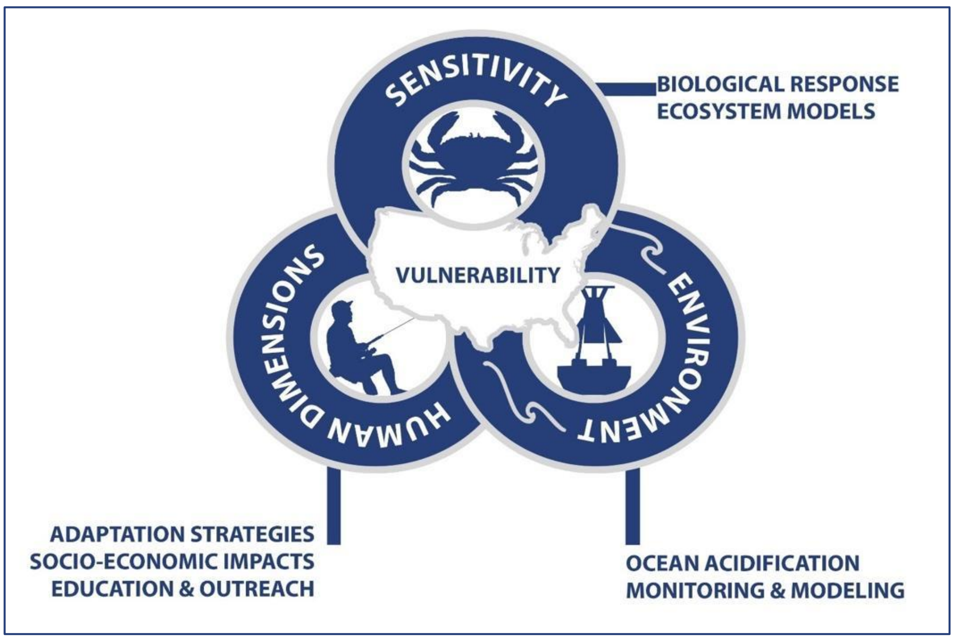
SOCAN WORKSHOP REPORT



12/01/2021

Coastal Vulnerability in the Southeast

OAP
NOAA OCEAN ACIDIFICATION PROGRAM

SECOORA
Southeast Coastal Ocean Observing Regional Association

USF UNIVERSITY OF SOUTH FLORIDA
COLLEGE OF MARINE SCIENCE

SOCAN
Southeast Ocean and Coastal Acidification Network

ACKNOWLEDGEMENTS

SOCAN graciously thanks the Southeast Coastal Ocean Observing Regional Association (SECOORA) and University of South Florida College of Marine Science for hosting and providing technical support for this workshop.

The SOCAN Meeting planning committee included Dr. Janet Reimer (SOCAN/University of Delaware), Dr. Emily Hall (SOCAN/Mote Marine Laboratory), Laura Korman (SECOORA), Victoria Parks (Sea Venture Clam Co), Dr. Kerri Dobson (NOAA Ocean Acidification Program), Courtney Cochran (NOAA Ocean Acidification Program), and Dr. Kimberly Yates (US Geological Survey).

Thank you to all our speakers for participating in this event. SOCAN relies on our engaged stakeholder group and their continued support of our mission to bring awareness to the issue of ocean acidification in the Southeast. Speakers are listed in order of their presentations: Janet Reimer (SOCAN/University of Delaware), Courtney Klepac (Mote Marine Laboratory), Ed Sherwood (Tampa Bay Estuary Program), Jennifer Hecker (Coastal and Heartland National Estuary Partnership), and Julianna Mullen (NERACOOS/OAIE).

SOCAN would also like to thank Melissa Sante and Amanda Quasunella (both of Mote Marine Laboratory) for meeting assistance and recording.

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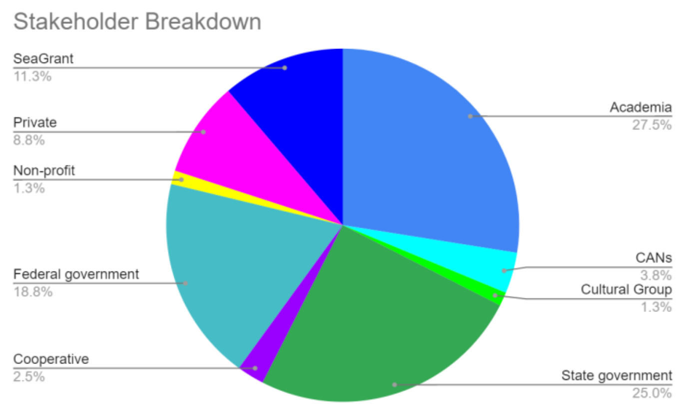
SUMMARY

The Southeast Ocean and Coastal Acidification Network (SOCAN) held a virtual, half-day long acidification workshop on December 1, 2021. Attendees included stakeholders from across the Southeast including natural resource managers, oyster growers, water quality experts, researchers, and cultural representatives. The workshop specifically addressed issues related to social and environmental vulnerabilities due to acidification in coastal and shelf waters in Florida, Georgia, South Carolina, and North Carolina.



Coastal communities across the Southeast could be vulnerable to acidification from one or more aspects: social, environmental, or lack of monitoring. The Interagency Working Group On Acidification (IWG-OA), comprised of representatives from the National Oceanic and Atmospheric Administration (NOAA), United State Geological Survey (USGS), United States Navy, the Bureau of Ocean Energy Management, National Park Service, Department of State, Environmental Protection Agency, Fish and Wildlife, Department of Agriculture, and the Smithsonian Institution, has been charged with assessing vulnerability of coastal communities across the USA by 1) assessing the gaps in monitoring and research that are needed to better characterize the **exposure** of regions to acidification and the **biological response** and 2) characterizing the **social vulnerability** resulting from impacts to marine resources, and the sensitivity and adaptive capacity of social and economic systems. Vulnerability has been defined as an organism's, system's, and/or human exposure, sensitivity and adaptive capacity to an environmental or anthropogenic stressor.

The objectives of the workshop were meant to mirror the IWG-OA's 2022 National Vulnerability Assessment. The general topics presented and discussed at the meeting were:

- **Exposure**: Discuss the current understanding and future levels of acidification in the Southeast
- **Biological response**: Gain a general understanding the sensitivity and adaptive capacity of organisms and ecosystems to acidification
- **Social Vulnerability**: Gain a general understanding of impacts to communities and their potential for adaptive capacity

The workshop aimed to bring together stakeholders and scientists to discuss how acidification in the Southeast could be presently causing vulnerability and future community resiliency. Meeting presentations focused on the general state-of-the-science, organismal case studies of resiliency, ecosystem mitigation, adaptation, and restoration, social understanding of acidification as an environmental problem, and education and stakeholder outreach.

PROCEEDINGS

The meeting was attended virtually by over 50 attendees, from all four states represented by SOCAN as well as locations outside of the Southeast (see Appendix II). Presentations were given in the first session (see Appendix I) by Dr. Janet J. Reimer (SOCAN), Dr. Courtney Klepac, (Researcher - Mote Marine Laboratory), Edward Sherwood (Executive Director - Tampa Bay Estuary Program), Jennifer Hecker (Executive Director - Coastal & Heartland National Estuary Partnership), and Julianna Mullen (Communications Manager at NERACOOS/Community Manager of the Ocean Acidification Information Exchange [OAIE]). There were three breakout sessions in the second session (see Appendix II), which were 25 to 45 minutes long, for smaller discussions about the topics outlined in the goals of the meeting. Breakout session moderators recorded notes on the discussion, which are summarized below. The goal of the breakout sessions was to get individual perspectives on the state and problem of acidification and where the Southeast is vulnerable.

A pre-meeting survey of participants asked, "what concerns you most about coastal acidification in the southeast". The responses were collected and reviewed by the SOCAN Meeting Planning Committee and sorted into the three main focus areas (goals) of the meeting. The responses to the question were used by breakout group moderators to guide the discussions. The discussion within the breakout groups is summarized below.

SETTING THE REGIONAL CONTEXT: STATE-OF-THE-SCIENCE

Invited speakers gave brief summary presentations on background and updates to the state-of-the-science in the Southeast region, specific recent case studies on species and ecosystems in the Southeast, and public perception of acidification as a potential source of vulnerability.

Exposure: Current and future levels of ocean acidification

Presentation by Dr. Janet Reimer, SOCAN Co-Coordinator & Ocean Acidification Researcher at The University of Delaware

Dr. Reimer (SOCAN) reviewed the general state-of-the-science in the Southeast, examples of the impacts of acidification in each of the four states in our region, an update on monitoring priorities, and introduced the different aspects of vulnerability addressed in the IWG-OA assessment.

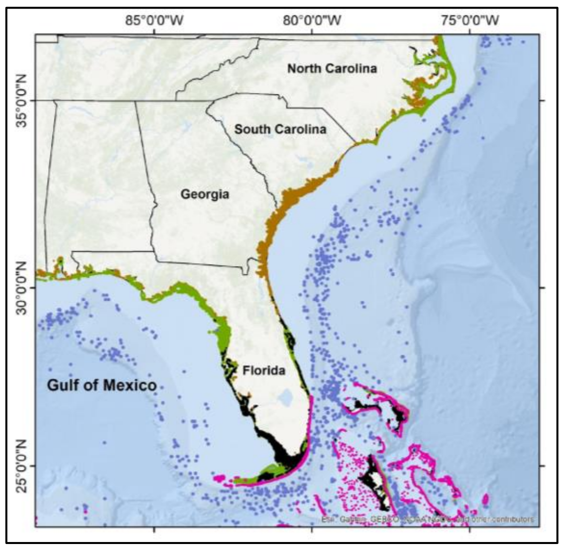


Fig. 1 The diverse ecosystems of the Southeast include estuaries, seagrass beds (green), salt marshes (brown), mangroves (black), deep corals beds (purple), and hard reef structures (pink) (https://data.unep-wcmc.org/)

There is a wealth of ecosystem diversity in the Southeast (**Fig. 1**), which includes: estuaries, seagrass beds, mangroves, shallow hard bottom reefs, deep soft bottom corals, salt marshes, shallow shelf regions, open bays, closed bays, and other intercoastal waters. The diversity also leads to chemical and biological heterogeneity. Therefore, the biogeochemical drivers of coastal acidification across the Southeast are due to the release of CO_2 by organic matter respiration, low pH-high DIC freshwater inputs from rivers and groundwater, atmospheric CO_2 dissolving into surface waters, upwelling and onshore transport, and seawater temperature increase.

