



## **Influence of Extreme Cold Air Outbreak on Food Web Dynamics in Baffin Bay**

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Coastal Bend Bays and Estuaries Program, Inc.  
Final Report

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## **Executive Summary**

In February 2021, an acute freeze event—Winter Storm Uri—caused a massive fish kill along the Texas coast, raising concerns about the capacity of estuaries to withstand climatic variability. The Upper Laguna Madre Estuary, including Baffin Bay, lost an estimated 82,560 black drum (*Pogonias cromis*). Baffin Bay is a low inflow estuary characterized by extended periods of hypersalinity, as well as presence of Serpulid reefs formed by tube-building polychaetes. Serpulid reefs are valuable habitat for a diverse community of fauna and provide support for fisheries, including a large and commercially important black drum population. This study used benthic community characterization to evaluate the impact of Uri on potential black drum prey, as well as stable isotope analyses to assess macrofauna and black drum resource use. Benthic macrofauna and stable isotope ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) samples from soft sediment and Serpulid reef habitats in Baffin Bay were collected and analyzed four times in the six months following Uri. Results from community characterization analyses indicate that after Winter Storm Uri, the abundance and biomass of benthic macrofauna on Serpulid reefs was higher and more stable than those on soft sediments, as in previous sampling periods. A large rain event in May 2021, following Uri, produced 46% of mean annual precipitation for the area. Bivalve *Mulinia lateralis*, a key species in soft sediments and potentially important black drum prey item, increased in abundance and biomass following the rain event, likely promoted by the associated reduction in salinity. Isotopic composition of surface sediment organic matter, which is representative of basal food resources in the bay, did not shift after Winter Storm Uri. Changes in suspended particulate organic matter and macrofauna resource use reflected increased terrestrial input, in comparison to previously published values. Black drum resource use did not appear restricted to Baffin Bay following Winter Storm Uri. Decreased salinity after Uri likely had more of an impact on soft sediment macrofauna communities and black drum resource use than did the acute freeze event. Overall, there were minimal effects of Winter Storm Uri on Serpulid reef and soft sediment macrofauna communities and trophic dynamics in Baffin Bay.

## **1. Introduction**

Baffin Bay is a secondary bay of the Upper Laguna Madre (ULM). The ULM is renowned for excellent recreational and commercial fishing, in particular for black drum (*Pogonias cromis*; Martinez-Andrade et al. 2005, Bohannon et al. 2015), which are abundant in Baffin Bay (Breuer 1957). Black drum are benthic predators that feed on infauna and epifauna in soft sediment, Serpulid reef and seagrass habitats in Baffin Bay and the wider ULM (Breuer 1957; Martin 1979; Hardegree 1997; Mendenhall 2015; Breaux et al. 2019; Palmer et al. 2022). The ULM boasts the greatest black drum catch rate across all Texas bay systems and black drum compose a majority of the commercial fishery associated economy in the ULM (Martinez-Andrade et al. 2005; Bohannon et al. 2015). A decrease in the ex-vessel value of black drum commercial landings across all Texas Bay systems from \$3.8 million in 1996 to \$1.4 million in 2012 (Bohannon et al. 2015) increased the need to better understand possible stressors on the black drum population.

Current understanding of ecological disturbances in Baffin Bay, and their impact on black drum, is shaped by the warm climate in this subtropical, semi-arid region. Hypersalinity and algal bloom (predominantly *Aureoumbra lagunensis*) disturbances, which correlate with warmer temperatures, are prevalent in Baffin Bay and have been the focus of previous studies (Simmons 1957; Eppley 1972; Mendenhall 2015; Rubio et al. 2018; Breaux et al. 2019; Cira and Wetz 2019). Hypersalinity and algal bloom disturbances can decrease the abundance of *Mulinia lateralis*, an important prey source for black drum (Montagna et al. 1993; Street et al. 1997; Rubio et al. 2018; Breaux et al. 2019). Hypersalinity may restrict movement of fish within the bay as it increases the energetic cost of osmoregulation (Gonzalez and McDonald 1992; Swanson 1998), which narrows available black drum food sources (Ajemian et al. 2018; Rubio et al. 2018; Breaux et al. 2019). While algal blooms reduce the diversity of benthic macrofauna and therefore alter the availability of food resources for high trophic level consumers, the flexibility of black drum diet allows the population to subsist (Street et al. 1997). Compared to the prevailing warm and dry conditions and associated tropical disturbances, freezing temperatures are uncommon in the area. The impact of a freeze event on benthic macrofauna and black drum diet remains unknown.

Winter Storm Uri brought freezing air temperatures to Texas in February 2021 and disrupted coastal ecosystems, including Baffin Bay. Water temperatures dropped to 4 °C and remained below 10 °C for eight days in February 2021 in the Laguna Madre near the mouth of Baffin Bay (NOAA CO-OPS 2022). In comparison, minimum February water temperatures from 2018 to 2020 were 10 °C . Fish mortality was the most highly-reported effect of freeze disturbance, with an estimated mortality of 82,560 black drum and 38,982 spotted seatrout (*Cynoscion nebulosus*) in the Upper Laguna Madre (Texas Parks and Wildlife Department 2021). However, this event was not unprecedented for the region. In 1951, Gunter & Hildebrand (1951) quantified mortality of finfish—including black drum, speckled seatrout (*Cynoscion nebulosus*), sheepshead (*Archosargus probatocephalus*), red drum (*Sciaenops ocellatus*), hardhead catfish (*Ariopsis felis*)—around Port Aransas after air temperatures remained below freezing for five consecutive days. It took black drum two years, and trout and red drum three years to recover from the 1951 cold disturbance, as measured by gill net catch rates in the Laguna Madre (Simmons 1957). The impact of the 1951 freeze event on lower trophic levels was not well documented and may not have been studied at all.

The recovery of fish populations following disturbance is contingent on the availability of prey (Lewis et al. 2021). However, the potential response of benthic macrofauna in Baffin Bay to a cold temperature disturbance is unclear. Studies of benthic macrofauna communities in Baffin Bay have recently been conducted under more typical water temperatures (Mendenhall 2015, Rubio et al. 2018, Breau et al. 2019, Palmer et al. 2022). The applicability of previous studies (Mendenhall 2015, Rubio et al. 2018, Breau et al. 2019, Palmer et al. 2022) to predict the effects of Winter Storm Uri is limited by differences in disturbance type (Zajac and Whitlatch 1982a, 1982b, Schroeder 2003, Boucek and Rehage 2014)—e.g. warm water temperatures promote invertebrate reproduction (Minchin 1992; Hoegh-Guldberg and Pearse 1995). While there is a large body of literature that identifies cold temperature as a key factor shaping macrofauna communities, these studies assess temperature at longer timescales or colder climates—e.g. severe winters in the North Sea (Kröncke et al. 1998 & 2001; Schroeder 2003; Reiss et al. 2006; Neumann et al. 2008)—in comparison to Winter Storm Uri’s acute disturbance in a subtropical climate. Organisms in southern Texas are less acclimated to sudden decreases in temperature than those in northern latitudes, which may accentuate the impact of winter storms



(Ward 2017). This study aims to address a gap in the literature regarding benthic macrofauna responses to cold disturbances in a subtropical climate.

The contribution of available prey to consumer diet, as measured by stable isotope analysis, is integral to understanding resource use. Stable isotope analysis is a method of tracing the flows of organic matter through an ecosystem, from primary producers to consumers. Basal food resources (e.g., suspended particulate organic matter [SPOM], and surface sediment organic matter [SSOM]) can be distinguished by carbon isotopic composition ( $\delta^{13}\text{C}$ ). Trophic levels of consumers (e.g., benthic macrofauna and black drum) can be distinguished by nitrogen isotopic composition ( $\delta^{15}\text{N}$ ). Flexibility in foraging is adaptatively beneficial for fish (Dill 1983) especially when recovering from disturbance (Venturelli and Tonn 2006). Black drum generally have an adaptable diet and can exploit a variety of prey from Baffin Bay's Serpulid reefs and soft sediments as well as from Laguna Madre's seagrass beds (Breaux et al. 2019). During hypersaline conditions, black drum movement decreases (Ajemian et al. 2018) and they rely on a narrower range of resources (Breaux et al. 2019), possibly explained by the energetic cost of osmoregulation (Gonzalez and McDonald 1992; Swanson 1998). Using stable isotope analysis to quantify food resource uses after Winter Storm Uri will provide insight into the black drum diet during a period of energetically costly thermoregulation.

With increasing climate variability, there is a need to understand how coastal ecosystems, including fisheries and their prey, will respond to cold temperature disturbances. For subtropical, semi-arid regions with a warm climate, the impact of an acute freeze on benthic macrofauna is vastly understudied. This study will characterize ecosystem recovery following Winter Storm Uri in Baffin Bay, which will support resource managers to make informed decisions that protect and sustain the black drum fishery.

