Meeting Report Summarizing the Flower Garden Banks Mortality Event Mini-Symposium

February 27-28, 2018
Flower Garden Banks National Marine Sanctuary
4700 Avenue U, Bldg. 216
Galveston, Texas
Organized by: US IOOS, GCOOS, and FGBNMS

Mini-Symposium Summary:

The Flower Garden Banks National Marine Sanctuary (FGBNMS), in partnership with the Gulf of Mexico Coastal Ocean Observing System (GCOOS) and the U.S. Integrated Ocean Observing System (IOOS), hosted a mini-symposium in Galveston, Texas on Feb. 27-28, 2018 to further investigate the localized mortality event that occurred at East Flower Garden Bank (EFGB) in July 2016. The event brought together approximately 40 key scientists and collaborators from a wide array of disciplines - all first responders to the 2016 mortality event that killed corals, sponges, crustaceans, mollusks, echinoderms, and all other invertebrates in a localized area on EFGB. Principle investigators presented their response activities, results, and hypotheses as to the causes of the event. The workshop reinforced the need for enhanced and sustained observations in and around the FGBNMS to support forecasting, mitigation and analysis of future events. This report summarizes the symposium, and numerous manuscripts are being prepared by participants. For more information, please contact Michelle.A.Johnston@noaa.gov

Mini-symposium participants at the Flower Garden Banks National Marine Sanctuary Office in Galveston, TX.

Mini-Symposium Funding and Organizers:

The mini-symposium was made possible with funding through a NOAA National Ocean Service (NOS) stimulus proposal. Partners included the Office of National Marine Sanctuaries, FGBNMS, IOOS, GCOOS, Texas A&M University (TAMU), the Marine Biodiversity Observation Network (MBON), and Smithsonian MarineGEO. Facilitation for the mini-symposium was provided by Heather Coleman (NOAA's Deep Sea Coral Research and Technology Program) through the NOAA Facilitation Network.

The mini-symposium organizers are listed below:

Michelle Johnston (FGBNMS) – Mini-symposium coordinator and planning team
Emma Hickerson (FGBNMS) – Planning team, mini-symposium concept initiation
Gabrielle Canonico (US IOOS) – Planning team
Barbara Kirkpatrick (GCOOS) – Planning team
Grant Craig (GCOOS) – Travel coordinator

Mini-Symposium Participant List (in alphabetical order):

Name (Last, First) and Email	Affiliation	Response/Role
Arnone, Robert Robert.Arnone@usm.edu	Univ. of Southern Mississippi	Ocean modeling
Belter, Mark mark.belter@boem.gov	BOEM	Benthic and fish Surveys
Buschang, Steve Steve.Buschang@glo.texas.gov	Texas General Land Office	Funding/Partner
Canonico, Gabrielle gabrielle.canonico@noaa.gov	IOOS	Funding/Partner
Clift, Leslie leslie.clift@noaa.gov	FGBNMS	SAC coordinator
Coleman, Heather heather.coleman@noaa.gov	NOAA Deep Sea Coral Program	Facilitator
Conetta, Dennis dc43@rice.edu	Rice University	Coral microbial community
Correa, Adrienne ac53@rice.edu	Rice University	Coral microbial community
Davies, Sarah daviessw@bu.edu	Boston University	Coral transcriptomics
DiMarco, Steve sdimarco@email.tamu.edu	TAMU	Oceanography - water quality
Doyle, Shawn sdoyle22@tamu.edu	TAMU	Water column microbes
Drummond, Jenn jenn@rice.edu	Rice University	Bioinformatics

Name (Last, First) and Email	**Affiliation**	**Response/Role**
DuPuy, Shelley shelley.dupuy@noaa.gov	FGBNMS	Education
Embesi, John john.embesi@noaa.gov	FGBNMS	Benthic and fish Surveys
Gaskill, Melissa mlg6310@sbcglobal.net	Science Writer	Reporter
Grimes, Michael mikegingalveston@hotmail.com	University of Houston	Sponge microbial community
Grupstra, Carsten cgg4@rice.edu	Rice University	Coral microbial community
Hetland, Robert hetland@tamu.edu	TAMU	Ocean circulation
Hickerson, Emma emma.hickerson@noaa.gov	FGBNMS	Benthic and fish Surveys
Howe-Kerr, Lauren lih2@rice.edu	Rice University	Coral microbial community
Hu, Xinping Xinping.Hu@tamucc.edu	TAMUCC	Carbonate chemistry
Johnston, Michelle michelle.a.johston@noaa.gov	FGBNMS	Benthic and fish Surveys
Johnstone, Thomas thomas.johnstone@noaa.gov	NOAA National Weather Service	Salinity/freshwater impacts
Kealoha, Andrea andreake@tamu.edu	TAMU	Carbonate chemistry
Kiene, Bill william.kiene@noaa.gov	ONMS Southeast Regional Office	Regional
Knapp, Anthony tknap@geos.tamu.edu	TAMU/GERG	Oceanography
Kuehl, Joe jkuehl@udel.edu	University of Delaware	Micro-movement of water
Le Henaff, Matthieu mlehenaff@rsmas.miami.edu	Univ. of Miami-RSMAS	Remote sensing
Lee, Michael mtlee@usgs.gov	U.S. Geological Survey	Water quality
MacMillan, Jimmy jimmy.macmillan@noaa.gov	FGBNMS	Water quality
Muller-Karger, Frank carib@usf.edu	Univ. of South Florida	Remote sensing
Slimak, Nadine nadine@vettedcommunications.com	GCOOS	Science writer
Nuttall, Marissa marissa.nuttall@noaa.gov	FGBNMS	Benthic and fish Surveys
Otis, Dan dotis@mail.usf.edu	Univ. of South Florida	Remote sensing

Name (Last, First) and Email	Affiliation	Response/Role
Santiago, Lory Santiago@uhcl.edu	University of Houston	Sponge microbial community
Schmahl, G.P. george.schmahl@noaa.gov	FGBNMS	Benthic and fish Surveys
Shamberger, Katy katie.shamberger@geos.tamu.edu	TAMU	Carbonate chemistry
Sterne, Travis travis.sterne@noaa.gov	FGBNMS	Benthic and fish Surveys
Sylvan, Jason jasonsylvan@tamu.edu	TAMU	Water column microbes
Vreeland-Dawson, Jennifer jen.vreeland@gcoos.org	GCOOS	Funding/Partner

Mini-Symposium Goals, Objectives, and Outcomes:

The goals, objectives, and potential outcomes of the meeting were:

Mini-Symposium Goals:

- To assess the causes and outcomes of the localized mortality event,
- Identify instrumentation needed to monitor for similar events in the future,
- Discuss applicability of monitoring in other locations, and
- Identify and explore other datasets (e.g. remote sensing) in context of the event.