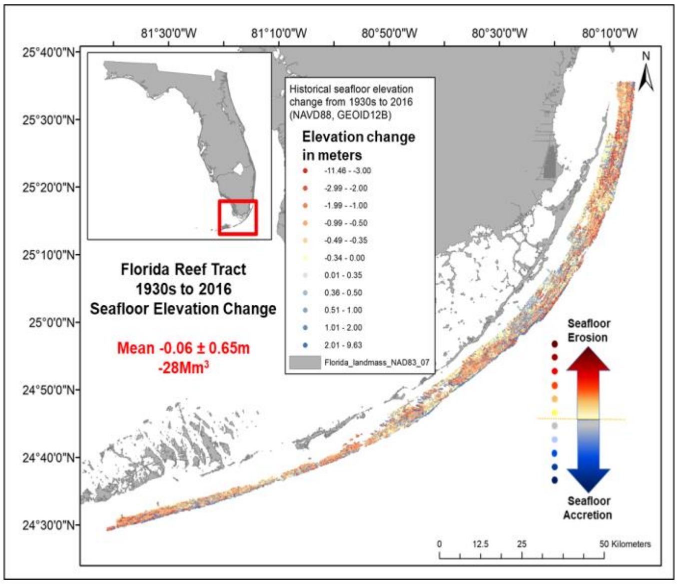


Fig. 2 Sea floor erosion has been largely negative since the 1930's. Calcium carbonate erosion of reef structures can lead to a decrease in wave attenuation (Yates et al., 2021. Therefore, putting coastal communities at risk during tropical cyclones.

Regional Impacts of Acidification

In the **Caribbean and Upper Florida Reef Tract (FRT)** seawater temperature increases and biological release of CO_2 drive the pH and aragonite saturation state (Ω) decreases off southwest **Puerto Rico** and the **Cheeca Rocks mooring** (Meléndez et al. 2020)(Meléndez et al. 2020). Additionally, ongoing laboratory studies show decreased coral, *Acropora sp.*, growth at a pH of 7.7 compared to higher ocean pH of 8.2. Low pH and Ω conditions could lead to dissolution of existing hard bottom reef structures, also known as negative calcification, in the region with implications for wave attenuation and shoreline erosion (Muehllehner et al. 2016; Yates et al. 2021)(Muehllehner et al. 2016; Yates et al. 2021). Since the 1930's, along the entire FRT, seafloor erosion has dominated accretion, or reef building (**Fig. 2**). There is ongoing research by the USGS to assess the impacts of seafloor erosion on man-made structures and beach erosion in the Florida Keys. Coral reefs provide cultural and regulating ecosystem services for ecotourism and wave energy regulation. Without these important ecosystem services, communities throughout the Keys may experience social, economic, and ecological vulnerability.

Tampa Bay, an example of an urbanized estuary in the Southeast region, is threatened by land-use change and eutrophication. Primary production has increased within Tampa Bay due to enhanced inputs of inorganic nutrients that come from runoff, seepage from septic systems, fertilizers, and other point-sources. The degradation of organic matter causes the release of large quantities of CO_2, which drive down the pH. Improved water quality management has decreased the amount of nutrients entering the bay and has allowed Seagrass beds to recover in Tampa Bay (Burke, 2016; (Burke, 2016; **Fig. 3**). Seagrass beds were declining until the 1980's because other species of marine plants and

Fig. 3 Decreased nitrogen and other inorganic nutrient levels in Tampa Bay have decreased the coverage of epiphytic algae, which has led to a clearer water column, thus increased seagrass since the 1980's. This positive feedback has also led to an increase in water column pH due to seagrass uptake of CO_2 (Burke, 2017).

phytoplankton in the water column were outcompeting seagrass. Seagrass helps to reduce the acidity of the water by consuming CO_2 through photosynthesis. Restoring natural seagrass beds could be an effective way to mitigate acidification in coastal waterways, especially in urban areas with eutrophication.

Pamlico Sound, which is an estuary with restricted exchange with ocean water, long water residence times, and several inputs from large rivers, is seasonally impacted by extreme precipitation associated with tropical cyclones. Increased freshwater from rivers, with inherently lower pH, release stored CO_2 and organic matter from wetlands. The organic matter that is delivered from the rivers degrades and releases additional CO_2. The enhanced CO_2 and low pH waters could cause sporadic low Ω conditions. In September 2018, after the passage of Hurricane Florence, over a 22-day period, pH in the Neuse River Estuary decreased from approximately 8.4 to 5.5 and up to almost 40 km downstream from the freshwater end-member (Paerl et al. 2020)(Paerl et al. 2020). Whereas, before the hurricane, pH was dramatically higher in the freshwater portion. There are many shellfish species and aquaculture sites within Pamlico Sound that could be affected by low Ω, however, there are few studies specific to acidification in North Carolina. Social and ecosystem vulnerability have not yet been identified in Pamlico Sound and its estuaries.

CO_2 in shelf waters of the **South Atlantic Bight (SAB)** has been increasing at rates of approximately 3.0 to 4.5 µatm y^{-1} from the coastal waters to the outer shelf, with pH decreasing up to -0.004 units y^{-1} (Fig. 4; Reimer et al., 2017)(Fig. 4; Reimer et al., 2017). The rates of CO_2 increase and pH decrease are greater than expected from atmospheric inputs alone. The CO_2 and pH rates of change are based on calculations from cruises and high frequency measurements from the mooring within the **Gray's Reef National Marine Sanctuary**, on the inner shelf. Acidification of subsurface waters of the SAB shelf is not yet known. In general, coastal, and open water acidification in the SAB is slower than in other regions, likely due to the high salinity-well buffered waters of the subtropical Atlantic (Egleston et al. 2010)(Egleston et al. 2010).

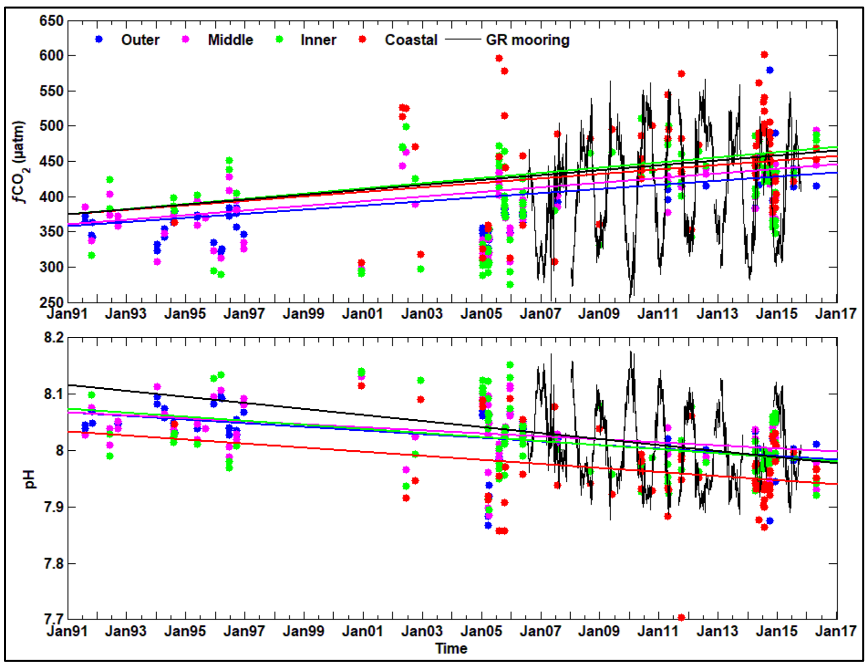


Fig. 4 Deceasing pH across the South Atlantic Bight shelf coincides with increasing CO_2 since the early 1990's. The coastal, inner, middle, and outer shelf regions have varying trends likely due to different sources of CO_2 (Reimer et al., 2017).

Current ongoing monitoring, future priority sites, and sites with pending awards

There are three high frequency, moored CO_2 and pH time series in the southeast: **Gray's Reef (SAB), Cheeca Rocks (FRT),** and **Tampa Bay**. These data are considered "climate quality" with high precision. There are six National Estuary Research Reserve (NERR) and three National Estuary Program (NEP) sites that measure pH with "weather quality", slightly lower precision than climate quality monitoring. Discrete water samples have been collected within the Georgia coastal salt marshes quarterly, since 2013, as part of the Georgia Coastal Ecosystems (GCE) Long-term Ecological Research project. Finally, there are 20 sites for CO_2 and/or pH from the ModMon Neuse River Estuary and Pamlico Sound project, since 1994.

Future research sites, which were determined at the 2017 SOCAN Monitoring Workshop (SOCAN, 2017;(SOCAN, 2017; **Fig. 5**). As of the beginning of 2022, funding has been awarded to SOCAN and collaborators to begin monitoring and/or synthesizing existing observations in the Lower FRT (priority site number 4) and in Long Bay and Murrell's Inlet, South Carolina (priority site numbers 6 and 12).

