4. NUTRIENT DYNAMICS AND OTHER WATER PROPERTIES

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BENTHIC NUTRIENT DYNAMICS

There have been very few benthic nutrient data collected in Puget Sound and less collected in the nearshore environments of WRIAs 8 and 9. One of the few studies examined nutrient limitation as part of work carried out during the Seahurst Baseline Studies in the mid-1980s (Thom et al. 1988; Thom 1985). Nitrate samples collected in the nearshore water column from reaches 7, 8, and 9 varied with season at the study sites in 1983. During late spring through summer (May through September), nitrate was generally below 10-ug at/l and was undetectable at times. Nitrate concentrations were highest and the least variable in winter. Total inorganic nitrogen to phosphate (N:P) ratio followed a similar cycle (Thom et al. 1988). The N:P ratio indicated that nitrogen was being preferentially taken up during spring and summer. N:P was below the Redfield ratio (1963) of 16, considered to be the threshold of nutrient limitation in algae, in approximately 97 percent of samples. Depleted nitrate concentration during times of high net primary productivity and algal biomass (see Benthic Primary Productivity) coupled with N:P ratios falling below growth-limiting levels provide strong evidence that nutrient limitation occurs under certain conditions in nearshore areas of central Puget Sound (Thom 1988).

As part of the Marine Outfall Siting Study (MOSS) Nearshore Program, an intertidal sampling program was initiated in March 2000 that includes nutrient analyses (ammonia nitrogen, nitrate + nitrite, total phosphorus, and silica). Nutrient results are listed in Table 2. Initial data were collected at the following sampling sites: Picnic Point Park, Meadowdale Beach Park, Ocean Avenue, Brackett's Landing, Edwards Point, Richmond Beach, Boeing Creek, Carkeek Park, Piper's Creek, Blue Ridge/North Beach, Golden Gardens Park, and Shilshole Bay. Without a full year of data, it is premature to examine trends; however, this is an ongoing program with sample collections taken on a regular basis (monthly).

Table 2: Nutrient results from the MOSS sampling program

		Ammonia Nitrogen (mg/L)			Nitrite + Nitrate (mg/L)			Silica (mg/L)		
Reach	Site	Min (Date)	Max (Date)	Average	Min (Date)	Max (Date)	Average	Min (Date)	Max (Date)	Average
West of 1	Admiralty Inlet	0 (7/26/99,9/20/99 10/20/99,12/7/99 1/18/00,2/14/00)	0.0276 (5/15/00)	0.0075	0 (7/26/99)	0.402 (1/18/00)	0.2144	0.334 (7/26/99)	4.07 (1/18/00)	2.22
1	Possession Sound	0 (7/26/99,9/20/99 10/20/99,1/18/00 2/14/00)	0.021 (6/19/00)	0.0087	0 (7/26/99)	0.406 (1/18/00)	0.2098	0.433 (7/26/99)	4.31 (1/18/00)	2.29
2	Point Wells	0 (9/20/99,12/7/99 1/18/00,2/14/00)	0.0251 (8/18/99)	0.0105	0.0806 (7/26/99)	0.407 (1/18/00)	0.2605	0.705 (7/26/99)	4 (1/18/00)	2.51
West of 2	Point Jefferson	0 (7/26/99,9/20/99 11/15/99,12/7/99 1/18/00,2/14/00)	0.015 (8/18/99 6/19/00)	0.0068	0 (9/20/99)	0.405 (1/18/00)	0.2271	0.284 (7/26/99)	3.85 (1/18/00)	2.28
4	West Point Outfall	0 (11/15/99,12/7/99 2/14/00)	0.0661 (10/20/99)	0.0182	0.037 (6/19/00)	0.435 (1/18/00)	0.2740	0.619 (7/26/99)	3.98 (2/14/00)	2.67
7	Renton Outfall	0 (9/21/99,11/17/99 12/8/99,1/19/00 2/15/00)	0.017 (10/19/99 5/16/00)	0.0081	0.0621 (7/27/99)	0.411 (2/15/00)	0.2577	0.703 (7/27/99)	4.13 (1/19/00)	2.58
6	Fauntleroy/Vashon	0 (9/21/99,11/17/99 12/8/99,1/19/00 2/15/00)	0.0255 (5/16/00)	0.0091	0.0992 (6/20/00)	0.43 (2/15/00)	0.2736	1.07 (7/27/99)	4.1 (2/15/00)	2.64
12	Colvos Passage	0 (11/17/99,12/8/99 1/19/00,2/15/00)	0.0285 (5/16/00)	0.0105	0.145 (7/27/99)	0.44 (2/15/00)	0.2928	1.3 (7/27/99)	4.17 (2/15/00)	2.81

