SOCAN

Southeast Ocean and Coastal Acidification Network

2016 STATE OF THE SCIENCE WORKSHOP REPORT

ACKNOWLEDGEMENTS

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SOUTHEAST OCEAN AND COASTAL ACIDIFICATION NETWORK

PURPOSE

From North Carolina to Florida, the effects of ocean acidification (OA) in the Southeast U.S. are largely unknown. Ocean acidification is a term that describes the change in the chemistry of ocean waters, largely due to increased carbon from the atmosphere entering the ocean. These changes in ocean and coastal water chemistry can affect the entire marine ecosystem. The complex physical and biogeochemical interactions of marine ecosystems present a challenge to understanding the influences of acidification in coastal areas, at both local and regional scales. On January 12 and 13, 2016 the Southeast Ocean and Coastal Acidification Network (SOCAN) Steering Committee with invited scientific experts held a meeting at the College of Charleston in Charleston, South Carolina to discuss the state of ocean and coastal acidification science, priorities and vulnerabilities in the Southeast region. The meeting sought to accomplish three objectives:

1. Summarize key findings, prioritize research needs, and identify research and laboratory capabilities to address ocean and coastal acidification research questions;
2. Identify unique aspects of the Southeast region and factors underlying its vulnerability to OA; and
3. Identify relevant stakeholders in the region to discuss their concerns related to ocean and coastal acidification.

About SOCAN

Formed in February 2015, the Southeast Ocean and Coastal Acidification Network (SOCAN) is an interdisciplinary network of scientists, resource managers, and industry, non-profit, and government representatives dedicated to supporting and encouraging discussions on ocean and coastal acidification in the Southeast region which spans from North Carolina to Florida. With the Southeast Coastal Ocean Observing Regional Association and NOAA Ocean Acidification Program as supporting structures, SOCAN will:

1. Synthesize and disseminate the most recent scientific, technical and socioeconomic information relevant to species and ecosystems that could be affected by acidification;
2. Identify knowledge gaps;
3. Set regional priorities for monitoring and research;
4. Collaborate in the development of a Southeast regional acidification monitoring network;
5. Encourage and support scientific research collaborations and data sharing; and
6. Respond to stakeholder needs, as appropriate.

What is ocean acidification?

The ocean absorbs excess carbon dioxide that has been increasing in our atmosphere, particularly over the last 200 years, from the burning of fossil fuels. As the ocean absorbs carbon dioxide it changes the chemistry in our oceans. These shifts in chemistry can make it more challenging for oysters, corals and other animals to build and maintain their carbonate shells and skeletons.

Contents

Executive Summary

The Southeast Ocean and Coastal Acidification Network (SOCAN) convened a meeting at the College of Charleston in Charleston, South Carolina to facilitate discussion about the state of ocean and coastal acidification science and the vulnerabilities of communities and ecosystems in the Southeast region. Key conclusions from the workshop included:

- Ocean and coastal acidification is driven by local and regional processes such as eutrophication, upwelling, and riverine inputs to the coast, in addition to global ocean uptake of carbon dioxide (CO_2) that is increasing in the atmosphere due to the burning of fossil fuels, land use change, and cement production. Global ocean acidification is an emerging threat that will exacerbate coastal acidification that is already occurring in the Southeast.
- The Southeast region is unique within the U.S. because it spans subtropical to tropical climate zones, and displays a broad range of environmental conditions, stressors and gradients. Many species in the Southeast are adapted to highly variable estuarine conditions, including wide fluctuations in pH, but how this affects their vulnerability to ocean and coastal acidification is unknown.
- Shellfish and coral reefs, which are important to the culture and the economy of the Southeast region, are particularly vulnerable because acidification can directly impair the growth of species with carbonate shells and skeletons.
- Some natural resources in the Southeast region, such as coral reefs, are already showing some effects of ocean and coastal acidification (1).
- Base knowledge is available to help build our understanding of future acidification impacts to the Southeast and prepare society to manage the potential consequences.

Background

Ocean acidification describes the process by which the chemical properties of the oceans are altered due to absorption of atmospheric carbon dioxide (CO_2) derived primarily from the burning of fossil fuels. Absorption of CO_2 by the ocean results in a reduction of seawater pH and carbonate ion concentration in addition to other changes to the carbonic acid system in the ocean. Reduction in the availability of aragonite, a form of calcium carbonate, has been shown to have consequences for marine life, most notably by reducing rates of calcification and growth for calcifying species, such as corals and oysters. Acidification of coastal regions can also occur through changes in hydrological cycles (e.g. increased freshwater and nutrient inputs) and eutrophication. These local and regional processes play a particularly important role in acidification of the Southeast region, creating spatial and temporal variability that exceed the current rates of change from atmospheric inputs (2).

Key species and ecosystems in the Southeast expected to be vulnerable to ocean and coastal acidification include bivalves (i.e. oysters and clams), crustaceans (i.e. shrimp and blue crabs), reef-building corals, and calcifying macro- and microalgae (3). While surface waters in the Southeast are expected to remain supersaturated with respect to aragonite through the end of this century (4), declines in saturation state have been shown to reduce calcification rates (5). Accordingly, studies of the Florida Reef Tract, comprised of coral formations extending from Soldier Key to the Tortugas Banks, indicate seasonal dissolution at some reef sites due to coastal acidification, with annual net erosion at the northernmost reef studied near Miami, Florida (1).

In a multidisciplinary analysis of coastal communities, North and South Carolina were identified as having relatively high social vulnerability to ocean acidification (6). Social vulnerability was defined using indicators of community dependence on bivalves, status of state government climate and acidification policies, employment alternatives and access to science (e.g. budget and laboratory presence). The results of this vulnerability assessment highlight the importance of the formation of the Southeast Ocean and Coastal Acidification Network (SOCAN).

In September 2015, the Ocean Conservancy and Mote Marine Laboratory facilitated a roundtable discussion of ocean acidification in Florida (7). The results of this meeting highlighted the imminent threat of acidification in Florida waters and the critical need for information to assess potential impacts to Florida's economy and human communities. The SOCAN workshop built on the outcomes of this meeting to facilitate discussion about acidification science and vulnerability for the entire Southeast region, including North Carolina, South Carolina, Georgia and eastern Florida.

Proceedings

Approximately 25 experts from science, management and industry gathered for this SOCAN State of the Science meeting to facilitate discussion and collaboration for ocean acidification research and management in the Southeast region (Appendix 2). The meeting began with opening remarks to provide an overview of the meeting structure, goals and objectives, and anticipated outcomes. The first day included an overview and summary of the key points from 20 SOCAN State of the Science Webinars that were presented between March 2015 and January 2016 (http://secoora.org/socan_webinars). These webinars were organized into six topic areas for the purpose of this meeting and formed the foundation for discussion with regards to the state of acidification research in the Southeast.

Each topic overview included a presentation summarizing the webinar content and a discussion of the key points. Following the topic overviews, participants were divided into three groups for rotating breakout sessions. The first day concluded after each group participated in each of the three breakout sessions to further refine and discuss key aspects of the research findings, Southeast vulnerabilities, and stakeholder engagement.

The second day began with a summary of the discussion from each breakout session. All participants then selected research priorities to identify those that were most important. Following a discussion of the breakout sessions, there was an open plenary discussion to share key points of the meeting and next steps. The workshop concluded with a discussion of the vision for SOCAN.

Figure 1. Workshop attendees, clockwise from back left: Charlie Phillips, George Sedberry, Jay Styron, Susan Lovelace, Lou Burnett, Denise Sanger, Libby Jewett, David Whitaker, Zackary Johnson, Leslie Wickes, Albert George, Bethney Ward, Kevin Craig, Dennis Hanisak, Karla Gore, Astrid Schnetzer, Leticia Barbero, Jennifer Mintz, Debra Hernandez, Kim Yates, Wei-Jun Cai. *Not pictured: Rick DeVoe, Paul Sandifer, Geoff Scott, Abbey Wakely, Jack McGovern, Scott Noakes*

Opening Remarks

The dean of The Graduate School of the College of Charleston, Dr. Amy McCandless, welcomed the participants to the College of Charleston facilities, highlighting the local and regional importance of the meeting. Dr. Libby Jewett, director of NOAA's Ocean Acidification Program, then reviewed the workshop goals (*see page 1*), agenda (Appendix 1) and desired outcomes of the meeting. The desired outcomes included an outline of a white paper focused on considerations for ocean acidification in the Southeast U.S. with key figures to describe current knowledge, prioritization of research needs, and a framework for the SOCAN vision and next steps. Debra Hernandez, Executive Director of the Southeast Coastal Ocean Observing Regional Association (SECOORA), discussed the extensive partnerships involved in the meeting between federal and state agencies, regional associations, industry leaders and academic institutions. Opening remarks concluded with an introduction of all participants and identification of their specific roles for the workshop.

Topic Sessions

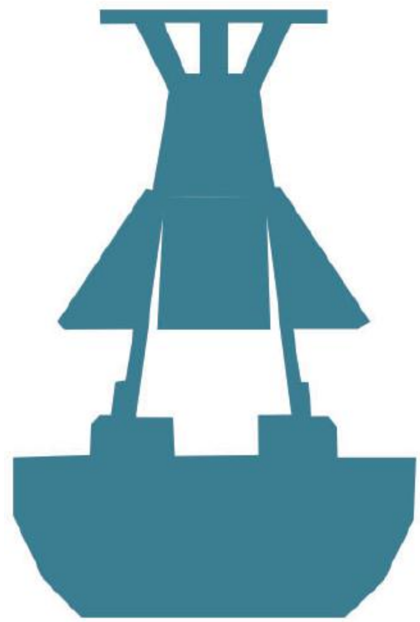
Chemistry and Other Stressors

Presenter: Leticia Barbero, NOAA Atlantic Oceanographic and Meteorological Laboratory

Moderator: Geoff Scott, University of South Carolina

State of the Science Webinars that were summarized during the “Chemistry and Other Stressors” topic overview:

- A Far-field View of Ocean Acidification in the South Atlantic Bight, Rik Wanninkhof (NOAA, AOML)
- Estuarine Acidification: A Conceptual Discussion with Examples, Wei-Jun Cai (University of Delaware)
- Ocean Acidification Time-Series Mooring at Gray’s Reef National Marine Sanctuary, Scott Noakes (University of Georgia)
- Acidification and Hypoxia in the Shallows- Patterns, Research Approaches, and Effects, Denise Breitburg (Smithsonian Environmental Research Center)
- Potential Effects of Climate Change on the Ecotoxicology of Pesticides and Contaminants of Emerging Concern: Implications for Ocean Acidification Interactions, Geoff Scott (University of South Carolina)
- Temporal Variability of the Carbonate System and the Microbial Community in a Dynamic Coastal NC System, Zackary Johnson (Duke University)



Six SOCAN webinars were summarized within the topic of “chemistry and other stressors.” The first, entitled **“A Far-field View of Ocean Acidification in the South Atlantic Bight,”** discussed the work from the Gulf of Mexico and East Coast Carbon (GOMECC) cruises. These research cruises provided a regional view of the carbonate chemistry in the Gulf of Mexico and along the U.S. East Coast. Surface-water aragonite saturation states (Ω_{arag}) were high within the Gulf of Mexico ($\Omega_{arag} \approx 4.5$), decreasing northward along the East Coast. Large decreases in Ω_{arag} shoreward along each sampling line were attributed to riverine outflow and excess remineralization from nearshore eutrophication. Results from these cruises showed not only low Ω_{arag} at depth, but that these low Ω_{arag} waters can shoal at the shelf break and are forced onto the slope at times by regional physical dynamics.

