Effects of Nutrient and Carbon Loadings on Dissolved Oxygen and Ocean Acidification Conditions in Puget Sound – Scientific Perspectives (March 16, 2020)

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***What is known, with what level of confidence, about the contributions of nitrogen and carbon inputs derived from regional human activity to changes in biogeochemical cycles, and in particular, dissolved oxygen reductions in bottom layers and ocean acidification in Puget Sound marine waters?***

**Concise Characterization of Agreements with Published Works**

A – Parts of Puget Sound experience low levels of dissolved oxygen, which is vital for aquatic life.

1. In several areas, and mostly in near-bottom waters, oxygen concentrations do not meet part 1 of the Washington State water quality standard (Washington Administrative Code 173-201A-210(1)(d)). (Albertson et al., 2002a; Roberts et al., 2008)
2. Lowest dissolved oxygen concentrations typically occur in late summer, when river flows are low, temperatures warm, and sunlight is available. (Albertson et al., 2002a; Roberts et al., 2008)
3. Areas of Puget Sound naturally experience low oxygen due to factors like bathymetry, and are susceptible to further decreases due to human-derived nutrients. (Albertson et al., 2002a; Roberts et al., 2008)
4. Primary productivity declines when sunlight and/or water temperature is low, as typically occurs in the winter in the Puget Sound region. (Albertson et al., 2002a; Roberts et al., 2008)
5. Low levels of dissolved oxygen result from decomposition of organic matter, driven by materials that settle through the water column and reach the sediment. Both water column and sediment processes influence the levels of dissolved oxygen in bottom waters, where oxygen is typically the lowest. (Pelletier et al., 2017a; Ahmed et al., 2014; Albertson et al., 2002a; Roberts et al., 2008)

B – Human activities increase nitrogen and carbon contributions through both wastewater treatment plant discharges and watershed activities, with wastewater loads the dominant source in the summer months.

1. Nitrogen from municipal wastewater treatment plants contribute much of the annual average load of dissolved inorganic nitrogen from human-derived activities and the vast majority of the load in the summer season. This finding has been consistent from the initial South Puget Sound Dissolved Oxygen Study to present. (Mohamedali et al., 2011a; Mohamedali et al., 2011b; Roberts et al., 2008; Albertson et al., 2002a)
2. Wastewater treatment plants typically discharge treated wastewater lower in the water column to keep nitrogen away from the surface layer where light drives primary productivity and nitrogen is generally the limiting nutrient. (Ahmed et al., 2014; Mohamedali et al., 2011a; Mohamedali et al., 2011b; Roberts et al., 2008)
3. Watershed human-derived activities add to the average annual load to Puget Sound but proportionally less of the summer load of dissolved inorganic nitrogen from human-derived activities than wastewater treatment plants. (Mohamedali et al., 2011a; Mohamedali et al., 2011b; Roberts et al., 2008; Roberts and Bilby, 2009)
4. Rivers and other freshwater sources typically discharge to the surface layer, where the presence of sunlight can accelerate primary productivity. (Mohamedali et al., 2011a; Mohamedali et al., 2011b; Roberts et al., 2008)

C – Added nutrients from human-derived activities cause or contribute to violations of the Washington State water quality standard for dissolved oxygen in Puget Sound due to complex circulation and biogeochemical processes.

1. Part 2 of the Washington State water quality standard for marine dissolved oxygen stipulates that the cumulative effect of all human sources cannot worsen oxygen by more than 0.2 mg/L. (Washington Administrative Code 173-201A-210(1)(d)(i))
2. Circulation is quite complicated throughout Puget Sound and the Salish Sea. (Khangaonkar et al., 2017; Banas et al., 2015; Roberts et al., 2014b)
3. Nitrogen is the primary nutrient driving primary productivity. (Ahmed et al., 2014; Albertson et al., 2002a)
4. Carbon contributions from human-derived activities also impact oxygen and acidification in Puget Sound. (Pelletier et al., 2017b)
5. Nitrogen and carbon from municipal wastewater treatment plants cause or contribute to violations of the Washington State water quality standard for dissolved oxygen in Puget Sound. (Ahmed et al., 2019; Pelletier et al., 2017a; Pelletier et al., 2017b; Ahmed et al., 2014; Roberts et al., 2014a; Khangaonkar et al., 2012b; Albertson et al., 2002a)
6. Nitrogen and carbon from watershed contributions of human-derived nutrients cause or contribute to violations of the Washington State water quality standard for dissolved oxygen in Puget Sound. (Ahmed et al., 2019; Pelletier et al., 2017a; Pelletier et al., 2017b; Ahmed et al., 2014; Roberts et al., 2014a; Cope and Roberts, 2013; Khangaonkar et al., 2012b; Albertson et al., 2002a)
7. Nitrogen and carbon released in one location negatively impact dissolved oxygen and acidification miles away. (Ahmed et al., 2019; Pelletier et al., 2017a; Pelletier et al., 2017b; Ahmed et al., 2014; Roberts et al., 2014a; Khangaonkar et al., 2012b; Albertson et al., 2002a)
8. The areas most impacted by human nitrogen and carbon contributions are distant from the sources of those contributions. (Ahmed et al., 2019; Pelletier et al., 2017a; Pelletier et al., 2017b; Ahmed et al., 2014; Roberts et al., 2014a; Khangaonkar et al., 2012b; Albertson et al., 2002a)
9. Human nitrogen and carbon cause dissolved oxygen levels to fall by more than 0.2 mg/L. (Ahmed et al., 2019; Pelletier et al., 2017a; Ahmed et al., 2014; Roberts et al., 2014a; Albertson et al., 2002a)

