Water Column Monitoring Results for Cape Cod Bay and Stellwagen Bank National Marine Sanctuary 2017-2019

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Water Column Monitoring Results for Cape Cod Bay and Stellwagen Bank National Marine Sanctuary 2017-2019

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Executive Summary

This report documents phytoplankton and zooplankton communities, nutrient and plant pigment chemistry, and right whale observation data in Cape Cod Bay (CCB) during 2017 through 2019. The data presented in the report were collected by the Center for Coastal Studies (CCS), to document conditions in the Bay, and to better understand the linkages between nutrient and plankton conditions in the Bay, and whale usage of the Bay. Data presented include data from the three locations in CCB and Stellwagen National Marine Sanctuary (SBNMS) MWRA is required to monitor. It also includes water quality data collected by CCS year-round at nine additional stations in CCB, and by CCS's right whale aerial and right whale habitat surveys in CCB conducted from January – May.

The physical environment, water chemistry, plankton communities, and whale sightings differed among years with no clear interannual patterns. The most notable event in the physical environment during these three years occurred in the fall of 2019 when bottom dissolved oxygen levels reached unusually low levels. Conditions leading up to this event included a strongly stratified water column and high phytoplankton biomass. It is thought that the persistence of a strongly stratified water column isolated a thin bottom water layer that, in combination with the increased flux of organic material to the bottom waters led to hypoxic/anoxic conditions. This is also reflected in the water chemistry with high bottom dissolved inorganic nitrogen (DIN) concentrations preceding the event, unusually low DIN concentrations during the event, and high ammonium concentrations following the event compared to 2017 and 2018.

While there was some variation among years in water chemistry, patterns were similar to those that were observed in the 2014-2016 report. Dissolved inorganic nutrients (nitrogen, phosphorus, and silica) were lower than the long-term averages at both near surface and bottom depths. Redfield ratios indicate phytoplankton productivity in the Bay was nitrogen limited relative to both phosphorus and silicate.

Annual average phytoplankton biomass (measured as chlorophyll *a*), both at near surface and bottom depths, was highest in 2019, likely due to a late fall bloom of *Karenia mikimotoi*. Phytoplankton cell counts, again averaged annually, were highest in 2018. Because cell counts are only done on surface water samples, the high chlorophyll levels recorded in 2019 in the bottom waters were not captured in phytoplankton cell counts. A moderate *Phaeocystis* bloom occurred in 2018, elevating the annual average abundance of phytoplankton cells in surface water compared to 2017 and 2019. In February of 2017 and February and March of 2019, the centric diatom *Guinardia delicatula* reached abundances of approximately 100,000 to 300,000 cells/liter indicating the occurrence of a winter/spring diatom bloom. There was no indication of a winter spring bloom in 2018.

Annual average zooplankton abundance, after increasing for the past several years, started to decline over this three-year period. Highest abundances were recorded in 2017 due to a peak in April of *Calanus finmarchicus* and *Pseudocalanus* spp. The timing and occurrence of these species are of particular importance in the Cape Cod Bay ecosystem because they provide a winter food resource for right whales. Of this three-year period, only in 2017 was zooplankton abundance in oblique samples taken around feeding right whales higher than the long-term average of approximately 8,000 organisms/m^3.

Despite what the declining zooplankton food resource would suggest, the number of sightings of individual right whales was high across all three years, comprising close to 60% of the entire population. The spatial distribution varied among years, as did the residency time, the period of peak numbers, and the predominant behaviors that were observed.

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1. INTRODUCTION

As part of the environmental monitoring program implemented by MWRA in Massachusetts and Cape Cod Bays in support of MWRA's outfall in Massachusetts Bay, the Center for Coastal Studies (CCS) has continued the ambient water column monitoring required at three locations by adding these three stations to CCS's ongoing Cape Cod Bay monitoring program. Two of the stations are located in Cape Cod Bay (CCB) and one in Stellwagen Bank National Marine Sanctuary (SBNMS).

CCB and SBNMS are both ecologically diverse and highly productive areas. They encompass essential habitats for commercially valuable species of finfish and shellfish as well as many species of endangered birds and mammals. Both these areas serve as feeding grounds for the critically endangered North Atlantic right whale. Several other species of whales including humpback, fin, and minke migrate to these waters each year to feed.

The environmental monitoring work conducted by CCS in collaboration with MWRA provides the data necessary to track the health of these waters. Water quality data, such as that collected as part of this project, are needed to safeguard these areas, and for tracking changes in them that may affect the whales and fisheries of the systems.

This report summarizes the finding of the monitoring work conducted by CCS from 2017-2019. The results of the monitoring of the three MWRA stations are presented in the context of some of the other work CCS does in this region, including the concurrent, year round water quality monitoring surveys at nine additional stations in CCB and the right whale aerial and right whale habitat surveys in CCB conducted from January – May. For certain variables, the 2017-2019 were also examined in context with some of the earlier data collected in the region by MWRA.

2. METHODS

Over the past three years, CCS has monitored MWRA's three stations in CCB and SBNMS (Figure 1, Table 1) as part of their on-going program to monitor for possible outfall impacts on areas downstream of the outfall. The three sites have been sampled nine times per year (Table 2).

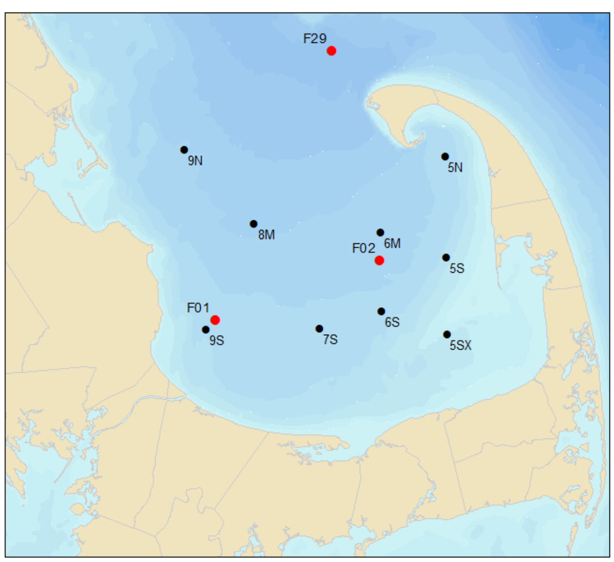

Figure 1. Sampling locations in CCB and SBNMS. CCS stations are in black; MWRA stations are in red

Water quality monitoring at these stations included measurements of surface photosynthetically active radiation (PAR); water column measurements of temperature, salinity, dissolved oxygen, fluorescence, PAR; near surface and near bottom nutrient concentrations (dissolved and total nitrogen and phosphorus, silicate); near surface and near bottom phytoplankton biomass (chlorophyll *a* and phaeophytin), and phytoplankton and zooplankton (identification and enumeration).

Table 1. Locations of MWRA and CCS stations

Station	Latitude	Longitude
	MWRA	
F01	41.8508	-70.4533
F02	41.9082	-70.2283
F03	42.1167	-70.2900
	CCS	
5N	42.0093	-70.1387
6M	41.9352	-70.2287
5S	41.9100	-70.1398
5SX	41.8830	-70.1400
6S	41.8572	-70.2283
7S	41.8408	-70.3135
9S	41.8415	-70.4677
9N	42.0202	-70.4937
8M	41.9457	-70.4002

Table 2. Sampling dates of surveys, 2017-2019.

2017			**2018**			**2019**		
Survey	Targeted	Actual	Survey	Targeted	Actual	Survey	Targeted	Actual
WN171	2/7/17	2/19/17	WN181	2/6/18	2/6/18	WN191	2/5/19	2/5/19
WN172	3/21/17	3/25/17	WN182	3/20/18	3/20/18	WN192	3/19/19	3/20/19
WN173	4/11/17	4/17/17	WN183	4/10/18	4/10/18	WN193	4/9/19	4/11/19
WN174	5/16/17	5/16/17	WN184	5/15/18	5/14/18	WN194	5/14/19	5/16/19
WN175	6/20/17	6/13/17	WN185	6/19/18	6/20/18	WN195	6/18/19	6/7/19
WN176	7/25/17	7/26/17	WN186	7/24/18	7/24/18	WN196	7/23/19	7/19/19
WN177	8/22/17	8/23/17	WN187	8/21/18	8/21/18	WN197	8/20/19	8/20/19
WN178	9/5/17	9/6/17	WN188	9/4/18	9/5/18	WN198	9/3/19	9/3/19
WN179	10/24/17	11/1/17	WN189	10/23/18	10/23/18	WN199	10/22/19	10/30/19

A complete description of methods is provided in the project QAPP (Costa *et al*. 2017). During each survey, hydrographic data were collected from all three stations, and samples were collected for analysis for dissolved inorganic nutrients (nitrate/nitrite, ortho-phosphate, ammonia), total nitrogen, total phosphorous, and chlorophyll from near surface (1-2 m from surface) and near bottom (3-5 m from bottom). Near surface water was also collected for phytoplankton analysis, and a zooplankton sample was collected with an oblique net tow (Table 3). All samples were processed according to SOPs included in the project QAPP.

