Ecosystem-Based Approach to Assess
Black Drum in Baffin Bay

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Final Technical Report

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Executive Summary

The Black Drum, *Pogonias cromis*, is a large-bodied sciaenid fish species of both recreational and commercial importance to the Texas coastal-bend. In 2012, a large proportion of Black Drum landed by both recreational and commercial fisheries in the Baffin Bay estuary exhibited abnormal physical characteristics. These included below average weights, transparent tissue morphology, and empty guts. Following the design of previous studies in the Baffin Bay estuary, we reinstituted a standardized benthic sampling program to understand the spatial and temporal patterns in the abundance of potential Black Drum prey (i.e., benthic invertebrates) (Objective 1). To examine Black Drum reliance on these potential resources and spatial variability in trophic role, we conducted comparative diet analyses from specimens collected from Baffin Bay and adjacent areas (Objective 2). The final component of this project examined movement patterns of Black Drum and how they relate to the environmental regime (Objective 3). Twenty-five Black Drum were fitted with coded acoustic transmitters and tracked across receiver arrays deployed in Baffin Bay and adjacent water bodies. Coupled with a concurrent, spatially explicit water quality study in Baffin Bay, the project integrated fine-scale environmental monitoring with tracking data to build a comprehensive picture of ecosystem dynamics in the Baffin Bay system.

Results from the benthic sampling program indicated that salinity and dissolved oxygen play a strong role in Baffin Bay macrofaunal community dynamics, with significant effects on species diversity, richness, abundance, and biomass. During the study period there were similar communities of benthic food resources available to Black Drum throughout the Baffin Bay Complex, although tertiary arms may support higher abundances. Results from the dual stable isotope ($\delta^{13}C$ and $\delta^{15}N$) approach demonstrated that Black Drum are utilizing the variety of food resources available in Baffin Bay Complex. Stomach content analyses indicate that Black Drum are opportunistic feeders that generally consume benthic prey items proportional to their availability, particularly for bivalve mollusks including the dwarf surf clam, *Mulinia lateralis*, and the pointed venus clam, *Anomalocardia auberiana*. Acoustic telemetry monitoring data showed that Black Drum exhibit relatively high mobility and do not appear constrained to a single sub-embayment or arm within this ecosystem. However, despite seasonal impacts on fish distribution with the complex, most individuals appear to be residing within the system for extended periods with little documentation of egress from the system.

Our multi-trophic level approach allowed us to better understand the impact of a potential decline in food sources or an ecosystem-wide trophic shift in Black Drum feeding mode. Black Drum are feeding on a number of lower level consumers in the Baffin Bay Complex. For these fish to starve, there are likely problems with both benthic and pelagic food resources, perhaps due to a larger system disturbance such as degraded water quality. It is likely that multiple stressors are acting on the benthic community in Baffin Bay, including high salinities (during drought) as well as hypoxia/anoxia. Additional sample collections are warranted to further elucidate the individual as well as combined effects of these parameters on the macrofauna community and, as a result, Black Drum. With ongoing dynamic changes in water quality being documented throughout the Baffin Bay Complex, it will be important to continue monitoring food web dynamics and trophic linkages to make explicit links between water quality parameters and estuarine resources.

Introduction

The Black Drum, *Pogonias cromis*, is a large-bodied sciaenid fish species that occurs throughout warm-temperate to subtropical estuaries in the northwest Atlantic Ocean, including the Gulf of Mexico (Leard et al. 1993). In Texas, Black Drum are an important commercial and recreational fish species. In 2010 alone, ~1.7 million pounds of Black Drum were landed in Texas, valued (ex-vessel) at ~$1.6 M, second only to Red Snapper (TPWD 2012). Despite this species' wide distribution and important fishery status, the ecology of Black Drum remains poorly characterized in the vast majority of its range, particularly along the Texas coast.

Black Drum are known to be primarily benthic, aggregating around a variety of bottom habitats such as seagrass, oyster reef, sand and mud bottoms (Leard et al. 1993). In these habitats, Black Drum diet varies ontogenetically, with smaller individuals preferring crustaceans and worms and larger individuals consuming large, hard-shelled mollusks such as eastern oyster, *Crassostrea virginica* (Leard et al. 1993). Due to their ability to impact oyster communities via predation, a considerable amount of research has been devoted to methods of deterring Black Drum from oyster lease areas off Louisiana (Brown et al. 2003, Brown et al. 2006) including studies of Black Drum feeding effects and fine-scale habitat use (George 2007, Brown et al. 2008). Unfortunately, despite the rather ubiquitous nature of this species, there have been no studies of Black Drum movement behavior in other habitats (sand and mud bottoms) or over large spatial scales (>10 km^2). As such, the factors explaining Black Drum spatial distributions (aside from oyster density) remain unknown, though studies of this type are sorely needed (Brown et al. 2008).

The Baffin Bay Complex (BBC, Figure 1; comprising Baffin Bay, Alazan Bay, Cayo del Grullo, and Laguna Salada) and Upper Laguna Madre (ULM) appear to support some of the highest catches of Black Drum throughout Texas bay systems, with abundances steadily increasing since the 1980's and saturating over the last decade (TPWD, unpublished data; Figure 2). However, in 2012, a large proportion of Black Drum landed by both recreational and commercial fisheries exhibited abnormal physical characteristics. These included below

Figure 1. Map of the Baffin Bay Complex

average weights, transparent tissue morphology, and empty guts (Grubbs et al. 2013).

The factors explaining the current condition of Black Drum in the BBC is an area of active debate. However, many researchers agree that these abnormal characteristics are due to some degree of resource limitation. For example, the saturating trend in abundance patterns in the nearby ULM may be indicative of the population reaching its carrying capacity. With few predators to control Black Drum populations in the hypersaline waters of the ULM and demonstrated fidelity of Black Drum to specific
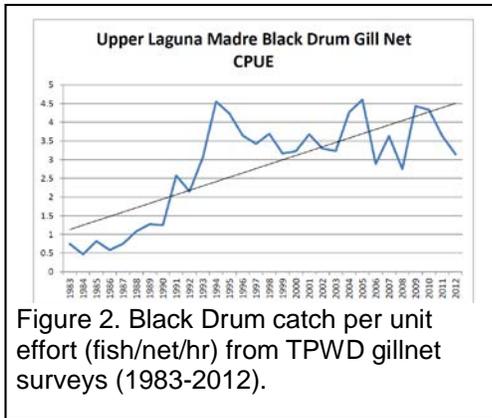
Figure 2. Black Drum catch per unit effort (fish/net/hr) from TPWD gillnet surveys (1983-2012).

embayments elsewhere (Osburn & Matlock 1984), this species may have reached maximum abundance in this protected water body. Alternatively, or perhaps coincidentally, altered water quality may have played a large role in reducing populations of Black Drum food resources or accessibility to these resources. For example, intermittent hypoxia, which has been noted in Baffin Bay in recent years, can concentrate demersal sciaenid fish in suboptimal (prey-deficient) habitats, thus reducing overall carrying capacity (Eby et al. 2005).

In the Baffin Bay Complex, populations of dwarf surf clam (*Mulinia lateralis*), a potentially major prey item of Black Drum (Breuer 1962, Simmons & Breuer 1962, Martin 1979), have not been assessed in nearly a decade. However, anecdotal evidence suggests major unpredicted die-offs of surf clams in recent years (Figure 3) that may be related to deteriorating water quality conditions, and which may have led to sub-lethal effects on Black Drum. The Texas Parks and Wildlife Department (TPWD) published a 2013 report "Emaciated Black Drum Event" highlighting the need for information on benthic food resources and Black Drum feeding dynamics in the Baffin Bay Complex (Grubbs et al. 2013).

The goal of this study was to conduct a comprehensive, multi-trophic level study to determine linkages between water quality, benthic food resources, and Black Drum in the Baffin Bay Complex. Our working hypothesis was that Black Drum exhibit strong fidelity to the BBC and prefer feeding on *M. lateralis*, which in turn exhibit distribution patterns related to the local environmental regime and water quality conditions.

Figure 3. Shell remnants of dwarf surf clams along the Baffin Bay shoreline 2012. (Photo: S. Murray)

Methods

Following the design of previous work by Dr. Paul Montagna and guidance from the Texas Parks and Wildlife Department, we reinstituted a standardized benthic sampling program to understand the spatial and temporal patterns in the abundance of potential Black Drum prey (i.e., benthic invertebrates) across Baffin Bay (Objective 1). To examine Black Drum reliance on these potential resources and spatial variability in trophic role, the research group conducted comparative diet analyses from specimens collected from Baffin Bay and adjacent areas (Objective 2). The final component of this project examined movement patterns of Black Drum (e.g., fidelity to Baffin Bay) and

how they relate to the environmental regime. Twenty-five Black Drum were fitted with coded acoustic transmitters and tracked across receiver arrays deployed in Baffin Bay and adjacent water bodies (Objective 3). To do this, an existing acoustic array deployed throughout the coastal bend was modified to examine Black Drum fidelity to Baffin Bay and potential connectivity with other embayments. Coupled with a concurrent, spatially-temporally explicit water quality study by Dr. Mike Wetz in Baffin Bay, the project attempted to integrate fine-scale environmental monitoring with tracking data and build a comprehensive picture of ecosystem dynamics in the Baffin Bay system.

Benthic Sampling

Seasonal benthic surveys were conducted to determine the distribution and abundance of potential food resources for Black Drum in the Baffin Bay Complex. Ten uniformly distributed sampling stations representing a broad range of salinity habitats throughout the Baffin Bay Complex were sampled quarterly for benthic macrofauna and water quality from March 2014-March 2015 (Figure 4). Four additional benthic sampling stations (CG3, AL6, AL7, AL9) were added in September and December 2014 and March 2015 to increase spatial coverage. Of these stations, three were previously surveyed from 1989 to 1993 (BB6, BB24, BB40) (Montagna et al. 1993; Street et al. 1997) and were chosen to allow for historical comparison.

Benthic macrofauna were sampled using a 35.4 cm^2 cylindrical corer to a depth of 10 cm. On each sampling date, 5 replicate cores were collected from each station. Three cores were sectioned into 0-3 cm and 3-10 cm sections, and preserved with 5% buffered formalin for analysis of macrofauna community structure (Palmer et al. 2011, Manly et al. 2002). Two cores were stored in a cooler to collect live macrofauna for stable isotope analysis of C and N.

In the laboratory, benthic macrofauna were extracted on a 500 µm sieve, sorted using a dissecting microscope, identified to the lowest possible taxonomic level (LPTL; usually species), and enumerated. Biomass measurements were obtained after combining individual macrofauna into higher taxa levels (e.g., Crustacea, Gastropoda, Bivalvia, Polychaeta, and others), drying at 55 °C for 24 hours, and then weighing. Mollusk shells were removed with 10% HCl prior to drying and weighing.

Hydrographic measurements (temperature, dissolved oxygen, pH, specific conductivity, turbidity, and salinity) were taken at the surface and bottom of the water column using a multiparameter instrument (Hydrolab Surveyor II or YSI 6 series). Water depth, wind speed, wind direction, cloud cover, and wave height were also recorded.

Spearman's partial correlation coefficients were calculated to determine the strength and direction of linear relationships between macrobenthic abundance and diversity (N1; Hill 1973, Sanders 1968) with hydrological variables. Partial correlations measure the degree of association between the macrobenthic and hydrological variables while statistically controlling for the potential effects of other hydrological variables in the model. Partial lag times were examined and incorporated into the correlations between

macrobenthic and hydrological variables when necessary. Principal Component Analysis (PCA) was used to assess relationships between hydrologic variables during the different sampling periods. All correlations were calculated using SAS software (SAS Institute Inc. 2009).

Similarities among macrobenthic communities were analyzed using non-metric multidimensional scaling (NMDS) using a Bray-Curtis similarity matrix (Clarke and Warwick 1994). Significant groupings of communities were determined using the SIMPER routine as part of cluster analysis (Clarke 1993, Anderson 2001). Correlations between hydrological variables and macrofauna community structure were examined using BIO-ENV, a multivariate procedure that calculates weighted Spearman rank correlations (ρ_w) between sample ordinations from all of the environmental variables and the ordination of species abundances for each sample (Clarke and Ainsworth 1993). All multivariate statistics were calculated using PRIMER 5 for Windows v5 (Copyright PRIMER-E Ltd.).

A benthic index was use to assess environmental quality of Baffin Bay macrofauna communities. The benthic index used was the same developed by Engle and Summers (1999) for estuaries throughout the Gulf of Mexico. The index used was a further development of that developed by Engle et al. (1994). The benthic index is created by first calculating an expected Shannon-Weiner (H') diversity based on a salinity-diversity relationship:

$$\text{Expected Diversity} = 0.75411 + 0.00078 * salinity + 0.00157 * salinity + -0.00030 * salinity$$

The sample diversity is then divided by the expected diversity to get a proportional diversity. A discriminant score is then calculated on standardized values (mean=0, standard deviation of 1) of: proportional diversity, and abundances of tubificid oligochaetes (n), capitellid polychaetes (% within each sample), bivalve mollusks (%), and amphipods (%).

Discriminant Score   =   1.5710 * Proportion of Expected Diversity
                    -     1.0335 * Mean Abundance of Tubificids
                    -     0.5607 * % Capitellids
                    -     0.4470 * % Bivalves
                    +   0.5023 * % Amphipods

The discriminant score is then normalized to a scale of 0-10 using the following formula:
Benthic Index   =   (Discr. score – Discr. score $_{min}$)/ (Discr. score $_{max}$ – Discr. score $_{min}$)

The community data from 4 sampling periods (March to December 2014) were composited and treated as one sample for the current analysis to keep the total sample area similar to that used by Engle and Summers (1999). Therefore, the Benthic Index calculated for Baffin Bay represents a year-long community rather than a one-time

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snapshot.

In order to measure stable isotope composition ($\delta^{13}C$, $\delta^{15}N$) of benthic samples, representative individuals of each macrobenthic species collected from core sampling were sieved live on a 500 µm mesh and kept alive in artificial seawater for 24-48 hours to remove gut contents. Organisms were then frozen at -20 °C, freeze dried and ground to a fine and homogeneous powder using a ball mill (Retsch MM 400). Three individuals of each macrobenthic species were processed from each station. When insufficient material was obtained for a particular species at a particular station, samples were combined with the same species from the closest station(s). Samples containing inorganic carbonates (e.g., macrofauna with shells) were decarbonated by adding 1-5 ml of 1 M HCl and then placing them in an ultrasonic bath for 1 minute. This procedure was repeated until the end of bubbling, indicating all carbonates were removed. Decarbonated samples were then placed in a dry block heater at 60 °C for 24 hours. Stable isotope analysis of nitrogen was conducted on raw sample material to prevent distortion that can be caused by acidification (Bunn et al. 2003).

