Influence of the Duwamish River on water quality in Elliott Bay, Seattle, WA

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INTRODUCTION

Elliott Bay is an urbanized bay surrounded by the city of Seattle and located within the Central Basin of Puget Sound (Figure 1). The primary influx of fresh water into Elliott Bay comes from the Duwamish River, which extends downstream of the Green River to the northern tip of Harbor Island. The net flow of fresh water entering the bay is northward along the Seattle waterfront, and during heavy rain events turbid discharge is visible in the bay (Figure 2). Elliott Bay water quality parameters could be substantially affected by the Duwamish River depending on the volume of discharge.

The Duwamish River is highly industrialized, receives heavy vessel traffic, and contains a number of point sources (combined sewer overflow and stormwater outfalls). Both water bodies routinely fail state water quality standards for a variety of parameters in sediments, tissues, and surface waters. In Elliott Bay, surface water criteria for bacteria and dissolved oxygen (DO) are the most frequently exceeded. It is essential to understand the linkage between the marine and freshwater systems' physical, chemical, and biological linkage to determine the sources and fates of contaminants. To this end, the correlation between upstream discharge volumes and physical parameters measured in Elliott Bay was examined, as well as the differences in bacteria and nutrient concentrations at sites various distances from the Duwamish River.

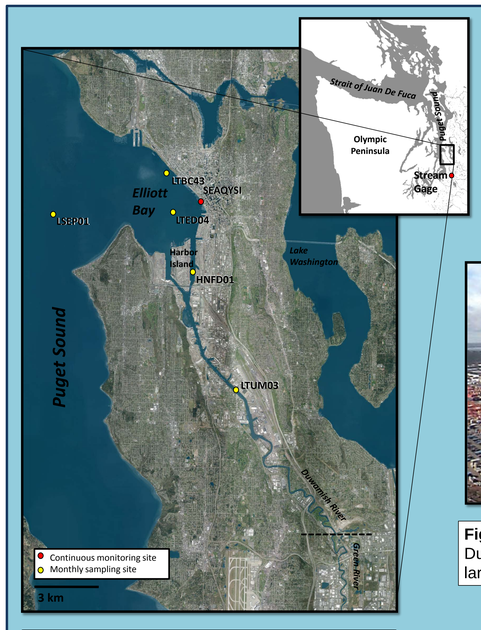

Figure 1. Map of study area including continuous (15-minute intervals) and monthly offshore monitoring sites.

Figure 2. View of discharge from Duwamish River into Elliott Bay after a large rain event.

METHODS

King County maintains a rigorous marine water quality monitoring program that measures physical parameters (temperature, DO, turbidity, salinity, etc.) as well as biological (chlorophyll-*a* and bacteria) and chemical (nutrient) concentrations monthly at several offshore sites within Puget Sound, Elliott Bay, and the Duwamish River (Figure 1). Data from 2004 to 2013 were used to analyze differences in water quality parameters between one site in Puget Sound (near a waste water treatment outfall), two in Elliott Bay, and two in the Duwamish River. Differences in nutrient and bacteria concentration distributions were compared between sites using Kruskal-Wallis one-way analysis of variance followed by a non-parametric post-hoc test (nparcomp, R).

In addition, data from a continuous monitoring site (mooring), which measures conventional parameters (temperature, DO, turbidity, salinity, pH, and chlorophyll-*a*) at 1 and 10 m depths at 15-minute intervals along the Seattle waterfront, (SEAQYSI; see Figure 1) were compared to river discharge from the closest upstream monitoring site (USGS 12113000, Green River, Auburn, WA). Spearman-rank correlation analysis was used on data from 2009 to 2013 (both yearly and seasonal) to determine the correlation between river discharge and physical parameters in Elliott Bay.