Table 3. Routine measurements conducted at the three stations

Type of measurement	Depth	Parameter
Hydro profile	From near surface (approximately 0.5-1.5 m) to near-bottom (3-5 m from bottom). Profiling at 0.5 m intervals	Surface PAR Temperature Salinity Dissolved oxygen Depth of sensor Chlorophyll fluorescence PAR
Water chemistry	Two depths: Near- surface Near- bottom	Nitrate + nitrite Ammonia Ortho-phosphate Silicate Total nitrogen Total phosphorus Extracted chlorophyll
Phytoplankton	Near-surface	Enumeration + Identification
Zooplankton	Oblique net tow	Enumeration + Identification

3. RESULTS AND DISCUSSION

3.3 Hydrographic Data

Annual average water temperatures and salinities did not vary significantly during the three years (2017, 2018, and 2019) (Figure 2). Average surface temperature during this time period was approximately 12°C. Average bottom temperature was approximately 7°C. Average annual salinites were lowest in both the surface and bottom waters in 2019 and highest in both surface and bottom waters in 2018.

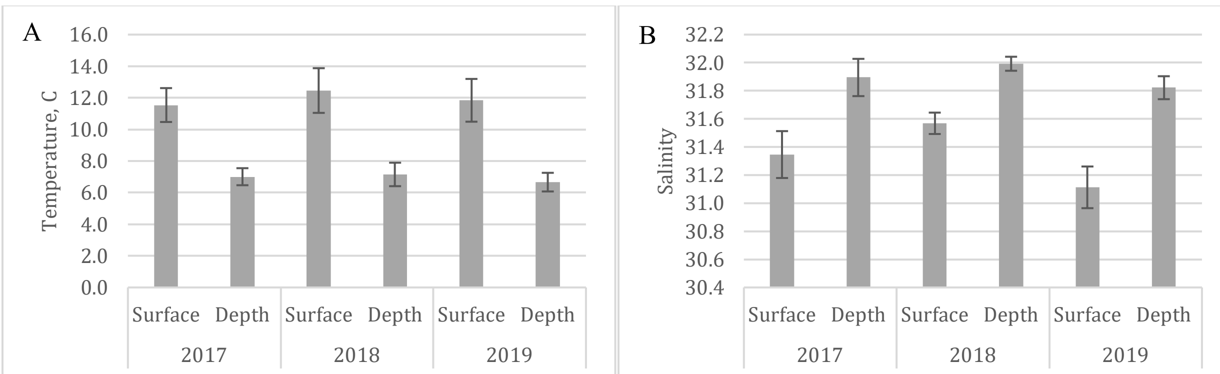

Figure 2. Average annual A) water temperature and B) salinity recorded in the surface and near bottom waters from 2017-2019

Although the annual average temperatures among the three years were not significantly different, 2018 experienced the largest range in temperature in both surface and bottom waters (Figure 3A). Surface waters ranged over 20°C, from a low of 2.3°C to a high of 22.5°C, and bottom waters ranged over 10°C, from a low of 2.8°C to a high of 13.4°C. Salinity (surface and bottom) varied the least in 2018 compared to the other two years (Figure 3B). During 2018 surface salinity did not decline as typically occurs during the spring months (May, Jun, year day ~120-180). This could be in part to the lower amount of precipitation (Apr-Jun) compared to years 2017 and 2019 (Figure 4). Additionally, although overall river flow was comparably high across all three years, in April to June of 2018, the Merrimack River flow was lower than typical (Libby et al. 2018, Libby et al. 2019, Libby et al. 2020).

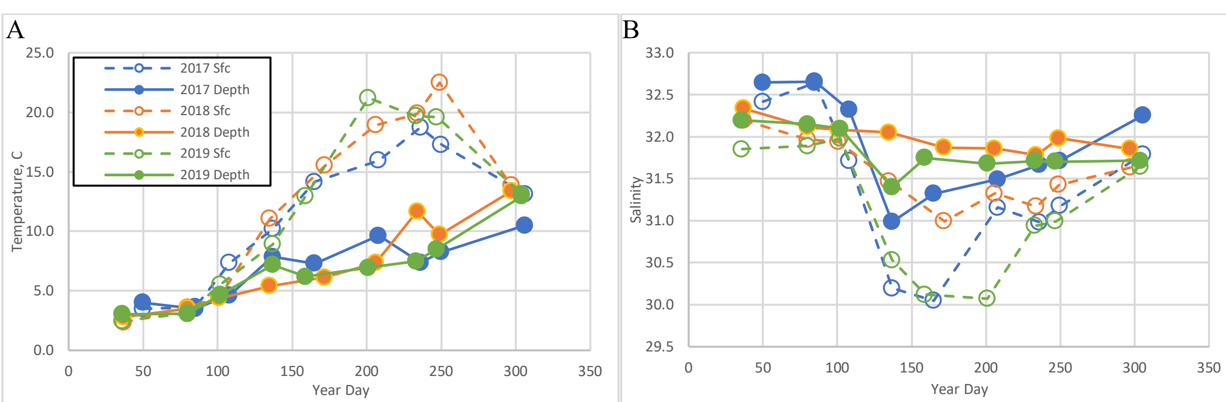

Figure 3. Average A) water temperatures and B) salinities for each survey recorded in the surface and near bottom waters from 2017-2019.

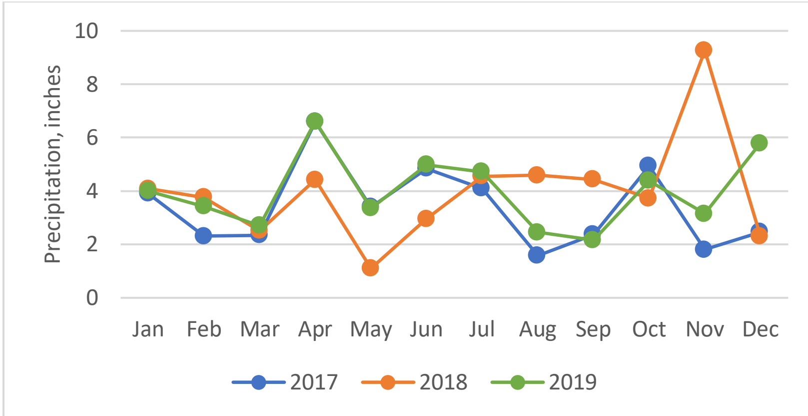

Figure 4. Sum of precipitation by month during 2017-2019.

During all three years stratification was greatest between days 150 to 250, with the exception of Aug 2017 (Figure 5). Libby et al. (2018) also made note of weaker than normal stratification during mid-June to late July of 2017 due to upwelling resulting from a June Nor'easter. The strongest stratification of the water column occurred during July 2019.

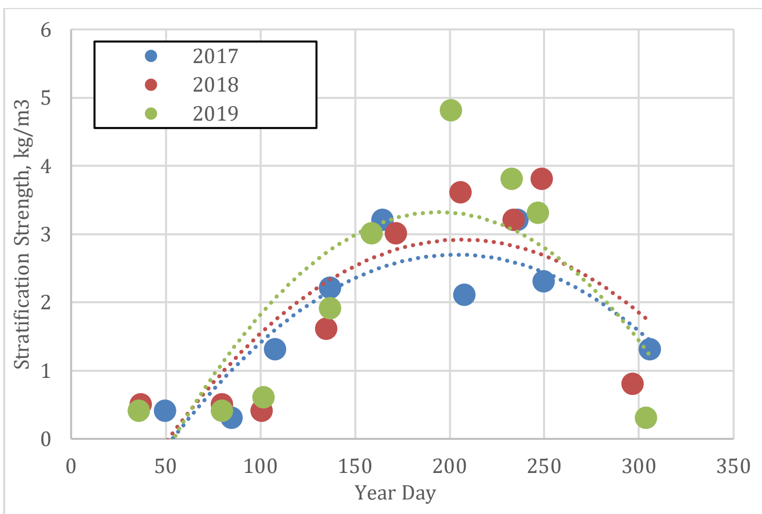

Figure 5. Average stratification strength (bottom density - surface density) for each survey from 2014-2016

During 2019, dissolved oxygen (DO) levels in the near bottom waters were lower than 2018 or 2017 (Figure 6). DO concentrations in the bottom waters of the Bay have been shown to be determined by the strength and duration of stratification (Jiang *et al.* 2007). Typically, the water column in CCB becomes well mixed by early September.

