Impact of the 2021 freeze event on Baffin Bay water quality

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Table of Contents

Executive Summary

This study evaluated the effect of a freeze event that occurred from February 14 to 16, 2021, on the water quality of Baffin Bay. We compared monthly water data from 2021 with historical data collected from 2014-2020 to evaluate potential freeze impacts. Despite a sharp but ephemeral drop in water temperature accompanying the freeze and a subsequent fish kill, there was no detectable impact on any of the physical (dissolved oxygen, pH) or nutrient indicators. In contrast, a companion study in the more restricted canal system of North Padre Island showed a sharp increase in nutrients and chlorophyll post-freeze, likely resulting from nutrient release from decaying fish. These findings suggest that restricted circulation settings such as canal systems may be more susceptible to disturbance events such as freezes than an open bay system such as Baffin Bay.

Acknowledgments

First and foremost, we thank the many volunteers who dedicated four years of their time and resources from 2013-2017 to the collection of the water quality data in the Baffin Bay. This study would not have been possible without their efforts. We are also grateful to the Celanese Corporation for funding the long-term monitoring program, and the Coastal Bend Bays & Estuaries Program for funding this analysis of freeze impacts. Finally, we thank the many technicians and students who have contributed to the data collection and analysis over the past nine years.

List of Figures

Introduction

Baffin Bay is a subtropical lagoon located on the south Texas (USA) coast and is part of the Laguna Madre estuary complex. Because it typically receives low base freshwater inflow and has no direct connection to the Gulf of Mexico, long residence times (> 1 year on average) are a common phenomenon (Montagna et al., 2018; Wetz et al., 2017). These long residence times increase the sensitivity of Baffin Bay to nutrient inputs. Indeed, high and increasing nutrient or chlorophyll levels over the past 3-4 decades, as well as the persistent, recurring blooms of harmful 'brown tide' phytoplankton (*Aureoumbra lagunensis),* are evidence of this sensitivity (Wetz et al. 2017; Bugica et al., 2020; Beecraft et al. in review).

Acute freeze events in subtropical regions can represent a disturbance event with significant impacts on ecosystems. On the Texas coast, for example, episodic freezing temperatures and associated abrupt water temperature decreases can lead to fish mortality events (Texas Parks and Wildlife Department, 2021; Thronson and Quigg, 2008). For example, three major freeze events that occurred during the 1980s, including December 1983, February 1989, and December 1989, killed an estimated 31.9 million fish (Texas Parks and Wildlife Department, 2021). The massive amount of dead marine organisms during freeze events can release nutrients during the decay process that may stimulate algal growth (Whitledge 1993). In the Baffin Bay-Upper Laguna Madre complex, an *A. lagunensis* bloom that began in late 1989/early 1990 was believed to have been stimulated in part by a pulse of nutrients from freeze-killed fish (Buskey et al., 2001), although the same period was preceded by, and coincided with, declining salinity that was indicative of increased rainfall and runoff from the watershed that could have also been a source of nutrients (see Whitledge 1993).

From February 14 to 16, 2021, a severe winter storm brought sub-freezing air temperatures to much of the Texas coast, resulting in rapid cooling of water temperatures and mortality of approximately 3.8 million fish along the Texas coast. Around 1.3 million dead fish were reported in Upper Laguna Madre alone. Although previous work documented the impact of a freeze on fish mortality and water quality in the region, it is unclear how uniformly applicable the results are in different freeze scenarios (timing, magnitude, scale of impacts). Given the ongoing concerns about water quality in the Baffin Bay, there was a strong desire to understand if the 2021 freeze and subsequent fish mortality would exacerbate the situation. The main goal of the present work was thus to understand the water quality impact of the 2021 freeze event.

Methods

Study area and sampling procedure

Baffin Bay is a shallow (~1 m) secondary bay of upper Laguna Madre, spanning an area of 220 km^2. It has a negative inflow balance on average, resulting in frequent hypersalinity in the upper reaches of the bay. The freshwater streams flowing into the Baffin Bay are ephemeral, while the nearest inlets to the Gulf of Mexico are Packery Channel (~41 km north of Baffin Bay) and Port Mansfield (~80 km south of Baffin Bay). Residence times range from ~3 weeks during high rainfall periods to many years during droughts, with an average residence time of > 1 year (Cira et al., 2021).

