dissolved oxygen trends when hypoxic risk is highest:
  - At the bottom of the water columns
  - During late summer/early fall (August – November)
- Used a Theil-Sen slope analysis to determine the trends at each location

*Hypoxia is defined as dissolved oxygen concentrations < 2 mg/L



Long-Term Trends During Fall at the Bottom of the Water Column

- Temperature at all 5 sites is **increasing at a rate of ~1-2 °C/century**
  - A qualitative review of the combination of local atmospheric and offshore warming indicates that these factors may be driving these warming trends in Puget Sound
- Salinity is generally **increasing at a rate of up to 0.5 PSU/century** at all 5 sites
  - Based on Puget Sound residence times, salinity increases during fall may be due to less river flow during spring
    - For example, using the Skagit River to represent a typical Puget Sound hydrograph, spring flow is reduced by approximately 25% over the century. Given that residence times are often several months, this shift in flow timing *may* manifest in increased bottom salinity during fall in the Main Basin
- Dissolved oxygen trends vary per site:
  - **No significant trend** in Saratoga Passage and Lynch Cove
  - **Decreasing at less than 1 mg/L/century** at the Main Basin sites: Point Jefferson and Near Seattle
  - **Decreasing by ~0.6 mg/L/century** in Carr Inlet
    - Warmer temperatures and higher salinity reduce the expected dissolved oxygen saturation. At sites where dissolved oxygen is decreasing (i.e., Carr Inlet, Point Jefferson, and Near Seattle), **warming and associated DO saturation reduction explains 50-100% of the observed loss of dissolved oxygen**



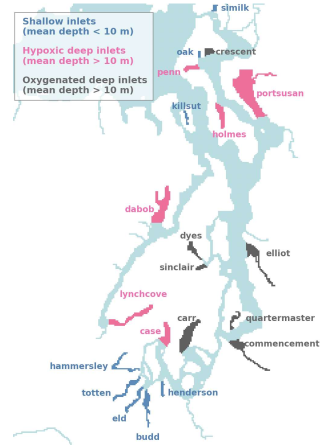
Aurora

Used the LiveOcean model to explore the dominant factors influencing hypoxia in Puget Sound, particularly in terminal inlets.

Note: The LiveOcean model currently underpredicts dissolved oxygen with a bias of -1 mg/L. There are ongoing efforts to improve the biogeochemistry module, which is expected to reduce this bias. The bias is currently the same in all terminal inlets.

