



Baffin Bay Water Quality Monitoring Study: Synthesis of May 2013-May 2022 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 three 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 of the tributaries (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 . Dense, spatially extensive blooms of the harmful alga *Aureoumbra lagunensis* (“brown tide”) occurred during low rainfall, long residence time conditions, 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 were still observed during or shortly after the flooding events in the dataset. Using a 90th percentile threshold of chlorophyll *a* concentration to classify blooms, 24% of high salinity (drought) observations were bloom-level and 12% of low salinity (flood) observations were bloom-level. Interestingly, DON generally increased 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 $\sim 60 \pm 6\%$ 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). Overall, 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 low and high inflow conditions, an artifact of the consistent availability of labile nutrients due to many decades of human influence on the watershed and subsequent eutrophication of the estuary.

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 eight 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). Unfortunately, Texas estuaries have been poorly represented in national eutrophication assessments such as the aforementioned report, largely due to lack of sampling efforts and data coverage. Nonetheless, there is growing concern fueled by public observations and recent scientific assessments that several systems in South Texas are indeed undergoing eutrophication (see e.g., Bugica et al. 2020). One example is Baffin Bay, which represents critical habitat for several economically- and ecologically-important fish species and is popular with recreational fishermen.

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; Ciria 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 ($\leq 2\text{-}3$ 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 5-9 sites in Baffin Bay (Figure 2). Water samples were collected by volunteer citizen scientists from the start of the study until May 2017. 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).

After May 2017, Wetz lab members took over sample collection. 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% acetone and analyzed fluorometrically. Inorganic nutrients (nitrate + nitrite (N+N)), nitrite, silicate, phosphate, ammonium) were determined in the filtrate of water that passed through GF/F filters using a Seal QuAAtro autoanalyzer. Dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) were determined in the filtrate of water that passed through GF/F filters using a Shimadzu TOC-V analyzer with nitrogen module. Dissolved organic nitrogen (DON) was estimated as the difference between TDN and inorganic nitrogen. Complete methodological details on wet chemical and YSI analyses can be obtained from Dr. Wetz.

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. From summer 2019-May 2022, below average rainfall was observed again with the exception of May-June 2021, when brief periods of very heavy rainfall were observed in the region.

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 2022, when a sharp decrease occurred resulting from heavy rainfall in the watershed in May-June. 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 tributary sites that were influenced by runoff, especially during 2015-2016, in late spring 2020, and in early summer 2022 (Figure 6).

Biological-chemical dynamics – Chlorophyll concentrations tended to be very high in Baffin Bay during this study, exceeding the TCEQ screening level (11.6 $\mu\text{g/l}$) in 413 of 636 samples (65%). Using a slightly more relaxed National Coastal Condition Report for “poor” condition (20 $\mu\text{g/l}$; NCCR 2012), chlorophyll was still in excess in 205 of 636 sample collections (32%). 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, as well as early-mid 2021 blooms) and during wet conditions (such as winter 2018-spring 2019 diatom blooms, summer-fall 2022 blooms) (Figures 7, 8). From a spatial standpoint, chlorophyll concentrations tended to be highest at site 2 ($20.5 \pm 13.0 \mu\text{g/l}$), followed by sites 1 and 4 ($17.7 \pm 11.8 \mu\text{g/l}$ and 17.7 ± 9.7 , respectively), site 3 ($17.2 \pm 9.4 \mu\text{g/l}$), site 5 ($16.9 \pm 10.4 \mu\text{g/l}$) and site 6 ($16.0 \pm 10.5 \mu\text{g/l}$) (Figure 7).

N+N concentration 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), 8 and 9 (north and central mouth; $< 1 \mu\text{M}$) (Figure

9). Aside from this, high ($>10 \mu\text{M}$) concentrations of N+N were only observed during wet periods, and these solely occurred at sites 1 and 5. Few 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 ($>10 \mu\text{M}$) were also observed during high rainfall conditions, especially (but not limited to) in the tributary 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 $40 \mu\text{M}$ (Figure 13, 15). No clear seasonal or interannual pattern was observed in terms of DON (Figure 13), and no 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 (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 $\sim 60 \pm 6\%$ 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). Highest DON concentrations were found at site 2 ($80.7 \pm 18.0 \mu\text{M}$) and site 1 ($76.3 \pm 15.1 \mu\text{M}$), and were lower at sites 3-6, ranging from 66.7 - $70.7 \mu\text{M}$ on average.

Higher phosphate concentrations were often observed during warmer months of the year (Figure 16). However, higher concentrations ($>1 \mu\text{M}$) 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). Early on in the study period, DIN:DIP varied from indicating nitrogen limitation ($N:P < 16$) to indicating phosphorus limitation ($N:P > 16$) (Figure 18). After the high rainfall period in spring 2015, DIN:DIP was more frequently indicative of phosphorus limitation until early 2018, when nitrogen limitation became more frequently observed. Nitrogen limitation persisted until spring 2019, when there was a sharp but ephemeral transition to phosphorus limitation. Since then, nitrogen limitation has been in place except during late winter-early spring 2021.

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 May-June 2021.

Dissolved organic carbon (DOC) concentrations roughly followed the same temporal pattern as DON. No clear seasonal or interannual pattern was observed (Figure 20). 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. Highest DOC concentrations were found at site 2 ($1064 \pm 252 \mu\text{M}$) and site 1 ($1021 \pm 232 \mu\text{M}$), and were lower at sites 3-6, ranging from 785-905 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 21). This pattern was less clear in summer 2021, 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 ($< 2 \text{ mg/l}$) 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 5.3-5.6 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. Recently, Cira and Wetz (2019) determined that water temperature may play a role in regulating the growth of *A. lagunensis*. 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 (this study), 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 massive 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 90th percentile threshold of chlorophyll *a* concentration to classify blooms, Beecraft and Wetz (in press) 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 is poised to experience phytoplankton blooms under both low and high inflow conditions, an artifact of the consistent availability of labile nutrients due to many decades of 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 sources of nutrients that are fueling these blooms in Baffin Bay. 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 tributary sites. Similarly, high phosphate concentrations were observed during these periods in the Cayo del Grullo and upper Alazan Bay. Coincidentally, it was during the wet periods that diatoms bloom, which is consistent with their preference for high/pulsed nutrient inputs. In contrast, the *A. lagunensis* blooms tended to occur during dry conditions. 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 an important source for *A. lagunensis*. Another source of nitrogen, either directly or indirectly, appears to be the DON in the system. 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 tributaries, decreasing towards the mouth. 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. Interestingly, DON generally increased when chlorophyll concentrations were low but decreased during blooms. At site 2 for example, there was a nearly 60% drawdown of DON as blooms developed, suggesting an important role for it in terms of fueling phytoplankton growth.

Output from a SPARROW nutrient loading model indicates 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). In terms of the source(s) of organic nitrogen, Ockerman and Petri (2001) pointed to crop residue as a major source of organic nitrogen during runoff events to Petronila Creek, a stream that flows into Baffin Bay. Alternatively, we have found very high (and increasing) chlorophyll levels in Petronila Creek based on TCEQ data (Wetz, unpubl. data), suggesting that this algal biomass may be flushed downstream to Baffin Bay during rain events and contribute to the organic nitrogen. During drought years however, other sources of organic nitrogen must be considered. Examples may include wastewater discharge, septic from surrounding communities, as well as biotic sources (e.g., algal and seagrass exudation).

Organic matter concentrations in Baffin Bay tended to be very high during the study period. As with DON, DOC concentrations tended to be much higher in the western portion of Baffin Bay, possibly indicating tributary sources 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/l) conditions, and oxygen levels 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 in the future.

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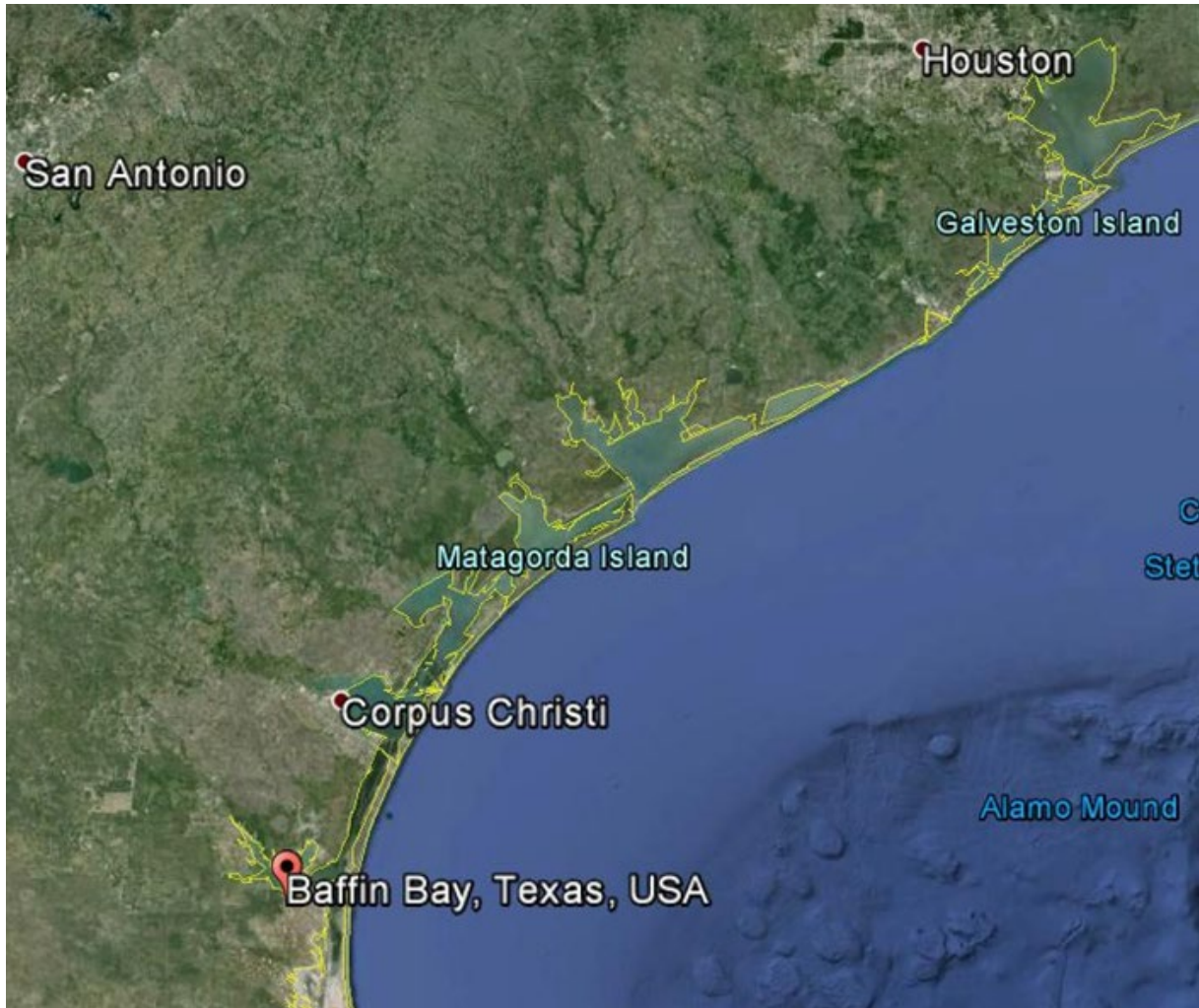