Fieldwork and ancillary data collection

The present study compared water quality monitoring data collected from February to August of 2021 with previous years, including 2014-2020, to evaluate the effects of the 2021 freeze on Baffin Bay water quality. Monthly water quality data, including physical parameters and water samples, were collected from six fixed monitoring stations located at different parts of Baffin and its tertiary bays (Fig 1). Specifically, three stations were located inside the tertiary bays, while the rest were inside Baffin Bay. They were 'BB1' inside Cayo del Grullo, 'BB2' inside Laguna Salada, 'BB3' located inside Baffin near the mouth of both Cayo del Grullo and Laguna Salada, 'BB4' situated in the middle of the Baffin Bay at the mouth of Alazan Bay, 'BB5' inside Alazan Bay, and 'BB6' positioned at the month of the Baffin Bay near upper Laguna Madre.

Physical water quality parameters included water temperature (°C), salinity, dissolved oxygen (DO, mg/L), and pH. A YSI® ProPlus was used to measure these parameters. The probes underwent the company-specified calibration procedure for all measured parameters before and after the fieldwork to ensure data quality. Water samples were collected from immediately below the surface in clean acid-washed, amber-colored high-density polyethylene (HDPE) bottles (1L). An extendable sampling stick was used to collect water samples. After collection, the samples were stored in an airtight cooler filled with ice and immediately transported back to the lab for filtration and further laboratory analysis.

Daily average ambient air temperature (°C) and average monthly precipitation (mm) data from 01/2014 to 01/2022 were obtained from a weather station located at the United States Naval Air Station at Kingsville (NAS). Data were downloaded from the National Centers for Environmental Information (ncdc.noaa.gov).

Laboratory Analyses

After homogenization, a portion of the sample was filtered through precombusted (450°C for 24 hours) 0.7 mm GF/F filters into acid-washed HDPE bottles (20 mL) in duplicate and stored frozen (-20°C) until nutrient analysis. Another portion (25 mL) was filtered (<5 mm Hg) through 25 mm Whatman® GF/F filters and stored in Vacutainers at -80°C until fluorometric analysis for chlorophyll-*a* (µg/L) (Wetz et al., 2016). Following the American Public Health Association (APHA) methods, the concentration of ammonium (NH_4^+), nitrate + nitrite (NO_3^- + NO_2^-), orthophosphate (PO_4^{3-}), and silicate (SiO_4^-) were determined in Seal QuAAtro® auto-analyzer. The dissolved organic carbon (DOC), total nitrogen (TN), total dissolved nitrogen (TDN), and total organic carbon (TOC) were measured in a Shimadzu® TOC-V TN-1 module with self-contained magnetic stirrers (ASTM 2015). Unfiltered samples were used for measuring TOC. Dissolved organic nitrogen (DON) is the difference between TDN and DIN. The PO_4^{3-} concentration is expressed as dissolved inorganic phosphorus (DIP). Dissolved inorganic nitrogen (DIN) is the sum of NH_4^+ and NO_3^- + NO_2^-. The details of the analytical procedures, including standard protocols, instrument calibration, standards, blanks, and quality control, can be obtained from the previously published literature (Wetz et al., 2016, 2017).

Statistical analyses

The water quality data from six monitoring stations (BB1 to BB6) were averaged to compare the bay water quality before (February to August of 2014-2020) and during/after (February to August of 2021) the freeze event. Mann-Whitney-U test ($\alpha \leq 0.05$) was performed to evaluate any significant change in monthly water quality before (February to August of 2014-2020) and during/after the freeze year (February to August of 2021). Statistical analyses were performed at a 95% confidence level (p-value < 0.05) in the RStudio 2022.02.0 version (R® Core

Team). The ggplot2 data visualization package of R was used for plotting figures. ArcGIS Desktop version 10.8.2. was used for the preparation of location map.

Results and Discussion

Temperature, precipitation and salinity

Exceptionally low temperatures (-0.6°C to -3.3°C) were recorded from 14-16 February, 2021 (Fig 2A &B). Relatively low water temperatures lasted ~1 week overall, but quickly returned back to more normal seasonal conditions. Based on the monthly water temperature recordings, there was no statistical difference between 2021 and 2014-2020 (Fig 2C; $p > 0.05$). Nevertheless, water temperature responds rapidly to air temperature changes in this shallow bay (Wetz unpubl. data) and higher frequency sampling would have been needed to capture the temperature effects of the short-lived freeze. Precipitation was generally comparable in the February-May timeframe between time periods (Fig 2D), but rainfall was much higher in the watershed in June-July 2021 compared to the previous years. Salinity was slighly higher from February-May 2021 than the same timeframe in 2014-2020, but a sharp decrease in salinity was observed from May to July of 2021 accompanying the heavy rainfall (Fig 2E).

pH and DO

The typical seasonal pattern in DO was observed, with higher levels observed during cooler months, decreasing through summer (Fig 3A). However, no statistical differences were detected in DO between 2021 and the previous years. pH was generally similar between years, but was substantially higher in July-August of 2021 compaired to the same period in 2014-2020, likely due to the delivery of watershed carbonate minerals during the period of high precipitation (Fig 3B).

