2008 – 2010 Marine Phytoplankton Summary

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The following pages provide a summary of phytoplankton data between 2008 and 2010 at three sites within the Puget Sound Central Basin. Sampling and analytical methods are provided in the Sampling and Analysis Plan available at the following web address: http://your.kingcounty.gov/dnrp/library/2008/kcr2077.pdf

Introduction

Phytoplankton are plant-like unicellular organisms that live in oceans, lakes and rivers. They are a critical part of the Puget Sound marine ecosystem, comprising the bottom of the food chain. Most phytoplankton require sunlight and nutrients for growth. Frequent or persistent phytoplankton blooms, however, can be an indicator of eutrophication, a process caused by an over-abundance of nutrients, generally from anthropogenic sources. This can lead to oxygen depletion and, in extreme cases, dead zones.

Relatively little is known about Puget Sound's phytoplankton community structure, particularly the annual and seasonal variability and how variations in nutrient availability affect phytoplankton populations. Most phytoplankton analyses conducted in Puget Sound focus on a few species known to cause harmful algal blooms due to their potential impact on recreational and commercial shellfish and salmon harvest. As such, there is still a need for basic comprehensive information on Puget Sound phytoplankton abundance and diversity,

Phytoplankton cells can reproduce extremely rapidly when light and nutrient conditions are favorable. Capturing their response to nutrients and other factors thus presents a challenge considering the limited temporal and spatial sampling resolution allowed by existing resources. King County began collecting and analyzing phytoplankton samples in 2008 from the three Central Puget Sound locations shown in Figure 1: Point Jefferson (KSBP01), East Passage (NSEX01), and Quartermaster Harbor (MSWH01). The inner Quartermaster Harbor station sampled in 2008 was moved to Dockton Park (NSAJ02) in the mid-harbor starting in 2009. Currently, phytoplankton samples are collected twice a month during the April-through-October bloom season, however, October samples were not collected in 2010.

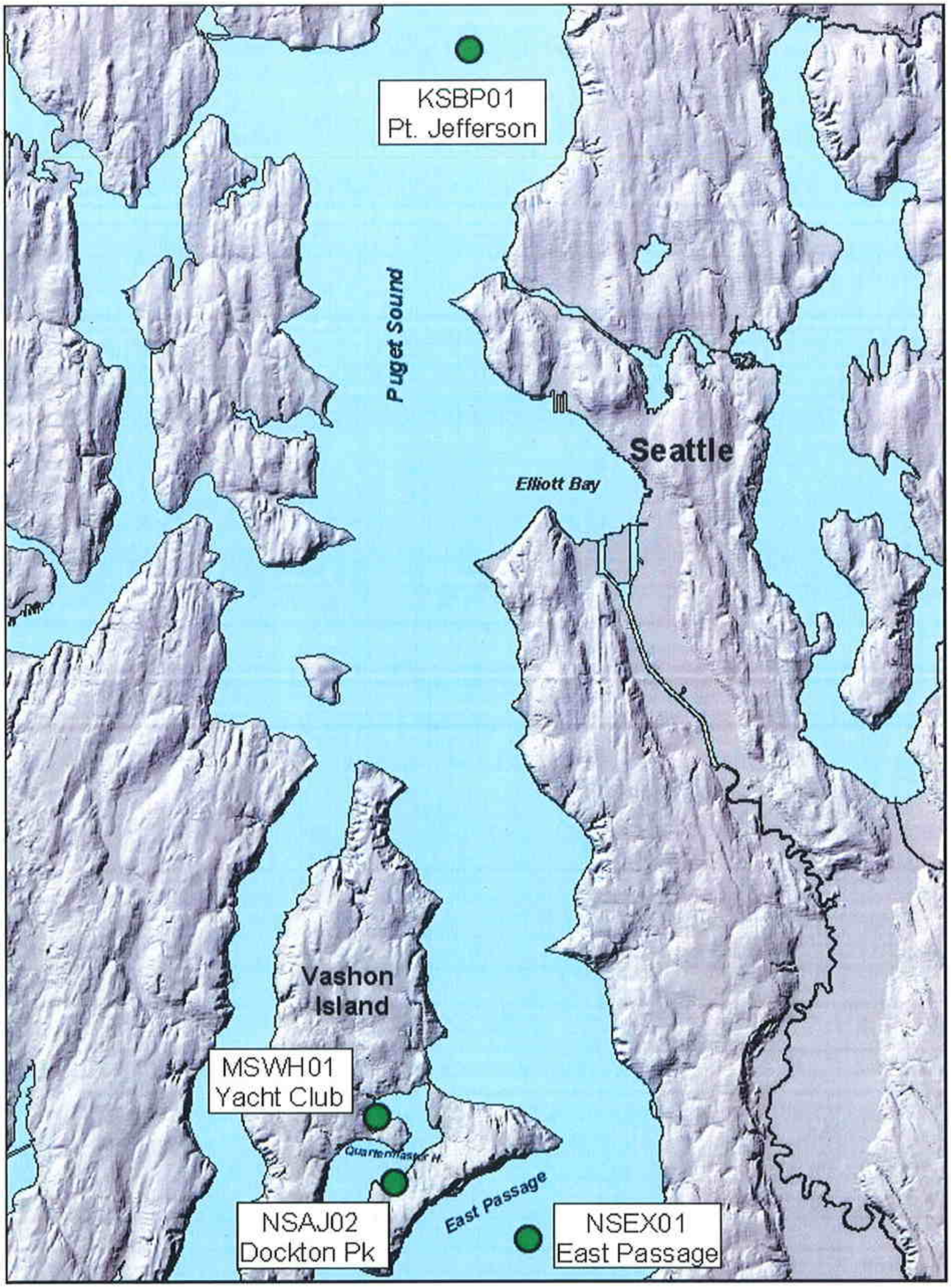


Figure 1. Phytoplankton sampling locations.

The main objectives of the phytoplankton monitoring program are to: assess relative abundance and community composition of the major taxonomic groups at three locations in Central Puget Sound; identify dominant species; document timing of seasonal shifts in major taxonomic groups; and detect long-term changes in taxonomic composition.

The following discussion provides a summary of results from the 2008 through 2010 phytoplankton monitoring seasons. All data are available upon request.

Sample Analysis and Data Limitations

Information obtained from microscopic observations of phytoplankton samples is primarily qualitative but, to a certain degree, semi-quantitative as well. Live and preserved concentrated samples are examined utilizing a compound microscope in order to determine taxon identities as well as relative abundance by tallying at least nine separate microscopic fields at 100-200x magnification. A taxon is categorized as 'dominant' when it is prevalent in at least 50% of examined fields, 'subdominant' when it is prevalent in at least 25% of examined fields, and 'present' when it does not fit into one of the above categories. Species that are common (i.e., in high numbers but not necessarily categorized as dominant) are also noted based upon professional judgment. Data analysis by this methodology provides the following types of information:

- inventory of identified taxa;
- taxa richness (number of species or genera per sample or location, which is an indicator of biodiversity);
- frequency of occurrence (identifies taxa of rare or common occurrence which is a relevant indicator for monitoring of long-term changes in species composition); and
- relative abundance (identifies taxa as dominant, subdominant, or present according to relative cell numbers, which provides information on identity of the major primary producers and bloom-forming species and is pertinent for analyses of trophic structure and anthropogenic impacts).