Figure 1. Map of Baffin Bay, located ~50 km south of Corpus Christi, TX.



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.

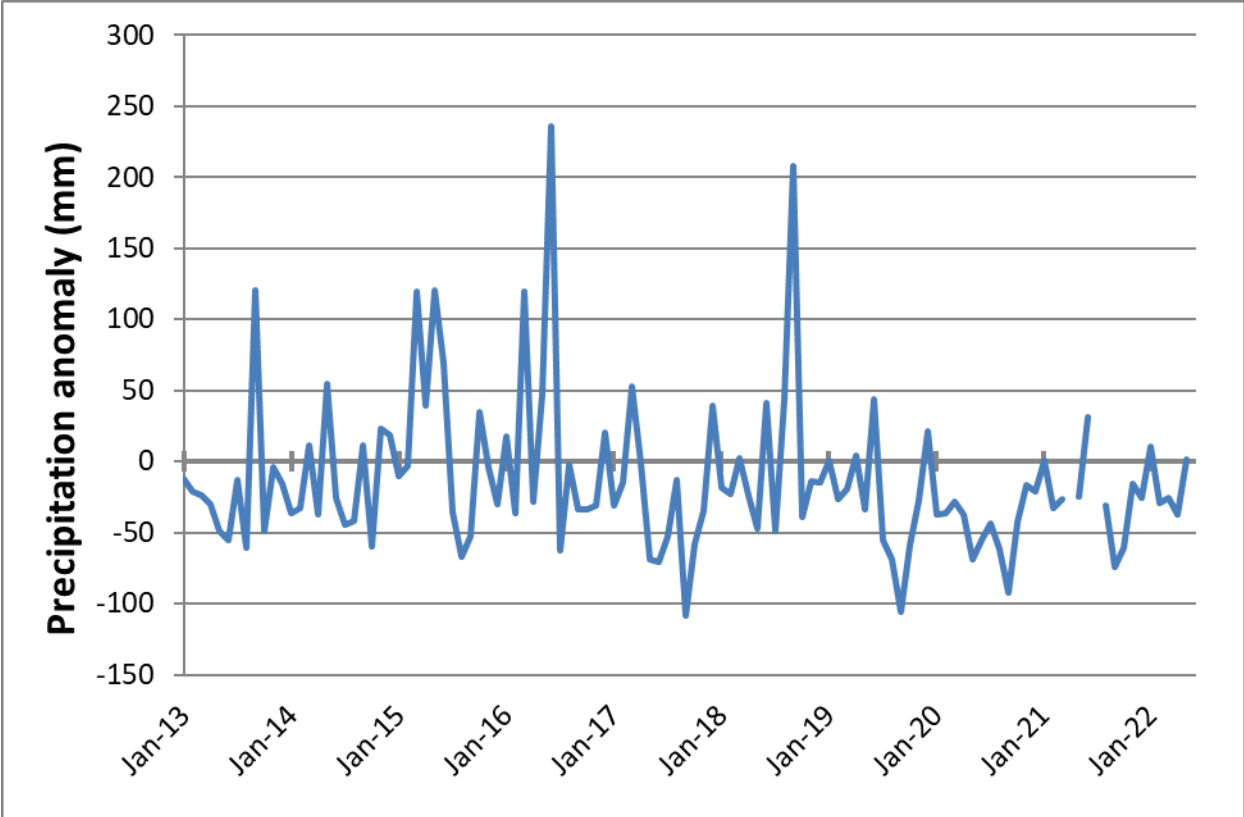


Figure 3. Precipitation anomaly for Baffin Bay.

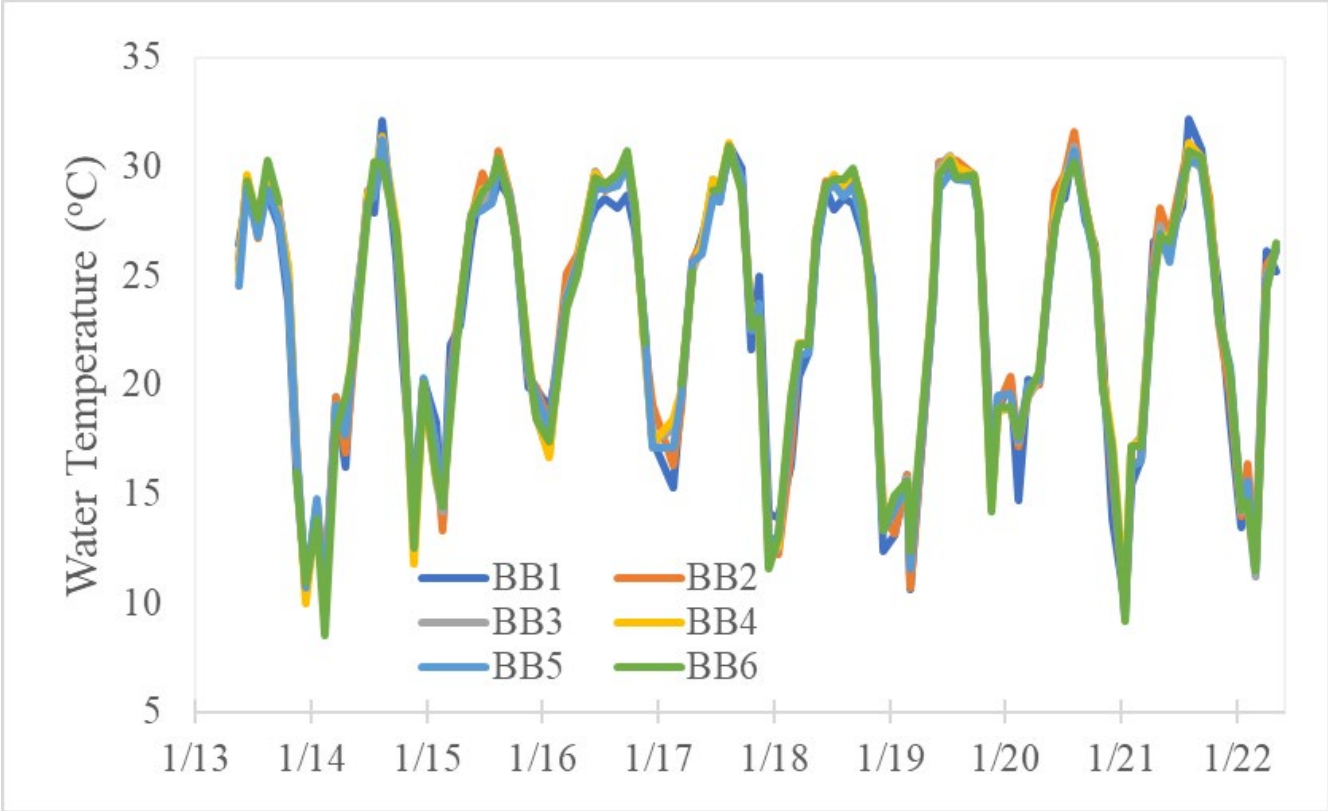


Figure 4. Surface water temperature in Baffin Bay.

