Baffin Bay Water Quality Monitoring Study: Synthesis of May 2013-September 2023 Data

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Executive Summary

The goal of this study was to quantify spatial-temporal distribution of key water quality variables in Baffin Bay. Sample collection began in May 2013 from 9 sites throughout Baffin Bay and continues to present, albeit from a reduced number of sites (6) since May 2017. Since the beginning of the study, Baffin Bay has undergone three wet periods and four dry periods. In general, nitrate plus nitrite and phosphate concentrations were very low in the system except for ephemeral peaks that primarily occurred in two tertiary bays (Cayo del Grullo, Alazan Bay) during rain events. Ammonium concentrations were variable and tended to peak during rain events, as well as during the warmer months resulting from remineralization. Dissolved organic nitrogen (DON) was consistently the largest nitrogen pool, with concentrations that routinely exceeded 40 µM and occasionally exceed 100 µM. High chlorophyll *a* concentrations (>20 µg/l) that were reflective of dense, spatially extensive blooms of the harmful alga *Aureoumbra lagunensis* ("brown tide") occurred during low rainfall, long residence time conditions in 2013-2015, whereas episodic floods acted to reset the system by creating conditions less favorable to *A. lagunensis* (i.e., short residence time, higher inorganic nutrients). Nonetheless, phytoplankton blooms consisting primarily of diatoms were still observed during or shortly after the several flooding events in the dataset. Interestingly, there were several instances between 2013-2021 where DON appeared to increase when chlorophyll concentrations were low but decreased during blooms, suggesting utilization of a fraction of the DON by phytoplankton to support growth. For example, at site 2 in the Laguna Salada, the DON pool decreased by ~60 ± 6% from non-bloom to bloom periods. Chlorophyll *a* exceeded TCEQ screening levels for impairment throughout much of the study period and was frequently at levels that would be considered excessive by National Coastal Condition Report (EPA, 2012) standards. These findings show that Baffin Bay is poised to experience phytoplankton blooms under both wet and dry conditions, an artifact of the availability of labile nutrients due to many decades of human influence on the watershed and subsequent eutrophication of the estuary. However, it is worth noting a recent (mid 2022-present) decrease in chlorophyll *a* to the lowest levels observed during the period of record. At this stage, it is too early to tell if this is indicative of the early stages of water quality improvements or simply natural variability, pointing to the need for continued monitoring.

Acknowledgements

First and foremost, I thank the many volunteers who dedicated four years of their time and resources to the collection of this water quality data in Baffin Bay. This study would not have been possible without their efforts. I am also grateful to the Celanese Corporation for funding. I thank partners at the Coastal Bend Bays & Estuaries Program for their ongoing support and interest. Finally, I thank the many postdoctoral researchers, technicians and students who have contributed to the data collection and analysis over the past ten years.

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Introduction

Cultural eutrophication is a major environmental threat facing coastal ecosystems worldwide (Nixon 1995; Diaz and Rosenberg 2008). Over the past 50 years, there has been a substantial increase in nutrient loading to the coastal zone, resulting in growing expression of symptoms such as harmful algal blooms and hypoxia/anoxia formation (Nixon 1995; Boesch 2002; Rabalais et al. 2009). These symptoms often have deleterious consequences for ecosystem structure and function, resulting in such visible effects as fish kills and other animal mortalities, alteration of food webs and economic losses (Diaz and Rosenberg 1995; Boesch 2002). The most recent synthesis of data from the U.S. indicates that as of 2007, at least 30% of estuaries were considered moderately to highly eutrophic, with eutrophication pressures expected to grow in 65% of estuaries over the next decade (Bricker et al. 2007).

In the past 3-4 decades, growing expression of symptoms of eutrophication such as hypoxia and dense algal (phytoplankton) blooms have been noted in Baffin Bay. Hypoxia and excessive phytoplankton growth, which are quite possibly intricately linked, are concerning because of their potential effects on ecosystem health and fisheries in estuaries. For instance, hypoxia has been linked to several large fish kills in Baffin Bay over the past 12 years (unpubl. Texas Parks & Wildlife Spills & Kills Team reports). Hypoxia formation tends to occur during warm summer-fall months, often following freshwater pulses that inject allochthonous nutrients and organic matter and induce stratification in the bays (unpubl. Texas Parks & Wildlife Spills & Kills Team reports). Co-occurrence of phytoplankton blooms and hypoxia have been noted in Baffin Bay as well (unpubl. Texas Parks & Wildlife Spills & Kills Team reports; Walker and Wetz, unpubl. data), and overall phytoplankton biomass frequently exceeds state screening levels, raising concerns about the potential role of nutrient-laden runoff (Montagna and Palmer 2012; this study). For instance, Baffin Bay has experienced prolonged, dense blooms of the brown tide organism, *Aureoumbra lagunensis*, since 1989 (Buskey et al. 1997; Buskey et al. 2001; Cira and Wetz 2019). A fish kill occurred in 2010 and coincided not only with hypoxia, but also with a dense phytoplankton bloom of the dinoflagellate *Pyrodinium bahamense* and the diatom *Thalassiothrix sp.* (unpubl. Texas Parks & Wildlife Spills & Kills Team report).

Using data obtained primarily from TCEQ quarterly sampling, Montagna and Palmer (2012) documented a long-term increase in Kjehldahl nitrogen, nitrate and phosphate in Baffin Bay. Ammonium, chlorophyll *a* and nitrate also regularly exceeded state screening levels in a number of years. While state agency sampling efforts in Baffin Bay have been valuable for documenting long-term water quality changes in the system, their limited spatial-temporal coverage hinders determination of the timing and location of symptoms of water quality degradation, and also preclude determination of the main cause(s) of water quality degradation in the system. Here results are presented from an ongoing water quality monitoring study, the goals of which are to quantify spatial-temporal distributions of key water quality variables in Baffin Bay, and to increase our understanding of the drivers of water quality change in this system.

Methods

Study location – Baffin Bay is a shallow (≤ 2-3 m depth) South Texas coastal embayment adjacent to the Laguna Madre (Figure 1). Residence time of water in Baffin Bay typically exceeds 1 year due to minimal tidal influence and freshwater inflows, although lower residence times on the order of weeks-months have been observed during high rainfall conditions (cira and Wetz 2021), and the system is prone to hypersaline conditions due to evaporation exceeding precipitation (Shormann 1992). Circulation in Baffin Bay is primarily driven by winds.

Meteorological data – Monthly mean precipitation data from the Naval Air Station Kingsville was obtained from the National Climatic Data Center. Using data from January 1973 through December 2013, monthly long-term mean precipitation was calculated. The deviation from this monthly long-term mean during the study period was then calculated, and is referred to as precipitation "anomaly".

Sample collection – Water samples were collected on a monthly basis from May 2013 to present at 6 sites in Baffin Bay (Figure 2). Water samples were collected by volunteer citizen scientists from the start of the study until May 2017 and from July 2022-present. In order to qualify for this program, volunteers had to undergo rigorous training in the lab of Dr. Michael Wetz (Texas A&M University - Corpus Christi) and demonstrate competency in field sample collection (documentation retained in Wetz lab). At each site, a profile of salinity, temperature, conductivity, dissolved oxygen and pH was obtained by lowering a YSI ProPlus sonde at 0.5 m increments through the water column. Surface and near bottom discrete water samples were collected in a Van Dorn sampling device and transferred to acid-washed amber polycarbonate bottles. Bottles were stored on ice until return to a shore-based facility where processing of samples occurred.

Sample analyses – Chlorophyll *a* was determined from samples collected on, and extracted from Whatman GF/F filters (nominal pore size 0.7 µm). Chlorophyll was extracted using 90% HPLC-grade acetone and analyzed fluorometrically on a Turner Trilogy fluorometer. Inorganic nutrient concentrations were determined from the filtrate of water samples that were passed through 25 mmGF/F filters and stored frozen (−20C) until analysis. After thawing to room temperature, samples were analyzed on a Seal QuAAtro autoanalyzer. Standard curves with five different concentrations were run daily at the beginning of each run. Fresh standards were made prior to each run by diluting a primary standard with low nutrient surface seawater. Deionized water (DIW) was used as a blank, and DIW blanks were run at the beginning and end of each run, as well as after every 8–10 samples to correct for baseline shifts.

For determination of DOC and TDN concentrations, water samples were collected in acid-washed amber polycarbonate bottles. Bottles were stored on ice until return to a shore-based facility where processing of samples occurred. DOC and TDN were determined using the filtrate of water samples that passed through precombusted 25 mm GF/F filters and stored frozen (−20ºC) until analysis. Samples were subsequently analyzed using the High Temperature Catalytic Oxidation method on a Shimadzu TOC-Vs analyzer with nitrogen module. Standard curves were run twice daily using a DIW blank and five concentrations of either acid potassium phthalate solution or potassium nitrate for DOC and TDN, respectively. Three to five subsamples were taken from each standard and water sample and injected in sequence. Reagent grade glucosamine was used as a laboratory check standard and inserted throughout each run, as were Certified Reference Material Program (CRMP) deep-water standards of known DOC/TDN concentration. Dissolved organic nitrogen (DON) was determined by subtracting dissolved inorganic nitrogen (ammonium, NOx) from TDN.

Results

At the beginning of the study period in spring 2013, Baffin Bay was experiencing a significant, prolonged drought (Figure 3). In early fall 2013, the drought began to lessen and precipitation patterns more in accordance with long-term monthly averages developed. By spring 2015, several periods of intense rainfall occurred in the Baffin Bay watershed. These conditions reoccurred in spring 2016. From summer 2016-summer 2018, average to below average rainfall was observed. In fall 2018, several months of above average rainfall were noted, followed by near average conditions through summer 2019. With the exception of a few brief periods of heavy rainfall in August 2022 and April 2023, and a more substantial wet period in May-June 2021, the period from mid-2019 to present has been relatively dry.