Nutrients

NH_4^+ and PO_4^{3-} concentrations did not significantly differ ($p > 0.05$) between February-August 2021 and 2014-2020 (Fig 4A,C). Noticeably higher PO_4^{3-} concentrations were observed in June-July 2021, likely due to runoff from the watershed. On the other hand, $NO_3^- + NO_2^-$ levels were lower between March-May of 2021 compared to the same timeframe in 2014-2020 (Fig 4B). It is unclear why this was the case, but one possibility may be that the slightly higher salinities during that timeframe in 2021 were indicative of less watershed-derived nutrients entering the system via runoff. TN was generally similar from February-May of 2021 compared to earlier years (Fig 4D). DON was slightly higher from February-May 2021 compared to 2014-2020, and the differences were significant ($p < 0.05$)(Fig 4E). After May 2021, much lower TN and DON concentrations were detected, likely due to either the flushing effect from the high rainfall and/or dilution with freshwater. SiO_4^- levels in the bay were significantly higher ($P < 0.05$) from February-August 2021 than in 2014-2020, increasing sharply in June and July due to the high runoff that occurred (Fig 4F).

Chlorophyll-a, TOC, and DOC

Chlorophyll-a was lower during February-May 2021 than in prior years, but increased to historical levels thereafter (Fig 5A). TOC and DOC were not significantly different between February-May of 2021 and 2014-2020 (Figs 5B,5C). Both decreased sharply thereafter, again likely due to the flushing effects of the high rainfall period in 2021 and/or due to dilution with freshwater.

Conclusions

Although 1.3 million fish kills were reported in Upper Laguna Madre, no obvious effects on water quality were noted in Baffin Bay. A companion study found noticeable increases in nitrate and ammonium accompanying a freeze-related fish kill in the North Padre Island canal system, which also led to a phytoplankton bloom (Cutajar 2022). Nonetheless, those effects were relatively short-lived (<1 month). To fully capture effects of future freezes and/or fish kills, it is clear that higher frequency (daily-weekly) will be needed. Regardless, results from both studies show that the effects of fish kills a) may be more pronounced in restricted circulation environments such as canal systems, and b) are not likely to have long-term impacts on the affected ecosystems.