## **2. Materials and Methods**

### **2.1 Study Design**

Spatiotemporal changes in water quality, benthic communities, and food web dynamics following Winter Storm Uri (February 2021) were assessed in this study. Water quality, benthic macrofauna, and stable isotopes of benthic macrofauna, surface sediment organic matter (SSOM) and suspended particulate organic matter (SPOM) were sampled four times in the six months

following the February 2021 freeze (3 March, 14 May, 23-28 June, 13 August 2021). Sampling occurred at four soft sediment stations and three reef stations in Baffin and Alazan Bays (hereafter termed Baffin Bay) on each sampling date (Figure 1). Black drum were collected from commercial anglers six to eight weeks after each of the four sampling dates for stable isotope (food web) analysis. This time lag allows for assimilation of the benthic food sources that were present during benthic sampling into fish tissues.

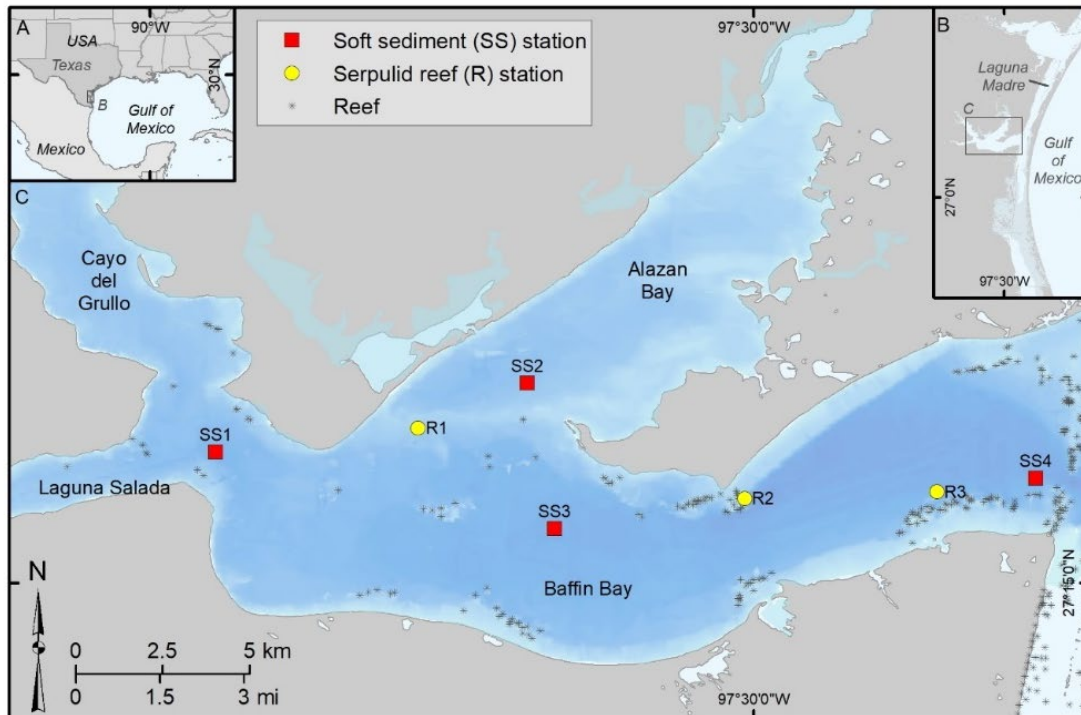


Figure 1. Map of (A) The Gulf of Mexico, (B) the Upper Laguna Madre, and (C) Baffin Bay with reef (R) and soft sediment (SS) sampling stations. Approximate locations of reef are derived from NOAA electronic navigation charts (NOAA 2018).

### 3.2 Water Quality Sampling

A multiparameter instrument (YSI ProDSS) was used to synoptically measure water temperature, dissolved oxygen, pH, specific conductance, and salinity during benthic sampling. Water depth, wind speed, wind direction, and cloud cover were also recorded alongside all sampling activities.

At each sampling event, the multiparameter instrument measured water quality at approximately 0.1 m below the water surface and 0.2 m above the sediment bottom.

## 2.3 Benthic Macrofaunal Community Analyses

### 2.3.1 Benthic Community Sampling

Small pieces of Serpulid reef ( $\sim 3 \text{ cm}^3$ ) were collected by hand in the field at each of the three Serpulid reef stations to extract benthic invertebrates for abundance and biomass determinations (following Hardegree 1997; Palmer et al. 2022). Reef pieces were immediately transferred to a 500  $\mu\text{m}$  mesh bag to prevent loss of invertebrates in the water column. Three replicate chunks were collected at each reef station and sampling date and fixed in 10% buffered formalin.

Benthic infaunal invertebrates were sampled at soft sediment stations using a 6.7-cm diameter core tube (35.4  $\text{cm}^2$  area) to a depth of 10 cm (following Street et al. 1997) to extract benthic infaunal invertebrates. Three replicate cores were collected from each station on each sampling date. Cores were split into 0-3 cm and 3-10 cm sections and preserved in 10% buffered formalin.

### 2.3.2 Benthic Community Laboratory Analysis

Reef sample volumes were measured using volume of water displaced, followed by determination of wet weights. Reef samples were then placed in 12  $\text{mol L}^{-1}$  hydrochloric acid (HCl) to dissolve calcareous reef substrate (e.g., Serpulid tubes, barnacle shells, mollusk shells). The remaining organisms were then rinsed onto a 500  $\mu\text{m}$  sieve, and identified under a dissecting microscope to the lowest possible taxon (usually species). Biomass measurements were obtained after combining individual macrofauna into species or family groups, drying at 55  $^{\circ}\text{C}$  for 24 h, and weighing to the nearest 0.01 mg.

Organisms in the soft sediment samples were extracted on a 500  $\mu\text{m}$  sieve, sorted using a dissecting microscope, identified to the lowest practical identifiable level (usually species), and enumerated. Mollusk shells were removed with 2  $\text{mol L}^{-1}$  HCl prior to drying and weighing.

When organisms in benthic samples were too abundant to be counted, a Folsom plankton splitter was used to obtain a subsample for processing.

### 2.3.3 Benthic Community Statistical Analyses

Spatiotemporal differences in total abundance and biomass of benthic macrofauna standardized by volume were illustrated using time-series plots. For between-habitat comparisons of abundance and biomass, the top 0-3 cm of soft sediment cores were compared to samples from Serpulid reef. Species richness, species evenness and Hill's N1 diversity were calculated on species-level data and visualized in time-series plots. To compensate for differences in volume sampled between reef and soft-sediment samples, diversity on the reef was calculated on the sum of three replicates and diversity in the sediments was calculated on the mean of individual replicates, at each station on each date. Differences in community composition were determined using non-metric Multi-Dimensional Scaling (nMDS) analyses performed using volume-standardized abundance data with species-level taxonomic resolution on a Bray-Curtis similarity matrix (Clarke 1993). Data were square-root-transformed prior to nMDS analysis. The similarity of sample clusters was determined using a cluster analysis with the group-average method and similarity profile (SIMPROF) tests. Because the hydroid *Obelia bidentata* and porifera are colonial and could not be counted, they were not included in analyses.

Univariate analyses and data management were performed using RStudio 4.1.3 (The R Foundation for Statistical Computing 2022). Multivariate analyses and diversity calculations were performed using PRIMER v7.0.13 (Clarke et al. 2014; Clarke and Gorley 2015).

## 2.4 Stable Isotope Analyses

### 2.4.1 Stable Isotope Analyses of Organic Matter

Suspended particulate organic matter (SPOM) and surface sediment organic matter (SSOM) were collected for stable isotope analysis. SPOM samples were collected just below the water surface, sieved through 250  $\mu\text{m}$  mesh in the field and stored on ice. Within twelve hours of collection, 30–100 mL (depending on turbidity) of water were filtered onto pre-combusted (4 hours, 450  $^{\circ}\text{C}$ ) glass fiber filters (Whatman GF/F, 0.7 mm nominal porosity) in the laboratory. Filters were then stored in the freezer (-20  $^{\circ}\text{C}$ ), before being freeze-dried (Labconco Freezone) and stored in a vacuum desiccator. Samples for analysis of carbon isotopic composition were decarbonated with HCl for four hours under vacuum, then encapsulated in silver capsules to

prevent corrosion, followed by a tin capsule. Isotopic compositions of nitrogen were determined on raw samples, with each filter encapsulated in two tin capsules (Bunn et al. 1995). Before encapsulation of both nitrogen and carbon samples, filters were scraped to remove excess fibers and improve sample quality.