A comparison between the two cruises showed large differences between 2007 and 2012, with latitudinal differences and much greater changes than those expected solely from ocean acidification. At shallow depths (10 m), regions from the Gulf of Mexico (GOM) to the Mid-Atlantic Bight showed a decline in Ω_{arag}, (on average Ω_{arag} -0.1-0.2), while further north there were increases up to Ω_{arag} 0.5. In contrast, at depth (100 m) there were larger decreases in Ω_{arag} in the GOM, with increases in Ω_{arag} at all other stations (Figure 1). These changes across years can largely be explained by circulation features (e.g. Loop Current and Labrador Sea inflow) and subsequent shifts in temperature and salinity.

The major points of this presentation emphasized:

(1) the validity of ocean acidification, noting that "it is real and here to stay"
(2) trends in ocean acidification chemistry parameters can be detected on 5-10 year timescales
(3) separating ocean acidification from other regional influences in the South Atlantic Bight (SAB) will be challenging
(4) far field influences (e.g. large-scale oceanographic features) and feedbacks on saturation states need to be considered
(5) changing ocean currents can have a first order effect on saturation states

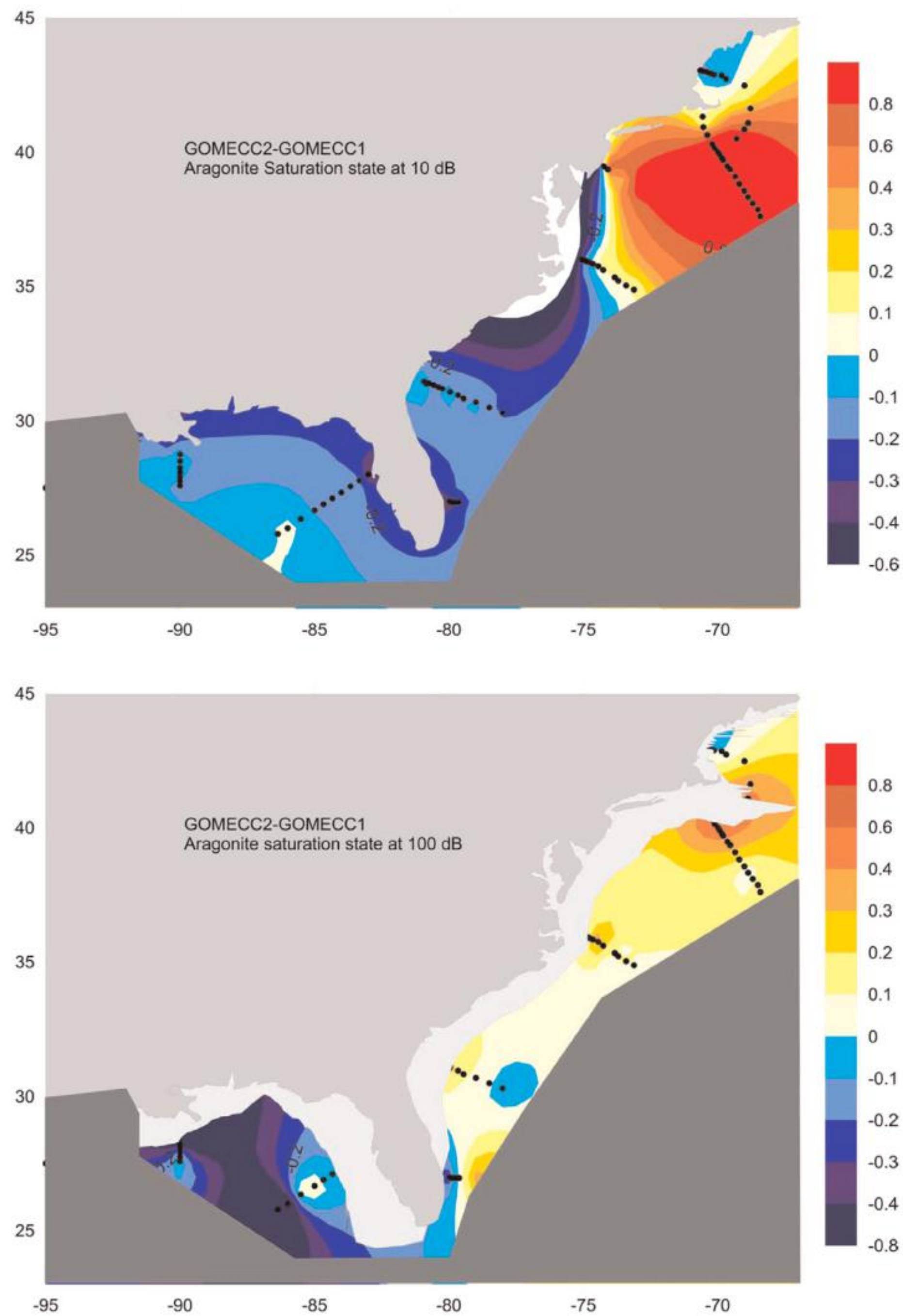


Figure 2. Differences in Ω_{arag} between the Gulf of Mexico and East Coast Carbon cruise (GOMECC)-1 and GOMECC-2 cruises at 10 db depth (top) and 100 db depth (bottom) from Wanninkhof et al. (2015).

The second presentation summarized within the chemistry topic was "**Estuarine Acidification: A Conceptual Discussion with Examples**," focusing on estuarine acidification and how effects of respiratory CO_2 interact with anthropogenic CO_2 inputs. The presentation described the mechanisms by which respiration can play a more important role in acidifying coastal bottom waters currently, but how anthropogenic CO_2 may play an increasingly important role in the future.

The presentation highlighted the importance of the initial carbonate concentrations in the enhancement of acidification, with temperature and salinity playing key roles. The greatest increases in respiratory CO_2 and decreases in pH occur at the lowest salinities and temperatures. These large differences are a function of higher solubility of CO_2 in colder, less saline waters and changes to dissociation constants. Differing sensitivities of respiratory CO_2 acidification to temperature and salinity are also driven by initial carbonate concentrations, as total alkalinity is higher at higher salinities.

The third summarized webinar, **"Ocean Acidification Time-Series Mooring at Gray's Reef National Marine Sanctuary"** described the ocean acidification time-series mooring at Gray's Reef National Marine Sanctuary (Figure 3). The Sanctuary provides habitat to numerous species that may be vulnerable to ocean acidification, including species of hard corals. This mooring (the only NOAA OA mooring off Southeast Coast), measures surface parameters with real time reporting (wave height, wind speed, water and air temperatures, atmospheric CO_2, pH, dissolved oxygen, salinity, chlorophyll and turbidity) as well as parameters at depth (dissolved oxygen, temperature, conductivity, salinity, pressure, chlorophyll, turbidity, pH and CO_2). Measurements at Gray's Reef have shown that this region is absorbing CO_2 at higher rates than the global average (2.4%/year vs. ~0.5%/year). There is also an occasional mismatch between surface pCO_2 and seafloor pCO_2, with large spikes in seafloor pCO_2 values not observed at the surface (Figure 4). These spikes are explained by high pCO_2 water pushed upwards along the seafloor, while not necessarily reaching the surface, highlighting the necessity for both surface and bottom measurements.

Figure 3. Mooring at Gray's Reef National Marine Sanctuary (Credit: NOAA Pacific Marine Environmental Laboratory)

The webinar "**Acidification and Hypoxia in the Shallows- Patterns, Research Approaches, and Effects**" explored co-occurring acidification and hypoxia in shallow settings of the Chesapeake Bay, describing wide fluctuations of both pH and oxygen. More complex than classic tidal diel cycles, large spatial and temporal variation both in timing and magnitude of cycles was documented across the region. Laboratory experiments were developed to replicate these cycles and their impacts on organisms. Among the many effects of diel-cycling acidification, the experiments showed slight stimulation of oyster filtration rates, altered immune response of oysters, decreased growth rate of oyster spat in low salinity conditions and an increased sensitivity of fish to hypoxia.