Objectives:

- To bring together responders and partners to evaluate preliminary data findings, and
- To agree on the suite of factors that most likely contributed to the event.

Outcomes:

- Publish a joint paper covering the event with the participants of the meeting (senior author will serve as coordinator and editor, and write the majority of the introduction, conclusions/synthesis).
- Create a plan for deployment of moorings and other observing capabilities to monitor, and to support forecasting, mitigation and analysis of future comparable events.

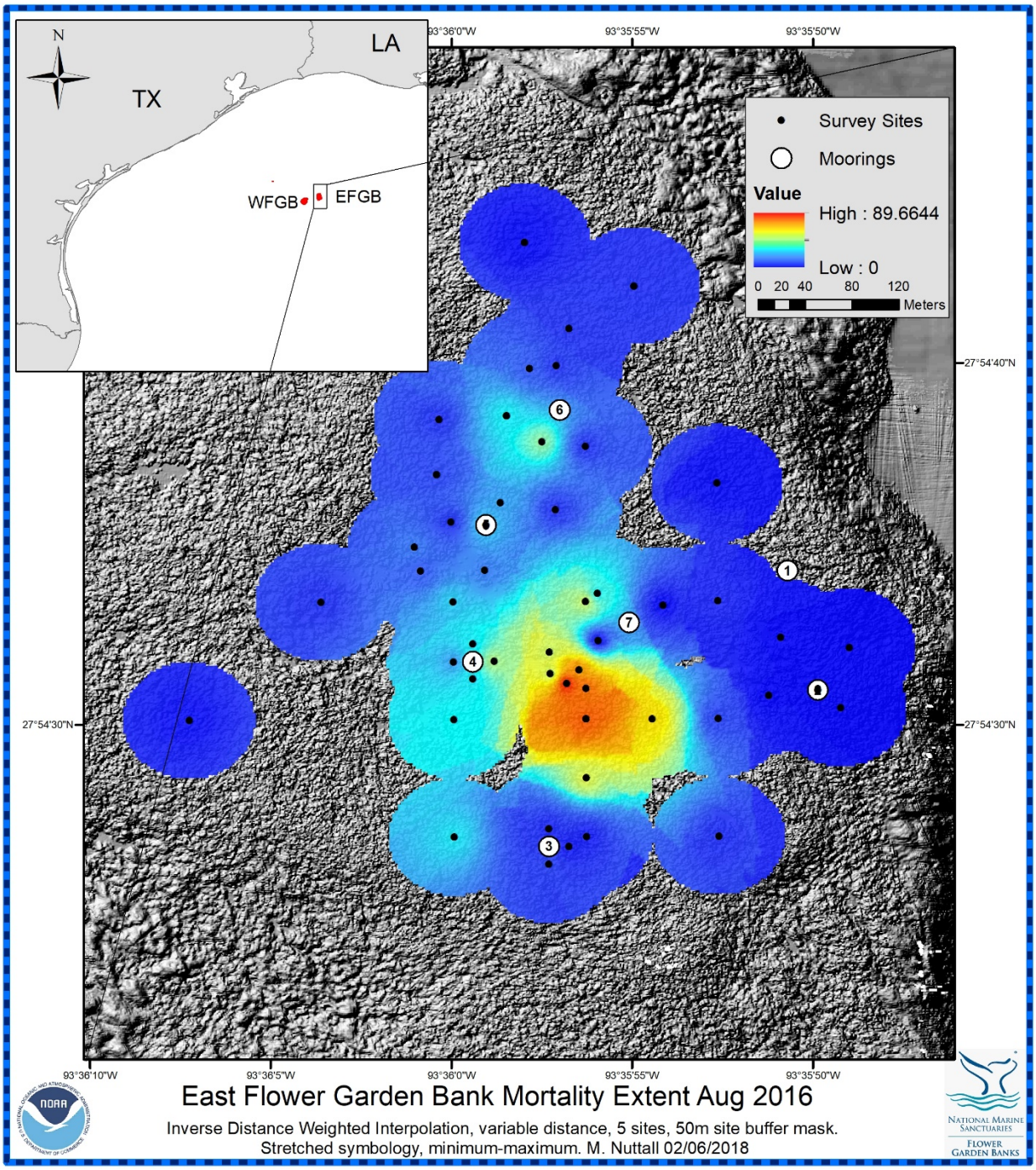
Meeting Format:

During the first day, event responders and/or response teams gave short presentations on their role during the response, highlighted data collected, analyses, and preliminary data findings and hypotheses. The presentations are summarized in the presentation section of this report.

On the second day, time was allotted for round table group discussions. Discussions focused on data overlaps and differences, a jointly formulated hypothesis, and future monitoring needs, such as early warning programs or integrated modeling/response tools, and publication planning.

Localized Mortality Map at EFGB:

The localized mortality event affected a portion of the central area of the EFGB reef cap, between buoys 4 and 7.



Extent of affected corals from benthic surveys at EFGB in 2016. Numbered circles represent mooring buoys and black dots are survey sites.