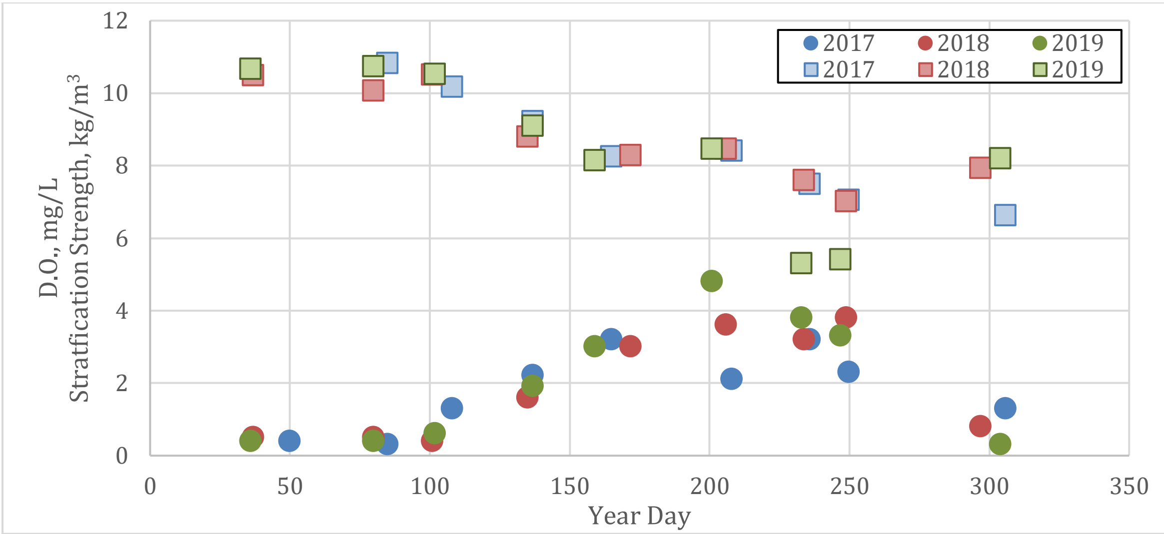

Figure 6. Comparison of stratification strength and near bottom dissolved oxygen levels, 2017-2019, averaged for the three stations. Squares = Dissolved Oxygen, Circles = Stratification.

In 2019, weather conditions were such that the fall mixing was delayed into October, prolonging the period of stratification (Libby et al. 2020). This and elevated phytoplankton biomass at depth (discussed later) together contributed to the dissolved oxygen levels in the bottom waters of CCB being lower during 2019 than in 2017 and 2018 (Figure 7). Bottom-water DO concentrations <4 mg/L were reported at F02 in August 2019.

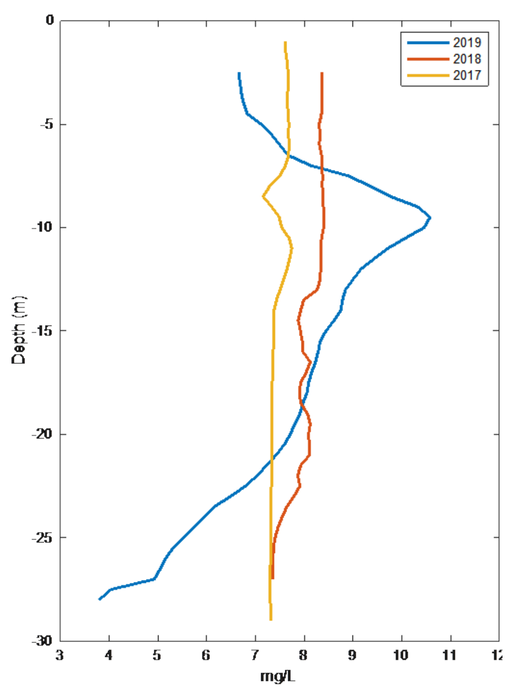

Figure 7. Dissolved oxygen profiles taken at F02 from August of 2017, 2018, and 2019.

3.3 Water Chemistry

3.3.1 Nutrient Concentrations

Annual averaged dissolved inorganic nitrogen (DIN) and ortho-phosphate at the three stations combined, declined from 2017 to 2019 (Figure 8A and Figure 8B). A similar decline over the three years was not observed in silicate concentrations, although concentrations were lowest in 2019 (Figure 8C). The declines in dissolved inorganic nutrients were most pronounced at depth.

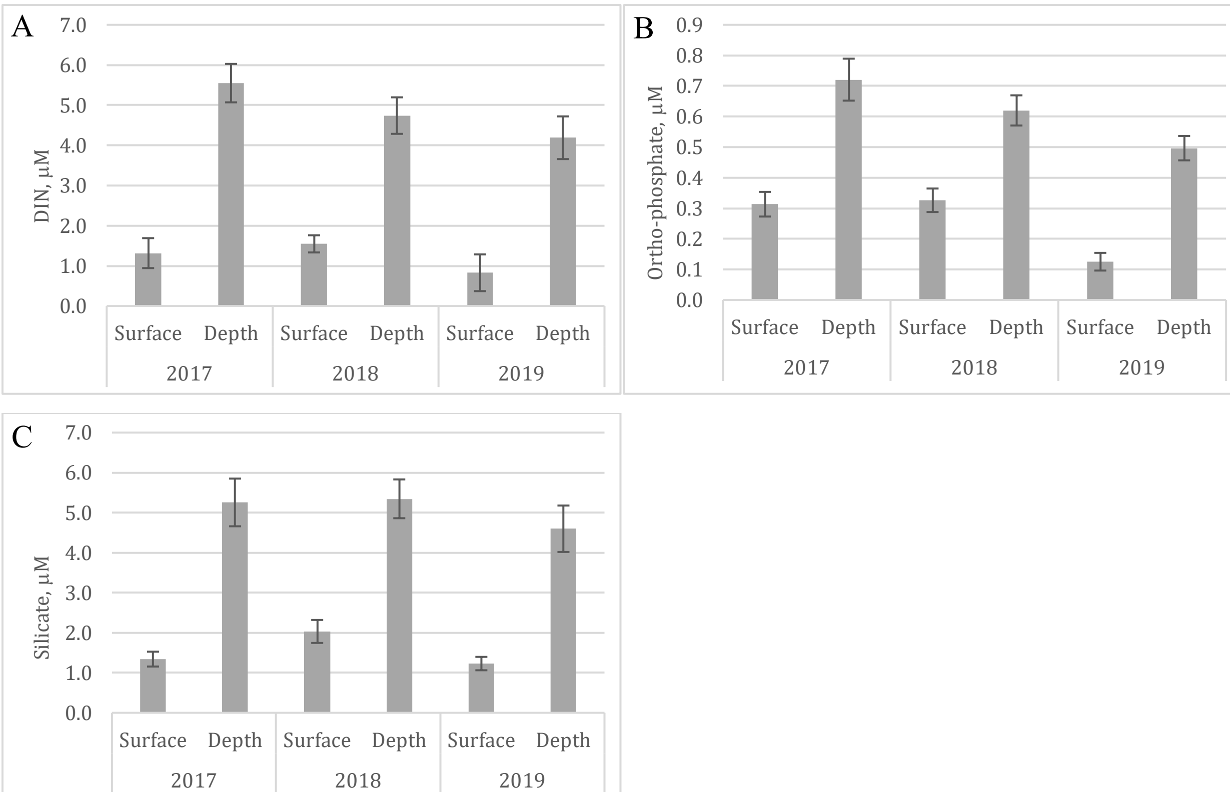

Figure 8. Average annual A) dissolved inorganic nitrogen (DIN), B) ortho-phosphate and C) silicate concentrations measured in the surface and near bottom waters from 2017-2019.

The water chemistry in CCB in the period surrounding the low dissolved oxygen event observed in 2019 differed from conditions recorded in 2017 and 2018 (Figure 9). During the July survey, both components of DIN (nitrate+nitrite and ammonium) were higher in the near bottom waters than in previous years. DIN concentrations remained moderately high through August, but by the September survey (which occurred two weeks after the August survey), concentrations of DIN dropped lower than seen during the previous two years. In October of 2019, ammonium concentrations in both surface and bottom waters were higher than both 2017 and 2018. These unusual patterns of DIN concentrations observed in 2019 are likely the result of stronger stratification, which would increase near bottom nutrients as seen in July and August, followed by a phytoplankton bloom which would deplete the waters of nutrients as seen in September. Higher than normal ammonium concentrations throughout the water column could be indicative of the decomposition of the senescent bloom.