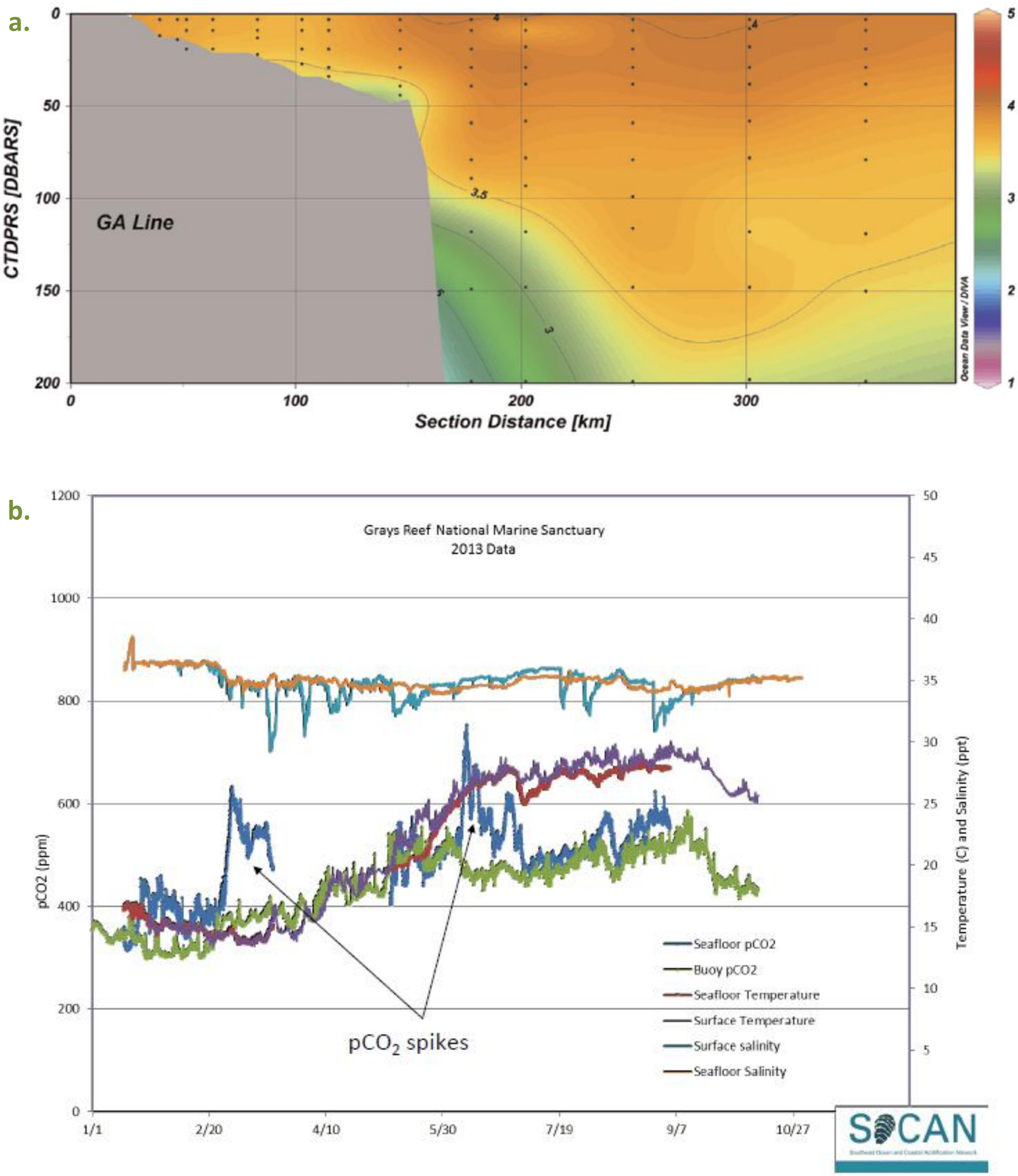


Figure 4. (a) Aragonite saturations (Ω_{arag}) with depth on the Georgia line from Wanninkhof et al. (2015) showing low Ω_{arag} shoaling along the bottom to shallower depths. The bottom graph (b) shows buoy measurements from Grays Reef National Marine Sanctuary revealing a mismatch between seafloor and surface pCO_2 measurements (Credit: Scott Noakes).

This presentation highlighted the necessity to understand the full environmental context, including spatiotemporal dynamics and multiple environmental factors, in which organisms live in order to predict consequences and manage these habitats effectively. Stressors must be considered together, as individual stressors can exacerbate or reduce the effects of other stressors. In the case of mobile species, behavioral responses of one (e.g. avoidance of low oxygen) may reduce or enhance exposure to co-occurring respiration-driven acidification. SOCAN is building on knowledge from OA research in other regions, such as the Chesapeake Bay, to better define methods and approaches to understanding OA impacts in the Southeast Region.

The next presentation summarized within this topic was **“Potential Effects of Climate Change on the Ecotoxicology of Pesticides and Contaminants of Emerging Concern: Implications for Ocean Acidification Interactions**.” The greatest rate of U.S. population change has been in the southeastern region, with subsequent increased impacts to the environmental quality of the coastal zone and coastal communities. As population density increases so does impervious cover (e.g. paved roads), leading to increased runoff and delivery of bacteria and pesticides to aquatic systems. Future climate change scenarios predict intensified precipitation during rain events, further increases in coastal runoff, and lower salinities and pH in coastal waters. Low pH and dissolved oxygen have been shown to increase the toxicity of some pesticides. Future pesticide and contaminant testing will need to consider these complex interactions to better assess risks with future climate change.

The final webinar summarized within the chemistry topic was **“Temporal Variability of the Carbonate System and the Microbial Community in a Dynamic Coastal NC System.”** This presentation emphasized the substantial spatial and temporal variability observed in carbonate chemistry in the Neuse-Pamlico Estuary over short timescales that exceeds long-term projected pH changes. Seasonal variability was largely driven by temperature, alkalinity and primary production vs. respiration, while higher frequency variability (hours to days) was driven by water mass movement, such as tidal cycles, and stochastic events, such as storms. Microbial communities respond to these changes, with pronounced shifts in community structure.

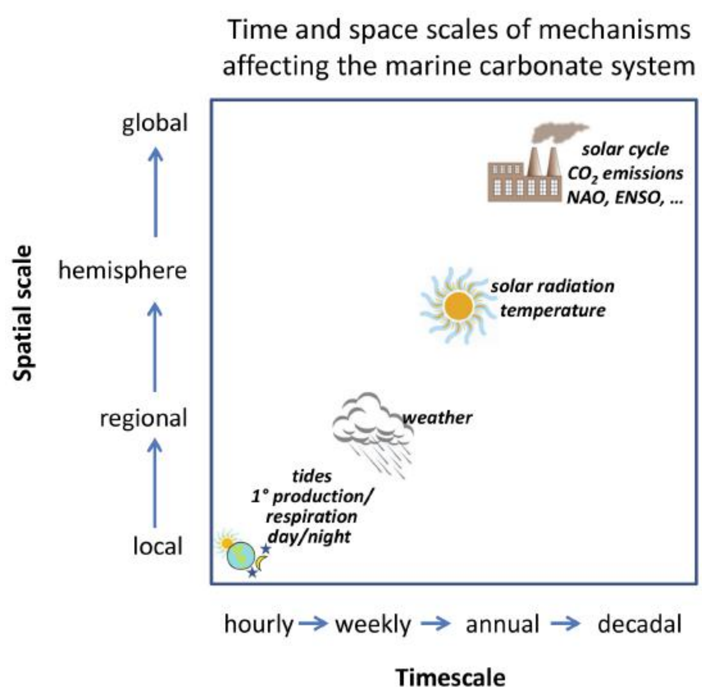


Figure 5. Conceptual diagram of major processes and space and time scales affecting the marine carbonate system in coastal marine ecosystems (Johnson et al. 2013)

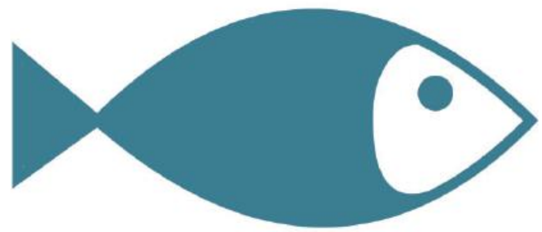
Fisheries Management Related to Human Dimensions

Presenter: Karla Gore, NOAA Fisheries Southeast Regional Office

Moderator: Charlie Phillips, Sapelo Sea Farms

State of the Science Webinars that were summarized during the "Fisheries Management Related to Human Dimensions" topic overview:

- Science, Industry, Management: Perception of Ocean Acidification and Fisheries in Georgia and Florida Virtual Panel**-** Brian Hopkinson (University of Georgia), Pat Geer (Georgia DNR), Holly Greening (Tampa Bay Estuary Program), and Curtis Hemmel (Bay Shellfish Co.)
- Science, Industry, Management: Perception of Ocean Acidification and Fisheries in the Carolinas Virtual Panel- Bob Rheault (East Coast Shellfish Growers Association), Mel Bell (South Carolina Department of Natural Resources), James Morris (Center for Coastal Fisheries and Habitat Research) and Erik Smith (North Inlet-Winyah Bay National Estuarine Research Reserve System)



The webinars presented on this topic were virtual panels with experts from science, industry, and management sectors to discuss considerations for ocean acidification and fisheries in the Carolinas, Georgia and Florida. These webinars included fisheries catch and value data for each state, along with perceived impacts and concerns about ocean and coastal acidification. Fisheries play an economically and culturally important role in North and South Carolina, though there is a large dichotomy in economic value between commercial and recreational fisheries. There is a relatively low diversity of commercially harvested species in the Southeast, many of which have calcified shells, rendering them potentially susceptible to acidification. Very little research on the effects of acidification on crustaceans and shellfish in the Southeast has been completed, and while there have been declines in some of the fisheries (e.g. blue crab), the cause of these declines is not well understood. The effect of ocean acidification on shellfish is of concern in the Southeast, but is not currently perceived as a critical issue to the same extent as in other U.S. regions.

During the topic session, Karla Gore (NOAA Fisheries Southeast Regional Office) presented an "**Overview of the Fisheries in the Southeast Region"** that built on the knowledge that had been shared about fisheries management and ocean acidification at the state level to look at the Southeast region as a whole from a federal fisheries management perspective.

NOAA Fisheries Southeast Regional Office is responsible for the management and protection of marine resources within the U.S. Exclusive Economic Zone (3-200 nautical miles). NOAA Fisheries manages fish stocks and compliance with federal regulations, some of which overlap with species managed by state plans. The major fishery management plans in the Southeast include: snapper-grouper, coastal migratory pelagics, shrimp, spiny lobster, golden crab, dolphin and wahoo, and coral/coral reefs/live bottom. There may be direct impacts of ocean acidification to some species (e.g. shrimp and golden crab) and indirect impacts for others (e.g. loss of coral reef habitat and changes to food web dynamics).

Coral and live bottom management areas include a state-managed octocoral fishery off Florida, federally managed areas off Georgia, South Carolina and North Carolina, as well as the recently implemented Coral Amendment 8 that extends protections for deep-water coral ecosystems, extending the boundaries of deep-water Habitat Areas of Particular Concern (HAPC) in the region. Many of the South Atlantic managed species are linked to these coral reef ecosystems at various life stages.

The NOAA Fisheries National Climate Science Strategy, published in 2015, identifies key steps to increase production, delivery and use of climate-related information required to fulfill NOAA Fisheries mandates and management. NOAA Fisheries is currently developing an Ecosystem-based Fisheries Management Policy that incorporates climate change and ocean acidification.

A workshop held in November 2015 aimed to identify science needs to address climate change impacts for Southeast fisheries. Ocean acidification was considered a key concern for fishery management by South Atlantic, Gulf of Mexico and Caribbean participants. Regional offices and science centers are developing action plans to address these issues over the next 3-5 years, for which acidification is likely to be included in one or all of the sub-regions.

Following the presentation on federally-managed fisheries, David Whitaker (South Carolina Department of Natural Resources) addressed state recreational and commercial fisheries in a presentation that reviewed the key species and their economic value for the region. The major commercial fisheries in North and South Carolina include oysters, clams, shrimp, blue crab, and finfish. Recreational fisheries exceed commercial fisheries in both states, with a combined economic impact of $2.24 billion, of which North Carolina makes up a much larger fraction (NC $1.96 billion, SC $282 million). Commercial landings of blue crabs, shrimp and clams in South Carolina have all declined in recent years, and while some contributing factors have been identified (e.g. drought, increase in mariculture activity), the causes are not well known.

