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Factors Affecting the Toxic Cyanobacteria Nodularia Spumigena in Farmington Bay of Great Salt Lake, Utah

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FACTORS AFFECTING THE TOXIC CYANOBACTERIA *NODULARIA SPUMIGENA* IN FARMINGTON BAY OF GREAT SALT LAKE, UTAH

by

B. Eric McCulley

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Watershed Science

Approved:

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ABSTRACT

Factors Affecting the Toxic Cyanobacteria *Nodularia spumigena*

in Farmington Bay of Great Salt Lake, Utah

by

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Utah State University, 2014

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Farmington Bay is a 140 km^2 estuary that has restricted mixing with the saltier main body of the Great Salt Lake due to an automobile causeway on the north that connects the mainland and Antelope Island. The bay receives a significant amount of the nutrient-polluted runoff from Salt Lake and Davis Counties, Utah. This nutrient-laden runoff has led to anthropogenic eutrophication and seasonal blooms of the toxic cyanobacteria *Nodularia spumigena*. *Nodularia* has been observed in many brackish estuaries across the globe and contains the liver toxin nodularin. This study focused on understanding the physical and chemical factors controlling the growth of *Nodularia* in order to improve our knowledge about nutrients and the dynamics of phytoplankton in the Great Salt Lake.

In 2012 and 2013 sampling was conducted across the bay at nine locations during five separate sampling events to help understand the seasonal and year-to-year changes in *Nodularia*, where the salinity ranged from fresh water (2 g L^{-1}) to saline (80 g L^{-1}). The

results showed that *Nodularia* densities and concentrations of the toxin nodularin exceeded World Health Organization "moderate" levels of adverse human health affect by as much as 1300%. The maximum concentration of *Nodularia* was up to 1,358,000 cells mL^{-1} and nodularin reached 69 µg L^{-1}. However, *Nodularia* were not present at salinities > 49 g L^{-1}. Correlation analysis and laboratory bioassays indicated that *Nodularia* responded to changes in both nutrients and salinity.

The relative concentrations of major nutrients changed along the gradient from the south to the north, with nitrogen increases possibly related to the fixation of atmospheric nitrogen by cyanobacteria. Mean and maximum concentrations of total nitrogen were 5.2 and 7.8 mg L^{-1}, whereas those of total phosphorus were 0.57 and 3.5 mg L^{-1}. Mean and maximum chlorophyll *a* concentrations were 110 and 267 µg L^{-1}. Decreasing nutrient loading to the bay, or increasing salinities by making the automobile causeway more permeable, are possible management options to constrain *Nodularia* population in the bay.

(71 pages)

PUBLIC ABSTRACT

Factors Affecting *Nodularia spumigena* in Farmington Bay of Great Salt Lake, Utah

B. Eric McCulley

Farmington Bay of Great Salt Lake receives a significant amount of the nutrient-polluted runoff from Salt Lake and Davis Counties, Utah. This nutrient-laden runoff has led to seasonal blooms of blue-green algae, *Nodularia spumigena*, which produce a toxin called nodularin that has been shown to be toxic to aquatic organisms, birds, and mammals. *Nodularia spumigena* are the most common algae found in Farmington Bay. This study focused on understanding the physical and chemical factors controlling the growth of *Nodularia spumigena* in order to improve our knowledge about how nutrients impact algae in the Great Salt Lake. The salinity of the bay ranged from almost fresh water (less than 0.2%) to water twice as salty as the sea (7.0%). Nutrient (nitrogen and phosphorus) levels were high in the bay, and showed patterns of change from south to north. *Nodularia spumigena* was found in concentrations that greatly exceeded the World Health Organization's standards for contact recreation. Laboratory studies suggest that nutrients and salinity are significantly correlated with levels of *Nodularia spumigena* from Farmington Bay. In combination with complex ecosystem interactions, nutrients and salinity in Farmington Bay apparently contribute to the high levels of *Nodularia spumigena* that we measured.

ACKNOWLEDGMENTS

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I give special thanks to my wife, Audrey, who tirelessly tended to the needs of our family as it grew over the last five years. I would also like to acknowledge my children Owen and Hazel, who inspired me to stay up at night working to complete these requirements. They now both love water, experiments, and sea monkeys.

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INTRODUCTION

Background

Blooms of *Nodularia spumigena* (*Nodularia*) have been documented in Farmington Bay of the Great Salt Lake (GSL), USA over the last several decades (Hayes 1971, Felix and Rushforth 1978, Wurtsbaugh and Marcarelli 2005, Marcarelli et al. 2006, Wurtsbaugh and Epstein 2011, Wurtsbaugh et al. 2012, Marden et al. in prep.). Two key factors that affect the growth of algae and autotrophic cyanobacteria, such as *Nodularia*, include salinity and nutrient availability. Bioassays using water from the GSL, ranging in salinity from 10-160 g L^{-1} (1-16 %), have shown that *Nodularia* can grow in water with salinity of 70 g L^{-1}, but growth was strongest between 10-40 g L^{-1} (Marcarelli et al. 2006). The optimum salinity for *Nodularia* growth in experiments using water from the Baltic Sea and lakes in Australia was 5-20 g L^{-1} (Blackburn et al. 1996, Moissander et al. 2002). *Nodularia* have been shown to fix atmospheric N_2 at rates of 8-35 μmol C_2H_4 mg chlorophyll a^{-1} h^{-1} (Moisander et al. 2002, Marcarelli et al. 2006). Hence, *Nodularia* growth is often limited by phosphorus (P). Consistent with its N-fixing capacity, low total nitrogen (TN) to total phosphorous (TP) ratios have been correlated with higher production of *Nodularia* in the Gippsland Lakes, Australia (Cook and Holland 2012). Bioassays using water from the Farmington Bay showed that P additions stimulated *Nodularia* growth in long-term (30-day) studies (Marcarelli et al. 2006).

Previous studies have identified a physiochemical gradient that exists within Farmington Bay, where factors such as salinity and nutrients change in concentration from south to north (Marcarelli et al. 2006). Goel and Meyers (2009) found little or no

Nodularia in open water areas in the far southern extent of Farmington Bay where salinities were low. More recent studies (Marden et al. in prep.) have shown more widespread *Nodularia*, still mostly found in the middle and north part of the bay. Other studies have found increasing concentrations of *Nodularia* and cyanotoxins along the south to north gradient (Marcarelli et al. 2006, Wurtsbaugh and Epstein 2011). Previous studies have also documented pronounced seasonality in *Nodularia* blooms, which peak from May-July, but can still persist into the fall. Our study helps to shed additional light on how salinity and nutrient limitation regulate the growth of *Nodularia* in Farmington Bay. We found *Nodularia* concentrations above 100,000 cells mL^{-1}, and nodularin concentrations above 20 $\mu g\ L^{-1}$, which are the World Health Organization's moderate risk level for contact with human skin (Chorus and Bartram 1999). Also, water collected for previous bioassay experiments was not collected during the early spring into summer, which may have affected the interpretation of results on nutrient limitation. Consequently, we conducted two experiments to determine if nutrient limitation changes along the gradient from south to north. In another bioassay experiment we modified salinity to determine its role in regulating the growth of cyanobacteria and other phytoplankton. We also collected zooplankton to assess whether their grazing pressure might be sufficient to decrease phytoplankton abundance. The observations presented here help us further understand how nutrients and biota interact, within the existing physical landscape and across time, so we can better understand the spatial and temporal variation of the algal blooms.

Watershed Context

Farmington Bay is located at the downstream end of the Jordan River watershed and receives surface runoff and secondary-treated waste water from the Jordan River, several small streams, state-run waterfowl management areas and wetland outfalls, the Salt Lake Sewage Canal, and waste water treatment plants in northern Salt Lake County and Davis County. In all, a total of thirteen waste water treatment plants serving approximately 1.5 million people provide inputs of water and nutrients to the bay. Some of this water has been filtered through managed wetlands and private duck clubs, but much of the water entering the bay is secondary-treated waste water.

The total watershed area of Farmington Bay is approximately 9,000 km^2 (3,500 square miles), which is the most highly-urbanized land in Utah. The bay covers approximately 140 km^2 (50 square miles), with depths at our sampling stations ranging from 0.2 meters (8 inches) to 1.5 meters (60 inches). The flow in Farmington Bay is from south to north (Figure 1). Mixing of Farmington Bay with the main lake (Gilbert Bay) is restricted by Antelope Island on the west, and an automobile causeway on the north. Bi-directional exchange of water between Farmington Bay and the more saline Gilbert Bay is primarily through a 16.5 meter (50 foot) breach/bridge near the west end of the causeway (Figure 1).

Farmington Bay is recognized as internationally important for migratory birds, has a beneficial use class of 5D, which has the designated use to protect for infrequent primary and secondary contact recreation, waterfowl, shorebirds, and other water-oriented wildlife including their necessary food chain. Farmington Bay includes

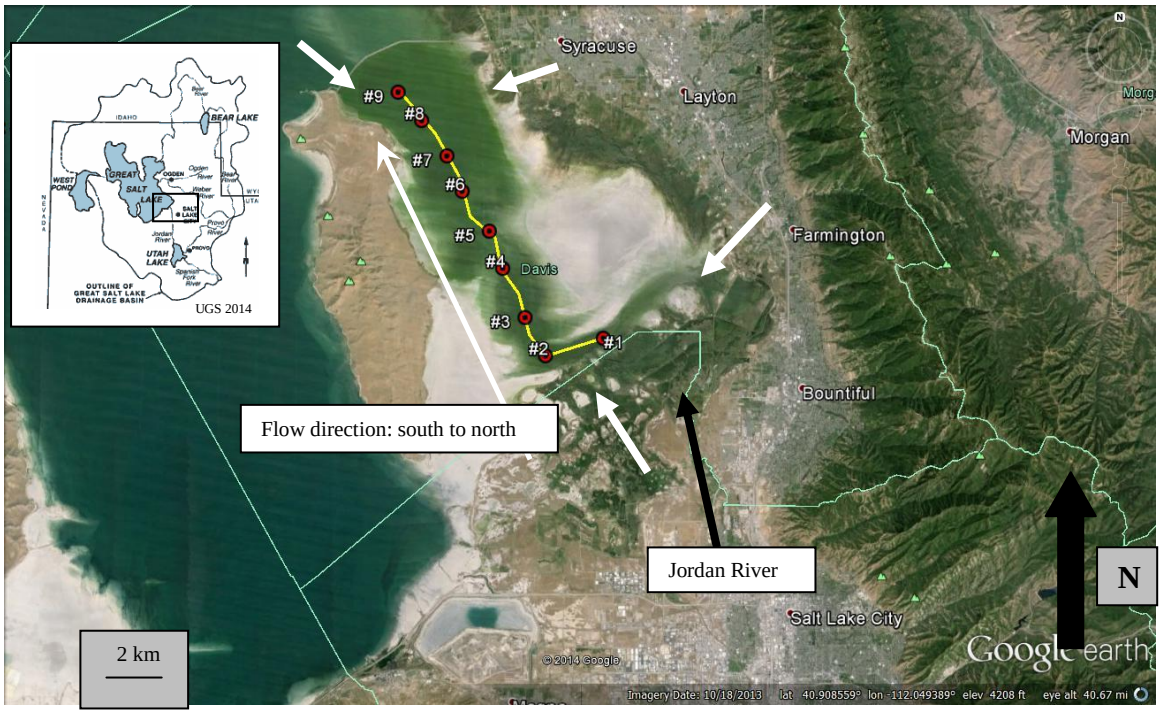

Figure 1. Overview of Farmington Bay showing some inputs. The arrow spanning the bay indicates the direction of flow in the bay from south to north. The smaller white arrows to the northeast, east and south indicate urban or wastewater treatment plant inflows, white arrow to the north shows the causeway, and the small black arrow indicating the location of the Jordan River. The circles show the sampling stations used in the transect.

Antelope Island and south of the Antelope Island Causeway (UDWQ 2012).

Whereas many communities around the world are concerned about *Nodularia* and other toxin producing cyanobacteria due to drinking water concerns, Farmington Bay is not used for drinking water, thus the issues are different. There have been reports of foul odors, bird deaths due to avian disease, and high levels of the liver toxin nodularin, but no significant environmental or human health impacts of these *Nodularia* blooms in Farmington Bay have been documented. It was important for us to study the bay in order

to determine if *Nodularia* blooms are common and if they have any adverse effect on the beneficial uses.

METHODS

Five separate sampling events were conducted at nine locations (Figure 1) along the physical and chemical gradient in Farmington Bay during the spring and autumn of 2012 and the spring and summer of 2013. These sampling points were selected to cover the length of the bay and were evenly spaced with approximately 1.6 km (1 mile) between each location. The Utah Division of Water Quality collects samples at two stations in the north end of the bay as part of the GSL Comprehensive Water Quality Strategy (UDWQ 2012). The location of those sampling points corresponds with our sampling Stations 7 and 9.

Study Site and Field Sampling

Field sampling was conducted at each location along the transect in June and September of 2012; and in May, early June, and late June of 2013. These sampling periods were selected because they represent distinct periods during the spring, summer, and autumn seasons where relative concentrations of nutrients and salinity were expected to be distinctly different, and when blooms of cyanobacteria have previously been highest (Wurtsbaugh et al. 2012). Particulate material (seston) in the water from Central Davis Sewer District outfall, two locations on the lower Jordan River (above and below the South Davis Sewer Improvement District outfall), and one sample from the Salt Lake Sewage Canal at Cudahey Lane (lat. 40.8424° / long. -111.9500°) was also collected on June 20, 2012 and analyzed for comparison with isotopic signatures found across the bay. This was done to determine: (1) if wastewater from the treatment plants might influence the isotopic signature, and (2) if varying levels of nitrogen fixation along the south to

north gradient lowers the $\delta^{15}N$ signal or if there were any interesting trends in carbon isotopes

At each site vertical profiles of temperature, oxygen, and conductivity were completed at 0.2 meters increments using an InSitu® data sonde (Appendix A). Salinity was measured with a refractometer and changed to units of g L^{-1} using the following equation derived from hundreds of measurements in the Great Salt Lake (Wally Gwynn, unpublished):

$$\text{Salinity (g L}^{-1}) = 0.08164\ (\%\ \text{Salinity})\ 2 + 9.96334\ (\%\ \text{Salinity}) - 0.43533 \quad (1)$$

Water for nutrient analyses, phytoplankton, cyanotoxins, pigments, and isotope samples were collected at "elbow-depth" or approximately 0.2 meters below the surface for laboratory analysis (Appendix B). Light attenuation was measured with a 20-cm diameter Secchi disk. Zooplankton were collected using a vertical haul of a 0.3 meter diameter, 153-µm meshed zooplankton net. However, on the first sample date half of the samples were collected in 2.0 liter jugs. The 153-µm mesh size should have collected nearly all the crustacean zooplankton, but most rotifers would have passed through it. During the May and late-June transects in 2013, water samples were collected at every other station for analysis of total mercury (Hg), methylmercury (MeHg), arsenic (Ar), copper (Cu), lead (Pb), cadmium (Cd), selenium (Se), and thallium (Tl). Additionally, Hg and Se in zooplankton samples were analyzed from these stations, but these parameters are discussed in a separate report. Table 1 provides a detailed list of laboratory samples and field parameters collected during each transect.

Table 1. Matrix of laboratory analyses and field parameters done in 2012-2013 in Farmington Bay.