List of Presentations:

Michelle Johnston, Ph.D. (FGBNMS) - Initial Benthic Cover and Fish Community Responses to the 2016 EFGB Localized Mortality Event

While conducting long-term monitoring at the East Flower Garden Bank (EFGB) study site on July 25, 2016, recreational divers from the M/V FLING, diving near buoy #4 (approximately 275 m away from the study site), reported dying coral, sponges, and invertebrates to researchers aboard the *R/V Manta*. The FGBNMS research team conducted a series of initial assessment dives in the mortality zone on July 27, 2016, followed by a separate response cruise nine days later. FGBNMS divers conducted benthic transect and fish surveys, as well as in-water scooter surveys, to determine the extent of the mortality area during a response cruise from August 4 to 7, 2016. The mortality zone was spread across approximately 6.5 acres, and some surveys exhibited up to 70% of affected corals between buoys #4 and #7. There was no evidence of the die-off within the long-term monitoring study site near buoy #2 or at West Flower Garden Bank (WFGB). For fish surveys taken within the mortality area, density and biomass was significantly less than in surveys taken outside the mortality area, or in the study sites at EFGB and WFGB. Due to a battery malfunction, temperature and salinity data from the 24 m SeaBird datasonde at EFGB were not available from February 18 to August 6, 2016. Therefore, backup temperature data from a HOBO logger was used for analysis during this time interval. Persistent seawater temperatures above 30 degrees C were recorded at the 24m depth at EFGB and WFGB from late June to mid September. Preliminary post-mortality surveys in the center of the mortality zone from October 2017 show low coral cover (17%, compared to 50% mean coral cover in the EFGB long-term monitoring study site), low algae cover (16%), and high substrate cover (62%). In summary, data from FGBNMS show decreased coral cover and fish avoidance behavior in the mortality zone, high seawater temperatures at depth, and gaps in salinity data on the reef cap. If time and funding allow, FGBNMS would like to conduct additional post-mortality surveys in the mortality zone.

Datasets available upon request (please email michelle.a.johnston@noaa.gov should you require these datasets):
- EFGB & WFGB 2016 Benthic Transect Percent Cover Data
- EFGB & WFGB 2016 Fish Biomass and Density Data
- EFGB & WFGB 2016 Temperature Data (24m, 30m, 40m depths)
- EFGB & WFGB 2016 Salinity Data (24m depth)
- EFGB & WFGB CTD Water Column Data (August 2016)
- EFGB & WFGB 0.5m Bathymetric Data (link to request access):
https://drive.google.com/open?id=0B5QgX1Its5DVflZUSzYzMGdPTWVWZHVWaE5heVMyRmI5Rm5jdmNTbEdLT3dfNlAyWXJrUlk
-EFGB & WFGB 4m Bathymetric Data (data available on FGBNMS mapping tool via link):
https://www.ncddc.noaa.gov/website/google_maps/FGB/mapsFGB.htm

Steve DiMarco, Ph.D. (TAMU) - Physical Oceanographic Observations on the Outer Texas-Louisiana Shelf near FGBNMS in Summer 2016

Oceanographic observations of the northwestern Gulf of Mexico and Texas-Louisiana continental shelf were collected during the summer of 2016 on a variety of moored, shipboard, and autonomous platforms. The Texas Automated Buoy System (TABS), in continuous operation at up to nine locations on the shelf, provided hourly observations of near-surface temperature, salinity, and current velocity, throughout the summer and before, during, and after the Mortality event of late July 2016.

In June 2016, the NOAA SEAMAP summer cruise collected fisheries-related observations, which included hydrographic (temperature and salinity) and dissolved oxygen concentration from the Rio Grande delta of southern Texas to the Mississippi River delta at Southwest Pass, LA. The observations reveal that the western regions, i.e., west of the Atchafalaya Bay were highly stratified due to the presence of freshwater likely the result of heavy rainfall in Texas and the Lower Louisiana coastal plain. Low oxygen bottom waters were present at locations of high stratification and extended from the coastline to about the 50 m isobath.

An NSF-funded REU cruise (run by TAMU-Oceanography) aboard the R/V Pelican (29 June – 2 July 2016) performed a line from Galveston Texas to EFGB of the FGBNMS. Near-surface salinity data along the cruise track show a plume of low salinity water (less than 22 ppt near Galveston to 28 ppt at the 40 m isobaths) that extended southeast toward EFGB. At EFGB the surface salinity was near 32 ppt. Vertical sections of oceanographic properties show hypoxic conditions nearshore beneath the freshwater plume and normal oxic conditions in the vicinity of the FGBNMS. A similar cruise track performed on 24-29 July 2016 aboard the R/V Manta show that this freshwater plume was not present in that location less than one month later and at the time of the onset of the mortality event.

After news of the event, a Rapid Response cruise was mounted aboard the R/V Manta by oceanographers at TAMU Oceanography, GERG, Galveston and TAMU-Corpus Christi, to collect observations to perhaps provide clues as to what contributed to the cause of the event. A 5x5 grid was planned, the survey region included both EFGB and WFGB. Observations include: lower CTD, six-bottle rosette, nutrient concentration (nitrate, nitrite, silicate, phosphate, urea, ammonium) as well as other biological and chemical constituents. The near bottom dissolved oxygen field shows normal oxygen values (3-4 mL/L) inshore of the 200 m isobaths and over WFGB. At the seaward stations south of EFGB, dissolved oxygen concentrations were depleted to nearly 2 ml/L. The presence of the low concentration were consistent with the presence of offshore derived waters of typically higher density and lower oxygen that that seen in waters of comparable depth on the shelf. Near surface salinity show relative freshwater over EFGB (34 ppt) than that at WFGB (35 ppt). Stable isotope data of oxygen and hydrogen are currently being analyzed in an attempt to identify the source of the freshwater masses, i.e., Texas rivers (Trinity, Brazos) versus Louisiana rivers (Mississippi/Atchafalaya). A second R/V Manta cruise, 5-8 August 2016, shows the entire FGBNMS surface salinity to be homogeneous and near 35 ppt.

The time series of temperature and salinity at TABS Buoy V deployed near the FGBNMS shows salinity values near 30 on July 1 and progressively increasing throughout July to 35 in early

August; temperature were consistently above 30°C throughout July and exceed 32°C by the end of the month of July. At TABS Buoy F, halfway between Galveston and the FGBNMS, surface temperature varied from 28 to 32°, while salinity showed a similar increasing trend from 26 to 34.5 showing the presence and variability related to the movement of the freshwater plume emanating from Galveston Bay.

A Teledyne-Webb Research Slocum G2 Buoyancy glider was deployed near the FGBNMS on August 2. The glider was piloted to patrol the waters in the vicinity of the banks for a duration of about 40 days, The gliders measures temperature, salinity, pressure, chlorophyll and CDOM fluorescence, and dissolved oxygen concentration a sampling interval of 1 Hz. The glider has the ability to oscillate through the entire water column from surface to bottom up to a maximum depth of 100 m. The glider data show depleted oxygen concentration near bottom and up to 30 m from the bottom. A relative high of DO concentration is observed between 50-70 m and is coincident with elevated chlorophyll fluorescence values, possibility indicating the influence of photosynthesis. The salinity observations from the glider show the presence of the freshwater plume early in the deployment, 3-7 August, however, after this date salinity values are 35 and above.