Surface sediment organic matter was sampled using a 35.4 cm^2 cylindrical corer to a depth of 3 cm. On each sampling date, 1 sediment core (0-3 cm) was collected at each of five benthic stations to determine the stable isotope composition of the surface sediment organic matter. Sediment samples were sieved through a 500 µm screen to remove shell hash and large organic material, then freeze-dried and ground using a mortar and pestle. Samples were decarbonated with 10% HCl prior to measurements of $\delta^{13}C$ values.

Figure 4. Map of the Baffin Bay Complex with benthic coring stations. Current stations are shown in yellow, while stations sampled currently and historically by Montagna (1997) are shown in maroon. Locations of Black Drum captured by TPWD are shown as black squares.
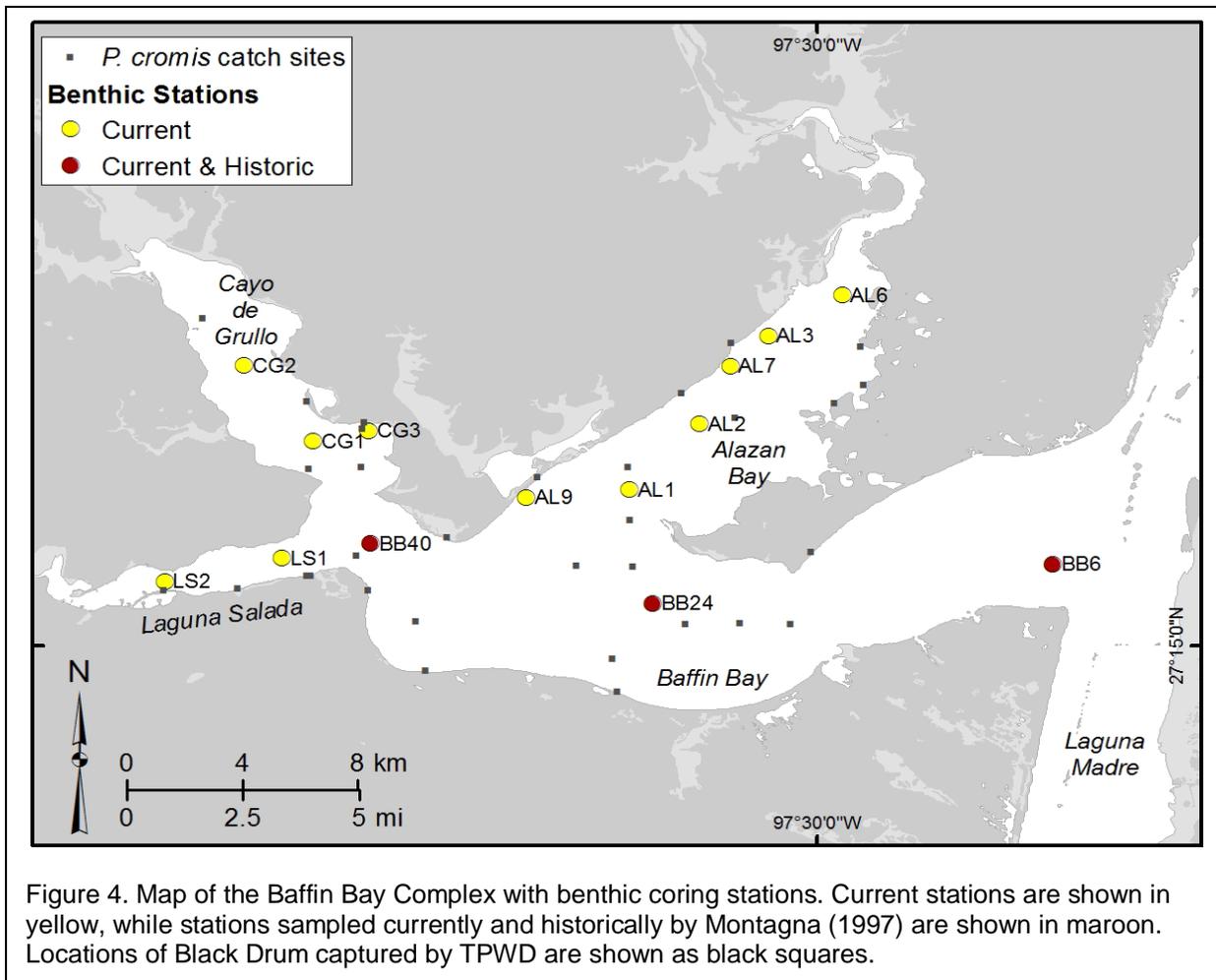
Gut Content and Stable Isotope Analysis

Black Drum were collected throughout the Baffin Bay Complex on a monthly basis in partnership with the Texas Parks and Wildlife Department fishery-independent surveys. Fish were collected using gill nets that were 183 m wide x 1.21 m deep, comprising 46 m sections of 7.6 cm, 10.2 cm, 12.7 cm, and 15.2 cm mesh. Nets were set overnight perpendicular to the shoreline beginning with the 7.6 cm mesh and extending to the 15.2 cm mesh at the deep end. Collected fish were immediately placed on ice in the field and then frozen (-20 °C) prior to processing.

In the laboratory, fish were measured for standard length (SL), fork length (FL), total length (TL), weight, otoliths, and sex (if possible) (Harrington et al. 1979). Whole digestive tracts of Black Drum were removed beginning with the esophagus and ending with the anal vent. Excised digestive tracts were fixed in 10% buffered formalin. After a 48-hour fixation period, digestive tracts were transferred to jars with 70% ethanol until further processing. All stomach content items were enumerated (if possible), weighed,

and identified to the lowest possible taxonomic level (LPTL). Stomachs collected for stable isotope analyses were not fixed in formalin but were instead frozen.

Gut contents were evaluated using a number of metrics. The percent frequency of occurrence was calculated as:

$$F_a = \frac{S_a}{S} X\ 100$$

where S_a is the number of guts containing prey item a, and S is the total number of non-empty guts examined (Hyslop 1980). Prey selection was assessed using the Strauss Index (Strauss 1979):

$$L = r_a + p_a$$

where r_a= relative abundance of prey type a in the diet (as a proportion of the total number of prey in the diet) and p_a= relative abundance of prey type a in the environment (from benthic core data). Values range from -1 to +1, with positive values representing preference and negative values representing avoidance or inaccessibility. Percent total weight (%W) and percentage of empty guts (Vacuity Index) were also calculated.

To determine the stable isotope composition of C and N for Black Drum, five individuals (200-400 mm TL) were selected from each sampling month. Epaxial muscle tissue was removed from the anterior portion of all specimens, avoiding presence of fish bones in samples. Samples were frozen at -20 °C, then freeze dried and then ground to a fine and homogeneous powder using a ball mill. Digestive tracts were cut open and emptied onto a 500 µm sieve over a glass bowl to collect any undigested food resources. Highly digested organic material passed through the sieve and into a glass bowl for weighing (Ohaus Discovery DV215CD analytical balance [Switzerland], readability (mg) 0.01*/0.1, repeatability (std. dev.) (mg) 0.02*/0.1). Digested material was then centrifuged to obtain a pellet, freeze dried then ground using a ball mill. Samples containing inorganic carbonates were decarbonated as for macrobenthic core samples.

Elemental stable isotope compositions for benthic, sediment, and Black Drum samples were determined using an elemental analyzer (ECS 4010 with a Zero Blank Autosampler, Costech, Valencia, California) connected to a continuous flow isotope ratio mass spectrometer (Delta V Plus, Thermo Scientific, Bremen, Germany) via a Conflo IV interface. Analyses were conducted at the stable isotope facility at Texas A&M University-Corpus Christi. Ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ are expressed in the delta (δ) notation in parts per thousand (‰) as deviation from international standards (Vienna Pee Dee Belemnite for $\delta^{13}C$ and N_2 in air for $\delta^{15}N$) and following the formula: δX (‰) = [(Rsample/Rstandard) - 1] x 103, where X is ^{13}C or ^{15}N and R is $^{13}C/^{12}C$ or $^{15}N/^{14}N$ isotopic ratios, respectively. Methionine (Costech, N = 9.39 % ; C = 40.25 %) was used as a standard for determination of carbon and nitrogen content. Two-point calibration was done using international reference materials (USGS-40: $\delta^{15}N$ = -4.52 ‰ ; $\delta^{13}C$ = -26.39 ‰ and USGS-41: $\delta^{15}N$ = 47.57 ‰ ; $\delta^{13}C$ = 37.63 ‰) (Paul et al. 2007). Laboratory standards (Acetanilide, GNPS, and rice [SIGF standards]; USGS40 and USGS41 [calibration]) were analyzed after every 12 samples to monitor instrument

performance and check data normalization. The precision of the laboratory standards was ± 0.2‰ for carbon and nitrogen.

Acoustic Telemetry

In 2014, 25 Black Drum were surgically implanted with Vemco V13 coded acoustic tags between 23-April and 20-May (Table 1). All individuals were tagged and released at the capture location. While we successfully released tagged individuals from all major arms of the BBC, we had the greatest success in Alazan Bay (n=17). Additional tagged animals were released from Cayo De Grullo (n=3), Baffin Bay (n=3), and Laguna Salada (n=2). No animals died during surgery, and all swam off strongly during release.

An array of 15 moored acoustic receivers (Vemco VR2W) was deployed throughout the BBC to remotely monitor movements and distribution of these tagged individuals (Figure 5). Due to the large size of the BBC, the array was positioned in a broad format to maximize coverage. An additional array of acoustic receivers was in place in several regions outside of BBC to monitor individuals that leave the system and thus examine the connected nature of the BBC and other water bodies along the south Texas coast. This broader scale array, the Texas Acoustic Array Network (TEXAAN), had the ability to track animals on the order of 100s of kilometers if necessary. Data downloads of the BBC passive monitoring array (i.e., 15 receiver stations) were conducted on 8/5/2014 and 12/8/2014 and a final download was performed 4/19/2015. Thus, Black Drum acoustic telemetry data reported here are for nearly a full year of monitoring.

Table 1. Location and capture information for 25 Black Drum fitted with acoustic transmitters. *LAT/LON = Latitude/Longitude (decimal degrees). Collection Gear types; GN = gillnet, HL = hook-and-line. TL_mm = total length in millimeters, W_kg = weight in kilograms. Embayment codes: AL = Alazan Bay, BB = Baffin Bay, CG = Cayo De Grullo, LS = Laguna Salada.*

DATE	LAT	LON	Collection_Gear	TL_mm	W_kg	Acoustic_ID	Dart_TagID	Embayment
4/23/2014	27.369	-97.497	GN	538	2.2	16456	1951	AL
4/23/2014	27.369	-97.497	GN	505	1.7	16457	1990	AL
4/23/2014	27.369	-97.497	GN	460	1.4	16458	1974	AL
4/23/2014	27.369	-97.497	GN	375	0.7	16459	1973	AL
4/23/2014	27.341	-97.529	GN	476	1.4	16460	1972	AL
4/23/2014	27.295	-97.548	HL	362	0.7	16465	1971	AL
4/23/2014	27.295	-97.548	GN	478	1.75	16464	1970	AL
4/24/2014	27.264	-97.728	GN	514	2.3	16463	1969	LS
4/25/2014	27.233	-97.536	GN	367	0.75	16466	1968	BB
4/25/2014	27.233	-97.536	GN	461	1.5	16462	1967	BB
4/25/2014	27.233	-97.536	GN	347	0.7	16461	1981	BB
5/14/2014	27.263	-97.728	GN	372	0.7	16467	1988	LS
5/15/2014	27.386	-97.487	HL	369	0.75	16468	1987	AL
5/15/2014	27.386	-97.487	HL	418	1	16469	1982	AL
5/15/2014	27.386	-97.487	HL	391	0.85	16470	1986	AL
5/15/2014	27.373	-97.497	GN	412	1.1	16471	1983	AL
5/15/2014	27.373	-97.497	GN	371	0.8	16472	1966	AL
5/15/2014	27.373	-97.497	GN	351	0.6	16473	1984	AL
5/15/2014	27.373	-97.497	GN	354	0.7	16474	1985	AL
5/15/2014	27.373	-97.497	GN	375	0.75	16475	1952	AL
5/15/2014	27.374	-97.705	GN	888	11.1	16476	1965	CG
5/15/2014	27.374	-97.705	GN	345	0.75	16477	1964	CG
5/15/2014	27.377	-97.709	HL	370	0.7	16478	1963	CG
5/20/2014	27.355	-97.486	GN	489	1.75	16479	1953	AL
5/20/2014	27.334	-97.485	GN	382	0.75	16480	1954	AL
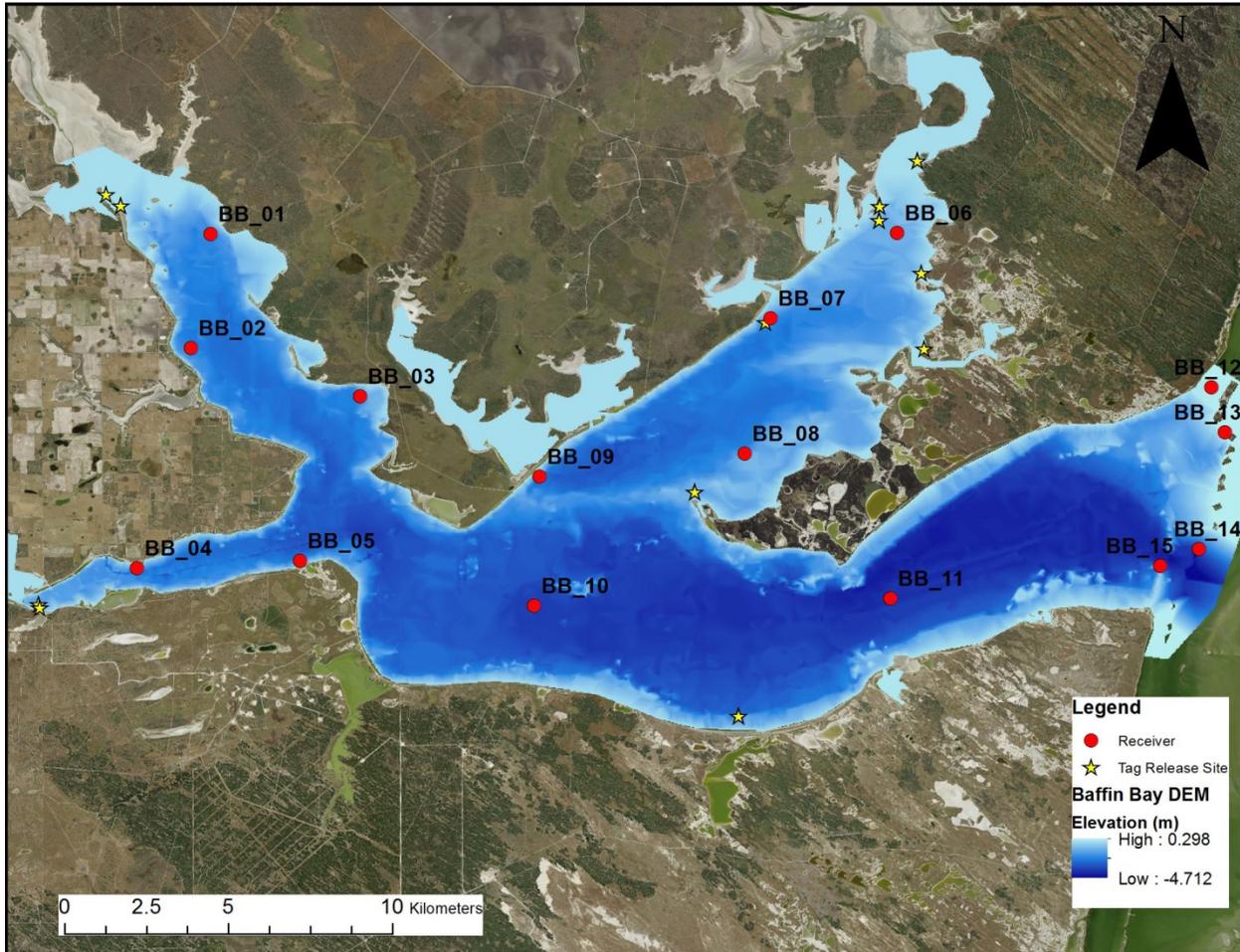
Figure 5. Map of the Baffin Bay Complex showing location of acoustic receivers (red circles) and release sites for acoustically tagged fish (yellow stars).