SSOM samples were collected by benthic core (3 cm deep, 35.4 cm<sup>2</sup> area) and stored in a cooler in the field before being moved to a freezer in the laboratory. Thawed SSOM samples were sieved over a 500 µm mesh sieve to remove large pieces of shell hash, then dried in a vacuum freeze-drier. The freeze-dried sample was manually ground using a mortar and pestle. For nitrogen isotope analysis, 8-10 mg of raw sample were encapsulated in a tin capsule. For carbon isotope analysis, samples were decarbonated in a diluted HCl solution (1–2 mol L<sup>-1</sup>, depending on carbonate content), which was added drop by drop until the HCl-calcium carbonate (CaCO<sub>3</sub>) reaction was complete (bubbling ceased). Decarbonated samples were dried in a dry-block heater, rinsed with deionized water, freeze-dried again, and homogenized with a stainless-steel spatula. A portion of the homogenized sample (29–30 mg) was encapsulated in a silver capsule to prevent corrosion, followed by a tin capsule.

#### *2.4.2 Stable Isotope Analyses of Macrofauna and Black Drum*

Benthic macrofauna were collected at soft sediment sites by benthic core, and at reef sites by small pieces, as in benthic community sampling (section 2.3.1). However, macrofauna samples for isotope analyses were placed in artificial seawater water at room temperature rather than being fixed in formalin. Samples were sieved live on a 500 µm mesh and three individuals of all dominant taxa were collected. Organisms were separated from sample detritus, held in artificial seawater for 24 hours to allow for gut content evacuation, and stored at -20 °C in the freezer. Gut evacuation was not necessary for larger organisms with extractable soft tissues (e.g., shrimp, toadfish, gobies). A portion of each sample (fauna: 0.3-0.5 mg; flora: 0.8-1.0 mg) was weighed and encapsulated in a tin cup.

Five commercially-caught black drum were collected per sampling period. Whole black drum were placed on ice. In the laboratory, length and weight were measured. Epaxial muscle tissue without skin, scales or bones was extracted from the anterior portion of the fillet using a clean stainless-steel scalpel rinsed with deionized water between each sample. Clean muscle tissue was

placed in individual microtubules and stored in the freezer (-20 °C), then freeze-dried. Freeze-dried samples were ground to a homogenous fine powder using a ball mill (MM 400, Retsch). A portion of each sample (0.3-0.5 mg) was weighed to the nearest 0.001 mg and encapsulated in a tin cup. Lipid extraction prior to stable isotope analysis was not necessary for black drum tissues because C:N ratios (by mass) of raw samples were < 3.5 (Post et al. 2007).

All encapsulated samples were stored in 96-well trays at room temperature in a box or vacuum desiccator. After initial preparation at TAMUCC laboratories, encapsulated samples were sent to be analyzed at the Littoral, Environment and Societies unit (LIENSs), University of La Rochelle.

#### *2.4.3 Determination of isotopic compositions*

At LIENSs, approximately 5 mg of dry ground tissue samples were placed in a tin boat with 10 mg of precombusted Vanadium pentoxide (V<sub>2</sub>O<sub>5</sub>). The isotopic composition of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  were analyzed with a continuous-flow stable isotope mass spectrometer attached to a Flash EA 1112 elemental analyzer following the batch analysis methods and standards used by Fry (2006). Replicate isotope analyses of N and C were performed to validate machine readings. Isotopic ratios are reported relative to the standards atmospheric N<sub>2</sub> for  $\delta^{15}\text{N}$  and Vienna PeeDee belemnite for  $\delta^{13}\text{C}$  using the formula:

$$\delta X \text{ sample} = \left[ \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} \right) - 1 \right] \times 1000$$

where X is  $^{13}\text{C}$  or  $^{15}\text{N}$ ,  $R_{\text{sample}}$  is the isotopic ratio of the sample and  $R_{\text{standard}}$  is the isotopic ratio of the standard. Calibration was carried out using reference materials (USGS-61, -62, -63 for both carbon and nitrogen). The analytical precision of the measurements was <0.10‰ for carbon and <0.15‰ nitrogen based on analyses of USGS-61 and USGS-63 used as laboratory internal standards.

#### *2.4.4 Stable Isotope Statistical Analyses*

Isotopic compositions ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ) of SPOM, SSOM, benthic macrofauna and black drum were illustrated on biplots. Isotopic compositions ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ) of SPOM and SSOM in each habitat were compared over time using non-parametric Kruskal-Wallis rank sum tests and visualized using time-series plots.

### **3. Results**

#### **3.1 Water Quality**

Water temperature in Baffin Bay after Winter Storm Uri increased from  $17.6 \pm 0.6$  °C (mean  $\pm$  SD) in March to  $30.3 \pm 0.2$  °C in August and was similar across all stations. Mean bay-wide salinity reflected hypersaline ( $>35$ ) conditions in March ( $44.5 \pm 2.8$ ) and May ( $46.0 \pm 0.7$ ). Salinity decreased over the following months (to  $24.6 \pm 2.0$  in June and  $16.9 \pm 1.8$  in August; Figure 2). Salinity at stations up Baffin Bay was higher in March and lower in June and August, compared to stations closer to the mouth of the bay (difference among stations: 6.8, 4.6, 4.2 respectively). Dissolved oxygen concentrations decreased over the study period from  $7.5 \pm 0.9$  mg L<sup>-1</sup> in March to  $5.1 \pm 0.8$  mg L<sup>-1</sup> in June, reflecting an inverse relationship with temperature. Variation in temperature, salinity, and dissolved oxygen among stations was smallest in May. pH levels were lowest in June ( $7.6 \pm 0.1$ ), particularly at sites BB40 and BBS1 (7.4 and 7.5 respectively), and highest in March ( $8.4 \pm 0.1$ ).

#### **3.2 Benthic Macrofaunal Community Analyses**

In March following Uri, benthic macrofauna in the top 10 cm of the soft sediments were low in abundance ( $9 \pm 11$  n L<sup>-1</sup>) and biomass ( $1.5 \pm 2.0$  mg L<sup>-1</sup>), with the exception of BB6 (abundance:  $42 \pm 9$  n L<sup>-1</sup>; biomass:  $21.8 \pm 30.2$  mg L<sup>-1</sup>; Figure 3). The polychaete *Streblospio benedicti* was the dominant benthic macrofauna species in the soft sediments throughout the study period, contributing 43% of total fauna for all soft sediment sites (Table 1). The polychaete *Mediomastus ambiseta* and bivalve *Mulinia lateralis* were also dominant contributors to macrofaunal abundance; each accounting for 22% of total fauna (Table 1). A four-fold increase in *M. lateralis* abundance from March ( $4 \pm 7$  n L<sup>-1</sup>) to May ( $17 \pm 10$  n L<sup>-1</sup>) resulted in a two-fold increase in biomass (March:  $5.8 \pm 16.0$  mg L<sup>-1</sup>; May:  $11.3 \pm 11.4$  mg L<sup>-1</sup>; Figure 4). In the following six weeks, *M. lateralis* biomass tripled (June:  $35.5 \pm 21.0$  mg L<sup>-1</sup>). Overall, the top 3 cm of soft sediment cores contained 91% of total abundance and 90% of total biomass. Therefore, only the top 3 cm of the soft sediments were used to compare with Serpulid reef stations.

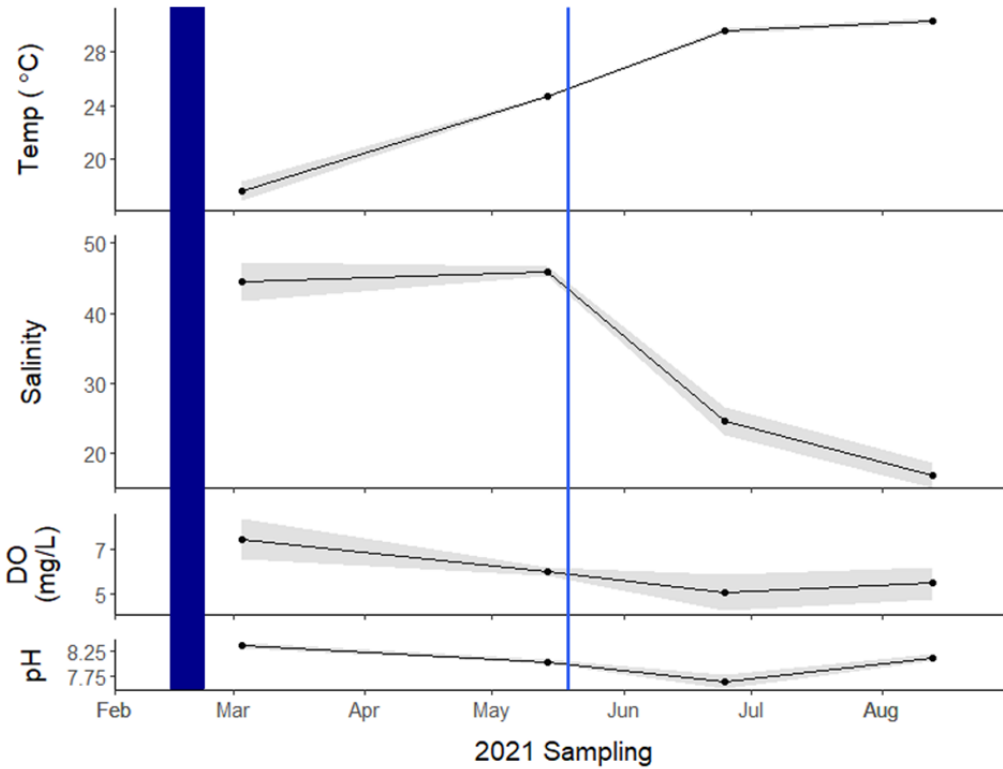


Figure 2. Mean temperature (Temp), salinity, dissolved oxygen (DO) and pH of bottom water. The vertical blue line from 14 to 22 February marks the duration of below average water temperature during Winter Storm Uri (NOAA 2021). The vertical blue line on 19 May, marks a large rainfall event. Shading indicates  $\pm 1$  standard deviation about the mean.