Physical setting – Water temperature varied little between sampling locations. A distinct seasonal pattern was observed, with temperatures increasing in late winter-early spring, peaking during summer, and then decreasing in early fall (Figure 4). No clear trends in maximum or minimum temperatures were observed in the time series. Salinity was very high at the start of the sampling period in May 2013, exceeding 70 at site 5 (upper Alazan) and site 2 (Laguna Salada) (Figure 5). Salinity tended to decrease through the middle of 2015, with the decrease accelerating in spring 2015 as a result of heavy rainfall in the watershed. From summer 2015 to summer 2016, salinity gradually increased to the mid-30's at most locations. After a brief period of above average rainfall in early-mid 2016 resulted in sharp salinity drops at sites 1 and 5, salinity resumed its increase and was ≥ 40 by October 2016. Salinity remained ≥ 40 until summer 2018, after which rainfall increased and salinities decreased in the bay to < 30 through February 2019. During spring 2019, salinity began to increase sharply and reached > 40 by September 2019. Salinity generally remained in the 30's-40's until June 2021, when a sharp decrease occurred resulting from heavy rainfall in the watershed. Salinity increased gradually thereafter and remained < 30 until May 2022, and reached >40 by July 2022. Strong salinity stratification (i.e., higher salinity in bottom waters than surface waters) of the water column was observed only episodically, being most pronounced at tertiary bay sites that were influenced by runoff, especially during 2015-2016, in late spring 2020, in early summer 2021, and May 2023 (Figure 6).

Biological-chemical dynamics – Chlorophyll concentrations exceeded the TCEQ screening level (11.6 µg/l) in 431 of 732 samples (59%). Using a slightly more relaxed National Coastal Condition Report for "poor" condition (20 µg/l; NCCR 2012), chlorophyll was still in excess in 207 of 732 sample collections (28%). From 2013-2017, the highest chlorophyll concentrations tended to be found in spring-summer coincident with higher water temperatures, especially when *A. lagunensis* was the dominant phytoplankton taxa from 2013-early 2015 (Figures 4,7). In 2018, a noticeably different pattern emerged, with a spring bloom noted at sites 1 and 2, followed by a much larger and more widespread winter (December 2018-March 2019) diatom bloom. During the time series, prolonged episodes of high chlorophyll were observed during both dry conditions (such as 2013-2014 and early 2018 *A. lagunensis* blooms) and during wet conditions (such as late 2018-early 2019 diatom blooms, mid 2011-mid 2022 blooms) (Figures 7, 8). It is notable that the lowest chlorophyll concentrations in the time series were observed from late 2022-present. From a spatial standpoint, chlorophyll concentrations tended to be highest at site 2 (18.5 ± 13.2 µg/l), followed by sites 1 and 4 (16.4 ± 11.7 µg/l and 16.4 ± 10.0, respectively), site 3 (15.8 ± 9.6 µg/l), site 5 (15.4 ± 10.5 µg/l) and site 6 (14.7 ± 10.4 µg/l) (Figure 7).

N+N concentrations were generally very low in the system. At the beginning of the study, N+N exceeded 5 µM at all sites except 1 (4.4 µM) (Figure 9). Aside from this, high (>10 µM) concentrations of N+N were only observed during wet periods, and these solely occurred at sites 1 and 5. Few obvious differences between surface and bottom N+N concentrations were observed, except during wet conditions when concentrations were occasionally higher in surface waters and during summer 2013 when N+N concentrations were occasionally higher in bottom waters (Figure 10). Ammonium concentrations exhibited a high degree of spatial-temporal variability. Higher concentrations were often observed during warmer months of the year (Figure 11). However, higher concentrations (>10 µM) were also observed during high rainfall conditions, especially (but not limited to) at the tertiary bay sites (1, 2, 5). Thus, ammonium appears to be indicative of both internal recycling (i.e., higher concentrations during warmer months) and watershed loading sources (higher concentrations during wet conditions). Higher ammonium concentrations were occasionally observed in bottom waters (Figure 12), consistent with a role for recycling in, and release from sediments. By far, the dominant form of dissolved nitrogen during the study period was dissolved organic nitrogen (DON), with DON concentrations routinely exceeding 40 µM (Figure 13, 15). No clear seasonal or interannual pattern was observed in terms of DON (Figure 13), and only slight differences between surface and bottom DON concentrations were observed (Figure 14). DON peaks in both mid-late 2016 and late 2019 both corresponded with relatively low chlorophyll levels, while DON "troughs" in late 2013 to mid-2015 and early 2018 to early 2019 corresponded with higher chlorophyll levels that (Figure 15), suggesting that phytoplankton may have been utilizing the fraction of the DON pool that increased in their absence or decreased in their presence. For example, at site 2 in the Laguna Salada, the DON pool decreased by ~60 ± 6% from non-bloom to bloom periods. The C:N of the dissolved organic matter (DOM) that was utilized (5.0 ± 0.6) was lower than that of the bulk DOM pool (13.5 ± 3.0), suggesting selective utilization of DON derived from sources that produce labile organic matter (such as wastewater). However, this pattern broke down starting in late 2021, after which DON and chlorophyll appeared to be positively correlated. Highest DON concentrations were found at site 2 (80.2 ± 16.6 µM) and site 1 (75.4 ± 14.1 µM), and were lower at sites 3-6, ranging from 66.2-70.7 µM on average.

Higher phosphate concentrations were often observed during warmer months of the year (Figure 16). However, higher concentrations (>1 µM) were also observed during high rainfall conditions, especially (but not limited to) at sites 1 and 5. Thus as with ammonium, phosphate appears to be indicative of both internal recycling (i.e., higher concentrations during warmer months) and watershed loading sources (higher concentrations during wet conditions). Higher phosphate concentrations were occasionally observed in surface waters than bottom waters during wet conditions at sites 1 and 5, and in bottom waters compared to surface waters during dry conditions (Figure 17). DIN:DIP varied from indicating nitrogen limitation (N:P<16) to indicating phosphorus limitation (N:P>16) (Figure 18), but there were no consistent temporal patterns. Out of the entire dataset, 492 of 720 samples total showed DIN:DIP<16 (68.3%) while 228 samples showed DIN:DIP>16 (31.7%).

Silicate concentrations were highly variable between sites and dates in Baffin Bay. Very low silicate concentrations were observed at various sites in 2015-2016 and late 2018-mid 2019, both of which corresponded with diatom blooms (Figure 19). Much higher concentrations were found at other times when diatom blooms were not present, most notably during the wet periods in late 2018 and in fall 2021. Across the entire time series, an increasing trend in silicate is apparent.

Dissolved organic carbon (DOC) concentrations roughly followed the same temporal pattern as DON. No clear seasonal or interannual pattern in DOC was observed (Figure 20), and no obvious differences were observed between surface and bottom DOC concentrations (Figure 21). DOC peaks in both mid-late 2016 and late 2019-mid-2021 both corresponded with relatively low chlorophyll levels, while DOC "troughs" in late 2013 to mid-2015 and early 2018 to early 2019 corresponded with higher chlorophyll levels (Figure 7), suggesting that phytoplankton may have been utilizing the fraction of the DOC pool that increased in their absence or decreased in their presence. However, this pattern broke down from late-2021 onward. Highest DOC concentrations were found at site 2 (1069 ± 232 µM) and site 1 (1024 ± 219 µM), and were lower at sites 3-6, ranging from 787-908 µM on average.

Dissolved oxygen (D.O.) displayed a clear seasonal pattern that can be linked to temperature, with lowest levels being observed in the warmer months and highest levels in cooler months (Figure 22). This pattern was less clear in summer 2022, when higher than normal D.O. levels were observed, likely due to the influence of lower salinity waters than can hold more oxygen. In summer 2013, several instances of hypoxic (<2 mg/l) bottom waters were observed. Yet in 2014, despite similarly high water temperatures, hypoxia was only observed at site 2 in July. The overall higher bottom D.O. levels in summer 2014 compared to summer 2013 may have been due to strong mixing (and less stratification; Fig. 6) in summer 2014. Hypoxia was occasionally observed at sites 1, 2 and 5 throughout the time series. Overall, the mean DO was lowest at site 2 (4.8 ± 1.8 mg/l) compared to the other sites (range from 5.2-5.6 mg/l).

Discussion

Results from this study show the presence of significant spatial-temporal variability in terms of water quality in the system. At the beginning of the study period, Baffin Bay was experiencing a prolonged drought and concurrently a major bloom of the brown tide phytoplankton species, *A. lagunensis* (Cira and Wetz 2019; Cira et al. 2021). Hypersaline conditions associated with drought have previously been shown to favor *A. lagunensis* growth in the system (e.g., Buskey et al. 1997, 2001). One factor that has not received as much attention has been the role of nutrients. During the early part of this study (2013-early 2015), nutrient ratios suggested alternating conditions of nitrogen and phosphorus limitation of phytoplankton growth. However, nutrient addition bioassays conducted in 2014-2015 showed that only nitrogen addition stimulated phytoplankton growth (Wetz et al. 2017). Sun et al. (2012) found that *A. lagunensis* has the ability to use organic forms of phosphorus, and thus may be less susceptible than other phytoplankton taxa to phosphorus limitation. The strong seasonal pattern of high chlorophyll in spring-summer during 2013-early 2015, when *A. lagunensis* dominated the phytoplankton community, can be explained in part by water temperature. Field and laboratory studies have determined that water temperature may play a role in regulating the growth of *A. lagunensis* (Buskey et al. 1998; Rhudy et al. 1999; Cira and Wetz 2019). Thus the lower levels of chlorophyll in winter could be indicative of the effects of low temperatures. Another possibility, not mutually exclusive with the temperature hypothesis, is that lower temperatures in winter reduced the availability of recycled nutrients that would otherwise support *A. lagunensis* growth. Additional field and experimental studies may be needed to further our understanding of seasonal controls on *A. lagunensis*.

From early fall 2013 through spring 2015, precipitation patterns developed that were more in accordance with long-term monthly averages, and salinities decreased. Despite the lower salinity levels, very high chlorophyll levels were noted in spring-summer 2014 as in spring-summer 2013. In spring 2015, chlorophyll noticeably decreased concurrent with several heavy precipitation events and lower salinity conditions, as did abundances of *A. lagunensis* (Cira and Wetz 2019). This was despite higher inorganic nutrient concentrations than during the earlier timeframe. There are several possible explanations for the decrease in chlorophyll. First, there was significant flushing as well as reduced light from high turbidity that accompanied the spring 2015 rains in Baffin Bay, which Cira et al. (2021) suggest may have led to the demise of the brown tide bloom. Another explanation (not mutually exclusive) is that microzooplankton grazing (e.g., Buskey et al. 1997, 2001) and/or benthic filter feeder removal of phytoplankton may have been depressed during the hypersaline conditions, but became important again with lower salinities.