In summary, Texas rivers likely provided freshwater input in June, which led to stratification of the western Texas-Louisiana continental shelf. The stratification led to widespread low oxygen and hypoxic waters nearshore. The hypoxic waters likely did not reach the FGBNMS. At the time of the event, the surface water of EFGB was relatively fresh compared to that at WFGB. Surface temperatures were warm compared to the climatology of the area. The EFGB shows an intrusion of a dense low oxygen water mass near bottom of offshore origin.

Datasets available up request (please email sdimarco@tamu.edu should you require these datasets):
-Teledyne-Webb Research Slocum G2 Buoyancy glider data (temperature, salinity, pressure, chlorophyll and CDOM fluorescence, and dissolved oxygen)
-REU cruise data (temperature, salinity, dissolved oxygen)
-Rapid response cruise CTD and nutrient concentrations (nitrate, nitrite, silicate, phosphate, urea, ammonium)
-TABS Buoy V and Buoy N (http://tabs.gerg.tamu.edu)

Andrea Kealoha, Ph.D. Candidate and NOAA Nancy Foster Scholar (TAMU) - Seawater Chemical Anomalies Following the 2016 EFGB Localized Mortality Event

On July 30-Aug 2, 2016, TAMU conducted a rapid response cruise to characterize the chemical properties of surface and deep water masses within and around the FGBNMS in order to uncover the mechanisms that led to the EFGB localized mortality event. Low sea surface salinity, total alkalinity (TA) and dissolved inorganic carbon (DIC) were measured over EFGB, and are clear evidence for freshwater. SSTs were approximately 5ºC warmer than bottom temperatures, indicating that the surface, freshwater layer induced stratification over both banks. Consistent with upwelling, a dense, low oxygen and high DIC tongue of water was observed extending from ~200 m to ~100 m on the SE side of EFGB. This deep-water tongue also contained high

phosphate and nitrate concentrations, relative to the surrounding water at similar depths. We hypothesize that the hazy, freshwater, surface layer, induced stratification and blocked sunlight and photosynthesis. At depth, net respiration of coral reef organic matter caused significant drawdown of oxygen to hypoxic levels. Upwelling of deep, dense water over EFGB would have aided in the localized effect of the mortality event. A residence time calculation suggests that hypoxia could occur in less than a day, given minimum movement of bottom water and a conservative estimate of net respiration. In addition to being hypoxic, these waters were likely acidified, since respiration concurrently consumes oxygen and releases carbon dioxide (e.g., lowers pH). Future management strategies should include the risk for threats such as hypoxia and acidification and increase efforts of detection through high-resolution monitoring systems.

Datasets available upon request (please email andreake@tamu.edu should you require these datasets):
- TAMU rapid response cruise (T, S, carbonate chemistry, DO, nutrients)
- TABS Buoy V and Buoy N (http://tabs.gerg.tamu.edu)

Shawn Doyle, Ph.D. (TAMU) - Microbial Community Dynamics in FGBNMS after the 2016 EFGB Localized Mortality Event

Water samples were collected from the FGBNMS during the TAMU rapid response cruise, filtered onto 0.2um PES filters, and frozen at -20°C. Total DNA was extracted from the filters from which the V4 variable region of the 16S rRNA gene was PCR amplified and sequenced (N=78; MiSeq v2 chemistry, PE250bp). Formalin-fixed water samples were also collected for direct microscopic counts via DAPI staining.

Mean microbial cell abundance 2×106 cells mL-1 and did not vary significantly between samples. Preliminary analysis of the 16S dataset revealed microbial community composition and structure was predominantly structured by water depth. Shallow samples were dominated by Cyanobacteria and clustered into two separate groups, located in EFGB and WFGB respectively. CCA (constrained correspondence analysis) revealed that the variations in microbial community structure between these two groups was primarily due to differences in salinity. EFGB surface waters were enriched with Synechococcus relative to WFGB, which instead harbored larger abundances of Prochlorococcus. Paired Spearman correlation analysis of bottom water samples identified 14 OTUs (operational taxonomic units) which were strongly correlated with low dissolved oxygen concentrations. Many of these OTUs belonged to taxa which are commonly associated with oxygen minimum zones (e.g. MGI Thaumarchaetoa, Marinimicrobia, SAR324, SAR86). The majority (50%) of these OTUs classified as MGI Thaumarchaeota, a clade of ammonia-oxidizing archaea which thrive in hypoxic conditions and have been implicated in maintaining sustained oxygen drawdown in environments with low dissolved oxygen. The largest relative abundance of this lineage was observed at station 43, near the EFGB coral cap.

Datasets available upon request (please email sdoyle22@tamu.edu should you require these datasets):
- Direct cell counts.
- Raw fastq files from sequencing. Data will be made publically available upon publication.

Lory Santiago, Ph.D. (University of Houston) - Were Bacteria Involved in the 2016 Localized Mortality Event at EFGB? A Case Study using *Agelas clathrodes* and *Xestospongia muta*

Our lab analyzed the microbiome associated with sponges *Xestospongia muta* and *Agelas clathrodes* collected on August 5-7, 2016 (EFGB affected, EFGB unaffected, WFGB unaffected). We isolated DNA, amplified the V4 16S rDNA region (primers 515F-806R, 12bp barcode on F primer), and pooled samples with Sylvan/Doyle's water microbiome dataset (105 samples all together). Out of the 33 sponge samples collected, 27 were submitted for sequencing. We were not able to PCR-amplify the remaining 6. The Sylvan lab sent all 105 samples to the Georgia Genomics Facility for MiSeq sequencing (2 x 250 bp). We used a pipeline and the open source Bioinformatics software MOTHUR to obtain and cluster operational taxonomic units or OTU's (identification of bacteria present in the samples). Healthy and unaffected samples of both species displayed a similar microbiome composed of the Phylum Actinobacteria, Chloroflexi, Proteobacteria, Acidobacteria, Gemmatimonadetes, and Cyanobacteria (*X. muta* only), expected for healthy organisms. Affected organisms were mostly associated with Proteobacteria and Bacteroidetes, Proteobacteria being the dominant Phyla in both sponges. We observed a dramatic decrease in diversity in affected sponges and did not observe any *Beggiatoa*, a γ-Proteobacteria known for forming white mats similar to the ones collected on the July 27 cruise. This was not fully unexpected as *Beggiatoa* is outcompeted by other bacteria quickly and white mats were no longer present when these samples were collected. Our lab is 1) in the process of clustering the OTU's at the genus/species level, 2) working on the initial set of samples from July 27 (some of these were unfortunately lost to Harvey but we decided to look at them nonetheless), and 3) follow-up collections in September and October 2017, after Harvey. Although we observed marked differences in the microbiome of affected vs. unaffected samples, we were not able to determine any causes for the die-off.