Black Drum acoustic data were plotted on a time-series (i.e., abacus plot) to examine temporal movement patterns among various arms of the BBC. To evaluate overall habitat use preferences within the BBC we examined the number of detections (using individuals as replicates) at each receiver using analysis of covariance (ANCOVA). For the ANCOVA, "site" (i.e., receiver) was considered the grouping factor, and distance to tag release of each individual was used as a covariate. For this analysis, only data from sites with at least 4 individuals detected were used (BB_01-11). To meet the ANOVA assumptions of normality and equal variances, detection data were log-transformed.

Qualitative assessment of spatiotemporal patterns was conducted using interpolation techniques. In this analysis, raw monthly detection data binned and imported into ArcGIS and interpolated using the "spine with barriers" function in the spatial analyst toolbox.

The passive acoustic monitoring array was supplemented with opportunistic active tracking surveys. These surveys involved the attachment of a Vemco mobile transceiver (VMT) to Dr. Mike Wetz's Autonomous Underwater Vehicle (AUV) during his concurrent

fine-scale water quality surveys. These AUV-based active tracking surveys were intended for the research team to understand the relationship between Black Drum fine-scale habitat use and the environmental regime of the BBC. The AUV logged position at the surface using an onboard GPS unit and estimated locations at depth using "dead-reckoning" techniques. Thus, using the synchronized timestamp between the AUV and VMT, all tag detections could be accompanied by water quality and position information. However, the two tracking days dedicated to these active telemetry efforts (9/8/2014, 9/25/2014) yielded no tag detections in the areas surveyed (center axis of Alazan Bay, junction between Laguna Salada and Cayo De Grullo). As such, we did not have sufficient active tracking data to analyze for the report.

Results

Water Quality Monitoring

Dr. Mike Wetz's group collected and shared monthly volunteer water quality data from May 2013-present. This data set documented spatial and temporal heterogeneity in the environmental conditions of the Baffin Bay Complex (Figure 6). With all samples pooled, the upper reaches and western half of the system (BB1-BB6) generally exhibited saltier conditions, higher turbidities, and higher concentrations of chlorophyll a than the eastern third of the bay adjacent to the Upper Laguna Madre (BB7-9). This disparity was most apparent between these two major regions during the months of May – September in 2014. Temperature appeared to be generally stable across sites, with maximum temperatures and minimum dissolved oxygen levels both occurring in August. Bottom dissolved oxygen displayed a strong temperature-dependent seasonal cycle, reaching minimum levels from late spring through fall. The monthly data collections are insufficient for characterizing the finer temporal scale dissolve oxygen dynamics, at least at levels relevant to fish and macrofauna. For example, data obtained from sonde deployments that began in January 2015 show that several regions of Baffin Bay are poised to develop hypoxia given the highly enriched nature of the system in terms of algal bloom prevalence and exceptionally high organic matter concentrations (Wetz unpubl. data), as well as appropriate physical conditions (i.e., light winds, stratification). At a shallow (1 m depth) site in the Cayo del Grullo, several periods of diel hypoxia and even anoxia were observed (Figure 7). In these cases, the water column was deficient in oxygen for a large portion of the 24 hour cycle. Most egregious was a period in late September 2015 at site BB40 (Figure 4), when hypoxia persisted throughout the entire 24 hour cycle over a 5 day span. Two days later, hypoxia developed again and reached all the way to the surface (Figure 8). While not overlapping with benthic sampling, this data highlights that benthic organisms as well as fish can experience significant hypoxia/anoxia related stress, which until now had not been demonstrated in an integrated fashion. The coolest temperatures and maximum dissolved oxygen levels occurred in February.
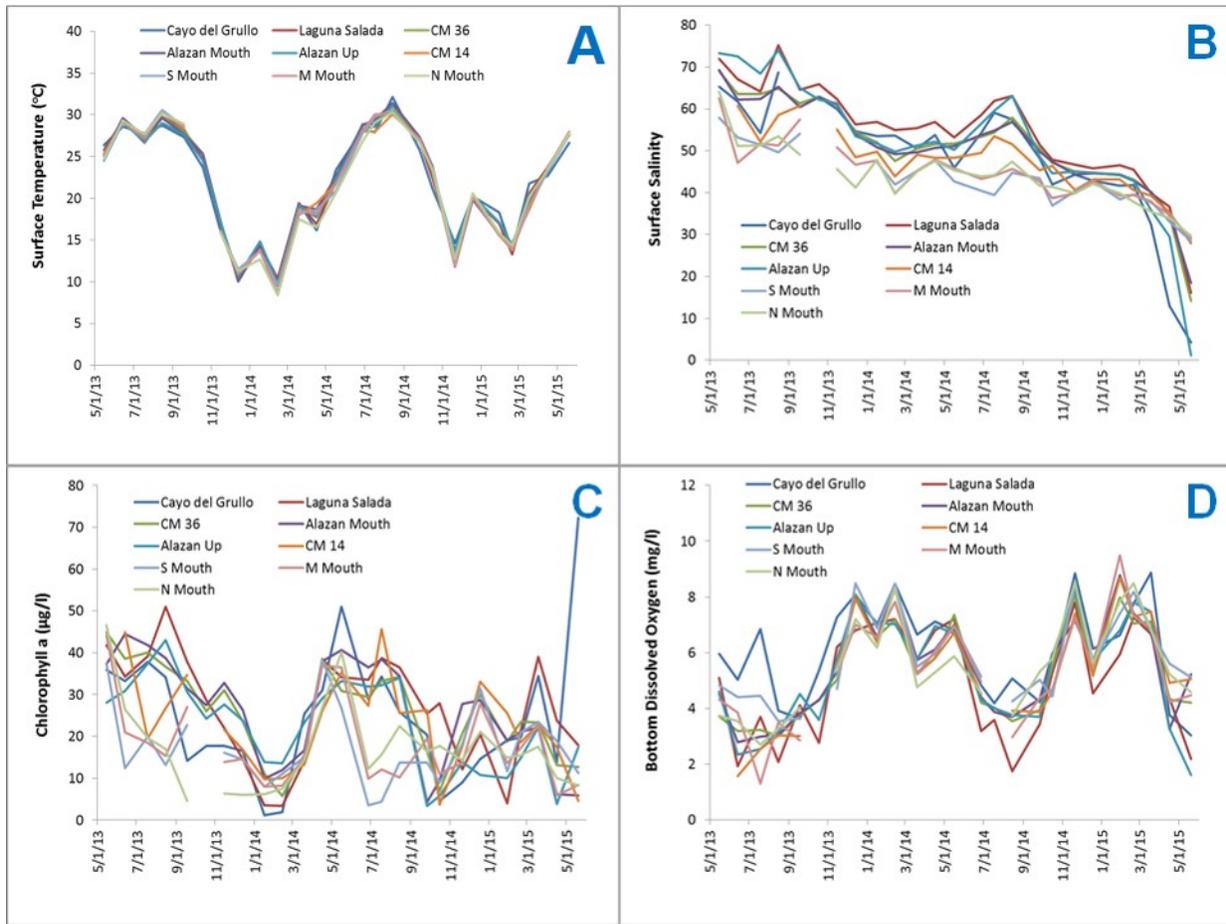
Figure 6. Time-series line plots of the environmental conditions (A: Surface Temperature, B: Surface Salinity, ppt; C: Chorophyll a; D: Bottom Dissolved Oxygen) in Baffin Bay over the project period. Data provided by M. Wetz.
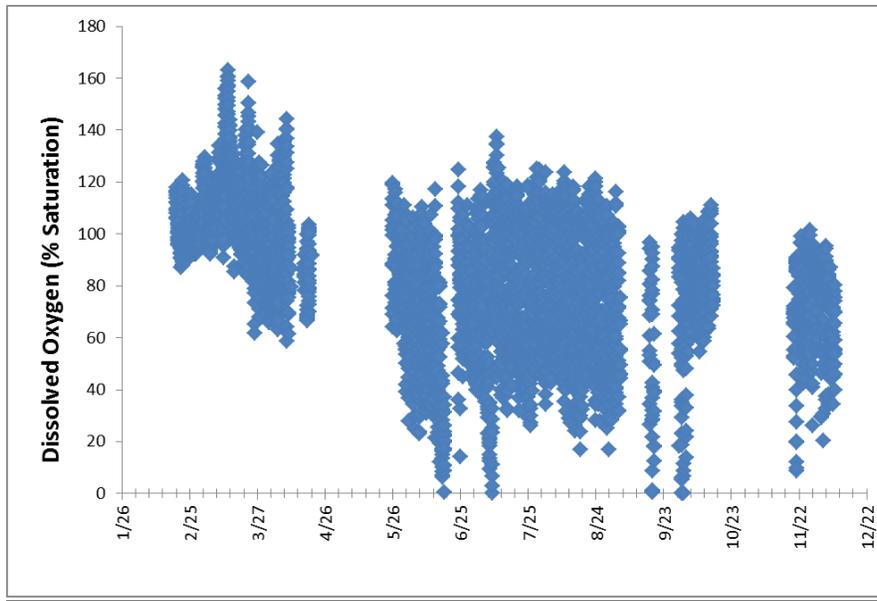
Figure 7. Dissolved oxygen measurements at a shallow (1 m) site in Cayo del Grullo illustrating observations of diel hypoxia and anoxia. Data provided by M. Wetz.
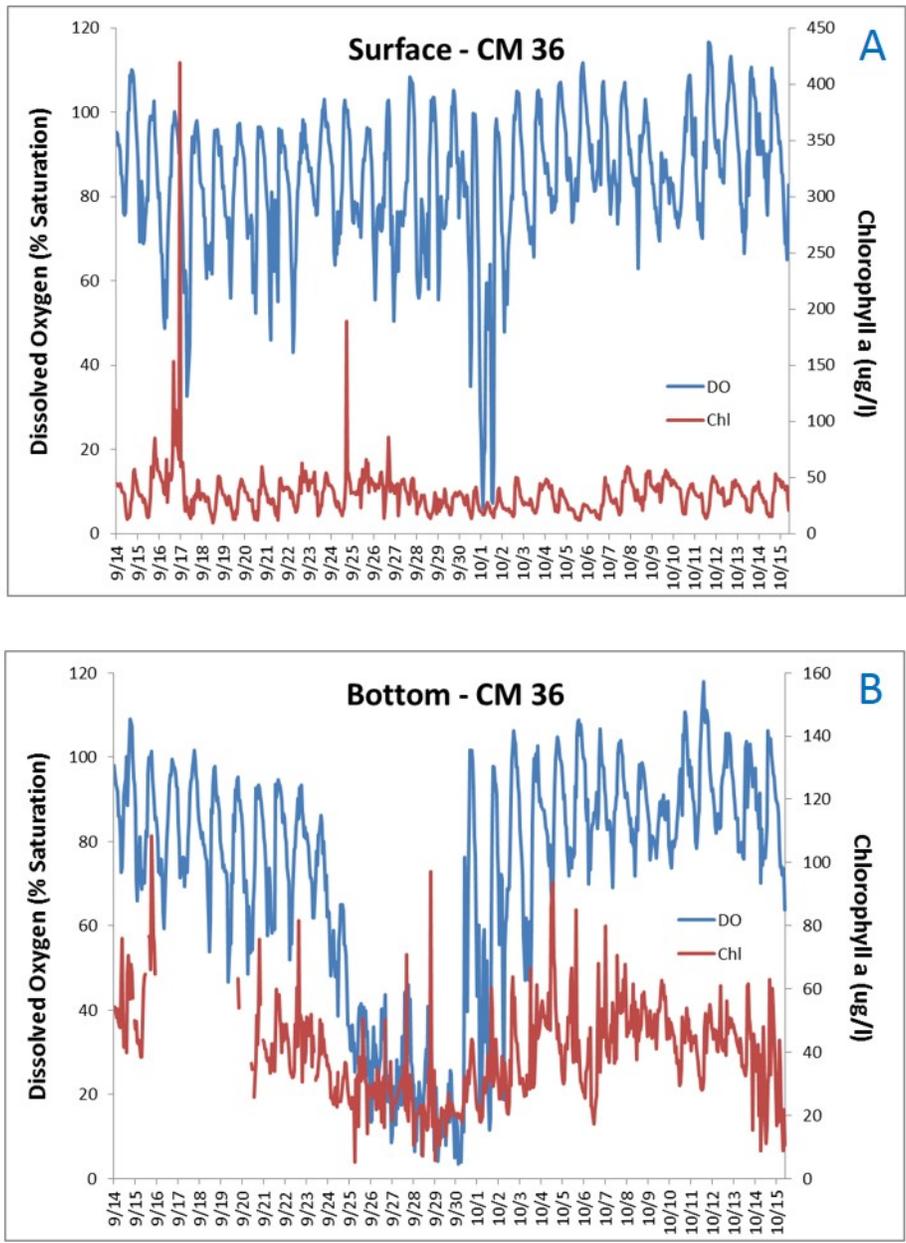
Figure 8. Dissolved oxygen and Chlorophyll-a measurements illustrating persistent bottom hypoxia throughout the entire 24 hour cycle over a 5 day span, followed by an episode where hypoxia extends to the surface.