A limitation of this methodology is that it does not provide absolute cell concentrations or biovolumes that might be useful for primary productivity models and in-depth data analyses. As relative abundance is based on cell number, the method tends to favor small-celled species while large cells, such as *Noctiluca scintillans* and some *Coscinodiscus* species, may never be categorized as dominant even when appearing as blooms. On the other hand, small cells (less than ~7 µm) are often difficult to identify, especially in preserved samples. Therefore, their relative abundances are most likely underestimated. As some cell types do not preserve well, relative abundances may be biased towards easily-preserved cell types, such as diatoms and some armored dinoflagellates. Lastly, marine phytoplankton populations are notoriously patchy in space and time and respond quickly to ambient change and the current biweekly sampling schedule captures just a small portion of this intricate system.

Although the current sampling program has limitations, the data collected so far have already yielded valuable information on phytoplankton diversity and seasonal dynamics at key locations in the Sound.

Identified Taxa

A total of 108 organisms have been identified to at least the genus level from samples collected between 2008 and 2010. Of those, 62 were diatoms, 40 were dinoflagellates, and 6 belonged to other taxa. Ninety organisms were identified down to the species level. Species richness, an indicator of biodiversity, was fairly uniform among the three stations. Point Jefferson (KSBP01) had a total of 63, 77, and 78 species identified to at least the genus level in 2008, 2009, and 2010, respectively, while East Passage (NSEX01) had a total of 59, 75, and 68 species identified to at least the genus level in 2008, 2009, and 2010, respectively. The station in inner Quartermaster Harbor (MSWH01) had the least diversity with only 47 species seen in 2008. However, the Quartermaster Harbor station at Dockton Park (NSAJ02) had 73 and 71 species in 2009 and 2010, respectively, which is similar to the numbers encountered at the two open water stations. The physical characteristics of inner Quartermaster Harbor, such as shallowness and restricted tidal flushing, contribute to the lack of diversity seen at Station MSWH01.

Table 1 provides an alphabetical listing of all identified taxa at the sampling sites from 2008 to 2010. The resolution of microscopic observation may at times be adequate for genus-level identification but preclude species-level identification. As a result, organisms classified as "*Genus* sp." may include one or more unidentified species, which may or may not be on the list of identified species. Thus, a listing of "*Genus* sp." in Table 1 should not be interpreted as a single unidentified species. Similarly, generic categories like "unidentified centric" or "diplopsalid dinoflagellate" contain a mix of cells that could not be identified further.

Species Richness and Seasonal Progression

The number of diatom species was typically greatest during April, May, and June followed by an increase in the number of dinoflagellate species in July and August. Overall, the proportion of diatom species to the total number of species present was highest during the spring bloom for all three years. In 2008 and 2009, the proportion of diatom species was highest during the third week of April; in 2010 this peak was delayed until the first week in May. Table 2 shows species richness and the percentage of diatom species to the overall number of species at each site.

In 2008 at the inner Quartermaster Harbor site, 7 of the 8 (87.5%) identifiable species present on May 6th were diatoms. However, by May 21st, only 4 of the 11 (36.4%) identifiable species present were diatoms, with dinoflagellates and species in other groups more abundant. A similar shift in taxa was also seen at the other two sites in 2008, but not to the same extent as in Quartermaster Harbor.

In 2009, the largest shift from the number of diatom species to dinoflagellate and other species occurred between the third week in June and first week in July at the Point Jefferson station. However, another large species transition occurred at this site two weeks later, during the third week in July, with a 44% increase in the number of diatom species.

Throughout the sampling season in 2010, the proportion of diatoms was generally higher at East Passage than at Point Jefferson. Dockton had a higher percentage of diatoms during the third week of June

Table 1. Identified taxa between 2008 to 2010 (page 1 of 3).

	2008			2009			2010		
	KSBP01	NSEX01	MSWH01	KSBP01	NSEX01	NSAJ02	KSBP01	NSEX01	NSAJ02
Actinoptychus senarius	●	●	●	●	●	●	●	●	●
Akashiwo sanguinea	●	●		●	●	●	●	●	●
Alexandrium sp.	●	●	●			●	●		●
Alexandrium catenella			●					●	●
Amylax triacantha			●		●	●			
Asterionellopsis glacialis				●		●	●	●	●
Asteromphalus heptactis	●	●	●	●	●		●	●	●
Cerataulina pelagica				●	●	●	●	●	●
Ceratium sp.	●				●		●		
Ceratium furca				●					
Ceratium fusus	●	●	●	●	●	●	●	●	●
Chaetoceros (Hyalochaete) sp.	●	●	●	●	●	●	●	●	●
Chaetoceros (Phaeoceros) sp.	●	●	●	●	●	●	●	●	●
Chaetoceros concavicornis	●								
Chaetoceros convolutus		●							
Chaetoceros contortus							●	●	●
Chaetoceros danicus	●			●	●	●			
Chaetoceros debilis	●	●	●	●	●	●	●	●	●
Chaetoceros decipiens	●	●	●	●	●	●	●	●	●
Chaetoceros diadema				●				●	
Chaetoceros didymus				●		●	●	●	●
Chaetoceros eibenii							●	●	●
Chaetoceros laciniosus				●	●	●	●	●	●
Chaetoceros lorenzianus						●		●	●
Chaetoceros radicans	●			●	●	●	●	●	●
Chaetoceros similis	●			●	●	●	●		
Chaetoceros socialis	●	●	●	●	●	●	●	●	●
Chaetoceros teres				●	●			●	
Chaetoceros vanheurckii				●	●	●	●	●	●
Corethron hystrix							●		
Coscinodiscus sp.	●	●	●	●	●	●	●	●	●
Coscinodiscus centralis	●	●							
Coscinodiscus concinnus		●							
Coscinodiscus curvatulus	●	●							
Coscinodiscus granii									●
Coscinodiscus oculus-iridis	●								
Coscinodiscus wailesii	●	●		●	●	●	●		●
Cylindrotheca closterium	●	●	●	●	●	●	●	●	●
Dactyliosolen fragilissimus			●	●	●	●		●	●
Detonula pumila	●	●	●	●		●	●	●	●
Dictyocha fibula	●	●	●	●	●	●			
Dictyocha speculum	●	●	●	●	●	●	●	●	●
Dinophysis sp.	●	●	●	●	●	●	●	●	

Table 1 (cont.). Identified taxa between 2008 to 2010 (page 2 of 3).

	2008			2009			2010		
	KSBP01	NSEX01	MSWH01	KSBP01	NSEX01	NSAJ02	KSBP01	NSEX01	NSAJ02
Dinophysis acuminata				●	●	●	●	●	●
Dinophysis acuta/norvegica				●	●	●	●		
Dinophysis fortii				●	●	●	●		●
Dinophysis rotundata					●		●		●
Dinopysis parva				●	●		●	●	●
Diplopsalid dinoflagellate				●	●	●	●		●
Dissodinium pseudolunula							●		
Ditylum brightwellii	●	●	●	●	●	●	●	●	●
Ebria tripartita	●	●	●						
Eucampia zodiacus	●	●	●	●	●	●	●	●	●
Gonyaulax sp.		●		●	●		●		
Gonyaulax digitale							●	●	●
Guinardia delicatula		●		●	●	●	●		●
gymnodinioid dinoflagellate				●	●	●	●	●	●
Gymnodinium sp.	●	●	●	●	●	●	●		●
Gymnodinium gracile							●		
Gyrodinium sp.	●			●	●	●	●	●	●
Gyrodinium spirale	●	●		●	●	●	●	●	●
Hemiaulus hauckii	●	●					●	●	●
Heterocapsa triquetra	●		●	●	●	●	●		
Heterosigma akashiwo	●	●	●	●	●	●			
Lauderia annulata			●	●	●	●	●	●	●
Leptocylindrus danicus	●	●	●	●	●	●	●	●	●
Leptocylindrus minimus				●	●	●			
Melosira moniliformis					●		●	●	
Meringosphaera mediterranea			●		●	●		●	●
Nitzschia acicularis	●	●	●	●	●	●	●	●	●
Noctiluca scintillans	●	●	●	●	●	●	●	●	●
Odontella longicruris	●	●		●	●	●	●	●	●
Oxyphysis oxytoxoides	●	●	●	●	●	●	●		
Oxytoxum sp.				●		●			●
Paralia sulcata		●		●	●		●	●	●
Phaeocystis sp.	●			●			●		●
Pleurosigma sp.	●	●	●	●	●	●	●	●	●
Polykrikos schwartzii								●	
Prorocentrum gracile	●	●	●	●	●	●	●	●	●
Prorocentrum micans	●								
Protoceratium reticulatum				●	●	●	●		
Protoperidinium sp.	●	●	●	●	●	●	●	●	●
Protoperidinium brevipes		●	●		●	●			
Protoperidinium conicum	●	●	●	●	●	●	●	●	●
Protoperidinium depressum	●	●	●	●	●	●	●	●	●
Protoperidinium excentricum	●								
Protoperidinium leonis		●		●				●	

