Chaetoceros eibenii

Akashiwo sanguinea

Puget Sound Phytoplankton, Nutrients, & Weather

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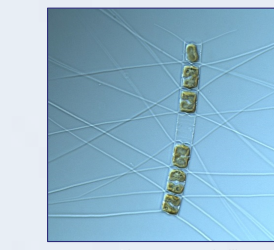
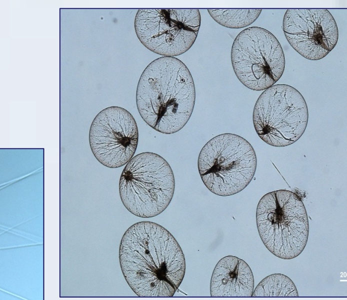


Chaetoceros similis



Noctiluca scintillans

INTRODUCTION

As part of a long-term marine water quality monitoring program, the King County Dept. of Natural Resources & Parks has collected nutrient and chlorophyll data for almost 20 years at multiple subtidal locations in the Puget Sound Central Basin (Figure 1). This monitoring program has yielded a unique dataset for evaluating the effects of both large and local scale climatic conditions on phytoplankton and nutrient dynamics.

It is apparent that weather and climate conditions have played a large role in the timing and extent of phytoplankton blooms in Puget Sound, particularly over the last few years. Phytoplankton seasonal bloom events in 2011 and 2012 were influenced by unusually cold and wet spring weather patterns, with a subsequent effect on nutrient concentrations. The unusually dry and warm 2013 Seattle summer (we actually had a summer!) also had an influence on phytoplankton and nutrients. The long-term nutrient and chlorophyll data, together with more recent phytoplankton community data, were analyzed in conjunction with local weather and large-scale climate patterns over the last few years and the results presented here.

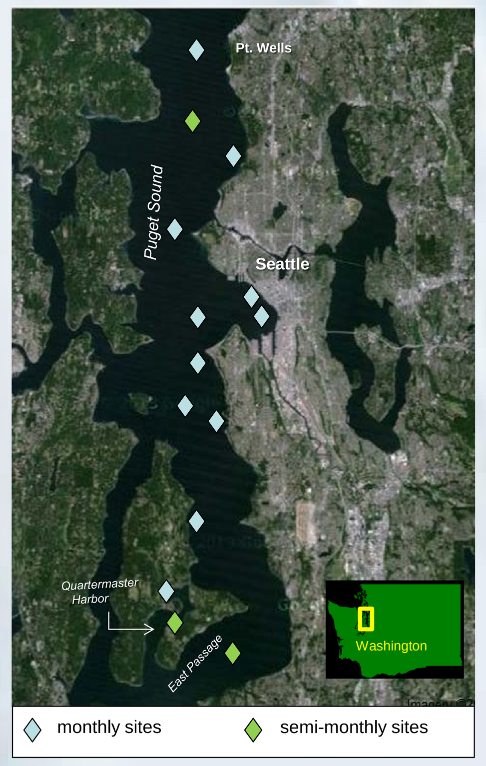


Figure 1. Sampling Locations

DATA PARTICULARS

Table 1 provides a summary of parameters measured for subtidal samples (bacteria & total suspended solids are also analyzed in discrete samples). Only nutrient, chlorophyll, & phytoplankton data are discussed further due to space limitations.

What & When

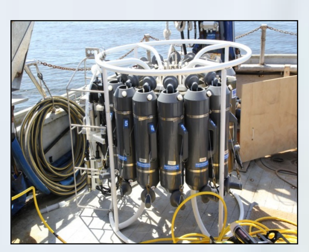
Table 1	General Sampling Location: open water: ambient	open water: outfall *	Elliott Bay **	Quartermaster Harbor
# of sites sampled	3	7	2	2
Sampling record	2 sites 1994-present; 1 site 2003-present	4 sites 1997-present; 3 sites various-present	1997-present	2006-present
Laboratory analyses: discrete samples (up to 7 depths)				
Ammonia nitrogen	●	●	●	●
Nitrate+nitrite nitrogen	●	●	●	●
Silica	●	●	●	●
Orthophosphorus	●	●	●	●
Chlorophyll-*a*	●	●	●	●
Pheophytin	●	●	●	●
Phytoplankton***	●			●
Field analyses began in 1998: water column sampled & binned at 0.5m intervals				
Temperature	●	●	●	●
Dissolved oxygen	●	●	●	●
Light intensity (PAR)	●	●	●	
Transmissivity	●	●	●	
Salinity	●	●	●	●
Chlorophyll	●	●	●	

* 4 WWTP outfalls have continuous discharge; 3 CSO/stormwater outfalls have intermittent discharge

** 1 CSO outfall site with intermittent discharge

*** 2 depths are sampled: 1m & chlorophyll maximum depth, began in 2008

Total phosphorus switched to orthophosphorus in 2010; Total Nitrogen added in 2011



Got Data? You Betcha!