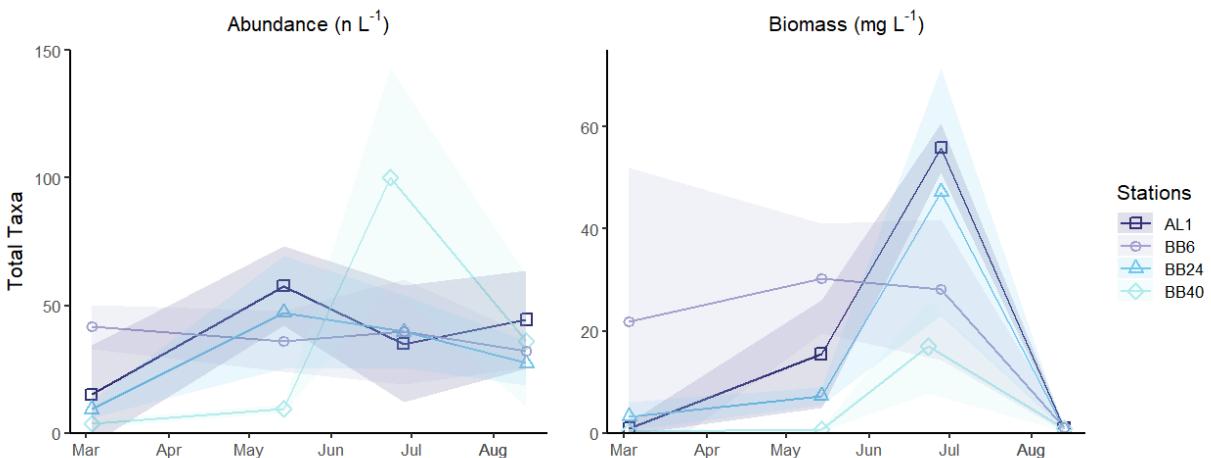


Figure 3. Mean benthic macrofaunal abundance ( $n L^{-1}$ ) and biomass ( $mg L^{-1}$ ) at soft sediment stations (0-10 cm). Shading indicates  $\pm 1$  standard deviation about the mean.



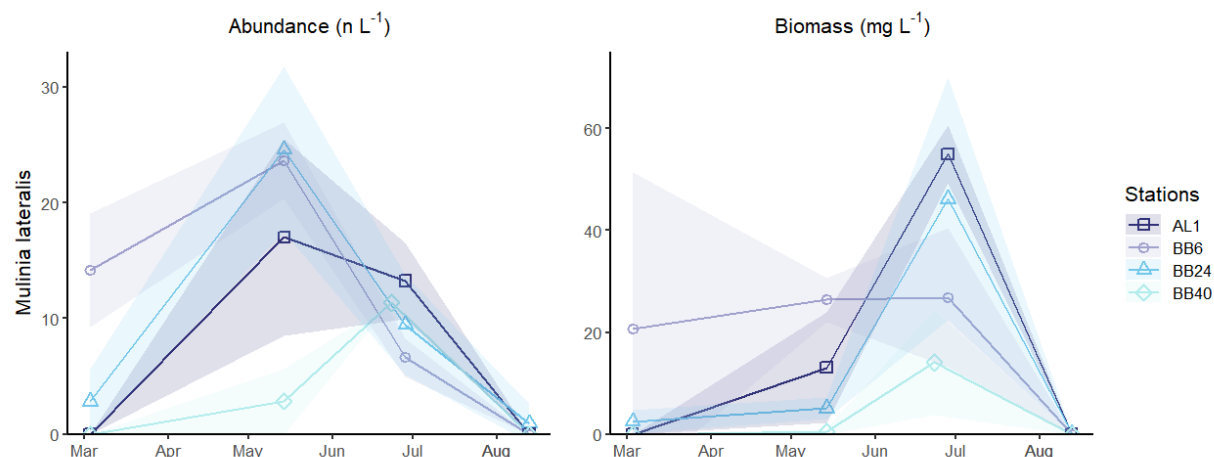


Figure 4. Mean *Mulinia lateralis* abundance (n L<sup>-1</sup>) and biomass (mg L<sup>-1</sup>) at soft sediment stations (0-10 cm). Shading indicates  $\pm 1$  standard deviation about the mean.

Among Serpulid reef stations in March 2021, benthic macrofauna at BBS1 was lower in abundance ( $8,546 \pm 8,397$  n L<sup>-1</sup>) and biomass ( $1,077.7 \pm 546.3$  mg L<sup>-1</sup>) than BBS2 and BBS3 (mean of both stations: abundance  $47,493 \pm 16,692$  n L<sup>-1</sup>, biomass  $5,068.8 \pm 2,161.1$  mg L<sup>-1</sup>; Figure 5). Benthic macrofauna at BBS1 was generally lower and more variable than the other two stations in subsequent months (August abundance:  $10,991 \pm 5,643$  n L<sup>-1</sup> vs.  $57,680 \pm 24,896$  n L<sup>-1</sup>; Figure 5). Average benthic macrofaunal biomass from May to August was relatively stable among all Serpulid reef stations ( $3,228.1 \pm 1,380.2$  mg L<sup>-1</sup>; Figure 5). The crustacean *Apocorophium louisianum* was the most dominant benthic macrofauna in the Serpulid reef community, contributing 61% of the total abundance, followed by the polychaete *Polydora ligni* (16%; Table 1). Five taxa—*Apocorophium louisianum*, *Polydora ligni*, and polychaetes *Syllis cornuta*, *Brania clavata*, *Naineris laevigata*—contributed 90% of the total abundance and were present at all Serpulid reef stations (Table 1). The serpulid polychaete *Hydroides dianthus* was most abundant at BBS1 and contributed 1.3% of the total reef macrofauna abundance (Table 1).

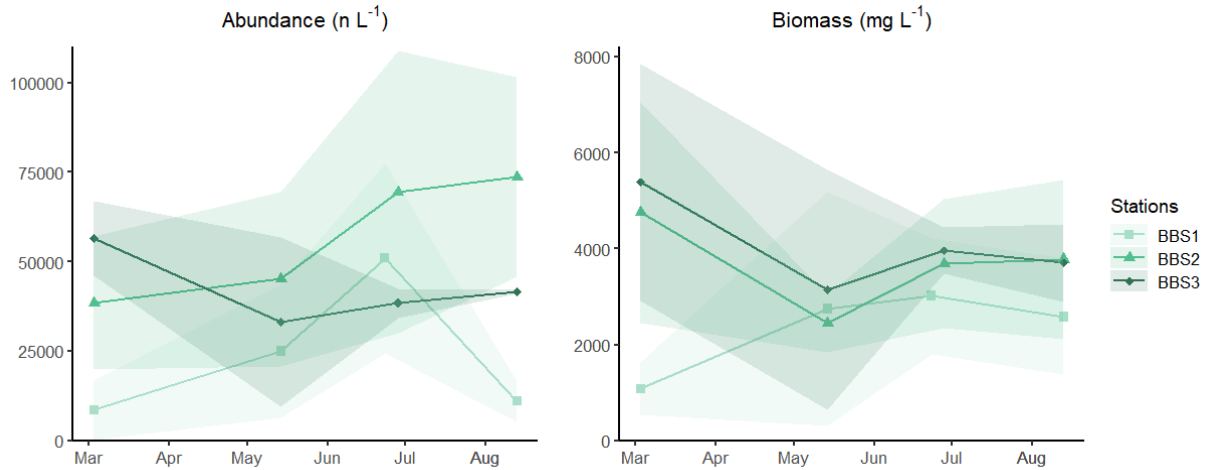


Figure 5. Mean abundance (n L<sup>-1</sup>) and biomass (mg L<sup>-1</sup>) at Serpulid reef stations. Shading indicates  $\pm 1$  standard deviation about the mean.