Table 1 (cont.). Identified taxa between 2008 to 2010 (page 3 of 3).

	2008			2009			2010		
	KSBP01	NSEX01	MSWH01	KSBP01	NSEX01	NSAJ02	KSBP01	NSEX01	NSAJ02
Protoperidinium oblongum								●	●
Protoperidinium oceanicum		●		●	●	●			
Protoperidinium steinii	●	●	●	●	●	●	●	●	●
Pseudo-nitzschia sp. (large)	●	●	●	●	●	●	●	●	●
Pseudo-nitzschia sp. (small)	●	●		●	●	●	●	●	
Pseudo-nitzschia americana				●	●	●	●	●	●
Pyrophacus horologium	●	●	●						
Rhizosolenia setigera	●	●	●	●	●	●	●	●	●
Scrippsiella trochoidea	●	●	●	●	●	●	●	●	●
Skeletonema costatum	●	●	●	●	●	●	●	●	●
Stephanopyxis nipponica	●	●		●	●	●	●		
Stephanopyxis palmeriana	●	●		●	●	●	●	●	●
Thalassionema nitzschioides	●	●	●	●	●	●	●	●	●
Thalassiosira sp.	●	●	●	●	●	●	●	●	●
Thalassiosira anguste-lineata	●	●	●	●	●	●	●	●	●
Thalassiosira eccentrica			●						
Thalassiosira nordenskioeldii	●			●	●	●	●	●	●
Thalassiosira pacifica/aestivalis							●	●	●
Thalassiosira punctigera	●	●		●	●	●	●	●	●
Thalassiosira rotula	●	●	●	●	●	●	●	●	●
Tropidoneis antarctica	●	●		●	●	●	●	●	●
unidentified centric	●	●	●	●	●	●		●	
unidentified dinoflagellate (<25 um)	●	●	●	●	●	●	●	●	●
unidentified dinoflagellate (>25 um)	●	●	●	●	●	●	●	●	●
unidentified nanoflagellates	●	●	●	●	●	●	●	●	●
unidentified pennate	●	●	●	●	●	●	●	●	●

Note: The resolution of microscopic observation may at times be adequate for genus-level but not species-level identification. Generic categories like "unidentified centric" or "diplopsalid dinoflagellate" contain a mix of cells that could not be identified further.

through the first week in July than the other two sites, particularly in July. For all three sites, particularly East Passage, the ratio of diatom species to the total number of species was higher in 2010 than in the previous two years and large fluctuations (>25%) between the number of diatom and dinoflagellate species from week to week were not seen.

The chrysophyte *Meringosphaera mediterranea* was observed in all three years but only at the Quartermaster Harbor and East Passage stations and never at the northern Point Jefferson station. This species was seen in East Passage in the months of June or September but earlier in the season in April and May in Quartermaster Harbor.

Table 2. Species richness and proportion of diatoms throughout the sampling season.

Total # of Species *	week	2008 KSBP01	2008 NSEX01	2008 MSWH01	2009 KSBP01	2009 NSEX01	2009 NSAJ02	2010 KSBP01	2010 NSEX01	2010 NSAJ02
April	1	--	--	15	20	25	26	32	36	22
	3	3	7	--	28	24	14	34	34	27
May	1	9	29	8	35	26	25	25	34	31
	3	18	12	11	31	18	14	42	42	21
June	1	--	--	--	36	39	22	39	32	20
	3	24	22	13	32	34	17	28	27	17
July	1	23	12	15	27	14	10	30	23	17
	3	17	17	13	23	17	20	26	23	12
August	1	24	25	22	33	17	9	23	21	17
	3	41	21	20	19	24	11	32	35	20
September	1	15	22	17	--	29	20	34	37	26
	3	35	27	10	18	30	17	27	29	18
October **	1	23	30	18	30	30	20	--	--	--

? 15	16 - 29	? 30

% Diatom Species	week	2008 KSBP01	2008 NSEX01	2008 MSWH01	2009 KSBP01	2009 NSEX01	2009 NSAJ02	2010 KSBP01	2010 NSEX01	2010 NSAJ02
April	1	--	--	46.7	75.0	68.0	76.9	87.5	86.1	86.4
	3	100.0	85.7	--	89.3	83.3	92.8	73.5	79.4	77.8
May	1	88.9	72.4	87.5	77.1	76.9	76.0	92.0	88.2	87.1
	3	55.6	58.3	36.4	77.4	83.3	85.7	80.9	85.7	90.5
June	1	--	--	--	77.8	61.2	63.6	71.8	87.5	80.0
	3	75.0	72.7	76.9	71.9	61.8	52.9	64.3	66.7	76.5
July	1	65.2	41.7	73.3	40.7	57.1	30.0	60.0	52.2	76.5
	3	52.9	58.8	46.2	87.0	58.8	45.0	57.7	82.6	66.7
August	1	50.0	60.0	45.4	54.5	47.0	55.6	69.6	85.7	64.7
	3	63.4	57.1	45.0	47.4	58.3	27.3	81.2	80.0	85.0
September	1	66.7	68.2	35.3	--	65.5	50.0	64.7	67.6	73.1
	3	65.7	66.7	40.0	55.6	63.3	58.8	70.4	75.9	50.0
October **	1	73.9	73.3	72.2	70.0	63.3	45.0	--	--	--

? 50	51 - 74	? 75

* Total # of species that were identified to either genus or species.

** October 2009 is week 3.

"—" Denotes not sampled.

The raphidophyte *Heterosigma akashiwo* was seen at all three sites but only during the summer to early fall months (July to September). Of note is that when observed, this species was dominant 50% of the time.

The majority of dinoflagellates were seen in the latter part of the sampling season, such as *Dinophysis parva*, that was only seen in either July or August.

Relative Abundance: Dominant Taxa and Blooms

Between 2008 and 2010, diatoms dominated throughout most of the sampling season, with *Chaetoceros Hyalochaete* species often comprising the dominant group from April through June. This was particularly true for 2010 at all three sampling locations. Of note, *Chaetoceros* is a very large, cosmopolitan genus that is often abundant in coastal and inland waters. Horner (2002) lists 19 species for the Pacific Northwest, most in the subgenus *Hyalochaete*. While phytoplankton sampling began the first week of April each year in order to capture the large spring bloom, chlorophyll-*a* values for 2008 and 2009 suggest that diatoms were already abundant in mid to late March at Point Jefferson and Quartermaster Harbor.