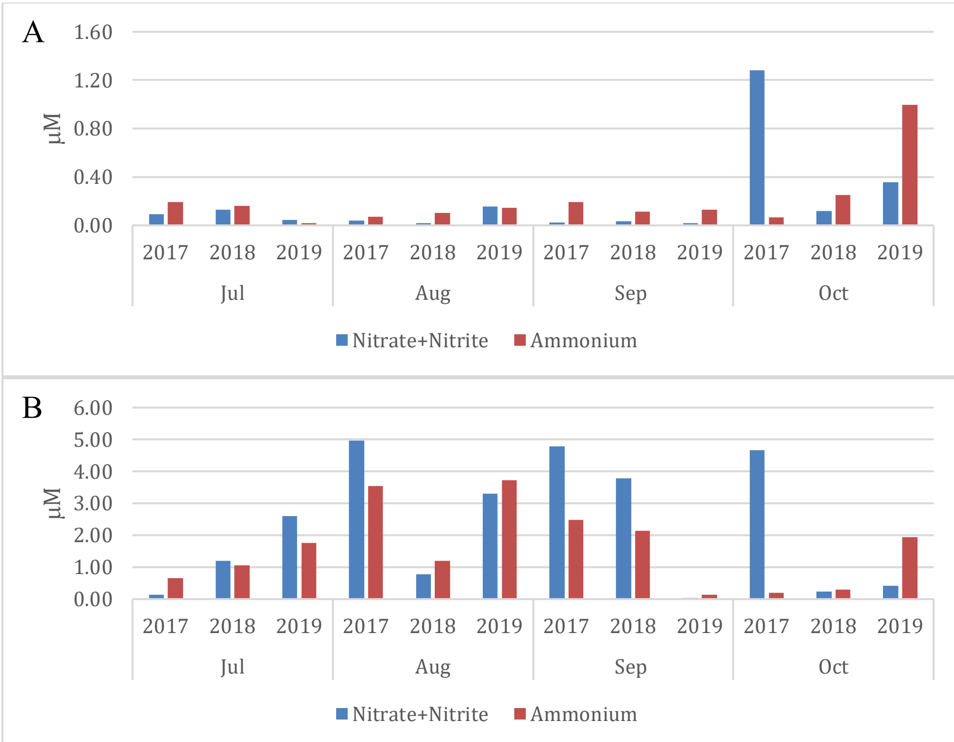

Figure 9. A) Surface and B) depth dissolved inorganic nitrogen concentrations in CCB (average of F01 and F02) preceding, during, and following the low dissolved oxygen event.

Overall nutrient concentrations from 2017-2019 were lower than the long-term average. The MWRA has been monitoring these three stations since 1994 (F01 and F02 since 1992). The long-term average DIN concentrations (1994-2019) were 2.18 µM and 5.59 µM for surface and bottom respectively. The 2017-2019 surface averages fell well below the average of 2.18 µM for the full period, continuing a declining trend observed since 2010 (Figure 10). The near bottom DIN concentrations were also below the long-term average (5.59 µM) during all three years.

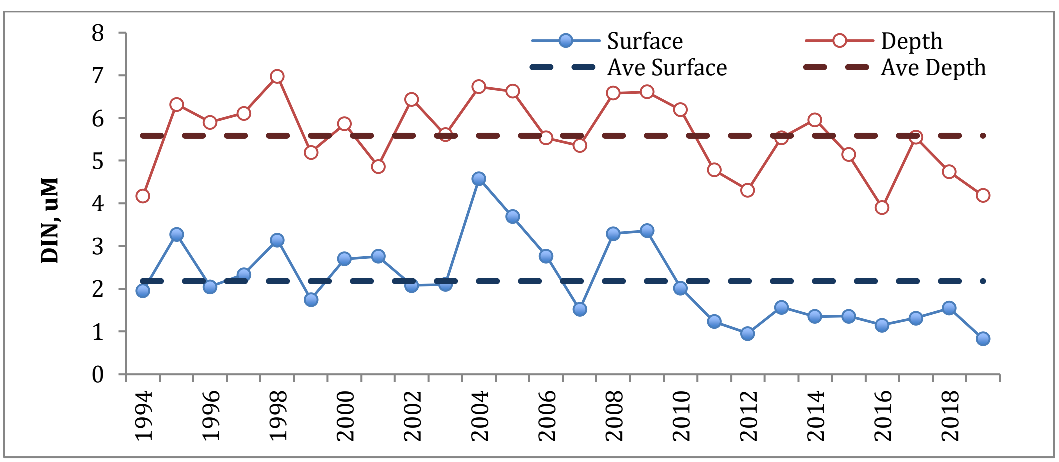

Figure 10. Average annual DIN concentrations in surface and near bottom waters at F01, F02 and F29 from 1994-2019. Long-term averages are indicated with the dashed line.

The 2017-2019 surface and bottom ortho-phosphate concentrations values fell at (2017) or below (2018 and 2019) their long-term averages of 0.389 µM and 0.714 µM for the 1994 -2019 period (Figure 11). Similarly, for silicate concentrations, the 2017-2019 surface and bottom values fell below the long-term averages of 2.75 µM and 6.50 µM for surface and bottom respectively (Figure 12).

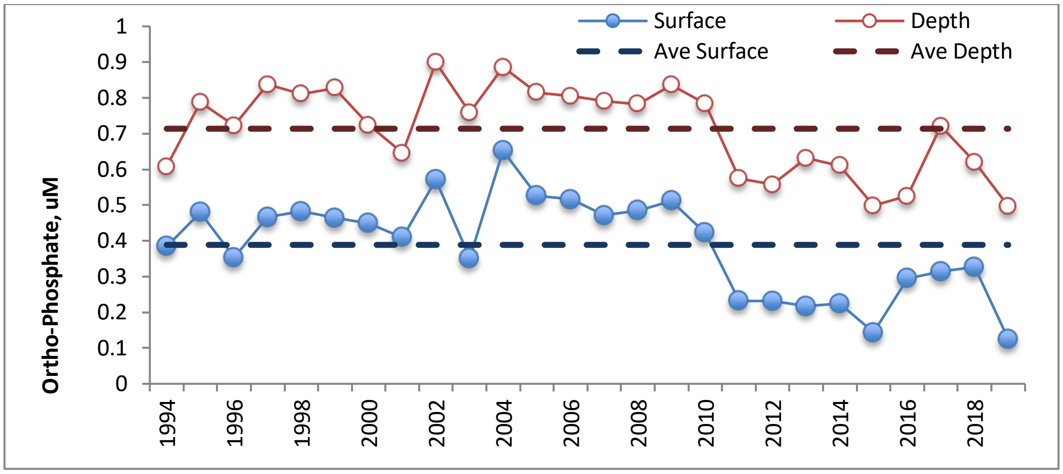

Figure 11. Average annual ortho-phosphate concentrations in surface and near bottom waters at the three MWRA stations from 1994-2019. Long-term averages are indicated with the dashed line.

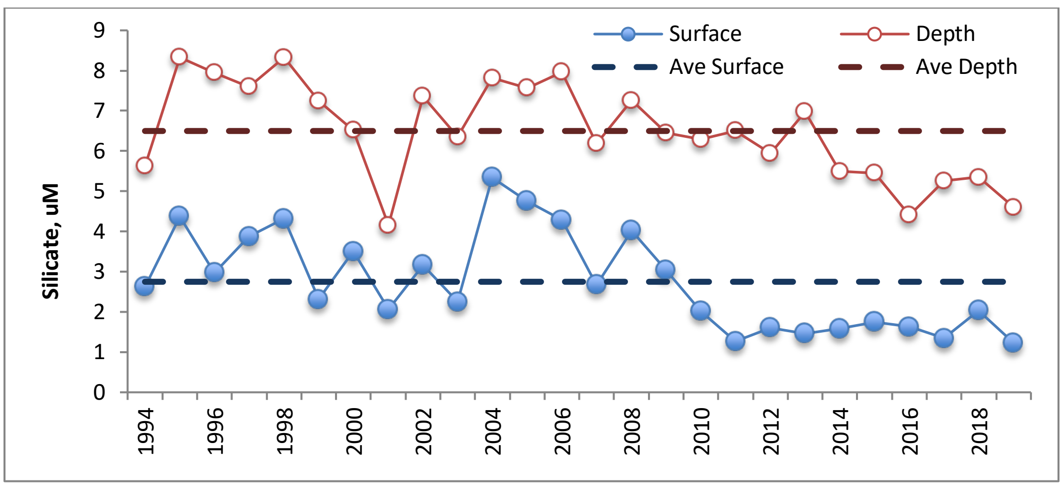

Figure 12. Average annual silicate concentrations in surface and near bottom waters at the three MWRA stations from 1994-2019. Long-term averages are indicated with the dashed line.

3.3.2 Nutrient Concentration Ratios

The ratio of dissolved inorganic nitrogen to phosphorus to silicate (DIN:DIP:DISi) provides information about which nutrient is potentially limiting production. This ratio, known as the Redfield ratio, is 16:1:1.07. For 2017-2019, the average DIN:DIP was less than 16:1 in both the surface and near bottom waters, indicating that the Bay's pelagic primary production was N relative to P limited and therefore especially sensitive to increased N inputs (Figure 13).