No. Stations per transect		2012		2013		
	Lab samples	**JUN 18-19**	**SEP 21**	**MAY 03**	**JUN 03**	**JUN 28**
9	Total and dissolved nutrients	¤	¤	¤	¤	¤
9	Chlorophyll *a*	¤	¤	¤	¤	¤
9	Phycocyanin	¤	¤	¤	¤	¤
9	$\delta^{13}C$ and $\delta^{15}N$ Isotopes	¤		¤	¤	¤
5	Algal taxonomy	¤		¤	¤	¤
5	Cyanotoxins (nodularin)	¤		¤	¤	¤
5	Zooplankton abundance	¤	¤	¤	¤	¤
1 or 3	Bioassays	3			3	1
	Field parameters					
9	Temperature and salinity	¤	¤	¤	¤	¤
9	Total depth, Secchi depth	¤	¤	¤	¤	¤

Analytical Methods

All water samples were first processed in the Limnology Laboratory at USU for chlorophyll *a*, phycocyanin, and zooplankton. Other parameters were analyzed at various commercial laboratories, as indicated in Table 2. To measure chlorophyll *a*, 10 mL of water was filtered through 1-μm Gelman A/E filters and frozen. Chlorophyll *a* from the frozen filters was extracted in 10 ml of 95% ethanol for 20-24 hours and analyzed with the non-acidification method of Welschmeyer (1994) on a Turner 10-AU fluorometer. A pigment indicative of cyanobacteria, phycocyanin, was analyzed with a Turner 10AU

filter kit which provided relative concentrations measured in Turner fluorometer units (TFU).

Nutrient samples from 0.2 meters were collected in 2.0 liter polyethylene bottles in the field and were analyzed for nitrate + nitrite ($NO_3 + NO_2$), ammonium (NH_4), total nitrogen (TN), soluble reactive phosphorus (including phosphate [PO_4]), and total phosphorus (TP). Raw water for total nutrient concentration was frozen at -20 C, and subsequently analyzed as described below. Water for dissolved nutrients was filtered in the laboratory using vacuum filtration pressures < 33 x 10^3 Pa through 1-μ m Gelman A/E filters and stored in polyethylene bottles at -20 C until analyzed using the persulfate digestion method of Valderrama (1981) using an Astoria Pacific autoanalyzer.

To measure $\delta^{15}N$ and $\delta^{13}C$ of particulate material in the water column, samples were filtered using a pre-weighed and pre-combusted, 25-mm Gelman AE filter. Samples for isotopic analysis were sent to the University of California - Davis Isotope Facility for analysis using GC-combustion isotope ratio mass spectrometry.

Algal composition in glutaraldehyde-preserved water sampled from the transects was determined by an outside laboratory (Phycotech, St. Joseph, MI). Identification and biovolume estimates were completed by mounting samples in resin on slides and counting and measuring cells at 100x-1000x magnification to the level of genus or species, where possible.

Concentrations of the toxin nodularin were analyzed with EnviroLogix (Portland, Maine) enzyme-linked immunosorbent assays (ELISA; Quantiplate Kit for detection of microcystin) by Limnology Lab personnel utilizing facilities in the Center for Integrated Biosystems at USU. Not all samples fell within the range of detection for the ELISA

standards. Nodularin levels were derived by using a 0.73 correction factor on the microcystin measurement following EnviroLogix protocol (EnviroLogix 2010).

The composition of zooplankton at every other sample location (Stations 1, 3, 5, 7, and 9) was analyzed using a dissecting microscope at 30x power after collection in the field. The total sample was shaken to allow for even distribution of organisms and a subsample was taken with a Hensen-Stempel pipette and put into a zooplankton counting chamber. All organisms in the subsample were identified to species using a higher magnification (up to 100x) then 10 individuals of each taxa were counted and measured using a micrometer scale at 30x. Measurements were used to calculate biomass following the length-weight regressions shown below given in McCauley (1984) and listed in Table 2, where α is equal to the length of the organism in millimeters (mm) and dry weight is in micrograms (µg):

$$\text{Weight} = \alpha * (\text{Length})^{-\beta} \qquad (2)$$

Table 2. Zooplankton length to weight coefficients used to derive the zooplankton biomasses from Reeve (1963) and McCauley (1984).

Taxa	Organism size (mm)	α	β
Artemia	4.9 (avg.)	0.9	3.0
Copepods	0.14-2.45	7.0	2.4
Daphnia	0.6-4.00	4.3	2.8

Bioassays

Three laboratory bioassays were conducted to test the influence of nutrients and salinity on chlorophyll *a*, phycocyanin, and nodularin levels. For each experiment, bottles

were incubated in a light- (150 µMol cm^{-2} sec^{-1}) and temperature- (20°C) controlled environment and agitated twice daily.

The June 4, 2013 bioassay was conducted with nutrient additions that were approximately 3x ambient background levels. In order to develop a better understanding of how nutrient limitation might vary across the spatial extent of the bay, naturally varying levels of salinity in lake water from three stations were used (see Table 3). Experiments were conducted with water collected from stations 1, 5 and 9 which provided phytoplankton communities growing at salinities ranging from 3-37 g L^{-1}. Nutrients were added to 900 mL glass jars with plastic tops. Each salinity combination was replicated three times for each treatment with control, +N, +P, and +N+P additions of 35 mg N (as NH_4NO_3) L^{-1} and 0.5 mg P (as Na_2HPO_4-$7H_2O$) L^{-1}. Chlorophyll *a*, nodularin and phycocyanin (as a measure of cyanobacterial levels) levels were analyzed before the bioassay commenced (as part of initial field sampling) and on day eight.

Two additional experiments were conducted between June 29 and July 5, 2013 using water collected on June 28, 2013. These experiments included an additional nutrient limitation bioassay and a salinity alteration experiment, both using water from Station 5. The initial salinity of water from this station was 16 g L^{-1}. For the salinity alteration experiment, salinity was increased using 400 mL of the raw lake water mixed with 400 mL of saline solution, which was created by mixing InstantOcean® aquarium salt to provide salinity treatments ranging from 16-59 g L^{-1}. To insure that phytoplankton in these treatments were not nutrient limited, N and P were also added to all of the jars at the same concentration used in the N+P bottles in the nutrient addition bioassay on June 28.

Table 3. Design of the three bioassays using water collected from different stations in Farmington Bay on June 3 and 28, 2013. In the Salinity Assay, salt concentrations were increased with InstantOcean® aquarium salt above the background concentration of 16 g L^{-1} measured at Station 5. The ¤ symbol indicates nutrients that were added to bottles in each experiment.

Station	Salinity	N	P	N and P	control
Nutrient Addition Bioassay (June 3, 2013)					
Station 1	3 g L^{-1}	¤	¤	¤	¤
Station 5	16 g L^{-1}	¤	¤	¤	¤
Station 9	37 g L^{-1}	¤	¤	¤	¤
Salinity Bioassay (June 28, 2013)					
Station 5	16 g L^{-1}			¤	¤
Station 5	26 g L^{-1}			¤	
Station 5	37 g L^{-1}			¤	
Station 5	48 g L^{-1}			¤	
Station 5	59 g L^{-1}			¤	
Nutrient Addition Bioassay (June 28, 2013)					
Station 5	16 g L^{-1}	¤	¤	¤	¤

Statistical Methods

Field data were analyzed using Pearson's product-moment correlation or linear regression using R (R Core Team 2014) to determine if there were any correlations between physical and chemical parameters as compared to cyanotoxins, *Nodularia*, phytoplankton levels, and pigment concentrations. Results of the bioassay experiments were analyzed in R using a one-way analysis of variance (ANOVA), with log-normalized values to meet ANOVA assumptions. Post-hoc Tukey's Studentized Range tests were used to evaluate which treatment responses were significantly different from each other.

RESULTS

The results of the study are discussed below first by physical parameters, which outline the south to north environmental gradient that is typically present in the bay. Chemical parameters such as nutrients and isotopes are then discussed, followed by phytoplankton and related parameters such as phycocyanin, chlorophyll *a*, the hepatotoxin nodularin and zooplankton densities. The final section provides observations of the laboratory bioassays, which help us understand both nutrient limitation and salinity controls on phytoplankton.

Environmental Conditions - gradients in physical factors

During the study, the depth of our sampling stations ranged from 0.2 meters at the south end to over 1.5 meter at the north end. The water in the bay generally flowed in a northerly direction and spanned about 3 kilometers (1.9 miles) across, or one-third of the total width when the bay is at a higher elevation. Temperature ranged from 13-29°C, which is within the range tolerated by *Nodularia* in other parts of the world (Hobson and Fallowfield 2003, Mazur-Marzek et al. 2006). Secchi depths ranged between 0.14 m to 1.1 m (Figure 2). The depth at which photosynthesis can occur is approximately 2-3x Secchi depths. Consequently, sufficient light for photosynthesis was usually available throughout most of the shallow water column at most locations.

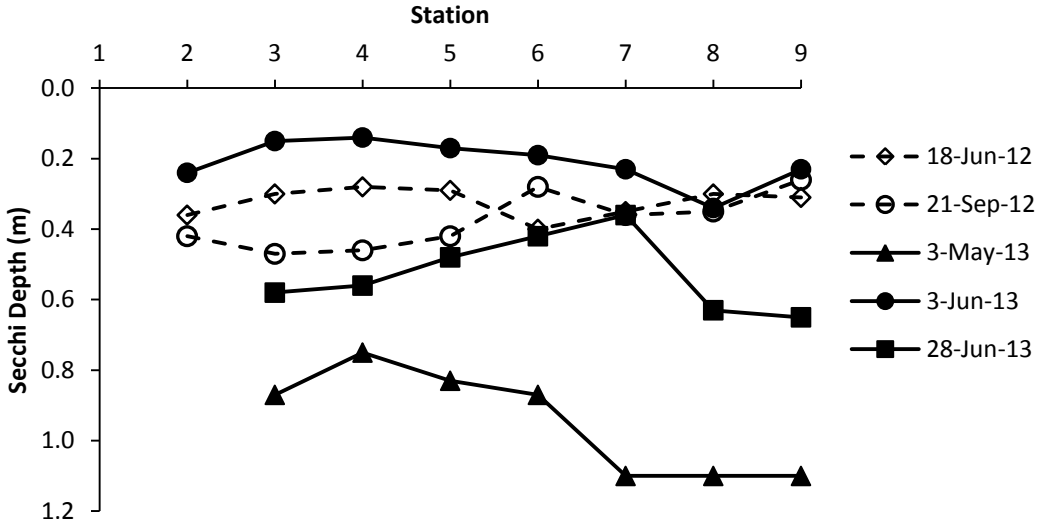

Figure 2. Secchi depth at the nine transect locations on five dates in 2012 and 2013. The water clarity at Station 1 was always greater than the maximum depth (0.2-0.5 m) so Secchi depth measurements were not possible at that location. On two transects Secchi depths were also greater than the maximum depth (0.4-0.6 m) at Station 2.

Chemical Gradients

Salinity

Spatial and temporal variation in the salinity was high across the bay during the study (Figure 3). During the runoff period in May and June of 2013, salinities ranged from 1-4 g L^{-1} near the freshwater inflows in the south, to 26-37 g L^{-1} in the north. In 2012, a low runoff year, salinities were higher, both in June, and particularly in September when they reached 74 g L^{-1} at the north end of the bay.

Nutirents

Total nitrogen concentrations were generally high in the bay, ranging from a low of 1.6 mg L^{-1} to over 7 mg L^{-1} (Figure 4). The nutrient concentrations differed across the

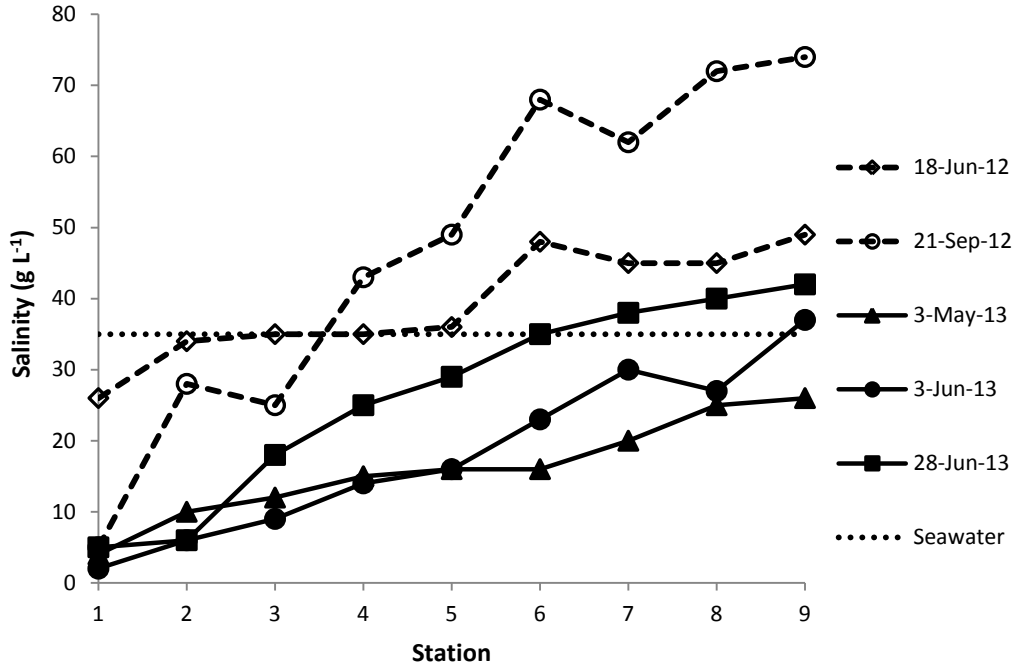

Figure 3. Salinities at the nine transect stations in Farmington Bay on five dates in 2012 and 2013. The salinity across the bay changes from south (Station 1) to north (Station 9) and is also variable based on the time of sampling. Seawater is represented at a dashed line at 35 g L^{-1} salinity. As shown, the salinity in the bay changes from below that of seawater to above, creating a complex interaction with physical parameters, nutrients and biota. Note that the salinities at most stations during the second year were below that of seawater.

bay on each of the different dates, but there were some similarities in patterns (Figure 4). Nitrogen patterns were similar on different dates, but the peak of TN shifted between sample events. For example, TN peaked at over 7 mg L^{-1} at Station 3 on June 3, 2013 and peaked at a similar level at Station 6 on September 21, 2012. TN was high across the bay on May 3, 2013 (3-4 mg L^{-1}) and increased approximately 2-fold by June 28, 2013 to over 7 mg L^{-1}. Dissolved inorganic nitrogen (ammonia, nitrate, and/or nitrite) had different patterns across the dates with a NH_4^+ maximum of 1.2 mg L^{-1} and NO_3^- maximum of 1.1 mg L^{-1} at Station 9 on September 21, 2012. On June 3, 2013 there was a consistent increase in dissolved inorganic nitrogen from the south to the north in the bay.