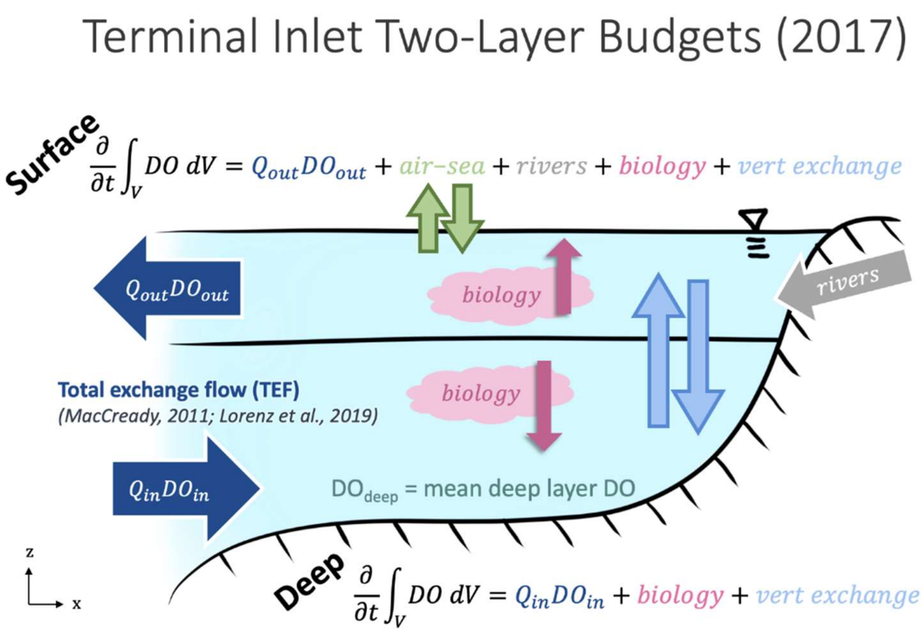
Budget for 13 Terminal Inlets

13 Terminal Inlets



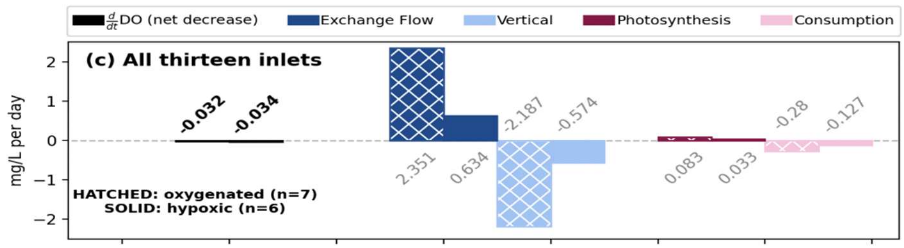
Penn Cove, Crescent Bay, Port Susan, Holmes Harbor, Dabob Bay, Lynch Cove, Case Inlet, Carr Inlet, Commencement Bay, Quartermaster Harbor, Elliott Bay, Dyes Inlet, Sinclair Inlet

- Used LiveOcean to develop a two-layer budget for 13 terminal inlets in Puget Sound and explore the dominant factors influencing hypoxia in Puget Sound. The analysis focused on:
  - Inlets deeper than 10 m because shallow inlets tend to have different processes that influence dissolved oxygen levels. Deeper inlets are generally not as well flushed, have less bottom water in the photic zone, and are less well-mixed than shallow inlets
  - Tidally-averaged daily values because they are representative of the daily state of the system and useful for understanding underlying processes
  - The deeper layer of the inlet during the period between mid-June through mid-August, when DO is decreasing in all inlets



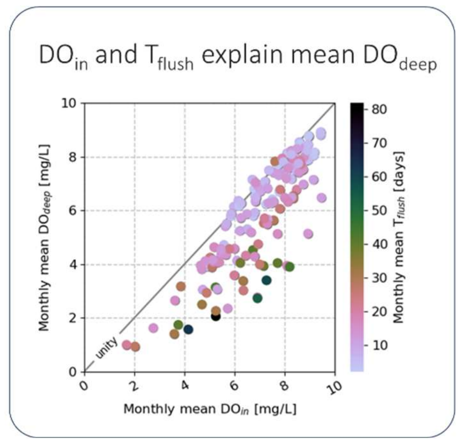
Dominant Factors Influencing Hypoxia in 13 Terminal Inlets

- Both hypoxic inlets and oxygenated inlets have a similar net decrease of oxygen between mid-June through to mid-August (-0.033 mg/L/day mean), which suggests that differences in hypoxia are **not** driven by differences in the rate that oxygen is being depleted



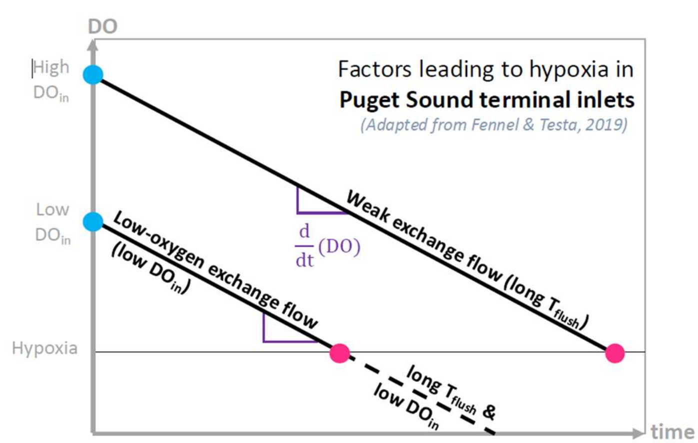
Mean budget rate terms for all 13 hypoxic and all oxygenated inlets. The rates for the single inlets that were averaged correspond to a time average between mid-June through mid-August.