Table 2 shows the amount of nutrient and chlorophyll data collected at each specific depth between 1994 and 2012.

Table 2	Depth 1m	15m	25m	35m	55m	100m	>100m
Nitrate+nitrite							
# of detected values	2056	1866	1805	1806	1653	964	1121
# of non-detected values	194	6	0	0	0	0	1
Total # values	2250	1872	1805	1806	1653	964	1122
Ammonia							
# of detected values	1097	946	935	928	801	530	639
# of non-detected values	1144	920	866	873	843	431	480
Total # values	2241	1866	1801	1801	1644	961	1119
Silica							
# of detected values	2222	1845	1779	1780	1595	936	1096
# of non-detected values	5	0	0	0	0	0	0
Total # values	2227	1845	1779	1780	1595	936	1096
Total Phosphorus							
# of detected values	1770	1547	1514	1515	1394	818	919
# of non-detected values	0	3	0	0	0	0	0
Total # values	1770	1550	1514	1515	1394	818	919
Orthophosphorus							
# of detected values	499	338	308	307	275	156	215
# of non-detected values	1	0	0	0	0	0	0
Total # values	500	338	308	307	275	156	215
Chlorophyll-*a*							
# of detected values	2245	1843	1783	1764	--	--	--
# of non-detected values	4	10	8	16	--	--	--
Total # values	2249	1853	1791	1780	--	--	--

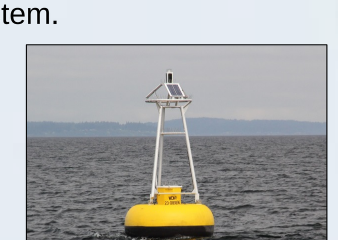
Field & Laboratory Methods

Laboratory methods:

- nutrients analyzed using an Astoria 2 segmented flow autoanalyzer
- chlorophyll-a and pheophytin-a analyzed using a fluorometric method (Turner Designs fluorometer) following cell disruption in an acetone medium using sonication
- phytoplankton identified using a Nikon 50i microscope with DIC and phase-contrast and a Palmer Maloney style chamber, and
- phytoplankton species and/or genera relative abundance assessed by categorizing as dominant, subdominant, present but common, or present.

Field methods:

- a SeaBird SBE 25 Sealogger CTD profiler used to profile water column
- a 12-bottle Niskin rosette used to collect discrete depth samples
- Li-COR LI-190-SA-50 and LI-193-SA-50 used for PAR analysis, and
- In situ monitoring systems comprised of YSI 6600 EDS V2 multi-parameter sondes connected to a remote data acquisition system.



King County

CHLOROPHYLL & PHYTOPLANKTON

Except where noted, the figures below show monthly (semi-monthly at 3 sites) chlorophyll-*a* levels at subtidal sites. These data should be used as an approximation of the occurrence of phytoplankton blooms due to the inadequate sampling frequency (i.e., monthly and even semi-monthly sampling does not always capture bloom activity, particularly blooms that are present on a weekly or less time-scale).

