A EUTROPHICATION ASSESSMENT OF TWO SOUTH TEXAS ESTUARIES

A Thesis

by

KENNETH C. HAYES

BS, Coastal Carolina University, 1998

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in

ENVIRONMENTAL SCIENCE

Texas A&M University-Corpus Christi
Corpus Christi, Texas

August 2020

A EUTROPHICATION ASSESSMENT OF TWO SOUTH TEXAS ESTUARIES

A Thesis

by

KENNETH C. HAYES

This thesis meets the standards for scope and quality of
Texas A&M University-Corpus Christi and is hereby approved.

Michael S. Wetz, PhD
Chair

Xinping Hu, PhD
Co-Chair/Committee Member

Jeffery Turner, PhD
Committee Member

August 2020

ABSTRACT

Texas's coast is one of the fastest growing regions in the United States, prompting a concern that the coastal development will lead to eutrophication. High nutrient levels associated with eutrophication have been associated with increased chlorophyll and phytoplankton concentrations, including nuisance and toxic algae, and hypoxic conditions. The U.S. EPA has encouraged states to adopt numerical nutrient criteria as a method to decrease nutrient pollution, but Texas is without numerical nutrient water quality standards. A needed first step towards development of these standards is to assess and prioritize coastal ecosystems in the region of interest (in this case, the Texas coast). This study focused on applying three different eutrophication assessment approaches (EPA, NOAA, and TCEQ) to determine if Oso and Baffin bays are experiencing degraded or impaired water quality due to excessive nutrient loading. Results from the study indicate that regardless of the classification approach used, Oso Bay is experiencing degraded water quality and its water quality would be considered "poor" and eutrophic. For Baffin Bay, the results from the study using both the EPA and NOAA classification approaches indicate that Baffin Bay is experiencing degraded water quality and its water quality would be considered "poor" and eutrophic. However, if using TCEQ as a classification approach Baffin Bays water quality would be "good". This discrepancy was due to all their criteria not having consistent indicators or cutpoint concentrations. These findings demonstrate the need for uniform numerical water quality standards and indicators.

DEDICATION

In 1989, the hand of Providence stepped in and changed my life forever. For that I am most grateful.

To my wife Debbie who has been my rock and my best friend for more than 32 years now. For whom pages could be written in gratitude so I will just say thank you Debbie.

To my parents and family, sadly so many have passed away during my time seeking this degree (Dad, Paul, Dennie, Darwin and Edith). My mother, Dr. Sarah Emerson, and grandmother, Arlys Emerson need mentioning as they have always supported me and never gave up on me regardless of life's circumstances.

To Burt, Darwin, Marshall, Jonathan, Bill, and many other men that make up the disciplined army of Life Changers who helped to give my life new meaning. "Be not deceived; God is not mocked: for whatsoever a man soweth, that shall he also reap."—Galatians 6:7

For generations, many in my family have served this country in times of peace and war. It is because of you that I live free. We stand on the backs of giants and I am forever grateful to you.

The Pledge of Allegiance

I pledge Allegiance to the flag

Of the United States of America.

And to the Republic for which it stands,

one nation under God, indivisible,

with Liberty and Justice for all.

ACKNOWLEDGEMENTS

I would like to thank my committee, Dr. Michael Wetz, Dr. Xinping Hu and Dr. Jeffery Turner. Working fulltime and seeking a degree is not easy, your patience and tolerance of life's constant challenges have made this process easier.

I would like to thank the many students who assisted with the Oso and Baffin Bay sampling programs, including: Michael Bailey, Victor Batres, Kalman Bugica Emily Cira, Kevin DeSantiago, Kelsey Fisher, Anne-Marie Gavlas, Toni Gee, Abigail Hobbs, Jennifer Feinstein, Charis Kehrer, Caitlin Mitchell, Diana Sokoly, Cory Staryk, Jessica Tolan, Sarah Tominack, Lily Walker and Hongjie Wang.

I would also like to thank the dedicated citizen scientist volunteers who were integral in the Baffin Bay data collections, including: Jim Atkins, Frank Baumann, Jerry Bjork, Jan Cannamore, Al Gordon, Michael Henry, Carl Hooker, Thomas Mullenix, Scott Murray, David Rowsey, Ron Ryon, Jim Scoggins, Charles Sellers, Diane Sellers, John Sutton and Paul Wimberly.

Thank you to my mentors who have instilled their wisdom, encouragement and knowledge, Dr. Alan Lewitus "Just do Good Science, it doesn't matter who gets credit because eventually everyone will know who did the work", Dr. Howard Glassgow "Keep some of the cards close to your chest; hard work + tenacity = success", and Dr. Niels Eriksen "The degree does not make the scientist". Nothing is selfish if I never compromise myself nor feed my ego.

This project was funded in part by a grant approved by the Texas Land Commissioner pursuant to National Oceanic and Atmospheric Administration (NOAA) award no. NA21NOS4190021, and by an Institutional Grant (award no. NA14OAR4170102) to the Texas Sea Grant College Program from the National Sea Grant Office, by a Texas Coastal Management Program Grant approved by the Texas Land Commissioner pursuant to National Oceanic and Atmospheric Administration award no. NA14NOS4190139, by NOAA's National Center for Coastal Ocean Science (award no. NA15NOS4780185), and by the Texas Water Development Board (award no. 1600011924). Additional funding was provided by the Celanese Corporation, Kleberg County, Coastal Conservation Association, Saltwater Fisheries Enhancement Association, and Coastal Bend Bays & Estuaries Program. All views, opinions, findings, conclusions, and recommendations expressed in this material are those of the author(s) and do not necessarily reflect the opinions of the Texas Sea Grant College Program, the National Oceanic and Atmospheric Administration or any of its subagencies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLES PAGE

INTRODUCTION

Population growth in coastal watersheds of the United States has significantly increased during recent decades and coastal areas are undergoing tremendous environmental changes. For example, it has been predicted that when compared to the population in 2000, the population living in coastal zones will increase 58% to 71% by 2050 (Merkens et al., 2016). Increased global populations, including in the coastal zone, will require more housing and food production that will likely increase stormwater runoff, wastewater discharge and fertilizer usage. One key impact of these changes is the potential for increased nutrient loading. For example, urban stormwater runoff can be 25-40% higher than forested areas with nitrogen loads being 45% higher in urban areas compared to forested areas (Wollheim et al, 2005; Toor et al., 2017). Wastewater discharge from industry and households can also contribute to elevated nutrient loads and concentrations in coastal waters (Bouwman et al, 2005; Clarke et al. 2006; Nagy et al. 2012; van Puijenbroek et al, 2019). Half of all the nitrogen-based fertilizer used on earth has been manufactured since 1985 (Howarth, 2008). Only a small fraction of the fertilizer (10-30%) is incorporated into food that is consumed, and approximately half is lost to rivers and estuaries as direct runoff and atmospheric deposition (Houlton et al. 2013; Galloway et al. 2014). The excessive nutrient loading associated with these anthropogenic influences has led to water quality impairment in the form of eutrophication (Smith, 2003; Doney, 2010), a complex process that is associated with the increase in phytoplankton biomass and harmful algal bloom prevalence, as well as hypoxia (Bricker et al., 2003).

Coastal regions of the Gulf of Mexico experienced a 150% increase in population from 1960 and 2008, which is more than double the rate of the nation's population (https://www.census.gov/topics/preparedness/about/coastal-areas.html). This has led to degradation of water quality, including growing expression of eutrophication symptoms in many estuaries surrounding the Gulf (Bricker et al. 2008). Coastal Texas experienced a 21% increase in population from 2000 to 2010, making its coastal communities the fastest growing in the country (U.S. Census Bureau, 2010). In Texas, it has been forecasted that population will increase 60% from 2020 to 2050 (https://demographics.texas.gov/Resources/publications/2019/20190925_PopProjectionsBrief.pdf). Previous assessments have determined that the eutrophication status of Texas estuaries is "moderate to high" or the water quality is "fair" (Bricker et al., 1999; Bricker et al., 2007). However, it is generally recognized that the recent high rate of population growth and urbanization has placed environmental pressures on Texas's estuaries. For example, Bugica et al. (2020) found that San Jacinto and Galveston Bays experienced increases in nutrients (primarily total phosphorus, dissolved inorganic phosphorus, total Kjeldahl nitrogen), and chlorophyll *a* (Chl). Similar trends in Chl were also seen in Oso Bay, an urbanized estuary, and Baffin Bay, a predominantly hypersaline bay.

A study addressing fish kills in Texas from 1951-2006 found that specific bays have higher levels of fish kills than others. Galveston, Matagorda, and Corpus Christi bays have the highest number of fish kills (Thronson and Quigg, (2008). In addition, 39% of the fish kills were attributed to non-point source runoff and low temperatures, 23% were to low dissolved oxygen (DO) levels related to permitted and unpermitted discharge and 15% were attributed to harmful algal bloom species and disease.

Given that previous eutrophication assessments in Texas are out of date and also lacked critical data for many estuaries, an updated assessment is urgently needed to guide coastal zone management (Bricker et al., 1999). In the U.S. and at the local level, there are several different assessment approaches, each differing in indicators and approaches used. The National Coastal Condition Report (NCCR) uses a weighted average of five primary indicators to rate water quality: 1) dissolved inorganic nitrogen (DIN), 2) dissolved inorganic phosphorus (DIP), 3) Chl, 4) bottom water dissolved oxygen (DO), and 5) water clarity (USEPA, 2012). The National Estuarine Eutrophication Assessment (NEEA) derives a eutrophication classification approach based on; 1) total dissolved nitrogen (TDN; which includes dissolved organic nitrogen), 2) total dissolved phosphorus (TDP; which includes dissolved organic phosphorus), 3) Chl, 4) DO and 5) water clarity. In Texas, the Texas Commission on Environmental Quality (TCEQ) does not produce similar water quality assessments. However, they do submit an integrated report of surface water quality to the USEPA every two years. This satisfies the requirements of the federal Clean Water Act sections 305(b) and 303(d). There are several key differences to these approaches. First, NCCR and TCEQ use DIN and DIP, whereas NEEA utilizes TDN and TDP. TCEQ uses DIN (NH_3-N + NO_3-N) and DIP in both classified and unclassified estuarine waters (Table 3). The inclusion of organic nutrients in the NEEA but not in NCCR or TCEQ could lead to different assessments, as organic nutrient loadings are becoming a major driver of eutrophication in many coastal systems (Glibert et al., 2006; Kudela et al., 2008; Li et al., 2020). Second, all three approaches use different nutrient and chlorophyll thresholds. Third, NCCR uses available data and randomized sampling data from the summer, whereas NEEA and TCEQ utilize all available data regardless of season. Finally, TCEQ does not use water clarity as an estuarine indicator. Bricker et al. (2003a) recommended that investigators use the national survey results as a starting point to assess estuarine eutrophication on different regional scales, but classification approaches should be customized based on the type of estuaries examined.

In this study, I analyze results of a water quality assessment of Oso Bay and Baffin Bay located in South Texas. We used investigator-led water quality data from these systems to compare site- and ecosystem-level assessments determined by NCCR, NEEA and TCEQ methods. Findings from this study will help to determine whether these estuaries are experiencing degraded water quality and are experiencing symptoms of eutrophication. This work also highlights how the key differences in approaches used by NEEA, NCCR and TCEQ can lead to differences in water quality assessment.

METHODS

Site Description

We studied two South Texas estuaries, Baffin Bay and Oso Bay. Baffin Bay is a shallow (<1-3 m) estuary that experiences high evaporation, low freshwater input, and has a long residence time (>1 year on average) (Wetz et al. 2017). Land use in the watershed is dominated by agriculture (32.2%) and rangeland (64%) (Bricker et al, 2007). Baffin Bay also receives wastewater effluent from several small municipal plants, some of which are poorly functioning. Oso Bay is a shallow (~1 m) microtidal urbanized estuary that drains into the larger Corpus Christi Bay. The land use in the watershed is dominated by agriculture (48%) and high-density development (17%), and the bay also receives municipal wastewater input from three facilities (Wetz et al. 2016; NOAA CCAP 2010).

Water Quality Measurements

Water samples were collected from eight sites in Oso Bay (Table 1, Figure 1) and nine sites in Baffin Bay, Texas (Table 2, Figure 1). Sampling occurred monthly from May 2013 to December 2018 for Baffin Bay and August 2011 to September 2017 for Oso Bay. Duplicate samples were collected in 1-L high-density polyethylene bottles from ~0.5 m below the surface. Prior to sampling, the bottles were washed in 10% HCl and rinsed six times with deionized water. Samples were kept on ice, transported to the laboratory and processed within four hours. Salinity, pH, temperature (˚C), and dissolved oxygen (DO) (mg/L) concentration were measured at the time of sample collection using field YSI meters (ProPlus). Secchi depth measurements were taken for in situ water clarity measurements.

Chlorophyll *a* (Chl) samples were collected by vacuum filtration of water through GF/F filters at ≤ 5 mm Hg. The filters were frozen at -20°C until laboratory analysis (within 28 days).

Chl was extracted from the filters using 90% HPLC grade acetone according to the freeze-thaw Standard Method (SM) 10200H of APHA (2005). Fluorescence was measured using a Turner™ Trilogy fluorometer using acetone blanks and calibrated solid standards. The fluorometer was calibrated quarterly. Dissolved nutrients were analyzed after filtering through pre-combusted (450°C for 24 h) GF/F filters. Ammonium (NH_4^+), nitrate + nitrite (NO_3^- + NO_2^-), nitrite (NO_2^-), orthophosphate (PO_4^{3-}) and silicate (SiO_2) were determined using a Seal QuAAtro™ auto-analyzer following APHA methods (SM4500-NH_3 G, SM4500-NO_3 F, SM4500-P F and SM4500- SiO_2 F of APHA (2005). Standards of equal concentration of NO_3^- and NO_2 were run to test the cadmium reduction column efficiency. The average daily efficiency was 98.7 ± 3.5 %. Standard curves using eight different standard concentrations were run daily. 18-ohm deionized water (DI) blanks were analyzed throughout the run. Check standards of known concentrations were used to correct for baseline drift (usually every 8-10 samples). Dissolved inorganic nitrogen (DIN) was determined as the sum of NH_4^+ and NO_3^- + NO_2^-, and dissolved inorganic phosphorus (DIP) as PO_4^{3-}. Total dissolved nitrogen (TDN) and total nitrogen (TN) were measured using a Shimadzu TOC-V TN-1 module (ASTM 2015) with self-contained magnetic stirrers. For TDN and TN analysis, calibration curves were run at the beginning and end of each run to account for baseline drift. Laboratory check standards were used in conjunction with Certified Reference Material Program deep seawater standards. Dissolved organic nitrogen (DON) concentrations were calculated by subtracting DIN from TDN.