Chlorophyll remained relatively low for an extended period after the 2015 wet period, except at site 2 where a bloom of *A. lagunensis* redeveloped by summer 2015 and continued through early 2016 (Cira and Wetz 2019; Cira et al. 2021). *A. lagunensis* abundances stayed low elsewhere, but were quantifiable at site 2 through early 2018 when another bloom developed (Wetz, unpubl. data). The persistence of *A. lagunensis* at site 2, along with other features of that site (discussed later), strongly point to the site as being an incubator for the brown tide organism in Baffin Bay.

Heavy rain that occurred in mid-2018 did two things to the ecosystem. First, it resulted in the dissipation of the *A. lagunensis* bloom at site 2, again pointing to flushing as being a contributing factor. However, chlorophyll increased during the wet period in 2018, with a diatom bloom developing throughout the bay, including at site 2 where it displaced *A. lagunensis*. A similar phenomenon was observed during/after the heavy rains that occurred in May-June 2021. Using a 90^{th} percentile threshold of chlorophyll *a* concentration to classify blooms, Beecraft and Wetz (2022) estimated that 24% of high salinity (drought) observations had bloom-level chlorophyll (>33.8 µg/l) and 12% of low salinity (flood) observations were bloom-level. These findings show that Baffin Bay can experience phytoplankton blooms under both low and high inflow conditions, an artifact of the consistent availability of nutrients due to human influence on the watershed and subsequent eutrophication of the estuary.

A longer-term goal of researchers working on Baffin Bay-related water quality issues is to identify which nutrients are fueling blooms in Baffin Bay, and sources of those nutrients. During the study period, surface N+N and ammonium levels were generally low except during wet periods, when high concentrations were commonly observed at the tertiary bay sites. Similarly, high phosphate concentrations were observed during these periods in the Cayo del Grullo and upper Alazan Bay. These findings suggest a contribution of watershed and/or atmospheric sources to the nutrient pools. Indeed, analysis of historical TCEQ water quality data suggests that concentrations of these nutrients in watershed streams, especially San Fernando Creek (upstream of site 1) are particularly high (Wetz, unpubl. data). Coincidentally, it was during the wet periods that diatoms bloom, which is consistent with their preference for high/pulsed inorganic nutrient inputs. In contrast, the *A. lagunensis* blooms tended to occur during dry conditions when inorganic nutrient concentrations were low. Elevated concentrations of ammonium and phosphate were also occasionally observed during summer in bottom waters, consistent with studies from this and other systems showing release of nutrients from suboxic sediments under warm conditions (e.g., An and Gardner 2002). These internal nutrients are likely important for *A. lagunensis* growth. Another important nitrogen pool is DON. DON concentrations were elevated throughout the year and in fact, the total dissolved nitrogen (i.e., DON + ammonium, N+N) and DON concentrations observed in Baffin Bay are consistently higher than many other estuaries in the Gulf of Mexico, including those of the central Texas coast (e.g., Bianchi 2007; Mooney & McClelland 2012; Wetz et al. 2017). Highest concentrations tended to be in the western part of Baffin Bay and its tertiary bays, decreasing towards the mouth. No large-scale differences were observed between surface and bottom DON or DOC concentrations, suggesting that sediment-derived sources are less pronounced compared to the inorganic nutrient pools. These findings point to the watershed as a possible source of DON, or alternatively may indicate that inorganic nitrogen forms transported to the bay from the watershed are rapidly transformed into organic nitrogen. Output from a SPARROW nutrient loading model indicated that fertilizers and atmospheric deposition are the dominant sources of nitrogen to Baffin Bay, while fertilizer was the dominant source of phosphorus (Rebich et al. 2011). However, more recent source tracking work has shown that sewage is a major contributor to inorganic nitrogen pools in watershed streams, whereas a mix of sources contribute to organic nitrogen pools (Wetz et al. 2023). There were several instances between 2013-2021 where DON appeared to increase when chlorophyll concentrations were low but decreased during blooms, suggesting utilization of a fraction of the DON by phytoplankton to support growth. For example, at site 2 in the Laguna Salada, the DON pool decreased by ~60 ± 6% from non-bloom to bloom periods. It is unclear why this pattern fell apart after 2021. One possibility is a general change in the phytoplankton community that affected nutrient utilization. For example, there have been no significant *A. lagunensis* blooms since 2018 in the system. The increasing silicate concentrations may be promoting a shift towards a diatom-dominated community, and diatoms are less likely to display significant utilization of DON compared to *A. lagunensis*.

As with DON, DOC concentrations tended to be much higher in the western portion of Baffin Bay, possibly indicating sources such as watershed streams and/or internal sources such as phytoplankton exudation. Regardless of source, these high levels of DOC as well as algal biomass are important because they may fuel microbial respiration and biological oxygen demand. Near bottom oxygen levels showed a distinct seasonal cycle that is undoubtedly temperature related, with lower temperatures capable of holding more oxygen than higher temperatures. Nonetheless, we occasionally observed hypoxic (<2 mg/) conditions, and oxygen levels and were generally <4 mg/l throughout summer, indicative of intensive microbial respiration and utilization of labile organic matter. Previous studies have shown that hypoxic dissolved oxygen levels, and in some cases oxygen levels of <3-5 mg/l, can have sublethal and/or lethal effects on benthic organisms (e.g., Ritter and Montagna 1999; Diaz and Rosenberg 2008).

Overall, Baffin Bay is displaying multiple symptoms of eutrophication including very high organic carbon, organic nitrogen and chlorophyll concentrations, episodic hypoxia as well as symptoms not quantified here such as fish kills. Given the strong linkage between total nitrogen and chlorophyll along the Texas coast (e.g., Wetz et al. 2017), as well as the stimulatory effects of nitrogen on Baffin Bay phytoplankton growth in bioassays, it is reasonable to conclude that nitrogen is an important driver of eutrophic conditions in Baffin Bay and needs to be a focus of targeted reductions. The 2022-2023 period is notable however in that the lowest chlorophyll levels for the entire period of record were observed. It is not clear whether this is indicative of the start of recovery in terms of water quality or simply symbolic of natural variability. Additional monitoring is clearly warranted to determine if this pattern persists or not.

References

An S, and W.S. Gardner. 2002. Dissimilatory nitrate reduction to ammonium (DNRA) as a nitrogen link, versus denitrification as a sink in a shallow estuary (Laguna Madre/Baffin Bay, Texas). Marine Ecology Progress Series 237:41-50
Bianchi, T.S. 2007. Biogeochemistry of Estuaries. Oxford University Press, Oxford, 702 pp.

Boesch DF. 2002. Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. Estuaries 25: 886-900

Bricker S, B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment In the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver spring, MD. 328 pp.

Buskey, EJ, Montagna, PA, Amos, AF, Whitledge, TE. 1997. Disruption of grazer populations as a contributing factor to the initiation of the Texas brown tide algal bloom. Limnology and Oceanography 42: 1215-1222

Buskey, EJ, Wysor, B, Hyatt, C. 1998. The role of hypersalinity in the persistence of the Texas "brown tide" in the Laguna Madre. J. Plankton Res. 20: 1553-1565
Buskey, EJ, Liu, HB, Collumb, C, Bersano, JGF. 2001. The decline and recovery of a persistent Texas brown tide algal bloom in the Laguna Madre (Texas, USA). Estuaries 24: 337-346

Cira, EK, and MS Wetz. 2019. Spatial-temporal distribution of Aureoumbra lagunensis ("brown tide") in Baffin Bay, Texas. Harmful Algae 89: 101669

Diaz RJ, and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology – an Annual Review. 33: 245-303

Diaz, RJ, Rosenberg, R. 2008. Spreading dead zones and consequences for marine ecosystems.

Science 321: 926-929

Montagna PA, and TA Palmer. 2012. Water and sediment quality status in the Coastal Bend, Phase 2: Data analysis. Report submitted to the Coastal Bend Bays & Estuaries Program for project 1206. 520 pp.

Mooney RF, and JW McClelland. 2012. Watershed export events and ecosystem responses in the Mission-Aransas National Estuarine Research Reserve, South Texas. Estuar. Coasts 35: 1468-1485

NCCR. 2012. National Coastal Condition Report IV. United States Environmental Protection Agency.

Nixon SW. 1995. Coastal marine eutrophication – a definition, social causes, and future concerns. Ophelia 41: 199-219

Ockerman, D.J., and B.L. Petri. 2001. Hydrologic conditions and water quality in an agricultural area in Kleberg and Nueces counties, Texas, 1996-1998. USGS Water Resources Investigations Report 01-4101

Rabalais, NN, Turner, RE, Diaz, RJ, Justic, D. 2009. Global change and eutrophication of coastal waters. ICES Journal of Marine Science. 66: 1528-1537

Rebich, R.A., and 5 others. 2011. Sources and delivery of nutrients to the northwestern Gulf of Mexico from streams in the south-central United States. J. American Water Res. Assoc. 47: 1061-1086

Rhudy, KB, Sharma, VK, Lehman, RL, and McKee, DA. Seasonal variability of the Texas “brown tide” (Aureoumbra lagunensis) in relation to environmental parameters. Estuar. Coastal Shelf Sci. 48: 565-574

Ritter, C., and P.A. Montagna. 1999. Seasonal hypoxia and models of benthic response in a Texas bay. Estuaries 22: 7-20

Shormann, DE. 1992. The effects of freshwater inflow and hydrography on the distribution of brown tide in South Texas. M.A. thesis, University of Texas at Austin, 112 pp.

Sun, M.M., J. Sun, J.W. Qiu, H.M. Jing, and H.B. Liu. 2012. Characterization of the proteomic profiles of the brown tide alga *Aureoumbra lagunensis* under phosphate- and nitrogen-limiting conditions and of its phosphate limitation-specific protein with Alkaline Phosphatase activity. Appl. Environ. Microbiol. 78: 2025-2033

Wetz, M.S., and 5 others. 2017. Exceptionally high organic nitrogen concentrations in a semi-arid South Texas estuary susceptible to brown tide blooms. Estuarine, Coastal and Shelf Science 188: 27-37

Wetz, M.S., J.D. Felix, D. Murgulet, H. Abdulla, and M. Ahmed. 2023. An integrated assessment of nutrient loadings to Baffin Bay, Texas. Final report to Texas General Land Office, 202 pp.