Across the study period, benthic macrofauna on Serpulid reefs were 374 times more abundant ( $41,013 \pm 26,078$  n L<sup>-1</sup>) and 77 times greater in biomass ( $3,355.7 \pm 1,749.2$  mg L<sup>-1</sup>) than benthic macrofauna in the top 3 cm from soft sediment stations (abundance:  $110 \pm 84$  n L<sup>-1</sup>; biomass:  $43.7 \pm 60.2$  mg L<sup>-1</sup>). Species richness (S) was higher on Serpulid reef ( $21.8 \pm 4.4$ ) than soft sediment ( $2.6 \pm 1.4$ ) stations across all months (Figure 6). Species evenness (J') on all Serpulid reef stations remained stable over the study period ( $0.44 \pm 0.12$ ). In the soft sediments, species evenness decreased in August ( $0.46 \pm 0.16$ ) from previous months ( $0.78 \pm 0.16$ ). Hill's N1 diversity was similar between habitats (Figure 6). Among Serpulid reef stations, Hill's N1 diversity of the benthic macrofauna was greatest at BBS1 across all months ( $4.9 \pm 0.2$ ), except in August (BBS3: 7.3; Figure 6).

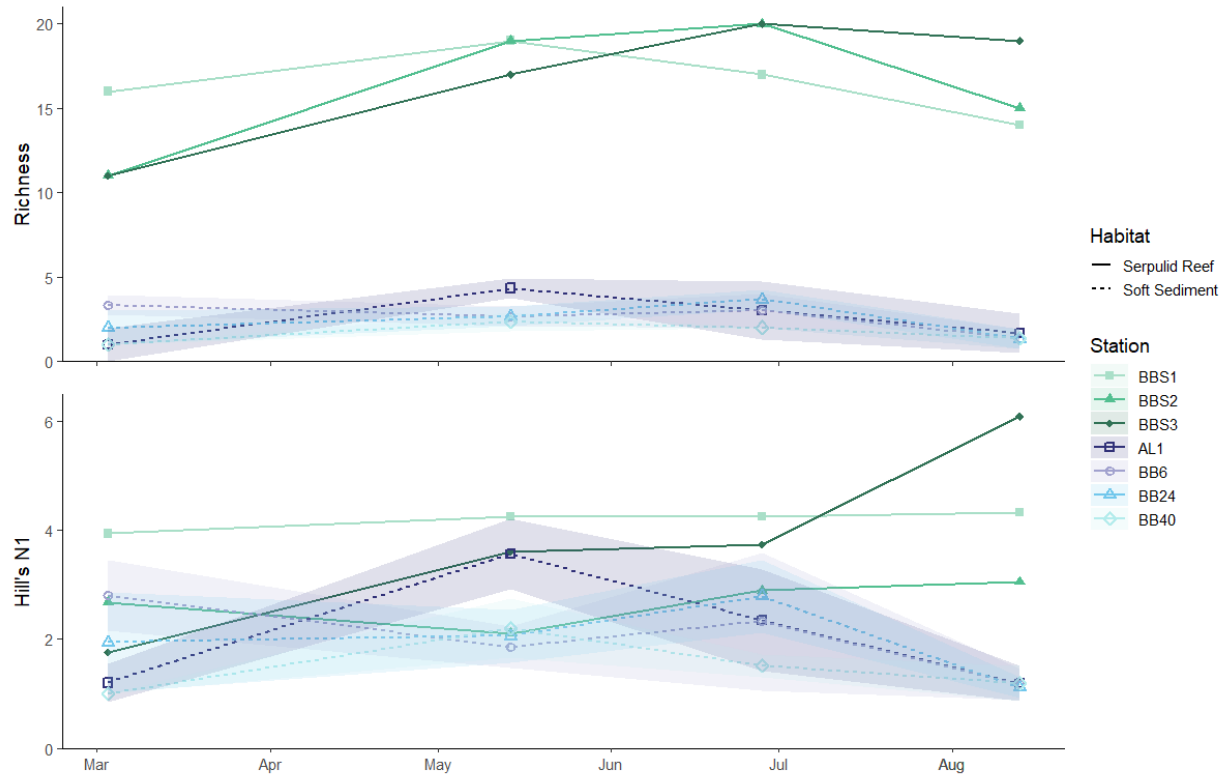


Figure 6. Richness (S) and Hill's diversity (N1) for benthic macrofauna, calculated as the mean of soft sediment (top 0-3 cm) replicates and sum of Serpulid reef replicates. Shading indicates  $\pm 1$  standard deviation about the mean.

Benthic macrofaunal community composition in soft sediments was most similar in August, with 82% similarity among all stations (Figure 7). Benthic macrofaunal community composition from Serpulid reef station BBS1 was different than all other stations in March but was 51% similar to that observed in August, indicating there were no real impacts from the freeze (Figure 8).

Benthic macrofaunal community composition was different between soft sediment and Serpulid reef stations (Figure 9). Serpulid reef communities over space and time were more similar to each other (48% similarity) than soft-sediment communities were to each other (17% similarity).

Nine species were unique to soft sediments and 43 species were unique to Serpulid reef.

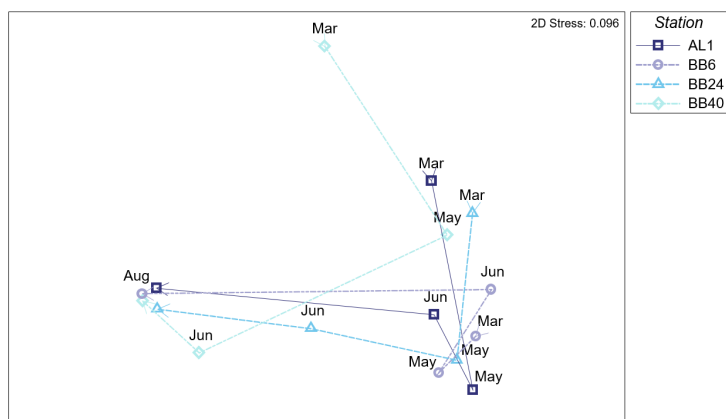


Figure 7. Non-metric multidimensional scaling plot of benthic community composition of soft sediment (0-10 cm) stations over the study period. Each point represents a mean of three replicates.

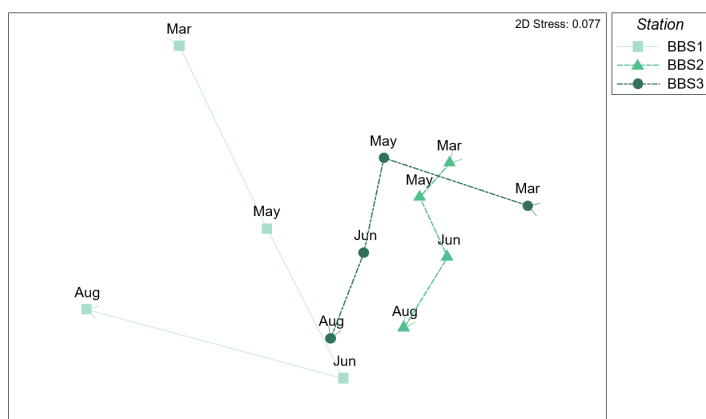


Figure 8. Non-metric multidimensional scaling plot of benthic community composition of Serpulid reef stations over the study period. Each point represents a mean of three replicates.

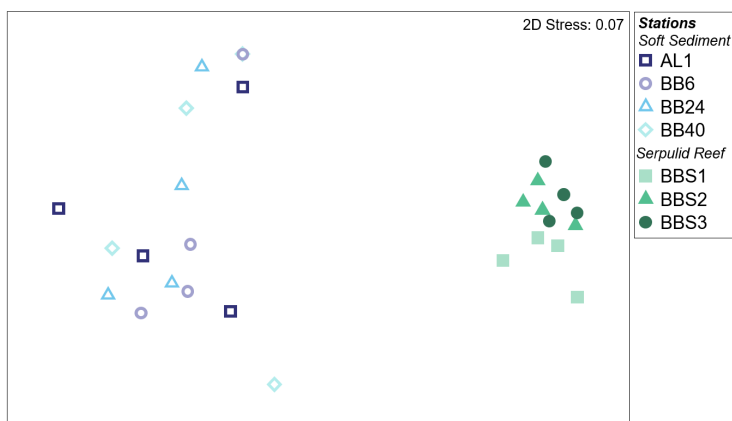


Figure 9. Non-metric multidimensional scaling plot of benthic community composition of soft sediment (top 0-3 cm) and Serpulid reef stations over the study period. Each point represents a mean of three replicates.