Water Quality Assessment

A water quality assessment was conducted using three different classification approaches: 1) the 2012 USEPA National Coastal Condition Report IV (NCCR) (USEPA, 2012), 2) the NOAA National Estuarine Eutrophication Assessment (NEEA) (Bricker et al., 1999), and 3) the

Texas Commission on Environmental Quality (TCEQ) 2018 Guidance for Assessing and Reporting Surface Water Quality in Texas (Table 3). NCCR and NEEA used five component indicators and TCEQ used four (Table 3). Using approaches outlined in each approach, I calculated a water quality index (WQI) for each site and bay to assess overall water quality conditions.

The five indicators used by NCCR were DIN, DIP, Chlorophyll *a*, Secchi depth (representing water clarity) and Bottom water DO. These were assessed based on three assigned cutpoints (good, fair, poor) that were established from Gulf Coast ranges (Table 3) (USEPA, 2012). For a given indicator, the percentage of samples falling into each of the three cutpoints was calculated for summer months (June, July and August; as per NCCR methods) as well as annually (to align with NEEA and TCEQ methods). To calculate the rank of each indicator, “good” values received a score of five, “fair” received a score of three and “poor” received a score of one. These values were multiplied by the percentage of samples found in each category and added up to calculate an overall indicator score for each site in each bay. Indicator score rankings were assigned to one of the following categories: “good” (>4.0), “good to fair” (3.7 to 4.0), “fair” (2.4 to <3.7), “fair to poor” (2.0 to <2.4) and “poor” (<2.0) (USEPA, 2012). The WQI for each site was considered “good” if a maximum of one indicator was rated ”fair”, and no indicators were rated “poor”; “fair” if one of the indicators was rated “poor”, or two or more indicators were rated “fair”; “poor” if two or more of the indicators were rated “poor”; “missing” if two component indicators were missing and the available indicators do not suggest a “fair” or “poor” rating (Table 4). At the bay-scale, the bay’s WQI was considered “good” if less than 10% of the sampling sites were in “poor” condition and more than 50% of the bay sites were in “good” condition; “fair” if 10% to 20 % of the bay sampling sites were in “poor” condition, or

50% or less of the bay sites were in “good” condition; “poor” if more than 20% of the bay sites were in “poor” condition Table 5).

The five indicators used by NEEA included TDN, total dissolved phosphorus (TDP), Chl *a*, Secchi depth and Bottom DO (Table 3) (Bricker et al, 1999). For a given indicator, the percentage of samples falling into each of the three cutpoints was calculated for summer months (June, July and August; as per NCCR methods) as well as annually (to align with NEEA and TCEQ methods). To calculate the rank of each indicator, “low” values received a score of five, “medium” received a score of three and “high” received a score of one. These values were multiplied by the percentage of samples found in each category and added up to calculate an overall indicator score for each site in each bay. Chl *a* had a “hyper” category indicating chlorophyll *a* > 60 µg L^{-1}, but its number was still assigned a “1” (“high”) for simplicity purposes in our assessment. Indicator scores were assigned to one of the following categories: “low” (>4.0), “low to medium” (3.7 to 4.0), “medium” (2.4 to <3.7), “medium to high” (2.0 to <2.4) and “high” (<2.0) (USEPA, 2012). The WQI for each site was considered “low” if a maximum of one indicator was rated ”medium”, and no indicators were rated “high”; “medium” if one of the indicators was rated “high”, or two or more indicators were rated “medium”; “high” if two or more of the indicators were rated “high”; “missing” if two indicators were missing and the available indicators do not suggest a “medium” or “high” rating (Table 4). At the bay-scale, the bay’s WQI was considered “low” if less than 10% of the sampling sites were in “high” condition and more than 50% of the bay sites were in “low” condition; “medium” if 10% to 20 % of the bay sampling sites were in “low” condition, or 50% or less of the bay sites were in “low” condition; “medium” if more than 20% of the bay sites were in “low” condition (Table 5).

The State of Texas does not have numerical water quality standards for nutrients in estuarine systems. In lieu of numerical values, ad hoc rankings were established using historical TCEQ surface water sample data for DIN, DIP, TP, dissolved oxygen and chl *a*. A "screening level of concern" for these water quality indicators was established by TCEQ to determine if the values are above the historical 85th percentile ("concern") or below it ("no concern"), and were assigned a number for each (i.e. 1 for "concern", 5 for "no concern") (Table 3) (TCEQ, 2019). For a given indicator, the percentage of samples falling into each of the two cutpoints was calculated for summer months (June, July and August; as per NCCR methods) as well as annually (to align with NEEA and TCEQ methods). Because TCEQ only used two cutpoints, essentially as pass/fail system (no concern/concern), it was necessary to apply the NCCR labeling approach. To calculate the rank of each indicator, "no concern" values received a score of five and "concern" received a score of one. These values were multiplied by the percentage of samples found in each category and added up to calculate an overall indicator score for each site in each bay. Indicator scores were assigned to one of the following categories: "good" (>4.0), "good to fair" (3.7 to 4.0), "fair" (2.4 to <3.7), "fair to poor" (2.0 to <2.4) and "poor" (<2.0) (USEPA, 2012). The WQI for each site was considered "good" if a maximum of one indicator was rated "fair", and no indicators were rated "poor"; "fair" if one of the indicators was rated "poor", or two or more indicators were rated "fair"; "poor" if two or more of the indicators were rated "poor"; "missing" if two indicators were missing and the available indicators do not suggest a "fair" or "poor" rating (Table 4). At the bay-scale, the bays WQI was considered "good" if less than 10% of the sampling sites were in "poor" condition and more than 50% of the bay sites were in "good" condition; "fair" if 10% to 20 % of the bay sampling sites were in "poor" condition, or 50% or less of the bay sites were in "good" condition; "poor" if more than 20% of the bay sites were in "poor" condition (Table 5).

RESULTS

Oso Bay Environmental Conditions

There was little difference in annual average temperature between sites with the highest being at WP (26 +/- 3.3 ºC) and lowest observed at SPID (23 +/- 4.9 ºC) (Table 6). Salinity was highest at YB (37 +/- 13) and lowest at WP (5.4 +/- 7.6). Bottom DO was highest at AG (6.7 +/- 3.0 mg L^{-1}) and lowest at WP (5.0 +/- 2.0 mg L^{-1}). The annual mean DIN concentration was highest at WP (11 +/- 4.9 mg L^{-1}) and lowest at OI (0.11 +/- 0.16 mg L^{-1}). Annual mean DIP concentration was highest at WP (2.1 +/- 1.1 mg L^{-1}) and the lowest at OI (0.05 +/- 0.06 mg L^{-1}) (Table 6). The annual mean Chlorophyll concentration was highest at MP (75 +/- 205 µg l^{-1}) and lowest at WP (7.1 +/- 18 µg l^{-1}) (Table 6). The annual mean TDN concentration was highest at WP (12 +/- 5.5 mg L^{-1}) and the lowest at OI (0.66 +/- 0.23 mg L^{-1}) (Table 6). Annual mean Secchi depth was highest at YB (0.41 +/- 0.22 m) and the lowest at IG averaging (0.09 +/- 0.05 m) (Table 6).

Oso Bay – NCCR

Annually, DIN was poor at two sites (MP and WP) and good at six sites (OI, IG, AG, SPID, YB and BO) (Table 7). During the summer two sites were poor (MP and WP), three were fair (IG, AG and BO) and three were good (OI, SPID and YB). Annually for DIP, four sites were poor, two were fair and two were good. During the summer for DIP, four sites were poor, one was fair to poor, two sites were fair, and one was good. Annually, chlorophyll was poor at two sites, fair to poor at one site, fair at four sites and good at one site. During the summer four sites were poor, three were fair and one was good. Annually, bottom DO was fair at one site and good at seven sites. During the summer, three were fair and five were good. For both an annual scale and during summer, secchi depth at all sites was poor (Table 7).

For the overall WQI, a water quality index was calculated for each bay by determining the percentage of each category using the criteria shown in table 5. Five sites were rated as poor (MP, WP, IG, AG and BO) during summer and three sites were rated as fair (OI, SPID and YB) (Table 5, Figure 2). Annually four sites were rated as poor (MP, WP, IG and AG) and four sites were rated as fair (OI, AG, SPID and YB) (Table 5, Figure 2).

Oso Bay – NEEA

Application of NEEA criteria for nitrogen (TDN) indicated that annually, four sites were high (MP, WP, IG and BO), two were medium to high (AG and SPID), and three sites were medium (OI and YB). During the summer two sites were high (MP and WP), four sites were medium to high (IG, AG, YB and BO), and two sites were fair (OI and SPID) (Table 8). TDP data was not collected as part of the Oso Bay sampling program. Annually, Chl was high at two sites, one site was medium to high, four were medium and one was low. During the summer four sites were high, three were medium and one was low. Annually, bottom DO was medium at one site and low at seven sites. During the summer, one site was medium, two were low to medium and five were low. For both an annual scale and during summer, Secchi depth at all sites was poor (Table 8).

Using the summer dates, five sites had high eutrophication status (MP, WP, IG, AG and BO) and three sites had medium (OI, SPID and YB) (Table 5, Figure 3). Annually four sites were rated as high (MP, WP, IG and AG) and four sites were rated as medium (OI, AG, SPID and YB) (Table 5, Figure 3).

Oso Bay – TCEQ

Application of TCEQ criteria for nitrogen (DIN) indicated annually two sites were poor, three were fair and three were good. During the summer two sites were poor and six were good (Table 9). Annually, phosphorus (DIP) two sites were poor, two were fair and three were good. During the summer two sites were poor, two sites were fair and four were good (Table 9). Annually, Chl *a* was poor at three sites, fair at four sites and good at one site. During the summer four sites were poor, two were fair and two were good (Table 9). Annually, bottom DO had one site that was fair and six sites that were good. During the summer three sites were fair and five were good (Table 9).

Using the summer dates, two sites were rated as poor (MP and WP), four sites were rated as fair (OI, IG, AG and BO), and two sites were rated as good (SPID and YB) (Table 5, Figure 4). Annually two sites were rated as poor (MP and WP), four sites were rated as fair (OI, IG, AG and BO), and two sites were rated as good (SPID and YB) (Table 5, Figure 4).

Oso Bay – Bay Score

The WQI was determined for the entire Oso Bay using all three criteria (Tables 3 and 5). Using the NCCR criteria, Oso Bay's WQI is poor for both the summer and the entire year using the three criteria (Table 5 and Figure 2 for NCCR; Table 5 and Figure 3 for NEEA; Table 5 and Figure 4 for TCEQ).

Baffin Bay Environmental Conditions

There was little difference in average temperature between sites with the highest being at BB2 and BB4 (24 +/- 5.8 ºC) and lowest at BB1 and BB5 (23 +/- 5.7 ºC) (Table 10). Salinity was highest at BB2 (45 +/- 15) and lowest at BB1 (39 +/- 17) (Table 10). Bottom DO was highest at BB7 (5.6 +/- 1.4 mg L^{-1}) and lowest at BB2 (4.9 +/- 1.8 mg L^{-1}) (Table 10). The annual mean DIN concentration was highest at BB5 (0.13 +/- 0.21 mg L^{-1}) and the lowest at BB8 and BB9 (0.054 +/- 0.064 mg L^{-1}). Annual mean DIP concentration was highest at BB1 (0.057 +/- 0.085 mg L^{-1}) and the lowest at BB9 (0.006 +/- 0.004 mg L^{-1}) (Table 10). The annual mean Chl *a* concentration was highest at BB2 (22 +/- 15 µg l^{-1}) and the lowest at BB7 (13 +/- 8.6 µg l^{-1}) (Table 10). The annual mean TDN concentration was highest at BB2 (Table 10) (1.2 +/- 0.28 mg L^{-1}) and the lowest at BB7 (0.84 +/- 0.18 mg L^{-1}). The annual mean TDP concentration was highest at BB1 (0.10 +/- 0.10 mg L^{-1}) and the lowest at BB9 (0.027 +/- 0.007 mg L^{-1}) (Table 10.). Annual mean Secchi depth was highest at BB8 (0.61 +/- 0.18 m) and the lowest at BB5 (0.37 +/- 0.20 m) (Table 10).

Baffin Bay – NCCR

DIN was good for all sites annually and summer months (Table 11). Annually for DIP, one site was fair and eight were good. During the summer for DIP, one site was fair and eight were good (Table 11). Annually chlorophyll had one site that was fair to poor and eight that were fair. During the summer two sites were poor, three were fair to poor, and four were fair. Annually, bottom DO was good to fair at three sites and good at six sites. During the summer, two sites were fair and seven were good. For both an annual scale and during the summer, Secchi depth at all sites was poor (Table 11).

For the overall WQI, two sites were rated as poor (BB2 and BB5) during the summer and seven sites were rated as fair (BB1, BB3, BB4, BB6, BB7, BB8 and BB9) (Table 5, Figure 5) Annually, all nine sites were rated as fair (Table 5, Figure 5).

Baffin Bay – NEEA

Application of NEEA criteria for TDN indicated that annually, three sites were high, three were medium to high and three were medium (Table 12). During the summer three sites were high, four sites were medium to high and two sites were medium (Table 12). TDP was identical for all sites regardless of season with all nine sites scoring medium. Annually, Chl *a* was medium to high at one site and medium at eight sites. During the summer two sites were high, three were medium to high and four were medium (Table 12). Annually, bottom DO was low to medium at three sites and low at six sites. During the summer, two sites were medium, and seven sites were low (Table 12). Secchi depth indicated that water quality was the same regardless of sampling period. For both an annual scale and during the summer, Secchi depth at all sites was poor (Table 12).