In 2010, *Chaetoceros Hyalochaete* was the dominant species group for 9 of the 12 weeks sampled (8 of 12 samples at Point Jefferson). The first week in July 2010 was an exception, with the large species of *Pseudo-nitzschia* sp. being dominant at Point Jefferson and *Chaetoceros convolutus* dominating at the other two stations. Besides *Chaetoceros Hyalochaete* spp., several other diatom taxa repeatedly displayed high relative abundances (were categorized as dominant or subdominant), most notably *Rhizosolenia setigera*, *Detonula pumila*, *Skeletonema costatum*, and *Thalassiosira* spp. (Table 3). *Detonula pumila* was repeatedly dominant at both Point Jefferson and inner Quartermaster Harbor, but only in 2008. A few diatom species, such as *Coscinodiscus* spp. and *Thalassionema nitzschiodes*, were only dominant at the inner Quartermaster Harbor site in 2008. The large forms of *Pseudo-nitzchia* were repeatedly dominant at Point Jefferson for all three years sampled and at Dockton Park once in October 2009.

Dinoflagellate relative abundance did not increase until summer in all three sampling years. The first week in July was the earliest any dinoflagellate species was either dominant or subdominant between 2008 and 2010. The most frequent dominant and/or subdominant dinoflagellate species were *Ceratium fusus* at the two open water stations and *Prorocentrum gracile* in Quartermaster Harbor. In 2008, dinoflagellates tended to dominate in inner Quartermaster Harbor from late July through early October. Dinoflagellates or the raphidophyte *Heterosigma akashiwo* tended to dominate from late August through September in 2008 and 2009, whereas diatoms remained dominant all throughout 2010. Some of the dominance patterns noted correspond to occasional mono-specific blooms which are typically sporadic, vary from year to year, and may be localized or span a large area within the basin. Examples of this are the blooms of *Akashiwo sanguinea* and *Alexandrium catenella* in 2008 and *Heterosigma akashiwo* in 2009. Diatoms also exhibited this mono-specific bloom pattern as seen with *Detonula pumila* in 2008, *Prorocentrum gracile* in 2009, and *Chaetoceros convolutus* in 2010. *Alexandrium catenella*, a toxin-producing dinoflagellate, has only been abundant in Quartermaster Harbor where cysts in the sediment help maintain a resident population. *Heterosigma akashiwo* is a harmful alga that frequently forms blooms in Puget Sound; the 2009 August bloom was widespread and spanned all three sampling sites.

Noctiluca scintillans is a large dinoflagellate that turns the water a reddish, tomato soup color when it forms dense concentrations. It is present throughout most of the sampling season, usually forming blooms in June and/or July. Particularly large blooms were observed at both Point Jefferson and East Passage on July 21, 2008 yet this species never received a 'dominant' categorization due to the methodology used for the abundance classification. Relative abundance classifications are based on the

Table 3. 2008--2010 Dominant and subdominant species (a blank box indicates no species was dominant).

		2008		
	week	Pt. Jefferson	East Passage	Quartermaster H.
April	1			*Coscinodiscus* spp.
	3			
May	1	*Thalassiosira* spp. *Detonula pumila*		*Detonula pumila*
	3	*Detonula pumila*		*Detonula pumila*
June	1			
	3	*Skeletonema costatum*	*Thalassiosira* spp.	*Thalassionema nitzschioides*
July	1	*Skeletonema costatum*		*Rhizosolenia setigera* *Chaetoceros (Hyalochaete)* spp.
	3	*Cylindrotheca closterium*	*Rhizosolenia setigera*	
August	1	*Detonula pumila* *Chaetoceros (Hyalochaete)* spp.	*Skeletonema costatum*	*Prorocentrum gracile*
	3	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp. *Ceratium fusus* unident. dinoflagellate(>25um)	*Chaetoceros (Hyalochaete)* spp. *Leptocylindrus danicus*
September	1	*Ceratium fusus* *Akashiwo sanguinea*	*Ceratium fusus* *Akashiwo sanguinea* *Thalassiosira sp.*	*Heterosigma akashiwo* *Prorocentrum gracile*
	3	*Ceratium fusus* *Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp. *Pseudo-nitzschia* spp. (large)	*Alexandrium catenella*
October	1	*Chaetoceros (Hyalochaete)* spp. *Pseudo-nitzchia* spp. (large)	*Chaetoceros (Hyalochaete)* spp.	*Alexandrium* sp.

		2009		
	week	Pt. Jefferson	East Passage	Quartermaster H.
April	1	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
	3	*Chaetoceros (Hyalochaete)* spp. *Thalassiosira spp.*	*Chaetoceros (Hyalochaete)* spp.	*Skeletonema costatum*
May	1	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
	3	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
June	1	*Chaetoceros (Hyalochaete)* spp. *Pseudo-nitzschia* spp. (large)	*Chaetoceros (Hyalochaete)* spp.	*Rhizosolenia setigera* *Chaetoceros (hyalochaete)* spp.
	3	*Rhizosolenia setigera* *Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Rhizosolenia setigera*
July	1	unident. dinoflagellate(<25um) *Prorocentrum gracile*		*Prorocentrum gracile*
	3	*Pseudo-nitzschia* spp. (large)	*Ceratium fusus* *Coscinodiscus wailesii*	*Chaetoceros (Hyalochaete)* spp.
August	1	*Thalassiosira rotula*		*Leptocylindrus danicus*
	3	*Heterosigma akashiwo*	*Heterosigma akashiwo*	*Heterosigma akashiwo*
September	1		*Heterosigma akashiwo*	unidentified dinoflagellate
	3			
October	3		*Leptocylindrus minimus* *Thalassiosira* spp.	*Chaetoceros (Hyalochaete)* spp. *Pseudo-nitzchia* spp.(large)

not sampled
black text = dominant
blue text = subdominant

Table 3 (cont.). 2008--2010 Dominant and subdominant species (a blank box indicates no species was dominant).

	week	2010 Pt. Jefferson	2010 East Passage	2010 Quartermaster H.
April	1	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros socialis*
	3	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
May	1	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
	3	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
June	1	*Chaetoceros (Hyalochaete)* spp. *Pseudo-nitzschia* spp. (large)	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
	3	*Chaetoceros (Hyalochaete)* spp. (subdominant) *Eucampia zodiacus* (subdominant)	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
July	1	*Pseudo-nitzschia* spp. (large)	*Chaetoceros convolutus*	*Chaetoceros convolutus*
	3		*Eucampia zodiacus* *Chaetoceros (Hyalochaete)* spp. (subdominant)	*Chaetoceros (Hyalochaete)* spp.
August	1	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
	3	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
September	1	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.	*Chaetoceros (Hyalochaete)* spp.
	3			
October	1	not sampled	not sampled	not sampled

not sampled
black text = dominant
blue text = subdominant

number of cells present, regardless of size. Individual *Noctiluca scintillans* cells are quite large (they can be up to 2 mm) and the 'present in >50%' of the subsample criterion is not achieved due to their size. However, although never classified as 'dominant' according to the methodology, the taxonomist noted when *Noctiluca scintillans* was present in sufficient numbers indicative of a bloom.