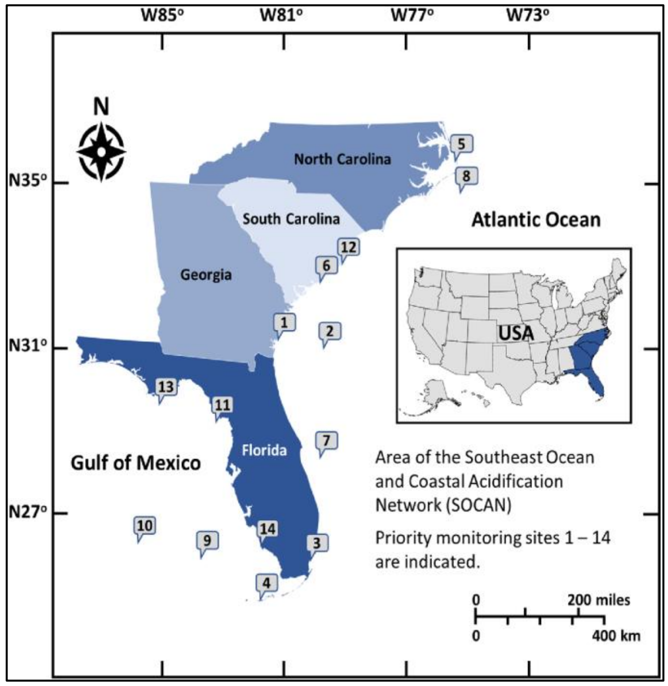


Fig. 5 Priority monitoring sites established at the SOCAN Monitoring Workshop in 2017. Sites 4, 6, and 12 have been selected for funding from the Southeast Coastal Ocean Observing Regional Association (SECOORA; site 4) and South Carolina Sea Grant (sites 6 and 12; SOCAN, 2017).

What do we know about Southeast vulnerability and what do we know that we don't know?

Acidification can have an effect on a societal level, or human dimension, through economic impacts to the shellfish industry, cultural groups that rely on harvesting, and the general well-being of people that take pleasure in marine habitats. There is a yet-to-be-determined impact on subsistence fishing in the Southeast. The Gullah/GeeChee Nation, a cultural heritage corridor, has publicly recognized that acidification is adversely affecting subsistence fishing and other cultural traditions. The Gullah/GeeChee Nation has created their own Ocean Acidification Action Plan in conjunction with the Ocean Acidification Alliance (https://www.oaalliance.org/). The reliance on subsistence fishing is not well understood across the Southeast but is likely a vulnerable practice in many other areas of the region.

Appropriate environmental monitoring strategies across space and time are needed to establish baseline carbonate chemistry conditions, create acidification forecasting models, and provide information to environmental managers and scientists. It has been generally expressed by SOCAN members that not enough information on acidification is available in the Southeast, which could be due to the high heterogeneity of the environment and low spatial coverage of existing monitoring systems. Therefore, the lack of monitoring is a vulnerability in the Southeast. Vulnerability has been defined by the IWG-OA as an organism's, system's, or human's exposure, sensitivity, and adaptive capacity to an environmental or anthropogenic stressor (**Fig. 6**). Management decisions for restoration, mitigation, and adaptation strategies need to be made based on results from monitored sites. Monitoring can also

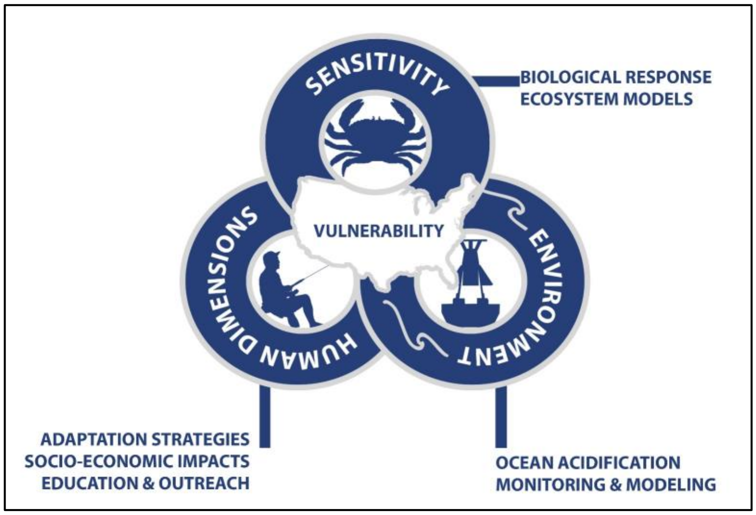


Fig. 6 Biological and ecosystem responses to acidification threaten the human dimension and make society vulnerable to environmental and economic deterioration.

include results of laboratory studies on different species. Some species are more sensitive to acidification than others, though without species-specific studies in the Southeast, it is unknown how the different chemical conditions in the various ecosystems will impact this region.

The impact of multiple stressors on acidification has also been identified as a knowledge gap in the Southeast and another source of vulnerability. General multi-stressors that stakeholders have been identified are sea level rise, temperature rise, Harmful Algal Blooms (HABs), the impact of extreme events (drought, storms, floods), and hypoxia.

Biological Response: Sensitivity and the adaptive capacity to ocean acidification Organismal Impacts

Presentation by Dr. Courtney Klepac, Coral Resilience Postdoctoral Researcher at Mote Marine Laboratory

Dr. Klepac summarized the importance of Florida's coral reefs, discussed the current decline in healthy reefs, and shed some light on promising research that may show coral resilience to increasing CO_2, one of the primary chemical drivers of acidification.

Florida's Coral Reefs attract more than 16 million visitors per year, support more than 71,000 jobs, and are valued at over $6 billion dollars. Once healthy reefs have been declining, however, it is unclear how vulnerable society and other ecosystems are at present. As some coral populations decrease, macroalgae cover can increase, potentially disrupting the natural balance in the ecosystem and making the reef less attractive to tourism (**Fig. 7**). Acidification reduces the aragonite mineral saturation state, which increases the energetic cost (energy used) of biomineralization and acid-base regulation by the coral polyp. This leads to the question, can different species cope with

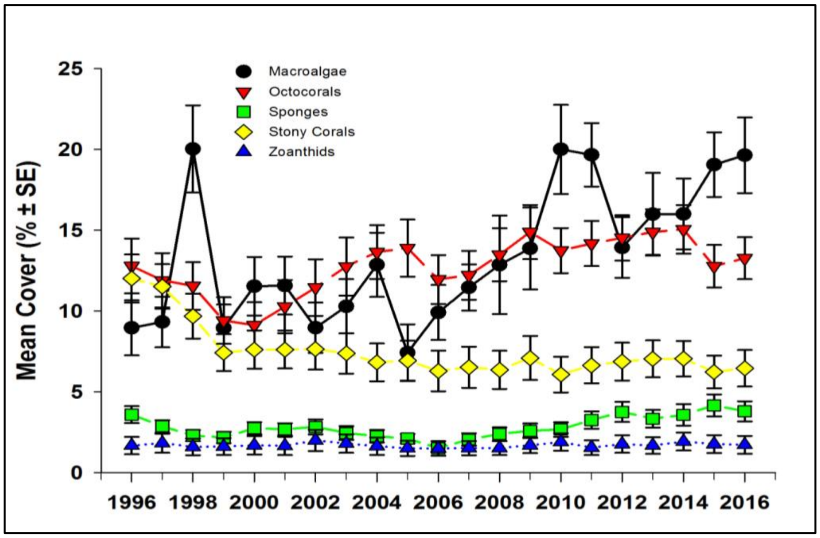


Fig. 7 Macroalgae (black) and Octocoral (red) populations have increased since 1996 while stony corals have decreased (Gilliam et al. 2017). This population shift can have negative aesthetic effects that could negatively impact tourism and the Floridian economy.

acidification or are they vulnerable to decreasing pH? To answer this question Dr. Klepac is studying the resiliency of coral species to ocean warming, acidification, and the combined effects of warming and acidification at Mote Marine Laboratory.

Two species of stony corals, *P. clivosa* and *O. faveolata*, showed either negligible or positive effect on physiology due to acidification, but a negative effect due to the combined effect of acidification and warming. It was also determined that Mote's land-based specimens of the same two species are naturally hardened to low pH conditions and are resilient to changes in pH at *in situ* restoration sites off the coast of Florida. Resilient species could be less vulnerable to climate changes.

Florida's coral reefs are not as healthy as they were in the 1970's and are vulnerable to erosion under acidic conditions. Dead and/or dying coral leave space for macroalgae and biofilms to take their place. A phase shift can occur from stony corals and sponges to algae, and bioflim communities after a heatwave (**Fig. 8**). Therefore, unable to maintain positive net carbonate mineral production, coral reproduction and recruitment will also decrease, leading to the disruption of ecosystem services, such as natural wave barriers.

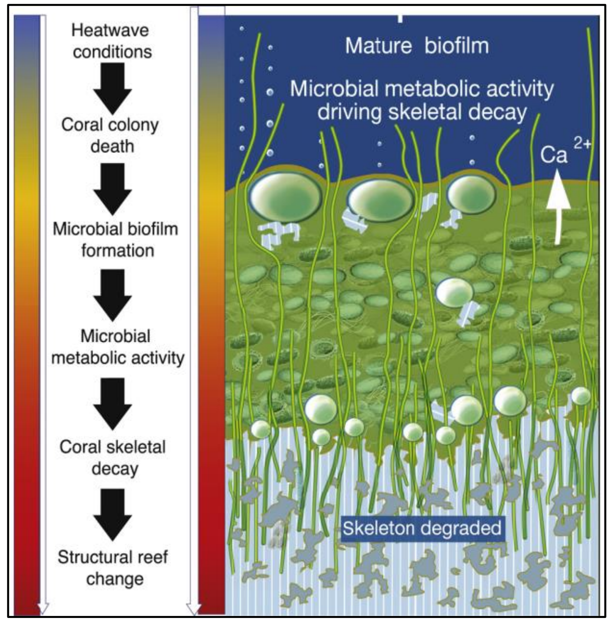


Fig. 8 Degraded coral skeletons may allow for increased surface are for macroalgae and biofilm growth, therefore, resulting in phase shift along coral reefs and an aesthetically negative experience for tourists (Fordyce et al. 2019).