D – Future growth and development will increase nutrients from human activities in the Puget Sound watershed, which will worsen dissolved oxygen impacts from local human activities unless nutrients and carbon are managed differently.

1. The population of the Puget Sound region is expected to double by 2070. (Estimates do not include any effect of climate refugees from other parts of the United States or abroad) (Roberts et al., 2014a)
2. Increasing the population will increased nitrogen from wastewater without changes to wastewater treatment plant technology. (Roberts et al., 2014a)
3. Technology exists today to upgrade plants to nutrient removal, which several have elected to plan and design for now (Roberts et al., 2014a). (Upgrades will require additional capital and operating expenditures, which will require creative solutions to implement and permit.)
4. Projected land development patterns will result in increased nitrogen contributions without substantial changes to managing nutrients from nonpoint sources including onsite sewage systems, fertilizer applications, and conversion from forests to developed land. (Roberts et al., 2014a)
5. Salish Sea Model scenarios indicate that increasing nitrogen from increased wastewater contributions will worsen dissolved oxygen concentrations in Puget Sound. (Roberts et al., 2014a)

E – The Salish Sea Model, built on years of application, is the most appropriate tool to explore the relative impacts of different natural and human stressors that influence dissolved oxygen. At each phase of model development, Ecology concluded that human nutrient sources likely were violating the dissolved oxygen criteria in portions of Puget Sound. The magnitude and location of the violations have remained remarkably consistent over 19 years, even as the modeling tools continued to be refined in response to uncertainties identified by the modeling team.

1. The Salish Sea Model and its precursors have been developed under the strict requirements of tools used for regulatory purposes at the Department of Ecology, including Quality Assurance Project Plans, peer review, documentation, and public and stakeholder engagement.
2. The Salish Sea Model represents the evolution of a model framework initially applied to South Puget Sound beginning in 2000 to understand whether low dissolved oxygen in South Sound inlets was due to natural factors or human nutrient contributions from wastewater treatment plants and/or watershed sources. The Phase 1 South Puget Sound model results indicated that wastewater treatment plants could be contributing to dissolved oxygen impairments. (Albertson et al., 2002a) However, lack of facility-specific data and the influence of sources near the northernmost boundary limited firm conclusions and additional data and model development were needed.
3. South Puget Sound modeling Phase 2 focused on the biogeochemistry and hydrodynamics of South and Central Puget Sound and the potential impacts of human nutrients on dissolved oxygen in South Puget Sound. The effort included effluent data collected from many wastewater treatment plants and model simulations for 2006 and 2007 (Mohamedali et al., 2011b; Norton, 2009; Albertson et al., 2007). Phase 2 of the South Puget Sound Dissolved Oxygen Study concluded with the finding that wastewater treatment plants could be contributing to dissolved oxygen impairments (Ahmed et al., 2014). However, the strong influence of sediment/water interactions limited firm conclusions and additional data and model developments were needed.
4. Ecology and Pacific Northwest National Laboratory began developing a model of the larger Salish Sea, including shared waters with Canada (Sackmann, 2009). Ecology refined loading estimates from wastewater treatment plants and watersheds (Mohamedali et al., 2011a). The initial findings of the Salish Sea Model were that wastewater treatment plants could be contributing to dissolved oxygen impairments (Khangaonkar et al., 2012a; Khangaonkar et al., 2012b). However, the strong influence of sediment/water interactions limited firm conclusions and additional data and model developments were needed.
5. The next iteration added sediment diagenesis to the Salish Sea Model (Roberts et al., 2015a). The refined model was used to quantify impacts from wastewater treatment plants and human sources in watersheds. The updated findings of the Salish Sea Model were that wastewater treatment plants could be contributing to dissolved oxygen impairments (Ahmed et al., 2019; McCarthy et al., 2018; Pelletier et al., 2017a).
6. The Salish Sea Model was adapted to evaluate impacts from wastewater treatment plants and human sources in watersheds on acidification in the Salish Sea (Roberts et al., 2015b). Increased dissolved inorganic nitrogen (DIN), phytoplankton biomass, and non-algal organic carbon caused by regional anthropogenic nutrient sources can constitute significant contributors to acidification in the Salish Sea (Bianucci et al., 2018; Pelletier et al., 2018; Pelletier et al., 2017b). These sources are impacting acidification parameters include aragonite saturation state. Decreasing regional human sources of nitrogen and carbon would improve acidification in the Salish Sea.