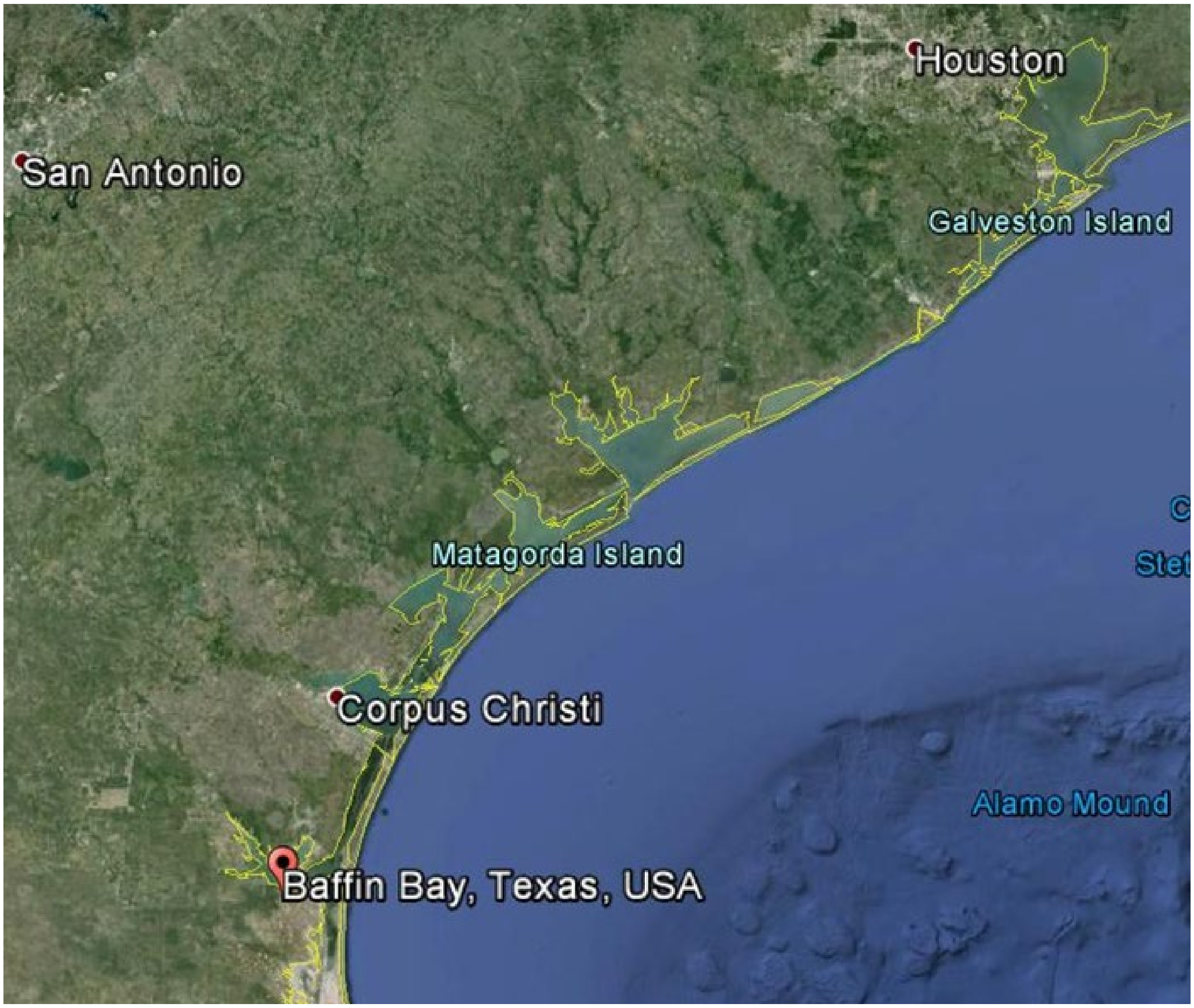

Figure 1. Map of Baffin Bay, located ~50 km south of Corpus Christi, TX.

Figure 2. Map of sampling locations in Baffin Bay. Red markers indicate two sites that are visited as part of TCEQ's quarterly monitoring program.

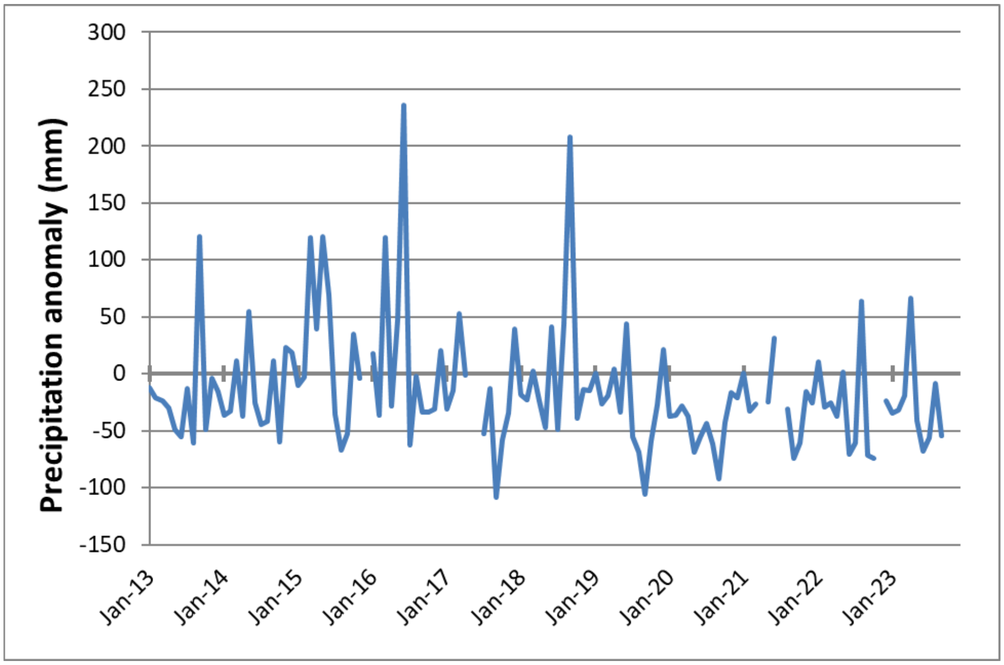

Figure 3. Precipitation anomaly for Baffin Bay.

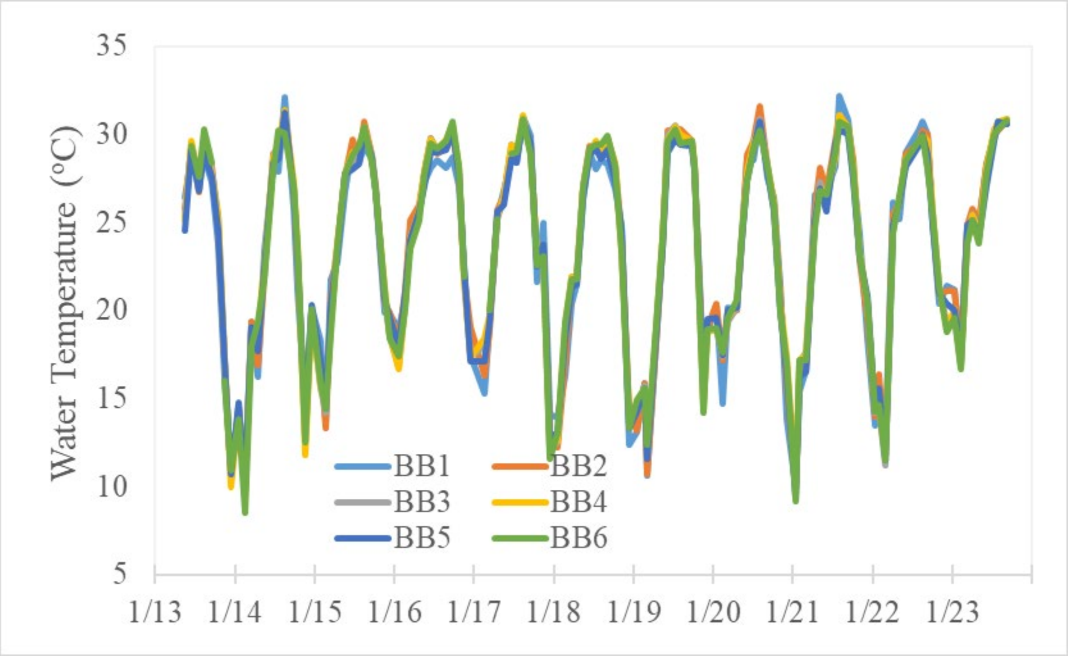

Figure 4. Surface water temperature in Baffin Bay.

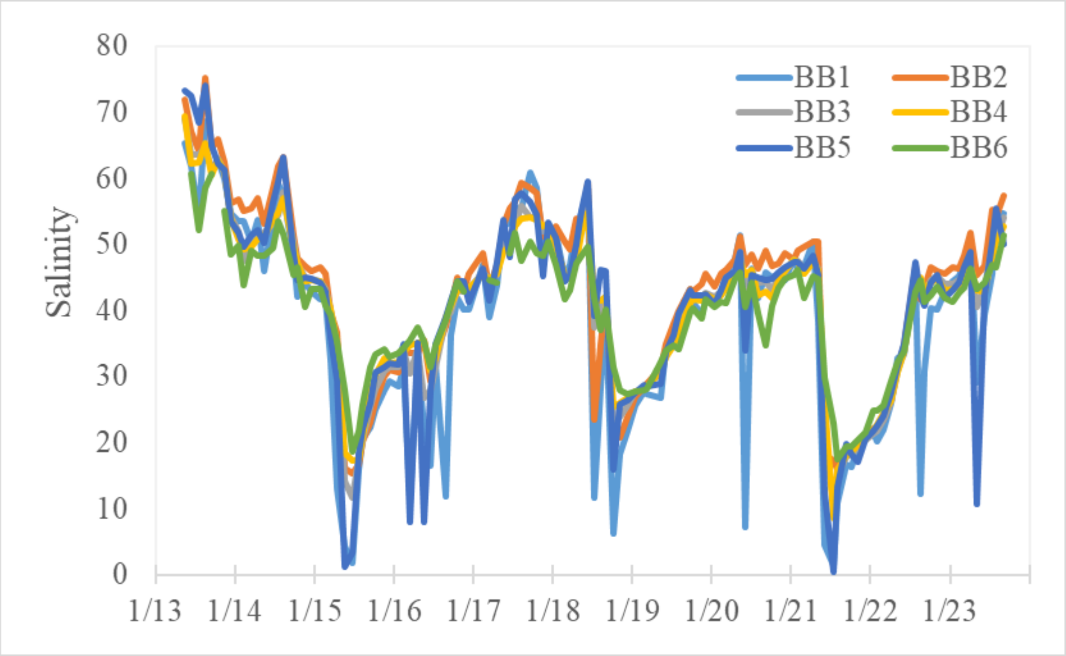

Figure 5. Surface salinity in Baffin Bay.