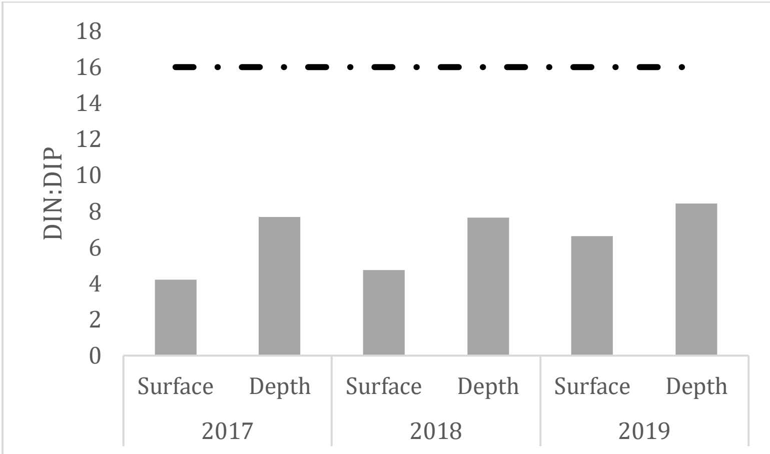

Figure 13. Average ratio of DIN to DIP for surface and near bottom waters from 2017-2019. The dashed line indicates the Redfield Ratio.

Since monitoring of these three stations began in 1994 the average annual ratio of DIN to DIP has always been well below (and one half or less of) the Redfield Ratio of 16:1 for both surface and bottom waters (Figure 14).

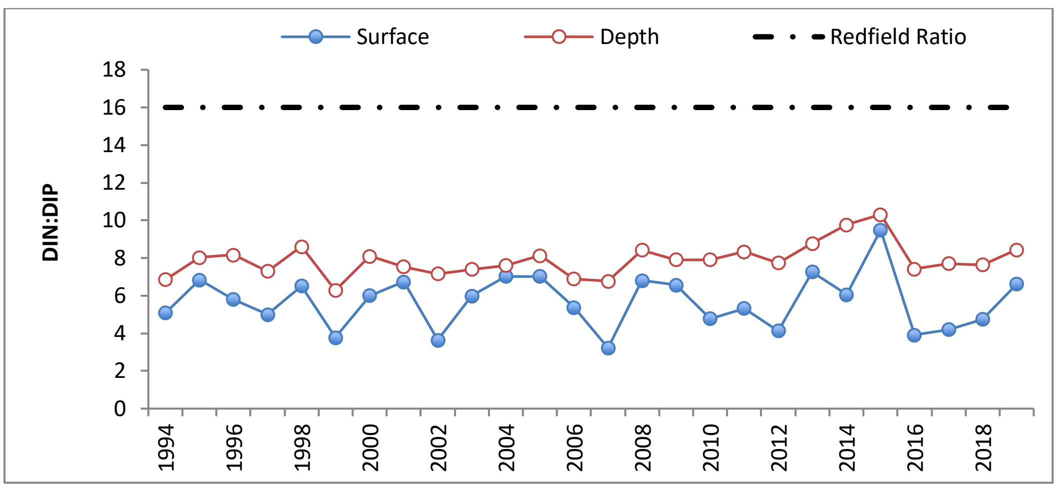

Figure 14. Average annual ratio of DIN:DIP at the three MWRA stations since 1994. The dashed line indicates the Redfield Ratio.

The ratio of DIN:DISi is particularly important for diatoms since they require silicate to form their external shell. If this ratio falls below 1.07, diatom productivity is N relative to Si limited. For all three years between 2017-2019, and especially at the surface, the annual average DIN:DISi ratios were less than Redfield (Figure 15) indicating that diatom production is not limited by Si availability.

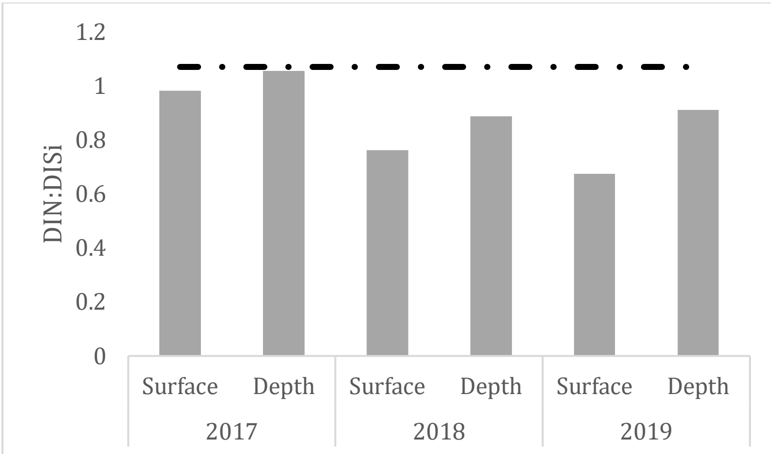

Figure 15. Average ratio of DIN to DISi for surface and near bottom waters from 2017-2019. The dashed line indicates the Redfield Ratio.

The longer time series of average annual DIN to DISi ratios shows that with only three exceptions in the surface waters (2001, 2009, and 2013) and two exceptions at depth (2001 and 2014), DIN:DISi ratios were less than 1.07:1 (Figure 16).

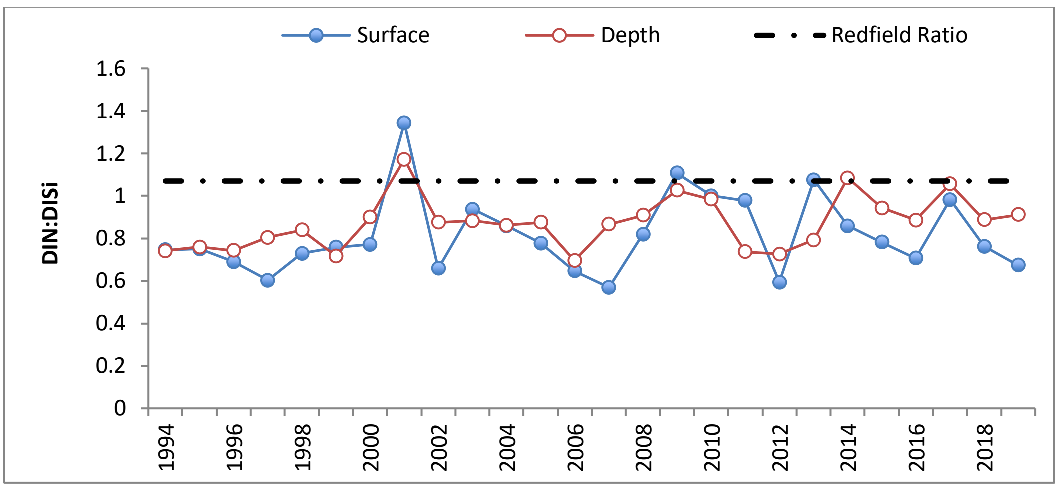

Figure 16. Average annual ratio of DIN:DISi at the three MWRA stations since 1994. The dashed line indicates the Redfield Ratio.

3.3.3 Phytoplankton Biomass (Chlorophyll a)

Chlorophyll *a* (chl-*a*) concentrations averaged for the three locations were greater in the surface compared to the bottom waters during 2017 and 2018. In 2019 average chl-*a* concentrations both at the surface and near bottom depths were the highest of the three years (Figure 17).

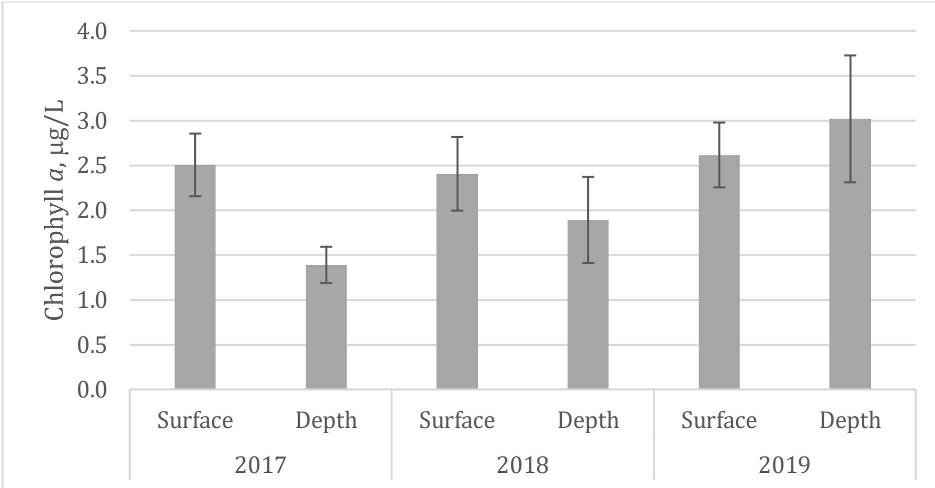

Figure 17. Average annual concentrations of chlorophyll *a* measured in the surface and near bottom waters from 2017-2019

Figure 18 shows average chl-*a* concentrations at surface and depth for the three stations combined during each survey. As can be seen from this plot, although the winter spring bloom was larger in 2017 and 2018 than 2019, the unusually high concentration of chl-*a* at depth during the fall of 2019 was the driver behind the high annual average for 2019.