Benthic Sampling

A total of 186 (0-10 cm) benthic cores were analyzed over the course of five seasonal sampling dates, yielding a total of 4924 individuals and 31 taxonomic groups of macrofauna (Table 2). Alazan Bay had the highest overall and mean macrofauna abundance (12,133 n m^{-2}) by bay across all sampling dates (Figure 9). The highest mean macrofauna abundance by date across all stations (10,407 n m^{-2}) was observed in September 2014. Macrobenthic abundance was dominated by polychaetes—specifically *Streblospio benedicti*—as well as bivalves and gastropods. Macrobenthic biomass was dominated by mollusks (bivalves, gastropods) and polychaetes (Figure 10). *Mulinia lateralis* abundance was highest at two stations in Alazan Bay (AL6 and AL9; Table 2, Figure 11). Species groups of regular occurrence across all stations (≥10) include *Anomalocardia auberiana* (bivalve), *Acteocina canaliculata* (gastropod), *Fargoa gibbosa* (gastropod), *Mulinia lateralis* (bivalve), Amphipoda (crustacean), *Eulimastoma harbisonae* (gastropod), and *Streblospio benedicti* (polychaete). Multiple ANOVAs showed no significant spatial trends in macrofauna abundance (n m^{-2}), biomass (g m^{-2}), Hill's N1 diversity (N1), or species richness (N0) between all 14 stations over the course of three sampling dates from September 2014 through March 2015, or between the 10 original stations over the course of all sampling dates. Using non-metric multidimensional scaling analysis, benthic communities from almost all samples grouped into one cluster with at least 40% similarity to one another (Figure 7).

Calculating Spearman partial correlation coefficients from the original 10 benthic stations across all five sampling dates resulted in significant, positive relationships between Hill's N1 diversity with salinity (ppt) (R=0.336; p=0.0316) and dissolved oxygen (mg L^{-1}) (R=0.374; p=0.0157). Species richness (N0) was also positively correlated with salinity (R=0.335; p=0.0319) and dissolved oxygen (R=0.405; p=0.0085). Macrofauna biomass was positively correlated with dissolved oxygen (R=0.302; p=0.0547). The BIO-ENV procedure indicated the best correlations existed between macrofaunal abundance and log-transformed salinity (ppt) (Corr=0.136, p=0.037) and log-transformed dissolved oxygen (mg L^{-1}) (Corr=0.135, p=0.037).

Water quality parameters for each site were merged using principal component analysis (PCA; Figure 13). The first and second principal components (PC1 and PC2) accounted for 64.5% and 22.2% of the sample variation, respectively (total 86.7%). Salinity and temperature were negatively related to dissolved oxygen along PC 1. High pH and turbidity corresponded to positive PC2 values. Station loading scores were separated along the PC1 axis, where March 2015 was characterized by higher dissolved oxygen and lower salinity and temperature than the other four sampling periods. March 2014 and 2015 and June 2014 separated away from other samples along the PC2 axis, and were characterized by higher turbidity and pH corresponding to higher primary production.

Table 2. Mean macrofauna abundance (n m^{-2}) at all 14 stations. Table values only include sampling dates where all 14 stations were sampled (3 sampling seasons). Bays: AL= Alazan, BB= Baffin Bay proper, CG= Cayo del Grullo, LS= Laguna Salada. Taxa groups: B=Bivalvia, C=Crustacea, CN=Cnidaria, G=Gastropoda, P=Polychaeta.

Taxa	Taxa Group	AL1	AL2	AL3	AL6	AL7	AL9	BB24	BB40	BB6	CG1	CG2	CG3	LS1	LS2	Mean
Anomalocardia auberiana	B	126	0	1008	1103	4034	14686	0	32	0	252	189	126	189	0	1553
Mactrotoma fragilis	B	63	32	0	0	158	252	0	0	0	189	0	189	0	0	63
Mulinia lateralis	B	536	662	315	1859	189	599	32	32	95	315	410	410	126	95	405
Amphipoda	C	0	0	0	0	32	0	0	0	0	0	0	95	0	0	9
Hargeria rapax	C	0	0	32	0	0	0	0	0	32	0	0	0	0	0	5
Sphaeroma terebrans	C	0	0	0	0	0	63	0	0	0	0	0	0	32	0	7
Anemone	CN	0	0	0	0	0	0	0	0	63	0	0	0	0	0	5
Acteocina canaliculata	G	158	63	32	788	0	599	63	32	0	252	126	32	252	63	176
Acteon candens	G	0	0	0	567	0	158	0	0	0	0	0	0	0	0	52
Bittiolum varium	G	32	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Cerithidea pliculosa	G	32	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Costoanachis semiplicata	G	0	0	0	0	0	0	0	0	0	0	0	32	0	0	2
Cycloscala echinatocosta	G	0	0	0	0	0	0	0	0	0	32	0	0	0	0	2
Eulimastoma didymum	G	0	0	0	221	0	126	0	0	0	0	0	0	0	0	25
Eulimastoma engonium	G	0	0	0	32	0	0	0	0	0	0	0	0	0	0	2
Eulimastoma harbisonae	G	189	284	378	315	1733	3908	32	126	32	0	0	0	0	32	502
Fargoa bartschi	G	0	0	0	0	0	32	0	0	0	0	0	0	0	0	2
Fargoa gibbosa	G	95	63	0	914	252	4822	0	0	0	315	32	63	32	126	479
Mitrella lunata	G	32	158	0	0	0	0	0	0	0	0	0	0	0	0	14
Nassarius vibex	G	0	0	0	0	0	0	0	0	0	32	0	0	0	0	2
Petitilla crosseana	G	0	0	0	0	0	32	0	0	0	0	0	0	0	0	2
Rissoella galba	G	32	0	32	0	0	0	0	0	0	32	0	0	0	0	7
Turbonilla spp.	G	0	0	0	32	0	32	0	0	0	0	0	0	0	0	5
Eteone heteropoda	P	0	0	0	0	32	95	0	0	0	0	0	0	0	0	9
Glycera tesselata	P	0	0	0	0	0	32	0	0	0	0	0	0	0	0	2
Goniadidae spp.	P	32	0	0	0	32	0	0	0	0	0	0	0	0	0	5
Nereididae spp.	P	0	0	0	0	0	0	0	32	0	0	0	0	0	0	2
Orbiniidae spp.	P	0	0	0	0	32	0	0	0	95	32	0	0	0	0	11
Phyllodocidae	P	0	0	0	0	0	63	0	0	0	0	0	0	0	0	5
Scoloplos foliocis	P	0	0	0	32	0	0	0	0	0	0	0	0	0	0	2
Streblospio benedicti	P	3025	5326	4727	10211	4664	2616	1922	3435	410	2962	3939	4444	7375	2175	4088
Total		**4349**	**6587**	**6524**	**16073**	**11157**	**28112**	**2049**	**3687**	**725**	**4412**	**4696**	**5389**	**8005**	**2490**	**7447**