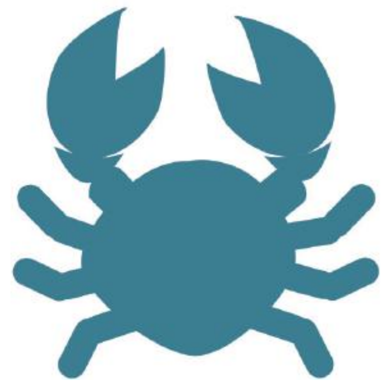
Organismal Response

Presenter: Zackary Johnson, Duke University

Moderator: Lou Burnett, College of Charleston

State of the Science Webinars that were summarized during the "Organismal Response" topic overview:

- Understanding Larval Bivalve Responses to Ocean Acidification, George Waldbusser (Oregon State University)
- Oceans More Acidic and Lower in Oxygen: Lessons from Estuarine Organism, Lou Burnett (College of Charleston)
- Crumbling Coral: Cold-water Reefs in the More Acidic Northeast Pacific and the Implications for Other Regions of the USA, Leslie Wickes (NOAA NCCOS)
- Effects of Elevated CO_2 on the Early Life-Stages of Marine Fishes and Potential Consequences of Ocean Acidification, Chris Chambers (NOAA NEFSC)



A major theme across all organismal response webinars was that acidification effects on individual organisms have generally been negative in laboratory experiments, but effects are variable across taxa and life stages. It is necessary to understand the synergistic and antagonistic interactions of varying stressors, but also uncouple the particular effects of each. The webinars targeted the importance of broader biological complexity, noting how food web interactions are included in the context of acidification. The organismal response research highlights the importance of understanding the rate of change and intrinsic variability in the system, particularly in context of the life history of the organism. The presentations related to coral impacts emphasized that acidification is happening currently and having effects at the organismal, community and population level.

Ocean acidification has been shown to have large effects on the early life stages of oysters in laboratory experiments, potentially creating a bottleneck that renders oyster populations susceptible. Key traits provided in the webinar **"Understanding Larval Bivalve Responses to Ocean Acidification"** that could lead to either resiliency or susceptibility to OA in oysters include:

1) the ability to compensate for internal acid-base chemistry
2) energy availability (bioenergetics)
3) shell mineralogy (thermodynamics)
4) shell formation rate (kinetics)

The importance of kinetics in saturation state vulnerability is a key feature in understanding organismal response of oysters to acidification. Calcification is rapid at early life stages and these regions of the shell appear to be more susceptible in dissolution experiments. Comparisons of oysters collected from lower pH regions of Oregon did not show reduced susceptibility when compared to oysters collected in the relatively higher pH region of Southern California, providing evidence that living in ocean acidification hotspots does not necessarily impart resilience.

Collectively, estuarine organisms are thought to be more resistant to acidification effects as variability in the seawater chemistry of their natural environment is orders of magnitude greater than the chemical changes expected from ocean acidification. The webinar "**Oceans More Acidic and Lower in Oxygen: Lessons from Estuarine Organism"** described the chemical environment of coastal South Carolina ecosystems (pH 6.0-8.1) and how organisms persist in these conditions. It was noted that understanding the "habits" of estuarine organisms is important for understanding the effects of acidification; for example, sedentary oysters will respond quite differently when compared to active crabs and shrimp that can move and migrate. Research has shown extremely low pH and high pCO_2 (>20,000 µatm) in the hemolymph of oysters. Hypoxia (low oxygen) and hypercapnia (high pCO_2) have been shown to compromise the immune system of estuarine organisms and that immune response alone can ultimately reduce performance of the organisms.

The webinar **"Crumbling Coral: Cold-water Reefs in the More Acidic Northeast Pacific and the Implications for Other Regions of the USA"** described cold-water reefs on the U.S. West Coast, which currently persist in low pH conditions, and compared these to reefs in the Southeast. Despite saturation states (Ω_{arag}) <1 deep-water coral reefs are found throughout the Southern California Bight, but these corrosive conditions appear to have consequences for reef structure and skeletal integrity. The Southeast harbors the most expansive deep-water reefs in the United States and preliminary findings that compared coral locations with oceanographic data provided evidence that low Ω_{arag} waters are impinging on these habitats.

The final webinar summarized within the organismal response topic was **"Effects of Elevated CO_2 on the Early Life-Stages of Marine Fishes and Potential Consequences of Ocean Acidification."** The effects of acidification on fishes vary widely and differ across populations and species. Results from summer flounder studies revealed an increase in embryonic mortality, changes to larval body size and earlier onset of metamorphosis in high CO_2 conditions. Results from two-way experiments (CO_2 and temperature) showed decreased fertilization success with elevated CO_2 in summer flounder experiments, while fertilization increased with elevated CO_2 for winter flounder. Meta-analyses of publications on acidification and fish show significant effects on survival, body mass, otolith size and olfactory capabilities, but that response differed among taxa and life history stages.

Ecosystem Response

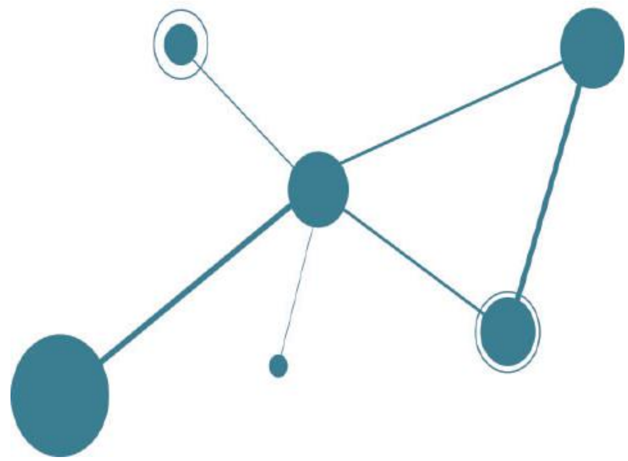
Presenter: Astrid Schnetzer, North Carolina State University

Moderator: Dennis Hanisak, Florida Atlantic University Harbor Branch

State of the Science Webinars that were summarized during the “Ecosystem Response” topic overview:

Webinars:

- Deciphering the Effects of OA on Microbial Assemblage Structure and Community Function, Astrid Schnetzer (North Carolina State University)
- Effects of Ocean Acidification on Tropical Coral Reefs in Florida and the Caribbean, Kim Yates (USGS)
- Integrating Multiple Experimental Approaches to Understand Climate Change Ecosystem Impacts: A Coral Reef Example, David Kline (Scripps Institution of Oceanography)



This topic session began with a discussion of planktonic microbial systems to convey both their utility and importance in ocean and coastal acidification science. One of the consistent themes across microbial research is adaptation across every level of the system, from organismal to ecosystem-level changes. Microbial communities can change their population structure within days and the molecular tools to resolve these dynamics have only recently become available or are still in development.

As ocean acidification research develops, the key to applying the research is to include experiments that move from microscale to meso- and macro-scale studies. These larger scale experiments can capture effects of multiple trophic levels, community structure and function, fluxes in populations, and biogeochemical cycles and feedbacks that cannot be deduced from single species or single factor trials. Acidification science should develop along geographic, environmental and “scientist” gradients. One strategy to achieve this goal is by building on existing resources (e.g. Southeast Acidification Laboratories or SEALS) that facilitate transition within and across these gradients.

One major knowledge gap in translating micro-scale microbial experiments to the ecosystem level is an understanding of micro-zooplankton grazers. While this functional group directly and indirectly affects energy and carbon transfer to higher trophic levels, relatively little research has been dedicated to this component within the microbial ecosystem. Overall, it has been suggested that the taxonomic and functional diversity within microbial assemblages (viral, bacterial and eukaryotic) provides innate resilience to acidification, but given their central positioning at the base of food webs, shifts from one group of key microbes to another in response to acidification could have considerable effects.

The economic costs of acidification have been relatively well quantified for coral reef ecosystems. Recreational coral reef diving and fishing in Florida generates $60 billion in local sales and 70,000 jobs. The ecosystem services these reefs provide are dependent on their three-dimensional structure. Degradation of these structures has been attributed to both local stressors, such as pollution, overfishing, land run-off, physical damage and disease, as well as global stressors, including sea level rise, ocean acidification and warming ocean temperatures. Local stressors have contributed to compromised coral reef ecosystem health and the baseline for coral reef health is already low as the effects of global stressors increase.

Growth of coral reefs is dependent on the balance between calcification and chemical dissolution of the carbonate structure and erosion and sediment export. Ocean acidification has been linked to reduced calcification rates, increased dissolution rates, and increased susceptibility to bleaching. While most effects of acidification appear to be negative, low pH has been shown to reduce the virulence and progression of some diseases. The interaction between these effects is still largely unknown.

Scientists from the United States Geological Survey (USGS) are studying reefs using an integrated approach across multiple locations, including the Florida Keys, US Virgin Islands, Puerto Rico and Hawaii. Across these sites, dissolution thresholds vary, but published studies for dissolution thresholds appear to converge on aragonite saturation states (Ω_{arag}) of 3.0-3.2 and pCO_2 530-600 ppm. Measurements of chemistry in the Florida Keys have shown pCO_2 values that exceed 500 ppm each fall and winter, with reefs showing corresponding net dissolution during these seasons. While reefs were not predicted to begin experiencing net dissolution until 2050-2060, these studies have shown seasonal net dissolution, providing evidence of the imminent threat of ocean acidification.

Seagrasses and particular reefs have been suggested as potential refugia for acidification and solar stress, respectively. The process of photosynthesis consumes carbon dioxide, increasing the pH in seagrass habitats and potentially in nearby reef ecosystems. Additionally, mangrove-coral habitats have been found to have lower pCO_2 and higher Ω_{arag} than coral habitats alone. These habitats may also function as shallow water refugia. Protection of these refugia is a direct measure that can be used to help mitigate climate and ocean change impacts.

Combined, the seminars discussing ecosystem response highlighted the diversity and magnitude of local and global stressors and the need to understand the interactive effects that the stressors may have on the ecosystem. Studies of whole community metabolism and the interconnectedness between ecosystems utilizing environmental datasets and multi-spatial designs will facilitate comparisons. Identifying proxies, tipping points and thresholds provide tools to effectively evaluate and manage these resources.