Using the summer dates, three sites had high eutrophication status (BB1, BB2 and BB5) and six sites were rated as medium (BB3, BB4, BB6, BB7, BB8 and BB9) (Table 5, Figure 6). Annually three sites were also rated as high (BB1, BB2 and BB5) and six sites were rated as medium (BB3, BB4, BB6, BB7, BB8 and BB9) (Table 5, Figure 6).

Baffin Bay – TCEQ

Application of TCEQ criteria for DIN indicated that water quality was the same between the annual scale and summer months. Annually and in the summer, all 9 sites were good (Table 13). For DIP annually and in the summer, all nine sites were good (Table 13). For chlorophyll annually, nine sites were fair (Table 13). During the summer three sites were poor and six were fair (Table 13). Annually, bottom DO was fair at three sites and good at six sites (Table 13). During the summer four sites were fair and 5 sites were good (Table 13).

For the WQI, four sites were rated as fair (BB1, BB2, BB3 and BB5) and five sites were rated as good (BB4, BB6, BB7, BB8 and BB9) (Table 5, Figure 7). Annually, three sites were rated as fair (BB2, BB6 and BB8) and six sites were rated as good (BB1, BB3, BB4, BB5, BB7, and BB9) (Table 5, Figure 7).

Baffin Bay – Bay Score

The WQI was determined for the entire Oso Bay using all three criteria (Tables 3 and 5). Using the NCCR criteria, Baffin Bay's WQI is poor for summer and fair annually (Table 5, Figure 5). Using the NEEA criteria, Baffin Bay's WQI is poor for both the summer and annual dates (Table 5, Figure 6). Using the TCEQ criteria however, Baffin Bay's WQI is Good for both the summer and annual dates (Table 5, Figure 7).

DISCUSSION

In estuaries and coastal waters, increased nutrient loading associated with point and non-point sources creates adverse responses in dissolved oxygen, chlorophyll, and changes in phytoplankton community structure by increasing harmful algal bloom (HAB) prevalence (Boesch, 2002; Cloern, 2001). The U.S. EPA has encouraged tribes and states to adopt numerical criteria as a method to decrease nutrient pollution. Section 304(a) of the Clean Water Act directs the USEPA to develop scientific information on pollutants and to publish "criteria guidance," often expressed as pollutant concentration levels, that will result in attainment of aquatic life uses. Texas' approach to developing numerical water quality standards is a phased approach where the development would address reservoirs first followed by streams then estuaries. In a March 16, 2011, memo to regional EPA offices, EPA's Acting Assistant Administrator Nancy Stoner summarized eight key elements needed for state programs to reduce nutrient loadings. The first step is to "Prioritize watersheds on a statewide basis for nitrogen and phosphorus loading reductions". The current study utilizes three different water quality assessment methods to determine the status of water quality in two South Texas estuaries exhibiting symptoms of eutrophication (Oso Bay, Baffin Bay). The last major national assessment, conducted as part of the National Estuarine Eutrophication Assessment (Bricker et al. 2007), indicated that there was no data available for Oso Bay. Data were also limited for Corpus Christi Bay as a whole and Bricker et al. (2007) were unable to assess future outlook or make an assessment of estuarine trophic status due to inadequate data. Data was also lacking for Baffin Bay and they were unable to assess primary or secondary symptoms or assess estuarine trophic status and future outlook. This emphasized the need for increased water quality monitoring in these systems, and since the last NEEA assessment, new datasets have become available from each system. The approach taken can serve as a model for broader assessment of Texas estuaries and ultimately to prioritize which estuaries require the most attention from a pollutant load abatement standpoint.

Oso Bay bisects the south side of Corpus Christi, TX, which has seen a sharp population increase from 35,000 to 117,029 between 2000 and 2018. This growth in population is more than twice as fast as the average growth rate for Corpus Christi as a whole (Caller Times, 2020). Recently, the city of Corpus Christi annexed approximately 880 acres of undeveloped land on the south side for the development of an additional 3,000 homes. Urbanization such as that in the Oso Bay watershed has been linked to water quality deterioration through input of pollutants via stormwater runoff in other systems (USEPA, 2002; Barbosa et al, 2012; Cargo, K., 2020). In addition to stormwater runoff, Oso Bay receives water from three different municipal wastewater treatment plants, with one that discharges directly into a segment of Oso Bay known as Blind Oso. The City of Corpus Christi has also considered closing the Greenwood, Alison and Laguna Madre plants and consolidating them while expanding the Oso plant (Woolbright, M. 2017). Wastewater pollutant loads have been shown to cause negative impacts on water quality in estuarine environments (Armstrong and Ward, 1998; Wetz et al. 2016).

Presumably because of its small size, previous large-scale eutrophication and/or water quality assessments have not included Oso Bay. Yet the aforementioned stressors as well as results presented in prior studies indicate a need for this. For example, Nicolau (2001) found that Oso Creek and Oso Bay were heavily influenced by wastewater treatment effluent, resulting in high nutrient and bacteria levels and low DO concentrations. In Oso Bay, the frequency of time that nutrient concentrations located near the Oso Bay wastewater treatment facility exceeds the Texas Surface Water Quality Standards (TSWQS) criteria are: ammonia (100%), nitrate + nitrite (75%) and chlorophyll *a* (25%) (Nicolau, 2001). Wetz et al. (2016) also found high nutrients and chlorophyll, and relatively low DO in Blind Oso, which appeared to be affected by nutrient-laden flows out of MP and WP. Wang et al. (2018) found that water column respiration is mainly attributed to phytoplankton degradation, and isotopic analysis revealed a strong wastewater nitrogen signature in the particular organic matter.

Regardless of the method used, the data used in this study indicates that Oso Bay had impaired water quality. Both the NCCR and NEAA schems indicated that the WQI for MP, WP, BO, IG and AG were Poor (NCCR) and High (NEAA). The TCEQ approach indicated that the WQI for MP and WP was Poor and for BO, IG and AG, it was Fair. This discrepancy is because

TCEQ does not have a cutpoint for Secchi depth, whereas NCCR and NEEA have Secchi depth as an indicator and all sites were always rated as Poor and/or High. As per the findings from Wetz et al. (2016) and Wang et al. (2018), the poor water quality in the Blind Oso region appears to be primarily associated with point source nutrients coming from the wastewater treatment plant and a municipal golf course that receives treated water from the plant for irrigation. The Blind Oso also has restricted water movement due to southwest wind that can cause the water to pile up (Islam et al., 2011). Functionally, the Blind Oso acts like a choked lagoon in that it has reduced tidal oscillation and long flushing times (Knoppers, 1994).

In contrast to the rapid population growth that has occurred around Oso Bay, population in the Baffin Bay watershed has been relatively stable since the 1960's. Baffin Bay is surrounded by three large active ranches (King, Chapman and Kenedy) that account for more than 1.1 million acres. Land use in the form of agricultural row crops significant in the watershed (Parsons, 2019). A study on nutrient loading to Baffin Bay estimated that fertilizer applied to crops and wet deposition each accounts for 30% of nitrogen loads, livestock manure from unconfined animal feeding operations accounted for 20%, urban runoff accounts for 9%, and combined industrial and municipal point sources accounted for 8% (Rebich et al., 2011).

Since 1989, Baffin Bay has been experiencing recurrent, long lasting blooms of *Aureoumbra lagunensis*, commonly referred to as the "Texas brown tide" (DeYoe, 1997; Liu and Buskey, 2000). *A. lagunensis* has been shown to proliferate under low inorganic nitrogen concentrations and has a high tolerance to phosphorus limitation (Liu et al., 2001). As a mixotroph, *A. lagunensis* can utilize DON. Evidence that Baffin Bay has high organic nitrogen concentrations year-round suggests that it is experiencing organic nutrient driven eutrophication (Wetz et al., 2016). High DON concentrations were also associated with *A. lagunensis* blooms in Indian River Lagoon, suggesting that high concentrations of DON are a facilitator of *A. lagunensis* blooms (Mulholland et al, 2004; Gobler et al, 2013).

Applying NCCR to the data indicated that the WQI at BB1 and BB5 was Poor year-round. The remainder of the sites were rated as Fair. All the sites were Fair when using the summer data. NEEA indicated that tBB1, BB2 and BB5 were High with the remaining sites rated as Medium. This was the same pattern regardless if it was annual or summer data. TCEQ indicated no sites were Poor and all the sites were Fair to Good regardless of sampling period. This discrepancy is also because TCEQ does not have a cutpoint for Secchi depth, whereas NCCR and NEEA have Secchi depth as an indicator and all sites were always rated as Poor and/or High (refer to last page Oso discussion).

One important finding from this study is that the NEEA, NCCR and TCEQ criteria yielded distinct patterns with respect to nitrogen classification in Baffin Bay. NCCR and TCEQ both utilize DIN and all sites ranked *Good* in the summer and annually. In contrast, NEEA utilizes TDN and the tributaries (BB1, BB2 and BB5) always ranked High (which would equate to Poor in NCCR or TCEQ terms) in the summer and annually, while the main channel sites (BB3, BB4 and BB6) always ranked *Medium* to *High* in the summer and annually. This finding can be attributed to the inclusion of DON in the NEEA (as TDN) but not in the NCCR or TCEQ approaches. TDN values were consistently high year-round in BB, and as previously noted, high DON (a large fraction of TDN) has been suggested as a driver of bloom of mixotrophic, harmful phytoplankton such as *A. lagunensis* (Berg et al. 1997). According to Bricker et al. (2003b), DON should be included in definitions of eutrophication because it can be an important form of labile N derived from many sources (e.g., atmospheric deposition, runoff from rain and irrigation events, phytoplankton DON release, N_2 fixation, and microbial regeneration).

It has been more than two decades since the EPA asked states to adopt numerical criteria to gauge nutrient pollution. Among the states surrounding the Gulf of Mexico, only Florida has determined criteria for nitrogen (TN), phosphorus (TP) and chlorophyll *a* in estuarine waters (https://www.epa.gov/nutrient-policy-data/state-progress-toward-developing-numeric-nutrient-water-quality-criteria#tb3). The EPA determined that numerical nutrient water quality criteria are necessary to meet the requirements of the Clean Water Act (CWA). This should motivate states to take responsibility to establish nutrient criteria for water quality protection in a timely manner. Unfortunately, Texas only has narrative criteria for nutrient enrichment and does not have numerical estuarine nutrient water quality standards. A major challenge for many states is the prioritization of systems to focus on given limited resources. This study and Bugica et al (2020) both identified high priority estuaries that Texas should focus on for developing numerical water quality standards, including Baffin Bay, Oso Bay and Galveston Bay. It is recommended that intensive studies including increased and targeted monitoring, development of watershed plans, and watershed remediation efforts will be needed for these systems.

Recommendations

As previously discussed, the type of indicator selected has a major influence on a system's overall water quality condition assessment. Based on findings here, I recomend Chlorophyll (biological), bottom water D.O., DIN, DIP, TDN and TDP (physico-chemical). The inclusion of TDN and TDP would include DON and DOP which are increasingly recognized as a source of nitrogen for phytoplankton and HABs (Karl 2014, Sipler and Bronk 2015). Water clarity should be dropped as an indicator, as Texas estuaries are typically shallow and regularly mixed by winds, which stirs up sediments into the water column. Data should be collected from the whole year rather than just summer months because symptoms of water quality degradation (high nutrients, algal blooms, low D.O.) can occur year round in many Texas estuaries. Since Texas does not currently have numerical nutrient WQS, it is recommended that the 75^{th} and 90^{th} percentiles of each indicator should be determined for the current decade. Any data above the 75^{th} percentile and below the 90^{th} percentile be reported as a concern. Any data above the 90^{th} percentile would triger additional sampling. Finally, collaborations with state and federal agencies and universities would be encouraged as a more robust dataset would better capture the condition of Texas estuaries.

REFERENCES

Anderson, D. M., Glibert, P.M., and Burkholder, J.M. (2002) Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries*,* 25: 704-726.

APHA (2005) Standard methods for the examination of water and wastewater. 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Armstrong, N.E. and Ward, G.H. (1998) Final report point source loading characterization of Corpus Christi Bay (Report No. CCBNEP-30). https://www.cbbep.org/publications/virtuallibrary/ccbnep30.pdf.

ASTM D5176-08 (2015), Standard test method for total chemically bound nitrogen in water by pyrolysis and chemiluminescence detection, ASTM International, West Conshohocken, PA, 2015.

Bamber, J.L., Oppenheimer, M., Kopp, R.E., Aspinall, W.P. and Cooke, R.M. (2019) Ice sheet contributions to future sea-level rise from structured expert judgment. Proceedings of the National Academy of Science 116(23): 11195-11200.

Barbosa, A.E., Fernandes, J.N., David, L.M. (2012) Key issues for sustainable urban stormwater management. Water Research 46(20): 6787-6798

Berg, G.M., P.M. Glibert, M.W. Lomas, and M. Burford. (1997) Organic nitrogen uptake and growth by the Chrysophyte *Aureococcus anophagefferens* during a brown tide event. Marine Biology 129:377-387.

Boesch, D. F. (2002) Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. Estuaries 25: 886−900.

Bouwman, A.F., Drecht, G.V., Knoop, J.M., Beusen, A.H.W. and Meinardi, C.R. (2002) Exploring changes in river nitrogen export to the world's oceans. Global Biogeochemical Cycles, 19(1). GB1002, doi:10.1029/2004GB002314

Bricker, S. B., Clement, C. G., Pirhalla, D. E., Orlando, S. P., and Farrow, D. R. G. (1999). National Estuarine Eutrophication Assessment: Effects of nutrient enrichment in the nation’s estuaries. National Oceanographic and Atmospheric Association, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Service. Silver Spring, Maryland.

Bricker, S. B., Ferreira, J. G., and Simas, T. (2003a). An integrated methodology for assessment of estuarine trophic status. Ecological Modeling, 169:39-60.