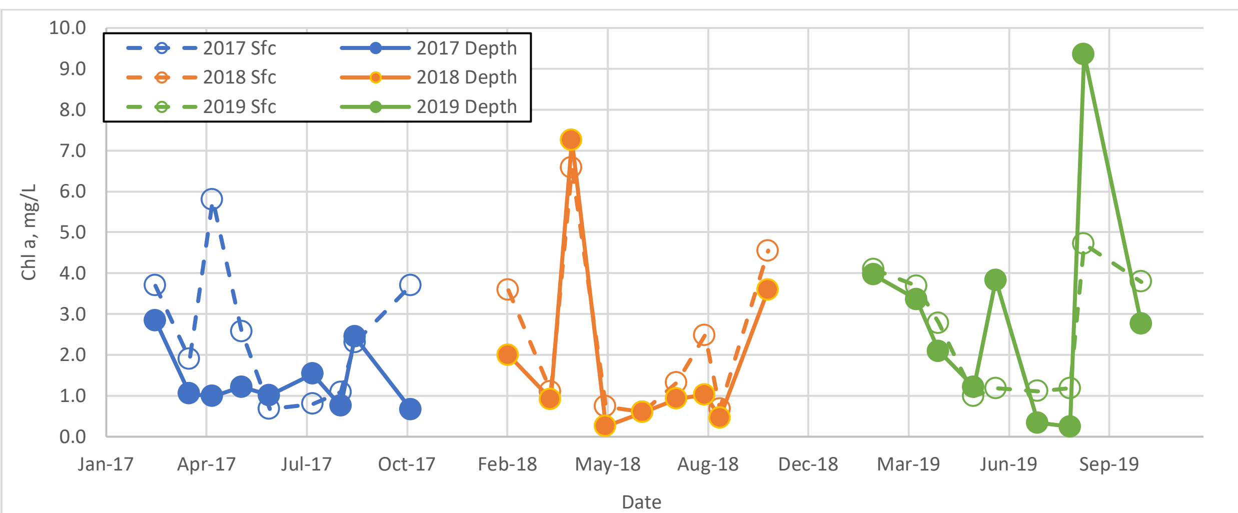

Figure 18. Average surface chl-a concentrations measured during each survey from 2017-2019

The surface contour plots (Figure 19) show the combined chl-*a* data recorded in September for the three MWRA locations, and CCS's nine additional monitoring stations. The top figures show the long-term (2010-2018) average September surface and bottom chl *a* concentrations. The bottom figures show the 2019 September surface and bottom chl *a* concentrations. The near bottom chl *a* concentrations in the southwest corner of CCB were significantly higher than seen in previous years. Bottom water is not sampled for phytoplankton counts, but it is thought that the high bottom chl *a* concentrations were the result of a bloom of *Karenia mikimotoi*. A large *K. mikimotoi* bloom was documented in Massachusetts Bay during August and September 2019 resulting in discolored water in Boston Harbor (Libby et al.

2019). We did find moderate abundances of *K. mikimotoi* in surface samples from the September survey (see section 3.3.4 of this report). However, concentrations at depth were likely much higher because *Karenia* is a low light specialist that grows well in the subsurface chl *a* maximum layer. Highest concentrations in Massachusetts Bay are usually found sub-surface with the exception of shallow areas like Boston Harbor (D. Borkman, pers comm).

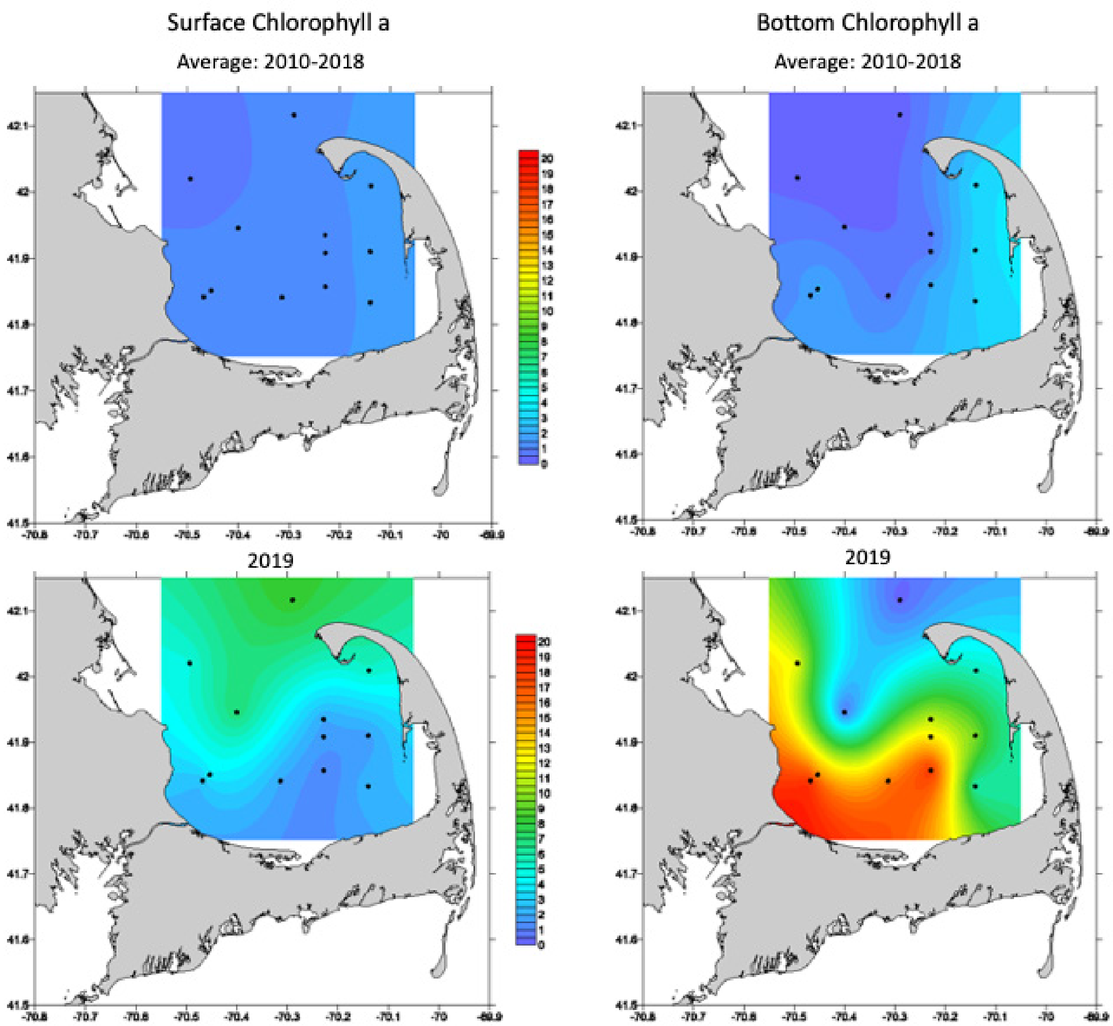

Figure 19. Concentrations of chl-*a* (μg/L) measured at MWRA and CCS stations in September in Cape Cod Bay

Coincident with these high chl-*a* levels at depth were low levels of bottom dissolved oxygen. Some areas of southern Cape Cod Bay experienced hypoxic to anoxic conditions, resulting in mortality of lobsters and bottom fish that were caught in traps in these areas. It is thought that the persistence of a strongly stratified water column isolated a thin bottom water layer that, in combination with the increased flux of organic material to the bottom waters when the *Karenia* bloom settled, lead to hypoxic/anoxic conditions (Pugh and Whitmore 2019).

Phytoplankton and Zooplankton

3.3.4 Phytoplankton

For the two CCB stations and one SBNMS station combined, average annual phytoplankton abundance was greatest in 2018 and least in 2019 (Figure 20). Samples were only collected from surface water.

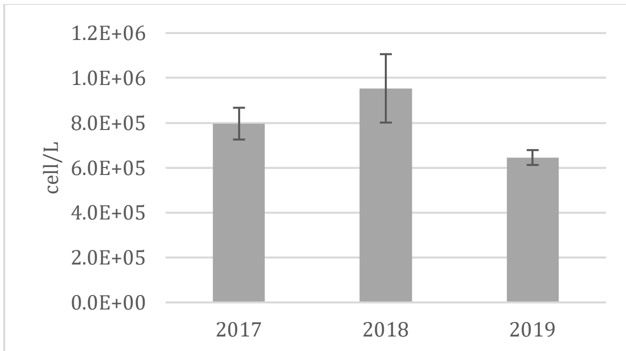

Figure 20. Average annual phytoplankton abundance, 2017-2019

A moderate *Phaeocystis* bloom in April of 2018 elevated the annual abundance during that year (Figure 21). During 2017 and 2019, the *Phaeocystis* bloom was negligible with abundances only around 40,000 to 60,000 cells/L compared to 2,500,000 cells/L seen in 2018.