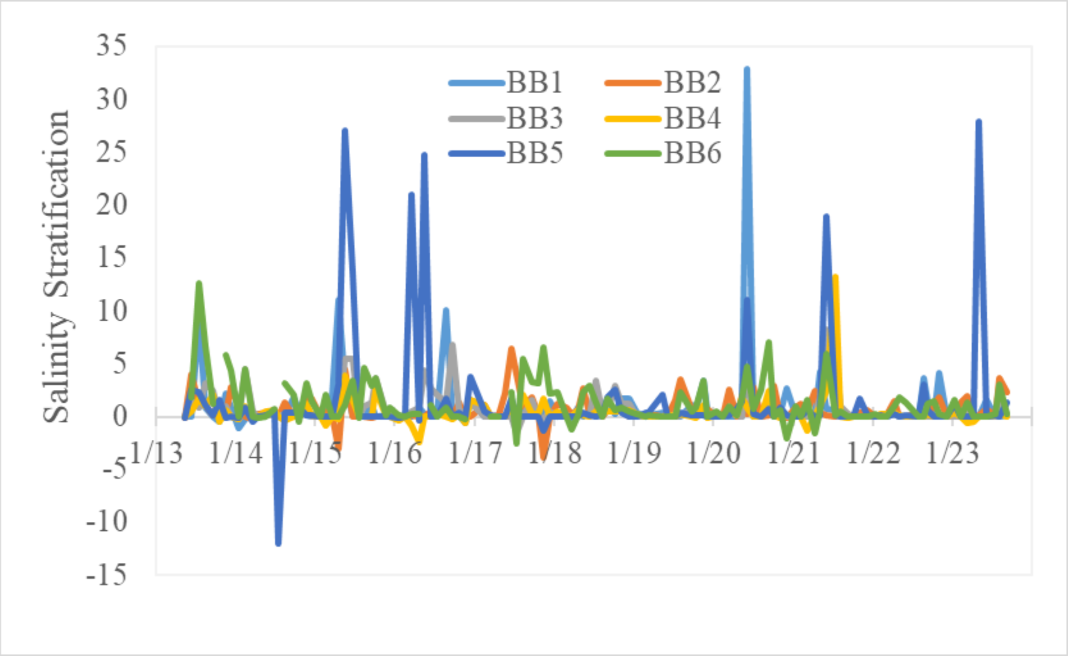

Figure 6. Salinity stratification in Baffin Bay.

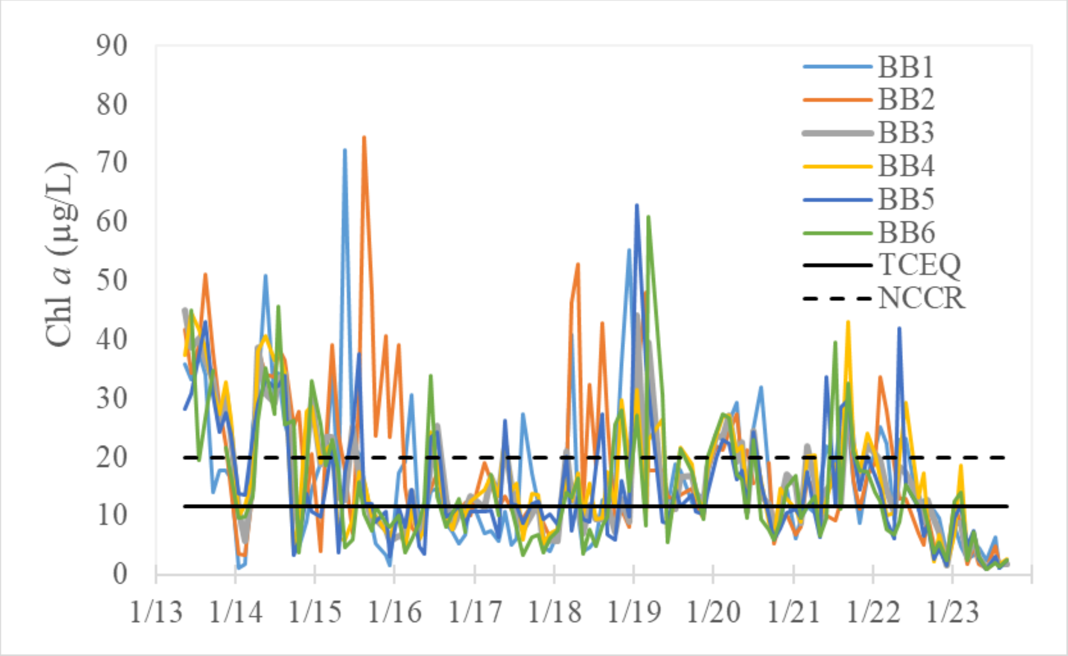

Figure 7. Chlorophyll *a* in Baffin Bay. The solid black line indicates the TCEQ screening level for nutrient concern (11.6 µg/l) while the dashed black line indicates a suggested level that is indicative of eutrophication (20 µg/l).

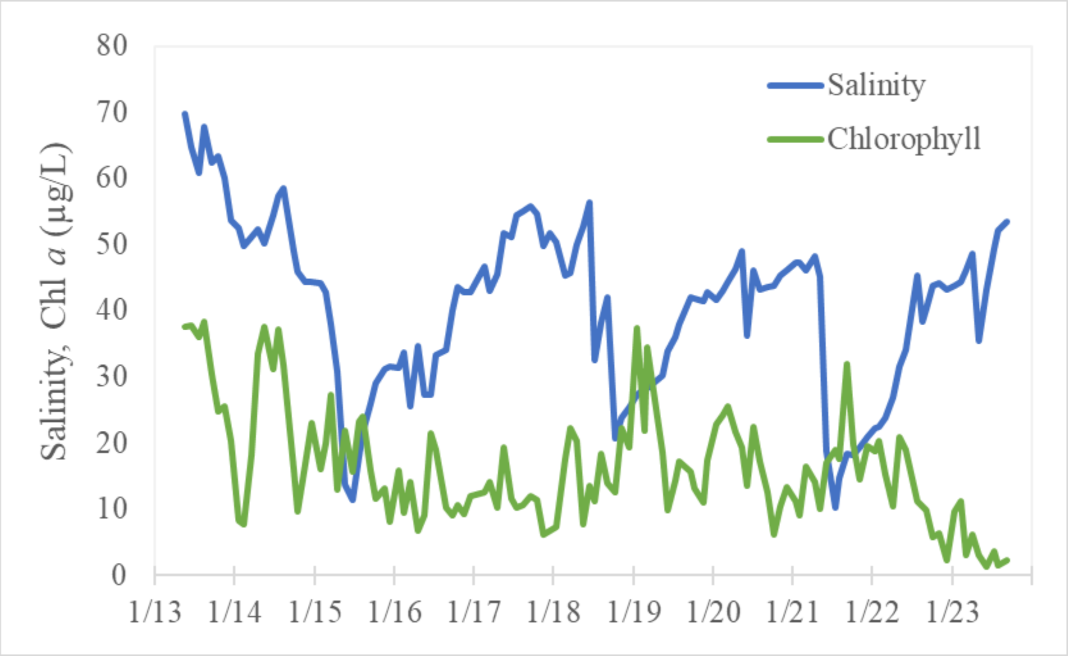

Figure 8. Mean chlorophyll and salinity in Baffin Bay.

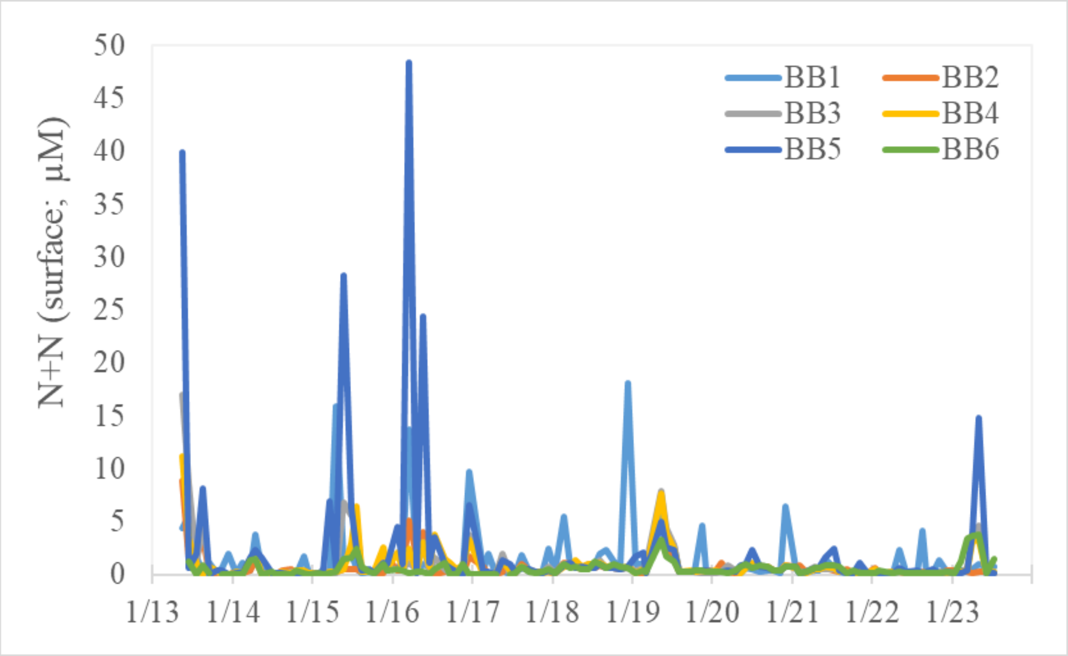

Figure 9. Surface N+N in Baffin Bay.