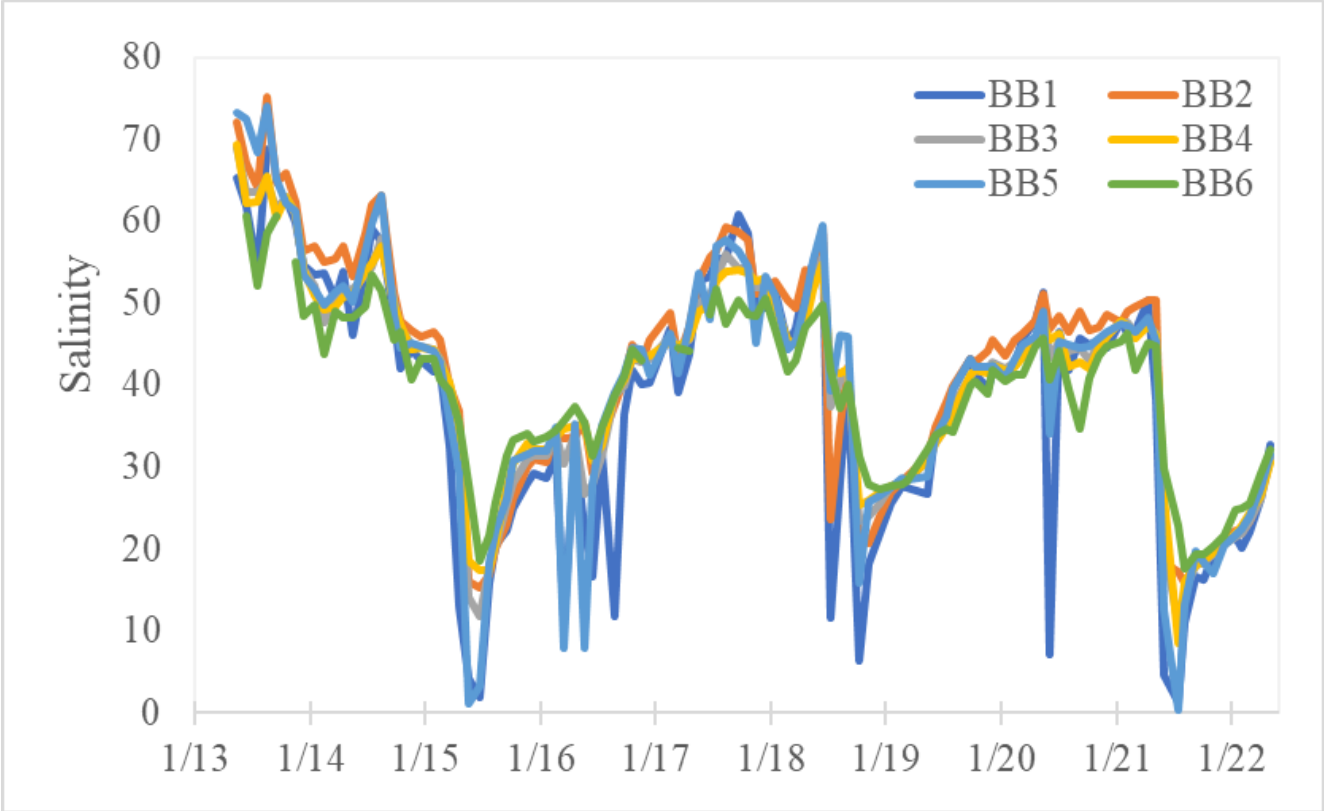


Figure 5. Surface salinity in Baffin Bay.

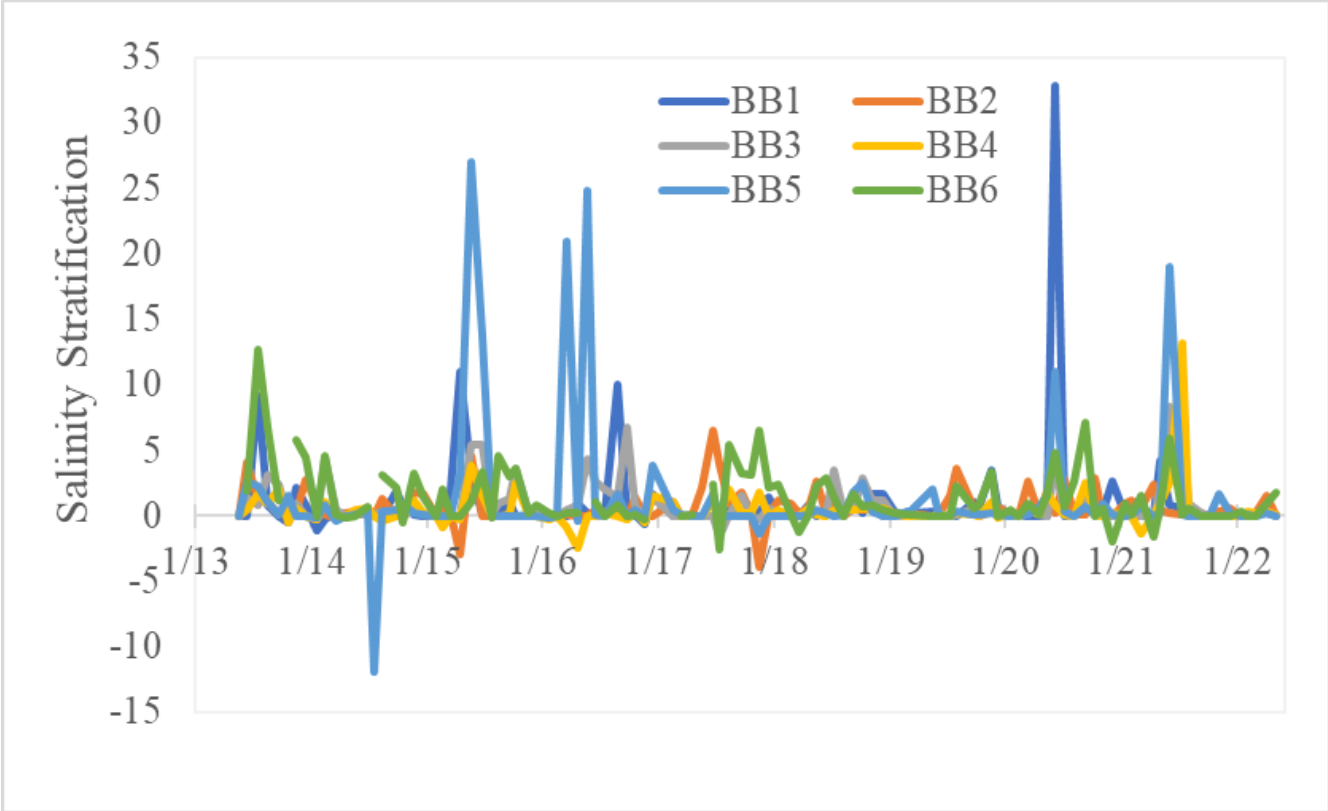


Figure 6. Salinity stratification in Baffin Bay.

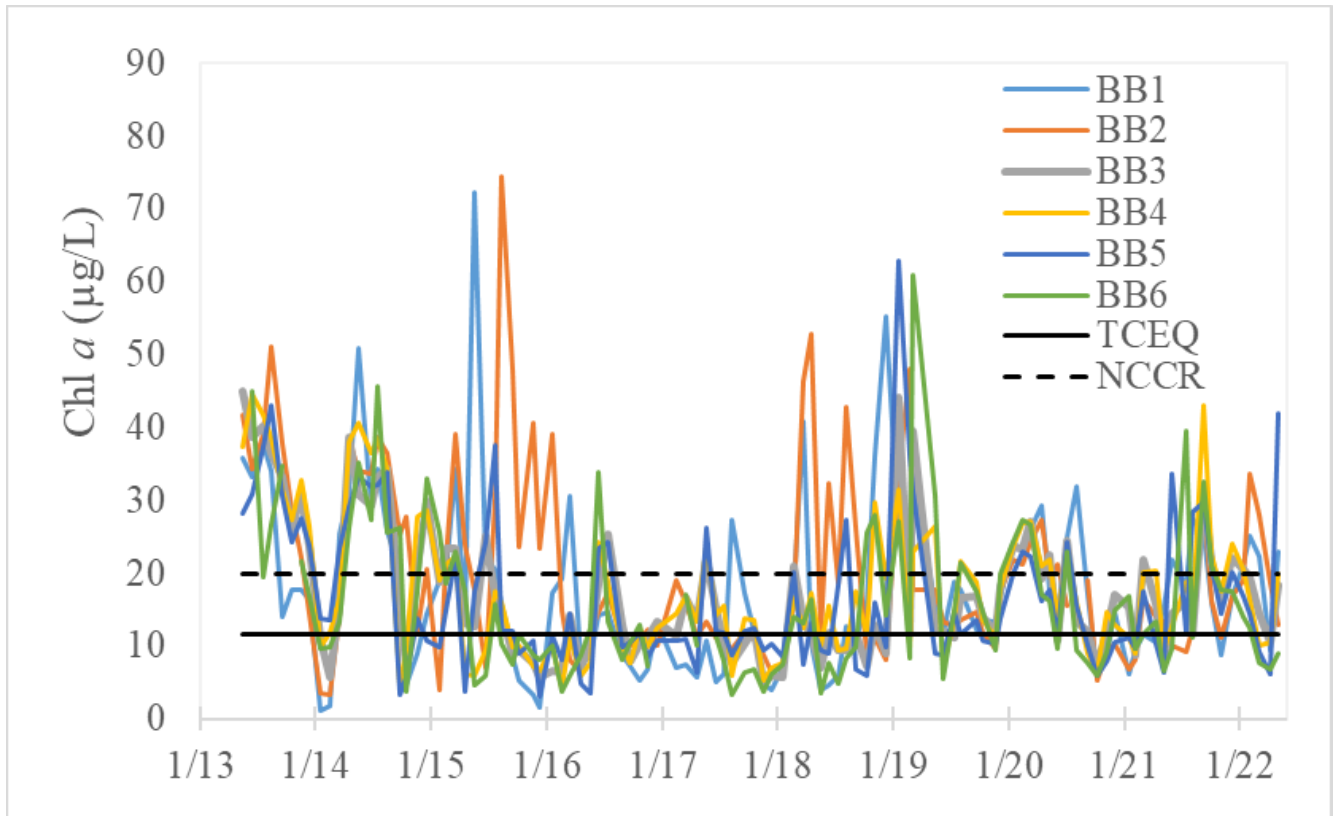


Figure 7. Chlorophyll *a* in Baffin Bay. The solid black line indicates the TCEQ screening level for nutrient concern (11.6 µg/l) while the dashed black line indicates a suggested level that is indicative of eutrophication (20 µg/l).