Bricker, S., Matlock, G., Snider, J., Mason, A., Alber, M., Boynton, W., Brock, D., Brush, G., Chestnut, D., Claussen, U., Dennison, W., Dettmann, E., Dunn, D., Ferreira, J., Flemer, D., Fong, P., Fourqurean, J., Hameedi, J., Hernandez, D., Hoover, D., Johnston, D., Jones, S., Kamer, K., Kelty, R., Keeley, D., Langan, R., Latimer, J., Lipton, D., Magnien, R., Malone, T., Morrison, G., Newton, J., Pennock, J., Rabalais, N., Scheurer, D., Sharp, J., Smith, D., Smith, S., Tester, P., Thom, R., Trueblood, D., and Van Dolah, R. (2003b, September). National Estuarine Eutrophication Assessment update: Workshop summary and recommendations for development of a long-term monitoring and assessment program. Proceedings of a workshop September 4-5, 2002, Patuxent Wildlife Research Refuge, Laurel, Maryland. National Oceanographic and Atmospheric Association, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Service. Silver Spring, Maryland: 19pp

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, Wicks, C. and J. Woerner. J. (2007) Effects of nutrient enrichment in the nation's estuaries: A decade of change. NOAA Technical Memorandum NOS NCCOS Coastal Ocean Program Decision Analysis Series 26. Silver Spring, MD. 328 pp.

Bugica K., Sterba-Boatwright B. & Wetz M.S., (2020) Water quality trends in Texas estuaries. Marine Pollution Bulletin 152:110903.

Cargo, K. (2020). 'Take a look at the future projects in the city's London and Southside development plans'. Corpus Christi Caller Times. Published 8:00 a.m. CT Feb. 4.

Clarke, A. L., Weckström, K., Conley, D. J., Anderson, N. J., Adser, F., Andrén, E., de Jonge, V. N., Ellegaard, M., Juggins, S., Kauppila, P., Korhola, A., Reuss, N., Telford, R. J., Vaalgamaa, S., (2006) Long-term trends in eutrophication and nutrients in the coastal zone. Limnology and Oceanography, 51(1, part 2):385-397

Cloern, J.E. (2001) Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series, 210:223-253.

Cloern, J.E., and Jassby. A.D. (2010) Patterns and scales of phytoplankton variability in eastuarine-coastal ecosystems. Estuaries and Coasts 33:230–241.

Deacutis, C. and Brown, P. (2011). Nutrient conditions in Narragansett Bay and numeric nutrient criteria development strategies for Rhode Island estuarine. Draft June 2011, Narragansett Bay Estuary Program, 60 pp

DeYoe, H.R. and Suttle, C.A. (1994). The inability of the Texas "Brown Tide" alga to use nitrate and the role of nitrogen in the initiation of a persistent bloom of this organism". Journal of Phycology 30 (5):800–806.

DeYoe H.R., Stockwell, D., Bidigare, R., Latasa, M., Johnson, P., and Hargaves, P. (1997) Description and characterization of the algal species *Aureoumbra lagunensis* gen. et sp. nov. and referral of *Aureoumbra* and *Aureococcus* to the Pelagophyceae. Journal of Phycology 33:1042–1048

Doney, S.C. (2010) The growing human footprint on coastal and open-ocean biogeochemistry. Science, 328 (5985): 1512-1516.

Fire S.E., Wang Z., Byrd M., Whitehead H.R., Paternoster J., Morton S.L. (2011) Co-occurrence of multiple classes of harmful algal toxins in bottlenose dolphins (*Tursiops truncatus*) stranding during an unusual mortality event in Texas, USA. Harmful Algae, 10 (3):330-336.

Glibert, P.M., Magnien, R., Lomas, M.W., Alexander, J., Fan, C., Haramoto, E., Trice, M., Kana, M., Kana, T.M. (2001). Harmful algal blooms in the Chesapeake and coastal bays of Maryland, USA: Comparison of 1997, 1998, and 1999 events. Estuaries 24: 875-883.

Glibert PM, Harrison J, Heil C, Seitzinger S (2006) Escalating worldwide use of urea—a global change contributing to coastal eutrophication. Biogeochemistry 77:441–463.

Glibert PM, Madden CJ, Boynton W, Flemer D, Heil C, and Sharp J. (2010) Nutrients in estuaries: a summary report of the National Estuarine Experts Workgroup (2005–2007). US EPA Report 68-C-02-091 and EP-C-07-025. United States Environmental Protection Agency, Washington, D.C. 188 p.

Glibert PM, Manager R, and Sobota DJ. (2014) The Haber-Bosch–harmful algal bloom (HB-HAB) link. Environmental Research Letters 9:105001 (13 p).

Gobler, C.J., Koch, F., Kang, Y., Berry, D.L., Tang, Y.Z., M. Lasi, Walters, L., Hall, L.,and Miller, J.D. (2013). Expansion of harmful brown tides caused by the pelagophyte, *Aureoumbra lagunensis* DeYoe et Stockwell, to the US east coast. Harmful Algae 27:29-41.

Goonetilleke A, Thomas E, Ginn S, Gilbert D. (2005) Understanding the role of land use in urban stormwater quality management. Journal of Environmental Management 74:31–42.

Groffman, P.M., Dorsey, A.M. and Mayer, P.M. (2005) Nitrogen processing within geomorphic features in urban streams. Journal of the North American Benthological Society 24(3):613-625.

Howarth, R.W. and Marino, M. (2006). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over three decades. Limnology and Oceanography 51(1, part 2), 2006, 364–376.

Howarth, R.W. (2008) Coastal nitrogen pollution: a review of sources and trends globally and regionally. Harmful Algae 8:14–20.

Ismael, A.A., (2003). Succession of heterotrophic and mixotrophic dinoflagellates as well as autotrophic microplankton in the harbour of Alexandria, Egypt, Journal of Plankton Research 25, Issue 2:193–202.

Islam, M.S., Bonner, J.S., Page, C. and Ojo, T.O. (2011) Integrated real-time monitoring system to investigate the hypoxia in a shallow wind-driven bay. Environmental Monitoring and Assessment 172:33–50.

Jani, J., Yang, Y.Y., Lusk, M.G., Toor, G.S. (2020) Composition of nitrogen in urban residential stormwater runoff: Concentrations, loads, and source characterization of nitrate and organic nitrogen. PLoS ONE 15(2): e0229715.

Kang, Y.,Koch, F.,Gobler, C.J. (2015) The interactive roles of nutrient loading and zooplankton grazing in facilitating the expansion of harmful algal blooms caused by the pelagophyte, *Aureoumbra lagunensis*, to the Indian River Lagoon, FL, USA. Harmful Algae. 49:162–173.

Karl, D. M. (2014). Microbially mediated transformations of phosphorus in the sea: new views of an old cycle. Annual Review of Marine Science 6, 279–337.

Kemp, W., Tesat, J., Conley, D., Gilbert, D., and Hagy, J. (2009) Temporal responses of coastal hypoxia to nutrient loading and physical controls. Biogeosciences 6:2985-3008.

Knoppers, B., (1994) Aquatic primary production in coastal lagoons. In B. J. Kjerfve [ed.], Coastal lagoon processes. Elsevier Oceanography Series, 60. Elsevier Science, Amsterdam, p. 243-286.

Kudela RM, Lane JQ, Cochlan WP (2008) The potential role of anthropogenically derived nitrogen in the growth of harmful algae in California, USA. Harmful Algae 8:103–110

Lewitus, A.J., Koepfler, E.T., and Pigg, R.J. (2000) Use of dissolved organic nitrogen by a salt marsh phytoplankton bloom community. Arch Hybrobiol Special Issues Advances in Limnology, 55:441-456

Li, M., Li, K., Chen, K., Liu, C., Wang, X. (2020) Size-based bioavailability of land-based DON and its impact on eutrophication of Jiaozhou bay. Marine Pollution Bulletin 152:110898.

Liu, H., Buskey, E.J. (2000) The exopolymer secretions (EPS) layer surrounding *Aureoumbra lagunensis* cells affects growth, grazing, and behavior of protozoa. Limnology and Oceanography. 45 (5):1187–1191.

Liu H, Laws E.A., Villareal T.A., Buskey E.J. (2001) Nutrient-limited growth of *Aureoumbra lagunensis* (Pelagophyceae), with implications for its capability to outgrow other phytoplankton species in phosphate-limited environments. Journal of Phycology 37:500–508

López-Veneroni, D., and Cifuentes, L.A. (1994) Transport of dissolved organic nitrogen in Mississippi river plume and Texas-Louisiana continental shelf near-shore waters. Estuaries, 17:796-808

Mallin, M.A., Johnson, V.L. and Ensign, S.H. (2009) Comparative impacts of stormwater on water quality of an urban, a suburban, and a rural stream. Environmental Monitoring and Assessment 159:475-491.

Merkens, J-L., Reimann, L., Jochen Hinkel, J. and Vafeidis, A.T. (2016) Gridded population projections for the coastal zone under the Shared Socioeconomic Pathways. Global and Planetary Change 145:57-66

Mulholland, M.R., Heil, C.A., Bronk, D.A., O'Neil, J.M., Bernhardt, P. (2004) Does nitrogen regeneration from the N_2 fixing cynaobacteria *Trichodesmium* spp. fuel *Karenia brevis* blooms in the Gulf of Mexico? In: Steidinger KA, Landsberg JH, Tomas CR, Vargo GA, editors. Harmful Algae 2002. Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography and Intergovernmental Oceanogrpahic Commission of UNESCO; 2004. pp. 47–49.

Nagy, R.C., Lockaby, B.G., Kalin, L., and C. Anderson, C. (2012) Effects of urbanization on stream hydrology and water quality: the Florida Gulf Coast. Hydrological Procedings 26:2019-2030.

National Oceanic and Atmospheric Administration, Office for Coastal Management. "2010 South Corpus Christi Bay Watershed." Coastal Change Analysis Program (C-CAP)

Regional Land Cover. Charleston, SC: NOAA Office for Coastal Management. Accessed Month Year at www.coast.noaa.gov/htdata/raster1/landcover/bulkdownload/30m_lc/.

Neumann B., Vafeidis A.T., Zimmermann, J., Nicholls, R.J. (2015) Future coastal population growth and exposure to sea-level rise and coastal flooding—A global assessment. PLoS ONE 10(3): e0118571.

Nicolau, B. A. (2001) Water quality and biological characterization of Oso Creek & Oso Bay, Corpus Christi, Texas. A report of the Coastal Coordination Council pursuant to NOAA Award No. NA97OZ017.

Nixon, S.W. (1995) Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia 41:199−219.

Paerl, H.W. (1997). Coastal eutrophication and harmful algal blooms: Importance of atmospheric deposition and groundwater as “new” nitrogen and other nutrient sources. Limnology and Oceanography 42:1152-1165

Rebich, R. A., Houston, N. A., Mize, S. V., Pearson, D. K., Ging, P. B., & Evan Hornig, C. (2011). Sources and delivery of nutrients to the Northwestern Gulf of Mexico from streams in the South-Central United States. Journal of the American Water Resources Association, 47(5):1061–1086.

Phlips, E.J., Badylak, S., Hart, J., Haunert, D., Lockwood, J., O’Donnell, K., Sun, D., Viveros, P. and Yilmaz, M. (2012) Climatic influences on autochthonous and allochthonous phytoplankton blooms in a subtropical estuary, St. Lucie Estuary, Florida, USA. Estuaries and Coasts 35:335–352.

P.J.T.M. van Puijenbroek, Beusen, A.H.W., Bouwman, A.F. (2019) Global nitrogen and phosphorus in urban waste water based on the Shared Socio-economic pathways. Journal of Environmental Management 231:446-456.

Rabalais, N.N. and Turner, R.E. (2019). Gulf of Mexico Hypoxia: Past, present, and future. Limnology and Oceanography Bulletin 28 (4):117-124

Sipler RE, Bronk DA (2015) Chapter 4: dynamics of dissolved organic nitrogen. In: Carlson DAHA (ed) Biogeochemistry of marine dissolved organic matter, 2nd edn. Academic Press, Boston, pp 127–232

Smith, V. H. (2003) Eutrophication of freshwater and coastal marine ecosystems a global problem. Environmental Science and Pollution Research 10 (2):126-139

Inia Soto, I., Hu, C., Steidinger, K., Muller-Karger, F., Cannizzaro, J., Wolny, J., Cerdeira-Estrada, S., Santamaria-del-Angel, E., Tafoya-del-Angel, F., Alvarez-Torres, P., Herrera Silveira, J. and Allen, J. (2012). Binational collaboration to study Gulf of Mexico's harmful algae. EOS Transactions of the American Geophysical Union 5, 49–50.

Steidinger, K.A. & Meave del Castillo, M.E. [Eds.]. 2018. Guide to the identification of harmful microalgae in the Gulf of Mexico, Volume I: Taxonomy. St. Petersburg, FL: Florida Fish and Wildlife Research Institute. PDF. Retrieved (06/10/2020) from http://myfwc.com/research/redtide/research/scientific-products/

TCEQ. 2019. 2018 Guidance for assessing and reporting surface water quality in Texas. March. https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/gawg/2018/2018_guidance.pdf

Thronson, A., Quigg, A. (2008). Fifty-five years of fish kills in coastal Texas. Estuaries and Coasts 31:802–813.

Toor, G.S., Occhipinti, M.L., Yang, Y.Y., Majcherek, T., Haver, D., Oki, L. (2017) Managing urban runoff in residential neighborhoods: Nitrogen and phosphorus in lawn irrigation driven runoff. PLoS ONE 12(6): e0179151.

U.S. EPA (Environmental Protection Agency). (1998) National Strategy for the Development of Regional Nutrient Criteria. EPA 822-R-98-002. 47 pp.

U.S. EPA (Environmental Protection Agency). (2001) Nutrient Criteria Technical Guidance Manual Estuarine and Coastal Marine Waters. EPA-822-B-01-003. 362 pp.

U.S. E.P.A (Environmental Protection Agency). 2002. 2000 National Water Quality Inventory. EPA-841-R-02-001. Office of Water, Washington, DC. 207 p. Available at: http://www.epa.gov/305b/2000report.

U.S. EPA (Environmental Protection Agency). (2008) State Adoption of Numeric Nutrient Standards (1998-2008). EPA-821-F-08-007.

U.S. EPA (Environmental Protection Agency). (2011). Water Quality Assessment and Total Maximum Daily Loads Information: Assessment, TMDL Tracking and Implementation System (ATTAINS).