Research goals for corals in Florida waters should be designed to help identify various points of vulnerability. Some of these goals should be: 1) determining what are effective timescales for understanding the effects of acidification on coral health; 2) which coral species are less affected by acidification; and 3) are there any low pH reef sites containing corals that are resilient to acidification?

Exposure: Current and future levels of ocean acidification

Addressing Ocean & Coastal Acidification Issues in the Tampa Bay Estuary

Presentation by Ed Sherwood, Executive Director of the Tampa Bay Estuary Program

Tampa Bay is an urbanized estuary on the west coast of Florida that receives freshwater from rivers and runoff from the surrounding region. Tampa Bay has experienced a coincident pH increase as seagrass has been restored through effective management since

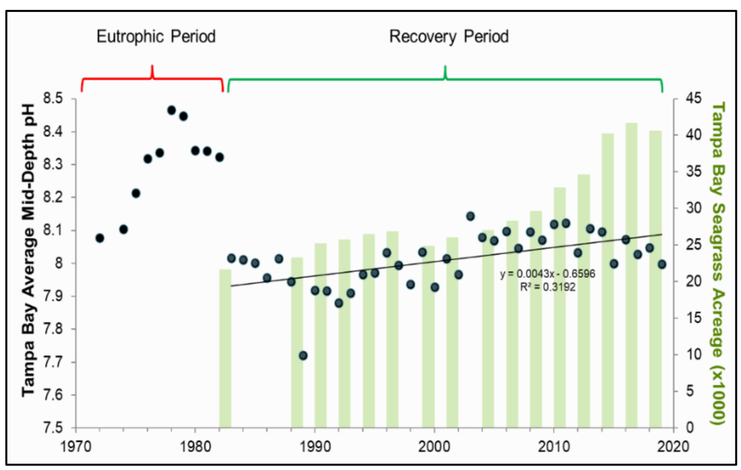


Fig. 9 After a decline in seagrass beds in Tampa Bay during the 1970's, pH also declined (black dots). An increase in seagrass bed acreage (green bars) has resulted in a slow increasing in pH since the eutrophic period. Sherwood et al. (2016).

the early 1980's. Due to continued eutrophication, there was a decline in seagrass coverage in Tampa Bay (acreage was not recorded before 1982) and a sharp drop in pH (**Fig. 9**). With restoration efforts, pH has begun to increase in parts of Tampa Bay, yet the recovery has not yet returned to higher pH levels from before the recovery period. Due to coordinated efforts between the US Environmental Protection Agency (EPA), the United States Geological Survey (USGS), the Tampa Bay Environmental Restoration Fund, Florida Fish and Wildlife, University of South Florida, and University of Tampa real-time monitoring sites inside Tampa Bay and adjacent to the bay in the Gulf of Mexico have been established. These sites measure hourly pH, dissolved oxygen, CO_2, temperature, salinity, and photosynthetically active radiation. Combined, the data can give a complete picture of biological, physical, and chemical changes due to acidification. Raw, real-time data and online data analysis tools are available and publicly accessible for both sites. Data can be accessed for research and educational purposes, as well as by natural resource managers for planning and monitoring needs.

The environment, economy, and community well-being are all interconnected within the Tampa Bay watershed, with one out of every five jobs within the watershed depending on the health of Tampa Bay (Muellner, 2015; **Fig. 10**). Restoring the health of the bay is essential to maintain the functionality of ecosystem services, such as oysters that provide a natural water filter. In 2020, the first oyster aquaculture lease site in Tampa Bay began production. Natural oyster population declines led to fisheries closures and decreased water quality. Restoring the fishery, even through increasing aquaculture, will have a significant impact on water quality and community well-being.

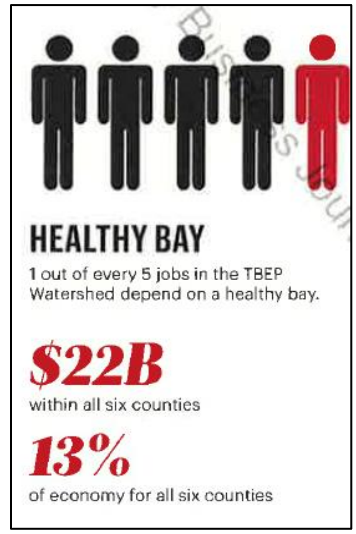


Fig. 10 The health of Tampa Bay impacts one in five jobs within the six counties that are located in the watershed. The Bay economy accounts for about $22 billion (Tampa Bay Business Journal, 1/16/2015).

Social Vulnerability: Impacts on communities and their adaptive capacity Regional Impacts

Presentation by Jennifer Hecker, Executive Director of the Coastal & Heartland National Estuary Partnership

The Coastal and Heartland National Estuary Partnership (CHNEP), which encompasses seven different estuaries across 10 counties, conducted a vulnerability assessment as it relates to acidification as a climate risk. The assessment included experts and the general public and was in support of the CHNEP Comprehensive Conservation and Management Plan (CHNEP 2018). Five experts and over 50 public participants were asked to create and rank a list of climate related risks in terms of likelihood of occurrence and if the risk occurred, how severe an impact it would create. The responses of the experts were compared with the responses of the public to determine the level of agreement.

The first acidification-related risk addressed was whether "ocean acidification may impact shellfish and condition of habitat created by shellfish" (**Fig. 11**). The experts thought there was a medium/high likelihood of occurrence and a medium/high chance that the impact would be severe. Whereas the public thought there was a low likelihood of occurrence, but if there was, the impact would have a high likelihood of being severe.

The second risk that was assessed was if "ocean acidification may impact shellfish populations" (**Fig. 12**). The experts were mostly in agreement that there was a medium/high likelihood of occurrence and severity of the impact. The public perceived a medium likelihood of occurrence and a high level of severity if acidification would occur. In general, it seems that the public does not agree well with experts on the severity but is in general agreement with the potential occurrence of the likelihood of acidification.

The report concluded that more education is needed, as identified by the public indicating low likelihood, while experts indicated a generally higher likelihood and impact. Research should focus on how to raise public awareness of acidification and then implement outreach plans.

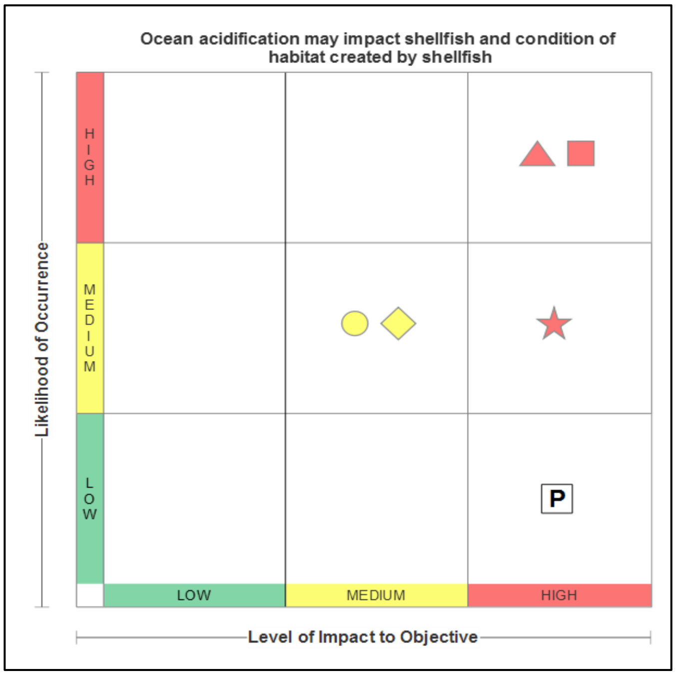


Fig. 11 Agreement between the public and experts was mixed, with the public thinking that there was a low likelihood that acidification would occur. The five experts also had mixed opinions.

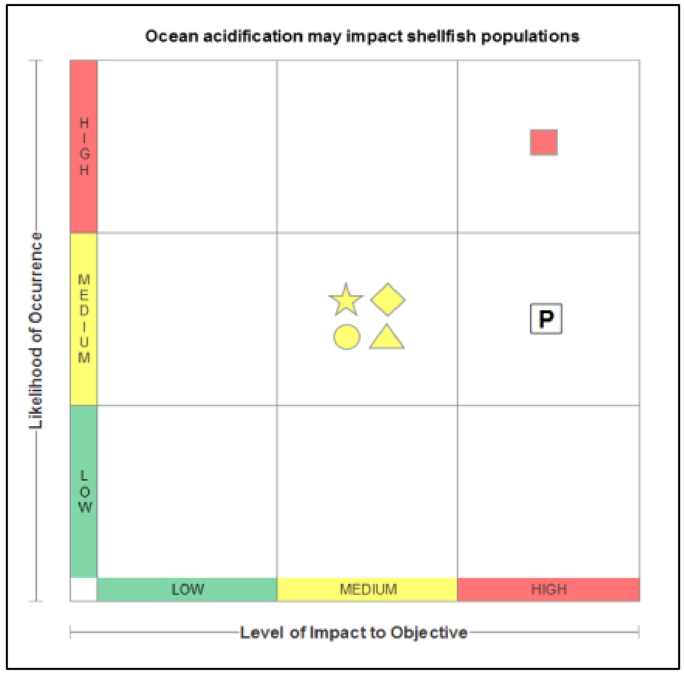


Fig. 12 Most of the experts thought the occurrence and severity of acidification to shellfish populations was medium. While the public thought that the level of impact could be high. Again, the public and experts are not in exact agreement.

Social Vulnerability: Impact on communities and outreach education

Stakeholder Engagement, The Ocean Acidification Information Exchange

Presentation by Julianna Mullen, Communications Manager at NERACOOS

The Ocean Acidification Information Exchange (OAIE) is a virtual international community for professionals working with, or interested in, ocean and coastal acidification (**Fig. 13**). The OAIE hosts virtual chats and discussions and is also a site for members to collaborate and share information. Members include researchers, managers, government employees, educators, industry professionals, students, and cultural representatives. The OAIE is funded through NOAA's Ocean Acidification Program and is directed through a steering committee composed of stakeholders and acidification experts.