Datasets/samples available upon request (please email santiago@uhcl.edu should you require this dataset):
- Raw fastq files. Data will be deposited in public databases upon publication.
- Limited amount of biological material (white mats, sponges, coral, sediment, algae, brittle stars, etc.) and water from the initial response cruise on July 27, 2016. These samples will be shared with the Correa and the Sylvan labs.

Adrienne Correa, Ph.D. (Rice University) - Coral Microbiome Responses to the 2016 EFGB Localized Mortality Event

On July 27, 2016, samples (N=8) of dying invertebrates and putative bacterial mats were sampled from the EFGB during a Localized Mortality Event (LME). Processing of these samples was delayed by Hurricane Harvey impacts to our Houston-based lab; findings from these samples will be available at a later date. From August 4-7, 2016, coral specimens (*Orbicella faveolata* and *Orbicella franksi*, N=79) and their associated microbial communities, as well as sediment samples (below affected and unaffected coral colonies) and their associated microbial communities (N = 26), were sampled from EFGB and WFGB. The LME occurred on EFGB only; no affected corals were observed on WFGB. On EFGB, three different types of tissue

samples were collected: healthy colonies (i.e., appeared to be unaffected), affected colonies along the lesion, and affected colonies above the lesion in an apparently healthy area of the colony. Both the July and August 2016 datasets are undergoing Illumina MiSeq analysis of the V4 region of bacterial 16S rRNA.

Preliminary results suggest that (1) microbial communities associated with *Orbicella* colonies are highly diverse; (2) within *Orbicella* colonies, microbial communities associated with affected colony lesions contain a lower phyletic diversity and higher relative abundance of proteobacteria than microbial communities associated with apparently healthy areas of affected colonies or unaffected colonies; and (3) microbial communities associated with sediments beneath *Orbicella* colonies contain a lower phyletic diversity than microbial communities associated with *Orbicella* colonies. Ongoing analyses of these data include in-depth investigations of particular bacterial types of interest and calculations of microbial community alpha richness, beta diversity, and metacommunity similarity. Future studies will also compare the 2016 coral and sediment microbial community results with controlled experiments that subject organisms to known stressors to test which stressor was the most likely cause of the mortality event.

Datasets available upon request (please email ac53@rice.edu should you require this dataset):
- Raw fastq files from sequencing. Data will be made publicly available upon publication.

Sarah Davies, Ph.D. (Boston University) - Coral Transcriptomic Responses to the 2016 EFGB Localized Mortality Event

On the August 4 to 7, 2016 our lab collected coral specimens for genome-wide gene expression analysis using tag-seq. First, we tested a novel underwater sampling technique for sample preservation at depth. This preservation method, which involved 200 proof ethanol in prefilled 15ml conical tubes was highly successful and we were able to isolate from all 76 samples collected. We collected tissue samples from two species (*Orbicella franksi* and *Orbicella faveolata*) from both EFGB and WFGB. Only healthy specimens were collected at WFGB given that this site was unaffected by the event. At EFGB three different types of tissue samples were collected: healthy colonies (i.e. appeared to be healthy), affected colonies along the lesion, and affected colonies above the lesion in a healthy area. A total of 76 samples were collected, their RNA was isolated, and their transcriptomes were prepped in house and sent off for *Illumina Hiseq* sequencing. Preliminary results suggest that affected colonies along the lesion were experiencing oxidative stress and enrichment of genes related to mitochondria, which is consistent with our low oxygen hypothesis. However, future examinations of these data will include comparing our gene expression results with controlled experiments that subjected organisms to known stressors to test which stressor was the most likely cause of the mortality event.

Datasets available upon request (please email daviessw@bu.edu should you require this dataset):
-Raw fastq files from sequencing. Data will be made publicly available upon publication.

Matthieu Le Henaff, Ph.D. (RSMAS, University of Miami) - Coral Mortality at FGBNMS in July 2016: The Consequence of Cross-Shelf Transport of Flood Waters?

Ocean color data showed the accumulation of riverine waters along the coast of Texas, supported by exceptional precipitation in the spring of 2016. These waters spread over the whole continental shelf of the Northwestern Gulf of Mexico, reaching the FGBNMS, during two episodes of upwelling favorable winds, in mid-June and early July. These riverine waters covered most of the shelf for the whole month of July, with a more intense signature in apparent chlorophyll-a at EFGB. In situ cruise data collected in June over the northwestern Gulf of Mexico continental shelf show the local formation of thin layers of near-hypoxic waters just below the turbid, low salinity surface layer. These mid-water low oxygen layers reached about 100 km offshore at the time. With a low salinity surface layer of about 20 m, as observed in July in the region, such mid-water layer of low-oxygen would be located at 20-25m depth, the range in which the mortality was observed. The results thus suggest that filaments of coastal waters, associated with such mid-water layers, reached EFGB, and that hypoxic conditions within those mid-water layers contributed to the observed mortality. Discussions during the meeting highlighted the possibility that interactions between the surface layer and EFGB could be involved in settling hypoxic conditions at the bottom of this surface layer as it intersected the EFGB seamount.

Available datasets:
- Ocean color: processed by processed and distributed by the Institute for Marine Remote Sensing at the University of South Florida (http://data.imars.marine.usf.edu).
- Winds: NDBC buoys 42020 and 42035 (http://www.ndbc.noaa.gov/)
- River discharge: USGS and Army Corps of engineers (https://waterdata.usgs.gov/nwis and http://rivergages.mvr.usace.army.mil).
- SST: GHRSST data (https://podaac.jpl.nasa.gov/GHRSST).
- In situ data: June 2016 Seamap cruise available at the NOAA National Centers for 405 Environmental Information (NCOI) portal (https://www.ncei.noaa.gov/), in the Oceans dataset.