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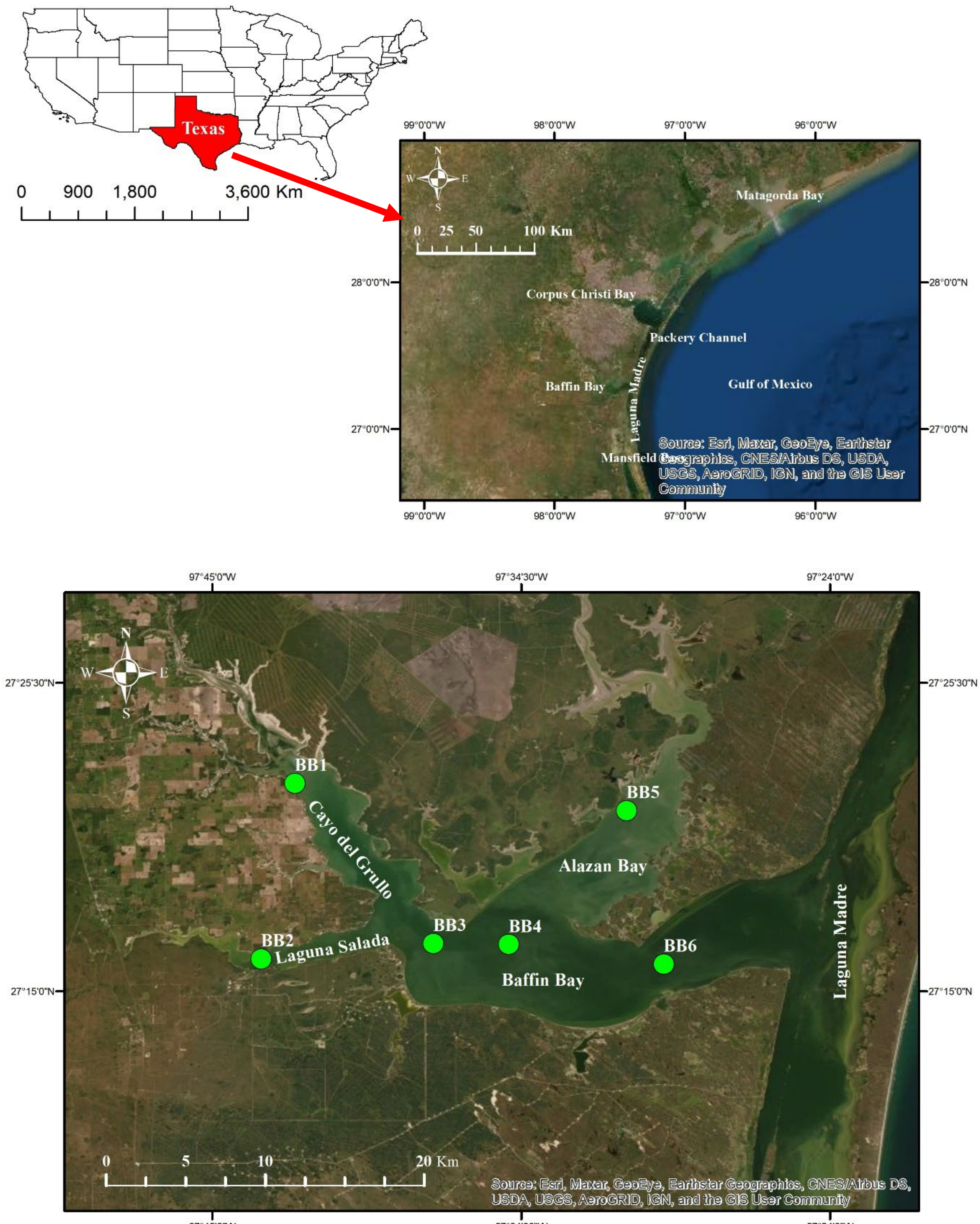
Fig. 1