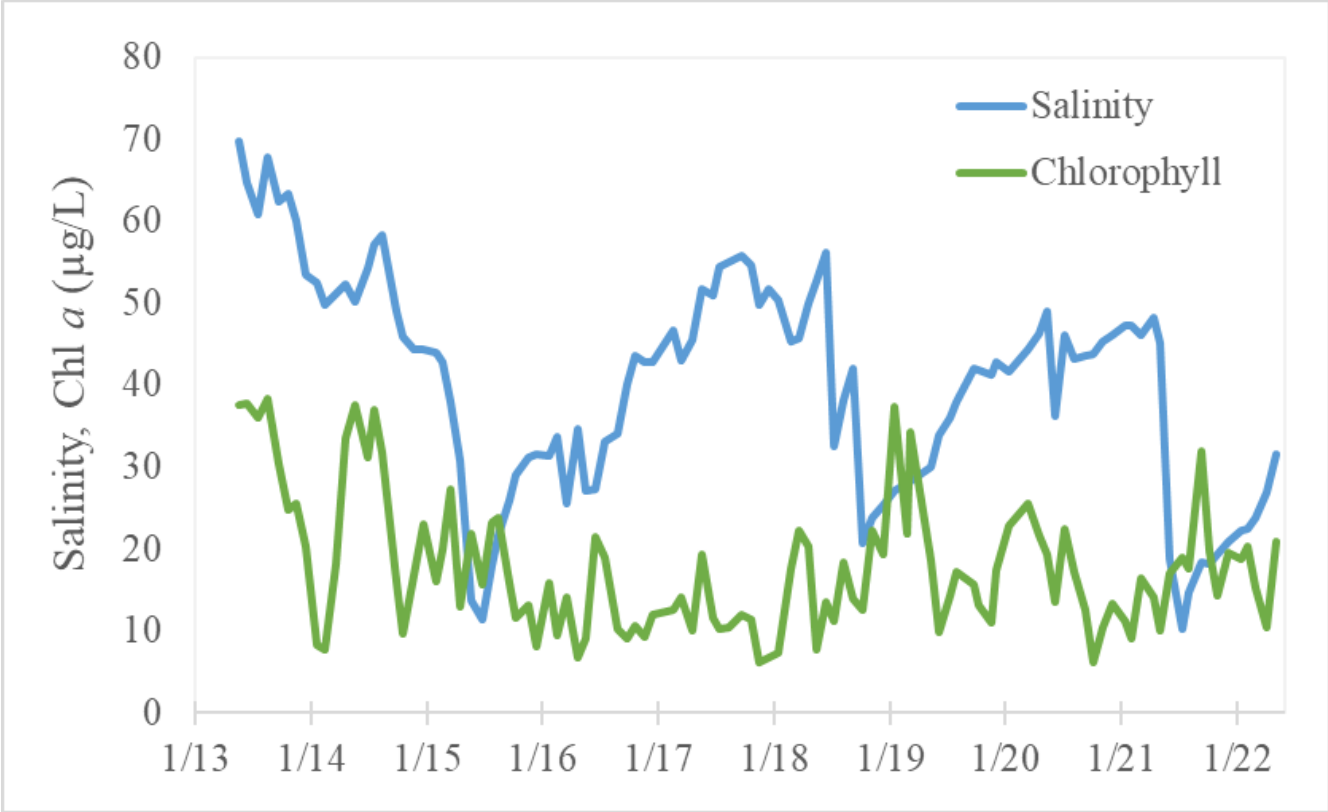


Figure 8. Mean chlorophyll and salinity in Baffin Bay.

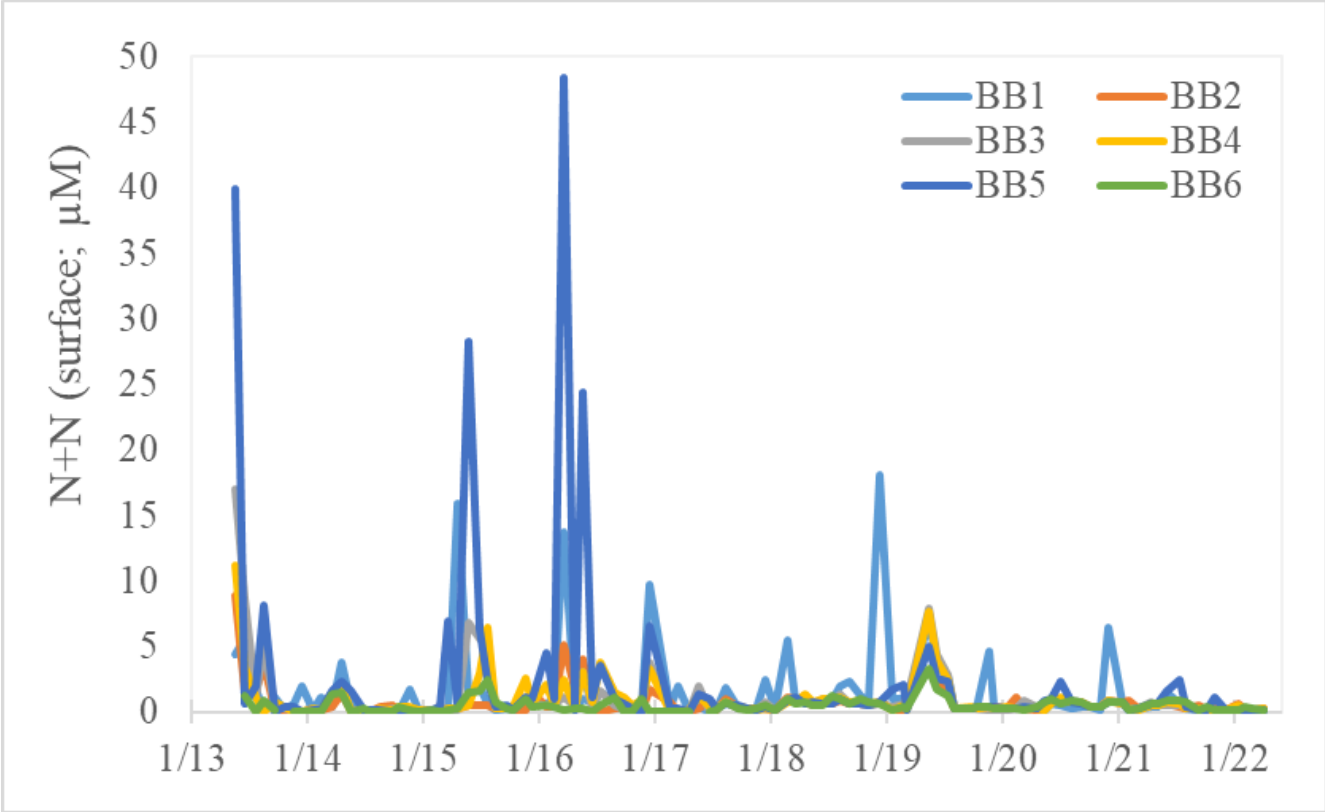


Figure 9. Surface N+N in Baffin Bay.

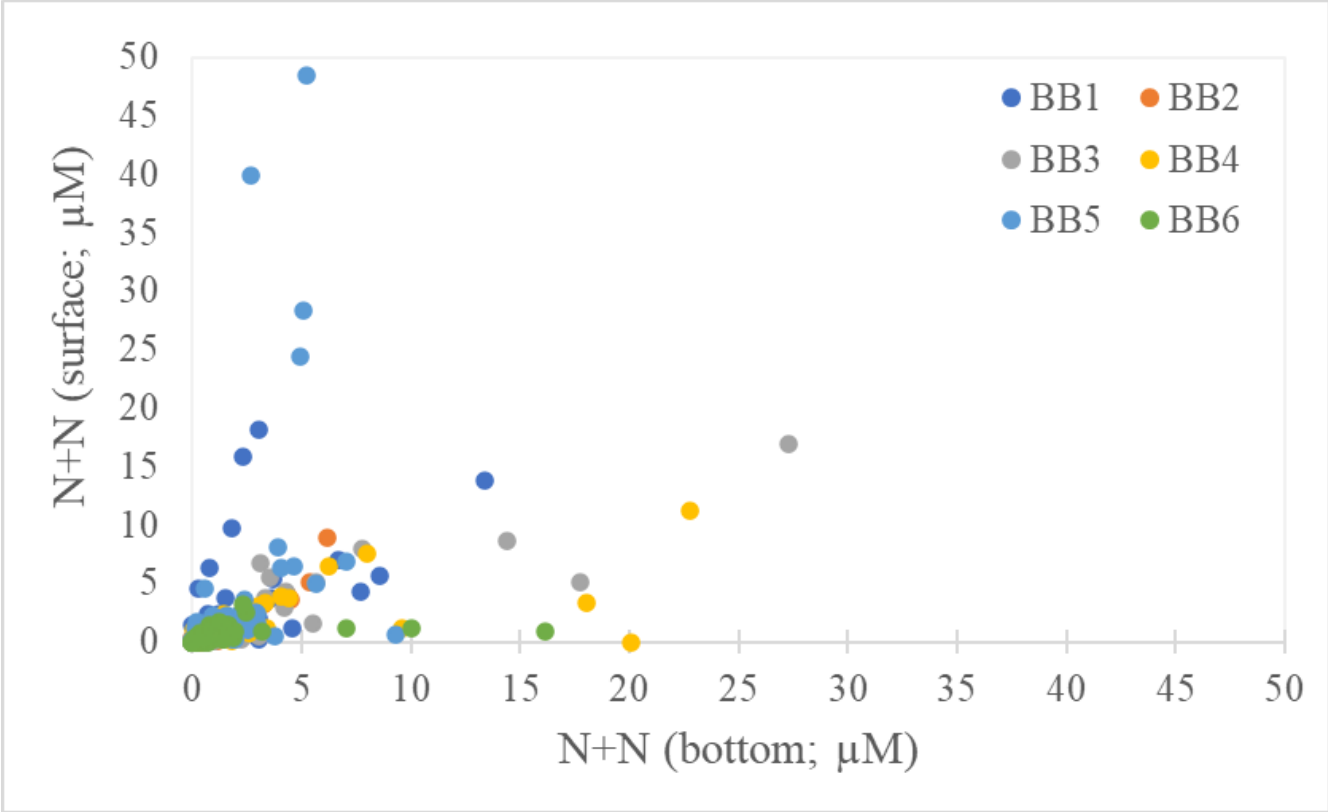


Figure 10. Surface vs. Bottom N+N in Baffin Bay.