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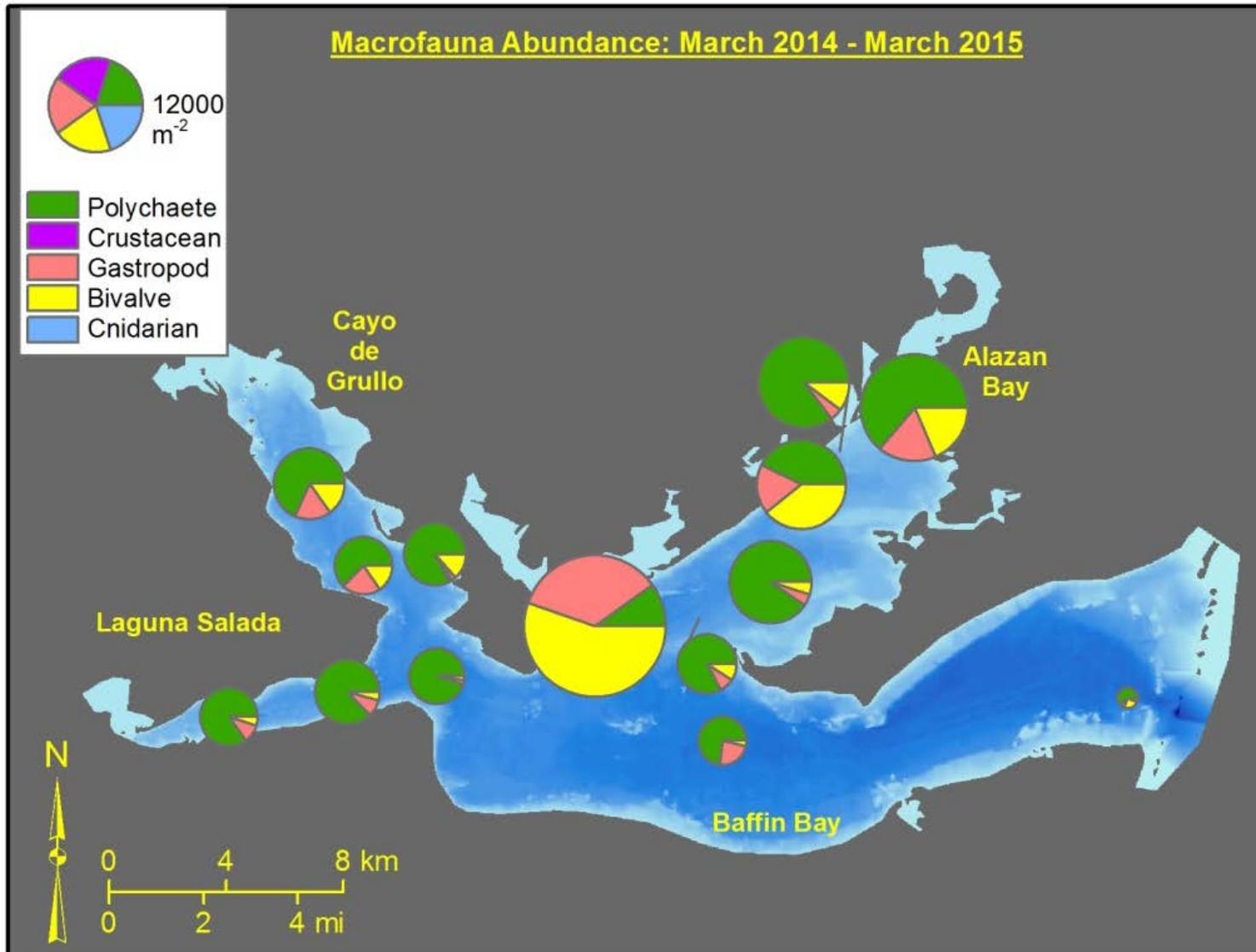
Figure 9. Map of macrofaunal abundance (m-2) by station (includes top 10 cm).
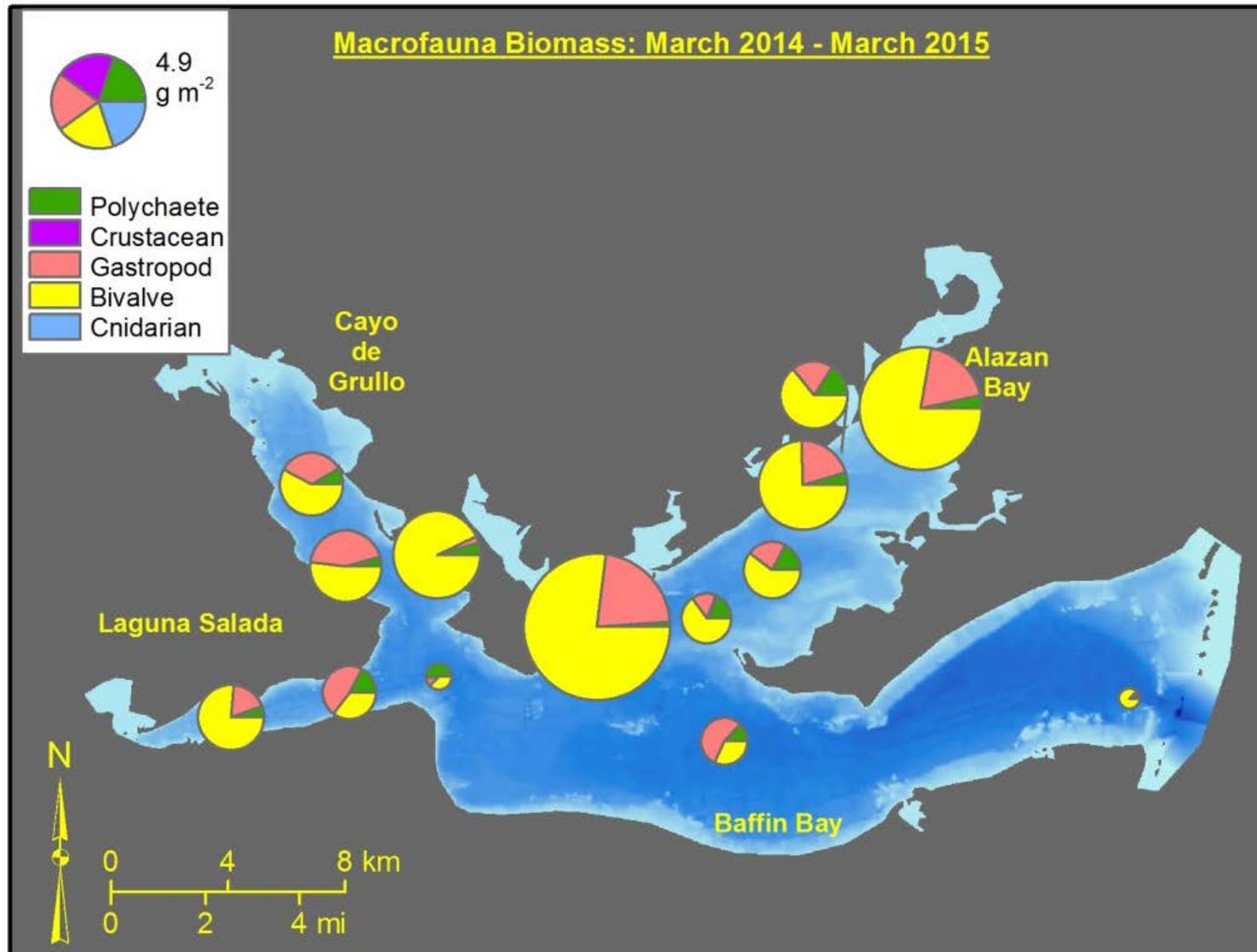
Figure 10. Map of macrofauna biomass (g m-2) by station (includes top 10 cm).
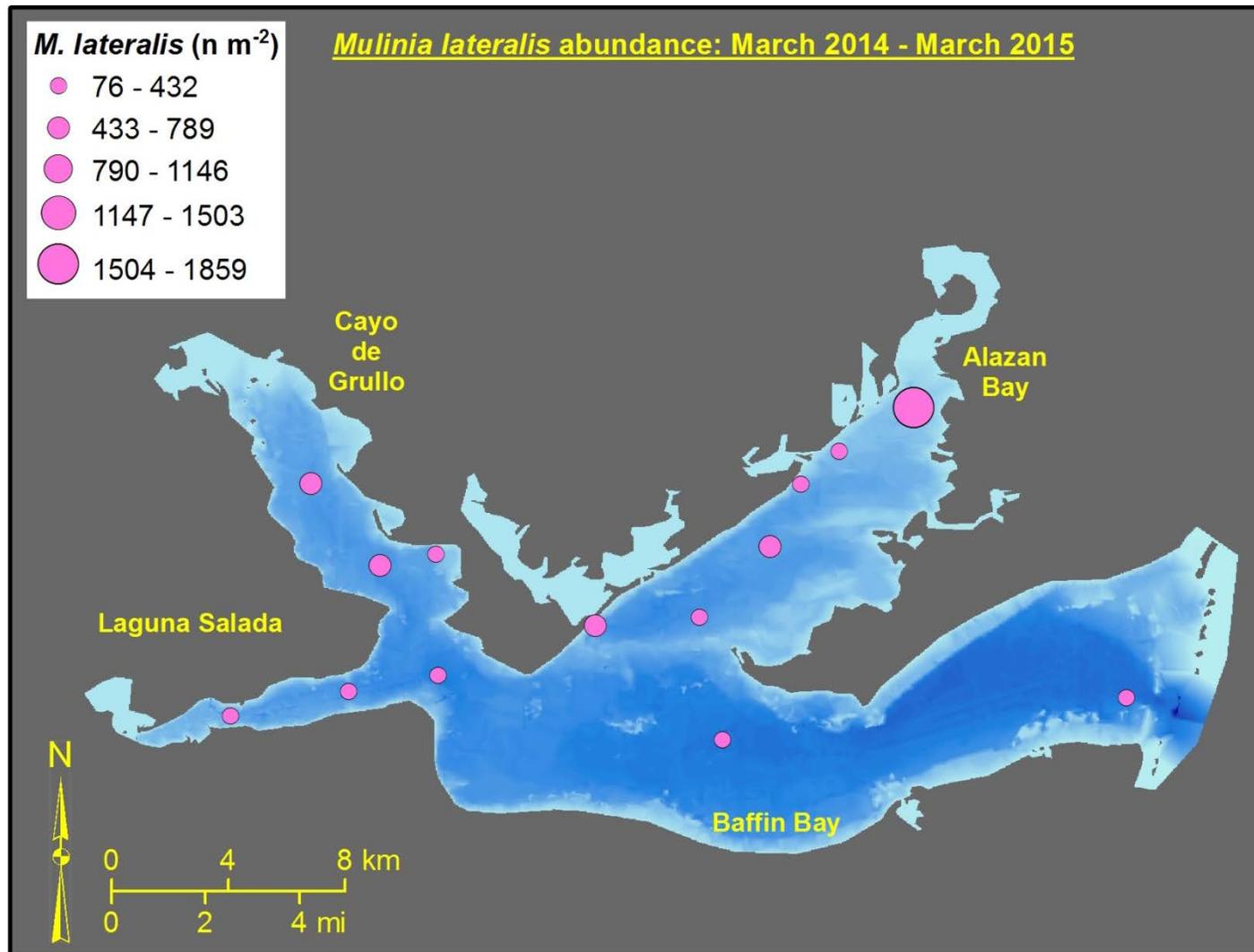
Figure 11. Map of *Mulinia lateralis* abundance (m-2) by station (includes top 10 cm).
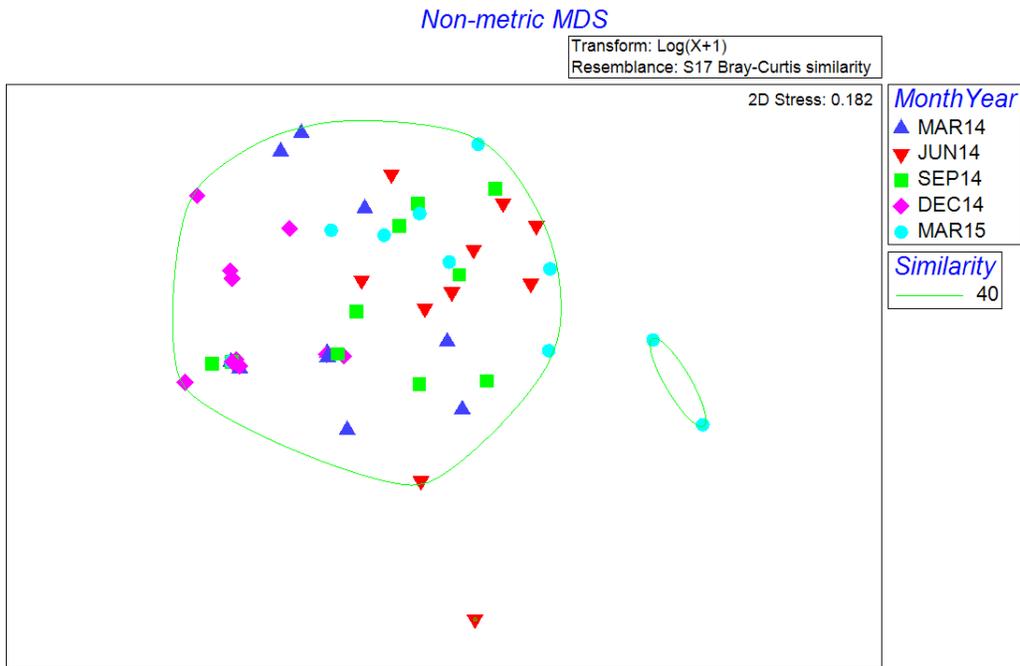
Figure 12. Non-metric multidimensional scaling (MDS) ordination plot of mean macrofaunal community structure for each survey sampling date overlaid with 40% similarity contour.
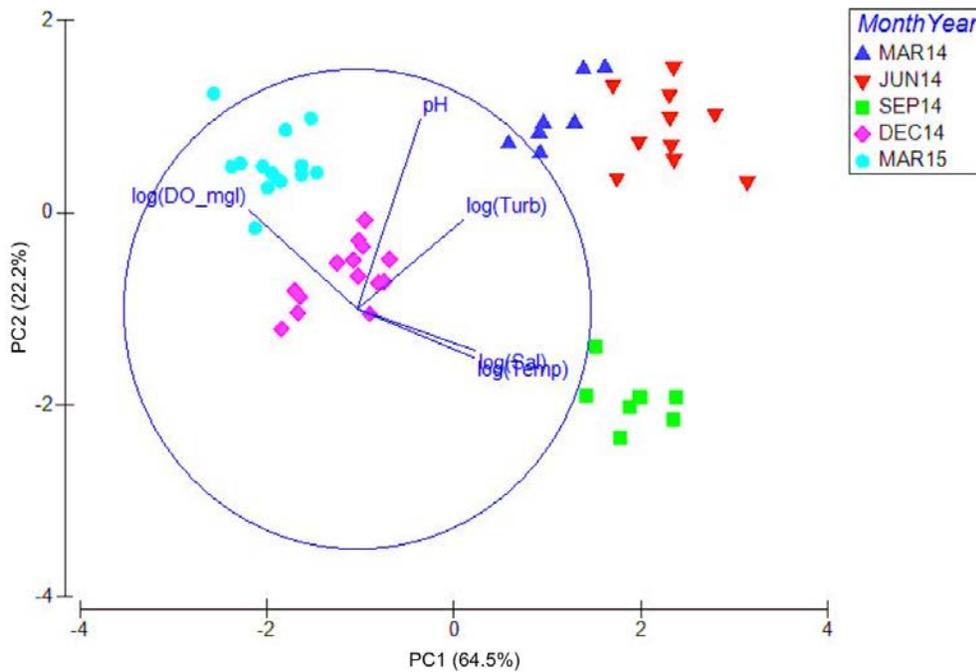
Figure 13. Principal component analysis (PCA) plot showing the degree of association between macrobenthic and hydrological variables in Baffin Bay. PC1 and PC2 are shown. Each benthic sampling season is represented by a different shape.

The Benthic Index used in this study was designed to distinguish anthropogenically disturbed from undisturbed estuarine areas (Engle and Summers 1999). The Benthic Index indicates that the most disturbed benthic environments (lowest scores) occur in Baffin Bay proper and Alazan Bay (Table 3 and Figure 14). According to the same calculations, Cayo del Grullo is the most undisturbed bay. These results are largely driven by diversity values because no oligochaetes or capitellids, and very few amphipods were found throughout the study area and sampling period. However, it is unlikely that the index is an adequate representation of benthic health for several reasons:

1) The components that were used in the index calculation are two fairly common disturbance indicators (tubificid oligochaete, and capitellid polychaete abundances) who's presence decreases an index score, and two common disturbance sensitive components (macrobenthic diversity and amphipod abundance who's presence increases an index score. A fifth component, bivalve mollusk abundance, is considered to be a disturbance indicator taxa, even though bivalves are not generally considered to be good indicators of disturbed environments. In fact, given that bivalves have been shown in this and other studies to make up a large proportion of fish's diets, high abundances of bivalves should be considered as a positive indicator of environmental health in Baffin Bay.

2) This index is heavily influenced by proportions of indicator taxa and not by raw abundances. This potentially leads to a labelling of benthic communities such as at those at Baffin Bay station BB6 as being moderately healthy even though the abundance of macrofauna is an order of magnitude less than at all other stations.

3) The calculation of expected diversity is based on a polynomial relationship derived between communities occurring between salinities of 0 and 40 ppt salinity. Salinities in the Baffin Bay complex were consistently above this range (mean 44 to 52 ppt), therefore it is unlikely that this salinity-diversity relationship applies to Baffin Bay.

Table 3.Benthic Index scores and components used in calculations for each station (samples were composited from March to December 2014).

Bay	Station	Salinity	Expected Diversity	H' Diversity	Total abundance	Bivalves		Amphipods		Benthic Index
						n	%	n	%	
Alazan	AL1	48.7	0.85	0.68	227	15	6.61	0	0	4
Alazan	AL2	48.5	0.85	0.36	492	23	4.67	0	0	0.3
Alazan	AL3	47.7	0.85	0.48	576	33	5.73	1	0.17	2.9
Baffin	BB24	49.4	0.86	0.98	157	6	3.82	0	0	8.4
Baffin	BB40	50.4	0.86	0.32	198	5	2.53	0	0	0
Baffin	BB6	44.1	0.84	0.90	21	5	23.81	0	0	4
Cayo del Grullo	CG1	51.3	0.86	1.24	215	28	13.02	0	0	10
Cayo del Grullo	CG2	51.0	0.86	1.08	338	47	13.91	0	0	7.8
Laguna Salada	LS1	51.2	0.86	0.44	271	5	1.85	1	0.37	4.6
Laguna Salada	LS2	52.1	0.86	0.61	227	11	4.85	1	0.44	6.8
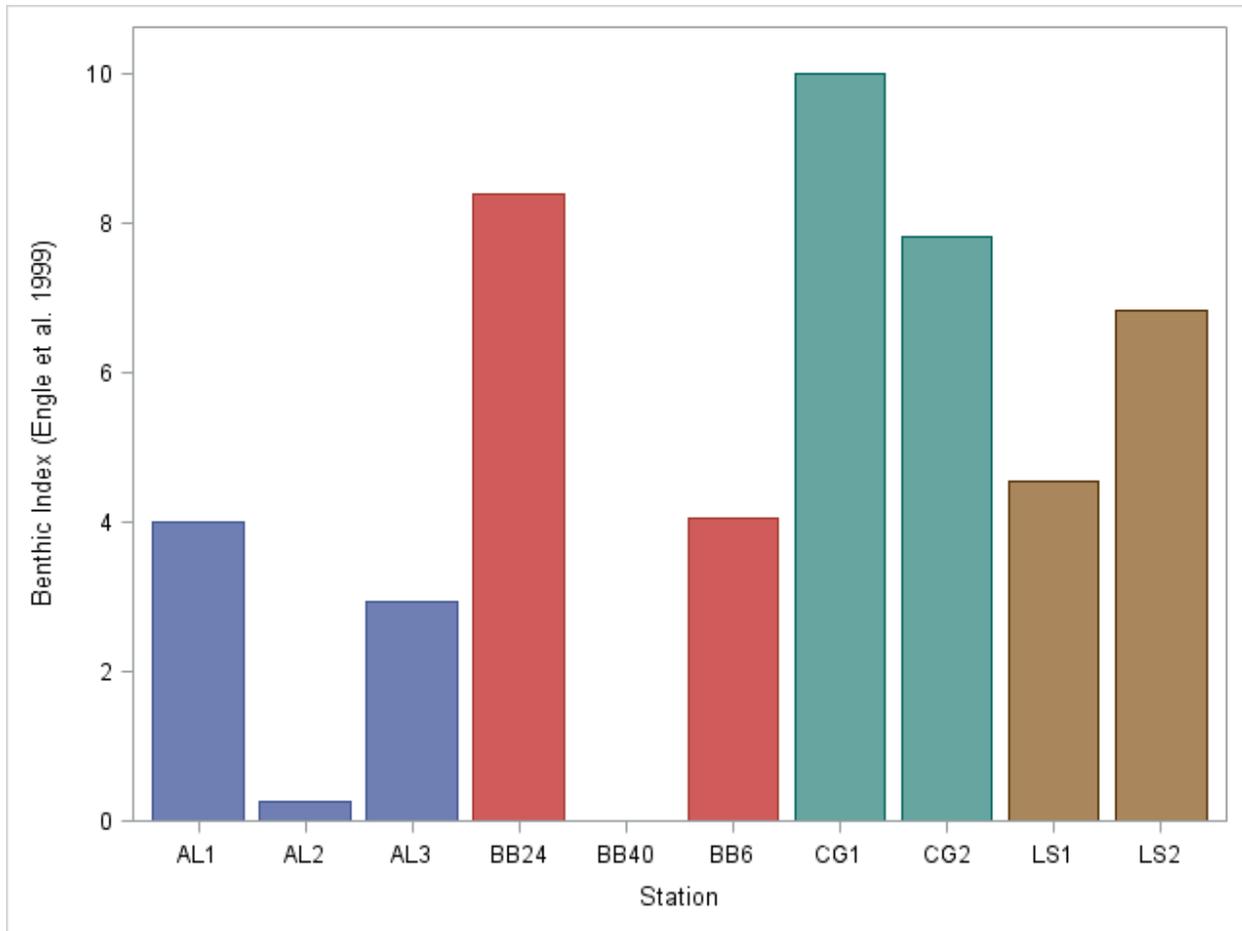
Figure 14. Benthic Index scores at each station (encompassing March to December 2014).