Fig. 13 The Ocean Acidification Information Exchange is a virtual platform dedicated to coastal and ocean acidification activities and exchange of ideas www.oainfoexchange.org .

In 2020, the OAIE, funded through NOAA, held a competitive call for micrograntss of up to $5,000 to fund the creation of education and outreach materials. A proposal by Queen Quet Marquetta Goodwine, Chieftess of the Gullah/Geechee Nation (coastal North Carolina to northern Florida) was selected for funding. The project delivered educational outreach materials including a video, an infographic, and a lesson plan to introduce the concept of acidification to school aged children. Another funded project was granted to the Chugach Regional Resources Council (CRRC) from Alaska. This project produced a video on community water sampling for acidification. All materials and videos are available, free of charge, on the OAIE.

A recent survey of OAIE members asked, "has your involvement with the OAIE catalyzed offline 'real life' collaborations, discussions, or activities?" More than a third of OAIE members responded that yes, that OAIE involvement had enhanced their experience. The over 1,500 members of the OAIE are an active community broken down into teams of regions and expertise. Team leaders have been charged with leading discussions and posting relevant information and material. As the OAIE grows, so will acidification awareness and knowledge.

DISCUSSION

All participants were asked to participate in breakout sessions based on input that was provided by participants when they registered of the workshop. Participants were asked what about coastal acidification in the Southeast concerned them the most. Prior to the workshop the questions submitted by participants were grouped into the following sessions, which are the three main objectives originally identified in the IWG-OA vulnerability report draft:

- Exposure: Discuss the current understanding and future levels of acidification in the Southeast
- Biological: Gain a general understanding of the sensitivity and adaptive capacity of organisms and ecosystems to acidification
- Social Vulnerability: Gain a general understanding of impacts to communities and their potential for adaptive capacity

Here we summarize these discussions and include an overall list of southeast vulnerabilities identified during the workshop and the needs of stakeholders.

Objective 1: Biological Response and Exposure: Sensitivity and the Adaptive Capacity to Ocean Acidification

What are the effects on local shellfish? Shellfish are an important resource (economically and ecologically) in the Southeast US and include a broad range of species including clams, oysters, and scallops. Harmful algal blooms (HABs), survival rate of larvae in hatcheries, and salinity were the most important concerns discussed while acidification was the least important or least understood for shellfisheries in this region. Acidification on shellfish in the southeast is a major gap in research and in stakeholder response. The Tampa Bay area has a science-friendly aquaculture community where stakeholders have been open to new research and technology. South Carolina has had good success in recent growth of the aquaculture industry; however, South Carolina does have many freshwater inputs, which may contribute to low pH levels in the coastal zone. Data recording of harvests has been difficult due to reliance on people who are not compensated financially or who are unaware of, or unconcerned, about the effects of acidification. The Fish and Wildlife Conservation Commission (FWC) monitors oysters in Florida, however, the impact of acidification is not currently examined. Many commercial shellfisheries are aware of acidification but are uncertain of impacts. Any hatchery area in the Southeast that has river input can be affected by different alkalinity values where the river endpoint could have effects on natural habitats. Estuaries tend to have large freshwater shifts, especially in the Southeast (including wet zones and wet seasons), which can affect the overall pH of that system. As stakeholders learned about these changes, questions were brought up including: Are these short-term changes? Is there a long-term shift occurring? Can we infer that those individuals surviving in low pH areas (e.g., South Carolina) have resilient genetic lines? Could these communities be buffer systems? Are there delayed effects of freshwater events? Many agreed that there needs to be more research in this area including more monitoring and identification of organisms that would be good indicators for shifting chemistry.

How is OA affecting other estuarine systems and benthic organisms? There are many other benthic organisms and infauna communities that could be affected by acidification in the Southeast, however, there are very few references that document these effects specific to this region. There have been a few studies on Stone Crabs (larval and adults) that show a negative effect on growth and survival from acidification (see Gravinese et al., 2018). Other than that, no other benthic organisms were mentioned. Research is lacking in **freshwater mixing environments** though some areas within the region have initiated this type of work. Tampa Bay has not seen effects of acidification largely because of elevated seagrass and submerged aquatic vegetation in recent years, which has also resulted in an increase in benthic diversity and species over time. Optical models have been used to explain how light saturation can inhibit carbonate uptake (Enríquez et al. 2019) and would be a good example to use in the Southeast along with C14 uptake where seagrass growth might be considered carbon limited for many species. The Indian River Lagoon has done a wide study on aragonite saturation temporally and spatially, which includes a network of sensors in the lagoon (pH and now CO_2). They are looking at real time aragonite, turbidity, nutrients, such as phosphate and nitrate (PO_4 and NO_3), and chlorophyll on an hourly scale.

There are large dissolved inorganic carbon fluxes from **mangroves** (as studied in other parts of the world) and mangroves are an important source of organic alkalinity. In Florida, mangroves are expanding into saltmarshes and not much is known about the dynamic and alternation of biogeochemistry in these newly populated habitats that are likely driven by climate change. Mangroves in some tropical carbonate areas in the Caribbean can be acidification/climate change refugia (see Yates et al., 2014) and this may be important in the southeast region. **Specific needs for understanding mangrove ecosystems and other systems where freshwater mixes with ocean water include**: lab protocols that are specifically tailored to lower salinities; more information on groundwater impacts that may be affecting estuaries and inland estuaries; more monitoring to show heterogeneity of estuaries; information on mangrove systems and saltmarshes is lacking yet they are a huge component of parts of the Southeast; more information on impacts to sediment microbial communities, especially in environments where dissolution may buffer acidification; more information on seagrasses and how carbonate chemistry shifts may promote seagrass growth; understanding multistressors (e.g., anaerobic oxidation/reduction of organic matter in sediments and acidification); and understanding the upstream consequences (e.g., impacts from acidification for species that feed on shellfish).

How is OA affecting corals and coral reefs? The Southeast US has the third largest coral reef barrier reef in the world and is the only extensive reef system in the continental US. This reef system is intricately tied to economy, recreation, and providing homes for many commercially important fish species. Corals are affected by acidification via dissolution of coral skeletons, reduced growth, reduced health, and other negative impacts. Mote Marine Laboratory and other partnering institutions in Florida are currently researching resiliency of corals to acidification. They are also planning on deploying a SeapHOx at Looe Key (lower keys; there is an existing acidification NOAA CO_2 and pH mooring in the upper keys at Cheeca Rocks), possibly in 2022, to examine temporal fluctuations in carbonate chemistry and to inform managers how this may affect coral restoration/growth on the reefs. They are also planning on studying corals that are found growing on mangroves (in collaboration with FWRI and USGS) to understand the benefits and interactions based on carbonate chemistry differences. The USGS is examining climate change and acidification impacts to coral reef ecosystem seafloor erosion and socioeconomic consequences (e.g., dissolution of carbonate seafloor sediments). **Panelists identified gaps including** looking for areas of refugia for corals; effects on calcifying algae in coral reefs (where algae may be outcompeting corals under climate change); effects of acidification on Sargassum (is becoming more predominant in the Florida Keys, though already problematic throughout the Caribbean); and a broader understanding of the different ecosystem scale processes.

What is the impact on coastal organisms, especially those that are both economically and environmentally valuable? What are the gaps in research to better understand these impacts? There are many coastal organisms throughout the Southeast that are economically and ecologically important including (but not limited to) finfish (sport fishing and commercial fishing) and other megafauna. There is a need for baseline records and baseline monitoring on organism communities and diversity. This includes socioeconomic baselines, of which there are few in this region. There was concern about how economically valuable species are identified and how to merge the gaps in understanding the links between acidification and socioeconomics (if the impacts of acidification are not well understood on organisms, how will it be known how socioeconomics are impacted). Some are concerned about which species contributes the most to the economy (in dollar value), but there are other socioeconomic factors including cultural value and subsistence fishing that also need to be understood. Finfish are one of the most understudied groups in the Southeast region. Some studies have shown negative effects of acidification on larval finfish, though this is not currently taken into account in fisheries stock assessment models. In the Indian River Lagoon, there is a large aquaculture program and there are commercial limits on some fish species (e.g., flounder) due to environmental impacts. However, warming seems to be the biggest concern in the commercial industry, with very little discussion on acidification impacts. **Gaps identified include** understanding the socioeconomic value of organisms in the southeast; how acidification will impact socioeconomics; and how fisheries regulations might respond to acidification impacts to help the fishing industry.

What examples are there of refugia and restoration? A few areas have been recognized as possible areas of refugia to acidification in the Southeast, though there are limited studies. Some include seagrass and coral (Manzello et al. 2012); seagrass in Tampa Bay (Sherwood et al. 2017); mangroves (Yates et al. 2014); blue holes (Patin et al. 2021); carbonate sediment buffering(Yates and Halley 2006) (Yates and Halley 2006); and spring and river water with higher carbon (Amergian et al. 2022). The Tampa Bay seagrass recovery is unique but can be done with community investment. The Indian River Lagoon is actively working on seagrass restoration (from the NASA Space Coast area down to St. Lucie) and will ultimately look at the monitoring data to identify potential links and effects on carbonate chemistry. Refugia is important in the future of many organisms and ecosystems and is not well understood in the Southeast.

How can we adapt or mitigate increasing acidification? Without fully understanding the effects of acidification on organisms and ecosystems in the Southeast, there is still a need to understand how to respond. Some examples of active responses include recovering or restoring seagrasses; recovering and restoring mangroves or other vegetation; restoring corals that are more resilient to acidification; addition of artificial reefs to promote calcifier and other organism growth; and other ways of extracting CO_2 from seawater. Careful thought and planning must go into these efforts and will likely be different for each unique ecosystem and region within the Southeast. There are concerns with these approaches including: small scale mitigation efforts might be feasible but large scale seems nearly impossible (in scale and financially); multistressors need to be considered (e.g., nutrients, warming, hypoxia) along with acidification; extracting CO_2 from seawater is an engineering problem, but needs to be done in collaboration with chemists; and evidence from seagrass mitigation banking might not sequester carbon long-term and might be putting dissolved inorganic carbon back into the water column as bicarbonate.