F – At each phase of model development, Ecology was held to the highest standards of peer review, stakeholder input, and public review to ensure the integrity of the work and to hold up in a court of law.

1. Each modeling and monitoring stage included Quality Assurance Project Plans (McCarthy et al., 2018; Roberts et al., 2015a; Roberts et al., 2015b; Sackmann, 2009; Albertson et al., 2007; Roberts, 2007a; Roberts, 2007b; Roberts and Pelletier, 2007).
2. Where monitoring data limited interpretations, refined monitoring programs were developed (Gonski et al., 2019; Norton, 2009; Roberts et al., 2008; ; Roberts, 2007a; Roberts, 2007b; Roberts and Pelletier, 2007).
3. Where work by others lacked documentation or public review, Ecology summarized their work and had that publicly reviewed and independently reviewed (Cope and Roberts, 2013).
4. Ecology published interim and final data reports for public review and comment (Mohamedali et al., 2011a; Mohamedali et al., 2011b; Roberts et al., 2008).
5. Ecology published model calibration and scenarios reports for public review and comment (Ahmed et al., 2019; Pelletier et al., 2017a; Pelletier et al, 2017b; Ahmed et al., 2014; Roberts et al., 2014a; Roberts et al., 2014b).
6. Given the complexity of the issues, Ecology developed simple summaries of the findings (Roberts and Kolosseus, 2011; Albertson et al., 2002b).
7. Ecology authors published journal articles (Pelletier et al., 2018; Bianucci et al., 2018; Khangaonkar et al., 2017; Khangaonkar et al., 2012a; Roberts and Bilby, 2009).

G – Ecology’s regulatory processes protect public health and aquatic life.

1. Ecology has no history of weakening water quality standards, other than an interim measure related to Total Dissolved Gas in the Columbia River system related to increasing spill for the benefit of salmon survival.
2. Weakening the water quality standards for dissolved oxygen in Puget Sound would not likely be supported by the public, based on polling on the value of clean water.
3. Models developed by Ecology have long been used to make regulatory decisions for multiple purposes (Albertson, 2013).

**Rationale for any Points of Disagreement**

While I do not disagree with the statements in the references cited in the call for papers, I feel compelled to document my concerns regarding the scientific integrity of this process.

Academic-oriented journals require peer review of typically three anonymous reviewers, who must agree that a paper and revised versions of a paper pass scientific muster before they can be published. Otherwise, the journal loses credibility and scientific integrity would be lost. This does not mean that every scientist gets to weigh in on every paper before it is published. The journal articles included in the references list in the call for papers have passed scientific muster by the review process before they were accepted for review. Opinions to the contrary in no way rebut these published works.

The Department of Ecology is required to follow strict procedures for ensuring that technical products like the Salish Sea Model are developed transparently and without bias. At each stage in its development, Ecology modelers developed Quality Assurance Project Plans and results reports all subject to strict peer review and public review. Ecology documented these critical quality assurance and public review steps from its earliest related publications in 2002 through present day.

Finally, this process concerns me as a credentialed and published scientist and engineer. The Halo Effect occurs when society attributes a set of skills to someone beyond their actual areas of expertise due to favorable impressions, hierarchical standing, or credentials. Experts routinely overestimate the breadth of their own expertise, in part due to society’s impressions. The Halo Effect negatively impacts decisionmaking when it substitutes expert opinions for evidence-based findings in fields as wide ranging as pharmacology (Austin and Foster, 2019) and avalanche risk assessment (McCammon, 2004). Opinions and unsubstantiated hunches are no substitute for scientific process.

**Scientific Confidence**

It is virtually certain that human-derived nutrients, primarily from municipal wastewater treatment plants, cause or contribute to violations of the water quality standards for dissolved oxygen standards in Puget Sound. Throughout its 19-year investigation of the impacts of human-derived nutrients on Puget Sound dissolved oxygen levels, Ecology’s findings have consistently identified impacts from human nutrients as early as 2002 through recent analyses.

It is virtually certain that adopting nutrient-control technology, which is available today, would more than offset the expected increases in nitrogen contributions expected from doubling the regional population by 2070. This will substantially but not completely resolve dissolved oxygen impairments.

It is virtually certain that human nitrogen and carbon sources in watersheds must be reduced to resolve dissolved oxygen impairments.

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