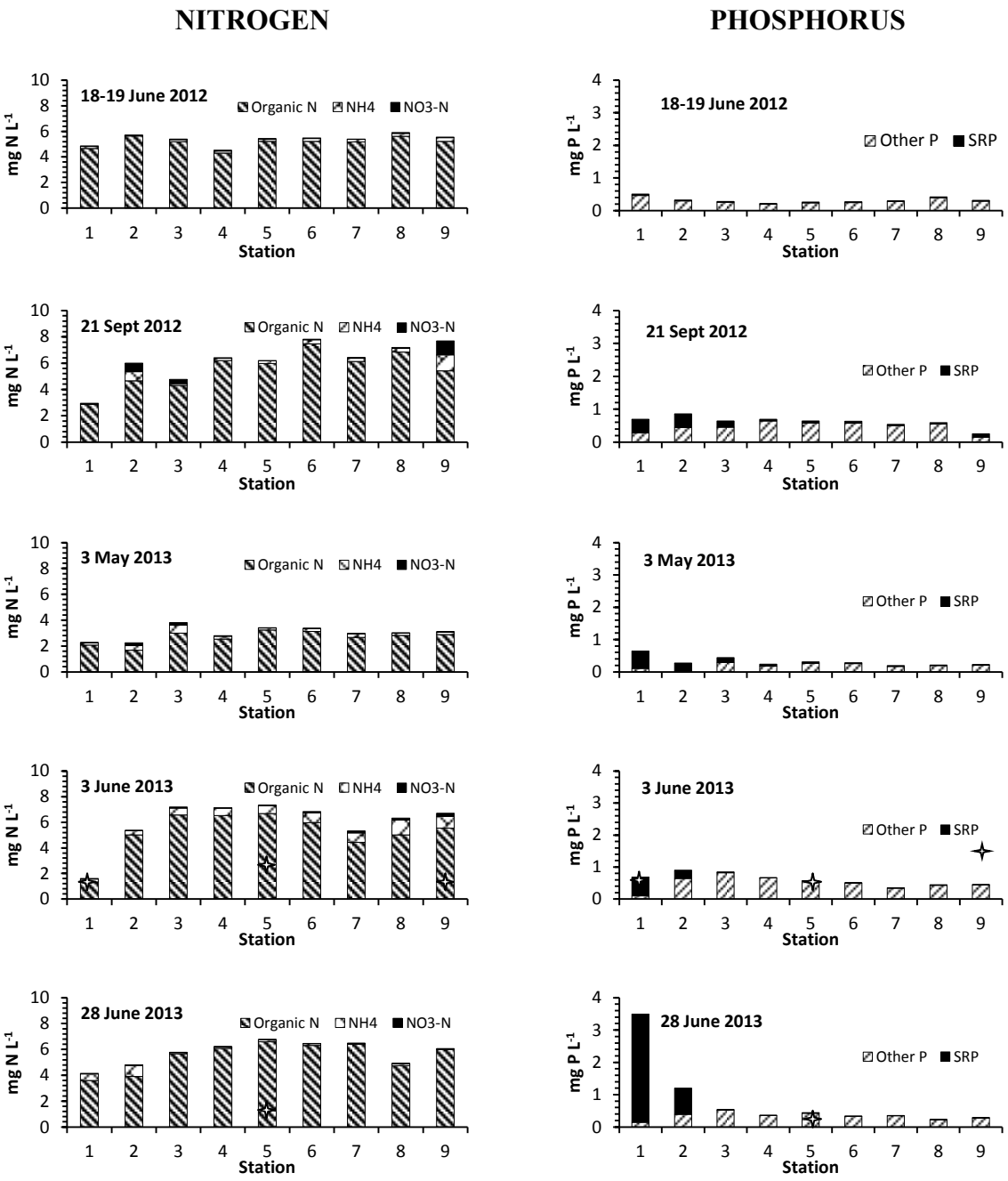

Figure 4. Nutrient concentrations in the surface (0.2 m) water at nine stations in Farmington Bay for the five transects completed in 2012-2013. The top line on these charts represents the total nitrogen (TN) and total phosphorus (TP) in the samples. ✧ Denotes stations where bioassay water was collected. SRP = soluble reactive phosphorus.

Total phosphorus concentrations were fairly consistent across the bay, but with slightly higher concentrations in the south end (Figure 4). Soluble reactive phosphorus (SRP) was most pronounced in the south end of the bay and was consistently reduced to very low or non-detectable concentrations (below 0.01 mg L^{-1}) by Station 3.

TN:TP ratios always increased from the southern-most stations to the north (Figure 5). At Stations 1 and 2 the TN:TP ratio was usually below or near the Redfield ratio of 7.2:1 (by mass), but further north the ratio increased to more than 15:1. The increase in this ratio indicates increasing P limitation as you go to the north. If the Redfield ratio is applicable in the bay, the nutrient limitation may change from N limited in the south to P limited in the north end of the bay.

Isotopes

The results of the isotope ratios for $\delta^{15}N$ and $\delta^{13}C$ in the bay and from some specific sources showed consistent trends across the bay, with minor variations for each date (Figures 6 and 7). Sources included the Jordan River above and below the South Davis Improvement District South Outfall, the Salt Lake Sewage Canal, and the Central Davis Improvement District. The water collected from the Central Davis Improvement District outfall showed the highest level of $\delta^{15}N$ (+15.6), which is typical of sewage effluent (Onodera et al. 2015). The reduction in $\delta^{15}N$ from the source areas in the south (left) to the north (right) indicate increasing levels of atmospheric nitrogen (with $\delta^{15}N$ of 0.0) may have been fixed by cyanobacteria. The Salt Lake Sewage Canal and the Central Davis Improvement District outfall showed the highest values in comparison to levels across the bay, which decreased (became more negative) to the north.

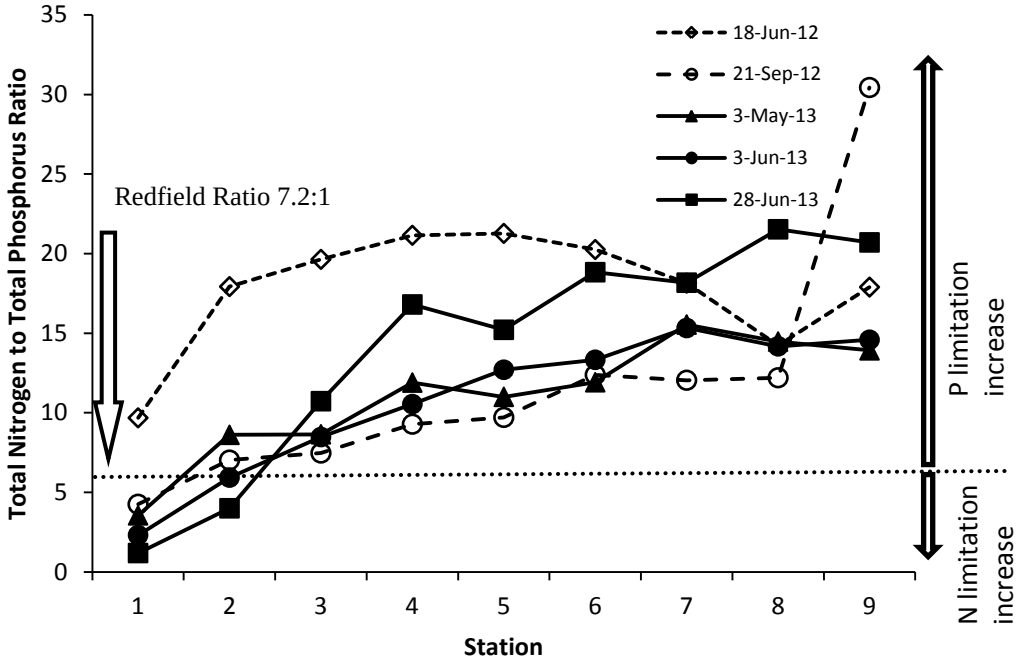

Figure 5. Total nitrogen to total phosphorus ratios across the bay on each transect date. The general trend of TN:TP is to increase from south to north, with the exception of June 18, 2012. This trend indicates increasing P limitation towards the north. The N:P ratios giver here are based on weight:weight.

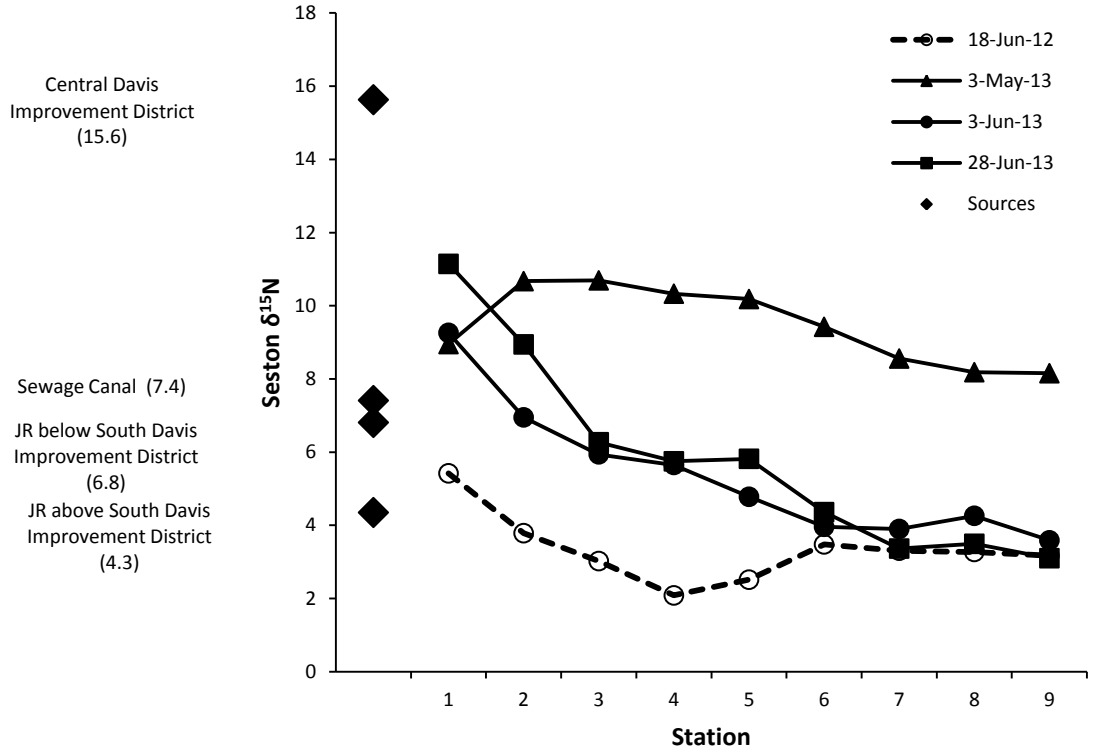

Figure 6. Particulate material δ15N levels at nine stations across Farmington Bay on four dates. δ15N levels of four wastewater discharges (♦) and the Jordan River (JR) that enter at the south end of the bay are plotted to the left of the Station 1 data and were collected on June 20, 2012.

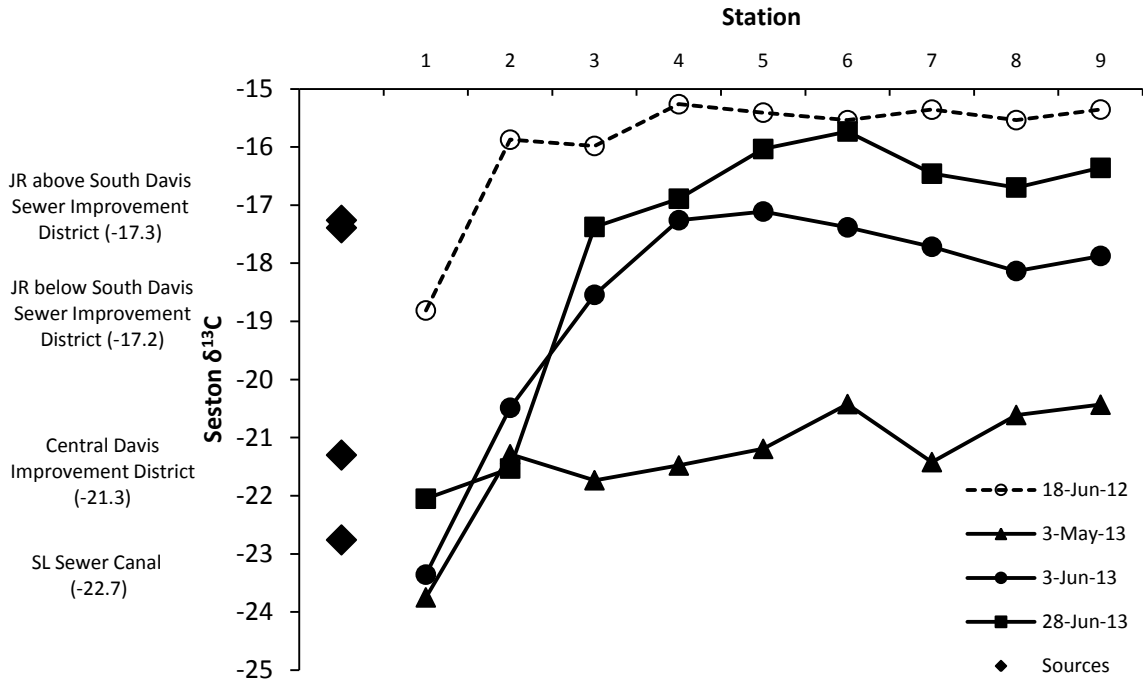

Figure 7. Particulate material $\delta^{13}C$ across Farmington Bay with some source water levels on the left of the chart. $\delta^{13}C$ levels of four wastewater discharges (♦) and the Jordan River (JR) that enter at the south end of the bay are plotted to the left of the Station 1 data and were collected on June 20, 2012.

The $\delta^{13}C$ values also changed across the bay, generally increasing from south to north (Figure 7). Particulate matter in the Salt Lake Sewage Canal and Central Davis Sewer District outfall showed the most negative values for $\delta^{13}C$ and most values across the bay were similar to those found in the Lower Jordan River.

Cyanobacteria and other phytoplankton

On most dates and at most stations, cyanobacteria dominated algal cell density in Farmington Bay (Figure 8). Other abundant taxa included Bacillariophyta (diatoms) and Chlorophyta (green algae), which had different abundances and distribution depending on the time of the year. In general, the highest levels of both cyanobacteria and

phytoplankton were observed in June for both years, but the temporal extent of our study was limited. On some dates Bacillariophytes and Chlorophytes had a larger percentage of the total concentrations in the bay. The difference between concentrations on each of these dates indicates that there can be major swings in the biota on any given period.

On June 18, 2012 the highest levels of cyanobacteria (primarily *Nodularia*) were observed at Station 3, which is approximately 3 km (2 miles) north of the outfall for the Salt Lake Sewer Canal, with up to 1.3 million cells mL^{-1} (Figure 8). This level was approximately 1500% of the World Health Organization's (WHO) indicator level for "moderate" effects with exposure to human skin, which is 0.10 million cells mL^{-1}. Diatoms and green algae were relatively consistent across the bay representing 10-30% of the cell count.

The June 3, 2013 sampling date showed a similar pattern with the cyanobacteria peak at Station 3, but concentrations were slightly lower than June, 2012, but still were 700% of the WHO "moderate" health risks of exposure to skin for humans. Green algae also peaked at Station 3 with concentrations of 15-20% of the total phytoplankton, with a similar peak in diatoms at >10% of the total.

On September 21, 2012, the cyanobacteria species shifted away from the *Nodularia* domination to that of *Synechocystis* sp. at the south end and *Pseudoanabaena* sp. at the north (Appendix C). *Pseudoanabaena* can produce the hepatotoxin microcystin (Paerl and Otten 2012), which is similar to the nodularin produced by *Nodularia*. *Synechocystis* can also produce cyanotoxins. Green algae were also a larger component of the cell concentration towards the north end of the bay.

