Tools to Evaluate Water Quality Summary

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Overview

On September 29, 2022 the University of Washington Puget Sound Institute hosted a workshop on *Tools to Evaluate Water Quality*. The discussion highlighted analyses from long-term monitoring, isotopic studies, and modeling that help us better understand water quality and potential eutrophication impacts, particularly in embayments. We also highlighted that the Salish Sea Model already calculates additional parameters beyond dissolved oxygen for each cell and layer, daily. So please do not hesitate to reach out if you would like access to or analyses of these existing parameters (Stefano Mazzilli mazzilli@uw.edu and Marielle Larson marlars@uw.edu), or on related topics from any of the workshops. The discussion explored the driving scientific question:

> *How do we evaluate water quality with the tools that we have relative to the needs of key species, food webs, and habitats?*

Dr. Joel Baker with the University of Washington Puget Sound Institute framed the discussion:

- It is important to consider multiple stressors and the range of possible impacts nutrients may have on the Salish Sea beyond low dissolved oxygen
- Nutrient impacts, particularly low dissolved oxygen, are often seasonal and primarily a challenge in embayments so it is beneficial to focus modeling, monitoring, and solutions to understand local impacts on biota in these locations

Stephanie Jaeger (now with the City of San Diego) shared highlights from and opportunities with long-term monitoring in the Salish Sea from her prior work in the region, including:

- Analyzing the historical Collias data shows a monthly mean temperature increase of 0.5 – 1 °C in deep waters, from the available data that has been analyzed no clear change in salinity or dissolved oxygen, and similar nutrient levels
- Variability is the backdrop to assessing change, so consistent long-term monitoring is key
- Stephanie provided some lessons learned on analysis of the Collias data set, considering inter-annual and longer-term variability. This includes methods to compare the same seasons and months across years (e.g. use of the Mann-Kendall test), integration of similar depth data, etc.
- In understanding a complex ecosystem such as Puget Sound it is important to consider multiple biological indicators, as well as combined water quality impacts other than eutrophication, such as increasing temperatures and other climate change impacts

Dr. Gordon Holtgrieve with the University of Washington shared how N isotopic studies can help us understand if nutrient dynamics have changed over time and where nitrogen is coming from.

- $\boldsymbol{\delta}^{15}$N and $\boldsymbol{\delta}^{13}$C can be tracked in essential amino acids that are relatively conserved as they are transferred through the food web to top predators. Combined analysis from historical samples allows us to more accurately analyze and track the a) isotopic signature of changes in primary production, and b) biological impact from changes in nutrients source (e.g., wastewater treatment plants vs. landcover change)
- In analyzing the historic record provided by isotopic analysis of seal skulls over almost 80 years (Feddern et al., 2020) and fish (Welicky et al., in review), we do not see a trend that is consistent

with dramatic changes in nutrients from land base sources, while some correlation is observed for climate-related indices
- In the Deschutes and the Nooksack Rivers rations of $\delta^{15}N$ suggest there is an anthropogenic source of nitrogen. Conversely in most other Puget Sound rivers though, the $\delta^{15}N$ rations indicate a dominance and increase in non-direct human sources associated with the soil. One potential theory that requires further investigation is that there has been a historic increase in N release due to the forestry practices and current succession of N fixing alders

Materials

Here are direct links to the materials for the *Tools to Evaluate Water Quality* workshop:
- Slides
- Full video
- Highlight video
- Chat
- Jamboard

A recap for each workshop in The Science of Puget Sound Water Quality workshop series is available on our website. The recaps include a summary, highlight video, full recording, chat, and slides. The videos from the workshop series are also available directly via this YouTube playlist.

Highlights

Note: for full presentation slides and resulting discussion please see the links above. Below are some highlights from the presentations, followed by questions and key discussion points.