Dan Otis, Ph.D. (University of South Florida) - Satellite-Based Early Warning System for FGBNMS

A user dashboard was created for the FGBNMS. This web-based tool is hosted at the University of South Florida and provides users with up to date satellite imagery and river discharge data for the northwest Gulf of Mexico. The dashboard displays mean and anomaly images of chlorophyll-a concentration from the Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) satellite sensor. Anomalies are calculated by subtracting a weekly climatological mean (using data from 2003-2010) from each weekly mean image. Users can access weekly chlorophyll-a images since 2002 using navigation buttons or changing the date in the dashboard URL. Time-series plots of chlorophyll-a since 2002 at Stetson Bank and EFGB and WFGB are also shown along with time-series plots of river discharge from five Texas rivers and the Mississippi River. Both satellite images and time-series plots are updated automatically every seven days. The initial version of the dashboard is currently available online (link below). An updated version is currently being

developed which will include surface chlorophyll-a concentrations at several sentinel sites between the FGBNMS locations and the coast, to indicate when plumes of coastal waters rich in organic material may become advected over FGBNMS locations. Email alerts for interested users will be generated when chlorophyll-a concentrations at the sentinel sites exceed a threshold value. The updated version of the dashboard will also contain gages for easy visualization of current river discharge and chlorophyll-a conditions, interactive time-series plots as well as links to other datasets (winds, currents, sea-surface temperatures).

Available datasets:
- FGBNMS Dashboard (https://usf-imars.github.io/img-dash/index.html)
- River discharge data obtained from the USGS National Water Information Service (https://maps.waterdata.usgs.gov/mapper/index.html)
- Ocean color satellite imagery was obtained from NASA's Ocean Biology Processing Group (http://oceancolor.gsfc.nasa.gov/)

Robert Hetland, Ph.D. (TAMU) - Characterization of Physical Environmental Conditions during the 2016 FGBNMS Localized Mortality Event

In summary, I found that the cause of the mortality event is difficult to identify because there were no clear anomalies in the regional environmental conditions prior to and during the event, except for the unusually high river discharges from Texas rivers. In particular, the primary forcing mechanisms over the Texas-Lousiana shelf, regional winds and Mississippi River discharge, were within the envelope of historical conditions. That said, it was clear that there was a fresh water bolus of water in the surface waters over the banks, with evidence from moored salinity observations indicating a plume that moved eastward over the banks. It is extremely unlikely that this intrusion pulled low oxygen water from the 'dead-zone' off of the shelf into the FGBNMS region. There is also some evidence for a dense water intrusion that primarily impacted the eastern bank from shipboard observations. There is evidence from the numerical model that fresh water from the shelf likely impacted the region of the FGBNMS around the time of the mortality event. However, there is also evidence from the numerical model output that this is not an unusual occurrence. Though the discharge from Texas rivers was anomalously high, the discharge is still small compared to that of the Mississippi/Atchafalaya system, and model results suggest that the water that impacted the FGBNMS was mostly from the Mississippi/Atchafalaya. This seems to preclude the idea that some water borne constituents from Texas rivers played a role in the mortality event. It is still very possible that the increased discharge played an indirect role, though, in directing the Louisiana shelf water, with Mississippi/Atchafalaya origins further offshore than might have otherwise occurred in a normal Texas river discharge year. We plan to investigate the impact of these rivers in future modeling studies.

Another notable fact is that July surface temperatures (from observations) and bottom temperatures (from the model) were the highest ever recorded. Higher temperatures may have impacted the corals by increasing respiration, or at least stressed them to the extent that they were less resilient to other events that would have otherwise gone unnoticed. In summary, there is no obvious, single cause. My assessment is that there were a variety of processes acting

together, and I have identified a few of these potential processes, but we don't have enough information to put together a single cohesive story with any certainty.

Available data:
- Model output:
http://barataria.tamu.edu/thredds/catalog.html?dataset=txla_hindcast_agg
- Animations of the model output:
http://pong.tamu.edu/tabswebsite/subpages/gallery.php

Xinping Hu, Ph.D. (TAMU-CC) - Temporal Variations in Carbonate Chemistry and Decadal Acidification in Flower Garden Banks Marine Sanctuary

We reported seasonal water column carbonate chemistry data collected over a three-year period (late 2013 to 2016) in FGBNMS. Water samples from upper 25 m were collected in partnership with NOAA's National Coral Reef Monitoring Program in 2013 and 2015, and the FGBNMS, as part of the sanctuary's quarterly water quality monitoring associated with long-term monitoring programs at FGBNMS. Following a localized mortality event likely associated with major continental flooding in summer 2016, water samples from up to ~250 m depth were collected in the broader FGBNMS area on a rapid response cruise to examine the seawater carbonate system. Based on the seasonal data, we found that both temperature and salinity played an important role in controlling the surface water carbonate system dynamics although temperature was the sole significant factor when there was no flood influence. Using the two summer cruises, i.e., the first Gulf of Mexico and East Coast Carbon Project (GOMECC-1) in 2007 and the rapid response study that took place in a 9-year time span, we observed decreases in both pH and carbonate saturation state with respect to aragonite, with the pH decrease rate being slightly faster than those reported for the open ocean.

Available datasets:
- Water column carbonate chemistry data in Flower Garden Banks National Marine Sanctuary (2013-2016) (https://data.gulfresearchinitiative.org/data/R2.x220.000:0006)

Joe Kuehl, Ph.D. (University of Delaware) - Current Observations over the Flower Garden Banks

In response to the recent localized mortality event which occurred at EFGB (July 2016) as well as an oil spill response workshop focusing on the banks, it was determined that a crucial piece of missing observational information was direct bottom measurements. To account for this need, a low-cost distributed sensor array was deployed at EFGB, WFGB and Stetson Bank beginning in August of 2016. The primary instrumentation utilized in this study were Seahorse Tilt Current Meters (TCMs), which provide bottom temperature and current data at 1-minute temporal resolution. In addition, RBR and Seabird conductivity, temperature and dissolved oxygen sensors where deployed along with a bottom mounted ADCP. The initial deployment (8/2016) consisted of 6 TCMs, 1 CT + DO sensor (as well as several additional short-term deployments). The array was expanded approximately one year later to include 12 TCMs, 2 CT + DO sensors and 1 ADCP. At the next planned expansion (4/2018), the array will include 13

TCMs, 3 CT + DO sensors and 1 ADCP. The recovered data are currently being processes with emphasis on seasonal bottom temperature (relevant to bleaching events) and kinetic energy (relevant to hypoxic layer formation) patterns as well as the micro-circulation patterns around the banks.