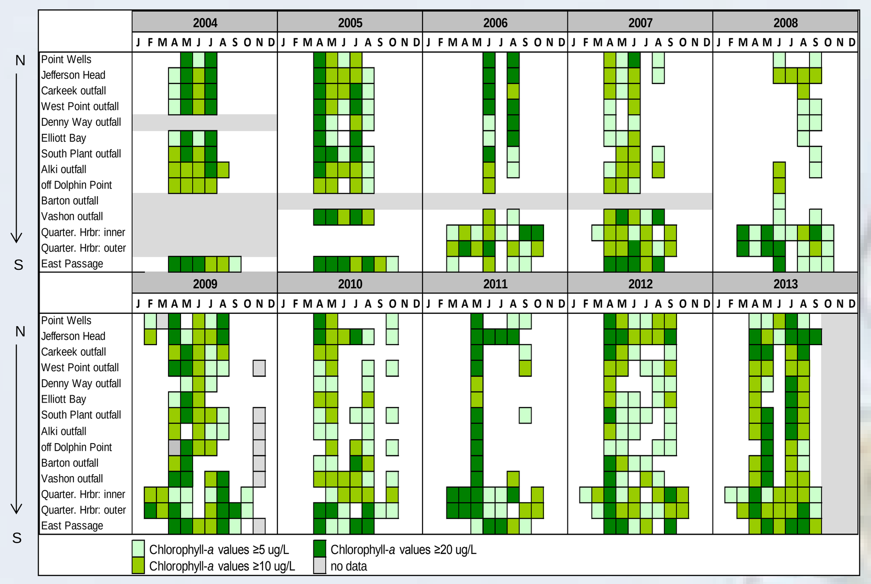


Figure 2 shows monthly chlorophyll-*a* levels since 2004. Months with no colored squares indicate chlorophyll-*a* values were <5 ug/L. Even monthly sampling shows the lack of the 2011 April bloom and large May bloom. The bloomy 2013 summer, thanks to the abnormally warm & dry summer, is also evident throughout the Central Basin.

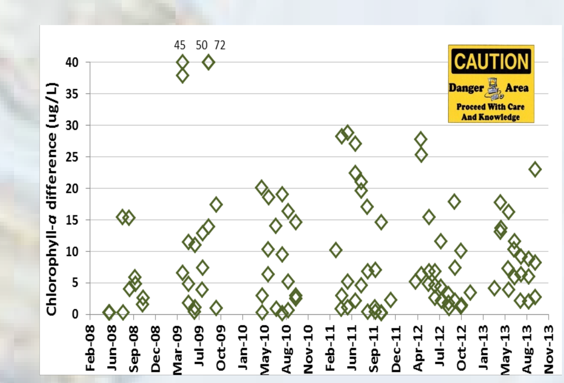


Figure 3 shows the absolute difference between the 1st & 3rd week sampling of each month for the East Passage site. Timing really is everything & there are often substantial concentration differences dependent upon which week sampling took place.

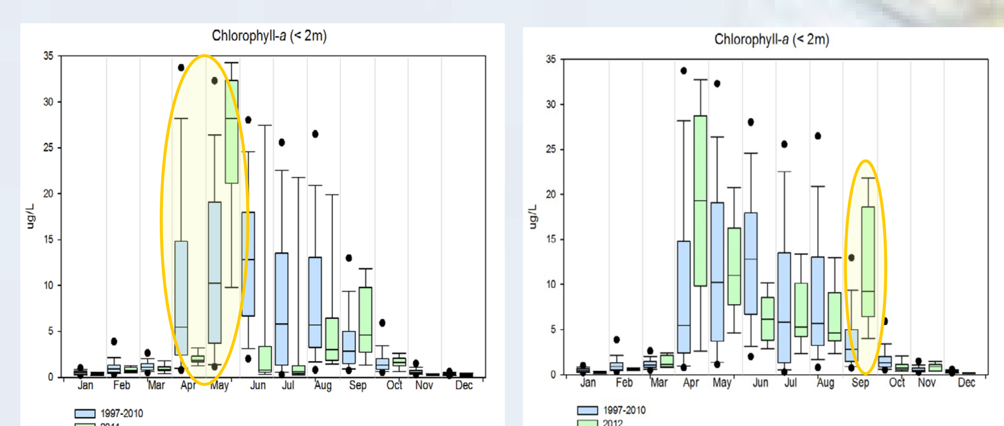


Figure 4 shows 2011 & 2012 chlorophyll-a values compared to a 14-yr baseline for 12 sites combined. Quartermaster Harbor was excluded due to atypical phytoplankton and nutrient dynamics. The typical April spring phytoplankton bloom was not evident in 2011 but was large throughout the Central Basin once the bloom got going in May. The unusually warm & dry 2012 August to early October contributed to the large September bloom.