RESULTS

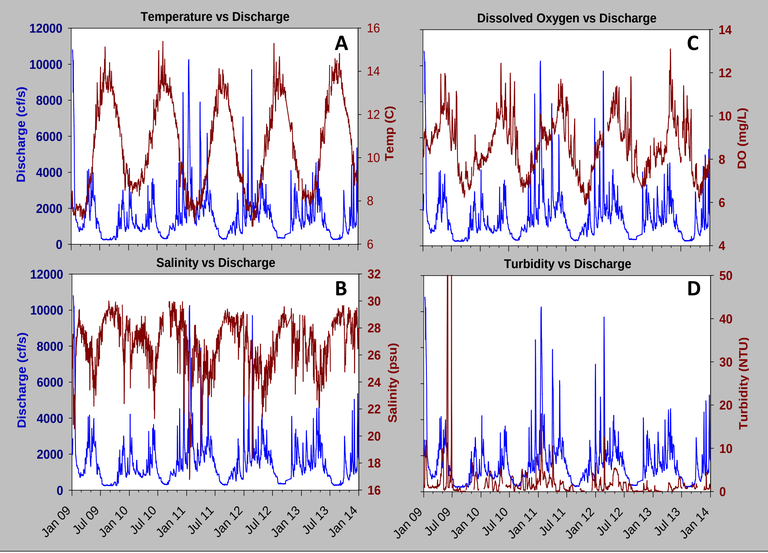

Figure 3. Relationship between mean daily discharge (blue) from upstream of the Duwamish River (USGS 12113000), and physical water quality parameters (red) at a site on the Seattle waterfront (1 m, SEAQYSI) from 2009-2013.

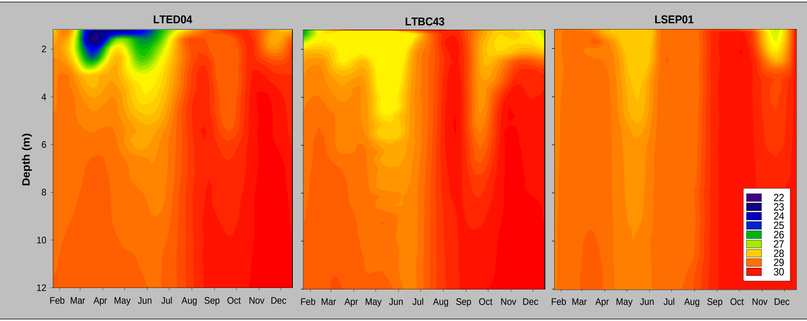

Figure 4. Salinity profiles in the upper 12 meters of two sites in Elliott Bay (LTED04 & LTBC43) and a site in Puget Sound (LSEP01) in 2013. A freshwater lens is most prominent at the site nearest the Duwamish River (LTED04) during the months when river discharge is the highest.

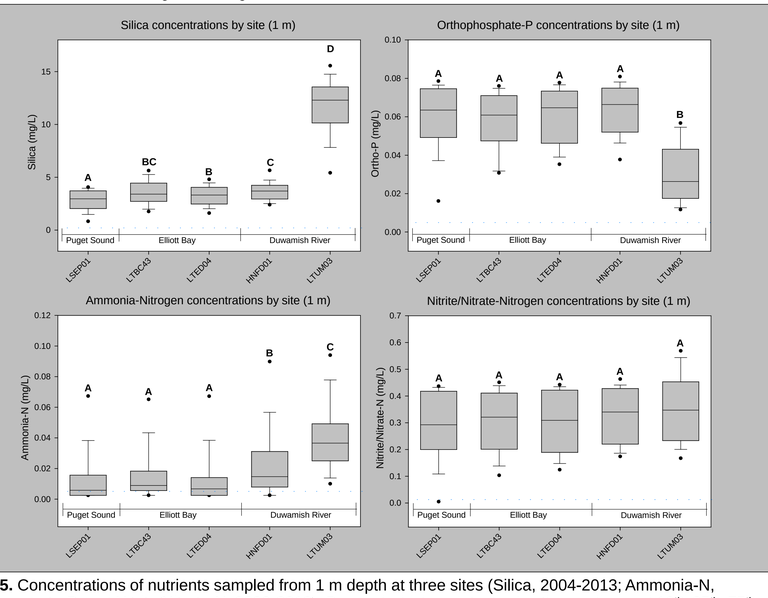

Figure 5. Concentrations of nutrients sampled from 1 m depth at three sites (Silica, 2004-2013; Ammonia-N, Orthophosphate-P, and Nitrite/Nitrate-N, 2009-2013). Box and whisker plots display the median and 10th, 25th, 75th, and 90th percentiles. 5th and 95th percentiles are represented by dots. The blue line indicates the highest detection limit during the sampling period. Letters indicate similar distributions of nutrient concentrations between sites at alpha=0.05.