U.S. EPA (Environmental Protection Agency). 2012. National Coastal Condition Report IV. EPA-842-R-10-003. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.

Walker, J.S., Shaver, D.J., Stacy, B.A., Flewelling, L.J., Broadwater, M.H., Wang, Z. (2018) Brevetoxin exposure in sea turtles in south Texas (USA) during *Karenia brevis* red tide. Diseases of Aquatic Organisms 127:145-150.

Wang, H., Hu, X., Wetz, M.S. and Hayes, K.C. (2018) Oxygen consumption and organic matter remineralization in two subtropical, eutrophic coastal embayments. Environmental Science & Technology 52 (22):13004-13014

Wells, M. L., Trainer, V. L., Smayda, T. J., Karlson, B. S., Trick, C. G., Kudela, R. M., Ishikawa, A., Bernard, S., Wulff, A., Anderson, D. M., & Cochlan, W. P. (2015). Harmful algal blooms and climate change: Learning from the past and present to forecast the future. Harmful algae, *49*, 68–93.

Wetz, M.S., Hayes, K.C., Fisher, K.V.B., Price, L., Sterba-Boatwright, B. (2016) Water quality dynamics in an urbanizing subtropical estuary (Oso Bay, Texas) Marine Pollution Bulletin 104:44-53.

Wetz, M. S., Cira, E. K., Sterba-Boatwright, B., Montagna, P. A., Palmer, T. A., Hayes, K. C. (2017) Exceptionally high organic nitrogen concentrations in a semi-arid south Texas estuary susceptible to brown tide blooms. Estuarine Coastal Shelf Science, 188, 27−37.

Woolbright, M. (2017) 'To build new or repair old is the question the Corpus Christi city council faces on a wastewater system overhaul, and both options aren't cheap'. Corpus Christi Caller Times. Published 6:00 p.m. CT June 10.

Wollheim, W.M., Pellerin, B.A., Vorosmarty, C.J., Hopkinson, C.S. (2005) N retention in urbanizing headwater catchments. Ecosystems 8:871–884.

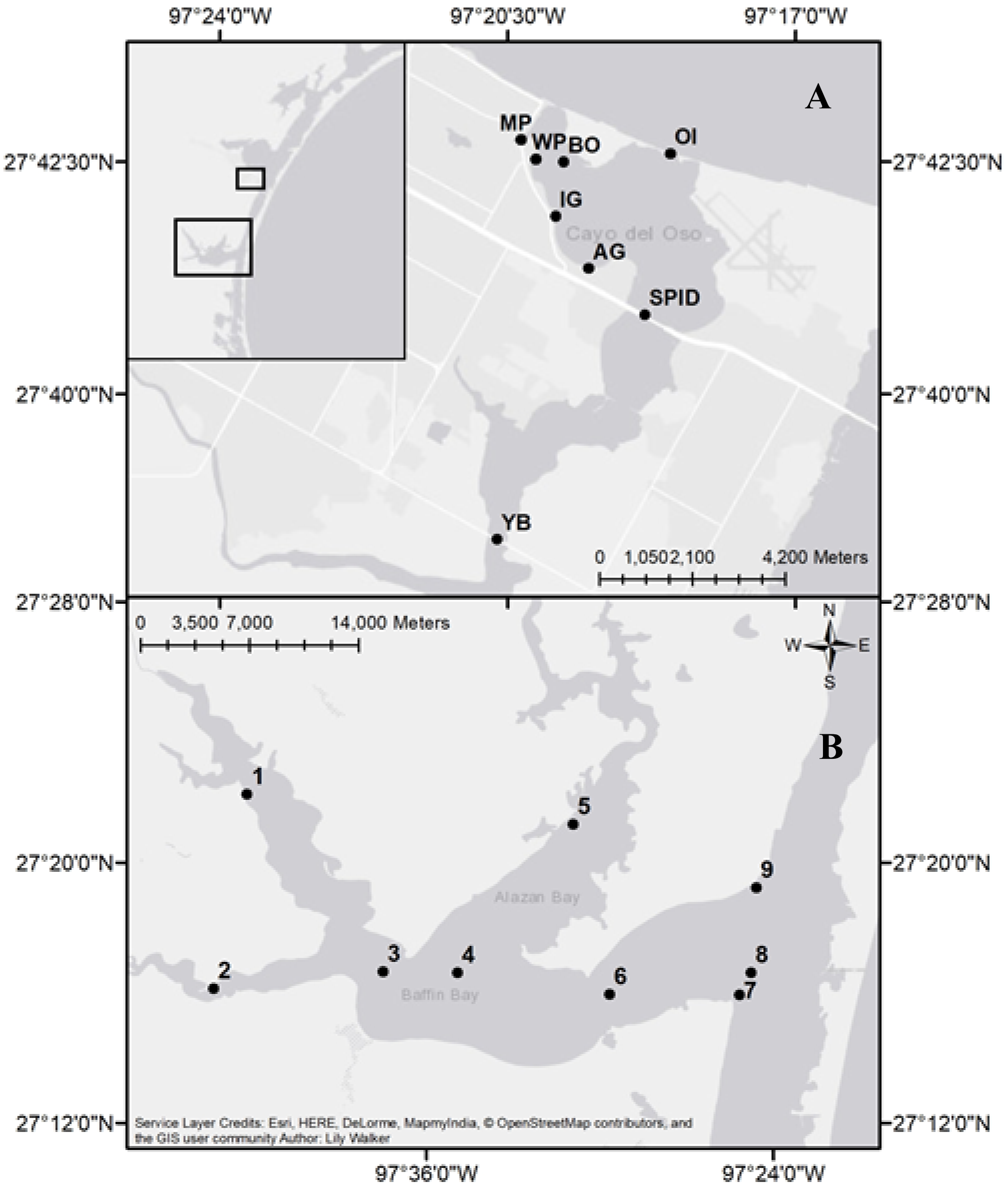

Figure 1. Water quality sampling stations sampled monthly August 2011 – September 2017, in Oso Bay, Texas (A) and water quality sampling stations sampled monthly May 2013 – December 2018, in Baffin Bay, Texas (B).

Table 1. Location of sample sites in Oso Bay.

Site	ID	Latitude	Longitude
Oso Inlet	OI	27.70985	-97.308683
Municipal golf course	MP	27.71239	-97.338947
Wastewater treatment plant	WP	27.70890	-97.335972
Inactive golf course	IG	27.69863	-97.331936
Creek draining farmland	AG	27.68921	-97.325247
South Padre Island bridge	SPID	27.68093	-97.313806
Yourktown bridge	YB	27.64056	-97.3438
Blind Oso	BO	27.70841	-97.330333

Table 2. Location of sample sites in Baffin Bay.

Site	ID	Latitude	Longitude
Cayo del Grullo	BB 1	27.36809	-97.70327
Laguna Salada	BB 2	27.26858	-97.72257
Upper main channel	BB 3	27.27725	-97.62487
Middle main channel	BB 4	27.27672	-97.58213
Alazan Bay	BB 5	27.35265	-97.51540
Lower main channel	BB 6	27.26562	-97.49437
North mouth	BB 7	27.26542	-97.41965
Mid mouth	BB 8	27.27667	-97.41287
South mouth	BB 9	27.32025	-97.40992

Table 3. Eutrophic response ranges for nutrients (mg L^{-1}), chlorophyll *a* (µg L^{-1}), bottom DO (mg L^{-1}), and water clarity depth (m) using the three assessment methods.

(a). National Coastal Condition Report IV

Classification	DIN	DIP	Chlorophyll *a*	Dissolved Oxygen	Water Clarity
good	< 0.1	< 0.01	< 5	> 5	≥ 3
fair	≥ 0.1 to 0.5	≥ 0.01 to 0.05	≥ 5 to 20	2 to 5	1.0 to 3.0
poor	> 0.5	> 0.05	> 20	< 2	< 1.0

(b) National Estuarine Eutrophication Assessment

Classification	TDN	TDP	Chlorophyll *a*	Dissolved Oxygen	Water Clarity
low	< 0.1	< 0.01	≤ 5	> 5	≥ 3
medium	≥ 0.1 to 1	≥ 0.01 to 0.1	> 5 to 20	> 2 to ≤ 5	1.0 to 3.0
high	≥ 1	≥ 0.1	*> 20	≤ 2	< 1.0

(c). TCEQ Guidance for Assessing and Reporting Surface Water Quality

Classification	DIN	DIP	Chlorophyll *a*	Dissolved Oxygen
no concern (This Study)	≤ 0.27	≤ 0.19	≤ 11.6	≥ 4.0
concern (> 85th percentile)	> 0.27	> 0.19	> 11.6	< 4

Table 4. Cutpoints for determining the water quality index rating by bay. Water quality index is applied to NCCR, NEEA and TCEQ approaches.

Rating	Cutpoints
Good	**A maximum of one indicator is rated fair, and no indicators are rated poor.**
Fair	**One of the indicators is rated poor, or two or more indicators are rated fair.**
Poor	**Two or more of the five indicators are rated poor.**
Missing	**Two component indicators are missing, and the available indicators do not suggest a fair or poor rating.**

Table 5. Cutpoints for determining the water quality index rating by bay. Water quality index is applied to NCCR, NEEA and TCEQ approaches.

Rating	Cutpoints
Good	**Less than 10% of the bay sites is in poor condition, and more than 50% of the coastal area is in good condition.**
Fair	**10% to 20% of the bay sites is in poor condition, or 50% or less of the coastal area is in good condition.**
Poor	**More than 20% of the bay sites is in poor condition.**

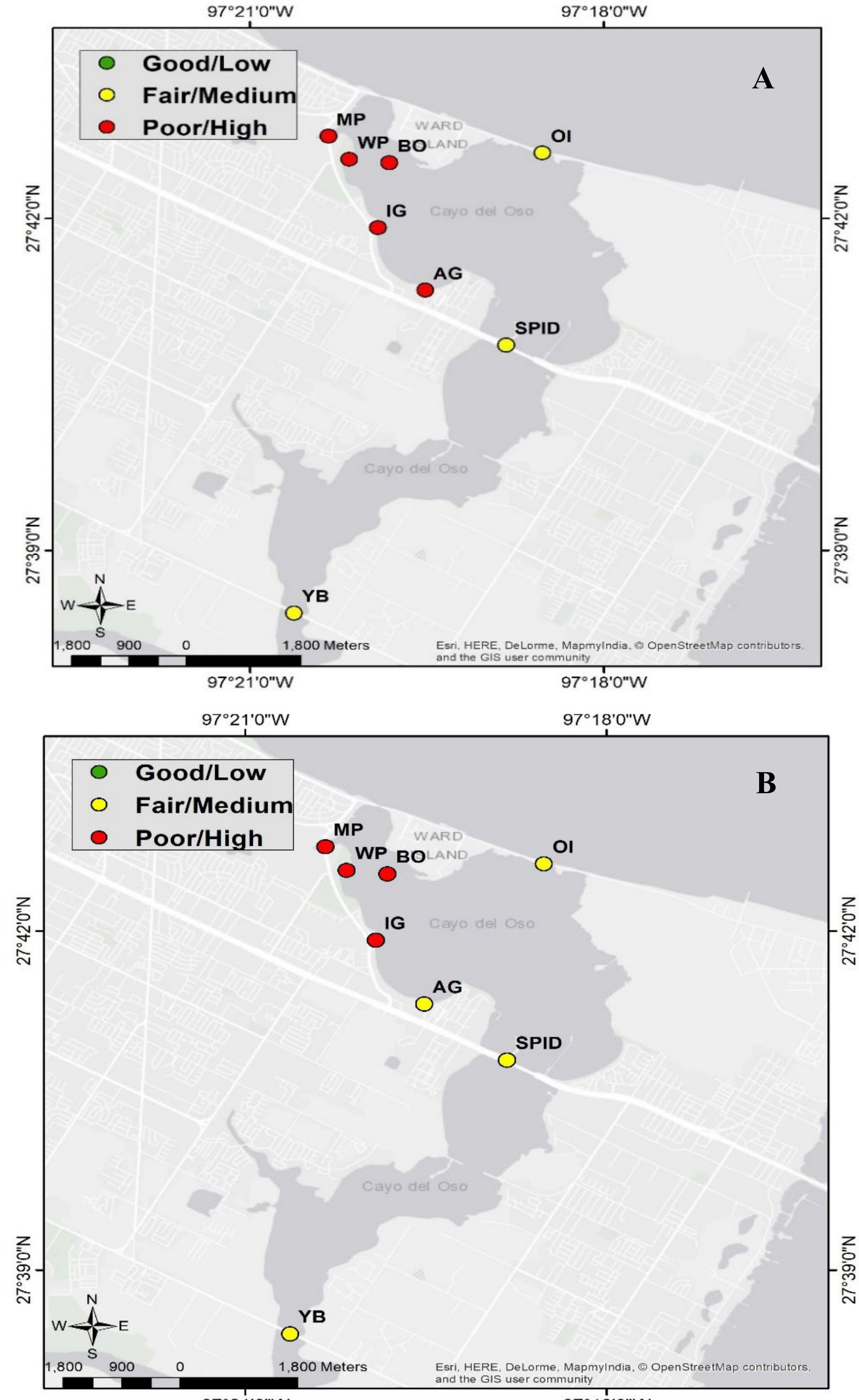

Figure 2. Oso Bay water quality index rating by site using NCCR (A) Annual (B) Summer).