It was initially thought by the authors of this report that these Benthic Index scores could be compared with those calculated throughout the Gulf of Mexico in Engle and Summers (1999). However, further investigation of the calculation revealed that the index components (e.g. % bivalve abundance) are standardized within each data set analyzed and the discriminant scores normalized from 0 to 10. The implications of this are that all data used in Engle and Summers (1999) would be needed to compare the Baffin Bay stations to other areas along the Gulf of Mexico.

The Benthic Index from Engle et al. (1994) was also calculated for Baffin Bay by the authors, however many of the same problems as within the Engle and Summers (1999) calculations exist.

<u>Stable Isotope Analysis</u>

No clear temporal or spatial patterns were observed for stable isotope signatures of surface sediment organic matter (SOM; Figure 15). δ^{13}C values for SOM ranged from -21.8 to -19.04‰. SOM from Alazan Bay were the most enriched in ^{13}C with mean δ^{13}C of -19.9, followed by Laguna Salada at -20.3‰, and both Cayo del Grullo and Baffin Bay at -21.1‰. Seasonally, SOM was more depleted in ^{13}C in spring with mean δ^{13}C values of -21.97, followed by winter at -20.8‰, summer at -20.5‰, and fall at -20.1‰. δ^{15}N values for SOM ranged from 4.1 to 10.2‰. Baffin Bay proper had the lowest mean δ^{15}N value at 5.7‰, compared to Alazan at 6.2‰, and both Cayo del Grullo and Laguna Salada at 6.7‰. δ^{15}N values were highest on average in spring with mean δ^{15}N of 7.7‰, followed by fall (6.2‰), winter and summer (both 5.7‰). Significant differences between sampling dates only occurred for δ^{15}N values in spring compared to summer (p=0.009) and winter (p=0.028).

Stable isotope composition of benthic food resources was variable for both carbon and nitrogen (Figure 15). Lower trophic level prey items included Oligochaete worms (δ^{13}C= -18.5‰, δ^{15}N = 6.5‰), bivalves (δ^{13}C= -20.3 to -20.4‰, δ^{15}N= 5.2 to 5.3‰), Capitellidae polychaetes (δ^{13}C= -18.0 to -19.5‰, δ^{15}N= 4.8 to 5.2‰), Spionidae polychaetes (δ^{13}C= -17.7 to -20.9‰, δ^{15}N= 4.7 to 4.5‰), Nereididae polychaetes (δ^{13}C= -19.5‰, δ^{15}N= 4.4‰), and crustaceans (δ^{13}C= -24.0 to -24.3‰, δ^{15}N= 4.4 to 4.6‰). Higher trophic level prey items included crustacean *Hargeria rapax* (δ^{13}C= -23.6‰, δ^{15}N= 11.4‰), nematodes (δ^{13}C= -20.0‰, δ^{15}N= 8.5‰), Goniadidae worm (δ^{13}C= -18.6‰, δ^{15}N= 7.6‰), other polychaetes (δ^{13}C= -18.8‰, δ^{15}N= 7.4‰), and fish *Anchoa mitchilli* (δ^{13}C= -24.9‰, δ^{15}N= 6.9). Assignments of δ^{13}C and δ^{15}N values for benthic and fish stomach fauna support previous isotopic values reported for Baffin Bay (Hardegree 1997).

Black Drum gut liquid had δ^{13}C values ranging from -26.7 to -12.8‰ and δ^{15}N values ranging from 4.7 to 11.4‰ (Figure 15). δ^{13}C and δ^{15}N values closely resembled those of sampled benthic food resources. Spatially, gut liquids from Baffin Bay were more depleted in ^{13}C (mean δ^{13}C=-24.0‰) than those from Cayo del Grullo (-21.9‰), Alazan (-20.7‰), or Laguna Salada (-20.3‰). δ^{13}C values of gut liquids from Laguna Salada were different than Cayo del Grullo. Gut liquids from Laguna Salada were more enriched in ^{15}N (mean δ^{15}N= 8.1‰) than those from the other Baffin locations (Alazan= 7.9‰, Baffin Bay= 7.4‰, Cayo del Grullo= 7.3‰). δ^{15}N values of gut liquids from Alazan were different than Cayo del Grullo. Temporally, gut liquids were most depleted in ^{13}C in the winter (δ^{13}C= -24.0‰) and most enriched in ^{13}C during the fall (-20.8‰). There were no temporal differences in δ^{15}N values of Black Drum gut liquids.
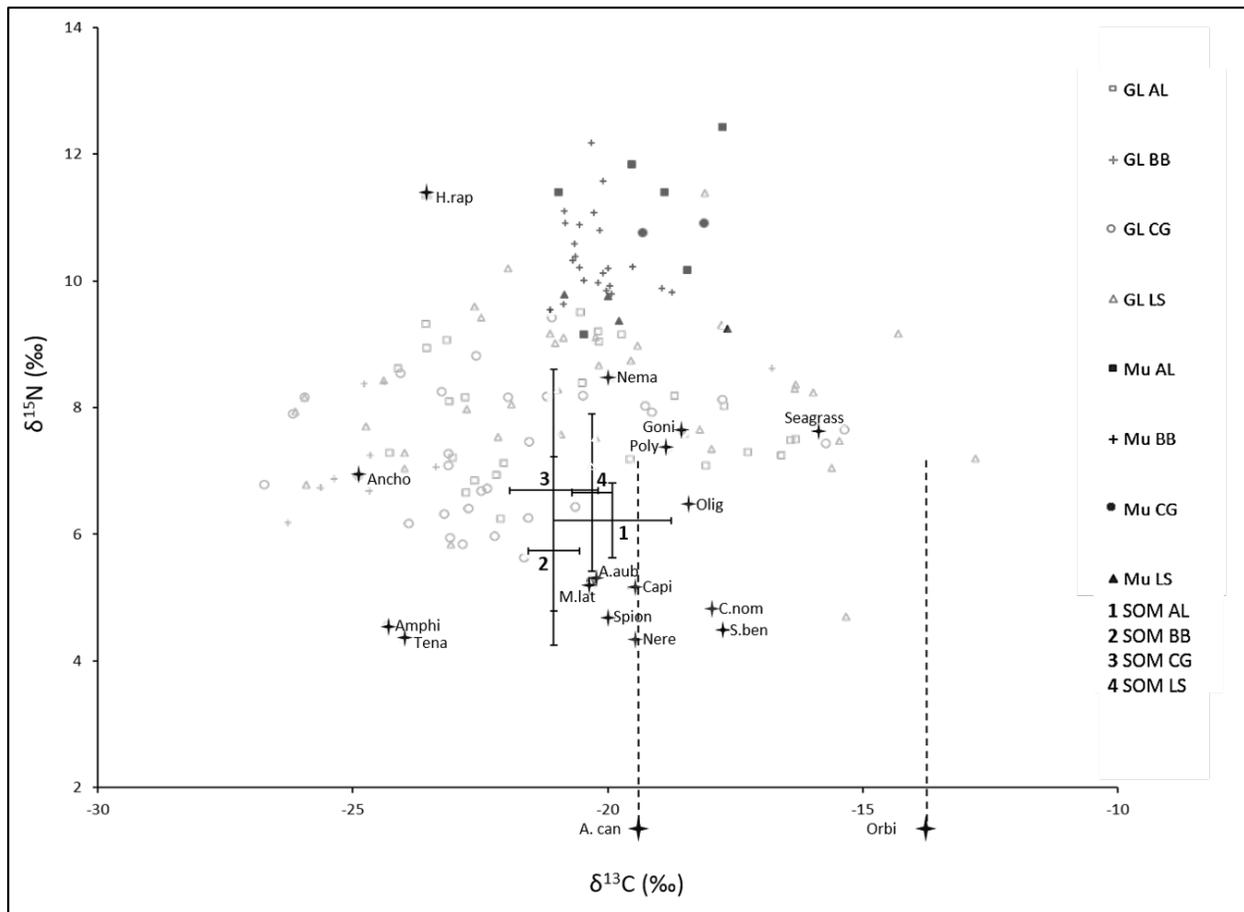
Figure 15. Stable isotope values ($\delta^{13}C$ and $\delta^{15}N$) of Black Drum gut liquid (GL=open points) and muscle tissue (MU=closed points) separated by bay AL=Alazan BB=Baffin Bay proper CG=Cayo del Grullo LS=Laguna Salada. SOM=sediment organic matter by bay. Potential food sources and prey: A.aub, Anomalocardia auberiana; A.can, Acteocina canaliculata; Amphi, amphipods; Anch, anchovy; Capit, Capitellidae; Goni, Goniadidae; H.rap, Hargeria rapax; M.lat, Mulinia lateralis; Nema, nematodes; Noto, Notomastus; Olig, oligochaetes; Orbi, Orbiniidae; Poly, general polychaetes; Spion, Spionidae; S.ben, Streblospio benedicti; Seagrass; Tena, Tenaidacea.

Black Drum (mean total length 342.7 ± 64.5 mm) muscle tissue $\delta^{13}C$ values ranged from -21.1 to -13.7‰ and $\delta^{15}N$ values ranged from 7.9 to 12.4‰. $\delta^{13}C$ and $\delta^{15}N$ values corresponded well with those of the gut liquid. No obvious spatial or temporal trends were observed. Muscle tissue from fish sampled in Cayo del Grullo was the most enriched in ^{13}C ($\delta^{13}C$= -18.7‰) and muscle tissue from Baffin Bay was the most depleted in ^{13}C ($\delta^{13}C$= -20.3‰). Significant differences between locations only occurred for $\delta^{13}C$ values between Baffin Bay and Cayo del Grullo, and for $\delta^{15}N$ values between

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Laguna Salada and Baffin Bay. There were no significant differences in $\delta^{13}C$ values between seasons. Samples from the summer season had the highest $\delta^{15}N$ values (11.4‰), and spring had the lowest (10.2‰). $\delta^{15}N$ values were different for summer versus spring samples, and summer versus winter samples. Stable isotope composition was consistent with values reported for benthic predators (Herzka 2005, Iken et al. 2001, Botto et al. 2005).

Gut Content Analysis

Of the 264 Black Drum collected at various locations within the Baffin Bay complex, 213 (80.6%) stomachs had contents with an overall vacuity index (annual) of 19.32 (Table 4). Spatially, fish stomachs from all BBC regions had a vacuity index in the 0-20% range, with the exception of Baffin Bay proper (63%). This subsample of fish with stomach contents had a mean total length of 335 mm ±92.9 and wet mass ranging from 0.06 to 3.003 kg.

Table 4. Vacuity indices (VI) of fish stomachs by bay. Bays: AL=Alazan, BB=Baffin Bay proper, CG=Cayo del Grullo, LS=Laguna Salada.

Bay	Total Stomachs Examined	Empty Stomachs	Vacuity Index
AL	51	7	13.73
BB	57	36	63.16
CG	35	1	2.86
LS	49	3	6.12
LM	21	4	19.05
TOTAL	**264**	**51**	**19.32**

A total of 21 different food categories were identified in the stomachs (Table 5). Bivalves were the most frequently occurring prey group recognized in the stomach contents across sites. Polychaetes were similarly encountered with high frequency in the gut contents from all sites. The most conspicuous and common bivalve that could be identified from the gut contents was *Anomalocardia auberiana*, followed by *Mulinia lateralis*. Gastropods were observed in approximately 40% of stomachs, with the two positively identified species being *Rissoina punctostriata* and *Acteocina canaliculata*. Crustaceans were encountered with substantially lower frequency and included amphipods, decapods, xanthid and portunid crabs, tanaid crustaceans, and peracaridean shrimps. In terms of biomass, gastropods (<1%) and crustaceans (<4%) contributed very little to the Black Drum diet. Seagrass and fish scales were found in stomach samples of 69 and 83 individuals, respectively, though we speculate these were incidentally consumed while foraging for benthic invertebrates.

Table 5. Dietary data of Black Drum showing frequency of occurrence and proportional weight of various taxonomic groups consumed. Data are presented by site. Unidentified categories were removed from the analysis, and pooled into larger taxonomic levels. Bays AL=Alazan, BB=Baffin Bay proper, CG=Cayo del Grullo, LS=Laguna Salada.