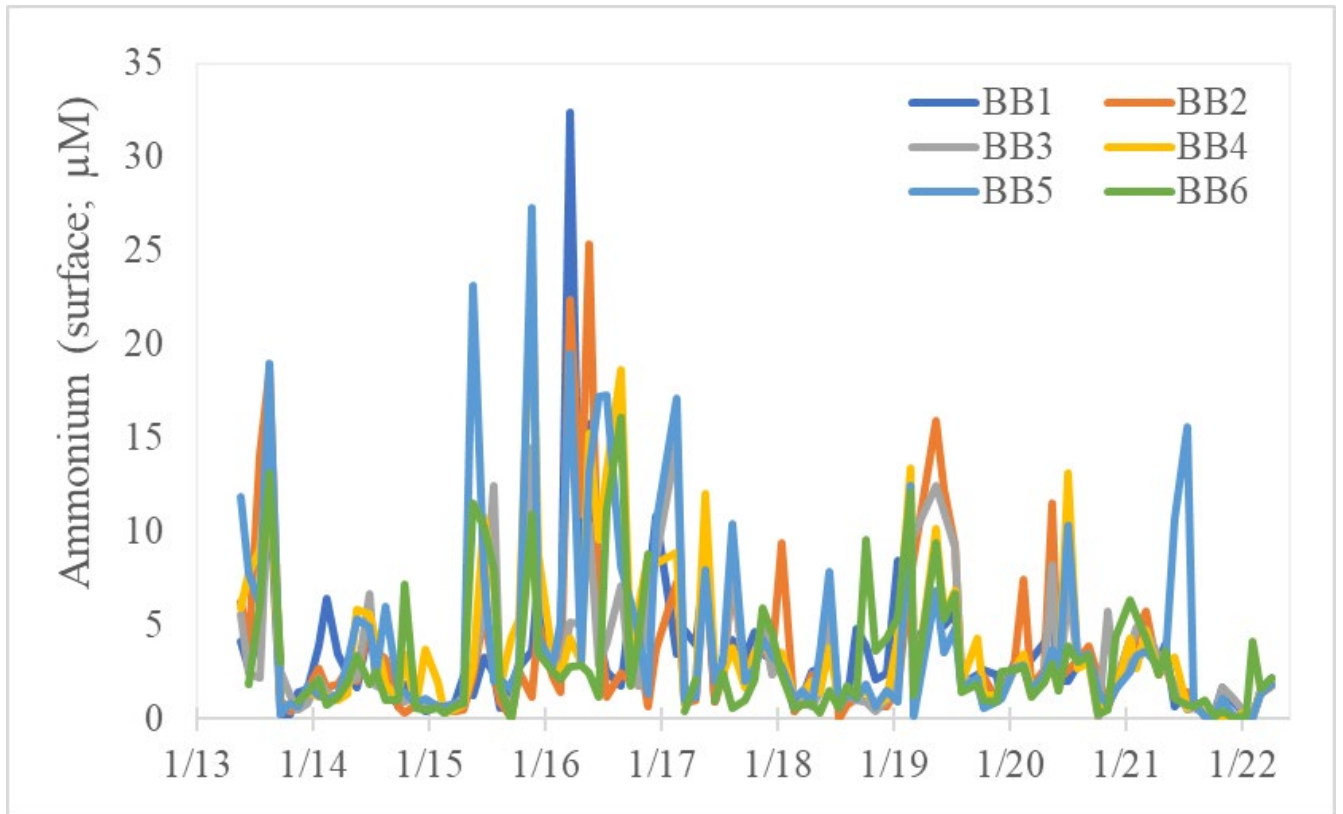


Figure 11. Surface ammonium in Baffin Bay.

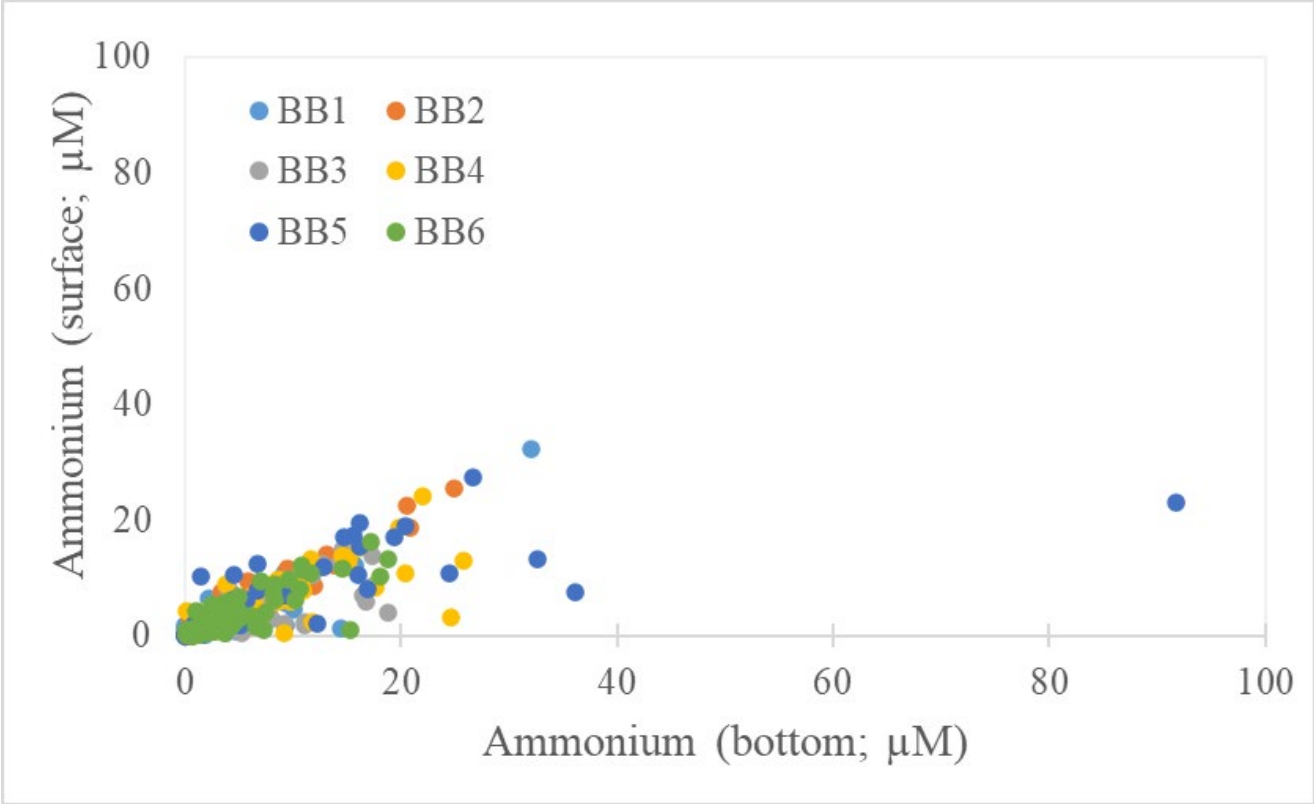


Figure 12. Surface vs. Bottom ammonium in Baffin Bay.

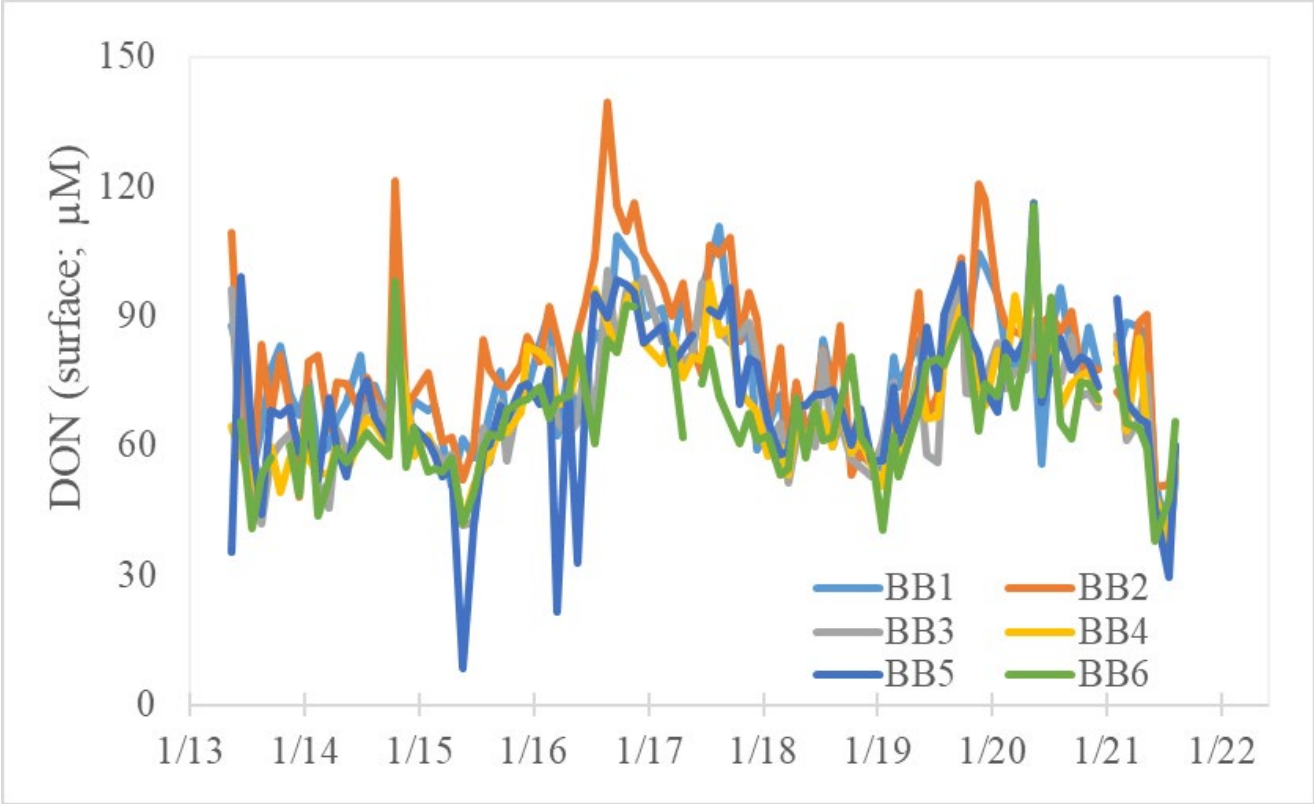


Figure 13. Surface dissolved organic nitrogen in Baffin Bay.