Quartermaster Harbor Mooring Data

In vivo chlorophyll-*a* fluorescence data (a semi-quantitative measure of phytoplankton biomass) collected in inner Quartermaster Harbor at 15-minute intervals in 2008 indicated a phytoplankton bloom from mid early to late March. A large phytoplankton bloom also occurred in April, then smaller blooms were seen throughout the summer with another large bloom occurring in the fall. The April bloom was dominated by the diatom *Coscinodiscus* with diatoms comprising half of the taxa present. In contrast, the mid-September fall bloom was dominated by the dinoflagellate *Alexandrium catenella* and 54% of the species present were dinoflagellates.

In vivo chlorophyll-*a* fluorescence data collected at Dockton Park at 15-minute intervals in 2009 indicated phytoplankton blooms from mid to late February and from mid to late March. A large phytoplankton bloom occurred in mid April and likely consisted largely of *Chaetoceros Hyalochaete* species and *Skeletonema costatum* as well as other diatoms. Chlorophyll-*a* levels remained elevated until mid to late October at this site. Although *Chaetoceros Hyalochaete* species and the large form of *Pseudo-nitzschia* were the most abundant component of the fall bloom at this site (see Table 3), the majority of the total species present were dinoflagellates.

Frequency of Occurrence

Species of the centric diatom *Chaetoceros* subgenus *Hyalochaete* were the most common (i.e., most frequently observed) and widespread. They were recorded in the majority of samples for all years and in over 89% of the samples from each sampling location. The large forms of the pennate diatom *Pseudo-nitzschia* were also present in most of the samples: 77% from Point Jefferson and East Passage and 64% from Quartermaster Harbor. The diatom *Cylindrotheca closterium* was also common at all three stations. Table 4 shows species that were present in over 50% of the total number of samples collected each year at each site.

Several diatom species, such as the centrics *Coscinodiscus* spp., *Chaetoceros* subgenus *Phaeoceros* and *Skeletonema costatum* were common at Point Jefferson and East Passage but not in Quartermaster Harbor. On the other hand, *Alexandrium catenella* (dinoflagellate), *Amylax triacantha* (dinoflagellate), *Meringosphaera mediterranea* (chrysophyte), and *Protoperidinium oblongum* (dinoflagellate) were seen only in samples from the southern East Passage and Quartermaster Harbor stations and not at the northern Point Jefferson station.

Some species were only identified at a specific site or in a given year, as they are either uncommon or their correct identification presents a challenge. Table 5 shows species that were only observed either once or twice at a particular location. Most of these species occurred at the northern Point Jefferson station (KSBP01) where species diversity tended to be the highest.

Potentially Harmful Phytoplankton Species

Several species, primarily dinoflagellates, have the ability to produce toxins which are harmful to marine organisms, either directly or indirectly (through the ingestion of shellfish that bioaccumulate toxins in their tissues). Toxins in shellfish may also be harmful to humans if sufficient concentrations are ingested. There are non-toxin producing species that can be harmful to fish, primarily farmed fish contained in small areas, as these species can clog or injure the gills causing irritation, hemorrhaging, and mucus production.

Several species capable of producing toxins were observed at the sampling sites between 2008 and 2010. These species include *Alexandrium* spp., *Pseudo-nitzschia* spp., *Dinophysis* spp., and *Protoceratium reticulatum*. *Heterosigma akashiwo* is capable of causing fish mortality but the toxicity mechanism is unknown. The toxicity mechanism of *Ceratium fusus* is also unknown, but this species has been linked to mortality of larval invertebrates.

Alexandrium was found at all three sites in 2008 and 2010 but only at the Quartermaster Harbor site in 2009. This species was dominant at the Quartermaster Harbor site in 2008 during the late fall months. The large form of *Pseudo-nitzschia* was found at all sites and years and, as stated previously, was dominant at the Point Jefferson station in October 2008, June 2009, and in July of both 2009 and 2010. This species was also dominant at the Quartermaster Harbor site in October 2009. Several of the *Dinophysis* species known to produce toxins were seen at all sites and in all years, but never in sufficient numbers to be categorized as dominant. *Protoceratium reticulatum* was observed at all three sites in

Table 4. Common taxa: genera or species present in over 50% of samples collected each year.

	KSBP01			NSEX01			Quartermaster H.		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
Diatoms:									
Actinoptychus senarius		●	●						
Asteromphalus heptactis					●	●			
Chaetoceros (Hyalochaete) sp.	●	●	●	●	●	●	●	●	●
Chaetoceros (Phaeocerus) sp.		●	●	●		●			
Chaetoceros debilis		●	●		●	●	●		●
Chaetoceros decipiens			●			●			
Chaetoceros didymus									●
Chaetoceros eibenii						●			
Chaetoceros socialis			●			●			
Chaetoceros vanheurckii			●			●			●
Coscinodiscus sp.	●	●	●	●	●				
Cylindrotheca closterium	●		●	●	●	●	●	●	●
Detonula pumila				●					
Ditylum brightwellii	●		●	●		●			●
Eucampia zodiacus		●	●			●			●
Guinardia delicatula		●							
Hemiaulus hauckii			●						
Leptocylindrus danicus			●			●			
Nitzschia acicularis					●				
Pleurosigma sp.		●							
Pseudo-nitzschia americana						●			
Pseudo-nitzschia sp. (large)	●	●	●	●	●	●	●	●	●
Rhizosolenia setigera		●			●			●	
Skeletonema costatum	●	●	●	●	●				
Thalassionema nitzschioides	●	●	●	●	●	●	●		
Thalassiosira nordenskioeldii						●			
Thalassiosira rotula		●		●					
Thalassiosira sp.	●	●	●	●	●	●	●	●	
Dinoflagellates:									
Ceratium fusus	●		●	●	●	●	●		
Dinophysis acuminata					●				
Dinophysis acuta/norvegica					●				
Dinophysis sp.	●			●			●		
Noctiluca scintillans			●						
Prorocentrum gracile	●						●		
Protoperidinium conicum	●			●		●	●		
Protoperidinium depressum	●			●	●				
Protoperidinium sp.		●	●			●			
Protoperidinium steinii	●	●	●	●		●	●		
Scrippsiella trochoidea	●	●						●	
Silicoflagellates:									
Dictyocha speculum				●					

2009 and at the Point Jefferson site in 2010. *Heterosigma akashiwo* was seen at all three sites in 2008 and 2009 and dominated at all the sites in late August 2009. This species continued to dominate at the East Passage station into the early September 2009. *Ceratium fusus* was found at all sites and years and was dominant at the two main channel stations in September 2008 and July 2009.

Chaetoceros convolutus and other species in the subgenus *Phaeoceros* do not produce toxins but can cause stress and mortality to farmed fish. The spines on the cells can penetrate or clog fish gills, causing irritation and mucus production and ultimately death. Species in the *Chaetoceros Phaeoceros* group were seen at all sites and in all years, but were rarely dominant. The only time a member of this group (*Chaetoceros convolutus)* was dominant was in early July 2010 at both the East Passage and Quartermaster Harbor stations.

The dinoflagellate *Akashiwo sanguinea* does not produce a toxin but can produce a water-soluble surfactant material that can cause seabird mortalities when blooms are substantial. The surfactant causes feathers to lose their water-repellent and insulative properties and the birds can die from hypothermia. This species was found at most sites in all years, and was dominant at the two main channel stations in September 2008. However, no seabird deaths caused by this bloom were reported.

Phaeocystis spp. is another genus that does not produce toxins, but does produce other substances and mucilage that can clog the gills of fish and shellfish, causing mortality. *Phaeocystis* spp. was seen at the Point Jefferson station in all three years and at the Quartermaster Harbor site in 2010, but never in sufficient numbers to be categorized as dominant.

Table 5. Infrequently observed species.