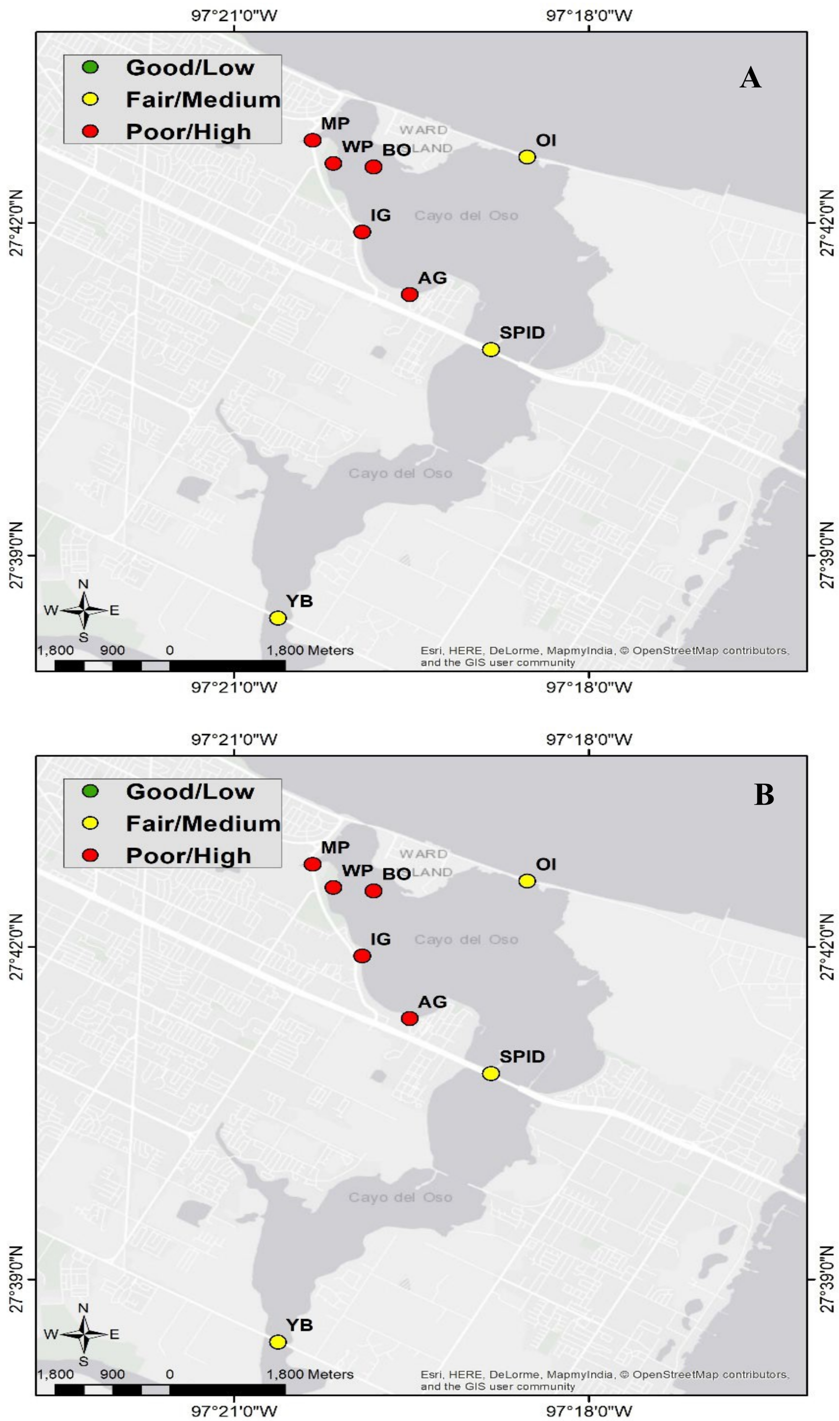

Figure 3. Oso Bay water quality index rating by site using NEEA (A) Annual (B) Summer).

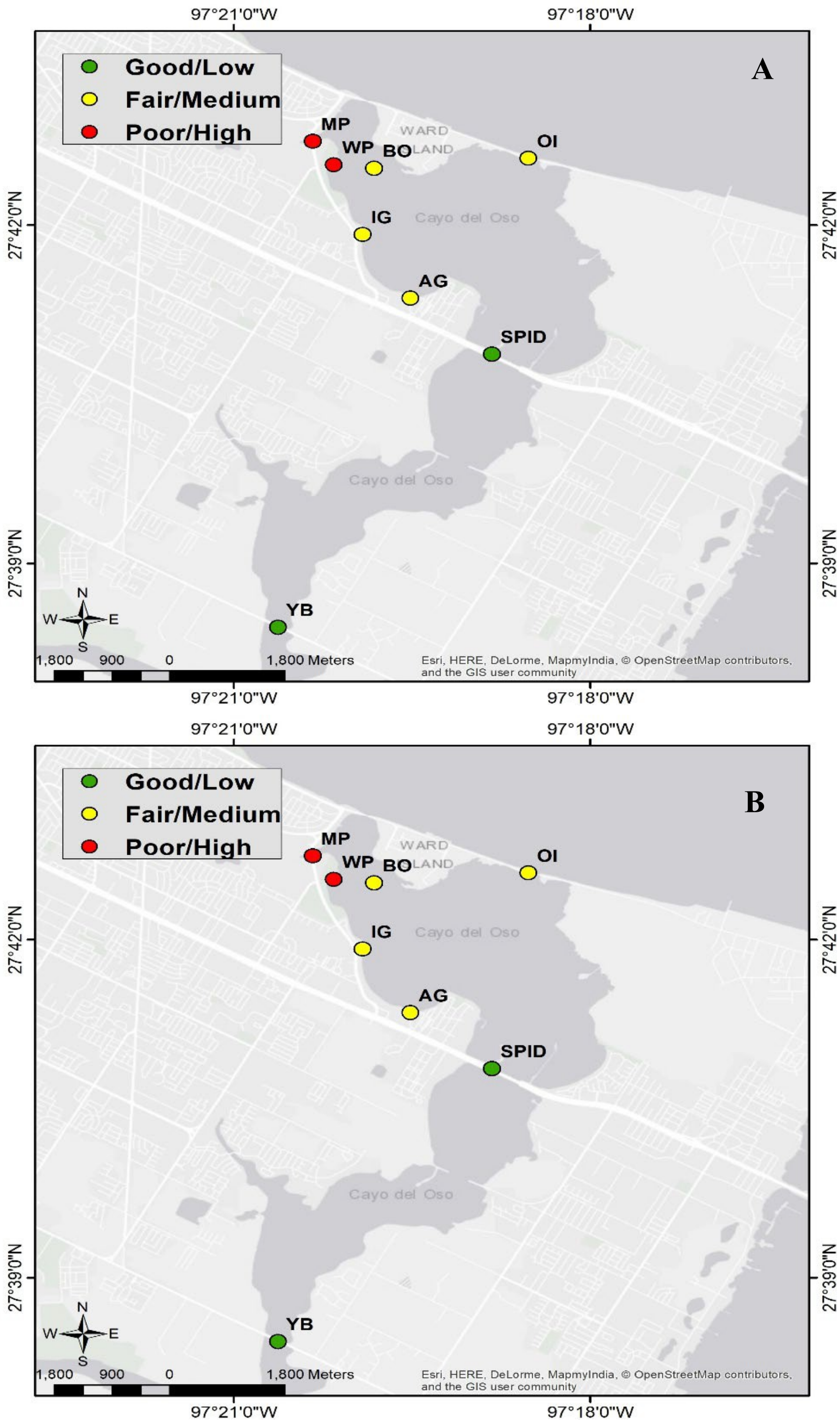

Figure 4. Oso Bay water quality index rating by site using TCEQ (A) Annual (B) Summer).

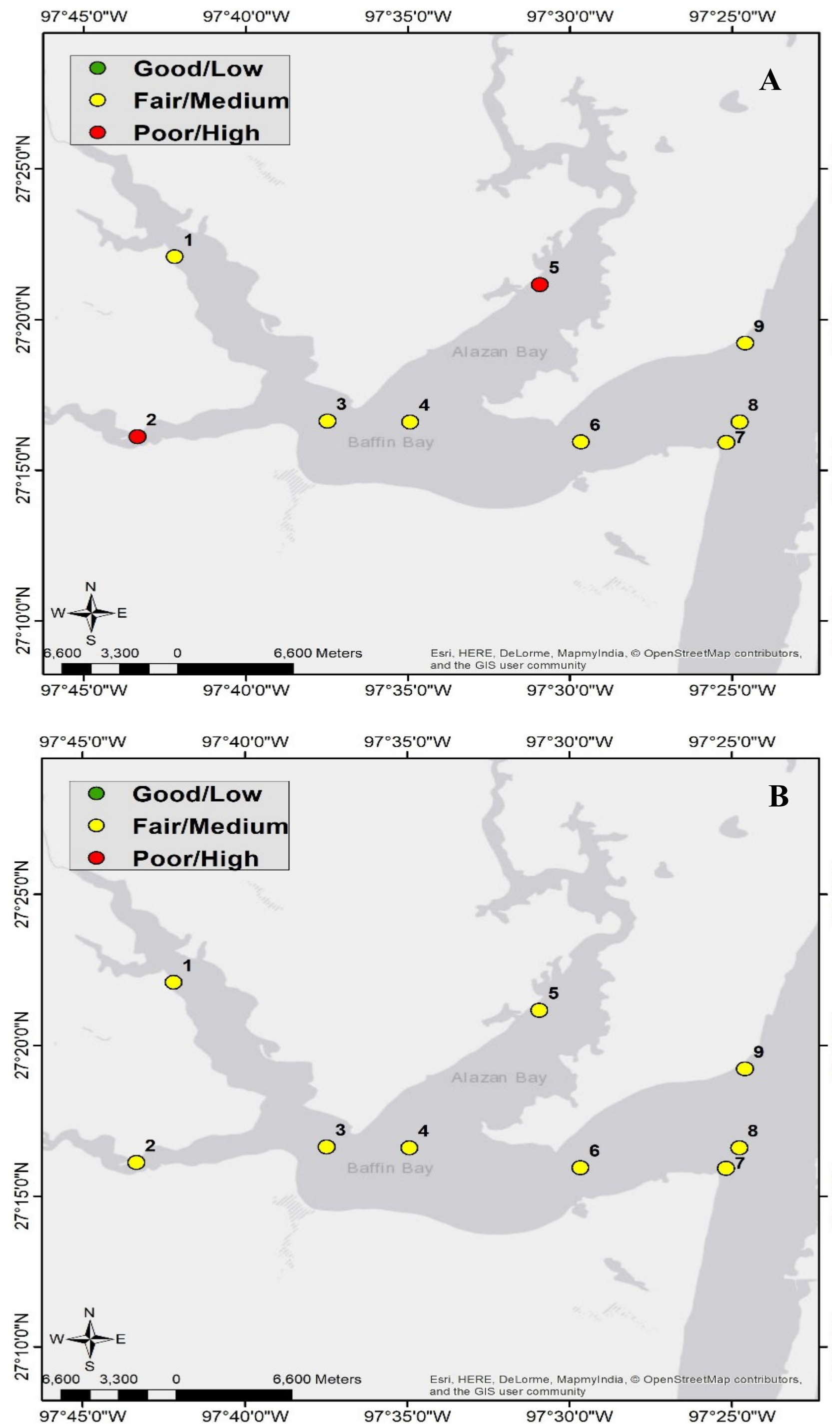

Figure 5. Baffin Bay water quality index rating by site using NCCR (A) Annual (B) Summer).

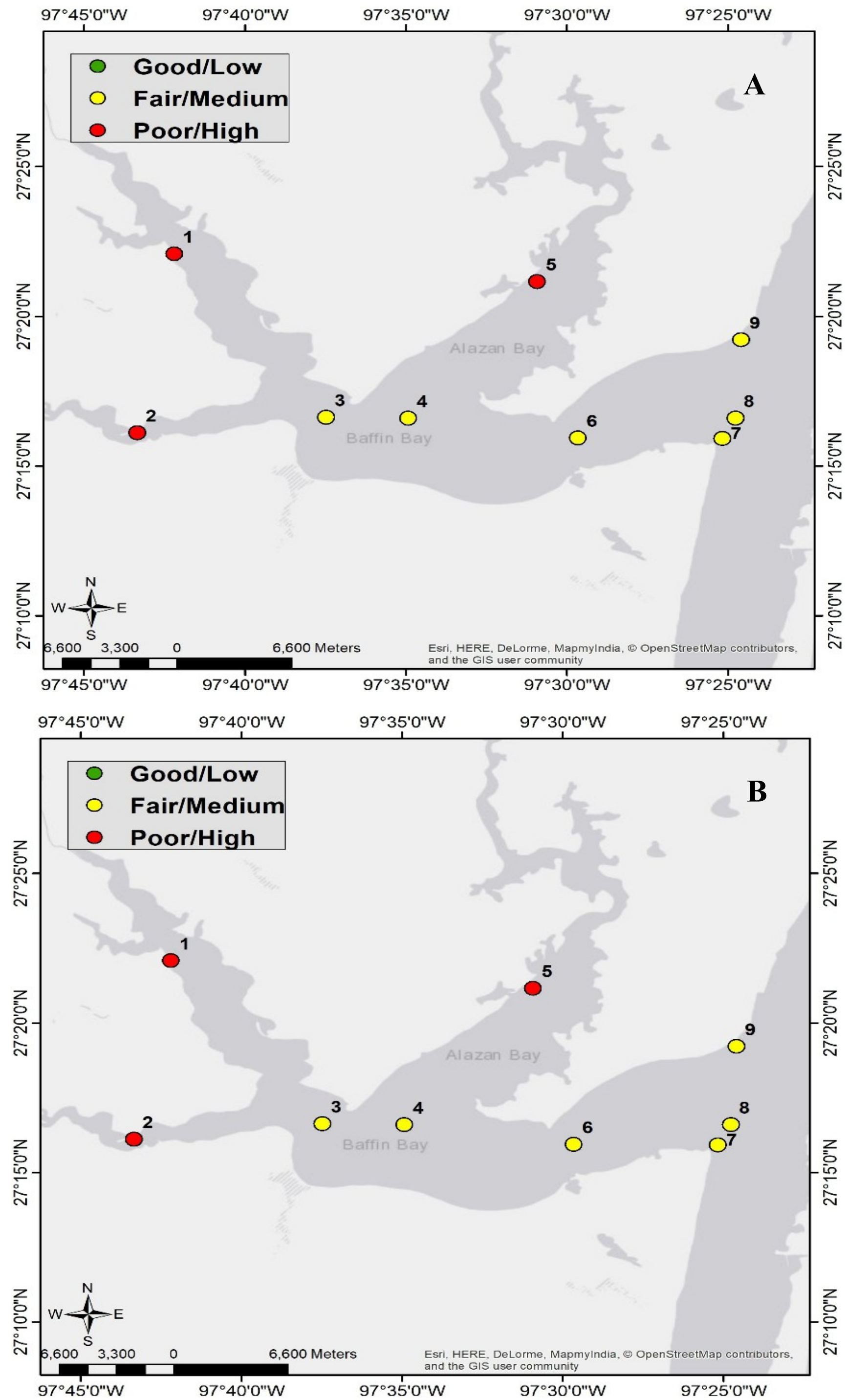

Figure 6. Baffin Bay water quality index rating by site using NEEA (A) Annual (B) Summer).