Source: King County Department of Natural Resources, unpublished data

WATER COLUMN NUTRIENT DYNAMICS

Three primary sources of nitrogen and phosphorus exist in coastal waters, including Puget Sound: (1) upwelling of nutrient-rich water; (2) input from land sources; and (3) recycling of nutrients with surface waters and sediments (Harris 1986). Nutrient-rich water from the Pacific Ocean provides a continuous supply of macronutrients to all of Puget Sound except surface waters of some restricted passages and embayments. During times of calm weather or reduced tidal action, the nutrients may also be limiting photosynthesis in surface waters in these areas. Increased river discharge, lack of wind, and neap tidal cycles enhance stratification and slow vertical mixing of nutrients to the surface (Rensel Associates and PTI Environmental Services 1991).

Harrison et al. (1994) presents a review of nutrient inputs from natural and anthropogenic sources in Puget Sound. The review found that the natural inputs of nitrogen to the Central Basin are several orders of magnitude greater than anthropogenic inputs. Anthropogenic sources include wastewater discharges, septic system drainage, stormwater, and non-point runoff from agricultural, residential, and forest lands. As a result, the effects of anthropogenic inputs of nitrogen on the nearshore environment are considered negligible where the Central Basin is well flushed, as it is in most of WRIAs 8 and 9. However, some inlets and bays, particularly in the south Sound, are poorly flushed and show signs of eutrophication. Harrison et al. (1994) include the inner portions of Quartermaster Harbor (reach 11) in the list of potentially nutrient-sensitive areas.

As with nitrogen, the amount of other dissolved nutrients discharged into the Main Basin of Puget Sound from municipal sources is considered small compared with the amount of nutrients from upwelling of deep water and oceanic sources (Duxbury 1975; Collias and Lincoln 1977). Monthly profiles of macronutrients in the Central Basin (Collias and Lincoln 1977) showed major inputs of nitrogen and to a lesser extent phosphorus, related to riverine sources during the winter months. In general, rivers carry proportionately more nitrogen (nitrate and ammonium) than phosphate. N:P ratios of large and small rivers entering Puget Sound are typically greater than 30:1 (Rensel Associates and PTI Environmental Services 1991).

King County has an ongoing sampling program for nutrients in both wastewater effluent and in the waters surrounding wastewater outfalls. Chlorophyll is also sampled. This sampling has not demonstrated any nutrient enrichment impacts near the outfalls. Ammonium levels are sometimes in excess of background near the outfalls; however, this condition seems to be seasonal in nature and is also seen in areas far away from wastewater outfalls. This finding suggests that our knowledge of nutrient dynamics, particularly with regard to ammonium, is lacking (R. Shuman, pers. comm.).

Duxbury (1975) sought to determine trends in nutrients and other factors that could influence, or be affected by, phytoplankton in Puget Sound. Records of orthophosphate and dissolved oxygen concentrations from a depth of 10 m in the Main Basin of Puget Sound during the 1930s were compared with those after 1950. A slight but real trend of increasing orthophosphate concentration between 1937 and 1952 was found. This was followed by a decline between 1952 and 1970, which occurred at the same time as an inverse trend in dissolved oxygen saturation. Further analyses attributed the changes in orthophosphate to interannual variability in the strength of upwelling or influx of seawater, not to anthropogenic effects.

Rensel Associates (1991) determined a relative ranking of potential nutrient sensitivity for monitoring stations from the Department of Ecology's Puget Sound database. The ranking was based on the frequency of dissolved inorganic nitrogen depletion (< 7 uM) between April and November of 1981 and 1985 as well as other indicators (i.e., the frequency of low dissolved oxygen occurrence, probable physical transport based on bathymetry, and frequency of paralytic shellfish poisoning (PSP) toxin in shellfish from algal blooms). From the study area, the potential nutrient-sensitive areas at that time included Quartermaster Harbor (reach 11). Areas unlikely to be nutrient sensitive included Elliott Bay (reach 4), Colvos Passage (reach 12), and the Central Basin of Puget Sound. As part of WDOE's Puget Sound Ambient Monitoring Program, nutrient-sensitive areas were determined based on the occurrence of more than three consecutive months of < 0.01 mg/L dissolved inorganic nitrogen. Based on data from 1996 and 1997, the two stations in the study area—Elliott Bay (reach 4) and West Point (reach 3)—were not considered nutrient sensitive (Newton et al. 1998) at that time.