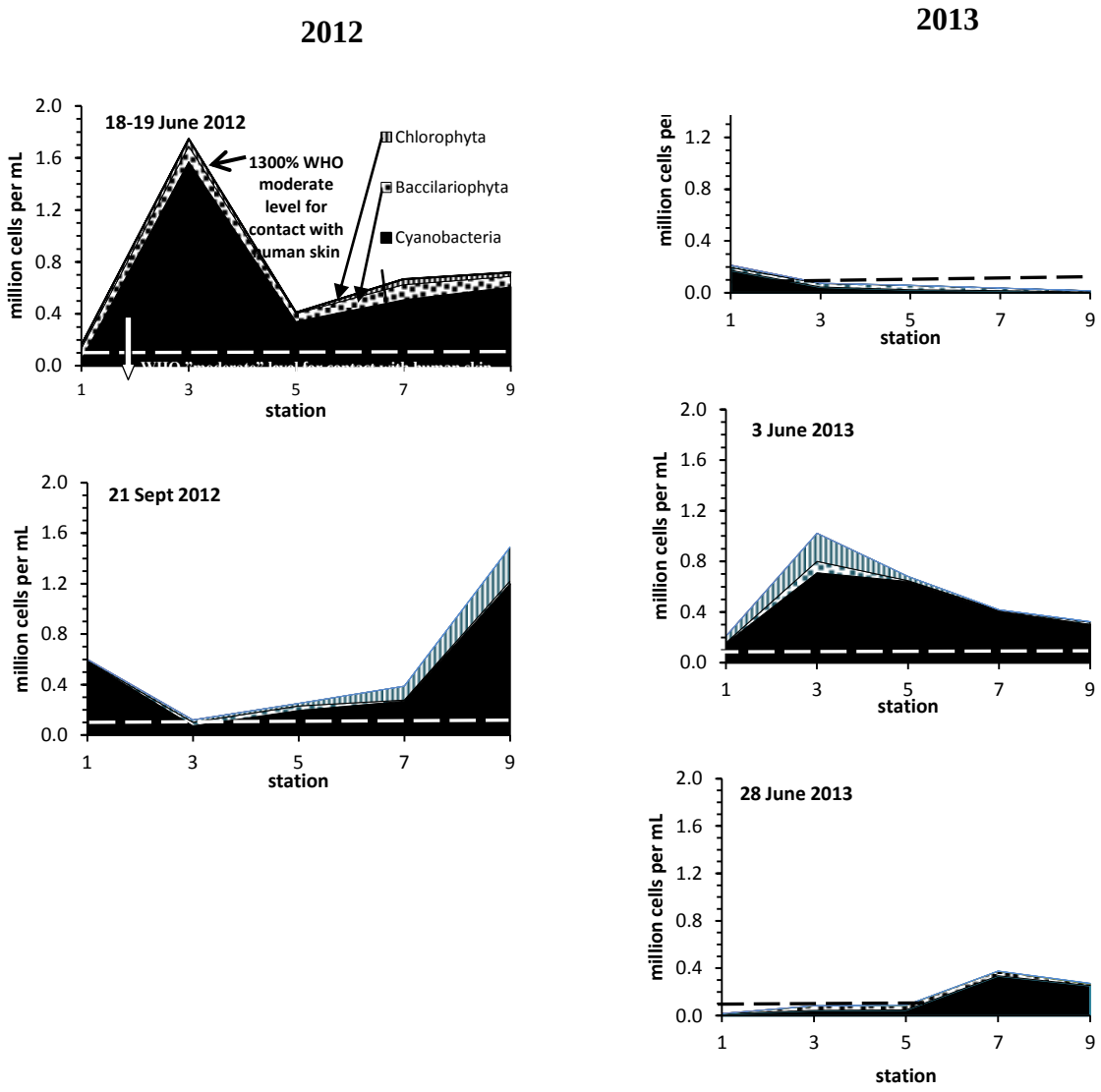

Figure 8. Cyanobacteria (blue-green algae), bacillariophyta (diatoms) and chlorophyta (green algae) concentrations in on five dates at Stations 1, 3, 5, 7, and 9 along the transect in Farmington Bay. Cyanobacteria (primarily *Nodularia*) dominated and the dashed line at 0.1 million cells mL^{-1} of cyanobacteria indicates where the World Health Organization (WHO) has designated a "moderate health risk" for human exposure to skin. Other taxa were usually insignificant in number.

The cyanobacteria and phytoplankton densities on May 3 and June 28, 2013 were relatively low compared to the other dates. In May there were more cyanobacteria (*Synechocystis*) at the south end than at the north end and in late June there were more cyanobacteria (*Nodularia*) at the north end.

Densities of *Nodularia* were highest on June 18, 2012 and were present in most of the phytoplankton samples we collected (Figure 9). In both years of this study, the highest *Nodularia* concentrations were found in June, but the limited number of sample dates did not cover the entire year, so higher values may have occurred on other dates. *Nodularia* concentrations were lower on the three other dates and a few samples were at or below the WHO risk level for moderate health effects from contact.

The cyanotoxin nodularin was observed at most locations on all dates, with the exception of September 21, 2012, when *Pseudoanabaena* was the most prevalent cyanobacteria. The highest levels of nodularin were observed on June 3, 2013 at 69 µg L^{-1} (LR equivalent microcystin), which is well above moderate risk of human contact limits of 20 µg L^{-1} of microcystin (Figure 10).

Chlorophyll *a* levels averaged 110 µg L^{-1} across all samples in the study with a maximum of 263 µg L^{-1} at Station 3 on June 3, 2013 and a minimum of 1.3 µg L^{-1} at the south end of the bay on September 21, 2012 (Figure 11). Total phytoplankton biovolume measured at the different stations and dates was weakly but significantly correlated with chlorophyll *a* levels (Pearson's $r = 0.56$, $t = 3.52$, $df = 27$, p-value = 0.0015).

Total nitrogen concentrations were weakly correlated to concentrations of *Nodularia* (Figure 12). The correlation with TN was partially driven by the low

concentration of *Nodularia* on May 3, 2013. TP was not correlated with *Nodularia* (Figure 13).

Phycocyanin levels, a metric of cyanobacterial abundances, were significantly ($p < 0.001$) log-linearly correlated with nodularin concentrations (Figure 14). This analysis did not include all of the stations where nodularin may have been present because levels sometimes fell outside of the range of ELISA standards. This result indicates that phycocyanin may be a good indicator for nodularin when *Nodularia* is the most prominent cyanobacteria.

Nodularia biovolume was limited to salinities below 48 g L^{-1} and phycocyanin was also mostly limited by salinity to below 48 g L^{-1}, with the exception of values recorded from water collected on September 21, 2012 when *Pseudoanabaena* sp. was present at salinities as high as 78 g L^{-1} (Figures 15a and 15b).

Zooplankton densities and biomass estimates

The density and biomass of zooplankton were highly varied between dates and were also extremely high on some dates (Figure 16). The most common zooplankton in the bay included *Moina macrocarpa*, other cladocera, harpacticoid copepods, and calanoid copepods, with smaller numbers of *Artemia fransicana*, corixids, and *Daphnia* spp. On June 18-19, 2012, *Moina* were the most abundant organism observed with some *Artemia fransicana* also observed. On September 21, 2012, corixids had increased to become the dominant organism across the bay in terms of biomass. In 2013, *Moina* were the most abundant organism for both densities and biomass, but densities and biomass of both copepods was also significant. On May 3, 2013, concentrations and biomasses of

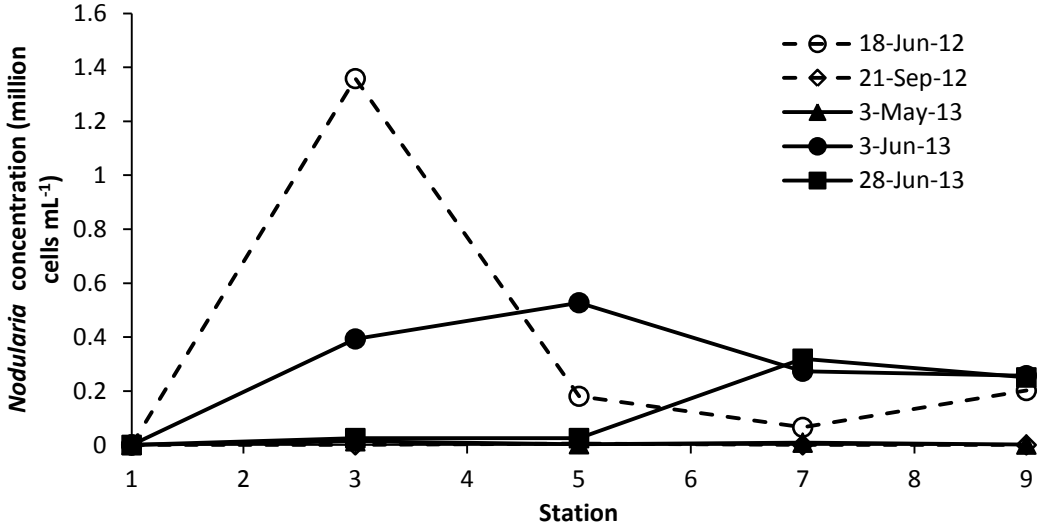

Figure 9. Concentrations of *Nodularia spumigena* at five stations on five dates in Farmington Bay. Concentrations on 21 September 2012 were all near zero and the data points are hidden by other symbols.

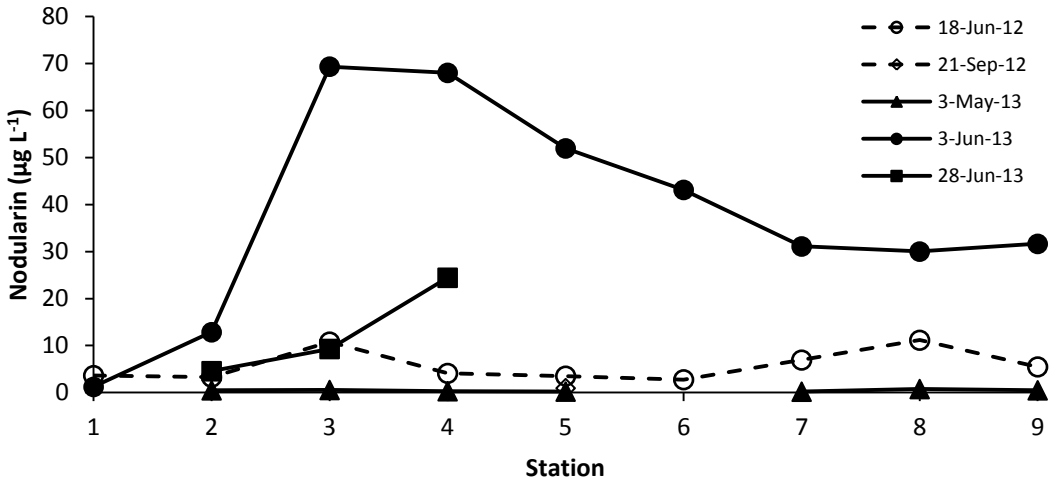

Figure 10. Cyanotoxin nodularin concentration across Farmington Bay on five dates. The level of nodularin, which is a liver toxin (hepatotoxin) was far above World Health Organization levels for "moderate" health effects on humans with exposure to skin (20 µg L^{-1}) on June 3, 2013. On some dates and stations, nodularin concentrations were outside of the range used in our standards.

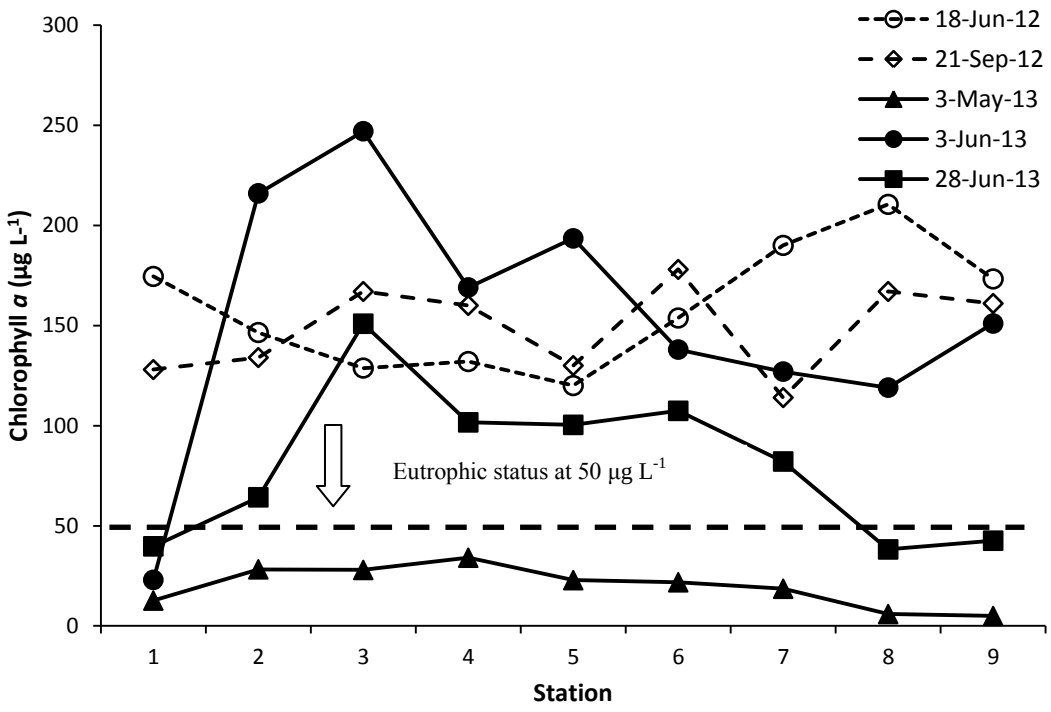

Figure 11. Chlorophyll *a* levels across Farmington Bay on five dates in 2012 and 2013. The horizontal dotted line at 50 µg L^{-1} shows the criteria for eutrophic classification using fresh water criteria (Carlson 1977).

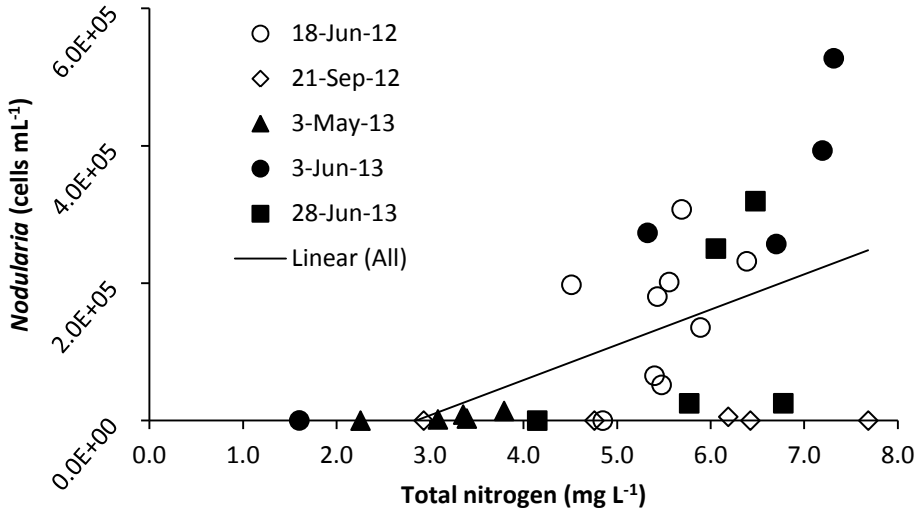

Figure12. Relationship between total nitrogen and *Nodularia* cell density measured at five transect stations on five dates in 2012 and 2013. Total nitrogen to *Nodularia* concentration in cells per mL showed a weak but significant correlation (Pearson's r = 0.55, t = 3.425, df = 27, p-value = 0.0020).