Is there a way to quantify the value of restoration of particular habitats for carbon storage to incentivize investments for local government agencies? There are established carbon markets in other parts of the world that value carbon sequestration by environments. There is a verified carbon standard that has been proposed to incentivize habitat restoration. There are groups within the southeast that are participating in studies to understand the value of carbon throughout the US. It has been proposed as a way to incentivize restoration, but there needs to first be an established carbon market. NOAA is also looking at this broadly and includes co-linkages with acidification mitigation as an intersection that could be leveraged.

It seems that ocean acidification is happening, but there is less effort to control or reduce it, can you comment on that? Education is the key to understanding acidification and determining how to put efforts in to reduce or control it in the Southeast. Acidification and the chemical processes involved with it might be difficult for some to understand, so educational messages need to be clearer, emphasizing the fact that it is due to human practices in addition to natural processes. Communities and public understanding and engagement are also needed to be able to tackle acidification. Communications can back-build from already existing adaptation activities (e.g., Florida sea level rise is already being addressed by counties. The problem is clear, and it is easy to communicate what exacerbates sea level rise such as degradation of reefs, loss of seafloor elevation due to OA, etc.). **Education is highlighted as a key gap** to improving future acidification potential.

Objective 2: Update Monitoring Priorities

Who is measuring what, now, and how? There are few continuous carbonate monitoring stations, some regularly occurring research cruises, and a number of other water quality monitoring programs throughout the Southeast. Continuous monitoring sites include: a mooring in middle to lower Tampa Bay that monitors pH, $p\mathrm{CO_2}$ and total alkalinity; a University of South Florida-managed buoy 60 miles west of Tampa Bay ; the Indian River Lagoon has pH sensors and recently added $p\mathrm{CO_2}$ sensors; a NOAA acidification moorings (CO_2 and pH) at Cheeca Rocks in the Florida Keys and in the Gray's Reef National Marine Sanctuary. Current known research cruises include: the west coast of Florida FWRI/Mote HAB monthly monitoring program that includes discrete carbonate chemistry samples from Tampa Bay to South of Naples; GOMECC cruises in the Gulf of Mexico once every four to five years since 2013; East Coast Ocean Acidification (ECOA) cruises every three to four years since 2015 from Miami, FL to Newfoundland, Canada; NOAA AOML bimonthly cruises from Miami around the Florida Keys to north of Tampa; other NOAA sampling throughout the Florida Keys (with good spatial and temporal resolution); LTER site off Georgia; and open ocean ships of opportunity (SOOP-CO2, SOOP-OA). Other continuous water quality monitoring where at least pH is being monitored includes NERRS sites, National Estuary Programs, and local government programs. There have been other programs that were collecting continuous data but for short funding cycles (e.g., at Pivers Island Coastal Observatory through Duke University). The ModMon project in Pamlico Sound collects pH and inorganic carbon data. Many data are archived through the SECOORA data portal, NERRs system-wide websites, NEP websites, and the National Center for Environmental Information.

There is a difference between “climate quality” and “weather quality” data that is being collected, though all data is relevant. “Weather quality” data may not be as precise as “climate quality”, but that is not always necessary when looking for long-term trends. Stakeholders highlight the importance of using all available data that presently exists, even if it has a lower precision. There are **gaps in monitoring throughout the Southeast** including throughout coastal South Carolina and Northern Florida, which are considered a source of vulnerability.

What kind of seasonal variability has been observed? Examples throughout the Southeast show acidification variability. For example, Cheeca Rocks in the upper Florida Keys shows diurnal and seasonal variability (Meléndez et al. 2020). Tampa Bay also shows seasonal variability (larger variability than in the keys) and includes summer production vs. quieter winters. A study on available pH data in multiple coastal regions in the southeast showed that some areas had higher variability and were becoming more acidic than others (Robbins and Lisle 2018). Overall, CO_2 concentrations follow a general temperature variability in the Southeast (Xue et al. 2016; Reimer et al. 2017; Xu et al. 2017). There are a number of variables that contribute to the variability including rivers (typically variation is larger due to salinity differences and productivity), biological influences (though this is dependent on the ecosystem), presence of seagrass (as seagrass coverage increases, there is an increase in pH over a long timeframe), and sediment type. There are enough variables in these systems that it can be difficult to tease out drivers of seasonal changes. For example, in seagrass beds in Tampa Bay, how much of the increase in pH over time is due to the bicarbonate pathways from limestone sediment? Or could the elevated pH be due to a reduction in nutrients, which increases seagrass growth as well? Long term data sets still need to be analyzed in the Southeast.

Is there interest in future monitoring? Scientists say yes, but often the restrictions come from lack of funding or interest from the right groups. One big concern that has often been repeated is: is acidification strong enough of an impact in the region to make it into management plans? Much of the monitoring in the Southeast is run by local governments, estuary managers, policy makers, and state managers. The main climate focus that appears in many management plans in the Southeast is sea level rise. It is likely that there needs to be a targeted outreach and education effort at the state level to get regional/local governments to show more interest.

What technologies are used for the OA monitoring and in the analysis of the OA coastal variability drivers? Advanced technology and methods for analyses can be a barrier to implementing programs more broadly. There are also concerns that lower cost sensors do not have the highest resolution needed, yet the higher resolution sensors are often cost prohibitive. It is often important to have carbonate system parameters plus supporting variables measured (e.g., nutrients, currents, dissolved organic carbon, oxygen) to be able to accurately describe the system and drivers of acidification. Many sensors are not reliable enough yet and can be particularly difficult to interpret in estuarine environments. Specific skill sets are required to make “climate quality” measurements, with high precision and accuracy, including calculations of all carbonate parameters. Real-time data is difficult to achieve or afford. Another difficulty is availability of certified reference materials (CRMs, Dickson 2010). Since the Covid-19 pandemic began in the US, it has been difficult to get CRMs, since they are made in limited batches, however, the IWG-OA has been investing much time in trying to solve this problem. The IWG-OA have explored funding opportunities for the Dickson lab to develop standard operating procedures for “do it yourself” standard reference materials (SRMs). NOAA OAP, in collaboration with other federal agencies, is also examining longer term solutions at multiple labs. Current available technologies and systems include: pH_{NBS} probes, pH total instruments (e.g., SeapHOx), CO_2 sensors, dissolved inorganic carbon instruments, total seawater alkalinity titrators, spectrophotometric pH instruments, surface moored sensors, ships of opportunity, and seafloor moorings. There currently is only one citizen science program for collecting acidification samples in the Southeast (Georgia Coastal Ecosystems project at Doctortown, Georgia in the Altamaha River), though many groups are trying to come up with ways to accomplish that.

What are stakeholder's needs in terms of OA monitoring? The biggest need that was discussed is funding and recognition (showing the need for monitoring). **Education plays an important role in determining the need for funding and recognition.** The other issue is determining who the stakeholders are. Many have been identified, but there are other groups that have not been included in stakeholder discussions (e.g., military groups). An easy to access, centralized list of stakeholders in the region would be beneficial. It would also be pertinent to include stakeholders' needs in proposals at every level of writing proposals. **Collaboration between stakeholders and researchers is critical. Other needs include equipment that is reliable and easy to use with improvements in cost; monitoring in partnership with the commercial sector (e.g., fisheries), a central repository for data, providing data in a format that is easily understood by the public, and websites as a resource for stakeholders (especially the commercial sector) to check in on to see how their waterways are behaving.** There are a few regions throughout the Southeast that have gaps in data collection to provide information to stakeholders including the northern Indian River Lagoon (did just get funded to start), lower Florida Keys monitoring at nursery reefs (restoration sites) to capture seasonal variability, and in South Carolina coastal waters (though the South Carolina County Department of Health in Horry County, South Carolina will be adding OA monitoring in the next year and SOCAN is partnering with Coastal Carolina University on a Sea Grant that was funded for FY22-24). There has been some continuous monitoring done in specific regions (e.g., NOAA Cheeca Rocks) and groups are looking into **modeling that data to fill in gaps** and link to other areas of concern (e.g., harmful algal blooms) yet there are still major gaps including: small scale spatial variability relevant to species impacts and restoration (10s of meters or less like inside and outside of seagrass beds), broader scale subregional variability along habitat and environmental gradients (e.g., proximity to rivers, across habitats, carbonate content of sediments, within an ecosystem), offshore measurements to gauge the effects of local coastal acidification drivers relative to near-shore and open ocean acidification, and strategic monitoring to characterize hydrodynamic linkages across regions (e.g., the Gulf of Mexico and the Southeast regions). **It is also important to come up with ways to better engage existing monitoring programs to include acidification parameters.** Many county, NERRS, and aquatic preserve water quality programs exist and could be leveraged but the main difficulties are cost, staff, maintenance, repairs being expensive, and long-term investment of funding and human capital.

Discrete sampling is cheaper than sensors, but not as effective at filling temporal gaps. There is historical data that can be mined from many long-term monitoring programs (even using less sensitive pH_{NBS}) to look at long-term spatial and temporal trends that also typically collect dissolved oxygen, nutrients, chlorophyll, and other supporting variables. Getting research grade measurements is difficult. Some questions can be answered without "climate quality" measurements, but the appropriateness of the measurement is determined by the research question/goal. Therefore, it is important to indicate and quantify the uncertainty and limitations of application for any measurements that are collected and published to make sure they are appropriately applied to answering questions. Another important consideration is that long-term trends might need climate grade measurements while diurnal/seasonal trends can be captured by "weather quality" instruments.