Intro

Joel Baker, University of Washington Puget Sound Institute

- It is important to consider multiple stressors and the range of possible impacts nutrients may have on the Salish Sea beyond the acute and sub-lethal impacts of low dissolved oxygen. This includes:
  - Compounding ocean acidification impacts
  - Changes in seagrass community structure and abundance
  - Increases in harmful algal blooms
  - Changes in benthic community structure
  - Changes in pelagic species and food webs
  - Change in primary production and phytoplankton species and abundance
- Nutrient impacts are often more pronounced and low dissolved oxygen is primarily a challenge in embayments so we need to focus modeling, monitoring, and solutions to understand local impacts on biota in these locations
- Low dissolved is typically a seasonal issue in the Salish Sea
- Regional experts continue to emphasize that there is an opportunity to analyze existing monitoring data at the basin scale to understand nitrogen impacts and potential long-term changes
- The Salish Sea Model prompted additional monitoring in the nearshore to better understand water quality conditions in shallow embayments that could potentially be influenced by wastewater discharges
- The Salish Sea Model already calculates numerous parameters for each cell, each layer, daily. With some additional effort, the Puget Sound Institute can harvest and share this analysis

- There are different and equally valuable ways of interpreting the model outputs for multiple purposes; from comparing the outputs to a regulatory criterion, to tracking non-regulatory indicators like the Puget Sound Partnership Vital Signs, to answering fundamental scientific questions
- Organisms respond not only to dissolved oxygen concentrations but also the variability, so it can be helpful to analyze supporting lines of evidence like the volume of hypoxia, hypoxia exposure duration, metabolic index, etc. similar to what was done by Low et al. (2021)

Highlights from long-term monitoring: Opportunity for understanding change

Stephanie Jaeger, City of San Diego (formerly from King County DNRP)

- There is a significant amount of variability in environmental data, so a Mann-Kendall test can be an effective way to account for seasonal variability by comparing January to January in different years, etc.
- The period of record is important and can lead to different observations, particularly because there are large-scale climate oscillations and interannual variability
- Comparing long-term monitoring to historical data is valuable
    - The Collias data set shows a monthly mean temperature increase of 0.5 – 1 °C in deep waters. From the data that has been analyzed thus far, no clear change in salinity or dissolved oxygen, and based on limited data comparable nutrient levels
        - **Note:** Historical data requires careful evaluation, particularly due to method changes. Stephanie started to dig into the Collias data and is happy to discuss some of the quality assurance nuances with anyone who is interested in using the data
    - Integrating samples over a depth range from upper water layers can be used to compare datasets with different target depths, with an estimate of variance from continuous profiles
- Large-scale ocean patterns include a similar increase in temperature over time, widespread dissolved oxygen declines in the Pacific, and general nitrate increases in the deep waters of the Pacific
- Place matters: physical conditions impact susceptibility to eutrophication, it is important to evaluate impairment indicators beyond nutrient concentrations, and nutrient impacts can be far-field
- Variability is the backdrop to assessing change, so consistent long-term monitoring is key
    - For example, the Southern California Bight Regional Monitoring Program is a good example of a collaboration among 50 organizations that has conducted marine monitoring every 5 years, since 1994
- In understanding a complex ecosystem such as Puget Sound it is important to consider multiple biological indicators, as well as combined water quality impacts other than eutrophication, such as increasing temperatures and other climate change impacts

N Isotopic Studies

Gordon Holtgrieve, University of Washington

- Different sources of nitrogen have different isotopic ratios, which can help to answer scientific questions like:
    - Have N dynamics in the Puget Sound changed over time with human development?
    - Where is the nitrogen coming from?
- Three vignettes on N isotopic studies in the Puget Sound relevant to nutrients illustrate this