	Site					
	AL	**AL/CG**	**BB**	**CG**	**LM**	**LS**
Sample Size	51	6	51	35	19	49
Frequency of Occurrence						
Taxon						
BIVALVIA	**0.69**	**0.83**	**0.69**	**0.66**	**0.86**	**0.73**
Anomalocardia auberiana	0.25	0.67	0.25	0.14	0.57	0.29
Macrotoma fragilis					0.10	
Mulinia lateralis	0.10	0.67	0.20		0.24	0.06
Nuculana acuta		0.17				
GASTROPODA	**0.06**	**0.17**	**0.06**		**0.05**	**0.02**
Acteocina canaliculata						0.02
Rissoina punctostriata	0.02	0.17				
OTHER MOLLUSCA	**0.10**	**0.17**	**0.08**	**0.03**	**0.05**	
POLYCHAETA	**0.47**	**1.00**	**0.47**	**0.46**	**0.67**	**0.18**
CRUSTACEA	**0.02**		**0.27**		**0.38**	**0.04**
Pericarida			0.08		0.14	
Acanthomysis serrata					0.05	
Amphipoda	0.02		0.18		0.05	0.02
Panopeidae			0.02			
Pleocyemata			0.02		0.10	
Portunidae					0.10	0.02
Tanaidacea			0.02			
ACTINOPTERYGII			**0.02**	**0.06**		
SEAGRASS	**0.37**	**0.50**	**0.41**	**0.31**	**0.29**	**0.47**
FISH SCALES	**0.24**	**0.33**	**0.14**	**0.23**	**0.90**	**0.43**
Proportional Weight						
Taxon						
BIVALVIA	**0.76**	**0.81**	**0.84**	**0.68**	**0.67**	**0.79**
Anomalocardia auberiana	0.06	0.03	0.03	0.19	0.01	0.04
Macrotoma fragilis						
Mulinia lateralis	0.01		0.02			0.03
Nuculana acuta						
GASTROPODA	**0.01**					
Acteocina canaliculata						
Rissoina punctostriata		0.01				
OTHER MOLLUSCA	**0.05**	**0.14**	**0.05**			
POLYCHAETA	**0.10**		**0.01**	**0.03**	**0.01**	**0.03**
CRUSTACEA			**0.01**		**0.02**	**0.01**
Pericarida					0.01	
Acanthomysis serrata						
Amphipoda						
Panopeidae						
Pleocyemata					0.01	
Portunidae						0.01
Tanaidacea						
ACTINOPTERYGII			**0.01**	**0.08**		
SEAGRASS	**0.01**		**0.01**	**0.01**		**0.01**
FISH SCALES	**0.01**		**0.01**	**0.01**	**0.27**	**0.08**

A comparison of prey biomass (higher taxonomic categories) in cores (Figure 16) versus prey biomass in the diet (Figure 17) revealed that Black Drum appeared to be opportunistic feeders (generally consuming benthic prey items proportional to their availability). However, further bay-specific Strauss indices revealed that bivalves were partially selected for in Alazan (L=0.09) and highly selected in Cayo del Grullo (L=0.47), whereas gastropods were most selected for in Baffin proper (L=0.20) and Laguna Salada (L=0.39).

- Bivalvia, 68.4%
- Crustacea, 0.21%
- Cnidaria, 0.003%
- Gastropoda, 23.96%
- Polychaeta, 7.43%
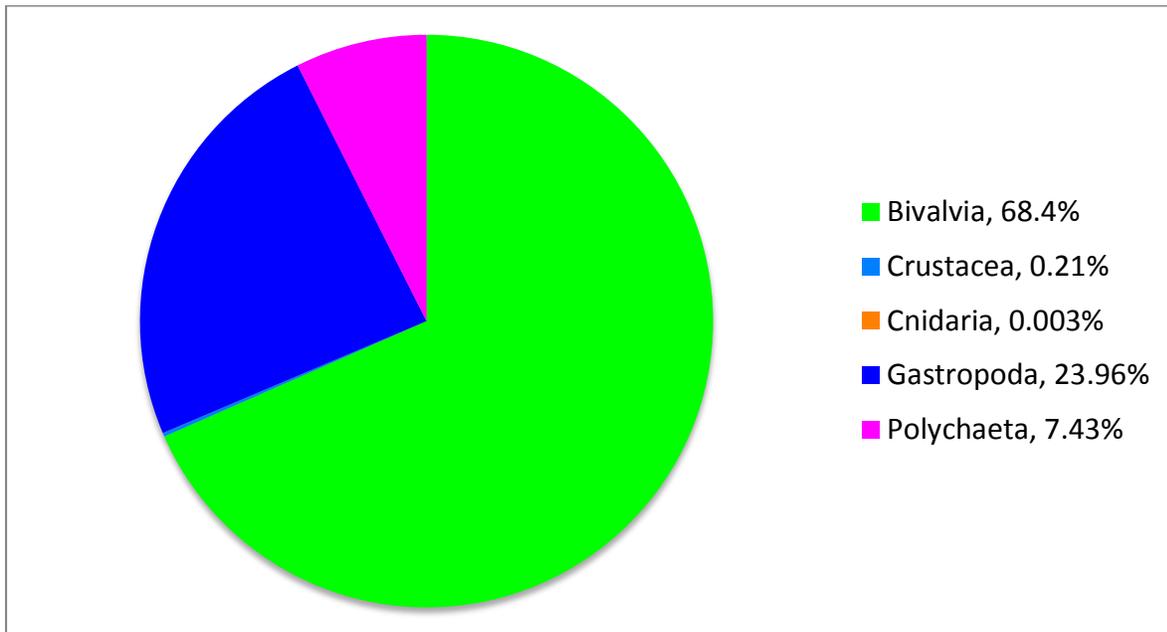
Figure 16. Pie chart of overall identified benthic taxa composition (by weight) in cores.
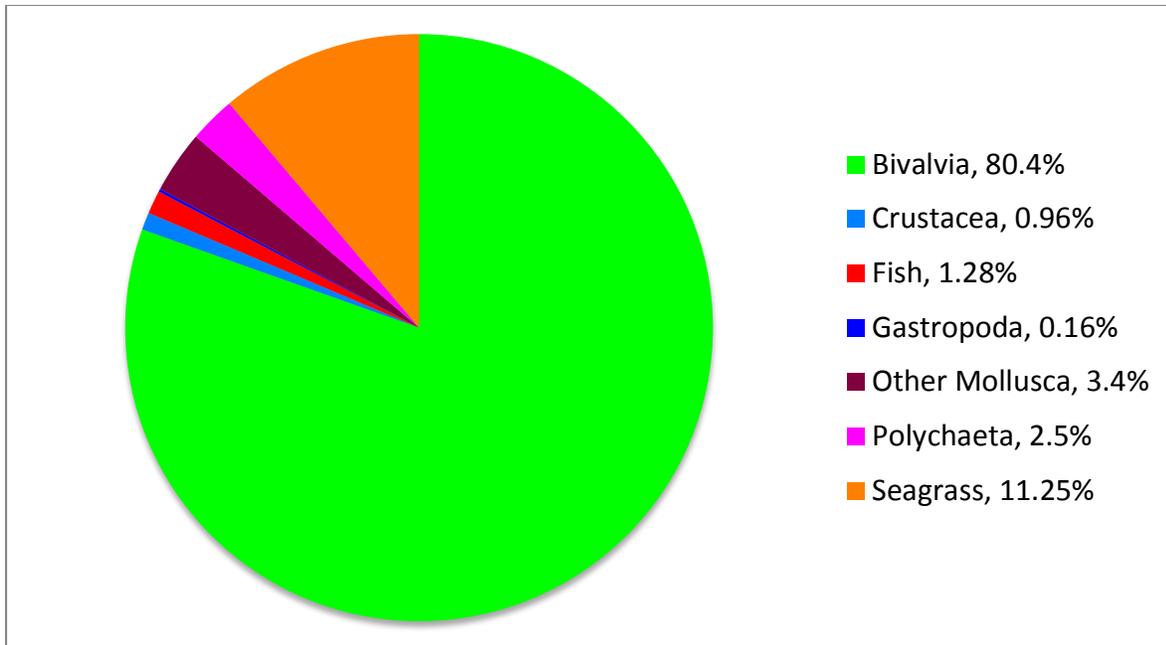
Figure 17. Pie chart of overall identified prey taxa composition (by weight) in Black Drum guts.

Legend:
- Bivalvia, 80.4%
- Crustacea, 0.96%
- Fish, 1.28%
- Gastropoda, 0.16%
- Other Mollusca, 3.4%
- Polychaeta, 2.5%
- Seagrass, 11.25%

Acoustic Telemetry

Over the course of an entire year of monitoring we detected 23/25 (92%) of our acoustically tagged Black Drum for a total of 30,351 detections. The only animals not detected during the study period were tags 16459 and 16465, which were both released in Alazan Bay on 4/23/2014. The remaining 23 individuals were detected across a wide range of receiver stations across the area. The station receiving the greatest number of detections throughout the project period was BB_03 (Table 6; Figure 18), which was situated in the southeastern portion of Cayo De Grullo. While 6 individuals were detected at this station, nearly all detections (i.e., 95%) came from two individuals – tags 16466, 16467. Other regions of high activity (>2000 detections) included a Laguna Salada station (BB_05) and Alazan Bay stations BB_06-07 (Table 6, Figure 18). The greatest number of tagged individuals was recorded at BB_06-07 (n = 11), although these stations were situated closest to the release sites in Alazan Bay.

Log-transformed detection data passed tests for normality (Shapiro-Wilk, $P = 0.323$) and homogeneity of variances (Levene's Test, $P = 0.125$). Using positively detected individuals as replicates, we observed no significant differences in Black Drum use of non-Laguna Madre receivers (ANCOVA, $F_{10,87} = 0.829$, $P = 0.602$; Table 7). Moreover, this variable was not found to be affected by the covariate, distance from the release (ANCOVA, $F_{1,87} = 1.491$, $P = 0.226$), suggesting that the number of detections per individual at a receiver was not explained by its proximity to where individual tags were released. The interaction effect of site and the covariate also did not affect the log number of detections (ANCOVA, $F_{10,87} = 0.975$, $P = 0.473$).

Six individuals were detected along the Laguna Madre stations (BB_12-15). This included tag 16456, which was tagged in Alazan Bay and only detected at BB_15, and no other stations during the monitoring period. This individual was recaptured by a fisherman in the Laguna Madre in October 2014, confirming egress from the BBC. Another individual detected at BB_15 was tag 16460, which was also tagged in Alazan Bay on the same date as the previous individual. Tag 16460 was also detected at BB_11 prior to BB_15, but was not re-detected anywhere after 4/29/2014, suggesting that this individual (along with 16456) emigrated from the BBC quickly after tagging. We saw a similar pattern for Tag 16476, an exceptionally large individual that was released near the interface of San Fernando Creek on 5/15/2014 that was detected on BB_13 on 5/23/2014. This individual was absent from the array throughout the summer, and returned in late-September, when it began to make repeated transitions between LM (BB_12, BB_13) and Cayo De Grullo stations through late fall, and again in early spring. Tag 16458 was briefly detected at BB_14 in September 2014, and was detected at BB_15 in late February and again briefly in mid- March. Tags 16470 and 16471 were briefly detected at BB_14 in January, otherwise spending the majority of the time in Alazan and the core region of Baffin Bay. Tag 16474 briefly visited BB_12 in mid-March 2015, but generally did not use this area over the monitoring period.

Only three individuals (Tags 16458, 16461, 16466) of the 8 total individuals released on the first tagging trip (4/23-4/25) were detected on our array after Mid-May 2014 (Figure 19). Many of these fish were released in Alazan Bay, were later detected in Baffin Bay, but were not re-detected in the Baffin Bay Complex through the lifetime of the tags. It is unclear as to whether these individuals simply avoided detection from our receivers, died, or were removed by fishermen without reporting.

We also observed animals undertaking several inter-bay movements throughout the Baffin Bay Complex (Figure 19). The majority of these habitat transitions and thus wider detection distributions occurred in spring and fall of 2014 (Figure 20). Inter-bay movements were minimized and or restricted within the three major arms during the summer, when large amounts of detections were recorded at the interface of CDG and Laguna Salada (Figure 18; Figure 19) with generally no animals detected at Upper Laguna Madre or Baffin Bay sites between June and September. During October and November, use of the core region of Baffin and main pass appeared to increase, with fish distribution beginning to spread eastward.

Table 6. Detection record data from the 15 receiver array in the Baffin Bay Complex (4/23/2014 – 4/19/2015). CDG = Cayo del Grullo, AL = Alazan Bay, BB = Baffin Bay, LS = Laguna Salada, ULM = Upper Laguna Madre.

| Receiver Station	Water Body	Number of Detections	Number of Fish
BB_03	CDG	12036	7
BB_05	LS	6150	7
BB_07	AL	2953	11
BB_06	AL	2485	11
BB_08	LS	1835	9
BB_04	AL	1723	6
BB_09	AL	1012	10
BB_11	BB	633	10
BB_10	BB	614	8
BB_02	ULM	363	5
BB_15	CDG	344	3
BB_01	CDG	147	4
BB_13	ULM	140	2
BB_12	ULM	77	2
BB_14	ULM	19	2
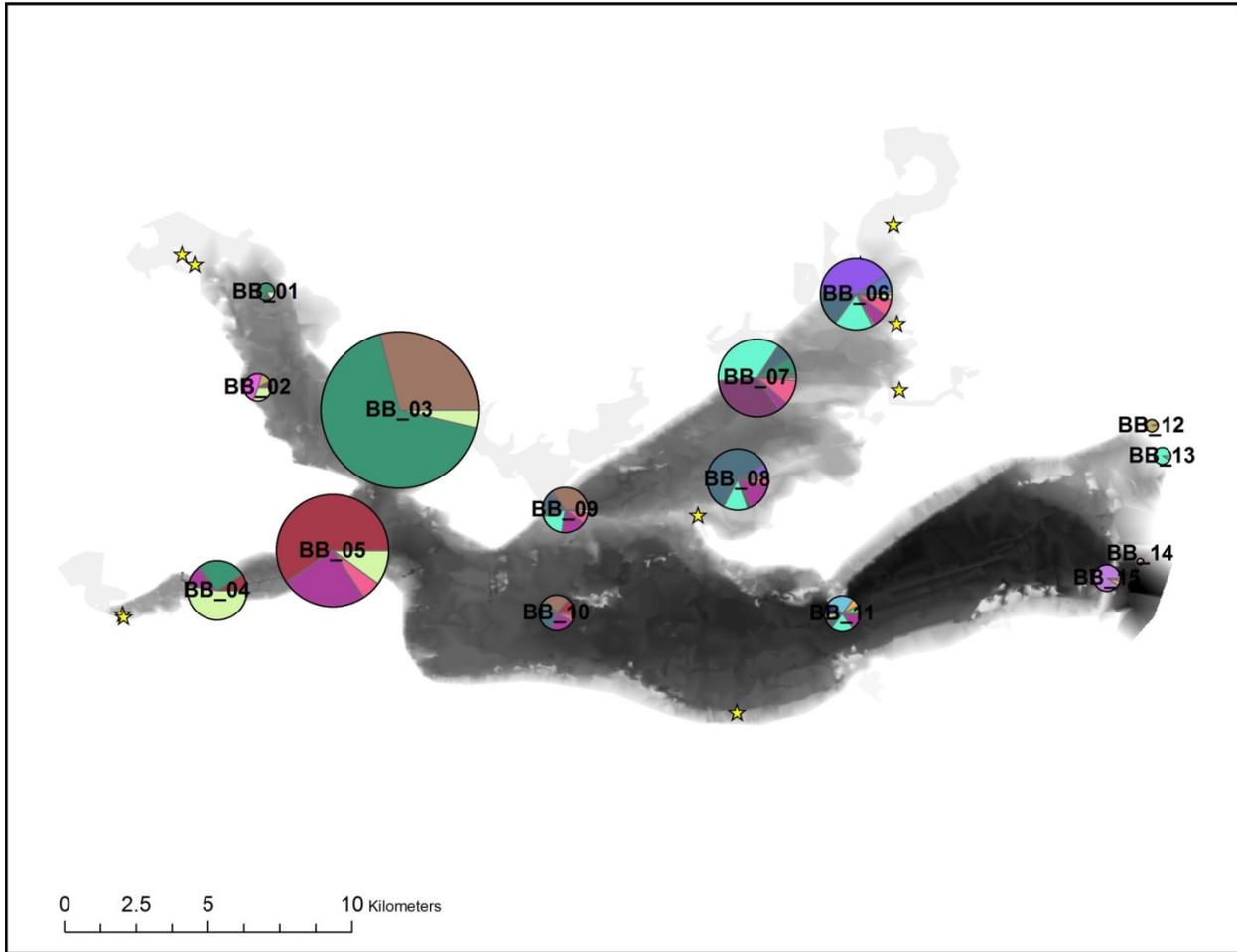
Figure 18. Detection pie charts (scaled to total number of detections) along the 15 receiver array in the Baffin Bay Complex (4/23/2014 – 4/19/2015). Various colors represent different individuals. Yellow stars represent release sites.