Are there hotspots of OA in the Southeast? In general, research in the Southeast has not identified, as of yet, hotspots for acidification. Part of the issue is that not all areas have long-term datasets, or those datasets have not yet been analyzed. Robbins and Lisle (2018)Robbins and Lisle (2018) assessed long-term datasets in a few representative spots and determined that pH has dropped in some areas and may represent acidification hotspots. There are also many factors that play a role in determining hotspots in the Southeast and include currents, upwelling, ecosystem type (coral reefs, seagrass, mangroves, marsh). **This is an important research gap in the Southeast**, yet there are researchers who are beginning attempts at determining hotspots throughout the Southeast.

Where should we monitor ocean acidification on the West Florida Shelf if we need to install sensors on platforms at fixed locations (e.g., moorings)? The West Florida Shelf is a region that is overlapped by both SOCAN and GCAN (Gulf of Mexico Coastal Acidification Network). There are currently monitoring stations in Tampa Bay and 60 miles offshore of Tampa Bay, however, there are gaps in monitoring in the northern Gulf of Mexico (e.g., Mississippi River down to Tampa Bay) yet there are unique systems in this region that might affect acidification (e.g., Suwannee River that drains almost all of Georgia and is an area that is highly used for bivalve aquaculture). There are also studies currently being done on Blue Holes throughout the eastern Gulf of Mexico (Patin et al. 2021). Other factors that may exacerbate or slow down acidification in this region include loop current influences, hurricanes, upwelling, and other seafloor phenomenon. SOCAN developed a monitoring prioritization plan for the Southeast 2017 (SOCAN 2017) and a manuscript (Hall et al. 2020)(Hall et al. 2020) that determined several potential locations for additional acidification monitoring. Monitoring priorities are being readdressed by both SOCAN and GCAN.

What do we know about the relative importance of different local drivers of coastal biogeochemical variability and OA stress in the region? This question really depends on the local area and what influences that area receives. Estuaries within the Southeast can vary significantly in shape, river influence, and border islands, which will have different impacts on those systems. There are a few coastal areas within the southeast that have data compiled and are currently being reviewed (e.g., Tampa Bay, Cheeca Rocks, Springs Coast) and there are areas where data could be mined (e.g., Water Atlases) but have yet to be done so far. One of the biggest setbacks to this question is the lack of training for non-experts to engage in the technical aspects of making accurate carbonate chemistry (and OA related) measurements and interpretations. There is a general lack of knowledge of local drives within the broader Southeast region.

Social Vulnerability: Gain a general understanding of impacts to communities and their potential for adaptive capacity

How best can we inform stakeholders of the OA problem and its risks, and how best can we address stakeholder needs? There are a number of ways to inform stakeholders locally and regionally throughout the Southeast. There are many different stakeholder groups and often materials/information need to be geared toward their specific interests. All **National Estuary Programs (NEPs)** have technical advisory committees (TACs) that hold meetings quarterly or biannually and include a number of scientific and community representatives. Many of those groups have often offered up meeting times to present research findings, opportunities, and new ideas; however, there are questions as to whether the information at those meetings drives home the message.

There have been numerous workshops by **SOCAN** that have been geared at different audiences throughout the past five years. It can be difficult to get stakeholders interested enough to come to workshops and often does require initial engagement (e.g., introductory emails or phone calls) prior to the workshops.

State Sea Grant is another institution that has been integral in reaching out to stakeholders and they provide concise materials for the general public. **Federal NOAA OAP** provided funding in the last year to **shellfishery stakeholders**, which encouraged more stakeholder participation. It is often difficult to explain the chemistry of ocean acidification, yet communities need to understand enough about it to reach out to policymakers with concerns as many agencies and NGOs cannot take on an advocacy role. **Other suggestions for reaching out to stakeholders include: seafood festivals, simpler visual methods to help people understand the problem** (e.g. polar bears on melting icebergs; most people don't understand the immediacy of the problem), **presentation of case studies** of immediate impacts and the dollars and lives it affects, better **monetary valuation** (socioeconomic vulnerability assessments) of the problem, OA **infographics within National and local parks systems**, information in **multiple languages**, and web pages specifically on OA.

What are ways of improving networking and collaboration opportunities to fill knowledge gaps? Improvement can be reached via workshops, webinars, public outreach events, more funding opportunities requiring inclusion of stakeholders or community involvement, Sea Grant extension agent involvement, direct contact (especially with cultural groups and tribal communities in the region), and inclusion of OA in climate change and vulnerability assessments. The Ocean Acidification Information Exchange (OAIE) is a useful website and community to connect people interested in OA (scientists, stakeholders, managers, students, educators), but it is important to inform the public and stakeholders that this tool is available. Many people who do not live near coasts do not realize they can contribute to OA efforts or even that they have an impact on it. Industry or individual-specific workshops and resources are available. The more personal they are, the more of an impact they might have. Coordinating the science and bringing the right people to the table has been the easy part; however, one major impediment for some institutions is the bottleneck of paperwork and approvals to be able to collaborate. Mission delineation and appropriate alignment (the bureaucracy aspect) and availability of human capital to push the paperwork to avoid misuse of funds and data gets expensive and difficult to coordinate.

How can people of interest in this area work together more to make climate research more useful and impactful? Competition, though a larger issue with research in general, makes it difficult to share information freely or give confidence in working together between groups. Scientists working together with managers can be a steppingstone to policymakers, however, sometimes there is a big gap from managers to policymakers depending on the level (city, county, state, federal). Training for scientists on how to communicate science to successfully convey messages to policymakers would be beneficial. Targeting specific issues with specific actions to achieve a specific outcome in each region would assist local managers. Artistic media would also help get the message across.

More funding is needed to address gaps in monitoring of coastal acidification in Indian River Lagoon and OA in nearshore/offshore waters of the SE Atlantic. Where can we find that? Current funding sources are limited and competition for those funding opportunities often range over multiple topics and regions, making them very difficult to obtain. The issue (OA, climate change, warming.) must be encouraged and deemed important enough at the city, county, and state-level for funding to even be provided at those levels. Funding typically follows the greatest perceived threats. Often there are small pockets of funding within regions that could initiate projects including: Sea Grant, license plate grants, within-institution academic funding, and foundations. The next few years will be telling in terms of research that will be funded (the COVID-19 pandemic has diverted a lot of funding in the last year). **So perhaps the bigger question will be, "how do we make the largest impact with the limited funding that is currently available?"**

What are the implications for ecosystems and social vulnerability? This likely depends on the location, ecosystem, or community of interest. Some implications may translate across communities, for example in fisheries from natural stocks to aquaculture to revenue drivers and job availability, but this may not be true for all (e.g., native communities may be more vulnerable due to social and cultural ties to shellfish and coastal waterways). This could also affect ecotourism and subsidence fishing. Many of these topics will be presented in future SOCAN-hosted workshops and town halls.

How will acidification affect my community's use of local waterways for recreational/commercial shellfish harvesting as well as other potential impacts to traditional uses? There are a number of different ways that these areas could be affected, though it will also depend on other stressors in combination with acidification (e.g., sea level rise, warming, eutrophication). Possible effects include reduced shellfish production (natural and in hatcheries), economic impacts (e.g., many commercial operations heavily depend on these harvests to survive), threats on recreational use of waterways (eutrophication and poor water quality, especially in heavily trafficked areas, may have ill effects on the water quality of a specific waterway by stirring up organics, erosion and loss of habitat), and loss of other fishery species.

How can the community participate in water sampling and citizen science around ocean acidification and its impacts on the Sea Islands? There is currently limited availability of citizen science and ocean acidification work, yet there are many great ideas that could be implemented. For example, surfboards with pH sensors attached, sensors on recreational boats, and sensors on personal and commercial dock spaces. Citizen science would benefit from easier, basic test kits, but would that provide enough information to the scientific community? Sampling could be completed by trained volunteers but would need to be standardized and constantly checked. There are already differences between trained labs and researchers so differences in citizen science collections could be magnified. **Technology in this field needs to advance to more cost effective and accessible systems.** The Global Ocean Acidification Observing Network (GOA-ON) in a Box is a low-cost kit used for collecting weather-quality ocean acidification measurements and includes videos in multiple languages. It is currently only available/distributed in Africa, Pacific Small Island Developing States, and Latin America but would be beneficial as a citizen science package in the Southeast.

How can the shellfish industry better prepare for the OA changes we are seeing? Industries can work with the scientists (and vice versa) to better understand how current acidification and future predicted levels of acidification might affect shellfish production. Some hatcheries have land-based nurseries where they can learn the chemistry of the incoming water, manipulate it in header or treatment tanks, then disperse it to the organism tanks. This would require maintenance on the treatment tanks and constant analyses but could be a way to overcome a global issue.

GENERAL POINTS FROM BREAKOUT DISCUSSIONS

Areas of Vulnerabilities Identified by Stakeholders

- Shellfisheries
- Ecosystems: coral reefs, seagrass beds, estuaries, mangroves, salt marshes
- Loss of recreational use of waterways
- Ecotourism

Socioeconomic

- Socioeconomic value of organisms in the Southeast is unknown
- There is a lack of a beneficial carbon markets
- Understanding social vulnerability is needed to plan for future effects of acidification

Monitoring

- More species- and site-specific information is needed
- Research and data synthesis is lacking in freshwater mixing environments
- More information is needed on multistressors
- More research and understanding of refugia are needed
- Understanding of the differences between climate and weather quality information
- Monitoring needs to be expanded
- Need more long-term dataset analyses in coastal waters
- Lack of cost-effective advanced technology and methods is a barrier to implementing programs more broadly
- Acidification hotspots need to be identified
- Priority monitoring sites need to be updated
- Identification of local vs. global drivers of biogeochemical changes for management plans

Education and Outreach

- Stakeholders perceive a lack of funding, interest, or recognition (especially at local and state government level) that acidification is an emergent issue
- There is a lack of citizen science programs for acidification sample collection
- Adaption, mitigation, and restoration efforts due to acidification need to be implemented
- More formal and outreach education in K-12 curricula on acidification is needed
- New methods to inform stakeholders about acidification are needed
- Improved networking and collaboration between researchers and stakeholders are needed