Frank Muller-Karger, Ph.D. (University of South Florida) - The FGBNMS Localized Mortality Event as a Case Study for Promoting Biological Time Series Observations

The Marine Biodiversity Observation Network (MBON) is a thematic node of the Group on Earth Observations Biodiversity Observation Network (GEO BON). MBON has a formal collaboration with the Global Ocean Observing System (GOOS) to develop Essential Biodiversity Variables (EBV) as a complement to GOOS Essential Ocean Variables (EOVs), and with the Ocean Biogeographic Information System (OBIS) regarding data management and publication.

In general, MBON seeks to understand change in the diversity of organisms and communities (coral, plankton, fish), and what drives change (i.e., consequences of upwelling, coastal advection, offshore dynamics, River plumes, coastal materials, oxygen minima, climate change, etc.). The US Sanctuaries MBON program (sponsored by several NOAA offices, US IOOS, NASA) collaborated with the FGBNMS in examining remote sensing and other observations to help understand the conditions associated with the localized mortality event that occurred in the EFGB in July, 2016.

The purpose of this talk was to provide an introduction to MBON and emphasize that an important outcome of the meeting is to design/propose a multidisciplinary monitoring program integrating marine biology and environmental observations for FGBNMS. This program should collect a minimum of subsurface biogeochemical and biodiversity observations to address basic scientific research, which can then address questions of societal and resource management concern. The GOOS EOVs and the GEO BON EBVs provide some guidelines on variables to collect. In general, multidisciplinary observations needed to inform about:

- Ecosystem status and trends
- Ecosystem services
- Monitor water quality
- Potential impacts on ecosystem and human health
- Environmental or human controls
- Bottom-up, top-down, competition processes
- Constrain models/predictions
- Impacts of disturbance
- Productivity
- Diversity
- Biogeochemistry
- Human health

The program should incorporate some new technologies, including:

- Sensors to measure life (imaging, genomics)
- Chemical sensors
- Optical sensors
- Vessel automatic identification systems and vessel monitoring systems
- Fisheries monitoring data
- Remote sensing
- Unmanned UW/aircraft systems
- Citizen science

More broadly, governments and researchers around the world have recognized the need for information to evaluate changes in biodiversity as part of national biodiversity action plans and to respond to international treaties. Information on marine biodiversity is required to evaluate strategies and progress toward the U.N. Sustainable Development Goals (including SDG 14) and Aichi Targets of the Convention on Biological Diversity (CBD), and to conduct national, regional (i.e. spanning the continental margin of several countries or a specific ocean basin), and global assessments such as those attempted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and the UN World Ocean Assessment. These international activities embody the needs of nations and regions to understand how and why life in the ocean is changing and how local changes relate to changes taking place over larger regions. A pilot program in the FGBNMS can serve as a model program for monitoring biological diversity and other biological variables for management purposes.

Additional Presentations:

Mike Lee (USGS) - USGS Water Quality Monitoring at Texas Artificial Reefs

The U.S. Geological Survey, in cooperation with the Texas Parks and Wildlife Department (TPWD) Artificial Reef Program, collects physical and chemical water properties at selected Texas artificial reefs in proximity to the FGBNMS. Collecting long-term monitoring data, combined with targeted sampling for constituents of interest at these sites, aim to provide the foundation to establish the current status and long-term trends in the general environmental conditions and information essential for sound management decisions and long-term planning. Physical and chemical water properties measured at the artificial reefs provide context to the biological data already being collected by the TPWD and the combination of these data sets can be used to better understand ecosystem response to environmental changes. Five sites within the General Permit Area (GPA) have had repeated data collection efforts since 2012. The distribution of the sites selected provides maximum spatial variability within the GPA and a basis of comparison to natural reef environments. One of these sites, HI-A389A, lies within the EFGB marine sanctuary boundaries. At these sites, samples are collected for various constituents of interest including nutrients, metals, and chlorophyll at depth of approximately 70-100 ft. Additional monitored water quality parameters consisting of water temperature, specific conductance and salinity, pH, dissolved oxygen concentration, turbidity, chlorophyll, and blue-green algae are collected with a multi-parameter water quality sonde at the time of sample collection. From approximately mid-July to mid-September of 2016, a multi-parameter water

quality sonde was deployed at three of the collection sites corresponding to the Northeast corner, Central, and Southwest corner of the GPA at about 70-100 ft water depth providing a continuous record of these water quality parameters. Preceding and during the time of the sonde deployments, discharge from at least four major rivers in Texas (the Brazos River, the Colorado River, the Sabine River, and the Trinity River) were substantially above median daily averages for an approximate 4-6 month period of time as measured from USGS gaging stations near the Texas coast. A preliminary comparison of measured sonde data from these three sites and to sonde data collected during the same time period from the previous year at the Center location demonstrates both a spatial and temporal variability in measured water quality parameters across the general permit area. Notable observations include:

- A lower temperature in 2016 compared to 2015 at the Central location
- A period of lower salinity in the Southwest corner of the GPA during 2016 deployment
- A period of lower pH recorded in the Northeast corner during 2016
- A period of lower dissolved oxygen concentration in the Northeast corner with measurements dropping close to 2 mg/l
- A period of lower dissolved oxygen concentration from 2016 compared to 2015 at the Center location
- A substantial week long period of increased turbidity, chlorophyll, and blue-green algae in the Southwest corner during the 2016 deployment

Datasets available upon request (please email mtlee@usgs.gov should you require these datasets):
- Measured nutrient, metals, and chlorophyll data
- Multi-parameter sonde profile and deployment data

Robert Arnone, Ph.D. (University of Southern MS) - Monitoring Abnormal Bio-Optical and Physical Properties in the Gulf of Mexico, Flower Garden Banks