Texas
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99°0'0"W
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96°0'0"W
28°0'0"N
27°0'0"N
N
S
W
E
0 25 50 100 Km
Matagorda Bay
Corpus Christi Bay
Packery Channel
Baffin Bay
Laguna Madre
Gulf of Mexico
Mansfield Pass
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
97°45'0"W
97°34'30"W
97°24'0"W
27°25'30"N
27°15'0"N
BB1
BB2
BB3
BB4
BB5
BB6
Cayo del Grullo
Laguna Salada
Alazan Bay
Baffin Bay
Laguna Madre
0 5 10 20 Km
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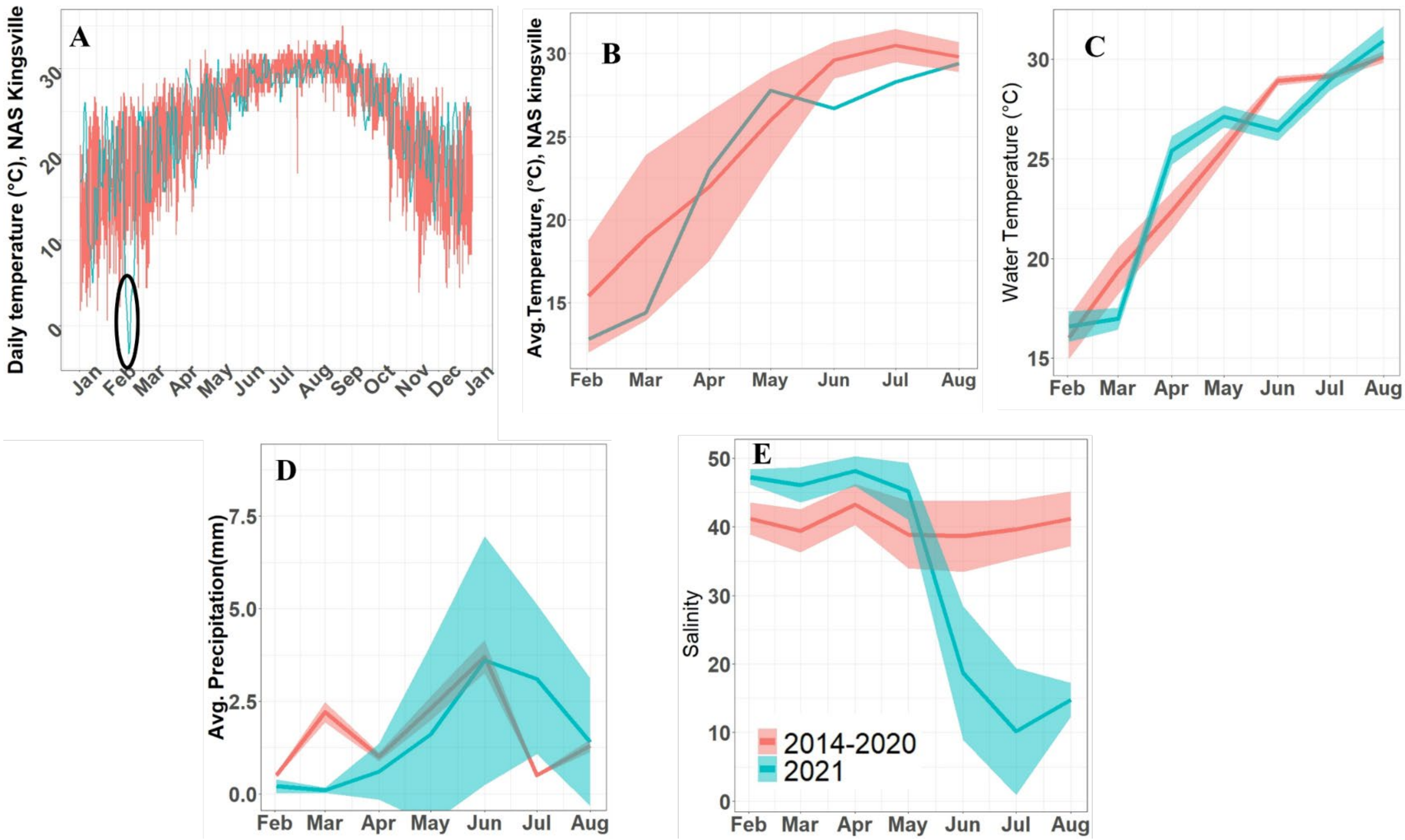
Fig. 2


A
Daily temperature (°C), NAS Kingsville
0
10
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30
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Feb
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May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
B
Avg.Temperature, (°C), NAS kingsville
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20
25
30
Feb
Mar
Apr
May
Jun
Jul
Aug
C
Water Temperature (°C)
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20
25
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Mar
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May
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Jul
Aug
D
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5.0
7.5
Feb
Mar
Apr
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Jun
Jul
Aug
E
Salinity
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50
2014-2020
2021
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Fig. 3