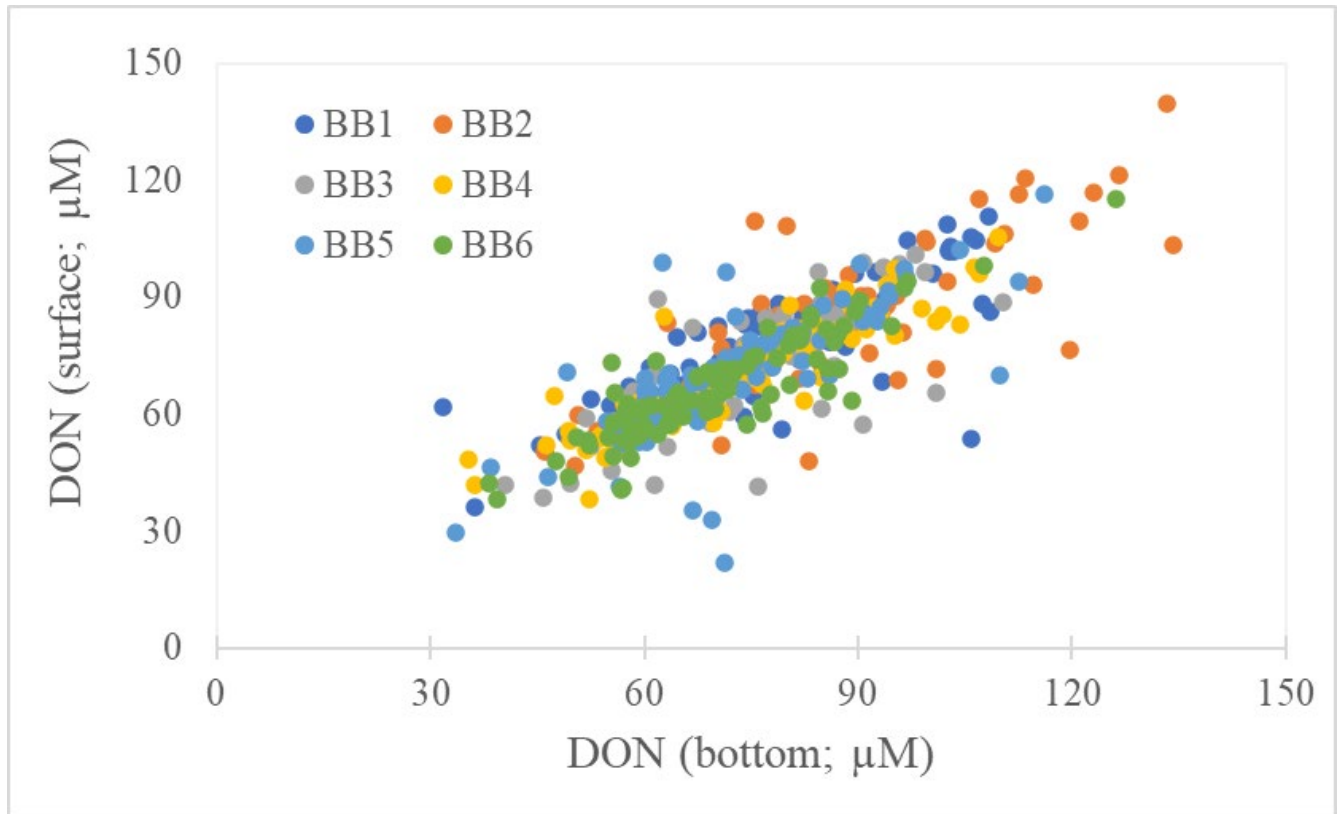


Figure 14. Surface vs. Bottom dissolved organic nitrogen in Baffin Bay.

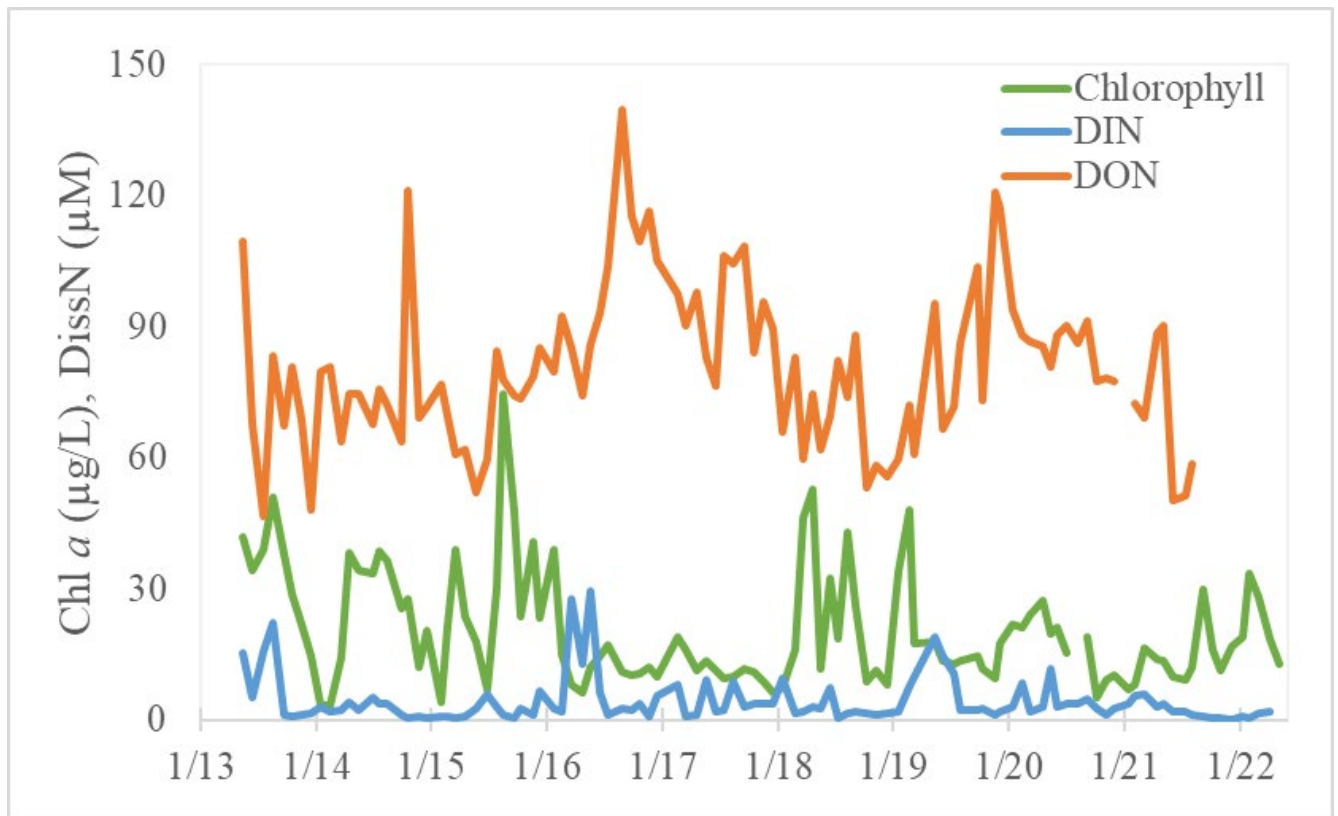


Figure 15. Mean chlorophyll, dissolved organic nitrogen and dissolved inorganic matter at site 2 in Baffin Bay. Note that the same temporal pattern holds for sites 1 and 3-6.