Table 1. Total abundance (n L<sup>-1</sup>) of benthic macrofauna in Serpulid reef and soft sediment samples during the study period. \* = abundance not determined. % of total = percent of total abundance.

Family	Taxa	Serpulid Reef				Soft Sediment				
		BBS1	BBS2	BBS3	% of total	AL1	BB6	BB24	BB40	% of total
Corophiidae	<i>Apocorophium louisianum</i>	9,204	39,835	26,524	61.41	0	0	0	0	0.33
Spionidae	<i>Streblospio benedicti</i>	0	0	0	0.00	11	8	12	31	43.26
Capitellidae	<i>Mediomastus ambiseta</i>	0	0	0	0.00	13	10	7	1	22.37
Mactridae	<i>Mulinia lateralis</i>	0	0	0	0.00	8	11	9	4	22.04
Spionidae	<i>Polydora ligni</i>	8,102	6,663	4,755	15.86	0	0	0	0	0.16
Syllidae	<i>Syllis cornuta</i>	1,169	2,554	2,714	5.23	0	0	0	0	0.00
Syllidae	<i>Brania clavata</i>	1,383	2,437	1,394	4.24	0	0	0	0	0.00
Orbiniidae	<i>Naineris laevigata</i>	957	1,544	1,107	2.93	0	0	0	0	0.16
Ampeliscidae	Ampeliscidae	0	0	0	0.00	3	1	0	0	2.96
Chordata	Fish larvae (unidentified)	0	0	0	0.00	0	4	0	0	2.96
Leptocheliidae	<i>Hargeria rapax</i>	0	1,083	1,652	2.22	0	0	0	0	0.00
Goniadidae	<i>Glycinde solitaria</i>	0	0	0	0.00	1	1	1	0	1.97
Syllidae	<i>Exogone dispar</i>	610	696	489	1.46	0	0	0	0	0.00
Terebellidae	Terebellidae	81	393	1,174	1.34	0	0	0	0	0.00
Gastropoda	Gastropoda	4	6	0	0.01	0	1	0	1	1.32
Serpulidae	<i>Hydroides dianthus</i>	868	387	327	1.29	0	0	0	0	0.00
Actiniaria	Actiniaria	463	118	590	0.95	0	0	0	0	0.16
Balanidae	<i>Balanus eburneus</i>	137	442	409	0.80	0	0	0	0	0.00
Dorvilleidae	Dorvilleidae	16	0	0	0.01	0	0	0	0	0.33
Turbellaria	Turbellaria	25	27	353	0.33	0	0	0	0	0.00
Eunicidae	Eunicidae	0	0	0	0.00	0	0	0	0	0.33
Orbiniidae	<i>Scoloplos fragilis</i>	0	0	0	0.00	0	0	0	0	0.33
Nereididae	<i>Nereis riisei</i>	153	82	78	0.25	0	0	0	0	0.00
Idoteidae	<i>Edotia triloba</i>	21	15	72	0.09	0	0	0	0	0.16
Syllidae	<i>Autolytus sp.</i>	43	3	225	0.22	0	0	0	0	0.00
Capitellidae	<i>Mediomastus sp.</i>	12	3	2	0.01	0	0	0	0	0.16
Hesionidae	<i>Gyptis brevipalpa</i>	3	10	0	0.01	0	0	0	0	0.16
Cylichnidae	<i>Acteocina canaliculata</i>	0	0	0	0.00	0	0	0	0	0.16
Veneridae	<i>Anomalocardia auberiana</i>	0	0	0	0.00	0	0	0	0	0.16
Cerithiidae	<i>Cerithium lutosum</i>	0	0	0	0.00	0	0	0	0	0.16
Pectinariidae	<i>Pectinaria gouldii</i>	0	0	0	0.00	0	0	0	0	0.16
Orbiniidae	<i>Scoloplos sp.</i>	0	0	0	0.00	0	0	0	0	0.16

Family	Taxa	Serpulid Reef				Soft Sediment				
		BBS1	BBS2	BBS3	% of total	AL1	BB6	BB24	BB40	% of total
Caprellidae	Caprellidae	35	82	82	0.16	0	0	0	0	0.00
Mytilidae	<i>Brachidontes exustus</i>	53	7	134	0.16	0	0	0	0	0.00
Syllidae	<i>Exogoninae spp.</i>	54	113	23	0.15	0	0	0	0	0.00
Capitellidae	<i>Mediomastus californiensis</i>	141	10	20	0.14	0	0	0	0	0.00
Nemertea	Nemertea	74	22	36	0.11	0	0	0	0	0.00
Dorvilleidae	<i>Schistomeringos rudolphi</i>	62	5	41	0.09	0	0	0	0	0.00
Melitidae	Melitidae	32	0	70	0.08	0	0	0	0	0.00
Polychaeta	Larval polychaeta (unidentified)	32	55	13	0.08	0	0	0	0	0.00
Melitidae	<i>Elasmopus levis</i>	5	0	93	0.08	0	0	0	0	0.00
Syllidae	Syllidae	50	5	8	0.05	0	0	0	0	0.00
Nereididae	Nereididae	30	9	15	0.04	0	0	0	0	0.00
Capitellidae	Capitellidae	3	3	24	0.03	0	0	0	0	0.00
Amphipoda	Amphipoda	0	19	5	0.02	0	0	0	0	0.00
Eunicidae	<i>Marphysa sp.</i>	0	17	0	0.01	0	0	0	0	0.00
Hesionidae	<i>Podarke sp.</i>	3	11	3	0.01	0	0	0	0	0.00
Capitellidae	<i>Capitella capitata</i>	15	0	0	0.01	0	0	0	0	0.00
Pycnogonida	Pycnogonida	0	15	0	0.01	0	0	0	0	0.00
Ischyroceridae	<i>Cerapus tubularis</i>	0	0	15	0.01	0	0	0	0	0.00
Phyllodocidae	<i>Paranaitis polynoides</i>	13	0	0	0.01	0	0	0	0	0.00
Aoridae	<i>Grandidierella bonnieroides</i>	11	0	0	0.01	0	0	0	0	0.00
Terebellidae	<i>Pista sp.</i>	0	9	0	0.01	0	0	0	0	0.00
Capitellidae	<i>Heteromastus sp.</i>	0	8	0	0.01	0	0	0	0	0.00
Phyllodocidae	<i>Eumida sanguinea</i>	4	3	0	0.01	0	0	0	0	0.00
Xanthoidea	Xanthoidea	4	3	0	0.01	0	0	0	0	0.00
Sipunculid	Sipunculid	0	0	6	0.01	0	0	0	0	0.00
Polychaeta	Polychaeta (unidentified)	0	6	0	0.00	0	0	0	0	0.00
Bivalvia	Bivalvia	5	0	0	0.00	0	0	0	0	0.00
Calyptraeidae	<i>Crepidula sp.</i>	4	0	0	0.00	0	0	0	0	0.00
Spionidae	Spionidae	0	4	0	0.00	0	0	0	0	0.00
Oligochaeta	Oligochaeta	3	0	0	0.00	0	0	0	0	0.00
Campanulariidae	<i>Obelia bidentata*</i>									
Porifera	Porifera*									
<b>Total</b>		23,883	56,702	42,453	100.00	38	37	31	37	100.00