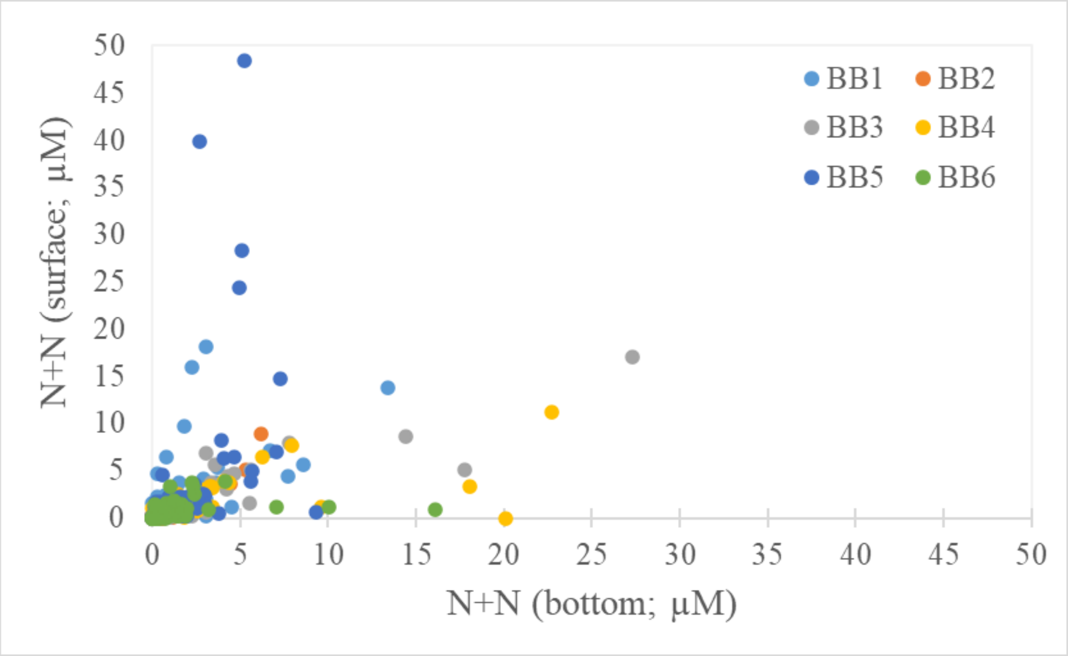

Figure 10. Surface vs. Bottom N+N in Baffin Bay.

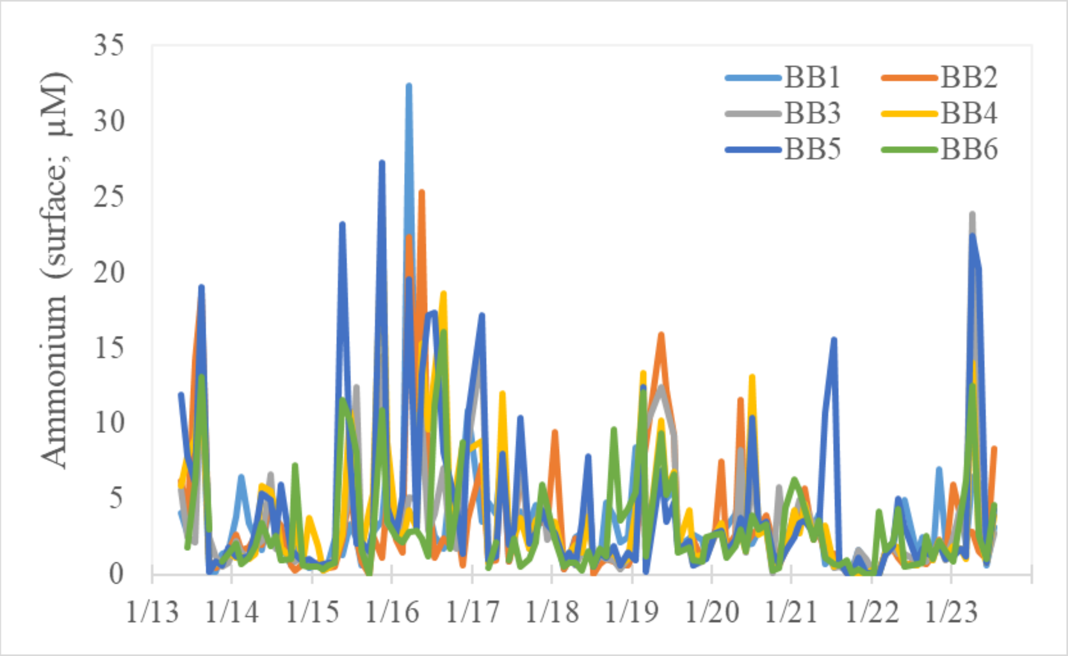

Figure 11. Surface ammonium in Baffin Bay.

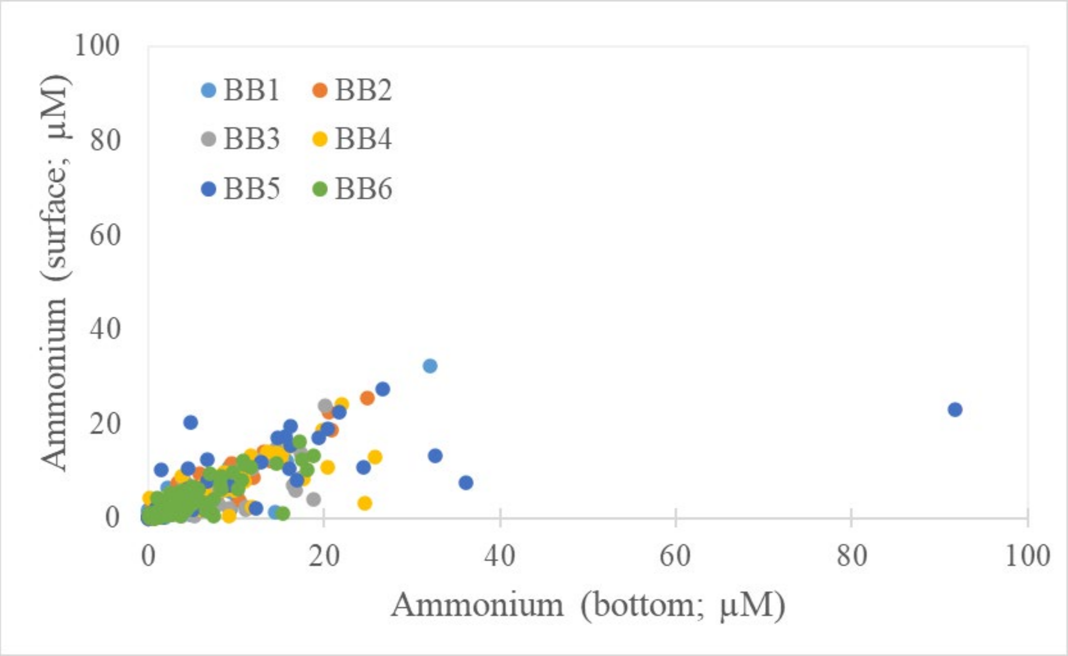

Figure 12. Surface vs. Bottom ammonium in Baffin Bay.

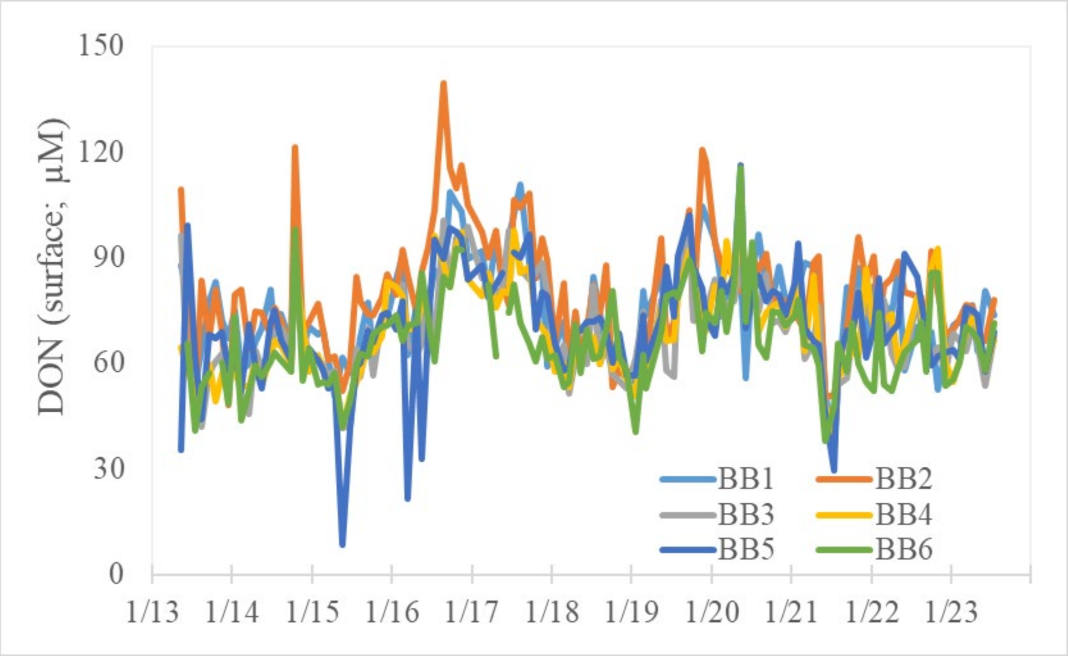

Figure 13. Surface dissolved organic nitrogen in Baffin Bay.