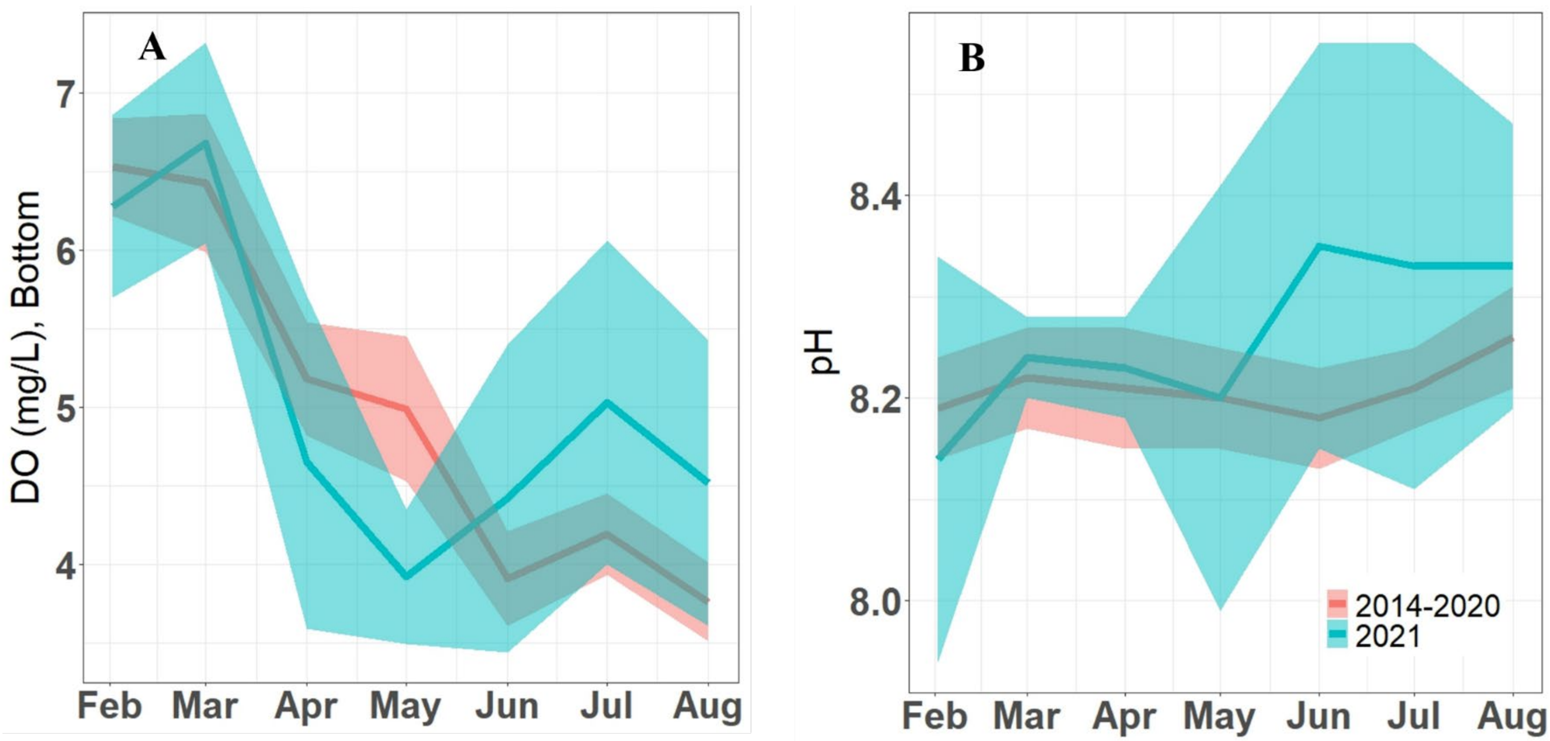

A
B
DO (mg/L), Bottom
pH
7
6
5
4
8.4
8.2
8.0
Feb Mar Apr May Jun Jul Aug
2014-2020
2021