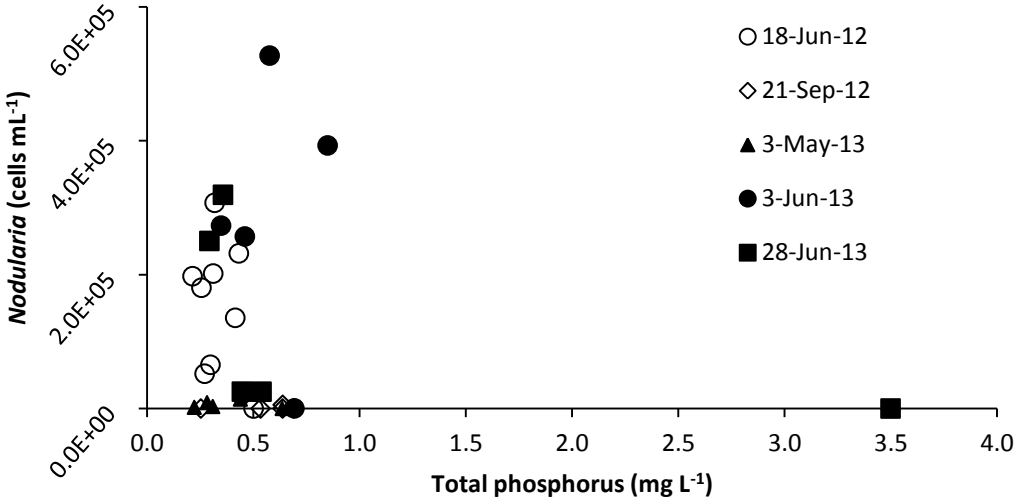

Figure 13. Relationship between total phosphorus and *Nodularia* cell density measured at five transect stations on five dates in 2012 and 2013. These two variables were not significantly correlated (p = 0.79).

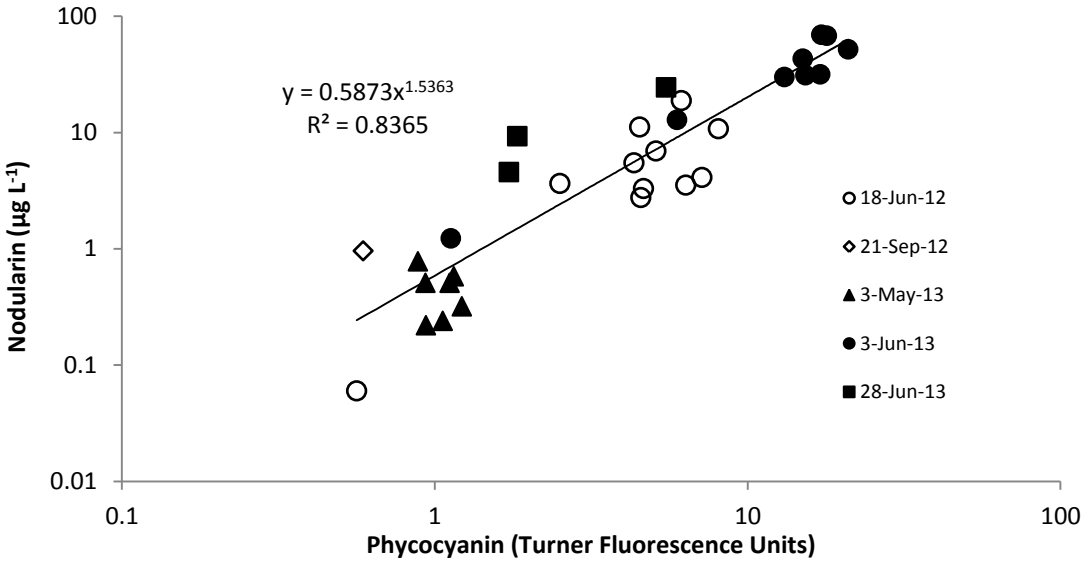

Figure 14. Correlation between concentrations of the cyanobacterial pigment phycocyanin and nodularin toxin measured with ELISA ($p = 0.00001$). Note the large ranges in phycocyanin pigment and nodularin depicted in this log-log plot.

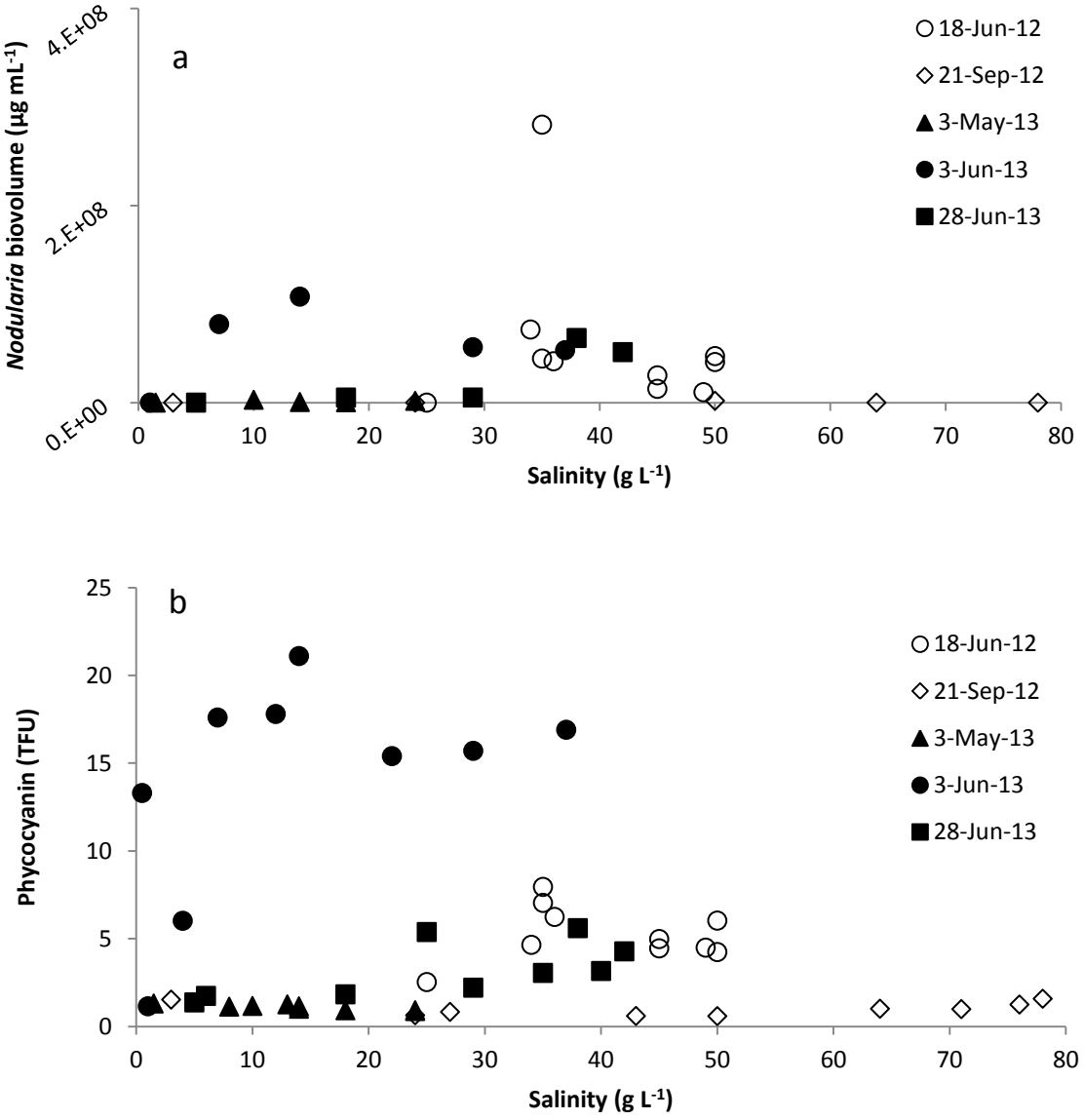

Figure 15. a) *Nodularia* biovolume as a function of salinity along transects in Farmington Bay in 2012 and 2013. Note that *Nodularia* was not found above 48 g L^{-1} salinity. b) Concentrations of phycocyanin pigment, a proxy for cyanobacterial biomass, along the transects. The low levels of phycocyanin pigment observed on September 21, 2012 at salinities above 50 g L^{-1} were from *Pseudoanabena* (see Appendix C).

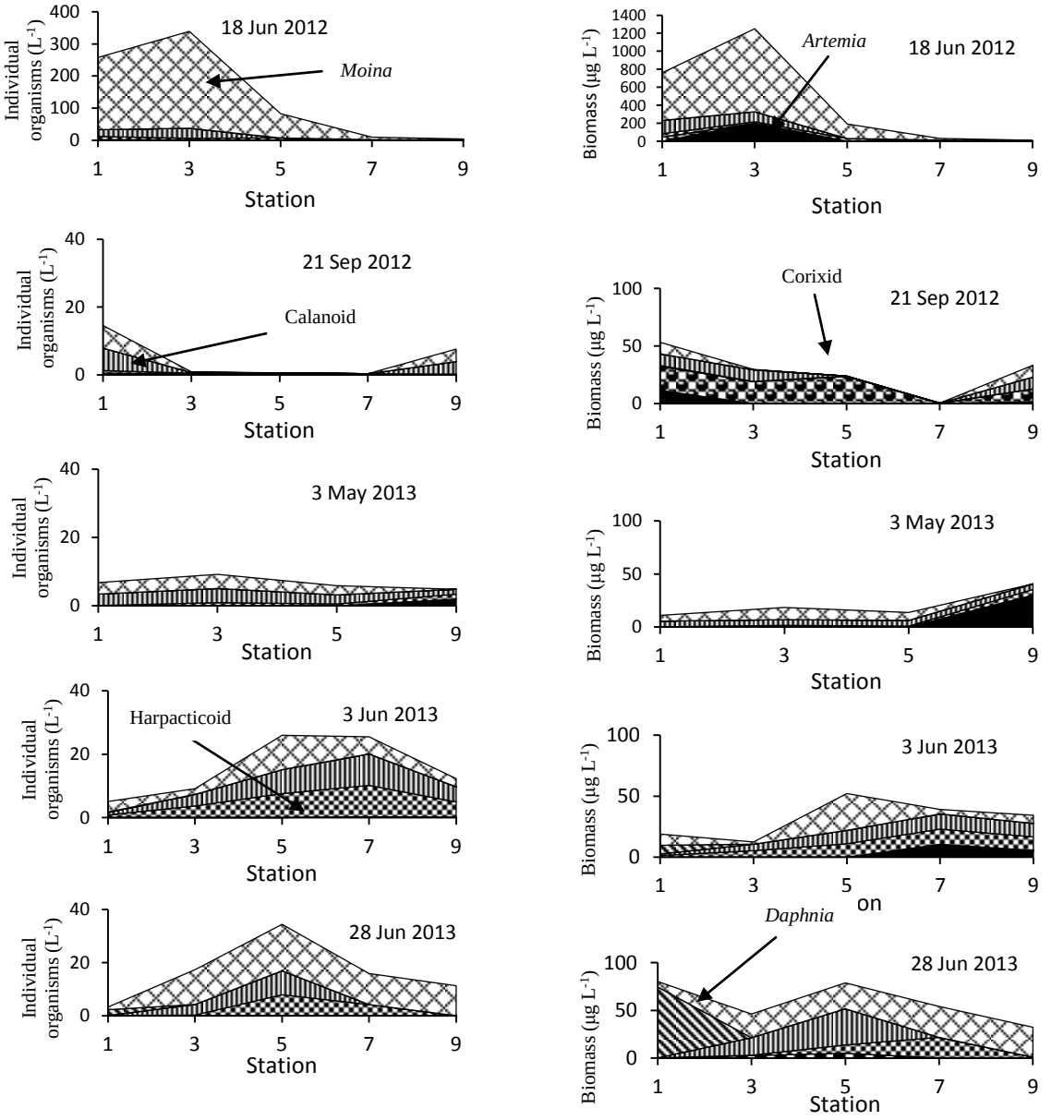

Figure 16. Zooplankton densities (left) and biomasses (right) at five stations along the Farmington Bay transects. Note different scales used on June 18, 2012 when abundances were extremely high.

Moina and copepods were consistent across the bay, with an increase in *Artemia* at the north end of the bay. On June 3, 2013, density and biomass of *Moina* and the copepods was highest in the central portion of the bay with increased concentrations of harpacticoid copepods and *Artemia* was also present in the north end of the bay. On June 28, 2013, *Daphnia* spp. was present in the south end of the bay, but was not observed north of the southern-most point along the transect. On the later date, copepods also increased in the middle of the bay, but *Moina* dominated by the north end of the bay and no *Artemia* were observed.

Bioassay results

June 3, 2013 Nutrient addition bioassay

The results indicated that nitrogen was the primary limiting nutrient, but there were different responses across the bay (Figure 17). Water from Station 1 at the south end of the bay the initial biovolume of taxa was dominated by diatoms (35%) and chlorophytes (46%), with only 7% cyanobacteria (Appendix C), and overall densities were moderate (Figure 8). At this station N and +N+P stimulated the production of chlorophyll *a*, but phosphorus alone did not stimulate the phytoplankton. There was also a stimulation of the cyanobacterial pigment phycocyanin with the addition of N and concentrations in the +N+P treatment were not significantly higher than in the +N treatment, indicating that P had no influence on pigment production. Similarly, addition of P alone did not result in any significant change in pigment concentrations. These results indicate that phytoplankton and cyanobacterial growth the south end of the bay was likely nitrogen limited on June 3, 2013.