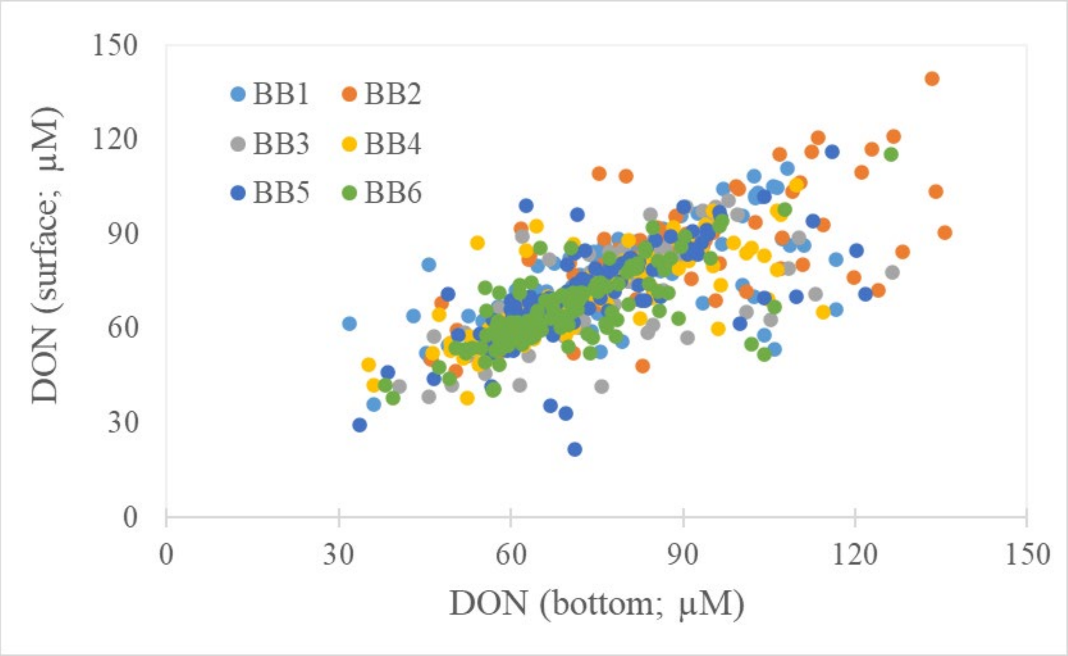

Figure 14. Surface vs. Bottom dissolved organic nitrogen in Baffin Bay.

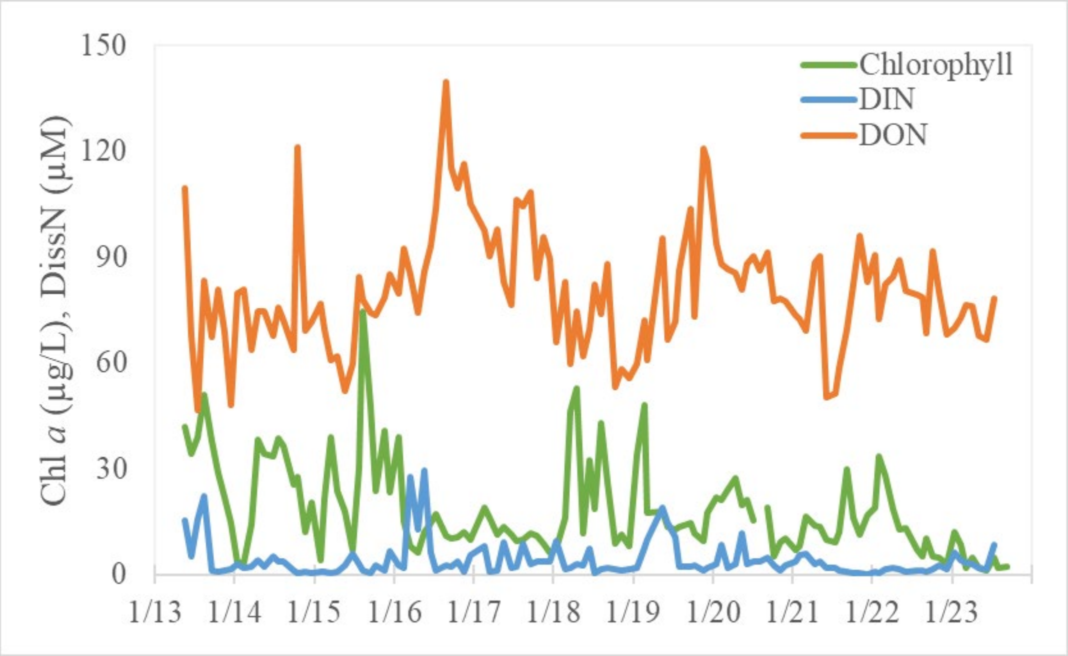

Figure 15. Mean chlorophyll, dissolved organic nitrogen and dissolved inorganic matter at site 2 in Baffin Bay. Note that the same temporal pattern holds for sites 1 and 3-6.

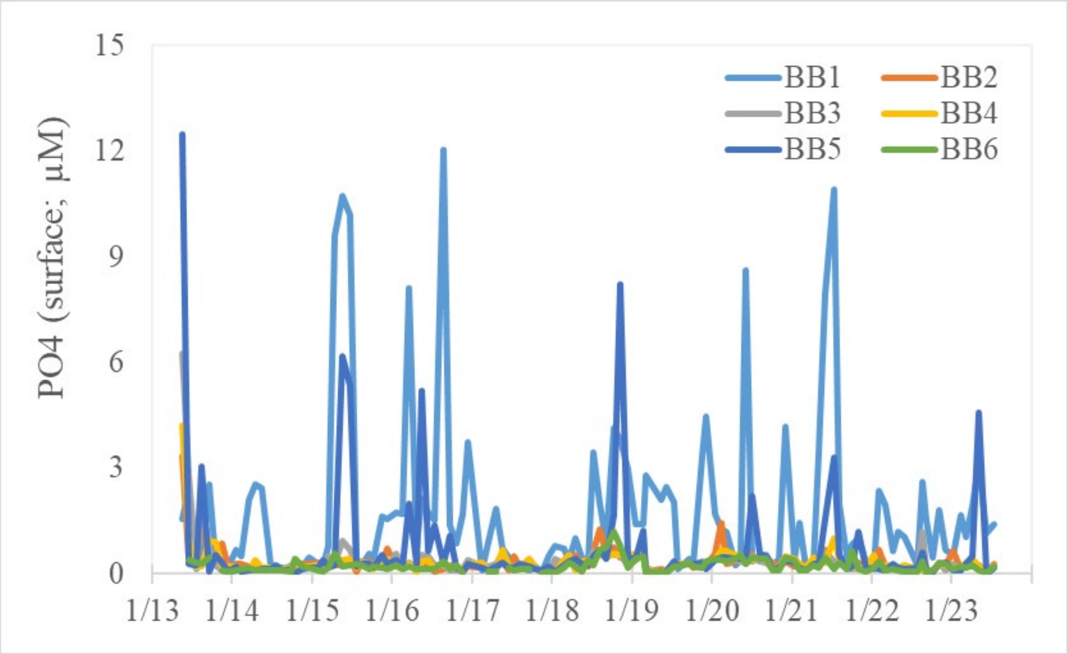

Figure 16. Surface phosphate in Baffin Bay.

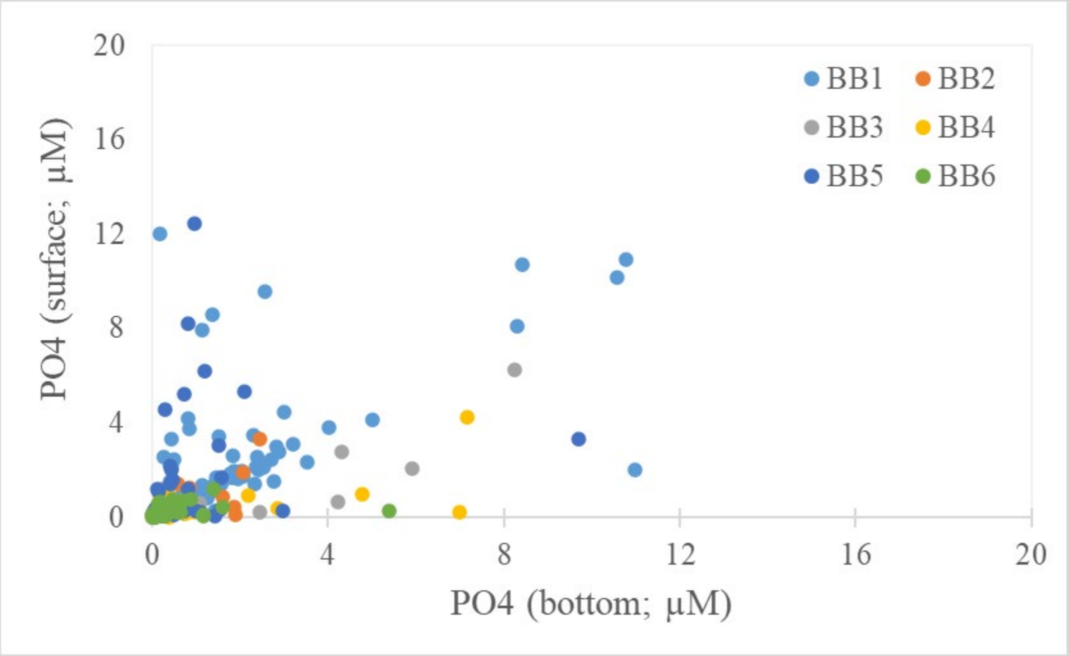

Figure 17. Surface vs. Bottom phosphate in Baffin Bay.

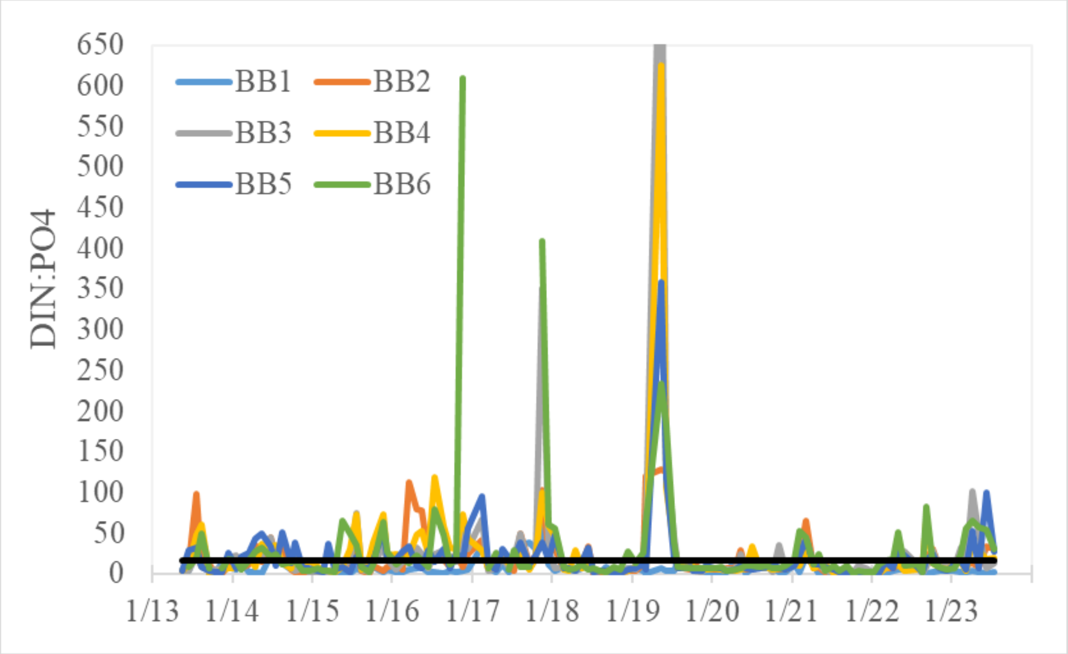

Figure 18. Ratio of inorganic nitrogen to phosphate in Baffin Bay. Solid black line indicates the theoretical boundary between N-limitation (<16) and P-limitation (>16). Note that the value for site 3 on 5/13/2019 (886) exceeds the scale.