Fig. 4

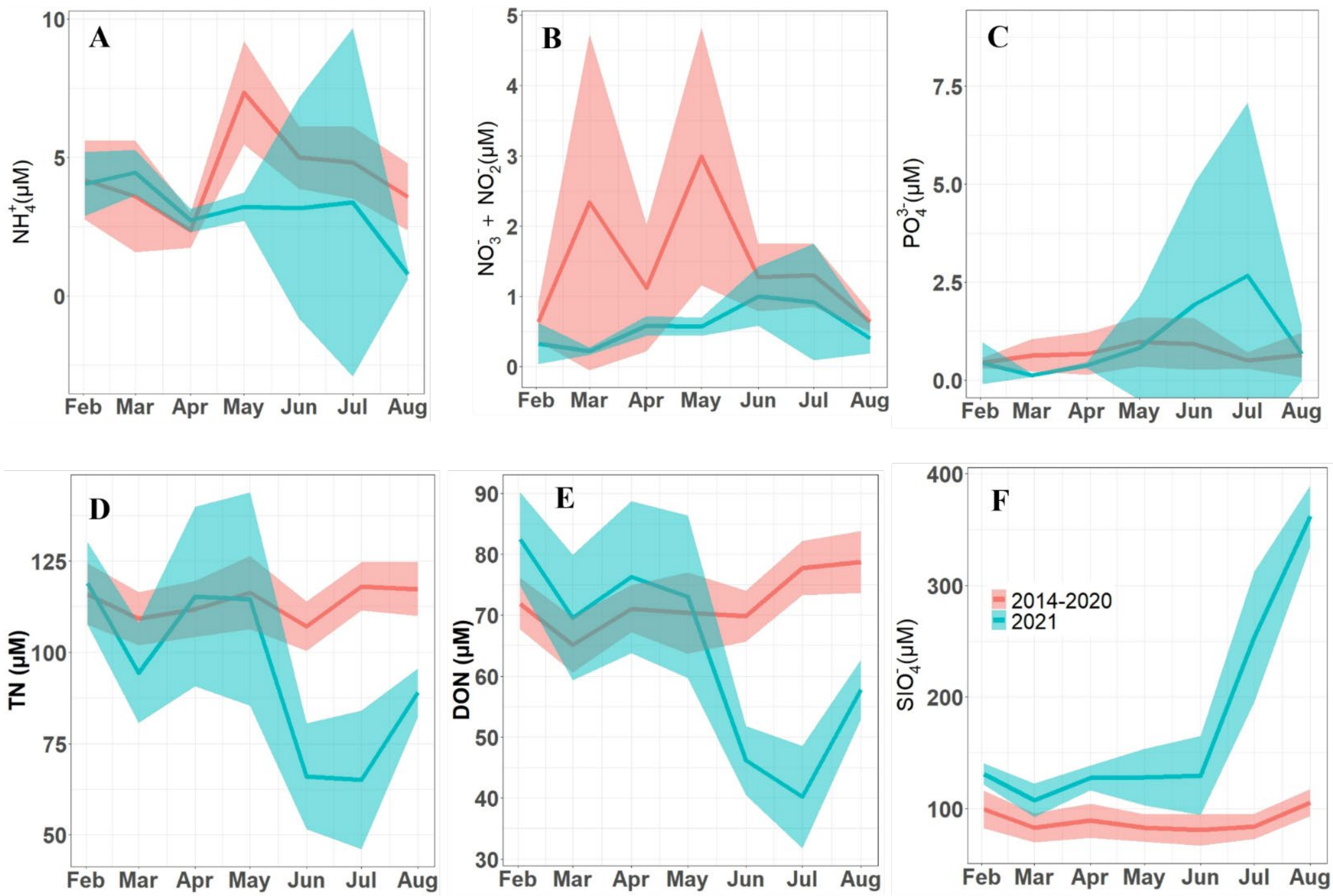
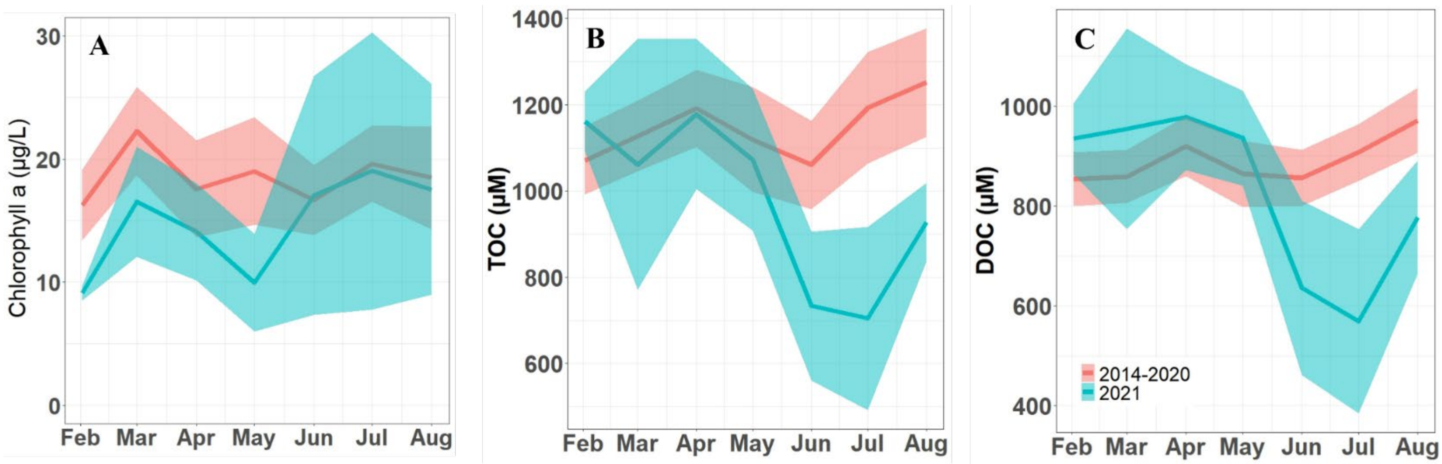


Fig. 5


A
B
C
Chlorophyll a (µg/L)
TOC (µM)
DOC (µM)
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20
30
600
800
1000
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1400
400
600
800
1000
Feb Mar Apr May Jun Jul Aug
2014-2020
2021