Species Name	Where Found	When Detected
Ceratium furca	Pt. Jefferson	Oct-09
Chaetoceros concavicornis	Pt. Jefferson	Jun-08
Corethron hystrix	Pt. Jefferson	Apr-10
Coscinodiscus oculus-iridis *	Pt. Jefferson	May-2008; Aug-2008
Dissodinium pseudolunula	Pt. Jefferson	Aug-10
Gymnodinium gracile	Pt. Jefferson	May-2010; Jun-2010
Prorocentrum micans	Pt. Jefferson	Sep-08
*Protoperidinium excentricum**	Pt. Jefferson	Sep-08
*Coscinodiscus concinnus**	East Passage	Sep-08
Polykrikos schwartzii	East Passage	Jun-2010; Sep-2010
*Coscinodiscus granii**	Dockton Pk.	Sep-10
*Thalassiosira eccentrica**	inner Quartermaster H.	Jul-08

* tentative identification

Nutrients and Chlorophyll-*a*

Nutrients, nitrogen and silica in particular, showed seasonal variation that reflected changes in phytoplankton abundance. Nitrate/nitrite and silica concentrations were highest from late fall through winter when phytoplankton abundance was the lowest. Conversely, the lowest nutrient concentrations occurred when phytoplankton abundance was high, especially during the spring and summer blooms. Figure 2 shows the relationship between nitrate/nitrite and chlorophyll-*a* based upon monthly data from the upper six meters of the water column at the Point Jefferson Site. Figure 3 shows the same relationship for silica.

Nitrate/nitrite and silica show a similar seasonal pattern, as shown in Figure 4, for the East Passage station, however, nutrient dynamics in Quartermaster Harbor differ from the other two sites (Figure 5). Quartermaster Harbor has extended periods of nitrate depletion generally lasting from March through September, corresponding to a longer and more intense phytoplankton bloom season. In addition, silica values are often below 1.0 mg/L during times when diatoms are the dominant species and chlorophyll-*a* levels are high. Figure 6 shows *in vivo* chlorophyll-*a* data (measured by fluorescence at 15-minute intervals) at Dockton Park in 2009 and 2010. Although chlorophyll-*a* data collected by a fluorometer is only semi-quantitative, the general seasonal pattern can be discerned with the early start and late end to the bloom season. Table 6 shows monthly chlorophyll-*a* concentration ranges for all sites and years.

The phytoplankton bloom at Point Jefferson during June 2009, comprised mainly of the diatoms *Rhizosolenia setigera* and *Chaetoceros Hyalochaete* spp., was so large that both nitrate and silica were depleted to levels below method detection limits (0.01 and 0.05 mg/L, respectively). A bloom of the large form of *Pseudo-nitzschia* was likely responsible for the depletion of nitrate and silica from surface waters at this location in July 2010. *Thalassionema nitzschiodes* in June 2008 and *Rhizosolenia setigera* and *Chaetoceros Hyalochaete* in July 2008 in inner Quartermaster Harbor were the species likely responsible for the depletion of nitrate and silica from surface waters at this location.

When nutrients are not limiting, the molar element ratio carbon: nitrogen: phosphorus (C:N:P) in most phytoplankton is 106:16:1 (Redfield ratio). For diatoms, which need silicic acid to create silica for their frustules, the proposed molar ratio is C:Si:N:P=106:15:16:1. Deviations from these ratios in the ambient water can indicate which nutrient is likely to be limiting phytoplankton growth. Regressions of silica vs. nitrogen concentrations for all three stations yielded slopes ranging from 5.9 to 7.1 by weight (molar equivalent 2.9 – 3.6) suggesting that although diatoms may control silica levels, it is nitrogen rather than silica that can become growth limiting (Figure 7).

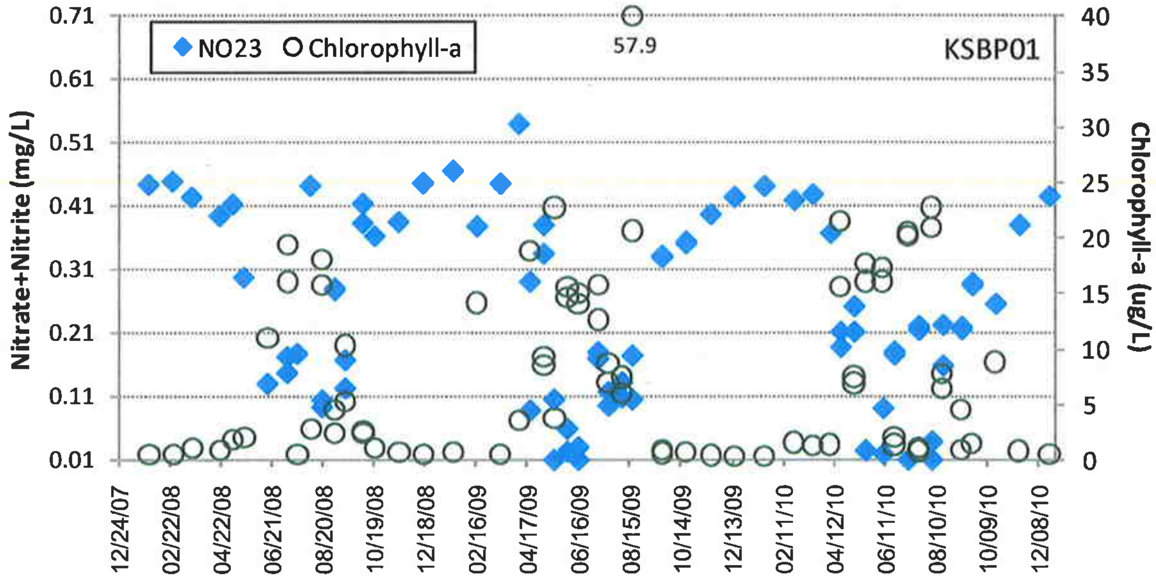


Figure 2. Nitrate and chlorophyll-*a* at Point Jefferson (upper 6 m).

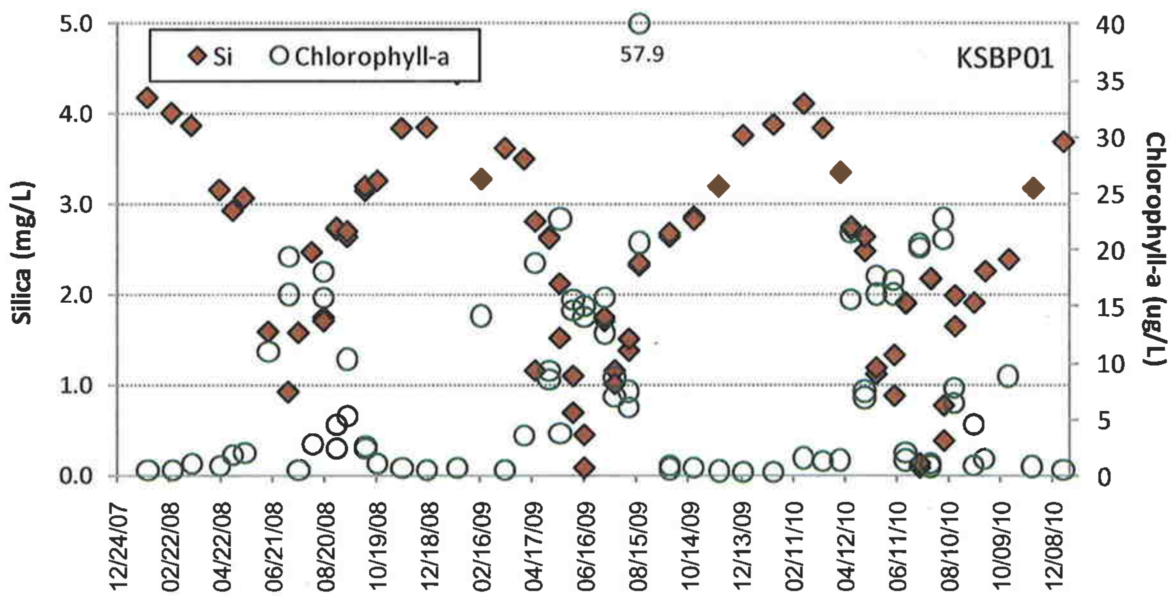


Figure 3. Silica and chlorophyll-*a* at Point Jefferson (upper 6 m).