1. Spatial variation in Puget Sound $\boldsymbol{\delta}^{15}N$ using mussels (James et al., 2020) and relative source influence from waste water treatment plants
   - As expected, we see a positive relationship between $\boldsymbol{\delta}^{15}N$ in biota and the influence of wastewater treatment plants but the relative contribution is likely small overall
     - Has not been studied extensively, but for $\boldsymbol{\delta}^{15}N$ we generally expect about 20 units per mill from wastewater treatment plants compared to the background in Puget Sound which is about 8-9 units per mill
   - Note, the total change spatially across these sites is 1 unit per mill, which is a relatively small variation
   - This sort of data could be quantified further in a simple two-source mixing models to understand what portion of the nitrogen in these mussels comes from wastewater treatment plants. Gordon stated that that from first look at this data the relative contribution is likely small (approximately 5%)
2. Temporal variation in Puget Sound $\boldsymbol{\delta}^{15}N$ using seal skulls (Feddern et al., 2020) and copper rockfish (Welicky et al., in review)
   - Examining a conservative tracer of $\boldsymbol{\delta}^{15}N$ and $\boldsymbol{\delta}^{13}C$ values (phenylalanine, which is an essential amino acid) we get an indication of phytoplankton change over time as they are transferred through the food web to top predators. This allows us to:
     - Track the isotopic signature and changes of source N to the primary producers at the base of the food web over almost 80 years using samples from seal skulls in museums
     - This helps to supplement our understanding when we do not have direct data on historical change in N dynamics and the biological impacts of these changes
   - In analyzing seal skulls, we do not see a trend that is consistent with dramatic changes in the nutrient dynamics in the Salish Sea
     - There is not a strong trend in change in wastewater discharge or watershed land-use sources
     - The most influential covariate for $\boldsymbol{\delta}^{15}N$ is sea surface temperature, upwelling, and a couple of climate indices
   - In analyzing the University of Washington's fish collection, there was similarly no trend over time in wastewater discharge or watershed land-use sources for copper rockfish, walleye, pollock, hake, herring, and English sole, which span a wider range of the water column
3. Temporal variation of river NO_3^- $\boldsymbol{\delta}^{15}N$ (Elizabeth Elmstron, pending master's thesis)
   - Pretty low concentrations of NO_3^- across the board
   - In the Deschutes and the Nooksack Rivers higher nitrate concentrations are associated with consistently high $\delta^{15}N$, which suggests there is an anthropogenic source of nitrogen. This is expected, since these basins have known nitrate pollution issues
   - However, in most Puget Sound rivers, higher nitrate concentrations are associated with lower $\delta^{15}N$. This suggests the nitrogen source is relatively depleted $\delta^{15}N$ form, and therefore not from human sources
     - Gordon is still exploring this, but a potential hypothesis is this lower $\delta^{15}N$ source of N is predominantly soil nitrogen, derived from alders. This would h reflects the current phase of forestry succession associated with

a long legacy of historical logging practices throughout the watersheds (Alders are N fixers with a $\boldsymbol{\delta}^{15}$N units of 0 per ml)

- Potential next steps:
  - Continued monitoring of rivers to look for changes over time and environmental controls
  - Combine isotope data and watershed N modeling analysis
  - Move from source identification to estimating rates of ecosystem processes (i.e., denitrification)

Discussion

- Mike Connor asked Gordon if he tried using S isotopes? Mike shared it was helpful to combine N & S when analyzing nutrient in Massachusetts Bay
  - Gordon responded that his research took a different approach and measured compound-specific isotopes. He highlighted that by measuring the δ^{15}N and the individual amino acids rather than the whole tissue, they can parse changes to the baseline and in the food web dynamics over time
- Tarang shared that in the Puget Sound Nutrient Reduction Project Application of the Salish Sea Model, predation/grazing is a fixed value throughout the domain. However, more recent versions of the Salish Sea Model incorporate zooplankton, so the grazing varies and depends on the availability of prey (i.e., phytoplankton)
  - Mike Connor noted that given the breadth of aquaculture in the region, grazing might have a bigger role in nutrient dynamics, so it might be beneficial to analyze areas with significant bivalve aquaculture further. He also shared that there is still significant debate in the Chesapeake Bay as to whether changes in water quality were driven by overharvesting oysters
- Mark Hersh highlighted that the nearshore is important for juvenile salmonids
  - Stefano shared that the more advanced version of the Salish Sea Model has higher resolution bathymetry in the masked nearshore and is ready to apply in many areas, but needs additional resources to develop the biogeochemistry module for these nearshore applications
- Mike Connor reflected that it is challenging to interpret a data set that is binary (i.e., impaired or not). He suggested it would help scientists interpret the model data to first show the actual numbers (e.g., concentration) for parameters that are relevant to nutrient dynamics and eutrophication and then do the regulatory calculation afterward
  - Tarang responded that the data is available as model outputs from these scenarios, and in the process of calibration these influences have been explored
- Scott Redman highlighted the importance of using a portfolio of models, including LiveOcean and SalishSeaCast. He also asked how to ensure research is well-funded and still perceived as legitimate by drawing on a range of funders
  - Parker MacCready noted that funding from King County is allowing more dialogue between the modelers and building towards multi-model experiments
  - Joel reiterated that independent science focuses first and foremost on the science and that universities are uniquely positioned to do this because their work is peer reviewed and publicly available
  - Stephanie reflected that in the Southern Bight, the science has benefited from the deep relationships, open collaboration, and funding from both wastewater dischargers and regulators that SCWWRP has facilitated