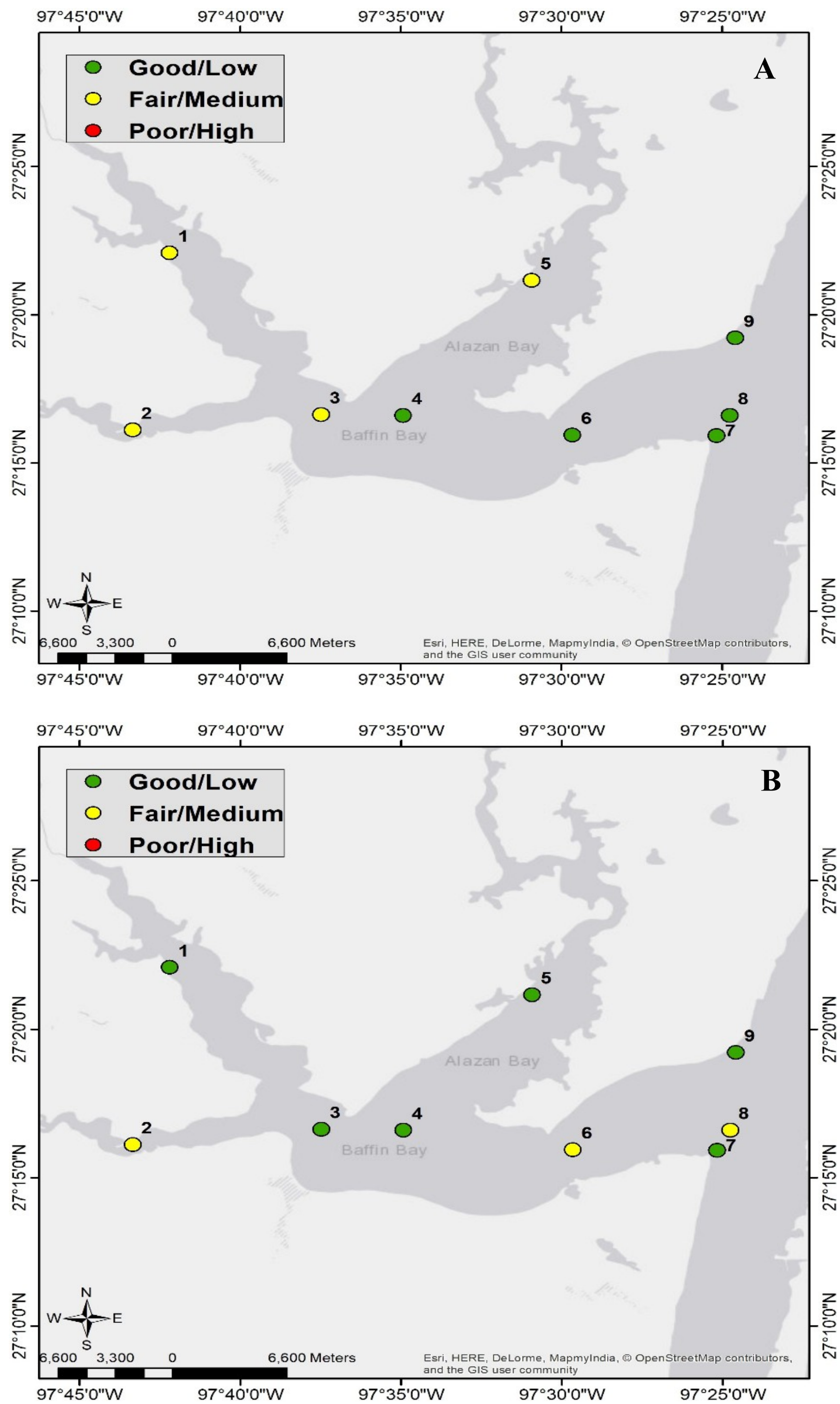

Figure 7. Baffin Bay water quality index rating by site using TCEQ (A) Annual (B) Summer).

Table 6. Oso Bay mean and standard deviation of annual temperature (ºC), salinity, nutrient concentrations (mg L^{-1}), chlorophyll concentrations (µg L^{-1}), Secchi depth (m) and dissolved oxygen (mg L^{-1}), August 2011 through September 2017.

Site #	Temperature	Salinity	DIP	DIN	TDN	Chlorophyll *a*	Water Clarity	Bottom Dissolved Oxygen
OI	25 ± 5.5	31 ± 12	0.048 ± 0.061	0.11 ± 0.16	0.66 ± 0.23	12 ± 10	0.34 ± 0.13	6.7 ± 2.1
MP	26 ± 5.8	15 ± 10	1.1 ± 0.76	2.7 ± 2.6	3.9 ± 2.8	75 ± 205	0.31 ± 0.18	5.3 ± 4.4
WP	26 ± 3.3	5.4 ± 7.6	2.1 ± 1.1	11.0 ± 4.9	12 ± 5.5	7.1 ± 18	0.27 ± 0.12	5.0 ± 2.0
IG	26 ± 6.2	27 ± 15	0.26 ± 0.21	0.62 ± 0.86	1.5 ± 0.87	32 ± 20	0.090 ± 0.050	6.4 ± 2.6
AG	25 ± 6.3	29 ± 15	0.14 ± 0.16	0.36 ± 0.64	1.1 ± 0.56	26 ± 18	0.13 ± 0.070	6.7 ± 3.0
SPID	23 ± 4.9	34 ± 10	0.095 ± 0.16	0.17 ± 0.27	0.94 ± 0.28	12 ± 6.7	0.25 ± 0.14	5.9 ± 1.6
YB	25 ± 5.8	37 ± 13	0.088 ± 0.20	0.28 ± 0.64	0.98 ± 0.51	13 ± 12	0.41 ± 0.22	5.9 ± 1.6
BO	24 ± 4.7	26 ± 9.0	0.34 ± 0.32	1.1 ± 1.4	1.4 ± 1.2	25 ± 23	0.11 ± 0.060	7.5 ± 3.1
Bay Average	25 ± 5.6	23 ± 16	1.0 ± 0.76	2.7 ± 2.5	3.4 ± 4.9	28 ± 95	0.33 ± 0.19	6.2 ± 2.9

Table 7. Oso Bay water quality assessment using National Coastal Condition Report IV: Summer (A) and Annual (B). Indicators ranked as Good (Green), Fair (Yellow), Fair to Poor (Orange) and Poor (Red), while overall site was ranked as Good (Green), Fair (Yellow) or Poor (Red).

A

Site	DIN			Rank	DIP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site Rating
OI	86%	14%	0%	4.7	25%	41%	34%	2.8	11%	81%	8%	3.1	72%	28%	0%	4.4	0%	0%	100%	1.0	Fair
MP	2%	15%	82%	1.4	0%	0%	100%	1.0	0%	12%	88%	1.2	53%	28%	20%	3.7	0%	0%	100%	1.0	Poor
WP	0%	0%	100%	1.0	0%	0%	100%	1.0	73%	19%	8%	4.3	43%	51%	6%	3.7	0%	0%	100%	1.0	Poor
IG	71%	13%	17%	4.1	0%	15%	85%	1.3	0%	26%	74%	1.5	61%	36%	4%	4.1	0%	0%	100%	1.0	Poor
AG	82%	12%	7%	4.5	5%	53%	42%	2.3	0%	26%	74%	1.5	55%	45%	0%	4.1	0%	0%	100%	1.0	Poor
SPID	100%	0%	0%	5.0	40%	20%	40%	3.0	20%	80%	0%	3.4	0%	100%	0%	3.0	0%	0%	100%	1.0	Fair
YB	95%	5%	0%	4.9	65%	32%	3%	4.2	16%	51%	33%	2.7	57%	43%	0%	4.1	0%	0%	100%	1.0	Fair
BO	67%	22%	11%	4.1	0%	11%	89%	1.2	0%	30%	70%	1.6	88%	0%	13%	4.5	0%	0%	100%	1.0	Poor

B

Site	DIN			Rank	DIP			Rank	Chlorophyll a			score	Dissolved Oxygen			Rank	Water Clarity			Rank	Site Rating
OI	71%	25%	4%	4.3	21%	46%	33%	2.8	25%	66%	9%	3.3	83%	17%	0%	4.7	0%	0%	100%	1.0	Fair
MP	1%	16%	83%	1.4	0%	0%	100%	1.0	4%	34%	62%	1.8	45%	39%	16%	3.6	0%	0%	100%	1.0	Poor
WP	0%	0%	100%	1.0	0%	0%	100%	1.0	68%	21%	12%	4.1	50%	49%	2%	4.0	0%	0%	100%	1.0	Poor
IG	46%	18%	36%	3.2	0%	11%	89%	1.2	2%	31%	68%	1.7	67%	31%	2%	4.3	0%	0%	100%	1.0	Poor
AG	55%	18%	27%	3.5	55%	18%	27%	3.5	9%	32%	59%	2.0	70%	30%	0%	4.4	0%	0%	100%	1.0	Fair
SPID	90%	8%	1%	4.8	90%	8%	1%	4.8	6%	82%	12%	2.9	56%	44%	0%	4.1	0%	0%	100%	1.0	Fair
YB	66%	22%	13%	4.1	66%	22%	13%	4.1	32%	51%	18%	3.3	75%	25%	0%	4.5	4%	0%	96%	1.1	Fair
BO	31%	20%	49%	2.7	3%	13%	85%	1.4	15%	46%	40%	2.5	90%	7%	3%	4.7	0%	0%	100%	1.0	Poor

Table 8. Oso Bay water quality assessment using National Estuarine Eutrophication Assessment: Summer (A) and Annual (B). Indicators ranked as Low (Green), Low to Medium (Light Green), Medium (Yellow), Medium to High (Orange) and High (Red), while overall site ranked as Low (Green), Medium (Yellow) or High (Red).

A

Site	TDN			Rank	TDP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site WQI
OI	0%	90%	10%	2.8	nc	nc	nc		11%	81%	8%	3.1	72%	28%	0%	4.4	0%	0%	100%	1.0	Medium
MP	0%	0%	100%	1.0	nc	nc	nc		0%	12%	88%	1.2	53%	28%	20%	3.7	0%	0%	100%	1.0	High
WP	0%	0%	100%	1.0	nc	nc	nc		73%	19%	8%	4.3	43%	51%	6%	3.7	0%	0%	100%	1.0	High
IG	0%	54%	46%	2.1	nc	nc	nc		0%	26%	74%	1.5	61%	36%	4%	4.1	0%	0%	100%	1.0	High
AG	0%	65%	36%	2.3	nc	nc	nc		0%	26%	74%	1.5	55%	45%	0%	4.1	0%	0%	100%	1.0	High
SPID	0%	83%	17%	2.7	nc	nc	nc		20%	80%	0%	3.4	0%	100%	0%	3.0	0%	0%	100%	1.0	Medium
YB	0%	65%	35%	2.3	nc	nc	nc		16%	51%	33%	2.7	57%	43%	0%	4.1	0%	0%	100%	1.0	Medium
BO	0%	50%	50%	2.0	nc	nc	nc		0%	30%	70%	1.6	88%	0%	13%	4.5	0%	0%	100%	1.0	High

B

Site	TDN			Rank	TDP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site WQI
OI	0%	91%	9%	2.8	nc	nc	nc		25%	66%	9%	3.3	83%	17%	0%	4.7	0%	0%	100%	1.0	Medium
MP	0%	7%	93%	1.1	nc	nc	nc		4%	34%	62%	1.8	45%	39%	16%	3.6	0%	0%	100%	1.0	High
WP	0%	0%	100%	1.0	nc	nc	nc		68%	21%	12%	4.1	50%	49%	2%	4.0	0%	0%	100%	1.0	High
IG	0%	44%	56%	1.9	nc	nc	nc		2%	31%	68%	1.7	67%	31%	2%	4.3	0%	0%	100%	1.0	High
AG	0%	59%	41%	2.2	nc	nc	nc		9%	32%	59%	2.0	70%	30%	0%	4.4	0%	0%	100%	1.0	High
SPID	0%	67%	33%	2.3	nc	nc	nc		6%	82%	12%	2.9	56%	44%	0%	4.1	0%	0%	100%	1.0	Medium
YB	0%	71%	29%	2.4	nc	nc	nc		32%	51%	18%	3.3	75%	25%	0%	4.5	4%	0%	96%	1.1	Medium
BO	0%	31%	69%	1.6	nc	nc	nc		15%	46%	40%	2.5	90%	7%	3%	4.7	0%	0%	100%	1.0	High

Table 9. Oso Bay water quality assessment using TCEQ Guidance for Assessing and Reporting Surface Water Quality: Summer (A) and Annual (B). Indicators ranked as Good (Green), Good to Fair (Light Green), Fair (Yellow), Fair to Poor (Orange) and Poor (Red), while overall site ranked as Good (green), Fair (Yellow), or Poor (Red).