The USM **Ocean Weather Laboratory (OWX),** created ocean weekly, 8-week and anomalous surface water products for the FGBNMS from satellite ocean color and SST and physical ocean model estimates (NCOM) during the 2016 die-off event (Arnone, 2017). Ocean surface products include: salinity, temperature, currents, chlorophyll, absorption443, Backscattering551, attenuation coefficient (486nm) and photic depth at a spatial resolution of 750m and 4km. **Dynamic Anomaly Properties (DAP)** at the FGBNMS are the difference of the weekly mean from the previous 8-week mean (2 week lag). The anomalous level of the DAP products is defined using different standard deviation masks. Anomalous surface salinity shows a low salinity event at FGBNMS strongly beginning the week of July 3, 2016 and extending through July,11, 19 and 27, 2016. Similarly, chlorophyll and absorption 443 anomalies were observed at the same dates. The week of July 18, 2016 was observed to be a major turbidity event (Kd486) which was prior to detection on July 27. The chlorophyll standard deviation for June-July period was determined for 2013, 2014, 2015 and 2016. Higher Standard deviation was observed in 2016 at the FGBNMS at time of event. The weekly DAP bio-physical products are available from 2013 to present and include the anomaly, weekly and 8 week average, standard deviation , and standard deviation masks. The data format includes both NetCDF and kml for animation on GOOGLE Earth, which are available at NOAA NCEI and DAP-USM. The products cover the

entire Gulf of Mexico so can track the migration of the coastal river plumes as these migrate offshore and are affected by the offshore eddies. The physical model (NCOM) has vertical physical properties which can be related to the surface waters. Daily OWX ocean products of satellite and several ocean models (NCOM, HYCOM) are created daily from 2013 in near-realtime which are using for adaptive sampling of ship and gliders etc. in a google earth format. The NOWCAST and the DAP products can provide adaptive sampling to watching the FGBNMS for a possible event occurrence and tracking mooring, gliders and data collection.

For more information, please reference:
Arnone, R. and Jones, B. 2017. Monitoring abnormal bio-optical and physical properties in the Gulf of Mexico, Proc. SPIE 10186, Ocean Sensing and Monitoring IX, 101860O; doi:10.1117/12.2266789

Available datasets (please email Robert.Arnone@usm.edu or E.Brooke.Jones@usm.edu should you need assistance with this dataset):
- USM DAP Data available to public: https://www.usm.edu/marine/dap
- DAP Product Description: https://www.usm.edu/sites/default/files/groups/division-marine-science/pdf/dap-description_page-v4.pdf
- KML data 2014-2018
https://ecowatch.ncddc.noaa.gov/thredds/catalog/usm_dap_kmz/catalog.html
- NCDF data 2014-2018
https://ecowatch.ncddc.noaa.gov/thredds/catalog/usm_dap_netcdf/catalog.html

In Memoriam – A Tribute to our Colleague and Friend:

Dr. Matthew K. Howard, Data Management and Communications Coordinator for GCOOS and Research Scientist in the Department of Oceanography, College of Geosciences at Texas A & M University passed away in February of 2018. Matt's pioneering contributions to oceanography, ocean observing systems and data management are wide-ranging and countless and matched only by his kindness, desire to help, quick response, wonderful wit and enthusiasm for life. Matt was the chief scientist for the first rapid response cruise to assess water quality parameters after the discovery of the mortality event at EFGB. His colleagues, friends, and family will dearly miss him.

Matthew K. Howard, 1952-2018

Group Discussion:

After key responders presented their data and hypotheses, facilitated group discussion outlined data overlaps and data gaps. Discussions revolved around the evidence that low dissolved oxygen/hypoxia was a likely case, but there was no direct data specifically from the mortality area to measure this at the time of the event. Factors detected and measured in the vicinity of EFGB and the region around the time of the event are listed below:

1. High river outflow
2. Low salinity
3. High chlorophyll
4. High organic matter
5. Low oxygen
6. Sustained high water temperature
7. Low fish density and biomass on reef
8. Benthic cover data showing mortality impacts

Group Summary Statement:

While no "smoking gun" evidence of direct causation of the mortality event is available, the general consensus was that low dissolved oxygen was a key factor. Several different hypotheses describing a low oxygen event as cause or consequence of the event were put forth by the various responders. After taking into consideration all of the evidence and hypotheses by all parties, with continued facilitated discussion, the mini-symposium group drafted the following agreed upon summary statements:

"Low dissolved oxygen was the most likely contributing factor of the 2016 highly localized mortality event at East Flower Garden Bank.

Instrumentation on and around the reef documented low surface salinity and higher than average seawater temperature. High organic matter was detected by remote sensing, and unusually high levels of freshwater outflow from Gulf Coast rivers were also measured. The linkages between the conditions measured on the reef at the time of the event, and dissolved oxygen factor, are undetermined.

The mechanism resulting in the highly localized nature of the mortality event cannot be determined from available data."

Monitoring Discussion:

Final group discussions revolved around current monitoring activities in place, and future monitoring needs. There was consensus among the group that a general lack of regional oceanographic instrumentation, both surface buoys and subsurface instrumentation, constrained the ability to precisely determine the cause/s of the localized mortality event. Recent funding

cuts have forced one (of the two) long term Texas Automated Buoy System (TABS) buoys near the sanctuary, to be removed, leaving just one TABS buoy (V) in place near the EFGB coral cap. Funding for this buoy is tentative.

The group also discussed ensuring sample kits and protocols are in place, so that in the event this should happen again, researchers would be prepared for sample collection offshore. Other actionable items included creating a photo mosaic of the mortality site for long-term monitoring purposes, deploying additional tilt meters across the banks to monitor micro-movements of water, and developing additional satellite based products as an early warning mechanism for potential future events.

Next Steps:

A shared Google Documents folder has been created and shared with all participants, including information such as meeting presentations, available data, timeline of event and response, maps, etc.

FGBNMS will draft a short paper documenting the basics of the event, targeting a Note style format in Coral Reefs. Principle investigators are strongly encouraged to author their individual manuscripts to be published in the most impactful journal of choice for their discipline, referencing the FGBNMS note reporting the event. This publication plan differs from the original planned outcomes, but meets the desires of the participants, and also the objectives of the organizers.

Acknowledgements: