Baffin Bay Volunteer Water Quality Monitoring Study: Synthesis of May 2013-October 2017 Data

Annual Report

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Prepared by:

Michael S. Wetz, Principal Investigator
Texas A&M University-Corpus Christi
6300 Ocean Dr., Unit 5860
Corpus Christi, Texas 78412
Phone: 361-825-2132
Email: michael.wetz@tamucc.edu

Submitted to:

Coastal Bend Bays & Estuaries Program
615 N. Upper Broadway, Ste 1200
Corpus Christi, Texas 78401

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Executive Summary

The goal of this study is to quantify spatial-temporal distribution of key water quality parameters 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. At the beginning of the study period, Baffin Bay was experiencing a significant, prolonged drought and hypersaline conditions. Chlorophyll *a* concentrations were very high in the system, owing to the presence of a "brown tide" phytoplankton bloom. In early fall 2013, the drought began to lessen and precipitation patterns more in accordance with long-term monthly averages developed, resulting in a gradual decrease in salinities. Despite the lower salinity levels, very high chlorophyll levels were noted in spring-summer 2014. By spring 2015, El Niño-like conditions developed, which led to several periods of intense rainfall in the Baffin Bay watershed and an acceleration of the decrease in salinities. Since then, chlorophyll noticeably decreased, possibly due to significant flushing and/or increased consumption by microzooplankton and benthic filter feeders. 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. A strong seasonal pattern of high chlorophyll in spring-summer and low chlorophyll in winter was observed. During the study period, surface nitrate + nitrite (N+N) and phosphate concentrations were relatively low except in May 2013 at several sites, and at the Cayo del Grullo and upper Alazan sites following the spring 2015 and 2016 rains. High ammonium concentrations were also observed from spring 2015-onward, especially at the tributary sites, pointing to watershed sources for both N+N and ammonium. Elevated concentrations of ammonium and phosphate were also observed during summer in near bottom waters, consistent with studies from this and other systems showing release of reduced nitrogen from suboxic sediments under warm conditions. DON concentrations were elevated throughout the year and accounted for the largest pool of nitrogen in the system. Compared to during drought conditions at the start of the study, DON concentrations were higher during and after the high precipitation conditions that developed in spring 2015, pointing to runoff as a possible source of DON. Overall, the total dissolved nitrogen 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. Prevalence of high concentrations of reduced nitrogen such as ammonium and DON are important because

they have been implicated as potentially favoring dominance by the brown tide organism over other healthy phytoplankton.

DOC concentrations were very high in Baffin Bay and tended to be much higher in the western portion of Baffin Bay, indicating tributary sources and/or internal sources such as phytoplankton exudation. 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 temperature dependent, with lower temperatures capable of holding more oxygen than higher temperatures. Nonetheless, hypoxic (< 2 mg/l) oxygen levels were occasionally observed, especially during the summer, indicative of intensive microbial respiration and utilization of labile organic matter.

In the fifth year of this study, we will continue to focus on additional data collection, which will be crucial given the apparent return to low precipitation, high salinity conditions in South Texas. Thus we now have an opportunity to capitalize on this natural, predictable climatic regime to gain a more complete understanding of the influence of hydrological and climatic variability on water quality in the system.

Acknowledgements

First and foremost, we thank the many volunteers who dedicated time and resources to the collection of this water quality data in Baffin Bay. This study would not have been possible without their efforts. We are also grateful to the entities who currently fund the study, including Celanese Corporation and the NOAA/Texas GLO Coastal Management Program, as well as past funding entities including Kleberg County, the Coastal Bend Bays & Estuaries Program, Coastal Conservation Association and the Saltwater Fisheries Enhancement Association. Finally, we thank our partners at the Coastal Bend Bays & Estuaries Program for their ongoing support and interest.

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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 persistent algal blooms, hypoxia/anoxia formation, and microbial pathogen growth among others (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 significant eutrophication. 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 1-2 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 coastal embayments. For instance, hypoxia has been linked to several large fish kills in Baffin Bay over the past 5-10 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), and overall phytoplankton biomass frequently exceeds state criteria, 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

1990 (Buskey et al. 1997; Buskey et al. 2001). More recently, 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 orthophosphate 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 the first four years of a volunteer water quality monitoring study, the goals of which are to quantify spatial-temporal distributions of key water quality parameters 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, and the system is prone to hypersaline conditions due to evaporation exceeding precipitation (Shormann 1992). Circulation in Baffin Bay is primarily driven by winds.

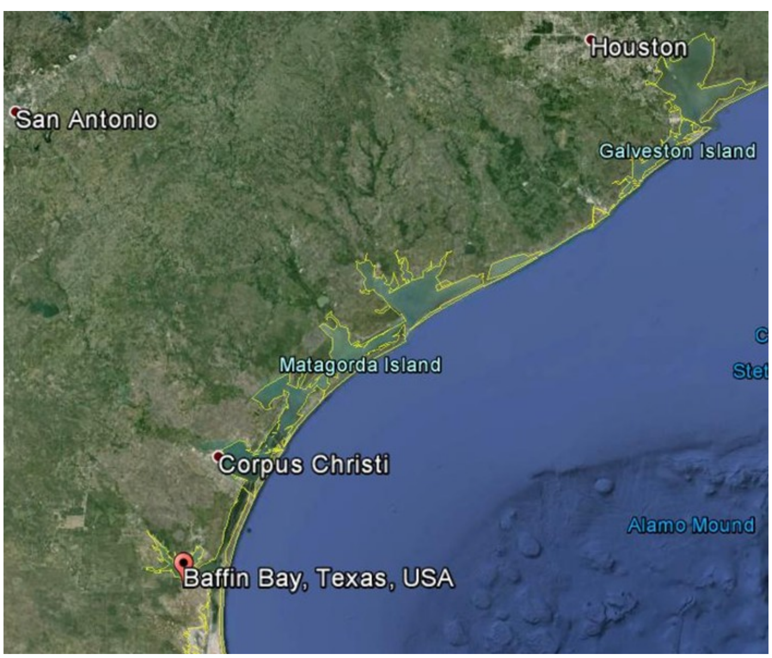


Figure 1. Map of Baffin Bay, located ~50 km southwest of Corpus Christi, TX.

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 June 2014, monthly mean precipitation was calculated. The monthly deviation from this long-term monthly mean was then calculated, and is referred to as precipitation "anomaly".

Sample collection – Water samples were collected on a monthly basis from May 2013 through October 2017 at 5-12 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). 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.

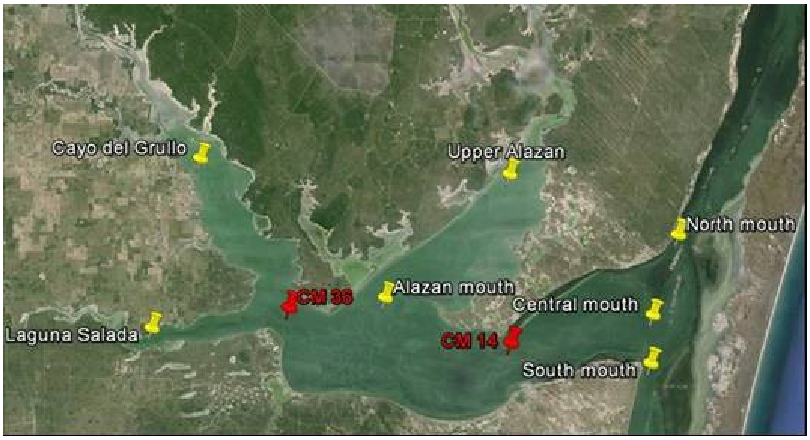


Figure 2. Map of sampling locations in Baffin Bay. Red markers indicate two sites that are visited as part of TCEQ's quarterly monitoring program.

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, orthophosphate, 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 (Fig. 3). By spring 2015, El Niño-like conditions developed, which led to several periods of intense rainfall in the Baffin Bay watershed. These conditions persisted through spring 2016, during which several additional high rainfall periods were observed (Fig. 3). Thereafter, precipitation conditions returned to near average until summer 2017, when drought conditions again developed (Fig. 3).

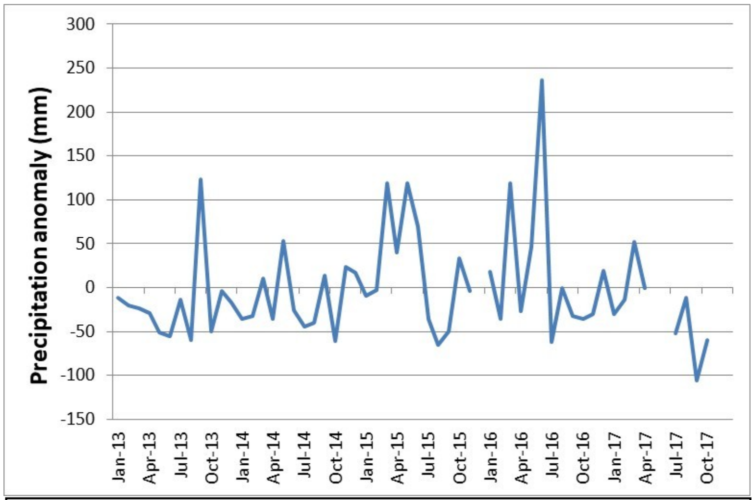


Figure 3. Precipitation anomaly (deviation from 1974-2014 monthly mean) at Kingsville Naval Air Station.

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). It is interesting to note that winter (December-January-February; DJF) water temperature increased in a step-wise manner from winter 2013-

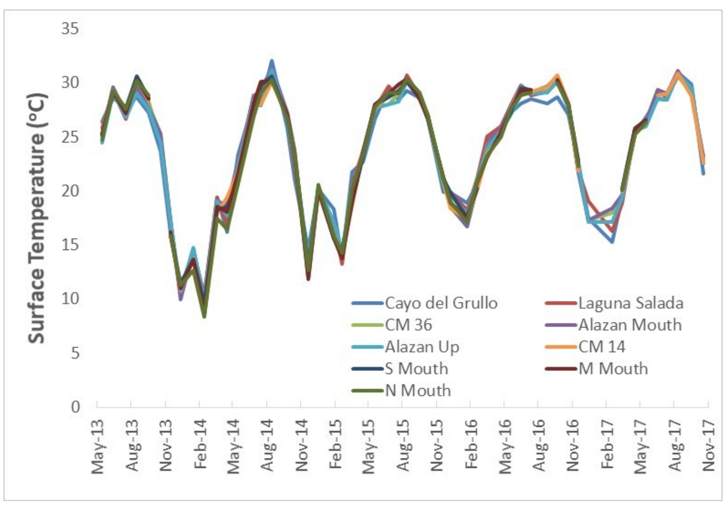


Figure 4. Surface water temperature in Baffin Bay.

2014 to winter 2015-2016. For example, the winter 2013-2014 average was 11.4°C compared to winter 2014-2015 (16.9°C) and winter 2015-2016 (19.1°C) (Fig. 4). Salinity was very high at the start of the sampling period in May 2013, exceeding 70 in the upper Alazan and 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 (Fig. 5). Prior to spring 2015, the highest salinity was consistently recorded in western Baffin Bay, particularly in the tributaries, while lowest salinity was observed near the mouth of Baffin Bay (Figure 6). Following the heavy rainfall in spring 2015, the pattern reversed, with highest salinities typically observed near the mouth of Baffin Bay and much lower salinities observed in western Baffin Bay (Fig. 6). Strong salinity stratification (i.e., higher salinity in bottom waters than surface waters) of the water column was observed during summer months, although this stratification was spatially heterogeneous (Figure 7).

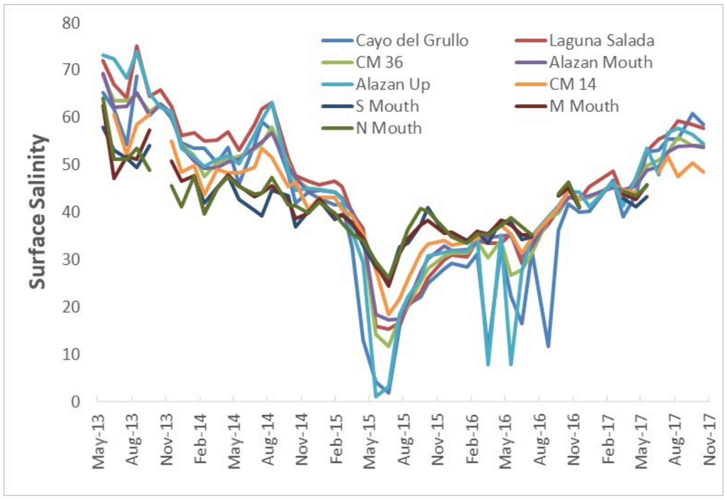


Figure 5. Surface salinity in Baffin Bay.

Figure 6. Surface salinity in western versus eastern Baffin Bay. "West" includes upper Alazan, lower Alazan, CM 36, Laguna Salada, and Cayo del Grullo. "East" includes CM 14, north/middle/south mouth sites.

Biological-chemical dynamics – Chlorophyll *a* concentrations tended to be very high in Baffin Bay during this study, exceeding the TCEQ criteria (11.6 µg/l) in 262 of 451 samples (58%). Using a slightly more relaxed National Coastal Condition Report for "poor" condition (20 µg/l; NCCR 2012), chlorophyll *a* was still in excess in 135 of 451 sample collections

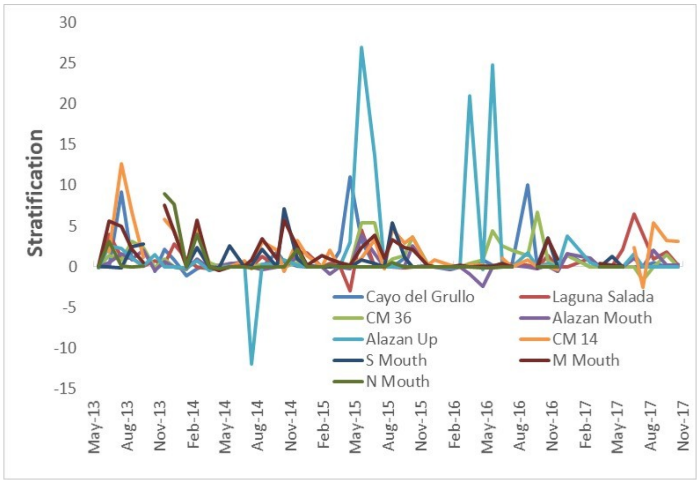


Figure 7. Stratification index (= bottom minus surface salinity) in Baffin Bay.

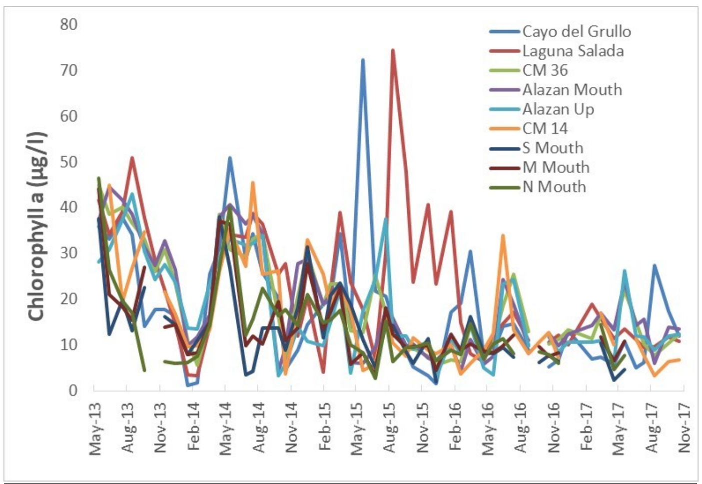


Figure 8. Chlorophyll *a* in Baffin Bay.

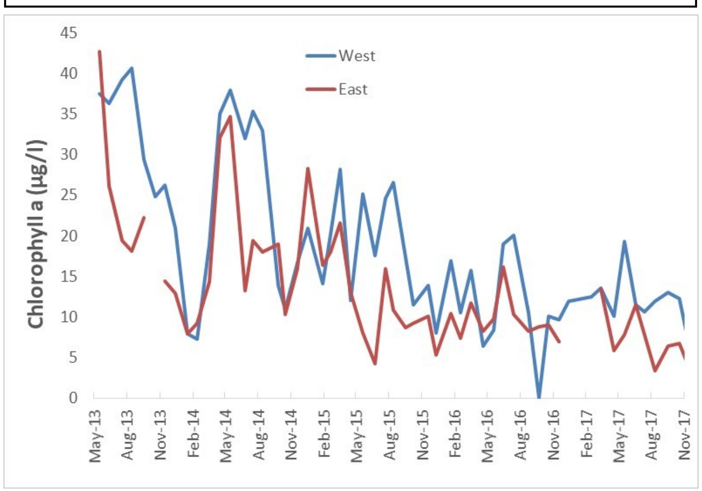


Figure 9. Chlorophyll *a* in western versus eastern Baffin Bay.

(30%). A distinct seasonal pattern was observed, with highest chlorophyll concentrations found in spring-summer, thereafter decreasing through fall-winter (Figure 8). Interestingly, chlorophyll *a* concentrations were nearly 2-fold higher in winter (DJF) 2014-2015 compared to winter 2013-2014, coincident with water temperatures that were ca. 5^{o}C warmer in winter 2014-2015 (Figs. 4, 8). Yet in winters 2015-2016 and 2016-2017 when water temperatures were warmer than the first two winters of this study, chlorophyll *a* concentrations were relatively low (Fig. 8). Distinct interannual variability was observed in addition to the seasonal patterns. For example, chlorophyll *a* tended to be lower during the lower salinity, "wet" conditions in spring-summer 2015 and 2016 compared to prior years, although localized very high chlorophyll was still observed (Fig. 8). From a spatial standpoint, chlorophyll concentrations tended to be highest in the tributaries of western Baffin Bay, with much lower concentrations typically observed towards the mouth (Figs. 8, 9).

In terms of the nutrients that may support phytoplankton growth, surface nitrate plus nitrite (N+N) concentrations

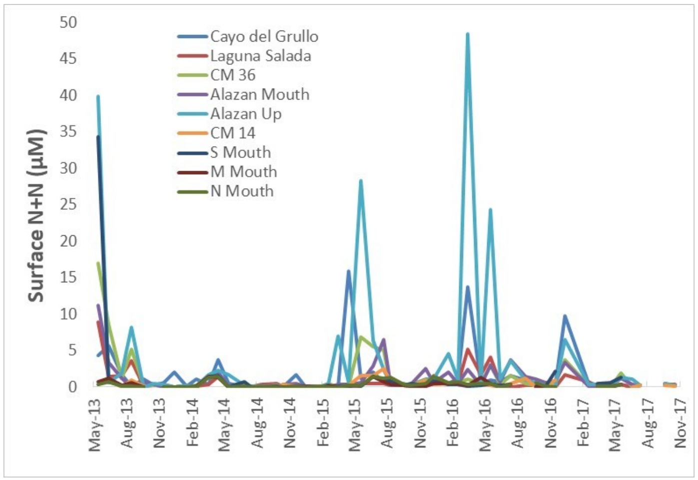


Figure 10. Surface N+N in Baffin Bay.

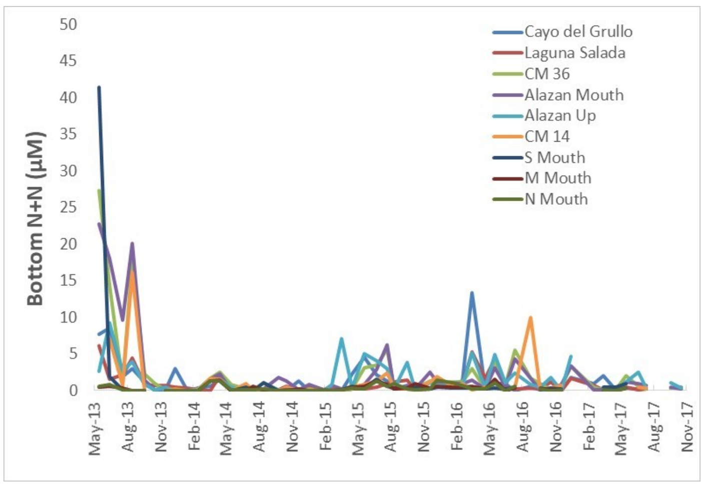


Figure 11. Bottom N+N in Baffin Bay.