- Deep layer dissolved oxygen in terminal inlets is strongly influenced by both what flows into inlets, and how long it takes to flush inlet
    - There's a strong correlation between the initial dissolved oxygen (i.e., from low-dissolved oxygen exchange flow inflow) and the monthly mean dissolved oxygen concentration of the deep layer of the inlet. For many of the oxygenated inlets, these are directly equal
    - Inlets where the deep dissolved oxygen is lower than the initial dissolved oxygen concentration tend to have longer flushing times which allow more time for biological processes to consume oxygen in the inlet before that water is flushed out
    - The seasonal cycle in the flushing time and exchange flow strength also aligns with the seasonal cycle of dissolved oxygen levels, with lowest dissolved oxygen during the late summer/early fall



- These preliminary results inform a conceptual framework for hypoxia in deeper terminal inlets of Puget Sound adapted from Fennel and Testa (2019), where: exchange flows drive both the initial low-dissolved oxygen at depth and the flushing time of the inlet (corresponding to weak exchange flow), which both contribute to hypoxic conditions

Conceptual Framework



Future Research for the Region to Consider

Aurora and Dakota highlighted some open questions to guide future research in the region. The lively discussion also generated recommendations for other researchers to expand on their findings. Please feel free to reach out to Dakota (dakotamm@uw.edu), Aurora (auroral@uw.edu), or Puget Sound Institute (marlars@uw.edu & mazzilli@uw.edu) with additional ideas or opportunities to collaborate:

- Dakota's future work: Understand specific mechanisms for hypoxia development in specific shallow, terminal inlets (e.g., Penn Cove and Lynch Cove) using observational data and high-resolution modeling
- Aurora's future work: Investigate the contribution of land-based loads to hypoxia relative to the effects of other underlying processes (e.g. exchange flow)
- Model how climate change may shift the relative impact of the underlying processes (e.g., exchange flow)
- Consider what's causing the other 50% reduction in dissolved oxygen levels at Point Jefferson, Near Seattle, and Carr Inlet
- Investigate salinity change impacts on exchange flow, local stratification, and dissolved oxygen
- Further research what controls the strength of the exchange flow in each of the terminal inlets and how this may influence management actions. For example, managing freshwater flows may be more relevant in terminal inlets that are controlled by classical gravitational circulation rather than tidal pumping
- Explore the historical influence of dams and other human-driven changes to the hydrographs. While there's not enough direct monitoring data that predates these hydrograph changes, there may be some other ways to investigate this, including sediment cores
- Further validate and complement the long-term trends in dissolved oxygen, salinity, and temperature trends with insights from sediment core profiles
- Measured and modeled long-term trend analysis of ocean and catchment biochemical changes, for comparison to the current long-term trends results in dissolved oxygen, salinity, and temperature changes. For example, one suggestion was to analyze (likely with modeling) how the slowing thermohaline circulation trends offshore may impact dissolved oxygen in Puget Sound
- Given that there's lower river flow prior to the drop in oxygen, consider using the Knudson relations to estimate how much a change in bottom water residence time potentially influences the decrease in dissolved oxygen levels in Point Jefferson, Near Seattle, and Carr Inlet
- Quantify the change in reflux and how this impacts dissolved oxygen levels, particularly since refluxing adds dissolved oxygen to the deeper incoming water
- Using bathymetric data, account for the influence of inlet shape and geometry (including geometry seaward of the entrance) on the dissolved oxygen budget for terminal inlets, in particular the tidal pumping and exchange flow parameters