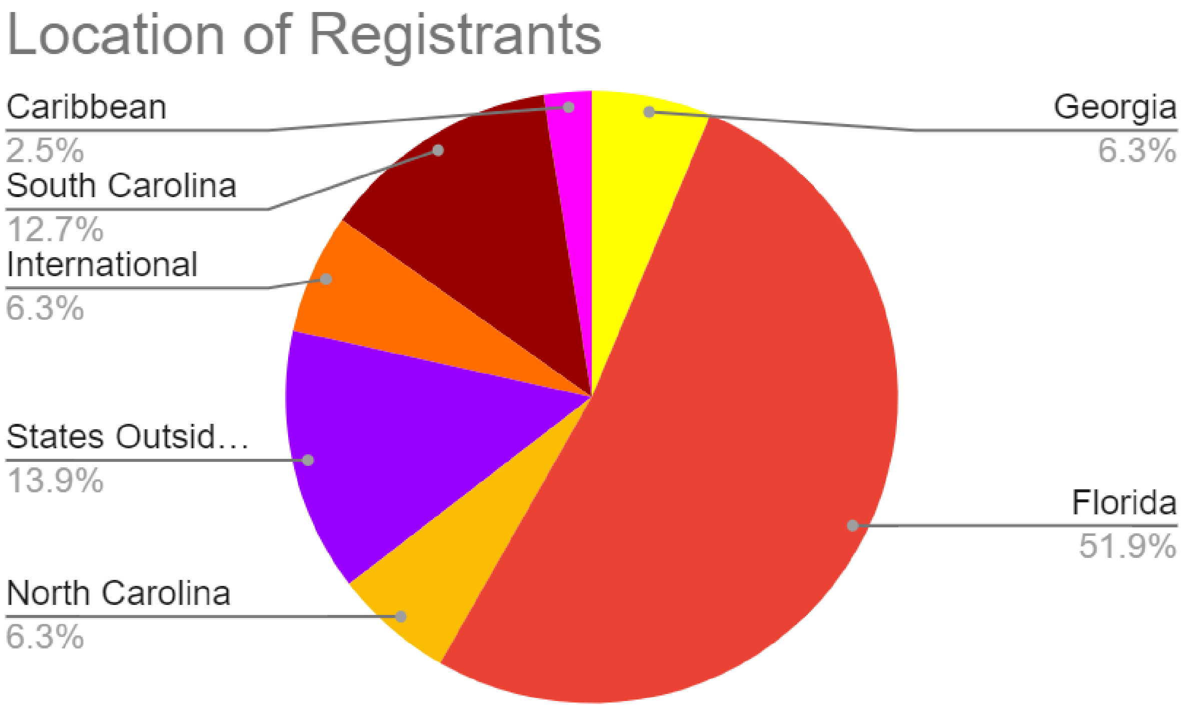
APPENDIX I: AGENDA

Morning Session	
Time	**Topic & Speakers**
10:00 am - 10:15 am 15 minutes	**Welcome** ● Zoom - Walkthrough **Introduction** ● SOCAN Introduction & Meeting Overview **Virtual Meeting Staff**: Melissa Sante, *Staff Chemist at Mote Marine Lab* Amanda Quasunella, *Research Technician at Mote Marine Lab*
10:15 am - 10:30 am 15 minutes	**Exposure: Current and future levels of ocean acidification** **General Information and Monitoring** Dr. Janet Reimer, SOCAN Co-Coordinator & Ocean Acidification Researcher University of Delaware
10:30 am - 10:35 am 5 minutes	**Questions/Feedback** **Moderator**: Dr. Kimberly Yates, Senior Research Oceanographer at the U.S. Geological Survey
10:35 am - 10:50 am 15 minutes	**Biological Response: Sensitivity and the adaptive capacity to ocean acidification** **Organism Impacts** Dr. Courtney Klepac, *Coral Resilience Postdoctoral Researcher at Mote Marine Lab*
10:50 am - 10:55 am 5 minutes	**Questions/Feedback** **Moderator**: Dr. Emily Hall, SOCAN Co-Coordinator & Senior Scientist and Program Manager at Mote Marine Lab
10:55 am - 11:10 am 15 minutes	**Biological Response: Sensitivity and the adaptive capacity to ocean acidification** **Mitigation, Adaptation, & Restoration** Ed Sherwood, *Executive Director at Tampa Bay Estuary Program*
11:10 am - 11:15 am 5 minutes	**Questions/Feedback** **Moderator**: Dr. Emily Hall, SOCAN Co-Coordinator & Senior Scientist and Program Manager at Mote Marine Lab
11:15 am - 11:25 am	**Social Vulnerability: Impacts on communities and their adaptive capacity**

10 minutes	**Regional Impacts** Jennifer Hecker, *Executive Director at Coastal & Heartland National Estuary Partnership*
11:25 am - 11:40 am 15 minutes	**Social Vulnerability: Impact on communities and outreach education** **Stakeholder Engagement, The Ocean Acidification Information Exchange** Video: Queen Quet, *Leader of the Gullah/Geechee Nation* Julianna Mullen*, Communications Manager at NERACOOS*
11:40 am - 11:45 am 5 minutes	**Questions/Feedback** **Moderator:** Dr. Janet Reimer, SOCAN Co-Coordinator & Ocean Acidification Researcher University of Delaware
11:45 am - 1:00 pm 1 hour 15 mins	**Lunch Break**
Afternoon Session	
Time	**Break-Out Sessions**
1:00 pm - 2:00 pm 1 hour	**Breakout Groups: Biological Response and Exposure** **Moderators:** ● Kerri Dobson, *International, and National Policy Fellow - NOAA Ocean Acidification Program* ● Victoria Parks, *Senior Hatchery Manager and Co-Founder of Seventure Clam Co.* ● Courtney Cochran, *Interagency Working Group on Ocean Acidification - NOAA Ocean Acidification Program*
2:00 pm - 2:10 pm 10 minutes	**Virtual Coffee Break**
2:10 pm - 3:10 pm 1 hour	**Breakout Groups: Updating Monitoring Priorities** **Moderators:** ● Kerri Dobson, *International, and National Policy Fellow - NOAA Ocean Acidification Program* ● Victoria Parks, *Senior Hatchery Manager and Co-Founder of Seventure Clam Co.* ● Courtney Cochran, *Interagency Working Group on Ocean Acidification - NOAA Ocean Acidification Program*
3:10 pm - 3:20 pm 10 minutes	**Virtual Coffee Break**

3:20 pm - 4:20 pm 1 hour	**Breakout Groups: Social Vulnerability** **Moderators:** ● Kerri Dobson, *International, and National Policy Fellow - NOAA Ocean Acidification Program* ● Victoria Parks, *Senior Hatchery Manager and Co-Founder of Seventure Clam Co.* ● Courtney Cochran, *Interagency Working Group on Ocean Acidification - NOAA Ocean Acidification Program*
4:20 pm - 4:40 pm 20 minutes	**Meeting Summary** **Speaker:** Dr. Emily Hall, SOCAN Co-Coordinator & Senior Scientist and Program Manager at Mote Marine Lab
4:40 pm - 5:00 pm 20 minutes	**Upcoming Events & Meeting Close** **Speaker:** Dr. Janet Reimer, SOCAN Co-Coordinator & Ocean Acidification Researcher University of Delaware ● SOCAN Town Hall Schedule ● Adjourn

APPENDIX II: LOCATION OF MEETING ATTENDEES



APPENDIX III: EXPANDED SUMMARY OF GENERAL NEEDS AND CONCERNS OF STAKEHOLDERS IN THE SOUTHEAST

Socioeconomic

- Understanding the socioeconomic value of organisms in the Southeast and how acidification will impact socioeconomics in the Southeast.
- There is a general lack of a beneficial carbon market and understanding what carbon markets are, in the Southeast.
- A general understanding of ecosystem and social vulnerability in this region is needed to plan for future effects of acidification. Stakeholders suggest that this can be accomplished through increased monitoring, stakeholder engagement, and formal education.

Monitoring

- More species- and site-specific information is needed on the effects of acidification on shellfish in the Southeast and how to get that information to shellfisheries.
    - Sites of research interest to stakeholders include, but are not limited to, local waterways, estuaries, shellfish lease sites, mangroves, and reefs.
    - Organisms mentioned include reef building corals and economically important shellfish, such as oysters and clams.
- Research and data synthesis is lacking in freshwater mixing environments.
- More information is needed on multistressors, organism interaction, and ecosystem impacts on coral reefs, mangroves, and seagrass beds.
- More research and understanding of refugia for various organisms in the Southeast are needed to better predict the future impacts of acidification on species and ecosystems.
- There is a need for understanding differences between climate quality and weather quality information and for using weather quality data in research efforts.
- Monitoring needs to be expanded throughout the Southeast, including data synthesis of existing coastal information.
- Need more long-term dataset analyses in coastal waters in the Southeast to discern seasonal variability.
- Lack of cost-effective advanced technology and methods for analyses can be a barrier to implementing programs more broadly. Therefore, stakeholders need research and development of more accessible methods that can be more easily implemented.
- Acidification hotspots need to be identified through data synthesis and monitoring.
- Priority monitoring sites need to be updated and data synthesis of existing data needs to be implemented.
- Identification of local vs. global drivers of biogeochemical changes is needed to implement realistic management plans.

Education and Outreach

- The perception of stakeholders is that there is presently a lack of funding, interest, or recognition (especially at local and state government level) that acidification is an emergent issue in the Southeast. Therefore, outreach education efforts need to increase.

- There is a lack of citizen science programs for acidification sample collection in the southeast. Development of a citizen-friendly method could improve participation and spatio-temporal data coverage.
- Adaption, mitigation, and restoration efforts due to acidification need to be implemented and understood in the southeast.
- More formal and outreach education in K-12 curricula on acidification is needed throughout the Southeast.
- New methods to inform stakeholders about acidification are needed to build relationships, especially with industry.
- Improved networking and collaboration, especially between researchers and stakeholders, is needed to make progress towards research goals.

APPENDIX IV: REFERENCES

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