were generally low, although ephemeral high concentrations were observed, primarily in the Alazan and Cayo del Grullo tributaries (Figure 10). N+N concentration exceeded 5 µM at the beginning of the study period at all sites except Cayo del Grullo (4.4 µM) and the north and central sites at the mouth (< 1 µM) (Fig. 10). Very high N+N concentrations (>35 µM) were noted at both the upper Alazan site and south site at the mouth. N+N concentrations decreased after May 2013 and were generally <1-4 µM thereafter through February 2015 (Fig. 10). In April 2015, N+N was 15.9 µM at the Cayo del Grullo, but <0.6 µM at the other sites (Fig. 10). In May 2015, two relatively N+N values were observed, 6.8 µM at CM 36 and 28.3 µM at the upper Alazan site (Fig. 10), while other sites had N+N

<1.5 μM. N+N concentrations were low again (<5 μM) at all sites from summer 2015 through early spring 2016. In March 2016, high N+N concentrations were observed at the upper Alazan site (48.5 μM) and Cayo del Grullo (13.8 μM), concurrent with low salinity conditions, while other sites had N+N <5 μM (Fig. 10). High N+N concentration was observed at the upper Alazan site in May 2016 (24.4 μM) (Fig. 10). Thereafter, surface N+N concentrations were generally low, with the exception of modest increases in December 2016 at the upper Alazan and Cayo del Grullo sites (Fig. 10). N+N concentrations in bottom waters were typically less than in surface waters (Figure 11), likely due to lower oxygen levels in the bottom waters. Overall, highest bottom water N+N concentrations were observed during

summer, and during summer 2013 in particular (Fig. 11). Surface ammonium concentrations were high in July-August 2013, with highest concentrations observed at the upper Alazan and Laguna Salada sites (Figure 12). Ammonium declined thereafter, remaining relatively low through April 2015 (Fig. 12). In May and June 2015, high (>10 µM) ammonium concentrations were once again observed, this time at multiple sites coincident with relatively low salinity conditions (Fig. 12). After decreasing at most sites through October 2015, high ammonium concentrations were observed in November 2015 at the Alazan and mid-channel sites, though this was not associated with a salinity decrease or rainfall event (Fig. 12). Ammonium concentrations moderated from December 2015-February 2016; thereafter, high ammonium concentrations were observed primarily at the tributary sites and the western part of the bay in March and May 2016, coincident with high rainfall, lower salinity conditions (Fig. 12). In July-August 2016, relatively high ammonium concentrations were observed in Alazan Bay extending out to the mouth (Fig. 12). Thereafter, ephemeral increases in ammonium were observed, primarily in the western part of the bay but occasionally at the mouth as well (Fig. 12). Overall, ammonium concentrations tended to be much higher in the system during the "wet" period of 2015-2016 than earlier years. Elevated ammonium concentrations were also observed from May through August 2013 in bottom water at most sites (Figure 13). Ammonium concentrations in bottom water declined thereafter and were generally low until spring 2015,

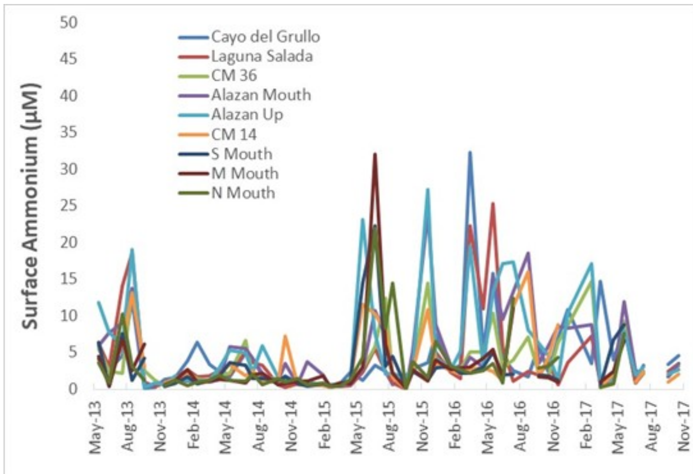


Figure 12. Surface ammonium in Baffin Bay.