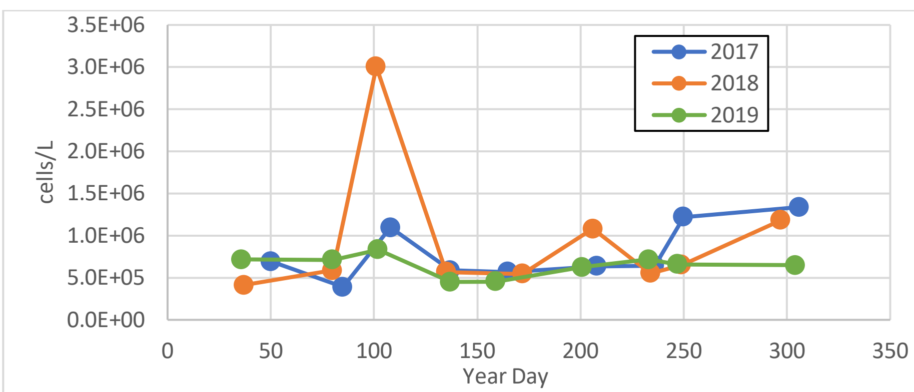

Figure 21. Average phytoplankton abundances during each survey, 2017-2019.

In Cape Cod Bay, the winter/spring bloom typically occurs during February or March and is usually driven by an increase in diatoms in response to increasing light intensities and water temperatures. During 2017, the bloom occurred during the February survey and was predominantly *Guinardia delicatula* which accounted for close to 30% of the species assemblage at all three stations with approximately 200,000-300,000 cells per liter. In February of 2018, the bloom was not as pronounced and the species comprising the bloom were more diverse with total centric diatoms only accounting for 10-15% of the species assemblage at all stations. Coincidently, in 2018 there was a large *Phaeocystis* bloom starting in March and peaking in April with abundances of close to 2.5 million cells/L at all three stations. During 2019, the diatom bloom started in February and extended into March. As in 2017, *Guinardia delicatula* was the dominant species during this year as well (Table 4).

Table 4. Dominant species of centric diatoms during the winter/spring bloom period

Month	Station	Species	Number of Cells/L	Percent Diatoms of Total Cells
2017				
Feb	F01	*Guinardia delicatula*	197,415	31
		Skeletonema costatum species complex	9,364	
Feb	F02	*Guinardia delicatula*	338,871	41
		Leptocylindrus minimus	18,776	
Feb	F29	*Guinardia delicatula*	171,564	33
		Leptocylindrus minimus	9,030	
2018				
Feb	F01	*Centric diatom* sp.	6,844	9
		Thalassiosira sp.	23,040	
		Skeletonema costatum species complex	2,509	
		Rhizosolenia hebetata	2,966	
Feb	F02	*Centric diatom* sp.	14,897	11
		Thalassiosira sp.	13,833	
		Skeletonema costatum species complex	17,911	
Feb	F29	*Centric diatom* sp.	19,773	16
		Skeletonema costatum species complex	32,040	
		Thalassiosira sp.	12,999	

Month	Station	Species	Number of Cells/L	Percent Diatoms of Total Cells
2019				
Feb	F01	*Centric diatom* sp.	50,149	26
		Guinardia delicatula	130,746	
		Thalassiosira sp.	47,164	
Feb	F02	*Centric diatom* sp.	16,634	34
		Guinardia delicatula	245,941	
		Thalassiosira sp.	28,515	
Feb	F29	*Centric diatom* sp.	57,030	25
		Guinardia delicatula	35,644	
		Thalassiosira sp.	30,000	
Mar	F01	*Centric diatom* sp.	64,158	27
		Guinardia delicatula	87,327	
		Thalassiosira sp.	33,267	
Mar	F02	*Centric diatom* sp.	9,695	47
		Guinardia delicatula	338,115	
Mar	F29	*Centric diatom* sp.	45,373	36
		Guinardia delicatula	192,239	
		Thalassiosira sp.	19,104	

Of note is the occurrence of *Karenia mikimotoi*. This species was first identified in surface samples from CCB and SBNMS in low numbers in the late summer/early fall of 2017. It appeared again in 2018 at very low abundances. Highest counts were found in September of 2019 (Figure 22).

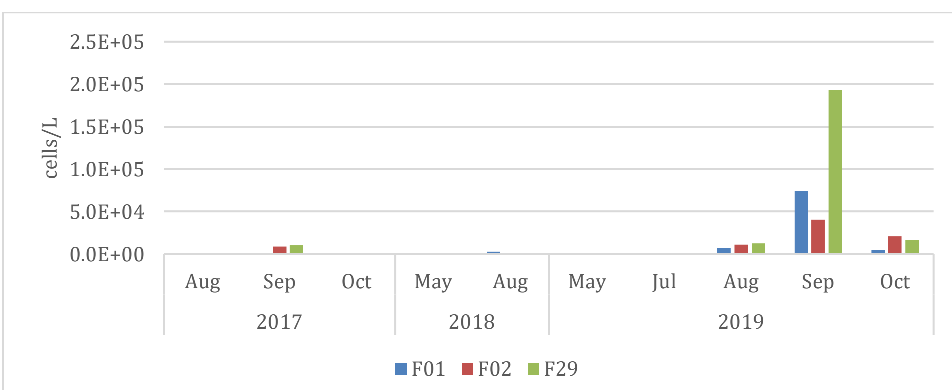

Figure 22. *Karenia mikimotoi* abundances recorded in surface counts, 2017-2019.

3.3.5 Zooplankton

Annual average total zooplankton abundances in CCB and SBNMS, after increasing for the past several years (Costa *et al*. 2017), have started declining over this three-year period (Figure 23). Although different protocols are followed for zooplankton collections in Massachusetts Bay (e.g. smaller mesh net) peak abundances in 2019 in Massachusetts Bay were also slightly lower than those seen from 2016 to 2018 (Libby *et al*. 2020).

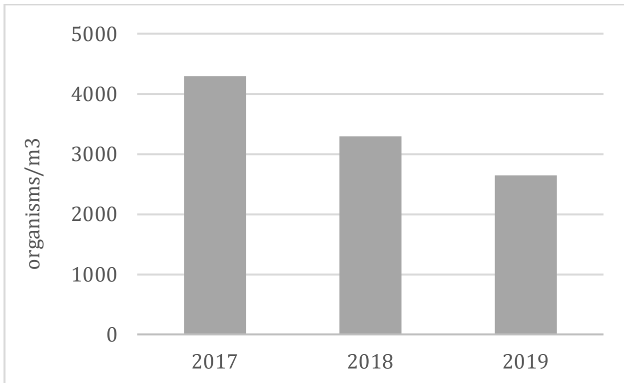

Figure 23. Average annual zooplankton abundance, 2017-2019

The comparatively higher total zooplankton abundance seen in 2017 was due to two peaks (Figure 24). The first and largest peak occurred during the April survey and was due primarily to high numbers of *Calanus finmarchicus* and *Pseudocalanus* spp. These species are the primary food source of right whales in Cape Cod Bay. The second peak in in July consisted primarily of the copepods *Temora longicornis* and *Centropages* spp. The highest abundances of zooplankton for 2018 and 2019 occurred during the summer (July and June, respectively). In addition to the copepod species common during this time (*Temora* and *Centropages*), the cladoceran *Evadne* was also seen in high numbers.

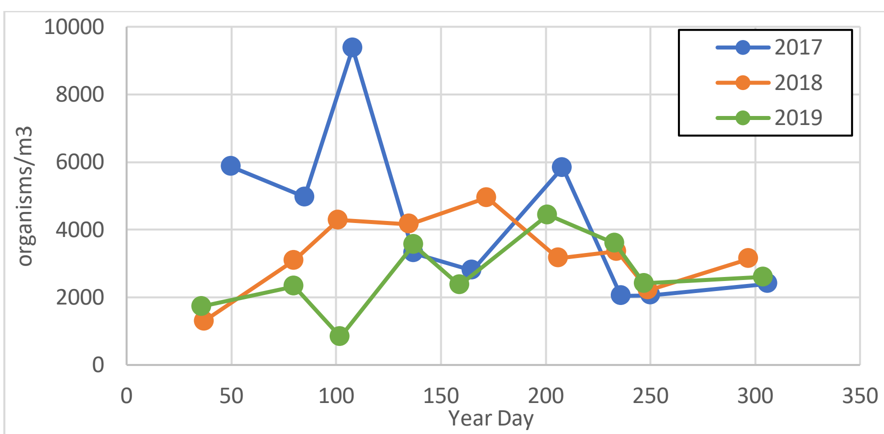

Figure 24. Average zooplankton abundance during each survey, 2017-2019

In Cape Cod Bay, zooplankton counts during the winter and spring months (Jan-May) are of particular interest. During this time, the Bay is the only known feeding ground for the critically endangered North

Atlantic right whale. CCS conducts weekly boat-based surveys to document the zooplankton resource and aerial surveys to locate, document and identify the whales. Zooplankton samples are taken in the vicinity of right whales using a 333 µm mesh net. This has been done routinely since 2000. Over the course of these 20 years, the long-term average zooplankton density was approximately 8,000 organisms/m^3. Samples have typically been dominated by calanoid copepods including *Centropages* spp., *Pseudocalanus* spp., and *Calanus finmarchicus*. Although 2017 was slightly above the long-term average, both 2018 and 2019 fell below (Figure 25). This corroborates the zooplankton data from the three MWRA stations which showed high abundances of *Calanus* and *Pseudocalanus* only during the spring of 2017.