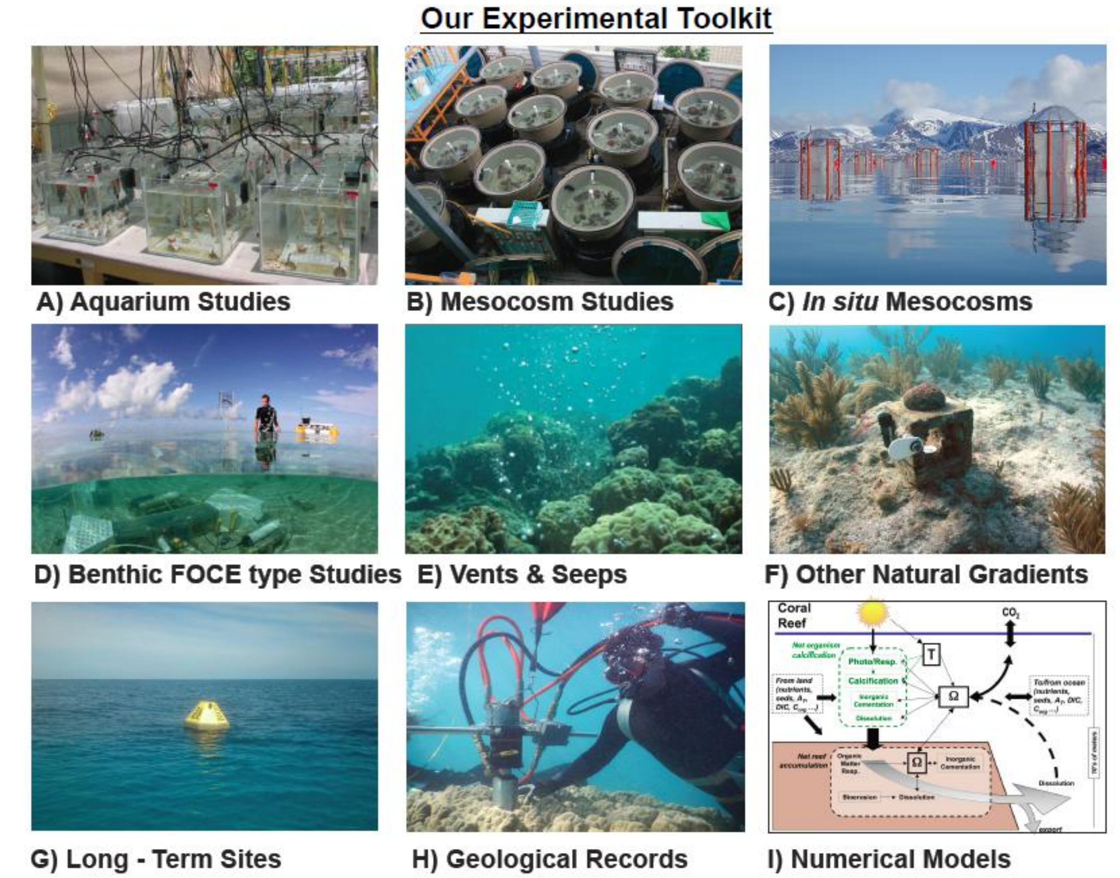


Figure 6. Summary of experimental approaches for ocean acidification research (Andersson et al. 2015)

Advantages/Disadvantages of Different Experimental Approaches

	Experimental Attributes	Aquarium Studies	Mesocosms	*In situ* Mesocosms	Benthic FOCE type Studies	Vents & Seeps	Other Natural Gradients	Long-Term Sites
Experimental	Natural realism	+	++	+++	+++	+++	+++	+++/?
	Replication	++++	++++	+++	+++	++	++	-
	Control over carbonate system parameters	++++	++++	++++	++++	-	-	-
	Multiple Drivers	++++	++++	++	++	-/+	-/+	-/+
	Cost	+++	+++	+	+	++/ +++	++/ +++	++
Types of Studies	Effects on individuals	++++	+++	+++	+++	++	++	+++
	Population and Community effects	–	+/++	+++	+++	++++	++++	++++
	Acute Effects	++++	++++	+++	+++	+++	+++	-
	Chronic Effects	++++	+++	+++	+++	++++	++++	++++
	Direct Effects	++++	+++	+++	+++	+++	+++	+/-
	Indirect Effects	-	+++	+++	+++	++++	++++	++++
Evolution	Adaptation	++++	-/ +++	-/ +++	-/ +++	-/ ++++	-/ ++++	-/ ++++
	Acclimation	++++	++++	++++	++++	++	++	-
	Acclimatization	+	+	++	++	++++	++++	++++

++++= Best, += Can do it, +/- = neutral, -= Can't do

Figure 7. Strengths and limitations of experimental approaches for ocean acidification research (modified from Andersson et al. 2015)

Modeling

Presenter: Libby Jewett, NOAA Ocean Acidification Program

Moderator: Kevin Craig, NOAA Fisheries

State of the Science Webinars that were summarized during the "Modeling" topic overview:

- Modeling Ocean Circulation and Biogeochemical Variability in the Southeast U.S. Coastal Ocean and Gulf of Mexico, Ruoying He (North Carolina State University)
- Modeling Coastal Acidification (and Hypoxia) Linkages with Land-Based Nutrient Loads, John Lehrter (EPA)

The first webinar summarized in the topic of modeling was "Modeling Ocean Circulation and Biogeochemical Variability in the Southeast U.S. Coastal Ocean and Gulf of Mexico," which highlighted the utility of coupled models to fill temporal and spatial gaps in observations in an effort to elucidate the underlying physical-biogeochemical dynamics that may be responsible for long-term trends and variability in coastal systems. To understand the long term response of the ocean to climate change, it is necessary to first define the intrinsic variability on multiple scales. By evaluating biogeochemistry in both land-based trends and coastal ocean trends, these models can assist in the attribution of carbon sources in coastal acidification. Attribution of acidification is extremely important from a management perspective, particularly in efforts to remediate acidification without a clear path toward control over atmospheric inputs.

The next webinar summarized in the topic session, "Modeling Coastal Acidification (and Hypoxia) Linkages with Land-Based Nutrient Loads," aimed to evaluate the linkages between coastal acidification, eutrophication and hypoxia. There is potential for mitigation of land-based contributors to acidification through directives under the Clean Water Act, Clean Air Act, Coastal Zone Management Act and various state and local policies (Kelly et al. 2011). Models provide the foundation to quantify nutrient sources, their transport, fate and ultimately their effects on the ecosystem. Integrating models with the guidelines set forth in the aforementioned policies can be used to predict the nutrient load reduction necessary to achieve management goals.

What makes the Southeast unique?

Presenter: Kim Yates, US Geological Survey

Moderator: Rick DeVoe, South Carolina Sea Grant

State of the Science Webinars that were summarized during the "What makes the Southeast unique?" topic overview:

- Vulnerability and adaptation of US shellfisheries to ocean acidification, Lisa Suatoni (Natural Resources Defense Council)

The Southeast spans subtropical to tropical zones, creating a large gradient that drives complexity and diversity of ecosystems in the region. The large distributions of water systems, including numerous estuaries and black water rivers, have significant effects on the geomorphology and the physical and chemical environment. Southeast marine habitats span salt marshes, wetlands, mangroves, shallow water coral reefs, deep water coral reefs and live bottom habitats.

Present ocean acidification models have only captured the current environmental context for certain regions, while not including the complex geomorphology and the interactions acidification may have with systems in the future. For example, the Florida peninsula is on a carbonate platform, characterized by Karst topography, with complex interactions between terrestrial and coastal hydrology. There is relatively large uncertainty in the interaction between this type of coastal topography and ocean acidification.

Recent research to gauge socioeconomic vulnerability from ocean acidification ranked North and South Carolina as having relatively high social vulnerability to ocean acidification (6). In contrast, Florida was assigned a relatively low social vulnerability score based largely on bivalve fisheries. However, Florida coral reefs have already experienced carbonate dissolution events caused by acidification and impacts to reef ecosystems and the socioeconomic resources they support have not yet been considered in vulnerability models.

Despite the large diversity of marine species and habitats in the region, the diversity of species commercially and recreationally harvested is relatively low. Many of these species are calcifiers, rendering them potentially susceptible to acidification.

More in depth discussion of the unique characteristics of the Southeast is included in Breakout Session: Objective 2.

Figure 7. The Southeast has a large diversity of ecosystems, including (clockwise from top left) estuaries, mangroves, deep-water *Oculina* and shallow-water reefs (Photo credits: NOAA)

Breakout Sessions

This section synthesizes the key points discussed during the breakout sessions. Lists of additional discussion points from both the topic and breakout sessions are included in Appendix 3.

Objective 1: Identify key findings from presented sessions, linkages between them and gaps that may still exist

The purpose of this breakout session was to discuss the findings presented in the SOCAN webinars and to prioritize research in the subjects of ocean chemistry, fisheries management, organismal response, ecosystem response, and modeling.

Chemistry

The chemical processes of ocean acidification at global scales are relatively well understood compared to local and regional processes. The greatest need to understand chemistry at more local scales is to capture the temporal and spatial variability in carbonate chemistry parameters and to understand how other regional dynamics may affect both carbonate chemistry and compound its effects on ecosystem response.

The Southeast chemical environment is both diverse and complex; the influence of atmospheric carbon dioxide is often masked by more localized chemical changes in the nearshore environment. To capture the relative contribution of each, key factors and indicators need to be identified. Key parameters include nutrients, pH, temperature, dissolved inorganic carbon (DIC), pCO_2, salinity, and chlorophyll. Aragonite saturation is proposed as the key indicator that can be compared across spatial and temporal scales.

These key parameters should be measured across spatial and temporal scales to develop algorithms specific to the region and allow for resolution of vertical and horizontal gradients (e.g. onshore to offshore, surface to depth and south to north). Beyond surficial and bottom water comparisons, it is important to understand the entire gradient and capture potential substrate effects.

Of critical importance in the Southeast is to identify local causes of acidification and to establish baselines so that these effects can be correctly attributed to multiple contributing processes. Acidification of the Southeast could be attributed to: atmospheric CO_2, biological respiration, urbanization, runoff, seasonal variability, episodic events, and upwelling.

What is coastal acidification?

While ocean acidification refers to the input of atmospheric carbon dioxide into the ocean, coastal acidification includes changes to the chemistry of seawater as a result of freshwater input, nutrient runoff (eutrophication) and coastal upwelling. These localized changes are already occurring in the Southeast and may be exacerbated by global ocean acidification.

In addition to establishing baseline information, there is a wealth of historic information and monitoring programs that can be used to assess ongoing changes. It important to consider the quality of the historic data used, particularly the scale and resolution of pH measurements. Other useful resources may include dated shells (e.g. clams, oysters) and corals.

Fisheries Management

Many of the commercially and recreationally harvested species in the Southeast are suspected to be vulnerable to ocean and coastal acidification. Effects to most of these species are yet to be determined and the extent to which ocean acidification will affect these fisheries is still unknown. State managed fisheries, including shrimp, crab, oysters, spiny lobsters and clams, should all be prioritized for vulnerability assessments.