### 3.3 Stable Isotope Analyses

Isotopic composition ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) of SPOM and SSOM were similar between habitat types (Serpulid reef vs soft sediment) within sampling events (Figure 10). Among sampling events, isotopic composition of SSOM was stable ( $p > 0.1$ ,  $df = 3$ ) and consistently more  $^{13}\text{C}$  enriched than SPOM (Figure 10). SPOM fluctuated over time in both carbon ( $\delta^{13}\text{C}$ ,  $p < 0.05$ ,  $df = 3$ ) and nitrogen isotopic compositions ( $\delta^{15}\text{N}$ ,  $p < 0.001$ ,  $df = 3$ ; Figure 10). Floating seagrass collected at BB6 in June was more  $^{13}\text{C}$  depleted ( $-12.6\text{‰}$ ) than other primary producers. Variation in mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of Serpulid reef suspension feeders was larger in March ( $\delta^{13}\text{C}$  range:  $-23.0\text{‰}$  to  $-20.7\text{‰}$ ;  $\delta^{15}\text{N}$  range:  $6.5\text{‰}$  to  $9.0\text{‰}$ ) than in June ( $\delta^{13}\text{C}$  range:  $-23.0$  to  $-21.6\text{‰}$ ;  $\delta^{15}\text{N}$  range:  $5.4\text{‰}$  to  $6.6\text{‰}$ ). Mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  composition of *M. lateralis*, a soft sediment suspension feeder, was  $-22.1\text{‰} \pm 0.6\text{‰}$  and  $5.3\text{‰} \pm 0.4\text{‰}$  respectively. Serpulid reef deposit feeders were more  $^{13}\text{C}$  depleted in March (range:  $-21.8\text{‰}$  to  $-20.4\text{‰}$ ) than in June (range:  $-22.4\text{‰}$  to  $-21.5\text{‰}$ ); conversely,  $^{15}\text{N}$  concentrations were less variable and higher in March (range:  $6.6\text{‰}$  to  $8.4\text{‰}$ ) than June (range:  $4.7\text{‰}$  to  $8.3\text{‰}$ ). Carbon isotopic composition of Serpulid reef carnivorous macrofauna was more variable in March (range:  $-21.3\text{‰}$  to  $-16.9\text{‰}$ ) than June (range:  $-21.1\text{‰}$  to  $-18.6\text{‰}$ ), and  $\delta^{15}\text{N}$  composition was similar among sampling months (average range:  $8.5\text{‰}$  to  $10.9\text{‰}$ ). Black drum  $\delta^{13}\text{C}$  isotopic compositions were highly variable among and within dates sampled.  $\delta^{13}\text{C}$  values range from  $-17.9\text{‰}$  to  $-14.0\text{‰}$  in March and May,  $-19.7\text{‰}$  to  $-17.5\text{‰}$  in June, and  $-19.4\text{‰}$  to  $-13.5\text{‰}$  in August (Figure 11). The  $\delta^{13}\text{C}$  isotopic composition of black drum is similar to that of SSOM, algae, and some invertebrate carnivores in June 2021, but generally higher in other months.

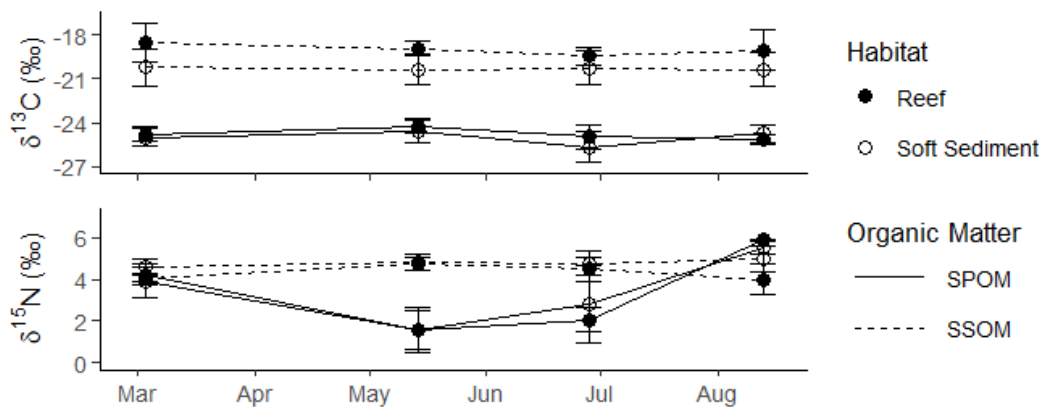


Figure 10. Mean isotopic composition ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) of Suspended particulate organic matter (SPOM) and surface sediment organic matter (SSOM) on Serpulid reef and soft sediment habitats. Error bars indicate  $\pm 1$  standard deviation about the mean.

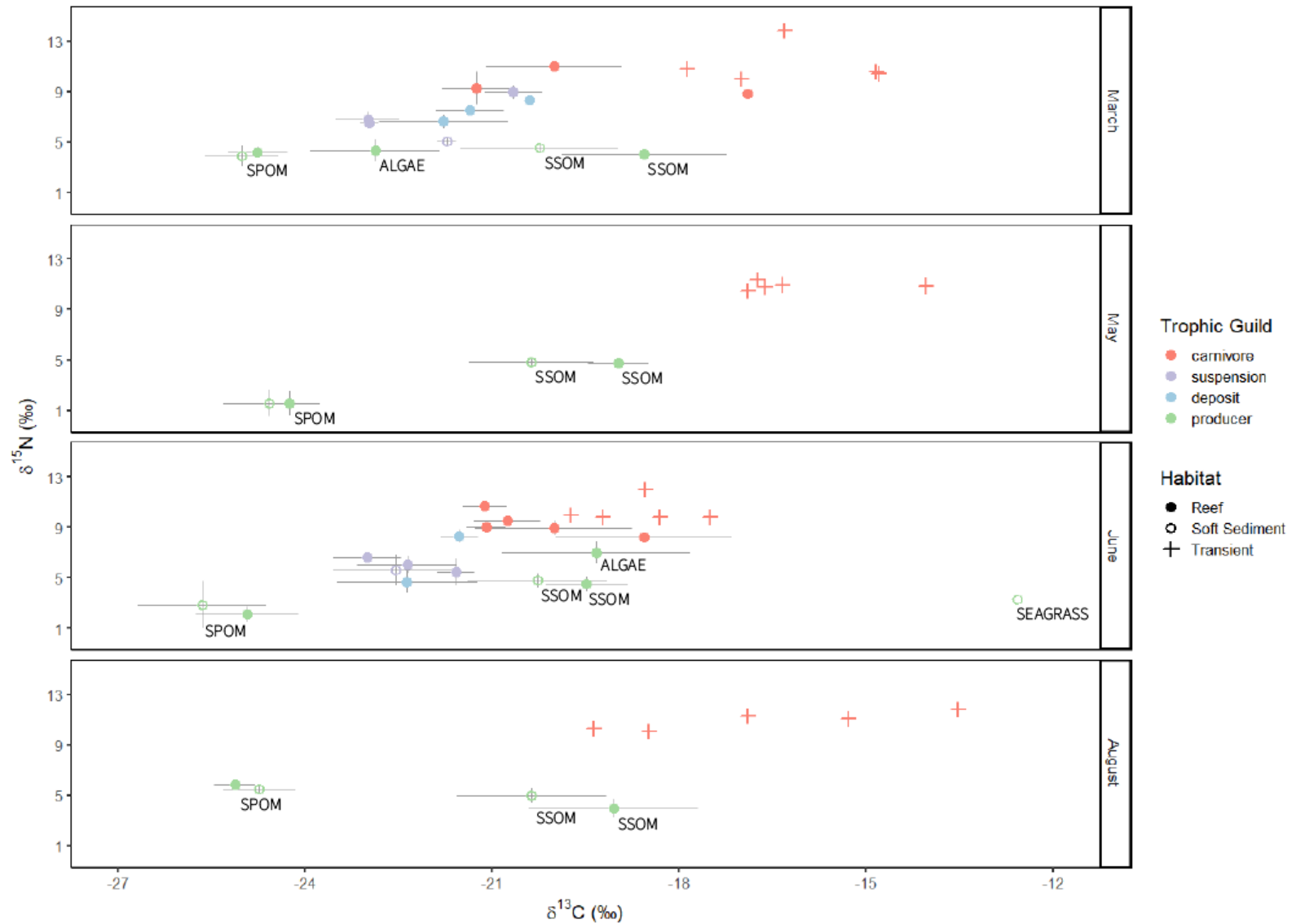


Figure 11. Stable isotope compositions ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ) of black drum food resources (circles) by trophic guild and habitat for each sampling month. Error bars are  $\pm$  standard deviation about the mean except for black drum muscle tissue (crosses), which are presented as raw values of individual fish. Species sampled in each trophic guild are listed in Table 2.



Table 2. Trophic guild and scientific name of flora and fauna used in stable isotope analyses.

<b>Trophic Guild</b>	<b>Scientific Name</b>
<b>Carnivore</b>	<i>Pogonias cromis</i>
	<i>Alpheus heterochaelis</i>
	Dorvilleidae
	<i>Gobiosoma bosc</i>
	Nereididae
	<i>Opsanus beta</i>
<b>Suspension feeder</b>	<i>Balanus eburneus</i>
	<i>Brachidontes exustus</i>
	<i>Hydroides dianthus</i>
	<i>Mulinia lateralis</i>
<b>Deposit feeder</b>	<i>Apocorophium louisianum</i> and other Amphipoda
	Orbiniidae
	Terebellidae
<b>Producer</b>	SPOM
	SSOM
	Algae
	Seagrass

#### **4. Discussion**

In February 2021, Winter Storm Uri impacted the Texas coast, causing a large and well-documented fish mortality event. The storm's effect on lower trophic levels like benthic macrofauna, however, was less clear. Soft sediment macrofauna communities in Baffin Bay, Texas are sensitive to environmental fluctuations (Buskey et al. 1997; Rubio et al. 2018; Breaux et al. 2019; Palmer et al. 2022), but their response to an acute freeze like Uri is not well known. Winter Storm Uri provided a unique opportunity to better understand impacts on benthic prey availability and resource use under atypical environmental conditions.