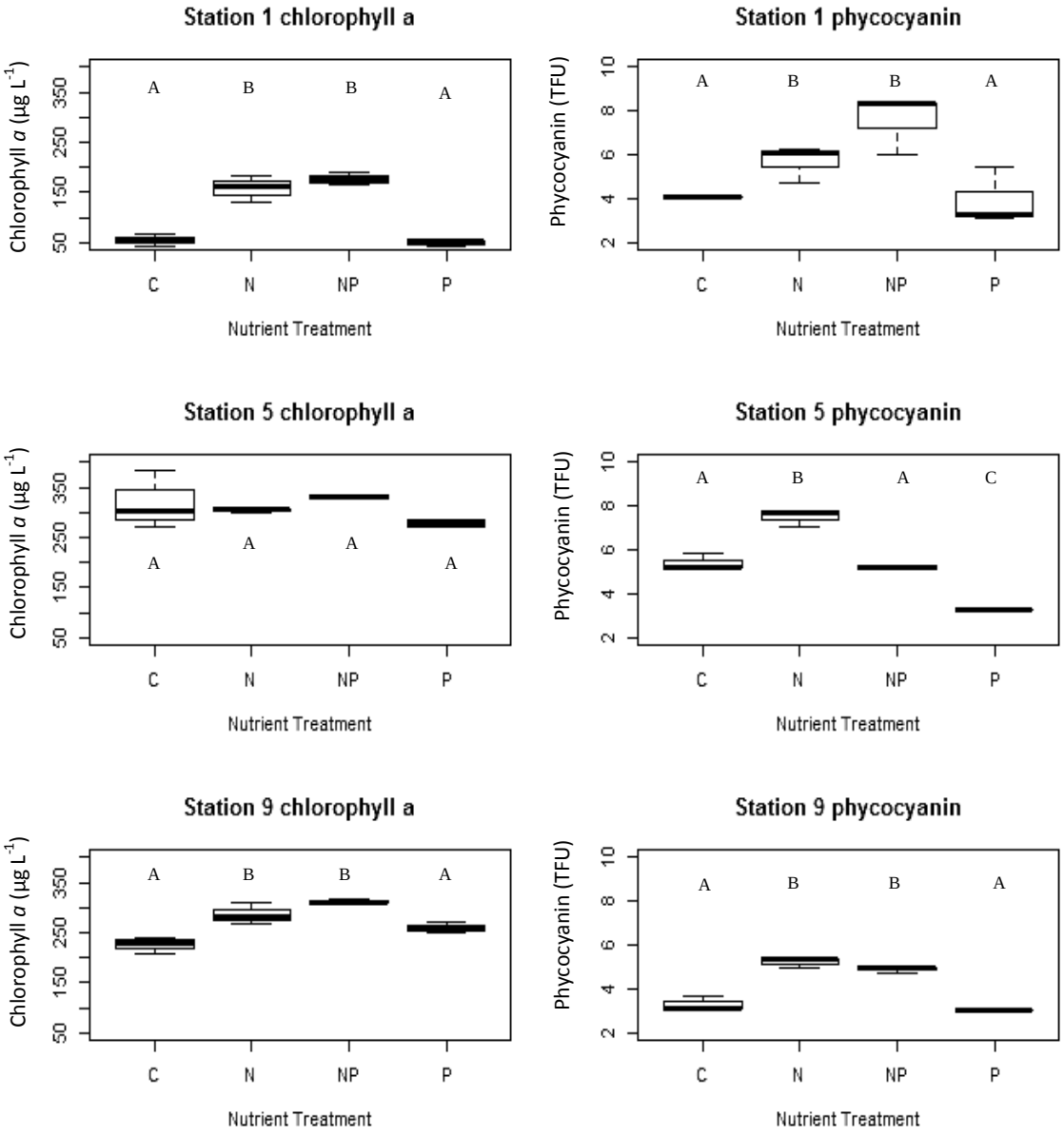

Figure 17. Boxplots of chlorophyll *a* (µg L^{-1}) and phycocyanin (Turner fluorescence units [TFU]) at the end of an 8-day nutrient addition bioassay experiment using water from three locations along the transect from south to north from water collected on June 3, 2013. Means are represented as thick black lines and ranges are represented with the whiskers. Treatments in the experiment were: C-Controls; N-NH_4NO_3 additions; P-PO_4 additions, and; NP-additions of both NH_4NO_3 and PO_4. Stations 1, 5, and 9 were located at the southern, middle, and northern parts of the bay, respectively. One-way analyses of variance done for each station indicated that there were significant differences between treatments, with the exception of Station 5 chlorophyll *a*. Letters indicate significant differences between specific treatments as determined by post-hoc Tukey's Studentized range tests. Treatments that share a common letter were not significantly different.

The initial phytoplankton biovolume at Station 5 was high and composed of 96% *Nodularia* (Appendix C). At this station in the middle of the bay chlorophyll *a* did not respond significantly from additions of N or P. Phycocyanin was increased with the addition of N and significantly reduced by the addition of P, but strangely a combination of both did not result in any significant difference. These results indicate that the cyanobacteria growth (as measured by phycocyanin) in the middle of the bay may have been limited by N, but other phytoplankton growth (as measured by chlorophyll *a*) was not limited by nutrients and instead may have been limited by another factor such as light or zooplankton grazing, which was high at this location.

At Station 9 (the north end of the bay) the addition of N and +N+P stimulated both phycocyanin and chlorophyll a, but P additions did not increase either parameter. These results indicate that both phytoplankton and cyanobacteria growth was N-limited at that location.

June 28, 2013 Nutrient addition and salinity bioassays

Water collected at station #5 in the middle of the bay was used to conduct two bioassay experiments designed to: 1) determine if any nutrient limitations existed at this location, and 2) determine if there was an effect from varying the salinity on the growth of cyanobacteria and phytoplankton, as measured by phycocyanin and chlorophyll *a*. The initial phytoplankton composition of the cultures was dominated by diatoms (64%, primarily *Cyclotella* sp.), and *Nodularia* (32%), but overall cell densities were low (Figure 8).

Nutrient addition bioassay—Both phycocyanin and chlorophyll *a* increased in controls from the starting value, but only phycocyanin levels showed a significant difference from the control at the end of the experiment ($p=0.0005$; Figure 18, lower frames). Phycocyanin concentrations increased with the addition of both N+P, but not when either nutrient was added separately. Chlorophyll *a* did not show a significant response to N, P or N+P, but the concentration did increase over 200% compared to the starting value measured on the day of field collection.

Salinity treatment bioassay – Both phycocyanin and chlorophyll *a* showed significant differences from the control (salinity not altered and remained at 17 g L^{-1}), but these measures responded in opposite directions to the changes in salinity (Figure 18, upper frames). Phycocyanin levels decreased as salinities increased from 17 g L^{-1} to 43 g L^{-1}, but did not significantly change above that level. In contrast, chlorophyll *a* levels increased significantly with each salinity increment from 17 g L^{-1} through 58 g L^{-1}.

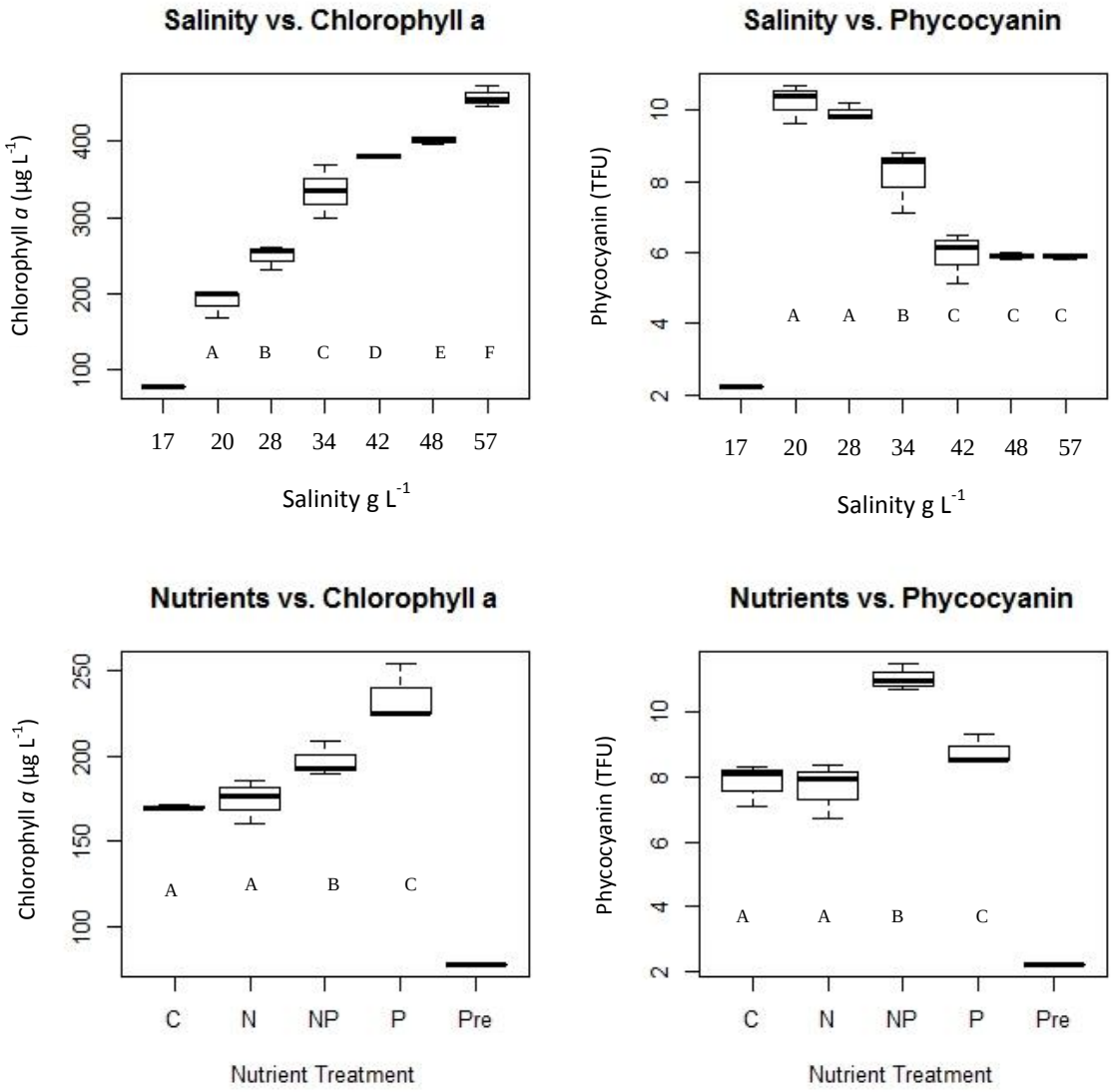

Figure 18. Chlorophyll *a* and phycocyanin concentrations in nutrient addition and salinity change bioassays conducted over 8 days starting on June 29, 2013. These bioassays used water from the middle of Farmington Bay (Station 5). The values for the 18g L^{-1} salinity indicate the phycocyanin or chlorophyll levels in the lake water at the start of the experiment. Bars indicate max, min and mean (dark bar) and boxes indicate quartiles. One-way analysis of variance indicated that there were significant differences between treatments and control for some treatments but not all. Letters indicate significant differences as determined by post-hoc Tukey's Studentized range tests. Treatments that share a common letter were not significantly different.

DISCUSSION

Nodularia, cyanotoxins, and eutrophication

The results of our study confirm that *Nodularia spumigena* is commonly found in Farmington Bay and the levels of it, and the toxin it produces, often exceed the World Health Organization's (WHO) advisory levels for adverse aquatic human health effects. We collected data on the concentration of *Nodularia* at five locations across the bay on five different dates and found that concentrations often exceeded 100,000 cells mL^{-1}, which is the WHO's moderate risk level for contact with human skin (Chorus and Bartram 1999). These values are comparable to concentrations found in other studies of the bay (Wurtsbaugh and Marcarelli 2005, Wurtsbaugh 2007, Wurtsbaugh et al. 2012, Marden in prep.; Table 4). We found a mean concentration of nodularin of 14 µg L^{-1} and a maximum level of 69 µg L^{-1} on June 3, 2013. Concentrations were often above the 20 µg L^{-1} level identified as moderate human health risk by the WHO (Chorus and Bartram 1999). These conditions can be toxic to aquatic organisms, birds, and mammals (Francis 1878, Paerl and Otten 2012, Drobac et al. 2013) and may have adverse impacts on nearby human populations if the cyanobacteria cells or cyanotoxins become entrained in dust storms blowing over populated areas (Metcalf et al. 2012).

Table 4. *Nodularia* concentration ranges (cells mL^{-1}) found in four studies of Farmington Bay.

This study	Marden et al. (in prep.)	Wurtsbaugh et al. (2012)	Wurtsbaugh and Marcarelli (2005)
0 - 1,358,000	0 - 900,000	0 – 238,000	0 - 897,000

Accounts of ecological and human health disasters related to cyanotoxins are common across the globe and there is little doubt that human inputs of nutrients usually cause the high concentrations that precipitate such events (Paerl and Otten 2012, Drobac et al. 2013). Other studies across the globe have also found direct or indirect links between blooms of *Nodularia* and toxic effects on mammals, including humans (Francis 1878, Nehring 1993, Mazur-Marzec et al. 2007, Simola et al. 2012, Drobac et al. 2013). Nonetheless, the official status of Farmington Bay is that the water meets the beneficial uses in the bay, including the needs of wildlife and aquatic life and the recreation needs of humans. Additionally, Farmington Bay is not typically used for contact recreation. Furthermore, there is no definitive information to link the cyanobacteria blooms and cyanotoxins to ill effects on wildlife or aquatic life in the Great Salt Lake. Many instances of harm to birds and aquatic organisms, possibly related to cyanobacteria exposure, have been recorded in recent years around the globe (e.g. Matsunaga et al. 1999, Alonso-Andicoberry et al. 2002, Landsberg 2002, Blaha et al. 2009, Da Ferrao-Filho and Kozlowski-Suzuki 2011, Paerl and Otten 2012, Lurling and Faasen 2013). Many of these events have occured at cyanobacteria densities and toxin levels well below those that have been observed in Farmington Bay.

The results of our study also confirm that hypereutrophic conditions occur regularly in the bay, where we observed mean and maximum chlorophyll *a* concentrations of 110 μg L^{-1} and 263 μg L^{-1}, respectively, across all samples in the study (Table 5). These concentrations are well above the 50 μg L^{-1} needed for a hypereutrophic classification (Carlson 1977) and are comparable to those observed in previous and ongoing studies (Wurtsbaugh and Marcarelli 2005, Wurtsbaugh 2012, Marden et al. in

Table 5. Mean and peak chlorophyll *a* concentrations (µg L^{-1}) found in four studies of Farmington Bay.

	This study	Marden et al. in prep.	Wurtsbaugh et al. 2012
Mean	110	NA	141
Peak	263	506	470

prep.). These hypereutrophic conditions have led to periods of anoxia throughout the water column, which may not be suitable to support aquatic life at all times (Wurtsbaugh 2012). Although there were highly variable conditions across the bay during our study, some general patterns were observed. Similar to the patterns seen in many inland lakes (Lampert et al. 1986), we saw diatom and green algae growth early in the year to mid-June, transitioning into mostly cyanobacteria in mid-summer of 2013. Although densities of mostly herbivorous zooplankton such as *Moina* sp. and *Daphnia* sp. were frequently very high (Figure 16), their grazing pressure was apparently unable to keep up with the growth of cyanobacteria and other phytoplankton.

Salinity Gradient as an Ecosystem Driver

The spatial extent and variability of cyanobacteria and other phytoplankton across the bay was related to salinity. We observed *Nodularia spumigena* in water with salinity between 7 and 50 g L^{-1}. Marden et al. (in prep) reported that no *Nodularia* was present over 59 g L^{-1} salinity in a concurrent study. This threshold for the persistence and growth of *Nodularia spumigena* is higher than that found in the Baltic Sea, where *Nodularia* is typically found between 7 to 20 g L^{-1} salinity. Lehtimaki et al. (1997) and Moissander et al. (2002) found that growth of *Nodularia* from the Baltic was inhibited above and below

those thresholds. The results of our bioassays conducted between June 29, 2013 and July 5, 2013 showed that the pigment phycocyanin decreased and chlorophyll *a* increased with incremental increases in salinity in the range of 16-58 g L^{-1} (Figure 18). These data indicate that increasing salinity diminished the growth of *Nodularia* in the natural range commonly observed in the bay. These results are similar to the bioassay results presented in Marcarelli et al. (2006), where *Nodularia* biomass decreased at salinities > 30-40 g L^{-1}. In contrast to the response of *Nodularia* in bioassays, our salinity assay showed that overall algal levels, as measured by chlorophyll *a*, increased with rising salinity (Figure 18). Consequently, trophic status could still increase with increasing salinity, even though cyanobacteria decline (as indicated by phycocyanin levels in the June 29 experiment).