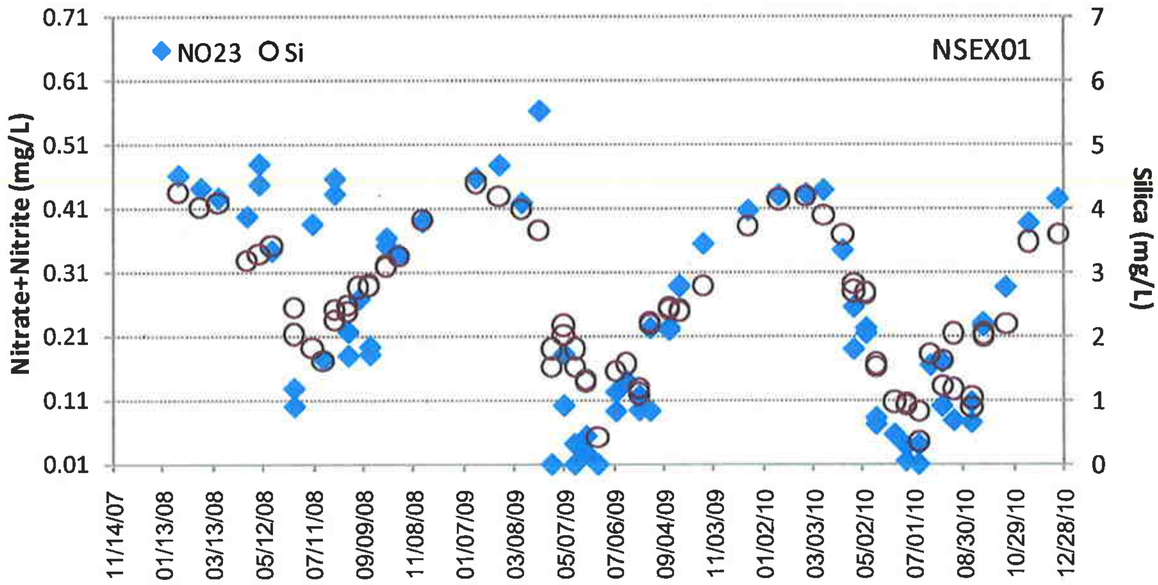


Figure 4. Nitrate and silica at East Passage (upper 6 m).

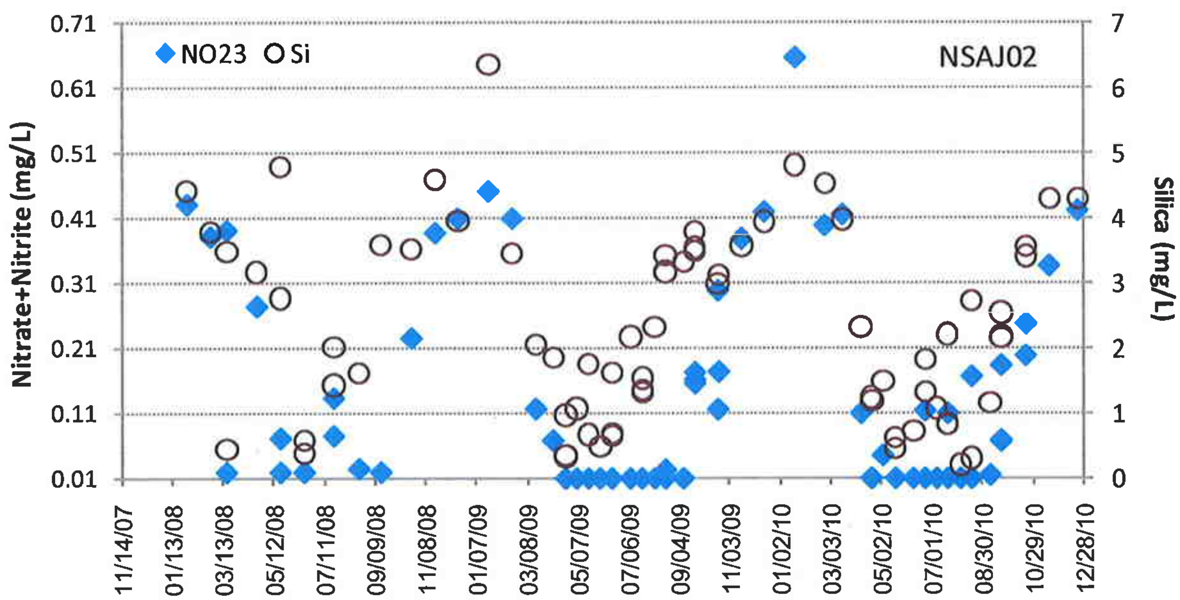


Figure 5. Nitrate and silica at Dockton Park (upper 6 m).

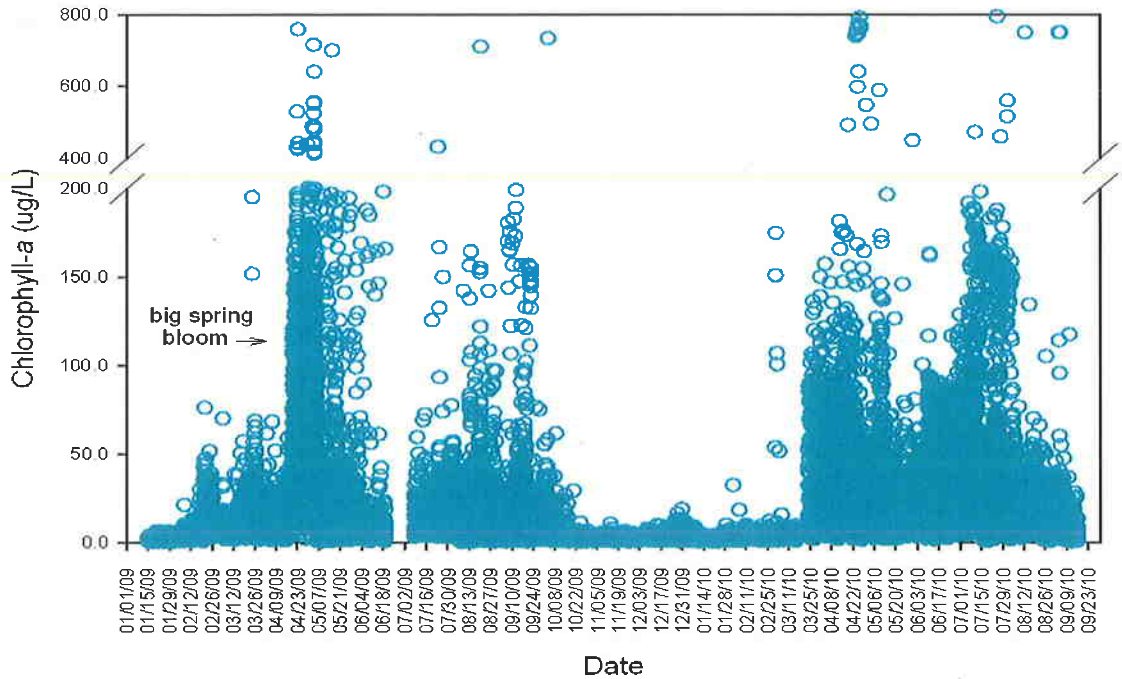


Figure 6. Chlorophyll-*a* values at Dockton Park measured at 15-minute intervals.