Organismal Response

Purposeful merging between physical, biogeochemical, organismal and ecosystem response will be essential in the development of an ocean acidification monitoring program. An understanding of the carbonate chemistry in the Southeast is underway, but few connections have been made between chemical and biological endpoints in the region. Essential to the momentum in making these connections is identifying key groups of indicator species that are functionally equivalent in particular aspects or vulnerabilities to acidification. Characterization of these cause-effect relationships in indicator species will provide a mechanism to more accurately predict the impacts of continued acidification.

Congruency among experimental approaches will be essential in establishing a cohesive understanding of organismal response to acidification. Methods should be standardized and baselines established to extend the applicability of experiments across laboratory studies and systems. Experiments should consider short term vs. long term responses as organisms differ greatly in their ability to acclimate and/or adapt. While an increasing number of studies aim to address molecular, cellular, organismal, population and ecosystem dynamics, challenges are presented in synthesizing findings over such broad scales. Proper scaling can be problematic, taking into account vital rates and early life history stages.

Experimental approaches need to consider localized stressors that co-occur with acidification. For example, in Florida, the most important additional key stressor may be temperature, while in North and South Carolina, it may be hypoxia and nutrient input. When identifying additional stressors for multi-

Many of the commercially and recreationally important species in the Southeast are calcifiers and may be vulnerable to ocean and coastal acidification

stressor experiments, the ecosystem, habitat and organism function should be considered.

Ecosystem Response

An understanding of the Southeast ecosystem response to acidification is in its infancy. Existing reports and datasets that allow for comparisons of key ecosystem characteristics need to be used together with new inventories to prioritize organisms and processes most affected by acidification. Using existing data, it is possible to synthesize generalized and projected responses for predictions that can apply to similar communities or habitats throughout the Southeast.

Comparisons across communities can be facilitated by identifying common factors between them, even if species composition is different. For example, calcification, dissolution, photosynthesis and respiration are common processes across all shallow-water reefs. These common factors comprise “functional health” that can simplify comparisons and act as high-level parameters that can be used as indicators for ecosystem health.

Natural gradients were highlighted as a key approach in making predictions for available resources. The U.S. East Coast provides a chemical gradient that can be combined with organismal distributions as a tool to assess large scale patterns and predict changes that may occur.

Modeling

There is a paucity of relevant observing data in the Southeast that can be used for model development and initialization, particularly with respect to the local hydrodynamics that will affect nearshore species. Furthermore, there is a disconnect between biogeochemical, ecological, population and operational models. Previous and existing data can be used to help guide research toward vulnerable areas and for comparisons with historic conditions.

Resulting messages from models should be carefully communicated to different audiences, as complex models can be misinterpreted outside the scientific community. Multiple models can be used to address audiences with different levels of scientific understanding. Qualitative models provide a mechanism to transition biogeochemical and physical models from complex scientific outputs to end-users. Qualitative risk assessments should be used to guide management decisions and can also be useful in outreach materials for the general public.

KEY RESEARCH PRIORITIES

In order of relative importance as voted by workshop attendees

1. Measure key ocean acidification parameters (pH, dissolved inorganic carbon, total alkalinity, pCO_2, temperature, dissolved oxygen, total alkalinity, salinity, chlorophyll, nutrients) across various spatial and temporal scales to characterize the region and develop algorithms and indicators on relevant spatial and temporal scales for ecosystems
2. Establish strong experimental approaches for organismal response (*see box below*)
3. Develop biogeochemical, operational and qualitative models that can transition to end users and adapt and assess current models that can be used to understand ocean acidification
4. Conduct vulnerability assessments for commercially and recreationally important species
5. Establish baseline information and target inclusion of microbes (viruses, bacteria, microeukaryotes) and microbial processes in ecosystem assessments, experiments and models
6. Identify sources of acidification: atmospheric, biological respiration, riverine inputs, and nutrient inputs and develop models to test our hypotheses of which aspects are driving changes to the carbonate chemistry across and within the region.
7. Identify available sources of historic data; use chemical data inventories to identify climatic envelopes and biological endpoints.
8. Create an inventory of chemical monitoring, ecosystem and experimental facilities in the region to try to build a larger network of facilities.
9. Determine effects of OA on protected species
10. Conduct research within the framework of local multi-stressors (e.g. HABS, coastal erosion, nutrient loading)
11. Collect water quality parameters in conjunction with sessile shellfish and shellfish industries
12. Identify and map OA refugia

SUGGESTIONS FOR A STRONG EXPERIMENTAL APPROACH

- Use a multi-stressor design. This is of particular importance for estuarine organisms that experience extremes in oxygen, temperature, salinity and other seawater parameters. To the extent possible, mimic in the lab the diel and seasonal variability found in the field.
- Evaluate the consequences for organismal and environmental interactions (e.g. predator-prey relationships) and multiple trophic levels.
- Assess the role of acclimation vs. adaptation in organismal response to ocean acidification.
- Strive to capture the "low hanging fruit" for experimental design. Use studies from other regions that could inform studies for the Southeast; identify indicator species; consider functional groups.
- Recognize molecular, cellular, organismal and population-level dynamics with attention to scaling.
- Consider indirect and direct responses, as well as non-linear responses

Objective 2: Key unique/notable characteristics and vulnerabilities of the Southeast

The ecosystem diversity of the Southeast includes global biodiversity hot spots located off the coast of Florida, where mangroves, wetlands and coral reefs converge to create a complex system unique to the southeast region. Deep water *Oculina* coral reefs (*Oculina varicosa*) are unique to the east coast of Florida, where expansive reefs extend along the continental slope, hosting a diversity of species and acting as important breeding grounds for snappers and groupers. The Southeast contains as much as 74% of the saltmarsh on the East coast; an ecosystem tightly linked to the historic and current culture of the region. The diversity of the chemical, physical and biological environment presents itself as both an asset and challenge in acidification science. Though there are challenges in measuring acidification parameters given the complex temporal and spatial variability in the systems, the natural gradients provide an opportunity for creating "natural laboratories" to study organismal response and ecosystem dynamics.

While the extent of their vulnerability in the Southeast is yet to be determined, shrimps, crabs and molluscs represent a large majority of the commercially harvested species in the region; as marine calcifiers, all have been recognized as potentially vulnerable to acidification. These species represent not only an economic resource, but a culturally important resource in the region. Despite the diversity of organisms in the Southeast, the low diversity of harvested species could render coastal communities vulnerable.

An additional key characteristic of the Southeast is the developmental pressure it faces as one of the fastest growing regions of the United States (8). Population increase in the Southeast is a relatively new phenomenon; low historic population density has contributed to coastal areas that are relatively healthy compared to other regions. The ACE Basin (Ashepoo, Combahee and Edisto river basin), the Albemarle-Pamlico estuary and Sapelo Island of Georgia have all maintained relatively high water quality. These wetlands create a vital buffer between coastal communities and the ocean, where they create "ecological infrastructure," providing mitigation risk to extreme events and ecosystem services.

Urbanization can cause significant changes to hydrological cycles as a consequence of an increase in impervious surfaces; water that would otherwise be absorbed into the ground flows into surrounding watersheds, where it can dramatically change the chemical environment (9). Large scale changes in freshwater input from river discharge can significantly affect the alkalinity of surrounding saltwater systems, a key feature of the temporal and spatial variability in acidification parameters in the Southeast (4).

In addition to changing hydrological cycles from freshwater discharge, contributions of organic carbon transported from estuarine marsh systems significantly alter the surrounding carbonate chemistry (10). Nutrient loading into estuaries further exacerbates acidification as a result of microbial degradation of algal blooms that produces carbon dioxide as a byproduct. This mechanism of coastal acidification may surpass the effects of atmospheric inputs for the foreseeable future. The regional dynamics of the Southeast highlight the need to distinguish between coastal acidification and ocean acidification, teasing the two apart and understanding how they are interlinked, perhaps addressing each through separate mechanisms.

The extent to which the aforementioned carbonate system variability and dynamics affect ecosystem vulnerability is unknown. The scale of natural variability is significantly higher than the projected near-term changes to the carbonate system from ocean acidification. To what extent this variability facilitates increased tolerance to acidification for species is not well known. Alternatively, acidification, perhaps in conjunction with other stressors, may cause populations and ecosystems to reach a tipping point, where there capacity to adapt to or mitigate the effects of environmental change are exceeded.

KEY CHARACTERISTICS OF THE U.S. SOUTHEAST

1. Large diversity of ecosystems, spanning subtropical and tropical environments
2. Significant developmental pressure as the Southeast is one of the fastest growing U.S. regions
3. Pronounced effect of coastal acidification with multiple diffuse contributors to changing seawater chemistry (i.e. land-use change, nutrient input)
4. Relatively high water quality as a baseline
5. Relatively information poor compared to other regions of the U.S.

KEY VULNERABILITIES OF THE U.S. SOUTHEAST

1. There is a gap in our understanding of how high variability ecosystems will respond to ocean and coastal acidification; will high variability result in tolerance or vulnerability of marine species?
2. The majority of the economically important species in the Southeast are calcifiers, which may be vulnerable to acidification
3. 80-90% of commercially harvested species depend on estuaries and wetlands for critical life stages, coinciding with regions susceptible to coastal acidification
4. Ocean acidification is already causing seasonal carbonate dissolution, and at some sites net dissolution, of Florida Keys reefs
5. Deep-water corals are located in areas where low pH and aragonite saturation states are already occurring

Objective 3: Summarize why ocean acidification matters to stakeholders

Stakeholders are people that are directly impacted, could influence, or that have a vested interest in coastal and ocean acidification. Key stakeholders identified for the Southeast region include the fishing industry (shellfish fisheries, aquaculture, recreation and commercial fisheries), and the tourism industry (particularly for coral reefs).

While key messages about ocean acidification should be tailored to the unique characteristics and needs of particular stakeholder groups, it is also important to establish a resonating mantra that can be easily communicated across audiences. The complexity of the issue and long-term timeline of impacts has hindered its prevalence in mainstream media and public consciousness. Ocean acidification occurs via multiple processes and its effects are likely to occur over multiple time and space scales, affecting different stakeholder groups in different ways. Locally relevant images and language to communicate the message is the best means to communicate with the public. Recognition of ecosystem resource value, stewardship and civic responsibility messages resonate with communities (Visualizing Change toolkit: vischange.org). It is important to relay actionable items to the public and to avoid scare tactics.

While the message should be straightforward, it should not oversimplify the complexity of the issue – acidification is not an isolated problem but has to be seen as an additional potential stressor or threat to 1) overall ecosystem and human health and 2) particular resources of ecological and socioeconomic importance. NOAA Sea Grant, NOAA Office of National Marine Sanctuaries, state natural resource agency educators, non-profits and estuary programs (e.g. NERR) were identified as key participants in delivery of messages and outreach material.