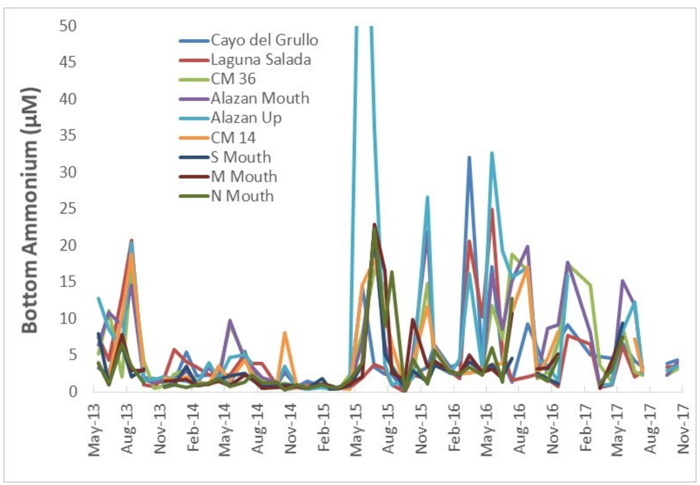


Figure 13. Bottom ammonium in Baffin Bay.

during and after which they were generally high, occasionally exceeding concentrations in surface waters (Fig. 13). By far, the dominant form of nitrogen during the study period was dissolved organic nitrogen (DON), with DON concentrations regularly exceeding 35 µM (Figure 14). No clear seasonal pattern was observed in terms of DON. However, DON concentrations began to increase in the high rainfall, low salinity summer of 2015, peaking in late 2016. Since then, it appears as if the DON has been decreasing concurrent with lower precipitation, higher salinity conditions (Fig. 14). Highest concentrations tended to be in the western part of Baffin Bay and tributaries, decreasing towards the mouth (Fig. 14).

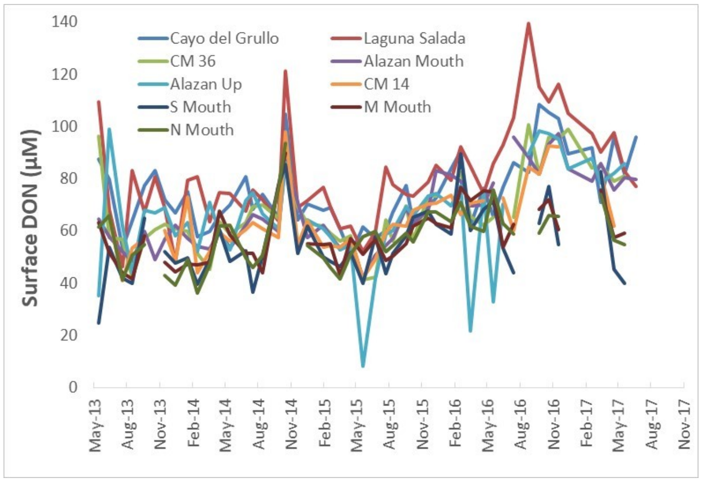


Figure 14. Surface DON in Baffin Bay.

Surface orthophosphate concentrations exceeded 1 µM at the beginning of the study period at all sites except the north and central mouth sites (< 0.5 µM) (Figure 15). Very high surface orthophosphate concentrations (>5 µM) were noted at CM 36, upper Alazan, and south site at the mouth (Fig. 15). Orthophosphate concentrations were generally low after May 2013, with the exception of a small secondary peak in July-August 2013 in western Baffin Bay and concentrations of 2.1-2.6 µM in Cayo del Grullo from March-May 2014 (Fig. 15). In April-June 2015, very high concentrations were observed in Cayo del Grullo, ranging from 9.6-10.7 µM (Fig. 15). Likewise, in May and June 2015, the orthophosphate concentration at the upper Alazan site ranged from 5.3-6.2 µM (Fig. 15). Orthophosphate concentrations were <0.6 µM from August-October 2015. Persistent high (0.9-12.0 µM) orthophosphate concentrations were

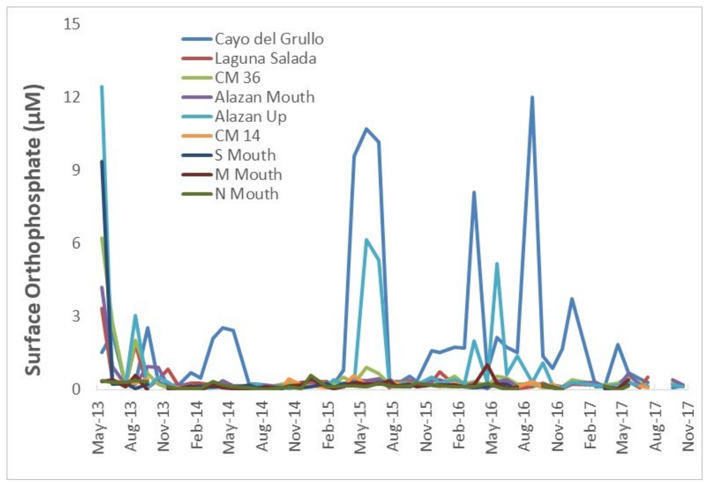


Figure 15. Surface orthophosphate in Baffin Bay.

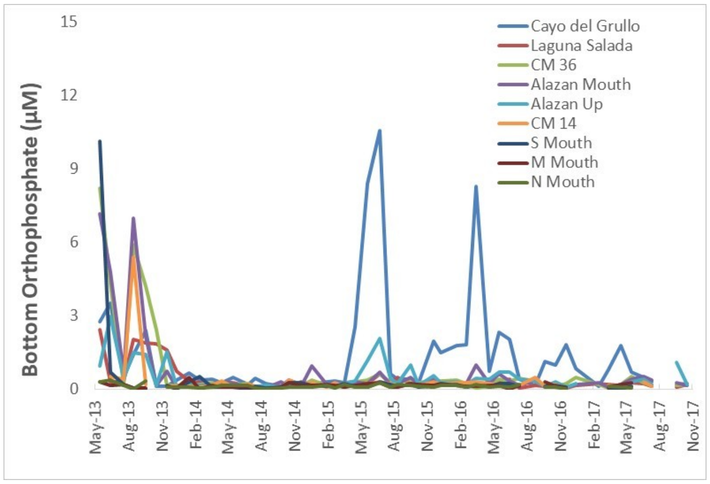


Figure 16. Bottom orthophosphate in Baffin Bay.