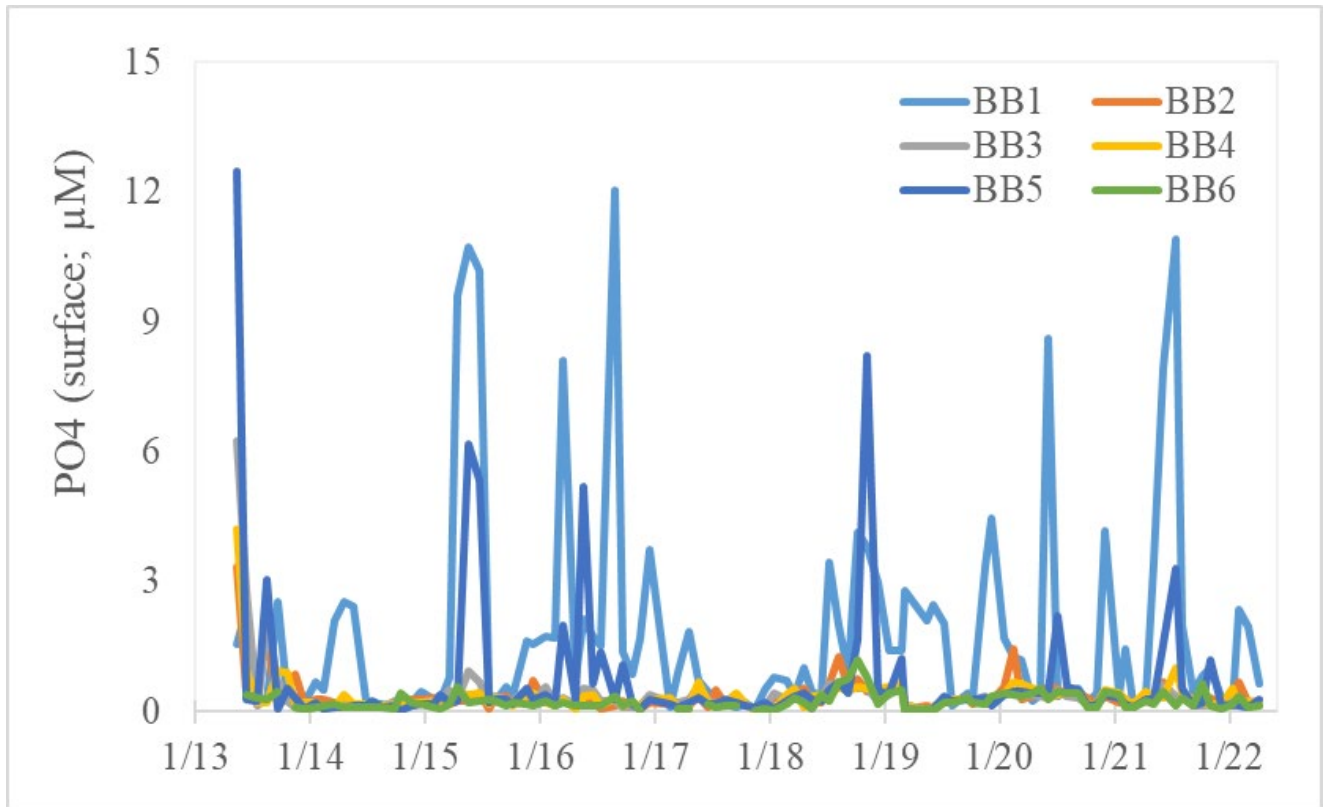


Figure 16. Surface phosphate in Baffin Bay.

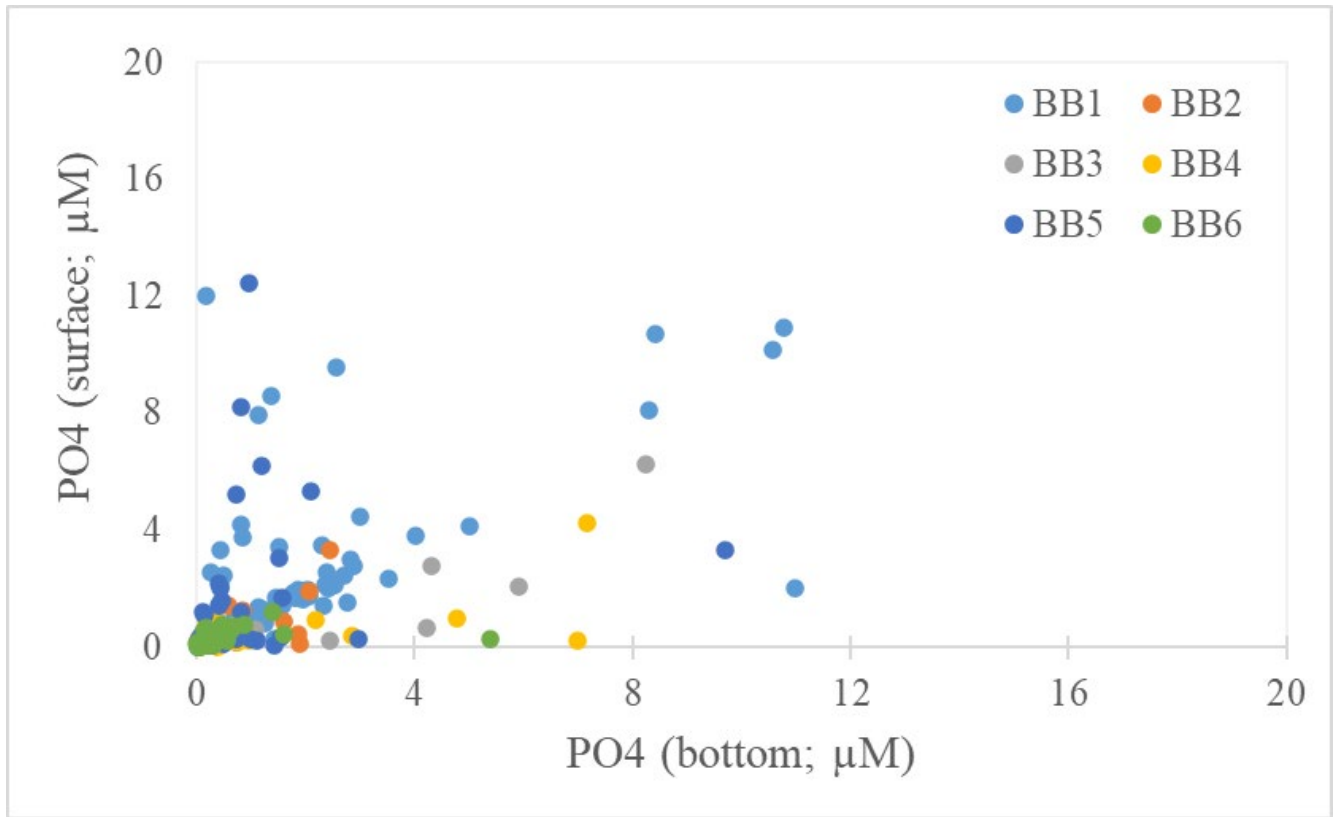


Figure 17. Surface vs. Bottom phosphate in Baffin Bay.

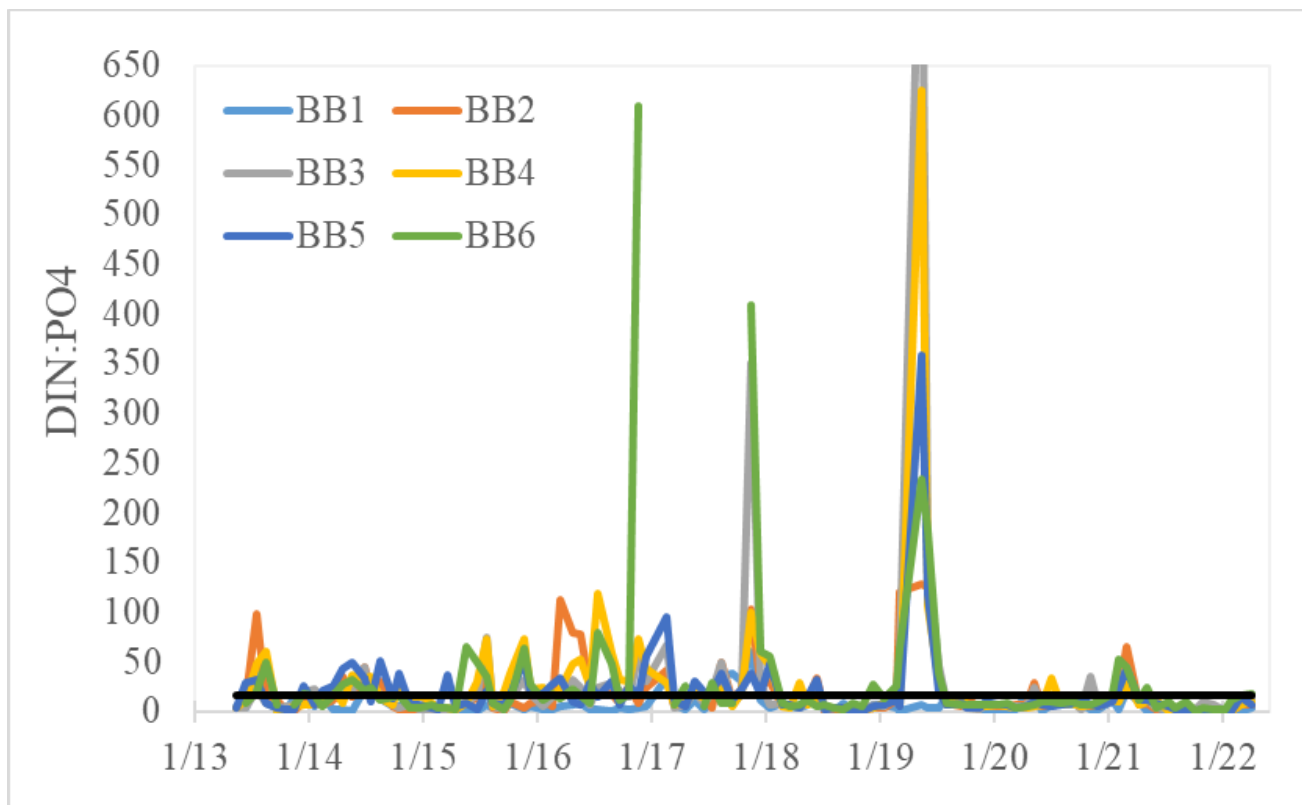


Figure 18. Ratio of inorganic nitrogen to phosphate in Baffin Bay. Solid black line indicates the theoretical boundary between N-limitation (<16) and P-limitation (>16). Note that the value for site 3 on 5/13/2019 (886) exceeds the scale.