It is possible that due to genotypic variability the *Nodularia* in the Great Salt Lake has a higher salinity tolerance than *Nodularia* in the Baltic Sea. Another possibility is that the growth of Farmington Bay *Nodularia* actually peaks in the same salinity range as those found in the Baltic Sea (Moissander et al. 2002, Marcarelli et al. 2006), and the high concentrations we observed in higher salinity areas was due to advection and mixing of low-salinity water masses with more saline water to the north that had mixed with the intrusions from Gilbert Bay of Great Salt Lake.

Nutrients across the bay

Nutrients from municipal waste, diffuse pollution, and natural sources nourish the phytoplankton community in Farmington Bay. We observed mean total nitrogen (TN) and total phosphorus (TP) concentrations of 5.2 mg L^{-1} and 0.57 mg L^{-1}, respectively. These values are comparable to those found in previous years (Wurtsbaugh et al. 2012).

The high levels of nitrogen we observed were weakly but significantly correlated to *Nodularia* in our study (Pearson's r = 0.55, t = 3.425, df = 27, p-value = 0.0020). Although our data indicates that total nitrogen was correlated with *Nodularia*, it is unclear if the high level of TN causes the *Nodularia* population to increase, or if high N-fixation rates of this species increases the TN concentration. Others have found no correlation between TN and *Nodularia*, but those surveys included data from outside the growing season, where nutrient cycling in the water column was likely different from our study due to the seasonality of biotic processes (Marcarelli et al. 2006, Wurtsbaugh et al. 2012, Marden et al. in prep.). TP was not correlated to *Nodularia* in our study. This is likely because *Nodularia* have the ability to collect and hold phosphorus through a process known as "luxury uptake", where this nutrient is held within *Nodularia* cells above the amount needed for growth and metabolism (Litchman et al. 2010). The high phosphorus concentrations found at the south end of the bay were likely from the waste water treatment works that discharge there, but we cannot rule out periodic releases of phosphorus from legacy sediments.

Our bioassay data indicate that phytoplankton in the bay (as measured by chlorophyll *a*) was limited primarily by nitrogen. This result is consistent with the results of Marcarelli et al. (2006) when compared to their 6-day long bioassays. However, they found that when the assays were allowed to continue for 30 days, nitrogen-fixation by cyanobacteria overcame the N limitation, and the phytoplankton communities became P-limited. Similarly, water column TN:TP ratios suggest that growth of phytoplankton in the south end of Farmington Bay may be nitrogen limited, with an increasing phosphorus limitation further to the north in the bay. This change may be due to fixation of

atmospheric N_2 in the heterocysts of *Nodularia* (Marcarelli et al. 2006), and to sedimentation losses of P. Our bioassay data also indicate that cyanobacteria in the bay (as measured by phycocyanin) was stimulated by the addition of N or both +N+P, with lower phycocyanin concentrations found in experiments where only P was added.

Between 40-60% of nutrients entering Farmington Bay are derived from human waste sources (Meyers and Houston 2006). This preliminary analysis of P loading to the bay from municipal wastes alone is 2.6 g P m^{-2} yr^{-1} (Meyers and Houston 2006), well above the 0.1 mg P m^{-2} yr^{-1} estimated to cause "dangerous loading" in shallow freshwater lakes (Wetzel 2001). Using phosphorus input and outflow data for Farmington Bay presented in Meyers and Houston (2006) we determined that the sediments there are a sink for phosphorus, with over 60% of the incoming P loading from municipal wastes remaining in the bay and not being flushed to Gilbert Bay. However, if external loading was reduced, nutrients would likely diffuse out of legacy sediments during anoxic conditions (Mortimer 1941, Van Luijn et al. 1999). Estimates from other systems indicates that over a decade is required for a new equilibrium to be established once loading is decreased (Jeppesen et al. 2007). Limited work has been done to establish the N loading to the bay, but Gray (2012) showed that ammonia release from the sediments just upstream from the bay in Farmington Bay Waterfowl Management Area had diel cycles of ammonia. That study suggested that release of N from sediments may also occur during times of low dissolved oxygen.

Top-down and Bottom-up Controls on Phytoplankton

Sommer et al. (2012) tested models that assess the limits on phytoplankton growth in lakes and the ocean and found that many factors play into the balance of different functional groups of phytoplankton. They looked at classic models that had a simple suite of parameters to determine the controls on phytoplankton growth, which included the physical controls of light and temperature combined with grazing of zooplankton and nutrient limitation (Sommer et al. 1986). In addition to those parameters, the more recent evaluation found several other factors that might control the growth of phytoplankton (Sommer et al. 2012). Those factors included overwintering populations of grazing zooplankton and grazing by heterotrophic protists which emerge early in the growing season, parasitism effects on grazing zooplankton, and the role of food quality in supporting grazing zooplankton populations.

We found high densities of zooplankton that likely grazed huge amounts of phytoplankton and preyed upon other small organisms, including smaller zooplankton, bacteria, fungi, and protists. Lampert (1987) estimated that a *Daphnia* could filter 2-15 mL of the water column per day. Although the majority of the zooplankton observed in our study were not *Daphnia,* zooplankton in high enough concentrations likely filtered significant portions of the algae in Farmington Bay, but the high chlorophyll levels normally observed indicate that there was insufficient grazing pressure to create clear water conditions.

Recommendations for Future Research

The findings in this report help us to prioritize the direction of future study in Farmington Bay. Although we found high levels of *Nodularia* in the bay, we did not address potential adverse impacts to wildlife or the aquatic food chain. Future studies should focus on this topic. In order to determine if *Nodularia* and nodularin are actually impacting birds or aquatic life, we should focus on areas that birds typically congregate during the months when *Nodularia* is present. Our study focused on the open waters across the middle of the bay and migratory birds use this area at times, but shoreline areas might be more likely areas for impacts because winds often push scums of cyanobacteria to the shore. It would be helpful to know if nodularin or other toxins are accumulating in sediments along these shorelines. This could be accomplished by collecting sediments during the most common bloom times (June) and testing for nodularin and other common toxins produced by cyanobacteria, including β-methyl-amino-L-alanine (BMAA). Once we determine what the concentration of key toxins are in the bay and what the legacy of those toxins is in surrounding sediments, relative risk models can be developed to compare the effect of cyanotoxins with other environmental contaminants such as metals and other pathogens.

The results of our study have also provided some guidance on future studies of the bay for the agencies charged with protecting Utah's natural resources. For the Utah Division of Water Quality's Great Salt Lake monitoring plan, at least one of the sample stations should be placed further south in the bay because conditions frequently were much different their than in the north. Researchers should look more closely at the ecosystem dynamics by using a phytoplankton ecology model that includes the inputs of

grazing of algae by macrozooplankton, protists, parasitism, the microbial loop, release of different forms of nutrients from the sediments, and overwintering zooplankton populations. Because ammonia tends to stimulate cyanobacteria, and nitrate increases populations of diatoms and green algae (Blomqvist et al. 1994), the importance of loading and recycling of these two types of nitrogen needs to be assessed. We should also assess the loading of both N and P into the bay and explore other possible limitation of toxic cyanobacteria growth.

We should continue to develop our understanding of the conditions under which we get the most concentrated blooms of the toxic cyanobacteria *Nodularia*. We should also attempt to develop a further understanding of the top-down grazing pressures or bottom-up nutrient limitation approaches that might provide some control of the phytoplankton growth. Furthermore, we may want to consider options for increasing the salinity in the bay above that tolerated by *Nodularia* by making the Antelope Island causeway more permeable to water from Gilbert Bay. This latter option may provide the most cost-effective solution, considering the limited resources available for implementing reasonable solutions, but may also produce some unexpected consequences. Overall, a collaborative approach to developing this understanding will lead to the best outcomes for all parties involved.

Some ideas for future research include developing better knowledge of the food web in the bay and its connection to the brine shrimp industry and human health. A better modeled food web would help us understand the dynamics controlling cyanobacteria and phytoplankton growth. We should also further develop the connection with nutrients and the brine shrimp industry and determine if the cyanotoxins adversely affect the brine

shrimp in the open waters. We also need to develop a better understanding of the human health effects of blowing dust on communities close to the lake as more dry lake bed emerges. If drought conditions persist and water withdrawals from source rivers continue unabated these dust events may become more common. We need to conduct further studies to see if there is a link between the conditions in the bay and bird health or the health of the ecosystem components that support healthy migratory bird populations. This should include the possible link to avian botulism or other bird health issues (Murphy et al. 2000).

Once we understand the conditions that support the growth and persistence of toxic cyanobacteria in the bay, we will be able to better predict when blooms might occur. Research funding might also be well spent on developing our understanding of the conditions that are most likely to produce toxins and release them into the environment effecting wildlife and other aquatic organisms.

Conclusion

In summary, our observations indicate that there are periods when high concentrations of cyanobacteria and high levels of the liver toxin nodularin are present in the bay. These conditions may be more prevalent in the future with lower levels of the Great Salt Lake and less freshwater input reducing the effect of dilution. Although cyanobacteria react to changes in the physical parameters such as light, temperature and salinity, they also react to changes in availability of key resources needed for cell building, such as nitrogen and phosphorus and grazing from herbivorous and omnivorous

metazoans. There are both top-down and bottom-up effects on the size and structure of algal and metazoan populations.

Sustaining the importance of Farmington Bay is of international importance because the bay has been designated as a Western Hemisphere Shorebird Reserve Network Important Bird Area (WHSRN, Audubon Society 1991). In some ways nutrients benefit the ecosystem of Farmington Bay and the Great Salt Lake because they stimulate the food web for migratory birds and aquatic organisms. On the other hand, the cyanotoxins that have been found in Farmington Bay have been implicated in acute poisoning of dogs, birds and humans across the globe (Francis 1878, Nehring 1993, Mazur-Marzec et al. 2007, Simola et al. 2012, Drobac et al. 2013). Murphy et al. (2000, 2003) have also suggested that cyanotoxins may be related to outbreaks of avian botulism. More work is needed to definitively link these toxins with detriments to wildlife and the aquatic life in Farmington Bay and the Great Salt Lake, but the precautionary principle provides some impetus to continue evaluating the conditions in the bay, for the health of humans and our environment.

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APPENDICES

Appendix A. Field parameters measured using a data sonde and sample locations during the 2012-2013 transects in Farmington Bay.

Date	Station	Identifier	Time	Latitude	Longitude	Depth Station (m)	Salinity (%)	Salinity (g L^{-1})	Temperature °C (0.2 m)	Dissolved Oxygen (µg/L)	Secchi (m)
18-Jun-12	1	FB-1	12:20 PM	40.91867	-112.03187	0.3	2.6	25	25.7	8.2	>0.28
18-Jun-12	2	FB-2	11:48 AM	40.91867	-112.03187	0.8	3.4	34	25.6	15.5	0.4
18-Jun-12	3	FB-3	1:30 PM	40.93062	-112.09158	1.4	3.5	35	26.0	16.3	0.3
18-Jun-12	4	FB-4	2:13 PM	40.95892	-112.1087	1.5	3.5	35	28.1	20.4	0.3
18-Jun-12	5	FB-5	2:38 PM	40.98033	-112.11893	1.2	3.6	36	28.5	20.2	0.3
19-Jun-12	6	FB-6	10:47 AM	41.00329	-112.13969	1.6	4.8	49	20.3	5.5	0.4
19-Jun-12	7	FB-7	11:47 AM	41.01264	-112.15137	1.6	4.5	45	20.7	5.2	0.4
19-Jun-12	8	FB-8	12:29 PM	41.04402	-112.17076	1.6	4.5	45	21.5	4.4	0.3
19-Jun-12	9	FB-9	1:57 PM	41.05915	-112.18826	1.6	4.9	50	23.0	5.6	0.3
21-Sep-12	1	FB-1	9:40 AM	40.91867	-112.03187	0.3	0.5	3	14.5	1.4	0.2
21-Sep-12	2	FB-2	10:23 AM	40.91867	-112.03187	0.4	2.8	27	23.0	4.6	0.4
21-Sep-12	3	FB-3	10:41 AM	40.93062	-112.09158	0.7	2.5	24	21.3	1.2	0.5
21-Sep-12	4	FB-4	11:09 AM	40.95892	-112.1087	0.9	4.3	43	20.3	11.2	0.5
21-Sep-12	5	FB-5	11:43 AM	40.98033	-112.11893	0.8	4.9	43	20.3	12.3	0.4
21-Sep-12	6	FB-6	12:26 PM	41.00329	-112.13969	1.0	6.8	50	22.8	12.6	0.3
21-Sep-12	7	FB-7	1:00 PM	41.01264	-112.15137	0.8	6.2	71	22.4	12.3	0.4
21-Sep-12	8	FB-8	1:26 PM	41.04402	-112.17076	1.2	7.2	64	21.7	13.2	0.4
21-Sep-12	9	FB-9	1:55 PM	41.05915	-112.18826	1.3	7.4	76	22.2	12.1	0.3
3-May-13	1	FB-1	10:53 AM	40.91867	-112.03187	0.4	0.4	78	13.6	5.5	>0.44
3-May-13	2	FB-2	12:21 PM	40.91867	-112.03187	0.7	1.0	2	15.7	11.0	>0.65
3-May-13	3	FB-3	12:34 PM	40.93062	-112.09158	1.0	1.2	8	15.9	11.1	0.9
3-May-13	4	FB-4	1:35 PM	40.95892	-112.1087	1.1	1.5	10	16.5	10.1	0.8
3-May-13	5	FB-5	2:00 PM	40.98033	-112.11893	1.0	1.6	13	18.1	9.9	0.8
3-May-13	6	FB-6	2:30 PM	41.00329	-112.13969	1.0	1.6	14	18.2	8.6	0.9
3-May-13	7	FB-7	2:52 PM	41.01264	-112.15137	1.3	2.0	14	16.8	8.6	1.1
3-May-13	8	FB-8	3:45 PM	41.04402	-112.17076	1.4	2.5	24	16.1	5.5	1.1
3-May-13	9	FB-9	3:52 PM	41.05915	-112.18826	1.5	2.6	25	15.6	4.5	1.1
3-Jun-13	1	FB-1	1:55 PM	40.91867	-112.03187	0.5	0.2	1	22.9	5.3	>0.5
3-Jun-13	2	FB-2	1:33 PM	40.91867	-112.03187	0.7	0.6	4	22.6	15.4	0.2
3-Jun-13	3	FB-3	1:05 PM	40.93062	-112.09158	1.0	0.9	7	21.5	10.1	0.2
3-Jun-13	4	FB-4	12:54 PM	40.95892	-112.1087	1.1	1.4	12	21.1	11.4	0.1
3-Jun-13	5	FB-5	11:54 AM	40.98033	-112.11893	1.0	1.6	14	20.0	4.4	0.2
3-Jun-13	6	FB-6	11:29 AM	41.00329	-112.13969	1.0	2.3	22	18.8	4.3	0.2
3-Jun-13	7	FB-7	10:55 AM	41.01264	-112.15137	1.2	3.0	29	18.1	5.1	0.2
3-Jun-13	8	FB-8	10:05 AM	41.04402	-112.17076	1.5	0.3	0.5	18.3	3.7	0.3
3-Jun-13	9	FB-9	9:23 AM	41.05915	-112.18826	1.2	3.7	37	17.5	3.1	0.2
28-Jun-13	1	FB-1	9:44 AM	40.91867	-112.03187	0.2	0.2	5	25.0	2.7	>0.15
28-Jun-13	2	FB-2	10:19 AM	40.91867	-112.03187	0.4	0.6	6	26.6	4.2	0.4
28-Jun-13	3	FB-3	10:44 AM	40.93062	-112.09158	0.7	0.9	18	28.2	4.6	0.6
28-Jun-13	4	FB-4	11:30 AM	40.95892	-112.1087	0.9	1.4	25	27.8	6.1	0.6
28-Jun-13	5	FB-5	11:50 AM	40.98033	-112.11893	0.7	1.8	29	27.5	3.1	0.5
28-Jun-13	6	FB-6	1:00 PM	41.00329	-112.13969	0.8	2.3	35	28.4	7.8	0.4
28-Jun-13	7	FB-7	1:18 PM	41.01264	-112.15137	1.0	3.0	38	28.8	12.1	0.4
28-Jun-13	8	FB-8	1:57 PM	41.04402	-112.17076	1.2	3.3	40	26.9	4.9	0.6
28-Jun-13	9	FB-9	1:57 PM	41.05915	-112.18826	0.9	3.7	42			0.7