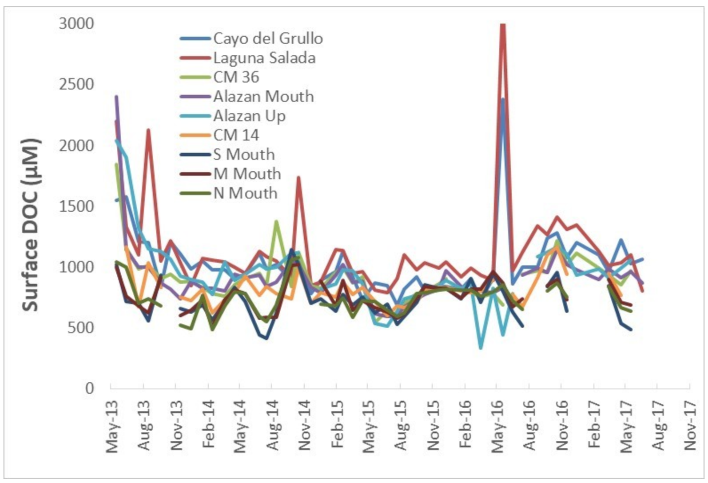
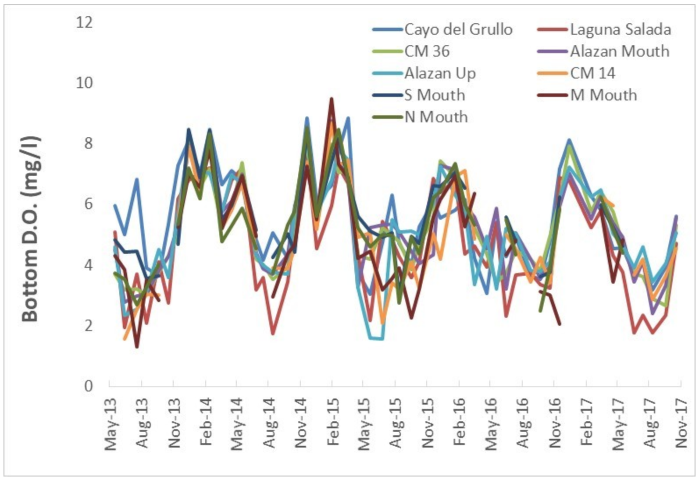


Figure 17. Surface DOC in Baffin Bay.

again observed at Cayo del Grullo from November 2015-December 2016, and at the upper Alazan site in March, May and June 2016 (2.0-5.2 µM) (Fig. 15). Orthophosphate concentrations were periodically elevated in near bottom waters, especially in May, June and August 2013 at various sites throughout Baffin Bay, April-June 2015 and November 2015-June 2016 in Cayo del Grullo (Figure 16).

Dissolved organic carbon (DOC) represents a biogeochemically important constituent of coastal waters, where it supports bacterial respiration. DOC concentrations were exceptionally high at the beginning of this study, exceeding 1000 µM at all locations (Figure 17). DOC subsequently decreased at most locations and was lower, but variable through spring 2016 (Fig. 17). Thereafter, it appears as if DOC increased concurrent with the return of higher salinity conditions. Overall, highest DOC concentrations tended to be found in the western portion of Baffin Bay (Fig. 17).



Dissolved oxygen (DO) displayed a clear seasonal pattern that can be linked to temperature, with lowest levels being observed in the warmer months and highest levels in winter (Figure 18). 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 in one location (Laguna Salada) in July (Fig. 18). The overall higher bottom DO levels in summer 2014 compared to summer 2013 may have been due to strong mixing (and less stratification; Fig. 7) in summer 2014. Hypoxia was observed again in May-June 2015, but only at the upper Alazan site coinciding during very low salinity conditions (Figs. 5, 18). Likewise, hypoxia was observed on two dates during summer 2017, but only at the Laguna Salada site (Fig. 18).

Figure 18. Bottom D.O. in Baffin Bay.

Discussion

Results from the first four years of a multi-year water quality data collection effort in Baffin Bay show the presence of significant spatial-temporal variability in terms of water quality dynamics in the system. Ultimately, this data, in conjunction with ongoing collections and a reanalysis of historical TCEQ data should provide a comprehensive understanding of water quality conditions, as well as environmental drivers that affect water quality in Baffin Bay.