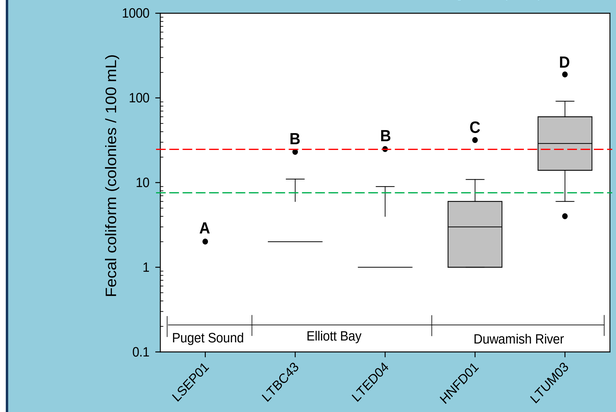

Figure 6. Bacteria concentrations in Elliott Bay, Puget Sound, and the Duwamish River at 1 m depth (2004-2013). Box and whisker plots display the median and 10th, 25th, 75th, and 90th percentiles. 5th and 95th percentiles are represented by dots. Note high bacteria concentrations in the Duwamish River. A large portion of sites in Elliott Bay and Puget Sound contained samples with < 1 colony / 100 mL. The green line indicates the Washington State marine geometric mean standard (14 colonies / 100 mL) and the red line indicates the peak standard (not to exceed 43 colonies / 100 mL in >10% of samples).

DISCUSSION

- Although **temperature** and river discharge were correlated (1 m; $p < 0.00001$, rho = -0.63), large discharge events did not correspond to changes in temperature (Figure 3A). The negative correlation is likely a seasonal effect (e.g., discharge is typically lowest in the summer when surface temperatures are highest), rather than discharge causing changes in temperature. For most of the year, marine waters are colder than those in the Duwamish River; therefore, an increase in discharge would more likely increase water temperatures in Elliott Bay.

- **Salinity** was negatively correlated with river discharge (Figure 3B). The strength of the correlation was greatest near the surface (1 m; $p < 0.00001$, rho = -0.78); however, discharge from the river also influenced salinity at depth (10 m; $p < 0.00001$, rho = -0.23). Sites closer to the Duwamish River had lower salinities near the surface than those further away from the river (Figure 4).

- **Dissolved oxygen** was positively correlated with river discharge (1 m; $p < 0.00001$, rho = 0.36) (Figure 3C), but the correlation was not significant in fall months when deep oceanic water, that is low in oxygen, is upwelled into Puget Sound. In addition, large discharge events did not correspond to increases in DO (Figure 3C), which was typically lower in the Duwamish River than Elliott Bay. Thus, DO is likely a parameter that co-varies with, but is not influenced by, river discharge, and is influenced by other seasonal parameters such as phytoplankton abundance.

- **Turbidity** was positively correlated with river discharge (1 m; $p < 0.00001$, rho = 0.36). Spikes in discharge corresponded to spikes in turbidity (Figure 3D).

- **Silica** and **ammonia-N** were found at higher concentrations further up the Duwamish River (LTUM03) and decreased in concentration into Elliott Bay and Puget Sound (Figure 5). **Orthophosphate-P** concentrations were lowest 5 miles upstream of the mouth of the river (LTUM03) and were otherwise found at similar concentrations in the bay and sound. **Nitrite/Nitrate-N** concentrations did not differ between sites through most of the year, although concentrations were higher in the river during the summer.

- **Bacteria** concentrations at offshore sites were highest in the Duwamish River, where water quality criteria were frequently exceeded (e.g., LTUM03 violates both the geometric mean and peak standards). Those sites in Elliott Bay that are closer to the river (e.g., LTED04) only occasionally fail geometric mean criteria (Figure 6). Additional studies are being conducted to identify shoreline reaches that contribute to bacterial contamination.

ACKNOWLEDGEMENTS

- Seattle Aquarium for allowing King County to deploy a continuous monitoring sonde
- King County Environmental Lab for collecting and analyzing field samples, and maintaining mooring stations