Key stakeholder groups: potential funders, fishing industry, coral reef industry, water quality managers, scientists, policymakers

Key messages:

- Keep it local
- Focus on what we know and keep it simple
- Discuss underlying factors, multiple stressors, synergistic effects
- Highlight economic impacts and loss of service/benefits
- Leverage existing campaigns and messages

Key figures:

- Identify existing resources and examples
- Focus on powerful images
- Create flow diagrams to convey how issues relate to stakeholders

Who should deliver the message?

- NOAA Sea Grant
- State natural resource agency educators
- Estuary programs
- Aquariums, museums, nature centers
- South Atlantic Fishery Management Council
- SECOORA
- NGOs: Pew, The Natural Conservancy, Ocean Conservancy

How should information be made available?

- Brochures with images, social media, video clip
- Targeted stakeholder workshops
- Scientific publications
- Create a mantra
- Create clear priorities and funding needs
- Education programs and networks (e.g. Phytoplankton Monitoring Network)
- Social media

End Products and SOCAN Vision

SUGGESTED WHITE PAPER OUTLINE

1. Start with a section about what is unique in the Southeast
    a. Issues, concerns, trends, defining coastal and ocean acidification
    b. Identify stakeholders and the risks to them
    c. Define the region
        i. Environmental gradients, stressors, key habitats
        ii. Break out habitats into example boxes: ACE Basin, coral reefs, salt marsh, time series, etc and provide stakeholder examples for these regions
    d. Species vulnerabilities
    e. Define available resources and facilities in the region
2. Research priorities
    a. Approaches
        i. Getting the chemistry right and synthesis of existing data
        ii. Getting the experiments right, linking chemistry biology and geology through modeling
    b. Outcomes
        i. Vulnerability assessments
        ii. Impacts to other coastal issues
        iii. Microbial work
        iv. Attribution to OA
3. Identify potential roles
    a. Agencies
    b. NGOs, etc.
4. Outreach approach
    a. Communication strategy
    b. Documents
    c. Education
5. Anticipated products based on end user needs
    a. Models, coastal reports, define products upfront
    b. Solving issues and providing tools for research and management
6. Next steps

The first product aimed to communicate the state of the science of coastal and ocean acidification in the Southeast will be an editorial lead by Dr. Geoff Scott (University of South Carolina) and Dr. Lou Burnett (College of Charleston). This editorial, along with this workshop report, will lay the groundwork for introducing more detailed peer review articles and technical memorandums. The “beige paper” will aim to distill the thoughts and ideas presented and discussed throughout this workshop.

Following the editorial, and if financially feasible, the steering committee would like to write individual articles on relevant topics that could be included in a special issue. The special issue should be open access and information easily accessible through presentation development and webinars. The timeline for the special issue is suggested as approximately one year.

Additional next steps:

- Continued distribution of SOCAN webinars
- Stakeholder engagement
- Map of regional assets, including identification of resources and facilities. SOCAN should send an email to the list serve to request information on current activities and capabilities (Volunteers: Abbey Wakely and Zackary Johnson)
- Generate key messages that are applicable to the general public (Kim Yates and Rick DeVoe)

Continued discussion on the SOCAN *vision* statement

- SOCAN is currently missing a vision statement
- We need to identify differences between mission vs. strategy vs. vision statement
- “Communities prepared to responds to the consequences of coastal and ocean acidification”
- Respond, adapt and mitigate
- Kim Yates and Rick DeVoe will parallel the editorial piece with constructing key messages, mission and vision statements, and strategies

Concerns over lack of funding were expressed following discussions of products and future steps. While there are small sources of funding available, opportunities will have to be leveraged. Education should be prioritized, as funding may be limited until the key messages related to OA in the Southeast are understood. There may be opportunities in education and outreach through piggybacking on existing sources and networks (e.g. Phytoplankton Monitoring Network). Through strategic and tactical planning, stakeholder engagement and public outreach can be sustainable and used to build capacity.

Summary

- The Southeast Coastal and Ocean Acidification Network (SOCAN) facilitates collaboration and communication on the regional drivers of ocean and coastal acidification, approaches to monitoring, state-of-the-art science, vulnerable species and ecosystems, among other concerns throughout North and South Carolina, Florida, and Georgia.
- Ocean and coastal acidification is driven by local and regional processes such as eutrophication, upwelling, and freshwater flow to the coast, as well as by global ocean uptake of carbon dioxide (CO_2) that is increasing in the atmosphere due to the burning of fossil fuels, land use change, and cement production.
- Ocean acidification affects all marine waters, and has been shown in laboratory experiments to negatively impact those marine species that grow by producing shells of calcium carbonate minerals such as oysters, clams, mussels, and corals
- The Southeast region is unique from other U.S. Coastal regions because it spans subtropical to tropical climate zones, and displays unique and extreme environmental conditions, stressors and gradients.
- Global ocean acidification is an emerging threat that will exacerbate the coastal acidification that is already occurring in the Southeast Region due to changing local environmental conditions, and that is already impacting coastal resources such as coral reefs.
- Shellfisheries and coral reefs, which are important to the culture and the economy of the Southeast region, are particularly vulnerable because ocean acidification can directly affect shell building process.
- Many studies have been conducted around the nation on the impact of ocean acidification on economically and ecologically important marine species and the environments in which they live. A library of webinars on different aspects of ocean acidification and its impacts is available on the SOCAN website.
- More specific effects to the Southeast region are largely unknown. However, we have a good base of information to help build our knowledge on impacts to the Southeast, and ways to prepare society to manage the consequences.
- What we do know about the potential impacts of OA in the Southeast Region:
    - Resources in the Southeast that many of us value (such as coral reefs) are already being impacted by ocean acidification.
    - In the Southeast, a number of shellfish hatcheries have experienced significant die-offs, although the cause is not currently known.
    - Many marine species in the Southeast have adapted to extreme environmental conditions. It is unknown whether this adaptability will make them less vulnerable to ocean acidification pressures, or if ocean acidification will be the pressure that tips their survivability into a decline.

- A diverse community of science, resource management, industry and policy experts from North and South Carolina, Georgia and Florida are working together to understand ocean acidification and how it is affecting our Region's ecological resources, and to develop ways to prepare our community to adapt, mitigate and manage.
- SOCAN is working to bring these experts together, identify the knowledge and information needs of the community, set regional priorities for research and monitoring, and communicate results to help address problems caused by ocean and coastal acidification.

Appendix 1: Agenda

SOCAN
Southeast Ocean and Coastal Acidification Network

SOCAN In-Person Meeting
Jan. 12-13, 2016

Location: College of Charleston, Alumni Center (86 Wentworth Street, Charleston, SC 29401)
Meeting Contact: Abbey Wakely, abbey@secoora.org, (863) 838-4699
Light Breakfast, Water And Coffee Provided

Meeting Objectives

1. Summarize key findings, prioritize research needs, and identify the research and lab capabilities that could address OA related research questions
2. Identify why the Southeast region is unique and this region's vulnerabilities
3. Summarize why Ocean Acidification matters to stakeholders

Meeting Outcomes

- Develop a White Paper Outline (Including a List of Key Figures)
- Prioritize Research Needs
- Outline SOCAN's Next Steps

Tuesday January 12, 2016

8:00am – 8:30am	Opening Remarks, Words from the Dean, and Meeting Overview Paula Keener, Amy T. McCandless, Libby Jewett, Debra Hernandez
8:30am – 9:15am	Topic 1: Chemistry and Other Stressors Presenter: Leticia Barbero Moderator: Geoff Scott
9:15am – 10:00am	Topic 2: Fisheries Management Related to Human Dimensions Presenters: Karla Gore and David Whitaker Moderator: Charlie Phillips
10:00am – 10:15am	Break
10:15am – 11:00am	Topic 3: Organismal Response Presenter: Zackary Johnson Moderator: Lou Burnett
11:00am – 11:45am	Topic 4: Ecosystem Response Presenter: Astrid Schnetzer Moderator: Dennis Hanisak
11:45am – 12:45pm	Boxed Lunch- Sponsored by Sunburst Sensors
12:45pm – 1:30pm	Topic 5: Modeling Presenter: Libby Jewett Moderator: Kevin Craig
1:30pm – 2:15pm	Topic 6: What makes the Southeast Unique?

	Presenter: Kim Yates Moderator: Rick DeVoe
2:15pm - 2:30pm	Break
2:30pm – 2:45pm	Breakout Sessions Process Kim Yates
2:45pm – 3:45pm	Breakout Session 1
3:45pm – 3:50pm	Rotate Clockwise to Next Facilitator
3:50pm – 4:35pm	Breakout Session 2
4:35pm – 4:40pm	Rotate Clockwise to Next Facilitator
4:40pm – 5:25pm	Breakout Session 3
5:25pm – 5:30pm	Wrap Up and Adjourn Libby Jewett
6:00pm – 8:30pm	Social at Mellow Mushroom (309 King Street, Charleston, SC 29401)

Wednesday January 13, 2016

8:00am – 8:30am	Welcome and Recap of Yesterday Libby Jewett
8:30am – 9:00am	Objective 1 Results Jennifer Mintz
9:00am – 9:30am	Lab Capabilities to Address Priorities Jennifer Mintz
9:30am – 9:45am	Objective 2 Results Debra Hernandez
9:45am – 10:00am	Objective 3 Results Bethney Ward
10:00am – 10:15am	Break
10:15am – 11:00am	Open Discussion Kim Yates
11:00am – 11:05am	5- Minute Stretch Break
11:05am – 12:00pm	SOCAN Vision Libby Jewett
12:00pm – 12:30pm	Wrap Up and Adjourn Debra Hernandez

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Appendix 3: Additional Points of Discussion