In March 2021 following Winter Storm Uri, total abundance ( $52 \pm 57 \text{ n L}^{-1}$ ) and biomass ( $20.7 \pm 53.3 \text{ mg L}^{-1}$ ) of benthic macrofauna in the top 3 cm of soft sediments were lower than those reported in a study occurring from June 2018 to March 2019 ( $157 \text{ n L}^{-1}$ ;  $87.3 \text{ mg L}^{-1}$ ; Palmer et al. 2022), although annual variability prevents direct attribution to Uri. Salinity in Baffin Bay was hypersaline from 2019 (Pollack unpub. data) through the freeze event, to May 2021. From 30 April to 2 May 2021—two weeks prior to May sampling—51 mm of rain fell in the region (NOAA National Weather Service 2022). In May sampling, the population of *M. lateralis*—a common benthic species in Baffin Bay soft sediments and important prey item for black drum

(Darnell 1961; Sutter et al. 1986; Montagna and Kalke 1995; Grubbs et al. 2013)—increased in abundance. It is possible that temporary salinity reductions may have promoted *M. lateralis* reproduction, leading to an increase in *M. lateralis* abundance in May samples, even though any short-term change in salinity was not detected in our quarterly sampling.

After May sampling, a mesoscale convective system (large thunderstorm complex) generated up to 364 mm of rain in the Baffin Bay watershed from 18 – 20 May 2021 (including 278 mm on 19 May 2021; NOAA National Weather Service 2022). The amount of precipitation comprised 46% of the annual average for the area (786 mm/y for 1991 – 2020); this event and associated transition from hypersaline to normal estuarine salinity conditions likely influenced *M. lateralis* biomass in June sampling. The response of *M. lateralis* to salinity change after Uri was similar to previous studies (Rubio et al. 2018; Breaux et al. 2019); it is possible that *M. lateralis*, a burrowing bivalve, benefited from the thermal stability of deeper sediments (Watson et al. 2018) during Uri, allowing them to flourish during later months.

Polychaetes *S. benedicti* and *M. ambiseta* in the soft sediments, as well as *P. ligni* on Serpulid reefs, were abundant during this study. High abundances of small-bodied, opportunistic species, including these three species, can be indicative of frequent disturbance (Grassle and Grassle 1974; Pearson and Rosenberg 1978). Of the eleven opportunistic species listed by Dauer (1993), six species—*S. benedicti*, *P. ligni*, *M. lateralis*, *Glycinde solitaria*, *Leitoscoloplos fragilis*, and *Mediomastus ambiseta*—were present in the current study. The benthic macrofaunal community in Baffin Bay is often subjected to warm-temperature, low-inflow disturbances (e.g., hypersalinity); *S. benedicti* historically withstands these variable conditions and dominate numerically (March 2014 – July 2017; Rubio et al. 2018; Breaux et al. 2019). After Uri, *S. benedicti* continues to be abundant, contributing 43% of the total taxa abundance in the soft sediments (Table 1). The contribution of *P. ligni* increased from 2.7% in 1991 (Hardegree 1997) and 5.4% in 2018-2019 (Palmer et al. 2022) to 15.9% in the current study—a possible response to Uri.

Serpulid reefs in Baffin Bay have been studied less extensively than soft sediments. Reef macrofaunal communities appear to be resistant to typical disturbances in the bay (Palmer et al. 2022). Total abundance and biomass of Serpulid reef benthic macrofauna in March and May

( $36,747 \pm 25,796 \text{ n L}^{-1}$ ;  $2,967.8 \pm 2,305.7 \text{ mg L}^{-1}$ ) were similar to previous sampling ( $29,951 \text{ n L}^{-1}$ ;  $8,498.6 \text{ mg L}^{-1}$ ; Palmer et al. 2022), which indicates that reef communities are also resistant to cold-temperature events. Community composition was also more similar over time on reef than at soft sediment stations after the cold event. The five taxa that contributed 90% of the total abundance to the Serpulid reef community during the current study similarly contributed 81% of abundance in 2018- 2019 (Palmer et al. 2022) and commonly occurred in 1991 (Hardegree 1997). Throughout the study period, total abundance and biomass of benthic macrofauna were higher on Serpulid reef than soft sediments. The difference between habitats is greatest in March 2021 (following Uri), with 664 times greater abundance and 181 times higher biomass of benthic macrofauna on Serpulid reefs compared to soft sediments (top 3 cm of sediment).

Stable SPOM and SSOM  $\delta^{13}\text{C}$  values, as well as stable SSOM  $\delta^{15}\text{N}$  values indicate that organic matter inputs to the bay did not change as a result of Winter Storm Uri. Temporal variation in  $\delta^{15}\text{N}$  values of SPOM can be a result of daily inflow or turbid conditions. Wastewater inputs are generally  $^{15}\text{N}$  enriched (McClelland et al. 1997; McClelland and Valiela 1998), so a depletion as seen in May and June could be indicative of dilution of anthropogenic inputs. In March 2021,  $\delta^{13}\text{C}$  isotope compositions of some Serpulid reef macrofauna were lower than historic concentrations (June 2018-March 2019; Palmer et al. 2022): *Brachidontes exustus* (March -  $-23.0\text{‰} \pm 0.5\text{‰}$ ; historic  $-21.6\text{‰} \pm 0.6\text{‰}$ ), *Hydroides dianthus* (March  $-23.0\text{‰} \pm 0.1\text{‰}$ ; historic  $-21.1\text{‰} \pm 0.9\text{‰}$ ), Orbiniidae (March  $-21.4\text{‰} \pm 0.5\text{‰}$ ; historic  $-20.3\text{‰} \pm 0.5\text{‰}$ ) and Nereididae (March  $-21.3\text{‰} \pm 0.5\text{‰}$ ; historic  $-19.7\text{‰} \pm 1.2\text{‰}$ ). *Mulinia lateralis*, a soft-sediment suspension feeder, follow a similar pattern (March 2021  $-21.7\text{‰} \pm 0.2\text{‰}$ ; historic  $-20.35\text{‰}$ , March 2014 – March 2015, Mendenhall 2015;  $-20.5\text{‰} \pm 0.8\text{‰}$ , June 2018 – March 2019, Palmer et al. 2022). Depletion of macrofauna carbon values during the current study is indicative of a change in resource use with increased reliance on terrestrial sources.

Previous studies have found that black drum movement and resource use narrowed under prolonged hypersaline conditions in Baffin Bay, potentially because of the energetic costs of osmotic regulation (Ajemian et al. 2018, Breaux et al. 2019). We did not see evidence of a similar effect after Winter Storm Uri. Black drum tissue  $\delta^{13}\text{C}$  concentrations were  $>1\text{‰}$  higher than the Baffin Bay soft sediment and reef prey  $\delta^{13}\text{C}$  concentrations in March, July and August 2021, which indicates that they may have been feeding elsewhere. It is probable that black drum

were feeding on macrofauna in the neighboring Laguna Madre, which have higher  $\delta^{13}\text{C}$  concentrations than those typical to Baffin Bay (Breux et al. 2019). It is difficult to draw conclusions about the fish population as a whole in June because all fish sampled were larger than in other sampling events ( $691 \pm 27$  mm vs  $554 \pm 30$  mm). The sampling of the larger individuals is not likely to be representative of the available population in Baffin Bay because the fish were collected from commercial fishermen, who preferentially select large individuals. Rather, fish sampled during this period may reflect behavioral changes of black drum of many sizes associated with the May 2021 precipitation event. Immense congregations of black drum near Baffin Bay's freshwater inflow sources have been noted by Breuer (1957). Movement towards upper parts of the bay in June helps to explain black drum reliance on Baffin Bay resources (i.e., lower  $\delta^{13}\text{C}$  concentrations with less variability) rather than the ULM. Furthermore, increased availability of *M. lateralis* prey in June was likely beneficial for black drum. Movement up the bay, along with concentration of diets on *M. lateralis* could have contributed to the shift in  $\delta^{13}\text{C}$  values in fish tissues towards Baffin Bay resources during June.

## **5. Conclusion**

This study detected minimal evidence for impacts from Winter Storm Uri on reef and soft sediment macrofauna communities and trophic dynamics in Baffin Bay. However, it is difficult to robustly test for impacts without collecting and analyzing water quality and macrofauna community data both before and after a disturbance. Additional statistical tests (e.g., generalized linear models) that also incorporate data generated outside the scope of this project (collected outside of the Quality Assurance Project Plan) can be used in the future to test whether there are statistically meaningful differences in water quality, macrofauna communities, and trophic dynamics before and after Winter Storm Uri. Based on current findings, a release from hypersaline conditions in May 2021 affected soft sediment macrofauna communities and black drum resource use more than decreases in temperature as the result of Winter Storm Uri. However, it is possible that a cold disturbance during normal saline conditions would elicit a different response than observed from Winter Storm Uri.

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