Table 7. Results from ANCOVA on log detections at receiver sites across the BBC.

| Source of Variation	DF	SS	MS	F	P
Site	10	4.767	0.477	0.829	0.602
Distance To Release	1	0.857	0.857	1.491	0.226
Site x Distance To Release	10	5.607	0.561	0.975	0.473
Residual	66	37.954	0.575	--	--
Total	87	52.241	0.6	--	--
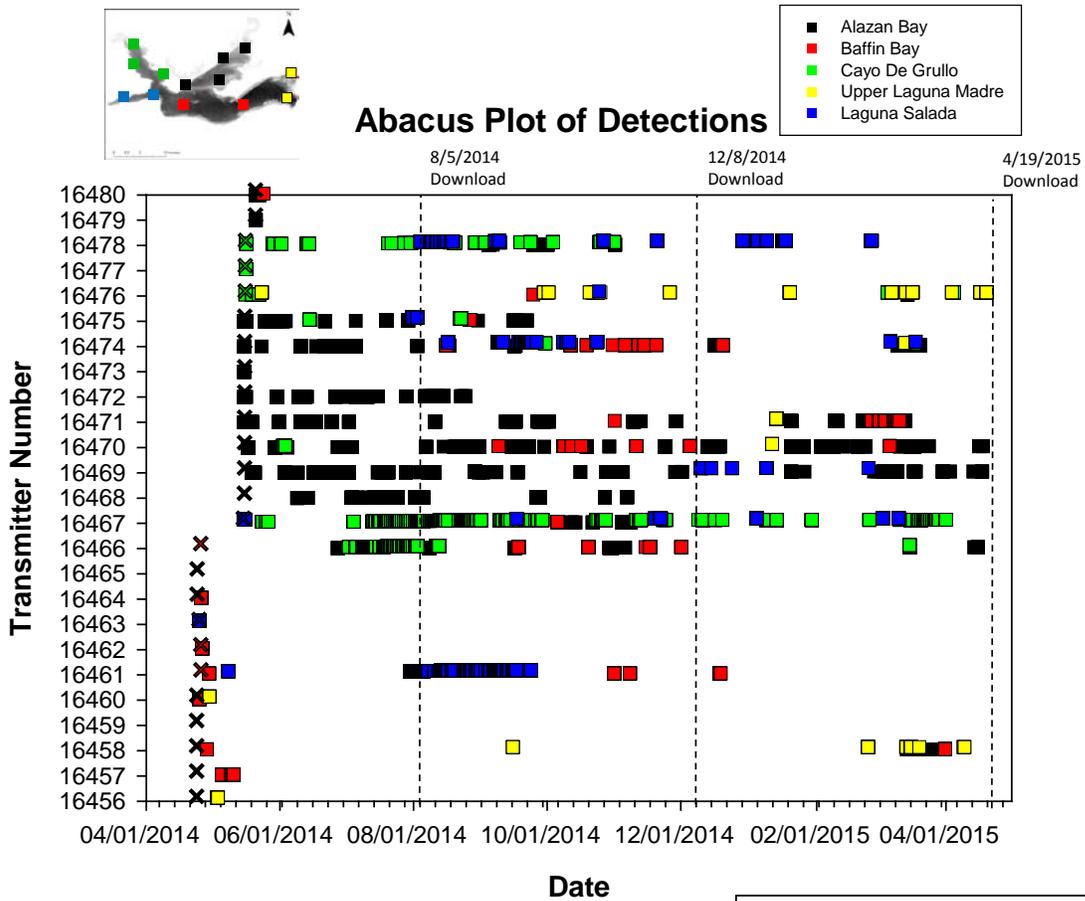
Figure 19. Abacus plot of detection history for 25 transmitters released in Baffin Bay. Colored "x" represent release area of each individual.

SPRING

Apr-14   May-14   Jun-14

SUMMER

Jul-14   Aug-14   Sep-14

FALL

Oct-14   Nov-14   Dec-14

WINTER

Jan-15   Feb-15   Mar-15
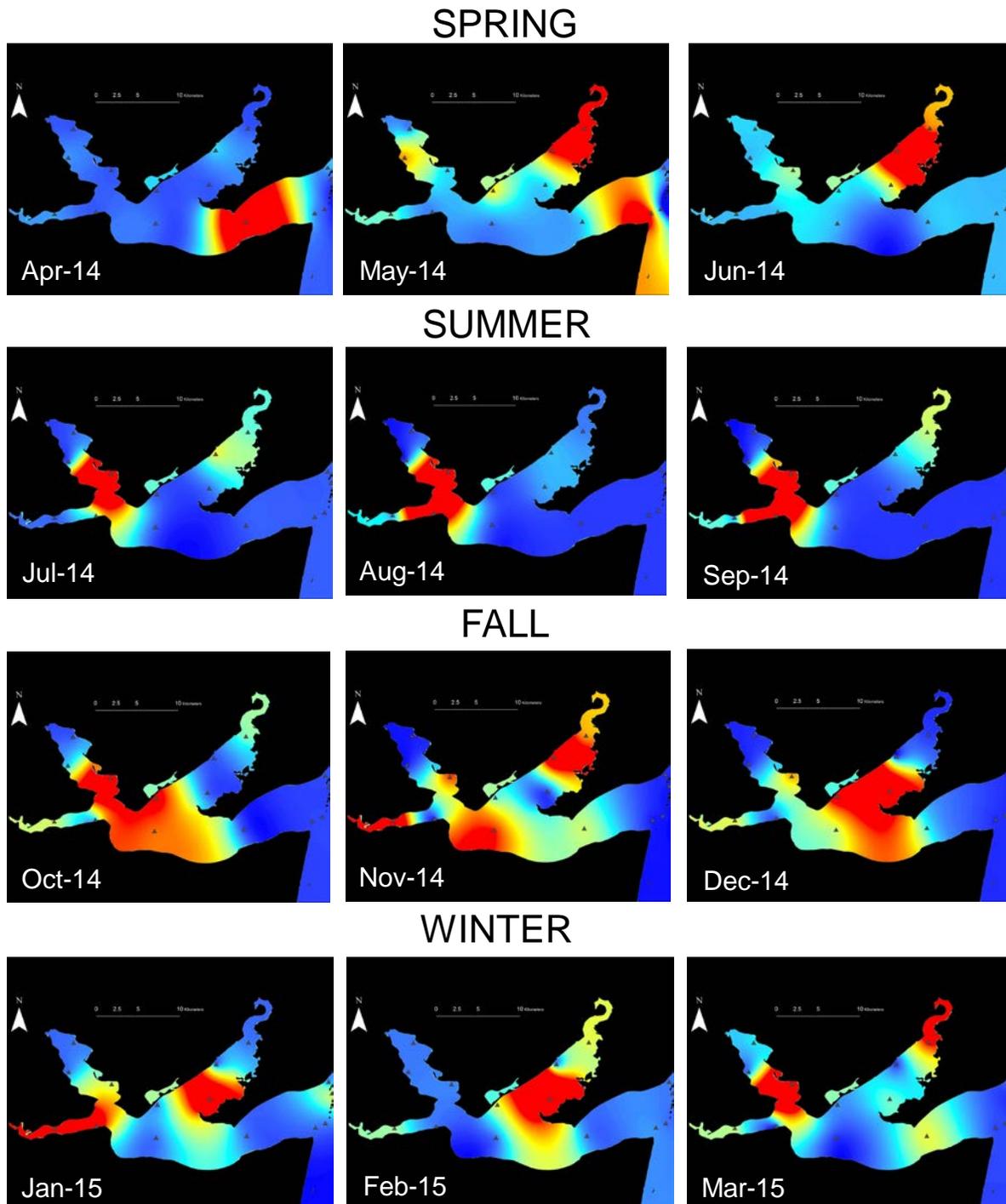
Figure 20. Monthly spline interpolations of acoustic detections across the BBC. Warmer colors (red) indicate regions of higher detections while cooler colors (blue) show regions of low or no detections.

Conclusions and Recommendations

In 2013, the Texas Parks and Wildlife Department (TPWD) released the report "Emaciated Black Drum Event," which highlighted the need for additional information on the benthic community and Black Drum feeding dynamics in Baffin Bay Complex (Grubbs et al. 2013). The current project was developed in response to this report, with the goal of conducting a comprehensive, multi-trophic level study to determine linkages between water quality, benthic food resources, and Black Drum in the Baffin Bay Complex.

Our ecosystem-based approach to assessing Black Drum in Baffin Bay has revealed important trophic and habitat linkages between this valuable fishery species and benthic communities of a unique hypersaline estuary. Moreover, incorporation of water quality, benthic sampling, and fish tracking has improved our understanding of the dynamics of this system. Quarterly core sampling strongly characterized a benthic community that had been sparsely sampled over the past few decades, and was used to determine whether benthic food resources are available throughout the Baffin Bay Complex. Results indicate that benthic food resources are available throughout the Baffin Bay Complex, with similar communities of organisms occurring throughout Baffin, Laguna Salada, Cayo del Grullo, and Alazan Bays. However, benthic prey density varied among bays, and was correlated with fish gut vacuity indices that were the highest (i.e., abstemious) in Baffin proper, and the lowest (i.e., edacious) in the tertiary arms. The latter suggests fish are regularly feeding when in the tertiary arms, while less often feeding in Baffin proper.

We examined stable isotope composition of carbon and nitrogen from sediment organic matter, benthic food resources, Black Drum gut contents, and Black Drum muscle tissue to determine whether Black Drum are using the food resources of Baffin Bay. Data indicate that the C and N isotopic composition of the prey is reflected in the gut content and muscle tissue of the fish, suggesting that Black Drum are feeding on a number of benthic food resources within the Baffin Bay Complex, and do not depend solely on *M. lateralis*. Acoustic telemetry data support this finding, with few individuals overall leaving the BBC and thus residing for extended periods. Gut content analysis was used to determine what kinds of benthic food resources the Black Drum are using. Data indicate that Black Drum in the Baffin Bay Complex are primarily consuming polychaetes, bivalves, and gastropods. The fish appear to be opportunistic, with gut content biomass closely reflecting benthic prey resources represented in the benthic core samples and modest evidence of selection for bivalves and gastropods in some regions. The widely available prey across the complex (in particular, the tertiary arms) supports the inter-bay movements within the BBC we observed from acoustic telemetry throughout the study period, particularly in fall and spring.

There are a number of reasons that could have led to the 2012 Black Drum emaciation event in the Baffin Bay Complex. Our multi-trophic level approach allowed us to better understand the impact of a potential decline in food sources or an ecosystem-wide trophic shift in Black Drum feeding mode. Results indicate that the Baffin Bay Complex

has a variety of benthic food resources available throughout the estuary, which Black Drum are utilizing as prey. Black Drum are feeding on a number of lower level consumers which themselves depend on either pelagic production (e.g. suspension feeding bivalves) or benthic production (e.g. deposit feeding polychaetes and gastropods). Therefore, if Black Drum starve, there are likely problems with both benthic and pelagic food resources. For this to occur, it is likely that a larger system disturbance—such as degraded water quality—affects the whole system, with effects on Black Drum several links down the chain. Our benthic macrofauna data provides a glimpse into how this occurs, specifically through the relationships we observed between several key water quality parameters (salinity, dissolved oxygen) and macrofauna biomass/diversity. For example, the positive relationship between biomass/diversity and dissolved oxygen argues that low dissolved oxygen events, such as was observed in the sonde study, may have negative consequences for these important Black Drum food resources. The positive relationship between macrofauna biomass/diversity and salinity would seemingly argue that higher salinities are generally favorable for macrofaunal communities. However, it is important to point out that our sampling started at the tail end of a major drought and maximum salinities were somewhat moderated (~40's to 60) compared to during the peak of the drought when salinities reached over 70. Furthermore, the recent Mulinia die-off corresponded with the peak of drought and presumably very high salinities. Thus it is possible that there may be a threshold salinity above which conditions become deleterious to macrofauna. Even more likely is that multiple stressors may at times act on the benthic community in Baffin Bay, including high salinities (during drought) as well as hypoxia/anoxia. Additional sample collections are warranted to further elucidate the individual as well as combined effects of these parameters on the macrofauna community. Fidelity of most Black Drum (particularly the "market size" individuals) to the BBC exemplifies how this species can be vulnerable to periodic perturbations on the scale of this estuary. During the summer, in particular, movements appear to be highly restricted and may be related to dissolved oxygen levels that constrain fish to a particular region of the BBC. Should that confinement occur in an area where food resources are limited, one can surmise that such conditions could indirectly lead to reduced fish condition.

While the occurrence of "jelly-flesh" and other emaciated conditions appear to have tempered since 2012, it is important to have relatively long-term monitoring periods in place in to be able to better document potential environmental drivers of these events (e.g. wet versus dry conditions). We are confident that our ecosystem-based approach has provided better insight into the dynamics and trophic connectivity of the Baffin Bay complex. With ongoing dynamic changes in water quality being documented throughout the Baffin Bay Complex by Dr. Mike Wetz, it is important to continue monitoring food web dynamics and trophic linkages to make explicit links between water quality parameters and estuarine resources.

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