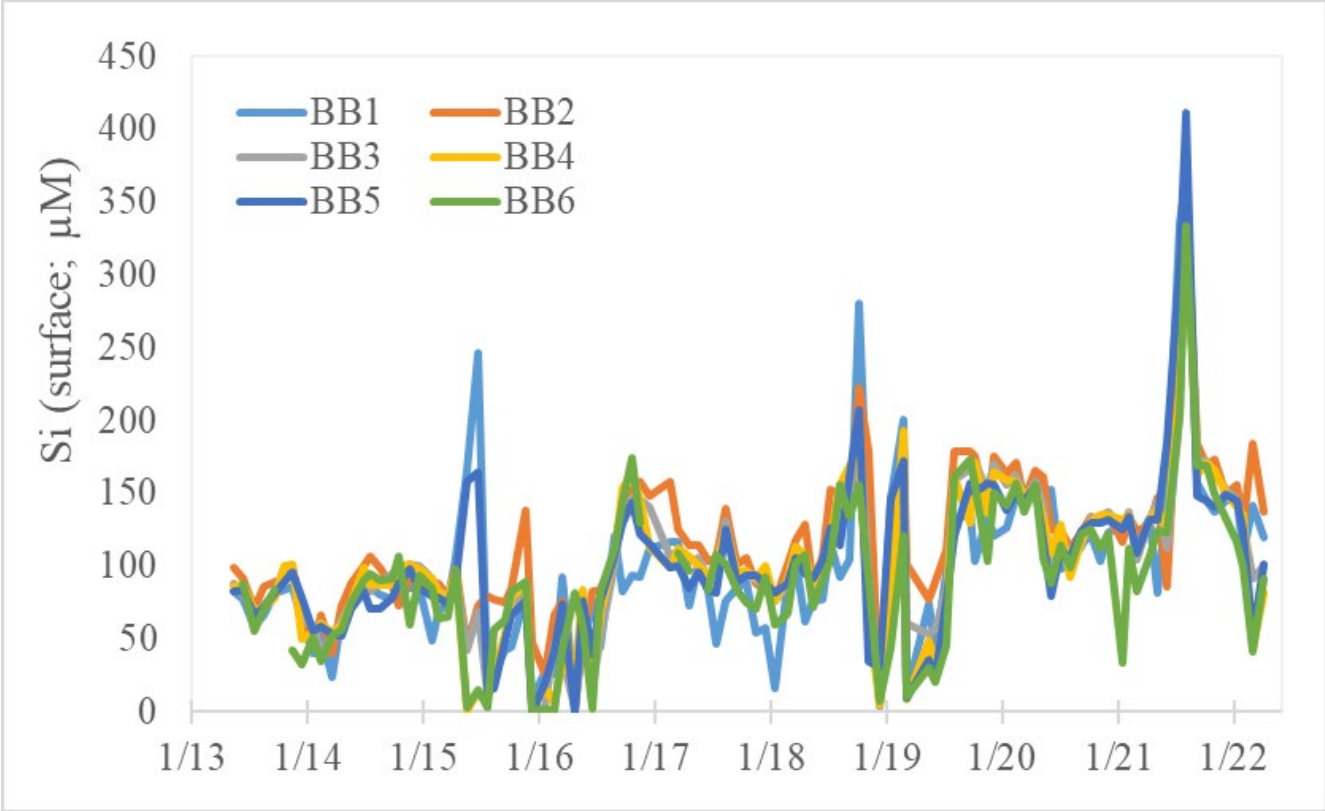


Figure 19. Surface silicate in Baffin Bay.

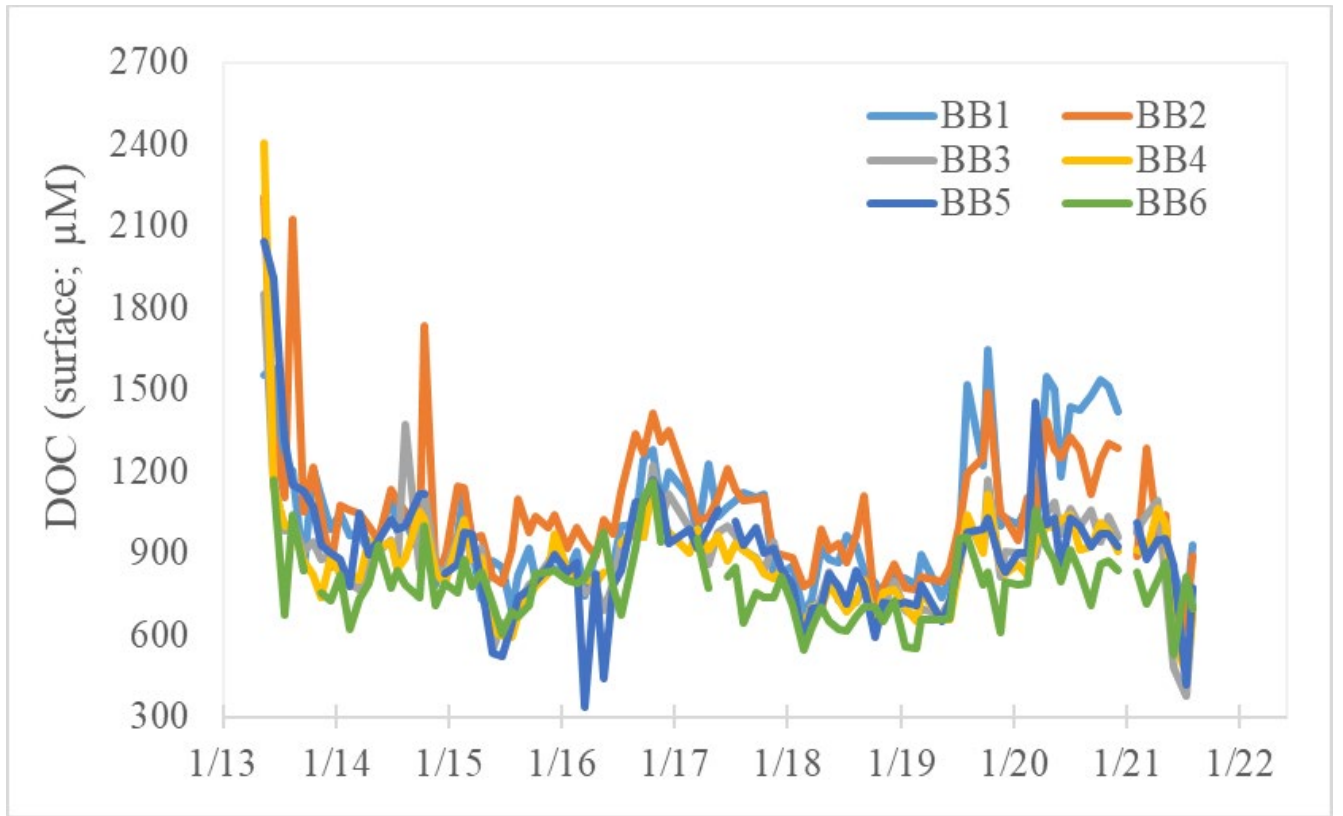


Figure 20. Surface DOC in Baffin Bay.

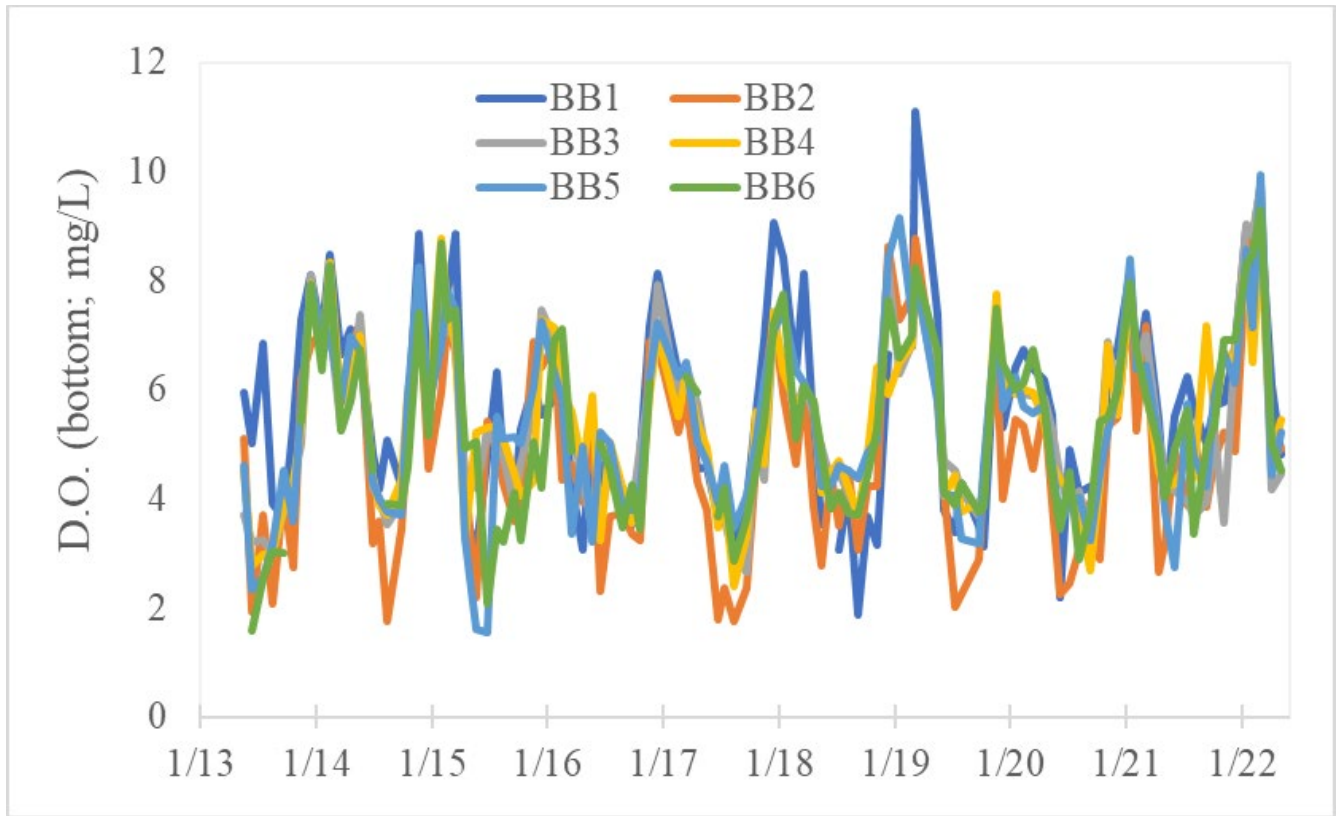


Figure 21. Bottom dissolved oxygen in Baffin Bay.