At the beginning of the study period, Baffin Bay was experiencing a significant, prolonged drought and concurrently a major bloom of the brown tide organism *Aureoumbra lagunensis* (Wetz, unpubl. data). Hypersaline conditions associated with drought have previously been shown to favor brown tide blooms in the system (e.g., Buskey et al. 1997, 2001). Chlorophyll *a*, a key indicator of phytoplankton (algal) biomass, exceeded TCEQ screening levels for impairment throughout much of the study period and was frequently at levels that would be considered excessive even by National Coastal Condition Report (EPA, 2012) standards. The strong seasonal pattern of high chlorophyll in spring-summer can be explained in part by light and temperature. That is, phytoplankton growth is dependent on ample light levels for photosynthesis, and is often correlated with water temperature as well. Thus the lower levels of chlorophyll in winter may be indicative of either low light, low temperatures, or both. As a case in point, chlorophyll levels were nearly 2-fold higher in winter 2014-2015 compared to winter 2013-2014, possibly due to water temperatures that were 5^{o}C warmer in 2014-2015. This suggests that future warming trends in terms of winter air and water temperatures, as is projected to occur due to climate change (Nielsen-Gammon 2011), may lead to an extended growing season for phytoplankton in the system. Yet in winter 2015-2016, which was warmer than both prior winter periods, chlorophyll was at lower levels similar to winter 2013-2014. One possibility is that high turbidity associated with lower salinity conditions, coupled with strong water column mixing (e.g., Fig. 7), prevent significant phytoplankton growth in winter 2015-2016 despite high water temperatures. If confirmed, this would highlight the complexity of physical factors regulating wintertime phytoplankton growth in the system. Additional experimental and field studies are underway to better discern controls on wintertime phytoplankton growth in Baffin Bay.

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. Only since spring 2015 has chlorophyll noticeably decreased concurrent with several heavy precipitation events and lower salinity conditions, despite higher inorganic nutrient concentrations than during the earlier timeframe. Although speculative at this point, it is possible that the recent decrease in chlorophyll may be attributed to significant flushing as well as reduced light from high turbidity that accompanied the spring 2015 rains in Baffin Bay. An alternative but not mutually exclusive explanation 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 have become important again with lower salinities.

In addition to light and temperature, nutrient (primarily nitrogen and phosphorus) availability is a major control on phytoplankton growth. During the study period, surface N+N levels were relatively low except in May 2013 and at Cayo del Grullo and upper Alazan sites following the spring 2015 and 2016 rains. Very high ammonium concentrations were observed from spring 2015-onward, especially in at the tributary sites, pointing to watershed sources for both N+N and ammonium. Elevated concentrations of ammonium were observed during summer in bottom waters, consistent with studies from this and other systems showing release of reduced nitrogen from suboxic sediments under warm conditions (e.g., An and Gardner 2002). 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). DON concentrations began to increase in the high rainfall, low salinity summer of 2015, peaking in late 2016. Furthermore, highest concentrations tended to be in the western part of Baffin Bay and tributaries, decreasing towards the mouth. These findings point to runoff as a possible source of DON. Prevalence of high concentrations of reduced nitrogen such as ammonium and DON are important because they have been implicated as potentially favoring dominance by the brown tide organism over other healthy phytoplankton (Gobler et al. 2013). Orthophosphate concentrations in surface waters were typically low, although high concentrations were observed at the Cayo del Grullo and upper Alazan sites in spring 2015 and 2016. High bottom water orthophosphate concentrations were occasionally observed during summer as well. Our group has collected additional samples to determine total dissolved phosphorus and dissolved organic phosphorus concentrations, and will report that data in future syntheses. A previous study (Cotner et al. 2004) highlighted the potential for phosphorus to become limiting (to phytoplankton growth) in Baffin Bay. As part of a GLO-funded study, we conducted nutrient addition bioassays seasonally in 2015. Our findings showed that despite the potential for P-limiting conditions based on nutrient ratios, only nitrogen had a significant influence on phytoplankton growth (Wetz et al. 2017). This is consistent with numerous studies from other estuarine systems, and highlights the difficulty in relying on nutrient ratios to determine the major limiting element.

A longer term goal of this study is to begin to identify sources of nutrients to Baffin Bay. The sharp increase in inorganic and organic nitrogen concentrations in both the upper Cayo del Grullo and Alazan Bay after heavy rain events in 2015 and 2016 point to watershed source(s). Output from the 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). Internal loading from sediments in this system appear to another important source of inorganic nutrients to the water column, at least during the warm summer months. 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 Petronilla Creek, a stream that flows into Baffin Bay. Alternatively, we have found very high (and increasing) chlorophyll levels in Petronilla 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 from Kingsville, Alice and NAS Kingsville, 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. Sources of DOC are unclear, though 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. 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). Unfortunately, monthly sampling is insufficient to quantify dissolved oxygen "mean state" as well as timescales of change in a dynamic system such as Baffin Bay. Consequently, our lab has been deploying sondes along the longitudinal axis of Baffin Bay since February 2015 to characterize these aspects of dissolved oxygen dynamics in Baffin Bay. Results from the sonde study will be reported elsewhere.

In the fifth year of this study, we will continue to focus on additional data collection, as it appears the region is returning to relatively low precipitation, high salinity conditions. Thus we now have an opportunity to capitalize on this natural, predictable climatic regime to gain a more complete understanding of the influence of hydrological and climatic variability on water quality in the system.

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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