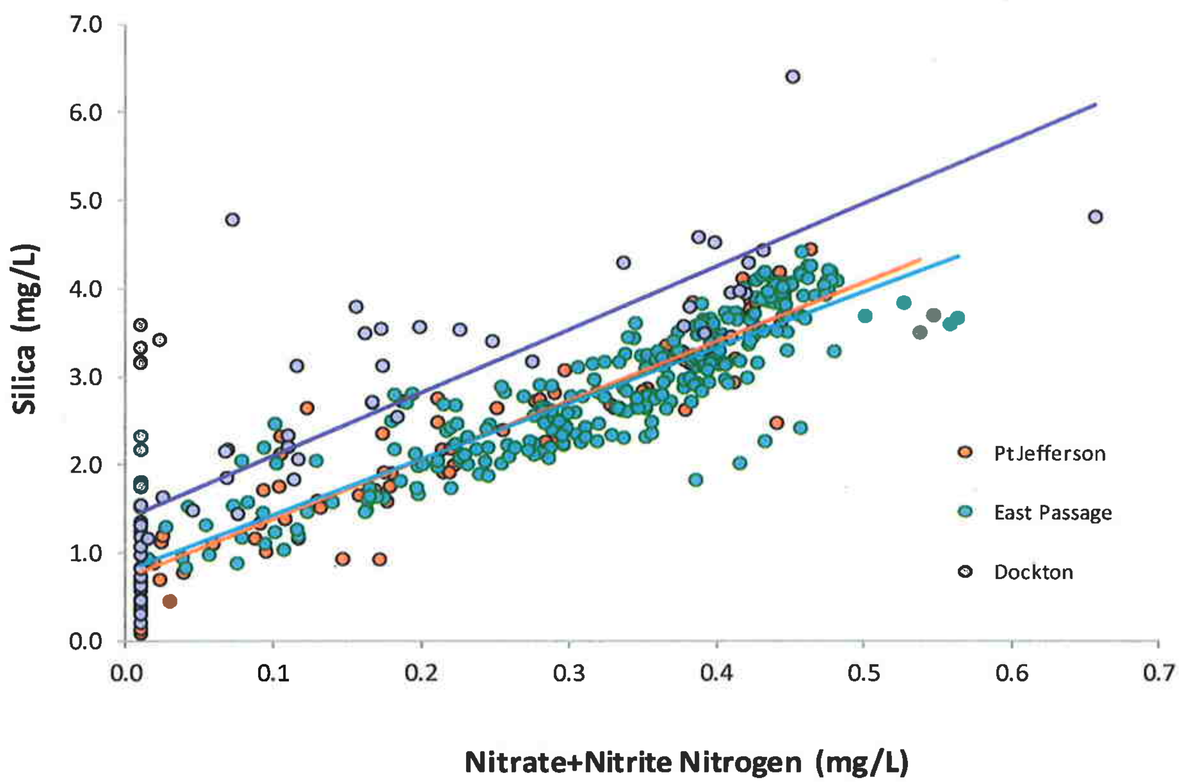
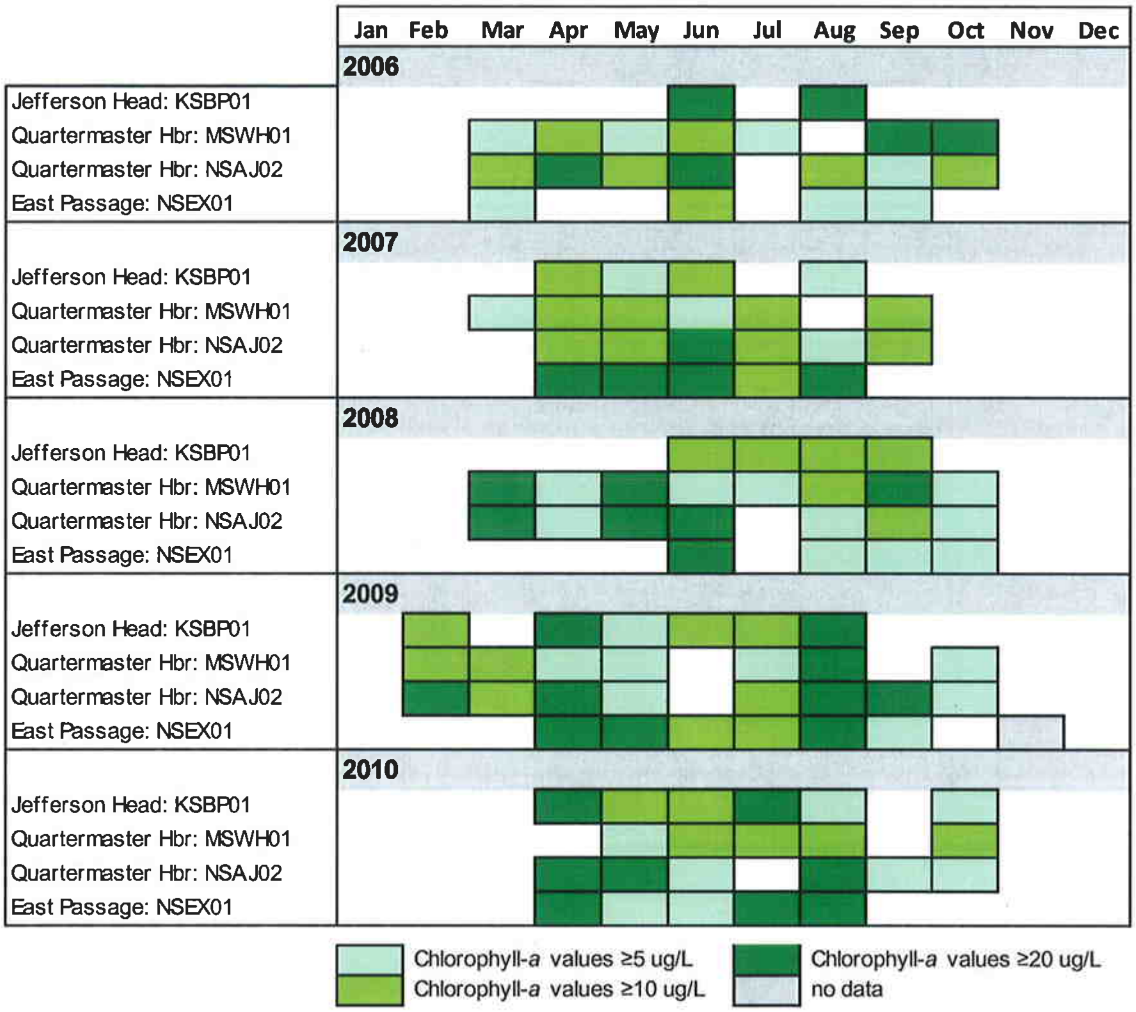


Figure 7. Silica and nitrate+nitrite linear regression for all three stations: 2008-2010.

Table 6. Monthly chlorophyll-*a* values at phytoplankton sampling stations.



note: 2008--2010 based on bi-weekly data. Highest value for the month is shown.