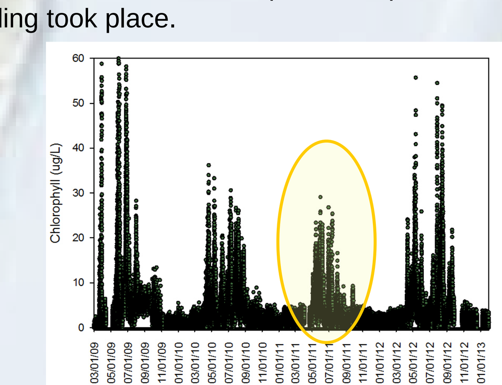


Figure 5 provides 15-minute interval chlorophyll data at 1m in Elliott Bay (Seattle Aquarium mooring) from 2009 through 2012. The delayed spring phytoplankton bloom in 2011 (due to the unusually cold April weather) is shown, as well as overall lower phytoplankton abundance in 2011.

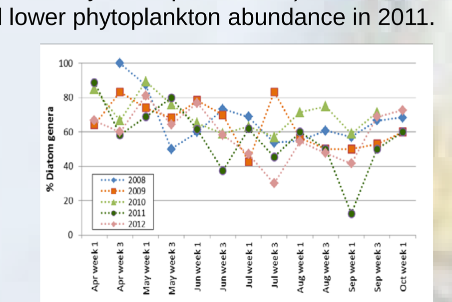
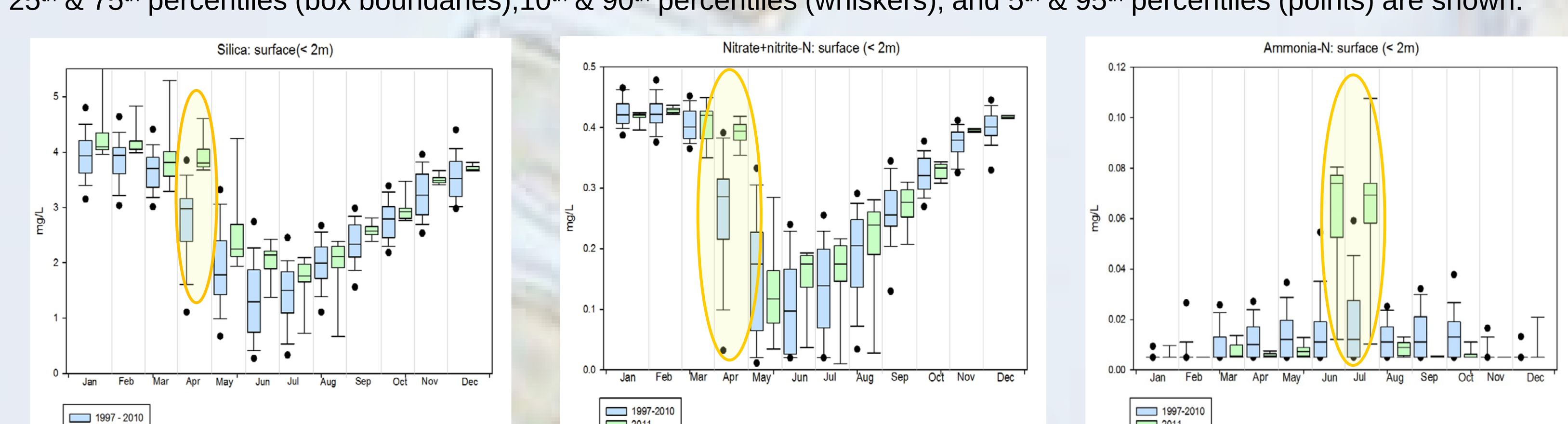


Figure 6 shows the percentage of diatom genera at the Pt. Jefferson site over the last five years. The seasonal transition from mainly diatoms in the spring to dinoflagellates in the summer and fall (mainly in response to nutrient limitation and warm water temperatures) is shown.

NUTRIENTS

Figure 7 below shows seasonal nutrient and chlorophyll patterns in 2011 & 2012 compared to a 14-yr baseline. Surface data were combined from 12 sites (Quartermaster Harbor was excluded due to unusual nutrient dynamics). Median (line within each box), 25th & 75th percentiles (box boundaries),10th & 90th percentiles (whiskers), and 5th & 95th percentiles (points) are shown.