A

Site	DIN		Rank	DIP		Rank	Chlorophyll *a*		Rank	Dissolved Oxygen		Rank	Site WQI
OI	98%	2%	4.9	98%	2%	4.9	46%	54%	2.8	93%	7%	4.7	Fair
MP	5%	95%	1.2	3%	97%	1.1	5%	95%	1.2	63%	38%	3.5	Poor
WP	0%	100%	1.0	0%	100%	1.0	82%	18%	4.3	55%	46%	3.2	Poor
IG	84%	16%	4.4	65%	35%	3.6	19%	82%	1.7	81%	19%	4.2	Fair
AG	87%	13%	4.5	92%	8%	4.7	3%	97%	1.1	66%	34%	3.6	Fair
SPID	100%	0%	5.0	80%	20%	4.2	100%	0%	5.0	83%	17%	4.3	Good
YB	100%	0%	5.0	97%	3%	4.9	40%	60%	2.6	91%	9%	4.6	Good
BO	78%	22%	4.1	44%	56%	2.8	18%	82%	1.7	88%	13%	4.5	Fair

B

Site	DIN		Rank	DIP		Rank	Chlorophyll *a*		Rank	Dissolved Oxygen		Rank	Site WQI
OI	89%	11%	4.5	96%	4%	4.8	62%	38%	3.5	96%	4%	4.8	Fair
MP	6%	94%	1.2	2%	98%	1.1	23%	77%	1.9	57%	44%	3.3	Poor
WP	0%	100%	1.0	1%	99%	1.0	89%	11%	4.5	70%	30%	3.8	Poor
IG	66%	34%	3.6	45%	55%	2.8	18%	82%	1.7	85%	16%	4.4	Fair
AG	66%	34%	3.6	72%	29%	3.9	19%	81%	1.7	81%	19%	4.2	Fair
SPID	88%	12%	4.5	82%	18%	4.3	65%	35%	3.6	94%	6%	4.8	Good
YB	81%	19%	4.3	87%	13%	4.5	62%	38%	3.5	95%	5%	4.8	Good
BO	40%	60%	2.6	42%	58%	2.7	39%	62%	2.5	90%	10%	4.6	Fair

Table 10. Baffin Bay mean and standard deviation of annual temperature (°C), salinity, nutrient concentrations (mg L^{-1}), chlorophyll concentrations (µg L^{-1}), Secchi depth (m) and dissolved oxygen (mg L^{-1}), May 2013 through December 2018.

Site #	Temperature	Salinity	DIP	DIN	TDN	TDP	Chlorophyll *a*	Water Clarity	Bottom Dissolved Oxygen
BB 1	23 ± 5.7	39 ± 17	0.057 ± 0.085	0.090 ± 0.12	1.1 ± 0.22	0.10 ± 0.10	17 ± 14	0.44 ± 0.19	5.5 ± 1.7
BB 2	24 ± 5.8	45 ± 15	0.011 ± 0.014	0.068 ± 0.089	1.2 ± 0.28	0.042 ± 0.0099	22 ± 15	0.46 ± 0.12	4.9 ± 1.8
BB 3	23 ± 5.9	43 ± 13	0.014 ± 0.025	0.065 ± 0.068	1.0 ± 0.23	0.038 ± 0.0098	17 ± 10	0.53 ± 0.25	5.2 ± 1.4
BB 4	24 ± 5.8	44 ± 12	0.011 ± 0.016	0.078 ± 0.076	1.0 ± 0.21	0.040 ± 0.011	17 ± 11	0.51 ± 0.23	5.3 ± 1.5
BB 5	23 ± 5.7	43 ± 17	0.029 ± 0.064	0.13 ± 0.21	1.1 ± 0.22	0.051 ± 0.038	16 ± 9.9	0.37 ± 0.20	5.3 ± 1.6
BB 6	24 ± 6.1	42 ± 9.8	0.0070 ± 0.0060	0.054 ± 0.055	0.98 ± 0.23	0.036 ± 0.0095	15 ± 10	0.55 ± 0.20	5.0 ± 1.6
BB 7	24 ± 5.9	41 ± 6.9	0.012 ± 0.044	0.060 ± 0.98	0.84 ± 0.18	0.030 ± 0.0072	13 ± 8.6	0.56 ± 0.20	5.6 ± 1.4
BB 8	23 ± 6.1	41 ± 7.2	0.0060 ± 0.0060	0.049 ± 0.072	0.88 ± 0.17	0.030 ± 0.012	13 ± 8.8	0.61± 0.18	5.0 ± 1.7
BB 9	23 ± 6.1	41 ± 6.9	0.0060 ± 0.0040	0.054 ± 0.064	0.86 ± 0.17	0.027 ± 0.0070	14 ± 8.9	0.57 ± 0.23	5.4 ± 1.5
Bay Average	23 ± 5.8	42 ± 13	0.018 ± 0.045	0.074 ± 0.11	1.0 ± 0.25	0.046 ± 0.045	17 ± 11	0.50 ± 0.22	5.2 ± 1.6

Table 11. Baffin Bay water quality assessment using National Coastal Condition Report IV: Summer (A) and Annual (B). Percentage of samples ranked as Good (Green), Good to Fair (Light Green), Fair (Yellow), Fair to Poor (Orange) and Poor (Red), while overall site ranked as Good (green), Fair (Yellow), or Poor (Red).

A

Site	DIN			Rank	DIP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site WQI
BB1	86%	14%	0%	4.7	39%	31%	31%	3.2	8%	42%	50%	2.2	24%	77%	0%	3.5	0%	0%	100%	1.0	Fair
BB2	81%	19%	0%	4.6	64%	31%	6%	4.2	0%	44%	56%	1.9	6%	72%	22%	2.7	0%	0%	100%	1.0	Poor
BB3	67%	33%	0%	4.3	66%	28%	6%	4.2	0%	56%	44%	2.1	6%	94%	0%	3.1	0%	6%	94%	1.1	Fair
BB4	56%	44%	0%	4.1	58%	37%	5%	4.1	0%	61%	39%	2.2	24%	77%	0%	3.5	0%	0%	100%	1.0	Fair
BB5	50%	50%	0%	4.0	61%	28%	11%	4.0	0%	39%	61%	1.8	22%	72%	6%	3.3	0%	0%	100%	1.0	Poor
BB6	72%	28%	0%	4.4	71%	29%	0%	4.4	11%	56%	33%	2.6	17%	67%	17%	3.0	0%	6%	94%	1.1	Fair
BB7	65%	35%	0%	4.3	95%	5%	0%	4.9	23%	77%	0%	3.5	30%	70%	0%	3.6	0%	9%	91%	1.2	Fair
BB8	77%	23%	0%	4.5	80%	20%	0%	4.6	9%	82%	9%	3.0	0%	91%	9%	2.8	0%	9%	91%	1.2	Fair
BB9	55%	46%	0%	4.1	79%	21%	0%	4.6	12%	66%	22%	2.8	20%	80%	0%	3.4	0%	0%	100%	1.0	Fair

B

Site	DIN			Rank	DIP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site WQI
BB1	77%	20%	3%	4.5	26%	43%	31%	2.9	16%	54%	29%	2.7	58%	41%	1%	4.1	0%	3%	97%	1.1	Fair
BB2	82%	18%	0%	4.6	66%	31%	3%	4.3	4%	55%	41%	2.3	44%	50%	6%	3.8	0%	1%	99%	1.0	Fair
BB3	80%	20%	0%	4.6	66%	31%	3%	4.3	4%	66%	31%	2.5	51%	49%	0%	4.0	0%	6%	94%	1.1	Fair
BB4	74%	26%	0%	4.5	63%	36%	1%	4.2	6%	64%	30%	2.5	56%	44%	0%	4.1	0%	7%	93%	1.1	Fair
BB5	71%	22%	7%	4.3	63%	25%	13%	4.0	10%	57%	33%	2.5	58%	39%	3%	4.1	0%	3%	97%	1.1	Fair
BB6	84%	16%	0%	4.7	81%	19%	0%	4.6	12%	61%	27%	2.7	47%	52%	2%	3.9	0%	5%	95%	1.1	Fair
BB7	86%	11%	2%	4.7	97%	1%	2%	4.9	15%	66%	19%	2.9	61%	39%	0%	4.2	0%	5%	96%	1.1	Fair
BB8	93%	7%	0%	4.9	84%	16%	0%	4.7	5%	78%	17%	2.7	43%	55%	2%	3.8	0%	5%	96%	1.1	Fair
BB9	84%	17%	0%	4.7	85%	15%	0%	4.7	7%	78%	15%	2.8	60%	41%	0%	4.2	0%	9%	91%	1.2	Fair

Table 12. Baffin Bay water quality assessment using National Estuarine Eutrophication Assessment: Summer (A) and Annual (B). Percentage of samples ranked as Low (Green), Low to Medium (Light Green), Medium (Yellow), Medium to High (Orange) and High (Red), while overall site ranked as Good (green), Fair (Yellow), or Poor (Red).

A

Site	TDN			Rank	TDP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site WQI
BB1	0%	21%	79%	1.4	0%	80%	20%	2.6	8%	42%	50%	2.2	24%	77%	0%	3.5	0%	0%	100%	1.0	High
BB2	0%	11%	89%	1.2	0%	100%	0%	3.0	0%	44%	56%	1.9	6%	72%	22%	2.7	0%	0%	100%	1.0	High
BB3	0%	50%	50%	2.0	0%	100%	0%	3.0	0%	56%	44%	2.1	6%	94%	0%	3.1	0%	6%	94%	1.1	Medium
BB4	0%	70%	30%	2.4	0%	100%	0%	3.0	0%	61%	39%	2.2	24%	77%	0%	3.5	0%	0%	100%	1.0	Medium
BB5	0%	29%	71%	1.6	0%	89%	11%	2.8	0%	39%	61%	1.8	22%	72%	6%	3.3	0%	0%	100%	1.0	High
BB6	0%	60%	40%	2.2	0%	100%	0%	3.0	11%	56%	33%	2.6	17%	67%	17%	3.0	0%	6%	94%	1.1	Medium
BB7	0%	91%	9%	2.8	0%	100%	0%	3.0	23%	77%	0%	3.5	30%	70%	0%	3.6	0%	9%	91%	1.2	Medium
BB8	0%	72%	28%	2.4	0%	100%	0%	3.0	9%	82%	9%	3.0	0%	91%	9%	2.8	0%	9%	91%	1.2	Medium
BB9	0%	81%	18%	2.6	0%	100%	0%	3.0	12%	66%	22%	2.8	20%	80%	0%	3.4	0%	0%	100%	1.0	Medium

B

Site	TDN			Rank	TDP			Rank	Chlorophyll a			Rank	Dissolved Oxygen			Rank	Water Clarity			Rank	Site WQI
BB1	0%	35%	66%	1.7	0%	74%	26%	2.5	16%	54%	29%	2.7	58%	41%	1%	4.1	0%	3%	97%	1.1	High
BB2	0%	23%	77%	1.5	0%	100%	0%	3.0	4%	55%	41%	2.3	44%	50%	6%	3.8	0%	1%	99%	1.0	High
BB3	0%	54%	46%	2.1	3%	97%	0%	3.1	4%	66%	31%	2.5	51%	49%	0%	4.0	0%	6%	94%	1.1	Medium
BB4	0%	58%	42%	2.2	0%	100%	0%	3.0	6%	64%	30%	2.5	56%	44%	0%	4.1	0%	7%	93%	1.1	Medium
BB5	0%	43%	57%	1.9	0%	93%	8%	2.9	10%	57%	33%	2.5	58%	39%	3%	4.1	0%	3%	97%	1.1	High
BB6	0%	63%	37%	2.3	0%	100%	0%	3.0	12%	61%	27%	2.7	47%	52%	2%	3.9	0%	5%	95%	1.1	Medium
BB7	0%	83%	17%	2.7	0%	100%	0%	3.0	15%	66%	19%	2.9	61%	39%	0%	4.2	0%	5%	96%	1.1	Medium
BB8	0%	74%	26%	2.5	0%	100%	0%	3.0	5%	78%	17%	2.7	43%	55%	2%	3.8	0%	5%	96%	1.1	Medium
BB9	0%	83%	17%	2.7	0%	100%	0%	3.0	7%	78%	15%	2.8	60%	41%	0%	4.2	0%	9%	91%	1.2	Medium

Table 13. Baffin Bay water quality assessment using TCEQ Guidance for Assessing and Reporting Surface Water Quality: Summer (A) and Annual (B). Percentage of samples ranked as Good (Green), Fair (Yellow), and Poor (Red), while overall site ranked as Good (green), Fair (Yellow), or Poor (Red).

A

Site	DIN		score	DIP		score	Chlorophyll *a*		score	Dissolved Oxygen		score	Site Rating
BB1	100%	0%	5.0	89%	11%	4.6	24%	77%	1.9	71%	29%	3.8	Fair
BB2	94%	6%	4.8	100%	0%	5.0	28%	72%	2.1	28%	72%	2.1	Fair
BB3	97%	3%	4.9	100%	0%	5.0	22%	78%	1.9	53%	47%	3.1	Fair
BB4	94%	6%	4.8	100%	0%	5.0	28%	72%	2.1	56%	44%	3.2	Good
BB5	89%	11%	4.6	100%	0%	5.0	20%	80%	1.8	56%	44%	3.2	Fair
BB6	100%	0%	5.0	100%	0%	5.0	47%	83%	3.2	28%	72%	2.1	Good
BB7	100%	10%	5.1	100%	0%	5.0	46%	55%	2.8	82%	18%	4.3	Good
BB8	91%	9%	4.6	100%	0%	5.0	33%	67%	2.3	36%	64%	2.5	Good
BB9	91%	9%	4.6	100%	0%	5.0	32%	68%	2.3	50%	50%	3.0	Good

B

Site	DIN		score	DIP		score	Chlorophyll *a*		score	Dissolved Oxygen		score	Site Rating
BB1	94%	6%	4.8	92%	9%	4.7	44%	56%	2.7	78%	23%	4.1	Good
BB2	94%	6%	4.8	100%	0%	5.0	31%	69%	2.3	65%	35%	3.6	Fair
BB3	98%	2%	4.9	99%	1%	4.9	41%	59%	2.6	78%	22%	4.1	Good
BB4	97%	3%	4.9	100%	0%	5.0	36%	64%	2.5	81%	19%	4.2	Good
BB5	89%	11%	4.5	97%	4%	4.9	44%	56%	2.7	79%	21%	4.2	Good
BB6	100%	0%	5.0	100%	0%	5.0	48%	52%	2.9	68%	32%	3.7	Fair
BB7	96%	5%	4.8	98%	2%	4.9	52%	48%	3.1	88%	12%	4.5	Good
BB8	98%	2%	4.9	100%	0%	5.0	49%	51%	3.0	67%	33%	3.7	Fair
BB9	98%	2%	4.9	100%	0%	5.0	54%	47%	3.1	81%	19%	4.2	Good