The MOSS Nearshore Program has recently implemented a water quality sampling program including nutrient sampling (i.e., ammonia, nitrite + nitrate, silica). Data have been collected monthly at selected offshore stations since February 1994. Seasonal trends can be observed (http://www.metrokc.gov/wlr/waterres/marine/marine.htm), with the data showing minimum nutrient concentrations generally appearing in the summer and the maximum concentrations occurring in winter.

WATER QUALITY PROPERTIES

Water quality data in the Duwamish River-Elliott Bay region (reach 4) were summarized in the mid-1980s as part of an evaluation of potential sites for a sewer outfall. Surface temperatures in Elliott Bay-Duwamish Estuary ranged from approximately 8˚C in January and February to 14˚C in July (Stober and Pierson 1984; Dexter et al. 1981; Pavlou et al. 1973; Krogslund 1975). At -50 m the mean temperatures ranged between 8.5˚C in January and February to approximately 12˚C in July. Mean salinity in the surface water ranged from 26.4 parts per thousand (ppt) in January and February to 29.2 ppt in September (Stober and Pierson 1984; Dexter et al. 1981; Pavlou et al. 1973; Krogslund 1975). A significant decline in salinity occurred between February and mid-June. Mean salinity at -50 m ranged from 29.6 ppt in January and December to 30.5 ppt in September (Dexter et al. 1981). Salinity in the surface water also varied with geographic location within Elliott Bay. The freshwater entering Elliott Bay forms a freshwater lens along the shore of the Bay, altering salinity slightly. Dissolved oxygen (DO) concentrations in the surface water ranged from 0.85 mg at/l in December and January to a maximum of 0.98-mg at/l in late May (Stober and Pierson 1984; Dexter et al. 1981; Pavlou et al. 1973; Krogslund 1975). The DO concentration declined from June through September and reached a minimum concentration of 0.56-mg at/l in late August and early September. Oxygen lows in Elliott Bay occurred in the area off Duwamish Head and at the mouth of the Duwamish River (Pavlou et al. 1973).

WDOE's Marine Waters Monitoring Program assesses conventional water quality parameters including DO, nutrients, and fecal coliform. Two water quality stations are located in the WRIA 8 and 9 study area: at West Point in reach 3 and Elliott Bay in reach 4. For stations assessed in water years 1996 and 1997 (Newton et al. 1998), 13 out of 38 stations in Puget Sound showed potential for sensitivity to impacts from eutrophication, including the Elliott Bay station. Because most stations in Puget Sound exhibit a density stratification based on salinity and temperature, all stations were ranked by the following categories: "persistent," which is stratification observed throughout the water year, "seasonal," stratification observed primarily between April and September, "episodic," isolated events or seasonally random, and "weak," relatively well mixed during all observations. The Elliott Bay station was ranked as persistent, while the West Point station was considered episodic. Density stratification was well correlated with low DO concentrations in the Sound. All stations in the Sound (including Elliott Bay) with persistent stratification exhibited low DO except one. Stations with concentrations less than 5 mg/l but greater than 3 mg/l typically reflect the influence of upwelled, naturally low-oxygenated Pacific Ocean waters that flow eastward through the Strait of Juan de Fuca beneath the less saline surface layer flowing west. The deeper water shoals when passing over the sill at Admiralty Inlet and mixes with more oxygenated waters as it enters Puget Sound (Newton et al. 1998). The Elliott Bay station showed a DO concentration of <5 mg/l but > 3 mg/l during three months (10/95, 9/96, 8/97) at depths of 40 m. Before that, only one date since 1992 showed a lower DO concentration. Low DO was also observed at West Point during late summer of 1997. Both the Elliott Bay and West Point stations also show elevated fecal coliform counts (> 50 org/100 ml) during the winter months. This has been persistent since 1993. High counts in the winter are not uncommon in Puget Sound and are associated with high runoff, which transports fecal coliforms to marine waters.