  - Gordon noted that similar questions arise in fisheries research. His perspective is the fisheries are using Puget Sound as a resource then they should pay for the research to protect it, so utilities funding nutrient research is similarly appropriate
  - Michael Connor reflected that in Massachusetts almost all of the funding and science was done by the utility. He added that this was balanced by collaborating with government and non-profit stakeholders as well as independent scientific review from experts like the Model Evaluation Group that Puget Sound Institute has convened
- Scott Redman noted it could be valuable for the Puget Sound Science Review to do a synthesis of how phytoplankton is controlled in the region, the conceptual model, interannual variability, and scientific unknowns for the common oceanographer
- The Department of Health conducted a physical dye study on the Oak Harbor wastewater treatment plant discharge. The data is being analyzed and may be available in Spring 2023
- Washington Department of Ecology's Sediment Monitoring Program has sampled N15 and C13 in Puget Sound since 2017
- Alan Mearn shared that Rau et al., 1981 studied the "LA County outfall during primary treatment. The biomass of Palos Verdes shelf demersal and bottom fish was huge and there was high survival of juvenile flatfish. On conversion to secondary (years later) the biomass/growth of flatfish dropped an order of magnitude. Unfortunately, Rau et al did not go back. Nonetheless, it looks like primary treatment was feeding the demersal food web until secondary treatment [was implemented]"

Jamboard

For ease of reference, the following documents the comments made on the Jamboard, verbatim.

1. **Given the focus on embayments and nutrient impacts more holistically, what existing parameters would you like to have access to and why?**
   - *Process rates (especially N-related processes) for comparison b/w models as well as to measured rates*
   - *Salish Sea Model output includes u,v,w, DO, etc, but (to my understanding), not eddy diffusivities. This makes use of the model output a challenge. (You can't run an advection-diffusion reaction model)*
   - *Uncertainty estimates around modeled DO*
   - *Data on TSS (total suspended solids) would provide valuable insight into the influence of light. Some people measure turbidity, some Secchi, but TSS is often a big long-term USGS measure that correlates in San Francisco Bay with dams and runoff controls*
2. **Given the focus on embayments and nutrient impacts more holistically, what additional modeling and monitoring interpretation tools would be useful?**
   - *Need more phytoplankton data, particularly in embayments and terminal inlets in different basins, to help adjust model parameterizations*
   - *Sediment coring studies in shallow embayments that might reveal long-term trends and cycles in response to human activities, climate variability, and climate change*
   - *You describe possible impacts associated with nutrient additions. You should also describe possible benefits as well. Reducing nutrients, to reduce productivity, may have more impact*
   - *Further evaluation of the use of stable isotopes to look for trends related to human nutrient inputs and land cover change as well as changes in trophic dynamics*

Resources

Additionally shared

- Analysis of the combined Collias + Ecology data
- Rau, G. H., Sweeney, R. E., Kaplan, I. R., Mearns, A. J., & Young, D. R. (1981). Differences in animal 13C, 15N and D abundance between a polluted and an unpolluted coastal site: Likely indicators of sewage uptake by a marine food web. *Estuarine, Coastal and Shelf Science*, *13*(6), 701–707. Available at: https://doi.org/10.1016/S0302-3524(81)80051-5