Appendix B. Database of laboratory results for nutrients, pigments, and isotopes

Identifier	Date	Chl (µg/L)	Phycocyanin (TFU)	Nodularin (µg/L)	NH4-N (mg/L)	NO3-N (mg/L)	Soluble reactive phosphorus (mg/L)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Organic nitrogen (mg/L)	Total inorganic nitrogen (mg/L)	Total phosphorus - soluble reactive phosphorus (mg/L)	Seston δ N15	Seston δ 13C
FB-1	18-Jun-12	175	2.53	3.7	0.15	0.04	0.04	4.85	0.50	4.66	0.19	0.46	5.42	-18.81
FB-2	18-Jun-12	165	4.65	3.3	0.01	0.04	0.02	5.69	0.32	5.64	0.05	0.29	3.78	-15.87
FB-3	18-Jun-12	125	7.95	10.8	0.15	0.05	0.03	5.38	0.27	5.18	0.20	0.25	3.02	-15.98
FB-4	18-Jun-12	141	7.04	4.1	0.15	0.06	0.03	4.51	0.21	4.30	0.21	0.19	2.08	-15.26
FB-5	18-Jun-12	124	6.24	3.5	0.16	0.06	0.02	5.43	0.26	5.21	0.22	0.23	2.51	-15.41
FB-6	19-Jun-12	150	4.49	2.8	0.23	0.05	0.03	5.48	0.27	5.20	0.27	0.24	3.48	-15.54
FB-7	19-Jun-12	175	4.98	6.9	0.20	0.04	0.02	5.40	0.30	5.16	0.24	0.27	3.31	-15.36
FB-8	19-Jun-12	205	4.45	11.2	0.23	0.05	0.03	5.89	0.41	5.61	0.28	0.39	3.27	-15.54
FB-9	19-Jun-12	171	4.24	5.5	0.31	0.05	0.03	5.56	0.31	5.20	0.35	0.28	3.17	-15.36
FB-1	21-Sep-12	128	1.53		0.06	0.02	0.41	2.93	0.69	2.85	0.08	0.28	NA	NA
FB-2	21-Sep-12	134	0.83		0.69	0.65	0.42	6.00	0.85	4.65	1.34	0.44	NA	NA
FB-3	21-Sep-12	167	0.64		0.14	0.32	0.19	4.76	0.64	4.30	0.46	0.45	NA	NA
FB-4	21-Sep-12	160	0.60		0.18	0.05	0.06	6.40	0.69	6.18	0.22	0.63	NA	NA
FB-5	21-Sep-12	130	0.59	1.0	0.20	0.03	0.06	6.19	0.64	5.96	0.22	0.58	NA	NA
FB-6	21-Sep-12	178	0.99		0.29	0.05	0.06	7.80	0.63	7.47	0.34	0.57	NA	NA
FB-7	21-Sep-12	114	1.01		0.24	0.06	0.04	6.42	0.53	6.13	0.30	0.49	NA	NA
FB-8	21-Sep-12	167	1.25		0.28	0.06	0.05	7.18	0.59	6.84	0.34	0.54	NA	NA
FB-9	21-Sep-12	161	1.58		1.20	1.08	0.11	7.69	0.25	5.41	2.28	0.14	NA	NA
FB-1	3-May-13	9	1.31		0.18	0.01	0.53	2.26	0.64	2.07	0.19	0.10	8.95	-23.75
FB-2	3-May-13	28	1.13	0.5	0.34	0.23	0.27	2.24	0.26	1.67	0.57	-0.01	10.67	-21.29
FB-3	3-May-13	29	1.17	0.6	0.60	0.20	0.15	3.79	0.44	2.99	0.80	0.28	10.69	-21.73
FB-4	3-May-13	27	1.26	0.3	0.23	0.04	0.06	2.78	0.23	2.52	0.27	0.17	10.33	-21.48
FB-5	3-May-13	33	1.01	0.2	0.15	0.01	0.05	3.39	0.31	3.23	0.16	0.26	10.18	-21.19
FB-6	3-May-13	14	1.15		0.24	0.01	0.03	3.35	0.28	3.11	0.24	0.25	9.42	-20.42
FB-7	3-May-13	17	0.93	0.2	0.28	0.01	0.02	3.35	0.28	3.07	0.29	0.26	8.56	-21.42
FB-8	3-May-13	6	0.88	0.8	0.18	0.01	0.02	3.00	0.21	2.82	0.19	0.19	8.18	-20.61
FB-9	3-May-13	6	0.93	0.5	0.20	0.01	0.03	3.08	0.22	2.88	0.21	0.20	8.16	-20.43
FB-1	3-Jun-13	19	1.15	1.2	0.22	0.04	0.59	1.60	0.69	1.33	0.27	0.10	9.26	-23.36
FB-2	3-Jun-13	224	6.02	12.9	0.33	0.03	0.26	5.37	0.91	5.01	0.36	0.65	6.95	-20.49
FB-3	3-Jun-13	267	17.60	69.4	0.53	0.09	0.02	7.20	0.85	6.57	0.63	0.83	5.94	-18.54
FB-4	3-Jun-13	175	17.80	68.0	0.57	0.01	0.01	7.11	0.67	6.52	0.59	0.66	5.65	-17.26
FB-5	3-Jun-13	193	21.10	52.0	0.64	0.00	0.01	7.32	0.58	6.67	0.65	0.57	4.78	-17.11
FB-6	3-Jun-13	131	15.40	43.1	0.75	0.11	0.01	6.83	0.51	5.97	0.86	0.50	3.96	-17.38
FB-7	3-Jun-13	116	15.70	31.1	0.73	0.17	0.01	5.33	0.35	4.43	0.89	0.34	3.90	-17.72
FB-8	3-Jun-13	122	13.30	30.0	1.16	0.14	0.01	6.32	0.45	5.02	1.30	0.43	4.26	-18.13
FB-9	3-Jun-13	146	16.90	31.7	0.91	0.24	0.02	6.70	0.46	5.55	1.15	0.44	3.59	-17.87
FB-1	28-Jun-13	45	1.37		0.50	0.04	3.36	4.15	3.50	3.60	0.55	0.14	NA	NA
FB-2	28-Jun-13	48	1.74		0.50	0.04	3.36	4.15	3.50	3.60	0.55	0.14	NA	NA
FB-3	28-Jun-13	54	1.83		0.09	0.01	0.01	5.77	0.54	5.67	0.10	0.53	NA	NA
FB-4	28-Jun-13	67	5.38		0.11	0.01	0.01	6.21	0.37	6.09	0.12	0.36	NA	NA
FB-5	28-Jun-13	78	2.21		0.16	0.02	0.02	6.78	0.45	6.61	0.17	0.43	5.35	-16.03
FB-6	28-Jun-13	118	3.05		0.13	0.01	0.01	6.47	0.34	6.32	0.15	0.33	4.36	-15.73
FB-7	28-Jun-13	85	5.60		0.06	0.01	0.01	6.48	0.36	6.41	0.07	0.35	3.36	-16.46
FB-8	28-Jun-13	39	3.16		0.14	0.01	0.01	4.91	0.23	4.76	0.15	0.22	3.49	-16.70
FB-9	28-Jun-13	47	4.28		0.05	0.01	0.01	6.06	0.29	5.99	0.07	0.28	3.10	-16.36

Appendix C. Database of phytoplankton densities measured in Farmington Bay on five dates in 2012-2013. The counts were done by Phycotech, Inc., St. Joseph, MI.

Identifier	Date	Zooplankton (individuals/L)	Zoop Biomass (µg/L)	Bacillariophyta Biovolume (µm/mL)	Chlorophyta Biovolume (µm/mL)	Chrysophyta Biovolume (µm/mL)	Cryptophyta Biovolume (µm/mL)	Cyanophyta Biovolume (µm/mL)	Euglenophyta Biovolume (µm/mL)	Haptophyta Biovolume (µm/mL)	Misc Algae (µm/mL)	Pyrrophyta Biovolume (µm/mL)	Tot. Phyto Biovolume (µm/mL)	Bacillariophyta (cells per mL)	Chlorophyta (cells per mL)	Chrysophyta (cells per mL)	Cryptophyta (cells per mL)	Cyanophyta (cells per mL)	Euglenophyta (cells per mL)	Haptophyta (cells per mL)	Misc Algae (cells per mL)	Pyrrhophyta (cells per mL)	Tot. Phyto (cells per mL)	Nodularia Biovolume (µm/mL)	Nodularia Concentration (cells per mL)	Dunalliela Biovolume (µm/mL)	Dunalliela Concentration (cells per mL)	Heterocysts per mL	Heterocysts per cell (ratio)
FB-1	18-Jun-12	258	1135	2649874	1541118	0	275529	33707	0	89506	0	354759	2294618	82999	23149	0	3105	51538	0	847	0	1129	162768	0	0	765531	12139	0	NA
FB-2	18-Jun-12	196	763	2295702	1712301	0	95785	74415866	0	0	0	214274	76438226	93105	22867	0	847	577821	0	0	0	565	695205	74210770	307363	222761	3105	28607	9%
FB-3	18-Jun-12	344	1802	5311601	4565783	0	766279	28243151	0	38420	0	0	28780199	118569	54556	0	1270	1571339	0	1270	0	0	1747004	28220763	1358169	1207162	16515	181665	13%
FB-4	18-Jun-12	112	423	1956832	574364	0	0	44781254	0	0	0	180927	45536545	86894	7602	0	0	297508	0	0	0	282	392287	44723235	197663	148999	988	13551	7%
FB-5	18-Jun-12	78	303	1624569	822231	0	136227	42072946	0	5123	0	106428	43142955	61250	6843	0	678	341100	0	169	847	339	411225	41982133	180494	204341	1355	13339	7%
FB-6	19-Jun-12	116	579	1443933	1658516	0	0	10700470	0	0	0	155384	12514370	69024	13381	0	0	307812	0	0	0	339	390557	10566434	51971	95785	508	2329	4%
FB-7	19-Jun-12	116	615	1588977	2571077	0	85142	14318703	0	0	0	340568	17315491	115605	41796	0	423	508647	0	0	0	847	667318	13976602	65319	170284	423	2964	5%
FB-8	19-Jun-12	31	321	2376159	6221738	0	0	27913121	0	0	0	0	34134859	145671	63519	0	0	559578	0	0	0	0	768768	27671171	135508	79821	423	8469	6%
FB-9	19-Jun-12	61	901	8691819	2447681	0	0	41487478	0	0	0	204341	44139499	81135	30489	0	0	607424	0	0	0	169	719218	41200245	201653	0	53214	1412	0	NA
FB-1	21-Sep-12	53	53	2122193	305199	75682	3611440	182562	30864	0	54988	0	6382929	4235	10728	2258	106430	585707	282	0	847	0	710487	847	0	53214	1412	0	NA
FB-3	21-Sep-12	30	30	5311534	1449352	0	7095	37868	0	0	14390	148112	6968351	28054	18971	0	212	72877	0	0	212	423	120749	212	0	0	0	0	NA
FB-5	21-Sep-12	24	24	5284129	2242618	0	15420	1513663	0	0	0	1227268	10283097	35571	20467	0	20	194624	0	0	0	3529	254211	1880221	5505	0	0	423	8%
FB-7	21-Sep-12	0	0	5284129	2242618	0	15420	1513663	0	0	0	1227268	10283097	7854	110312	0	0	269102	0	10163	0	2329	399761	0	0	0	0	0	NA
FB-9	3-May-13	33	33	2730089	2191744	0	0	6708764	0	742794	0	2043410	34144802	22020	268221	0	0	1197165	0	24561	0	3388	1515355	0	0	0	0	0	NA
FB-1	3-May-13	11	11	1892887	929947	115261	14190	147311	0	0	0	0	2971587	20750	18209	3811	423	174581	0	0	0	0	217774	0	0	0	988	0	NA
FB-3	3-May-13	18	18	2311113	300058	2478	8514	4310558	0	0	0	0	5999304	27086	2244	127	42	45132	3	0	85	0	74719	2890592	14009	0	0	1534	11%
FB-5	3-May-13	14	14	6073486	189993	0	0	924595	0	0	0	0	6768670	32797	1306	0	0	24100	0	0	0	0	58203	612370	2981	0	0	271	9%
FB-7	3-May-13	41	41	2861057	243872	479	0	2717365	180842	0	0	0	4937294	19107	796	34	0	16940	102	0	0	0	36979	1798055	8779	0	0	681	8%
FB-9	3-Jun-13	19	19	1107037	170773	0	0	536528	0	0	0	0	1526451	10267	271	0	0	5564	0	0	0	0	16102	356832	1737	0	0	157	9%
FB-1	3-Jun-13	12	12	844288	1104813	25700	20694	160748	125585	140875	0	3427	2426130	4658	52028	20	282	153742	141	4658	0	20	215551	45232	225	0	0	0	0%
FB-3	3-Jun-13	52	52	1193019	3262742	0	104765	79941523	0	461045	0	0	9570027	89632	222212	0	1270	710365	0	15245	0	0	1038723	7973641	393027	0	0	14221	4%
FB-5	3-Jun-13	39	39	930243	774217	41507	3548	10764983	0	38420	0	0	1094377	5964	33361	106	106	642059	0	1270	0	0	682866	10759982	527297	0	0	31442	6%
FB-7	3-Jun-13	34	34	1385403	195561	0	9978	56325311	0	51227	0	0	5796747	9422	2329	0	106	405875	0	1694	0	0	419426	56261247	273249	0	0	13318	5%
FB-9	28-Jun-13	80	80	2570285	242542	0	0	53270377	0	43909	0	0	5612711	17023	4065	0	0	302931	0	1452	0	0	325471	53258065	257007	0	0	22020	9%
FB-1	28-Jun-13	46	46	1608038	31669	0	4730	32343	0	0	106241	0	1762635	847	692	0	141	16766	0	0	1397	0	19844	0	0	0	0	0	NA
FB-3	28-Jun-13	79	79	1267105	539975	4989	4730	8385131	0	0	0	57944	1823475	36813	2400	353	141	45254	0	0	0	71	85031	5140898	25147	0	0	1759	7%
FB-5	28-Jun-13	54	54	1034884	1132049	11352	0	7784524	0	0	0	0	1605003	36813	2400	353	141	45254	0	0	0	71	85031	5182813	25229	0	0	2283	9%
FB-7	28-Jun-13	32	32	3377214	329247		0	9849155	0	0	0	66517	7090116	36813	2400	353	141	45254	0	0	0	71	85031	6560963	319345	0	0	2903	9%
FB-9	28-Jun-13			1243189	2520050	3991	0	77412037	0	0	0	25543	5402649	12446	6259	0	42	254277	0	0	0	42	273066	5127456	250365	0	0	19347	8%