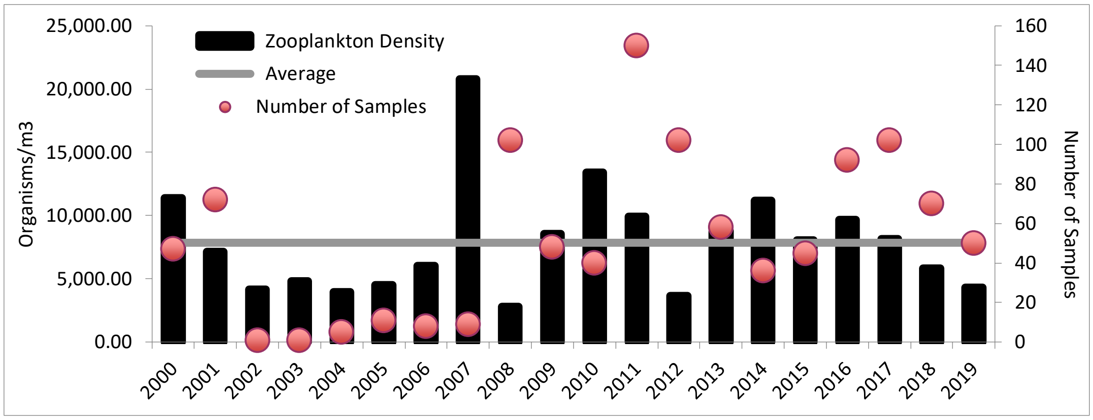

Figure 25. Average zooplankton density and number of samples taken in the vicinity of right whales. The gray line indicates the long-term average zooplankton density of these samples, 2000-2019.

3.3.5.1 Right Whales and Zooplankton

Right whale use of the bay was also highly variable from year to year. Since 2007, there has been an increase both in individuals identified and in the sightings per unit effort compared to the previous 9 years (Figure 26). Numbers of individual right whales that were observed in CCB during the 2017-2019 seasons were some of the highest seen over the past 22 years, comprising close to 60% of the population. This did not coincide with what would be expected based on the zooplankton data which indicated lower than average densities in 2018 and 2019, both overall and of the species preferred as food.

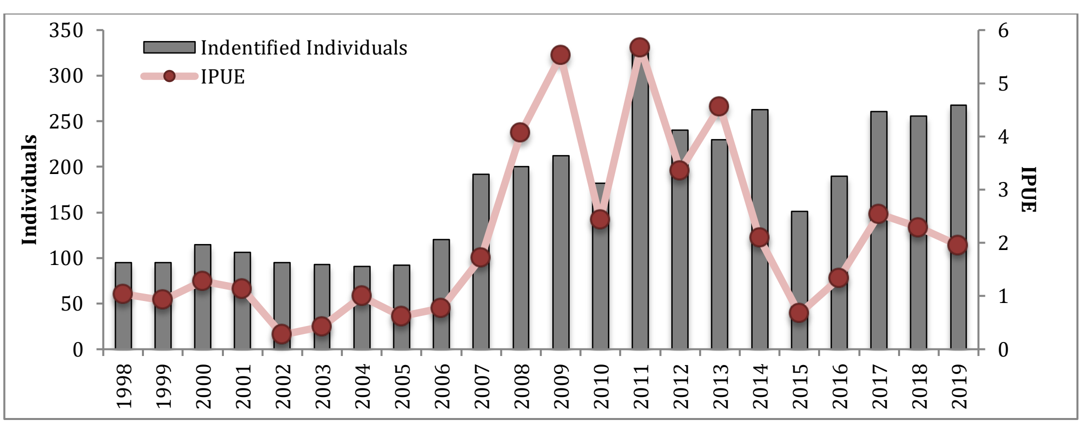

Figure 26. The number of right whales identified in Cape Cod Bay each year. The red line indicates the number of individuals per unit effort (IPUE) sighted during the aerial surveys

Although number of sightings was similar among the three years, the distribution, residency and periods of peak abundances of whales within Cape Cod Bay varied during this three-year period. The peak in 2017 and 2019 was what is typically observed, occurring in mid-April. In 2018, the peak was delayed until late April/early May. During 2017 and 2019 the distribution of whales was heavily concentrated in the mid to northeast portion of the Bay compared to the 2018 season's high densities in the northwest (Figure 27). Atypical behaviors (long dives) during the time of peak abundances in 2019 were observed which differs from the pattern of shallow subsurface and skim feeding that is more often documented during this time in previous seasons. During both 2018 and 2019 the long residency of right whales in CCB extended past the time of the typical exodus of whales from the Bay, which prompted the State of Massachusetts to extend the end date of the Trap Gear Closure from April 30 to May 6 and May 8 respectively.

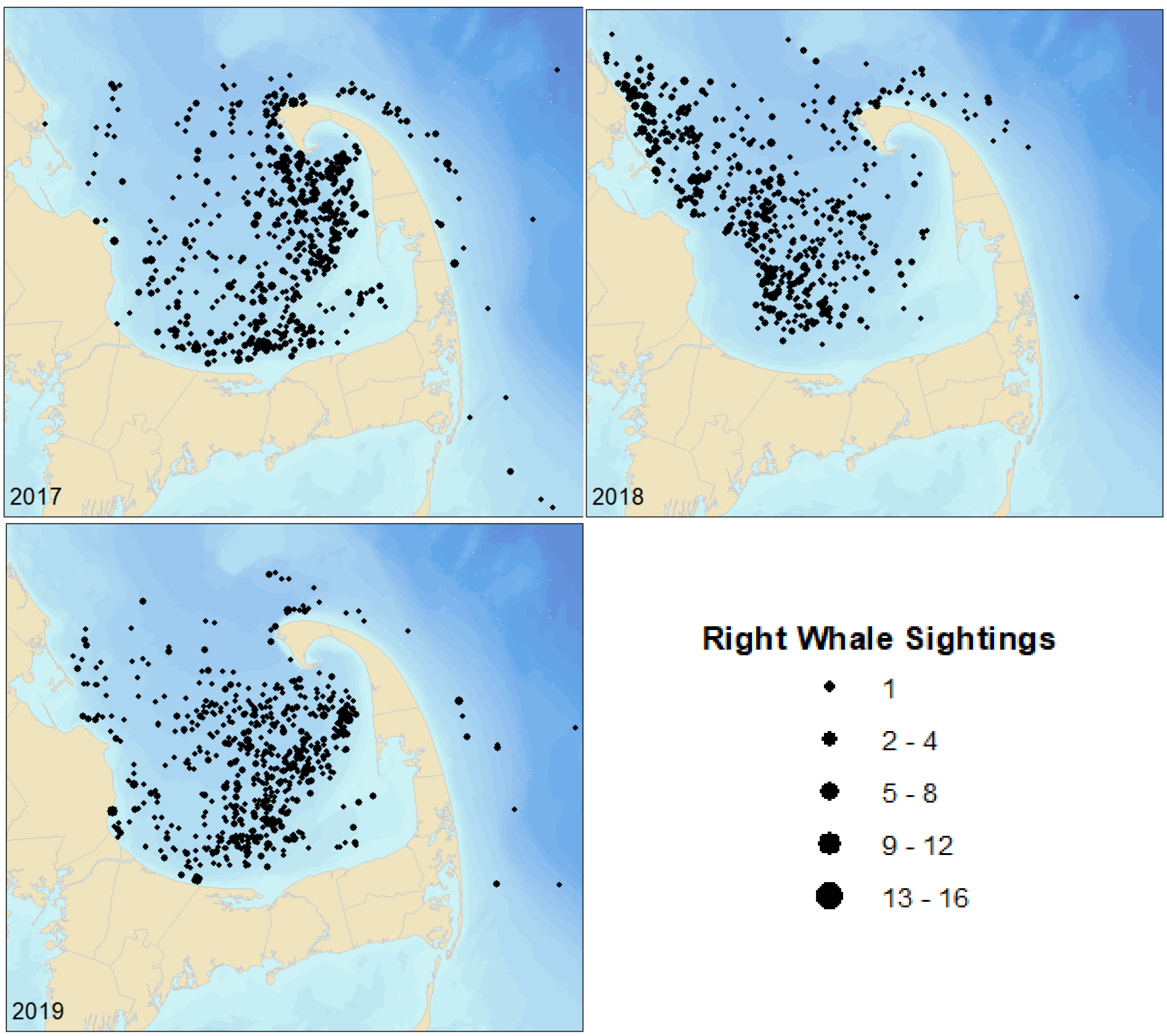

Figure 27. Distribution of right whale sightings each year, 2017-2019. CCS Image, NOAA Permit 14603 and 14603-1

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