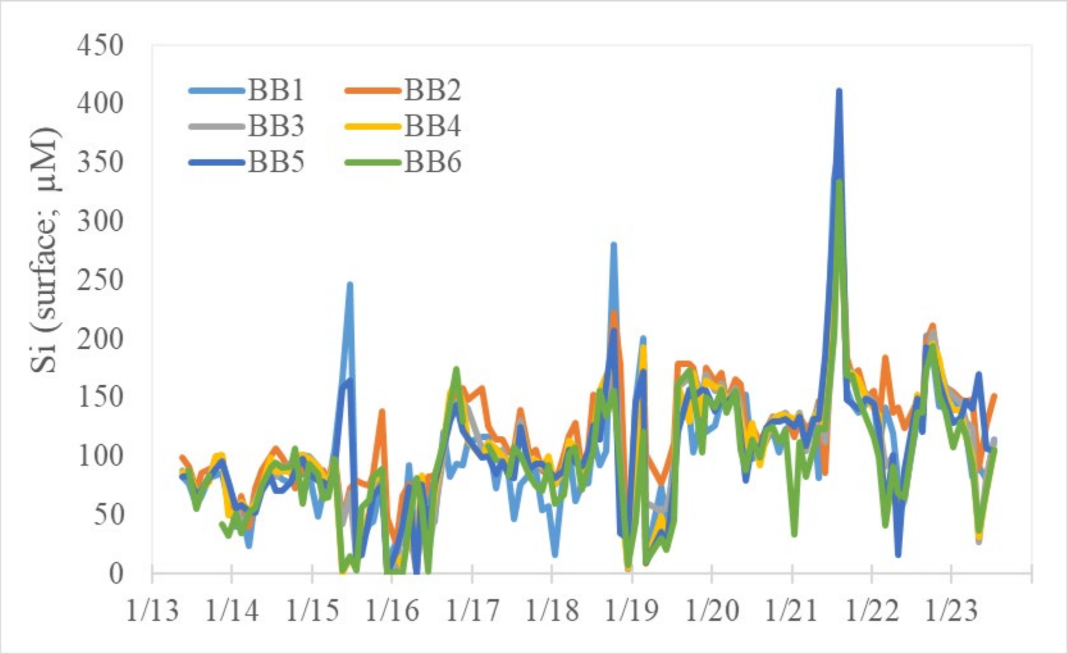

Figure 19. Surface silicate in Baffin Bay.

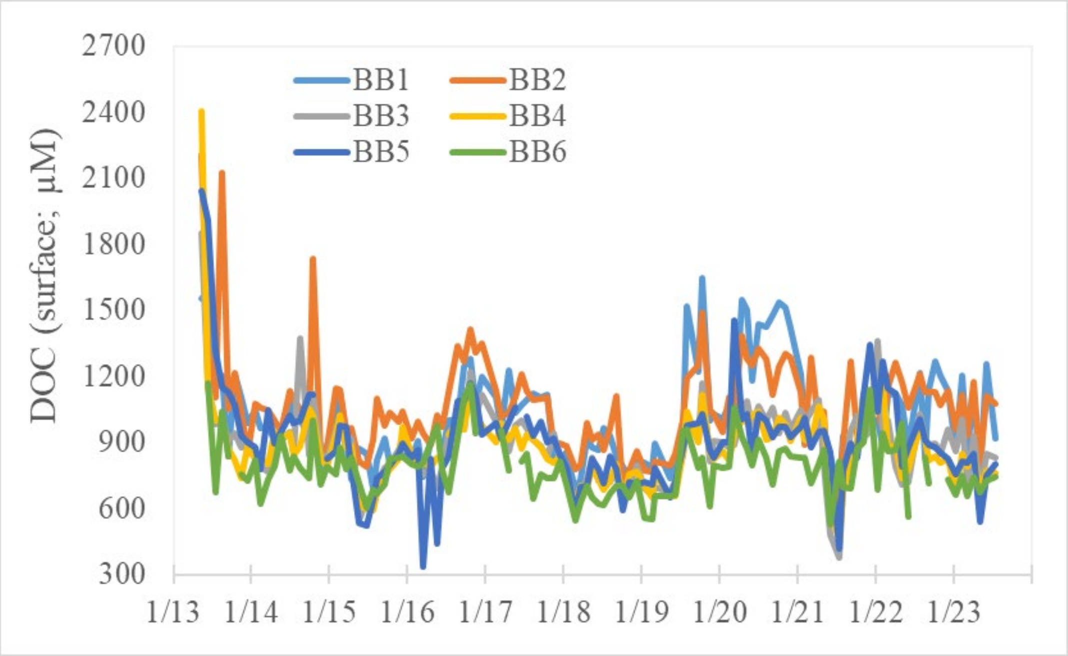

Figure 20. Surface DOC in Baffin Bay.

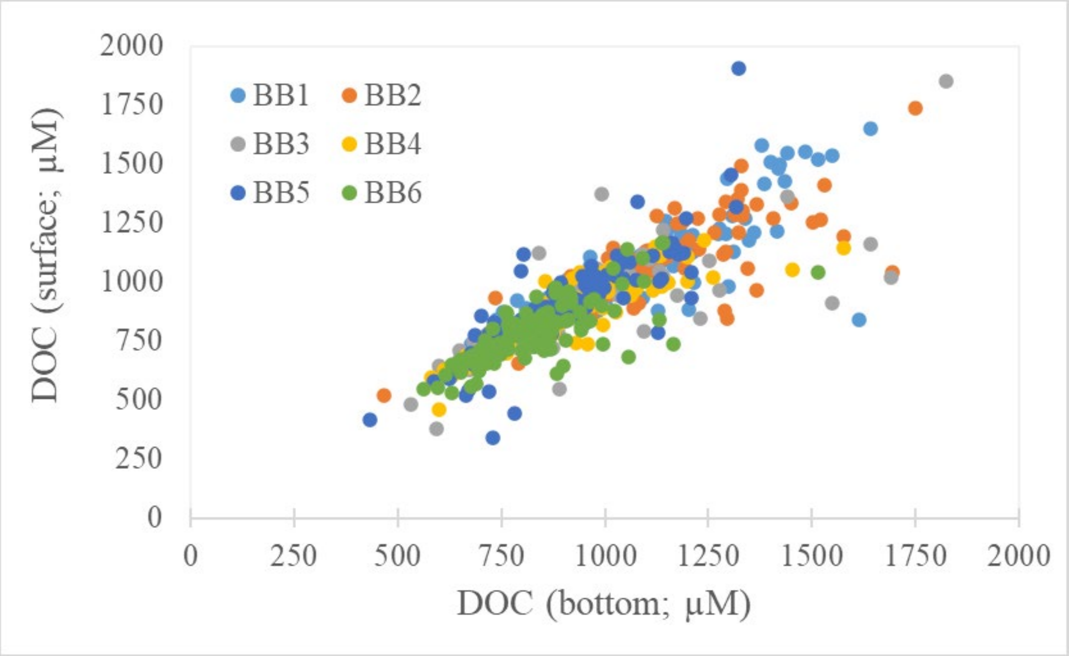

Figure 21. Surface vs. bottom DOC concentrations in Baffin Bay.

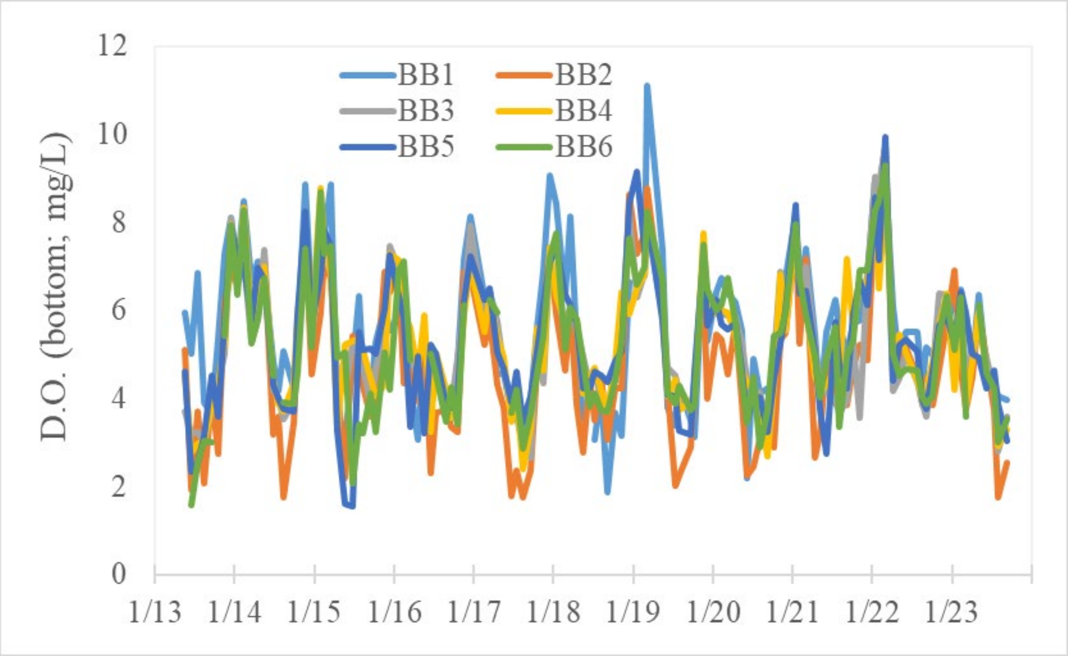

Figure 22. Bottom dissolved oxygen in Baffin Bay.