The King County MOSS Program is also collecting measurements of water properties. Water column properties (chlorophyll a, DO, and photosynthetically active radiation [PAR]) are collected monthly (since July 1999) from eight stations within WRIAs 8 and 9. Preliminary data (from July 1999 through June 2000) (King County Department of Natural Resources, unpublished data) shows DO concentrations between 6.0 and 11 mg/l (Table 3); however, these samples were taken from surface waters and are therefore not comparable to Department of Ecology's data discussed above. Chlorophyll concentrations ranged between 0 and 26.1 mg/l with lower concentrations in the summer and higher concentrations in the winter. The MOSS offshore and nearshore sampling programs are ongoing efforts, with additional information being added to the data set on a monthly basis.

Table 3: Water quality properties from the MOSS sampling program

	Water Properties	Chlorophyll-a (mg/m^3)			Dissolved Oxygen (mg/L)			Photosynthetically Active Radiation ($umol/m^2$)		
Reach	**Site**	**Min (Date)**	**Max (Date)**	**Average**	**Min (Date)**	**Max (Date)**	**Average**	**Min (Date)**	**Max (Date)**	**Average**
West of 1	Admiralty Inlet	0.28 (1/18/00)	24.7 (10/20/99)	7.26	7.4 (12/7/99)	11 (7/26/99)	8.6	87.4 (11/15/99)	1710 (8/18/99)	757.0
1	Possession Sound	0.45 (1/18/00)	23.7 (4/17/00)	7.17	5 (10/20/99)	11 (7/26/99)	8.4	72.8 (2/14/00)	1470 (7/26/99)	494.9
2	Point Wells	0.25 (1/18/00)	14.8 (5/15/00)	4.05	6.4 (8/18/99)	10.1 (5/15/00)	8.2	110 (11/15/99)	1350 (7/26/99)	464.7
West of 2	Point Jefferson	0.3 (1/18/00)	26.1 (9/20/99)	7.19	7 (12/7/99)	11 (7/26/99)	8.6	24.7 (2/14/00)	1410 (8/18/99)	618.6
4	West Point Outfall	0.21 (1/18/00)	15.8 (6/19/00)	3.74	6 (10/20/99)	10 (6/19/00)	7.9	108 (11/15/99)	1470 (8/18/99)	659.6
7	Renton Outfall	0.25 (1/19/00)	20.8 (6/20/00)	5.87	6.7 (10/19/99)	10.2 (5/16/00)	8.3	74.8 (12/8/99)	1610 (7/27/99)	779.1
6	Fauntleroy/Vashon	0 (4/18/00)	18.4 (6/20/00)	4.82	6.5 (10/19/99)	9.7 (5/16/00)	7.8	59.7 (12/8/99)	1460 (7/27/99)	789.8
12	Colvos Passage	0.2 (12/8/99)	12.9 (6/20/00)	3.53	6.2 (11/17/99)	8.9 (5/16/00)	7.5	87.9 (12/8/99)	1690 (8/17/99)	911.6

Source: King County Department of Natural Resources, unpublished data.

DATA GAPS

Water property data, including nutrient data, are lacking in the study area. No long-term data of offshore or nearshore water properties exist; therefore, changing conditions and human impacts cannot be evaluated. However, an encouraging first step is the WDOE Marine Water Monitoring program that was initiated in 1992. The program has two approaches: long-term monitoring and focused monitoring. Long-term monitoring consists of visiting numerous selected stations once per month with the goal of establishing and maintaining consistent baseline environmental data. Focused monitoring entails sampling individual locations for a short period of time with increased spatial and temporal resolution relative to long-term monitoring (Newton et al. 1998). This program, however, is focused in offshore waters of Puget Sound. Collection of nearshore data is seriously lacking as well. Most data collected to date have been part of a specific research agenda and in highly localized geographic regions. The recently implemented King County MOSS water quality sampling is collecting valuable data in WRIAs 8 and 9 that will begin to fill a gap in the nearshore data.

KEY FINDINGS

Based on limited data, it appears that nurient dynamics and other water properties may be modified by anthropogenic influences, particularly during seasonal periods with higher runoff. However, seasonal, interannual, geographic and spatial data are lacking to draw definitive conclusions.