2011

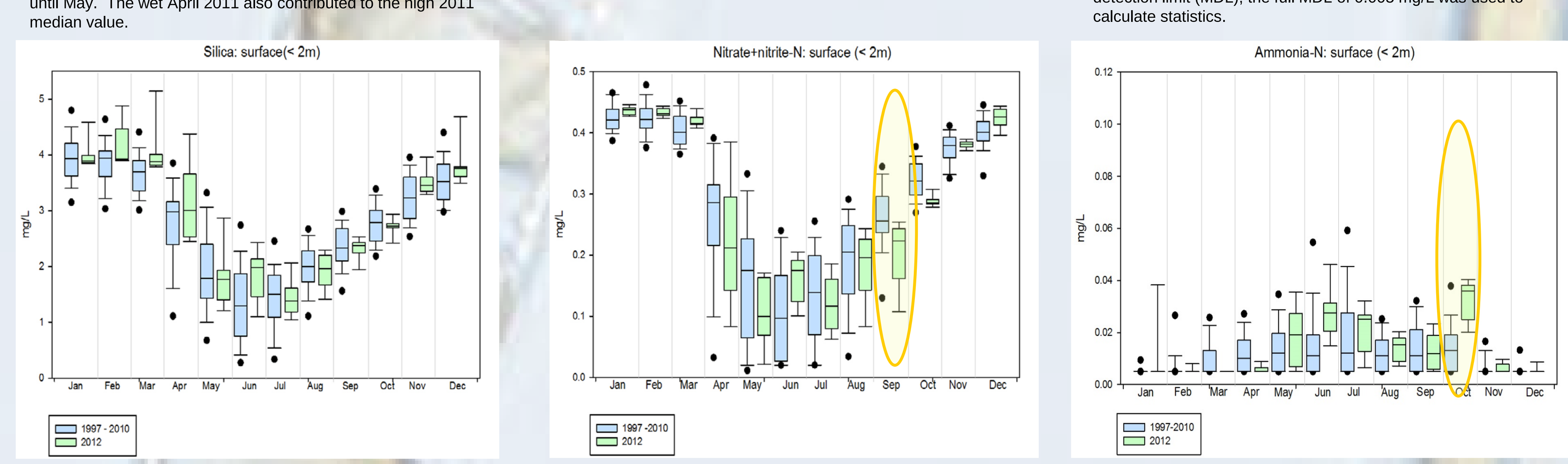


A typical silica drawdown occurs in April from the spring diatom bloom, but was not evident in 2011 as the bloom was delayed until May. The wet April 2011 also contributed to the high 2011 median value.

The lack of the April 2011 spring bloom resulted in increased nitrate/nitrite throughout the Central Basin.

The high ammonia-N values in June & early July followed degradation of the large May bloom. If a value was < method detection limit (MDL), the full MDL of 0.005 mg/L was used to calculate statistics.

2012



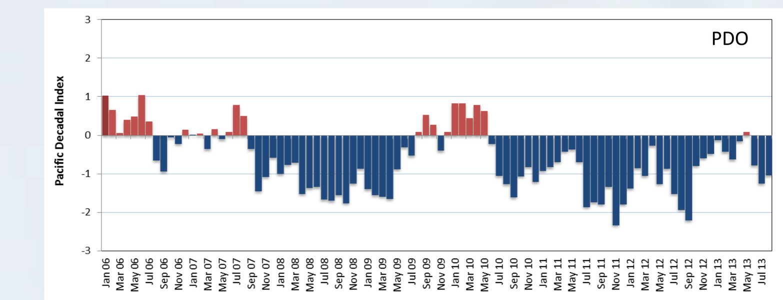
Although not readily discernible on ths graph, the wetter than normal March in both 2011 & 2012 resulted in increased silica, particularly at sites near a freshwater input.

The large September bloom following the warm & dry August-early October caused the September nitrate/nitrite drawdown.

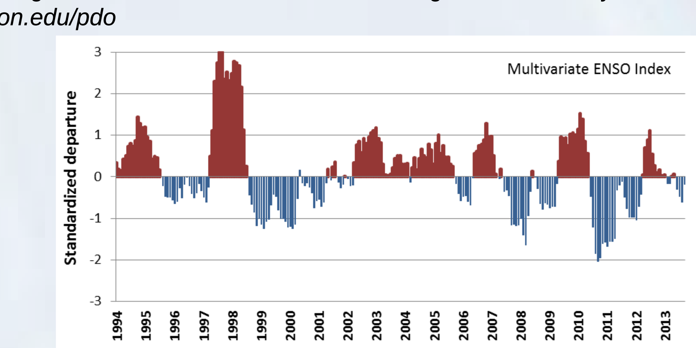
The high ammonia-N values in October followed degradation of the large September bloom.