Referenced in the presentations

- Low, N. H. N., Micheli, F., Aguilar, J. D., Arce, D. R., Boch, C. A., Bonilla, J. C., Bracamontes, M. Á., De Leo, G., Diaz, E., Enríquez, E., Hernandez, A., Martinez, R., Mendoza, R., Miranda, C., Monismith, S., Ramade, M., Rogers-Bennett, L., Romero, A., Salinas, C., … Woodson, C. B. (2021). Variable coastal hypoxia exposure and drivers across the southern California Current. *Scientific Reports*, *11*(1), 10929. Available at: https://doi.org/10.1038/s41598-021-89928-4
- Johannessen, S. C., Macdonald, R. W., & Strivens, J. E. (2021). Has primary production declined in the Salish Sea? *Canadian Journal of Fisheries and Aquatic Sciences*, *78*(3), 312–321. Available at: https://doi.org/10.1139/cjfas-2020-0115
- Stramma, L., Schmidtko, S., Bograd, S. J., Ono, T., Ross, T., Sasano, D., & Whitney, F. A. (2020). Trends and decadal oscillations of oxygen and nutrients at 50 to 300 m depth in the equatorial and North Pacific. *Biogeosciences*, *17*(3), 813–831. Available at: https://doi.org/10.5194/bg-17-813-2020
- Riche, O., Johannessen, S. C., & Macdonald, R. W. (2014). Why timing matters in a coastal sea: Trends, variability and tipping points in the Strait of Georgia, Canada. *Journal of Marine Systems*, *131*, 36–53. Available at: https://doi.org/10.1016/j.jmarsys.2013.11.003
- Whitney, F. A., Bograd, S. J., & Ono, T. (2013). Nutrient enrichment of the subarctic Pacific Ocean pycnocline. *Geophysical Research Letters*, *40*(10), 2200–2205. Available at: https://doi.org/10.1002/grl.50439
- Pierce, S. D., Barth, J. A., Shearman, R. K., & Erofeev, A. Y. (2012). Declining Oxygen in the Northeast Pacific*. *Journal of Physical Oceanography*, *42*(3), 495–501. Available at: https://doi.org/10.1175/JPO-D-11-0170.1
- Falkowski, P. G., Algeo, T., Codispoti, L., Deutsch, C., Emerson, S., Hales, B., Huey, R. B., Jenkins, W. J., Kump, L. R., Levin, L. A., Lyons, T. W., Nelson, N. B., Schofield, O. S., Summons, R., Talley, L. D., Thomas, E., Whitney, F., & Pilcher, C. B. (2011). Ocean deoxygenation: Past, present, and future. *Eos, Transactions American Geophysical Union*, *92*(46), 409–410. Available at: https://doi.org/10.1029/2011EO460001

Isotopic studies

- Feddern, M. L., Holtgrieve, G. W., & Ward, E. J. (2021). Stable isotope signatures in historic harbor seal bone link food web-assimilated carbon and nitrogen resources to a century of environmental change. *Global Change Biology*, *27*(11), 2328–2342. Available at: https://doi.org/10.1111/gcb.15551
- James, C. A., Lanksbury, J., Khangaonkar, T., & West, J. (2020). Evaluating exposures of bay mussels (Mytilus trossulus) to contaminants of emerging concern through environmental sampling and hydrodynamic modeling. *Science of The Total Environment*, *709*, 136098. Available at: https://doi.org/10.1016/j.scitotenv.2019.136098

Salish Sea Model

- Premathilake, L., & Khangaonkar, T. (2022). Explicit quantification of residence and flushing times in the Salish Sea using a sub-basin scale shoreline resolving model. *Estuarine, Coastal and Shelf Science*, *276*, 108022. Available at: https://doi.org/10.1016/j.ecss.2022.108022
- Ahmed, A., Figueroa-Kaminsky, C., Gala, J., Mohamedali, T., Pelletier, G., & Sheelagh, M. (2019). *Puget Sound Nutrient Source Reduction Project. Volume 1: Model Updates and Bounding Scenarios* (No. 19-03–001; p. 102). Department of Ecology. Available at: https://apps.ecology.wa.gov/publications/SummaryPages/1903001.html

Background

Our region is navigating complex and challenging decisions on how best to manage nitrogen, dissolved oxygen, and the potential impacts on the key habitats and species of the Salish Sea. The University of Washington Puget Sound Institute is supporting a series of scientific workshops to help address technical uncertainties, advance modeling, and refine monitoring to improve our understanding of nutrients and broader water quality in the Salish Sea. Learn more.

Continue the discussion

- If you have not already, please join the listserv to receive periodic updates about Puget Sound Institute's program to foster regional water quality science, including information about upcoming workshops
- Join us for the workshops later this year to dig into these technical uncertainties further
- Reach out to Stefano Mazzilli (mazzilli@uw.edu) and Marielle Larson (marlars@uw.edu) if you:
    - Are interested in contributing or helping with one of the upcoming workshops or modeling and monitoring analyses
    - Want to recommend another expert, program, or study for us to connect with to help advance the research
    - Have additional ideas or questions