WEATHER & CLIMATE

The Pacific Decadel Oscillation Index (PDO) and El Niño Southern Oscillation (ENSO) are large-scale climate variations that reflect patterns in the Pacific Ocean sea surface temperatures that can strongly influence atmospheric conditions. PDO climate cycles are on the order of 20-30 years, whereas ENSO cycles typically last around 6-12 months.



In the Pacific Northwest, a positive (warm phase) PDO generally relates with below normal precipitation and above normal air temperatures. A negative (cool phase) corresponds with relatively high precipitation and low air temperatures. The PDO has been mainly negative over the last five years, with the exception of a brief warm phase during the moderate El Niño event from August 2009 to May 2010. *Data source: http://jisao.washington.edu/pdo*



Positive Multivariate ENSO Index (MEI) values indicate warm phases (El Niño) and negative values indicate cool phases (La Niña). The MEI was strongly negative in June/July 2010 and remained negative until February/March 2012. *Data source: http://www.esrl.noaa.gov/psd/enso/mei/table.html*

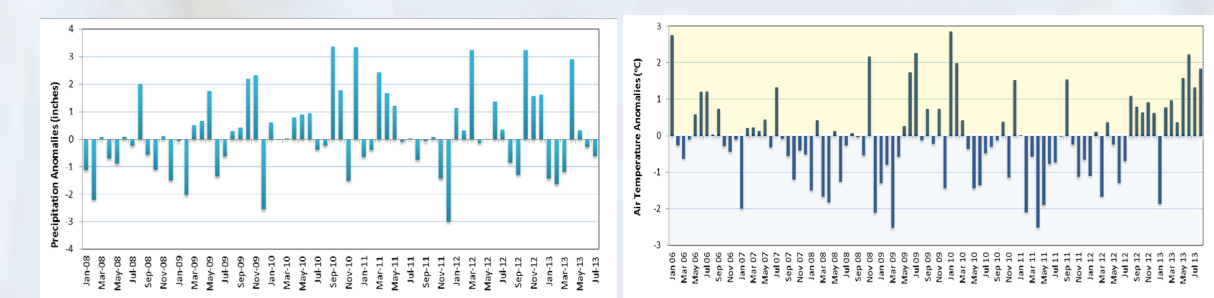


Figure 8 above shows precipitation and air temperature anomalies (departure from 30-year mean) at Sea-Tac airport. Although rainfall and air temperatures vary widely around Puget Sound, a long-term data record exists for the Sea-Tac weather station. The very cold April 2011 and lovely 2013 (so far) can be seen in the air temperature figure. The rainy March 2011 & 2012 can be seen in the precipitation figure. *Data source: http://www.nws.noaa.gov/climate/*

CONNECTIONS

- The strong La Niña in 2010 that persisted through the spring in 2011, along with historic record low air temperatures in April, contributed to the 2011 delay of the spring phytoplankton bloom throughout open waters in the Puget Sound Central Basin (the spring bloom wasn't evident until early May). This delay caused subsequent nutrient anomalies due to lack of phytoplankton uptake. Low phytoplankton abundance (below normal chlorophyll levels) during the latter half of July also resulted in nutrients above typical values.
- The negative phase PDO throughout 2012 and negative ENSO index during the first part of 2012 coincided with cooler than normal air temperatures through July but no observable phytoplankton or nutrient anomalies. The positive ENSO index from April through December 2012 coincided with abnormal dry and warm conditions from August to early October resulting in atypically high chlorophyll and low nitrate/nitrite values in September.
- The effect of 2013 climate conditions on phytoplankton and nutrient levels has yet to be fully assessed, however, the unusually warm May through August led to phytoplankton blooms throughout most of the spring/summer and a subsequent drawdown in nutrients. Many Washingtonians also had tans during this time, another unusual occurrence!

WHAT'S NEXT

- Complete trend and correlation statistical analyses for entire subtidal dataset. We were hoping to have this done by now, but the saying "confidence is the feeling you have before you really understand the problem" is appropriate.
- Expand sampling program to semi-monthly at all sites.
- Use recent (2013-present) quantitative phytoplankton data to assist with nutrient and chlorophyll data interpretation.

ACKNOWLEDGEMENTS

- King County Environmental Laboratory Field Science Unit (sample collection) & Conventionals Unit (sample analyses)
- Wendy Eash-Loucks (QC of Seattle Aquarium mooring data)