Chemistry and Other Stressors

- Participants were surprised by the rapid changes in aragonite saturation states between GOMECC cruises, though it is noted these changes were suggested to be a consequence of large-scale regional trends from source water rather than atmospheric carbon dioxide inputs
- The mismatch between surface and bottom carbonate chemistry measurements at the Grays Reef mooring is an important subject to further evaluate; Dr. Wei-Jun Cai's laboratory is evaluating how storms may affect this mooring data
- Analysis of the East Coast Ocean Acidification (ECOA) 2015 cruise data (the East Coast leg of the GOMECC cruises) is currently underway
- Remote sensing indicators for pH and algal bloom relations need to be evaluated. Heterotrophic bacteria would be difficult to sense, but different pigment groups could be evaluated
- Parasites and pathogens could function as climate change indicators (e.g. increase in Vibrio bacteria infection rates)
- Are there other candidate groups or species that may be useful as indicators?
    - Z. Johnson is working on bacteria, which are diverse but cluster into groups; it is not known if observed changes in microbial group dynamics are driven by acidification
    - Vibrio bacteria have been implicated as a potential climate change indicator, which have shown substantial increases in infections rates, mostly stemming from wound infections
    - A. Schnetzer is working on the relationship between phytoplankton dynamics (diversity and abundance) and global climate parameters (i.e., OA and temperature) – phytoplankton changes can at least be partially linked to large scale observations (remote sensing)
- Ocean Sampling Day does not provide great utility for these characterizations because collections are from many sites, but sampled only on one day
- Algorithms need to be developed for this region similar to those developed on the West Coast, but requiring different parameters
- Attribution of acidification
    - Gray's Reef CO_2 dynamics may be more related to hydrological (wet-dry) systems with wet periods causing pH changes. In 2006 and 2010 CO_2 increased much faster than atmospheric, which corresponded to a dry period
    - Long term observations are necessary to understand what drives these dynamics

Fisheries Management Related to Human Dimensions

- Pathogen dynamics with fisheries have not yet been considered for these plans, citing a lack of funding

- Gulf of Mexico fisheries are much larger than those in the Southeast, which is at least partially a function of tidal flux and the energy required by organisms physiologically and physically in dealing with tides
- Consideration of all life history stages; coastal life stages are often more sensitive to changing water quality
- Graphs of shrimp landings in the Southeast have shown very different trends over the same periods. The causes for these differences need to be accounted for and terminology standardized so comparisons can be made
    - External factors, such as shrimp prices and fuel, are encompassed by landing statistics. For example, high fuel prices in 2005-2010 may have been associated with reduced landings. These socioeconomic factors need to be untangled to detect environmental trends
    - Grass shrimp, for example, are not subject to commercial harvest but likely have similar sensitivities to water changes as commercially harvested species. These species could be coupled with penaid shrimp to tease out external factors and look at environmental trends
- Intertidal vs. subtidal oyster species: South Carolina oysters are largely intertidal while in the Northeast there are more subtidal populations. These oyster habitats likely have different vulnerabilities.
- Food web dynamics are yet to be included in assessments. Changes to the plankton food web due to OA can lead to major changes for fisheries

Organismal Response

- There has been very limited research on microbial communities (bacterial and microeukaryotes) that live on and within organisms (microbiomes). Given the wealth of insight that has only recently been gained on the importance of the human microbiome, these associations could be particularly important for ecologically key marine species (e.g., for corals)
- The entire carbonate chemistry system should be considered when reporting: What is the actual mechanism behind observed effects to consider both the chemistry and response holistically (e.g. is it changes to bicarbonate or carbonate concentrations that are important)?
- Individual immune responses may affect susceptibility
- Priorities: larval stages of organisms, impacts to life history, coral studies

Ecosystem Response

- There is major knowledge gap in our understanding of viral, bacterial, microzooplankton and phytoplankton dynamics particularly as it relates to the food web. As molecular tools come online to better characterize these microbial assemblages and their ecological roles, it will be key to identify indicator species or groups in both coastal and pelagic ecosystems at lower trophic levels. Comparisons between pristine environments and those with distinct stressors may facilitate development of these indicator species/groups.

- There is an emerging concept in the United States to put a value on marine resources, known in the European Union as "Blue Growth." Blue Growth is a strategy to support sustainable ocean resources by assigning economic value to the services they provide. Can we attempt to assign a value to the microbial communities?
- Interactions between ecosystems, such as seagrasses, corals and mangroves offer a key opportunity for a system for which stressors could be ameliorated at the local scale

Modeling

- Key processes in biogeochemical models still appear to be unknown and identifying these key processes may assist in prioritizing research (e.g. grazing community, benthic oxygen demand)
- It is important that models undergo validation before being incorporated into management
- There is a disconnect between biogeochemical models and fishery models and a limit to which they can be incorporated because of the mobility of fish (i.e. exposure is difficult to determine). Management plans are starting to incorporate food web models into ecosystem plans, but most biogeochemical models do not have enough data at the scales necessary to be used in stock assessments. There is a lack of data particularly in acidification for fisheries; an understanding of effects of OA on vital rates, mortality and food web would facilitate incorporating biogeochemical models with fishery models and stock assessments.
- Quantified models should be simplified into qualified models that use budgets and arrows to turn models into low, medium and high risk. These simplified models would provide the management community with a resource for risk assessments. In fisheries, there are models called "Only Reliable Data" that provide intermediate answers to management problems until better data is available.
- To what level can we generalize without losing accuracy and utility? Multiple models should be made to facilitate multiple users.
- Conceptual models in the Southeast may need to be separated into estuary, ocean and intertidal zones. These separate models may be easier to understand, both for the general public and in management decisions.
- Conceptual model components:
    - Budget and net sums of processes
    - Arrows for rates of transfer
    - Tagged for risk: high, medium, low
    - Algorithms to provide a sum gain/loss based on risk or vulnerability
- We need to create the best tools for vulnerability assessments, currently being done in the Northeast. These provide a quick overview of status of knowledge and potential exposure risk factors, followed by a ranking.
- One example of an effective model for management has been the impervious surface model for environmental quality

What makes the Southeast unique?

- Florida was considered less vulnerable because of the opportunity for alternative jobs. Sea level rise was not considered in the Ekstrom et al. (2015) paper, but local governments are starting to include it in regional planning
- Karst topography may help mitigate OA at local scales but buffering capacity may only be on short timescales
- Socioeconomic models do not always include all trajectory of changes in, for example, pulse waters from high humic rivers
- Florida hosts the third largest coral reef system in the world and one of the largest networks of deep-coral communities in the United States
- Societal linkages with Southeast natural resources may be in transition as population growth is a function of migration, not birth rate. Older population groups, as well as people that have relocated from other regions, may have different attitudes toward the Southeast environment.
- Need for an increase in institutional infrastructure to understand the institutions currently involved in ocean acidification research
- Ekstrom et al. (2015) suggested the Southeast marine ecosystem will not see effects until 2100. This paper focused on global models and did not include regional and local dynamics. The approach to address and publicize OA in the Southeast must bear in mind the results that have thus far been presented.

Breakout Objective 1

Chemistry

- Need to identify current long term monitoring datasets with key water quality parameters used to define algorithms
- Is the Southeast changing faster than Northeast?
- Drought/extreme weather a factor?
- There is a need to determine anomalies vs. trends for long term data

Fisheries Management

- How do pathogens affect commercially and recreationally important species?
- How are landings being calculated? Clarity in trends is necessary in order to relate impacts (e.g. shrimp prices/landings could be more correlated with fuel prices)
- Is there a need to look at intertidal vs. tidal oysters separately for OA vulnerability?
- What are the effects of acidification in the Sargasso Sea?
- Prioritize protected habitats where ancillary data and food web dynamics are already documented
- Look at water quality in conjunction with shellfish industries

Organismal Response

- Importance of reporting the entire carbonate system

- Resilience/resistance: need to evaluate the entire chemical system
- Oxygen and fish: lowered oxygen results in reduced reproduction and potential population level effects
- Distinction between sessile organisms and mobile species
- Comparison of microbial (short-lived, high adaptability?, more resilient?) species and larger taxa (long-lived, less adapatable?, less resilient?)
- Connection between assemblage diversity and OA
- Vulnerability of specific functional groups (e.g., primary producers, consumers, decomposers)

Ecosystem Response

- Health in terms of ecosystem function
    - A path to defining indicators
    - Applications to other ecosystems (e.g. coral metabolism, community composition)
- Integrate *scientists* that encompass molecular to ecosystem
- There are methodological and experimental challenges to fill knowledge gaps on the lower food web from a viral, bacterial, phytoplankton to zooplankton level (e.g. characterizing microbial diversity and abundance and linking it to ecosystem function)
- Consideration of ecosystem-based approaches (i.e., EU "Blue growth economy")
- Are there target indicator species in pelagic systems that are vulnerable to OA?
- Identify pristine environments that could be used in comparison studes

Modeling

- There is disconnect between stock assessment models and ecological models
- Gap: what portion of the population is being exposed for how long (especially in model species)?
- Food web models (e.g. EcoSim, EcoPath) could be useful if links, processes and the effects of OA on life stages could be understood
- Link quantitative and qualitative models; provide high/medium/low vulnerabilities to prioritize unknowns
- Is there an ecosystem model useful given the diversity and variability in the South Atlantic Bight?
- Use the question to drive the level, complexity and type of model used
- There is a lack of data on how OA effects vital rates and population dynamics
- Lack of higher trophic models and those with sensitive life stages
- Start small (e.g. Charleston Harbor) and then expand

Breakout Objective 2

- Extension of ranges and species invasions: evidence that seawater changes are not anomalies but based on trend?
    - Evidence in fish ranges, crab ranges, and mangrove habitat

    - Amplified by thermal expansion and sea level rise
    - Potential barriers to migration
    - Gains and losses: species moving North from the Southeast but also to the Southeast from the Caribbean
    - Change in red tide events
- Communication with stakeholders and the public needs to be mindful of natural conditions vs. ocean acidification as there are multiple stressors and contributors to low pH
- Significant habitats of concern: marsh, live hard bottom (note: managed under some fishery plans), coral, deep-sea coral. These habitats managed under fishery plans have avenues for action if susceptible to OA.
- Are we limiting ourselves by focusing on fishes and offshore work? Are we making an assumption that this is where the key is? We need to consider cross connections and ecosystem services
- Concepts of coastal vs. ocean acidification are beginning to gain traction; important to manage the whole system and be sure the EPA is embracing the full spectrum (i.e. managing nutrients)
- Is the Southeast "data poor?" It is argued that the Southeast may be data rich, just information poor. No consensus was reached.
- Reports have suggested it is "not an issue here" but the target group was bivalves; we must be mindful of the target group of interest [coral dissolution is an issue here now]
- Oyster hatcheries in Florida, Georgia and North Carolina have been experiencing significant mortalities but the cause is still unknown
- How does offshore diversity compare with inshore diversity?
- Importance of the Gulf Stream
- The ACE Basin is identified as highly vulnerable in studies but it also has a very low population density
- South Carolina and Georgia have less eutrophication than North Carolina because of large tidal ranges
- The danger in using the Gray's Reef Buoy in figures is that it "brands" the Southeast. This does not represent the extremes seen in other locations
- Need another mooring at Chico Rocks
- Mooring in NEERS might be better (Erik Smith)

Suggested figures to illustrate the unique and vulnerable aspects of the Southeast:

- Habitat diversity with respect to temperature range
- Symbolizing pH extreme locations
- Map of variability within each habitat and region
- Life cycle diagrams for commercially important species (e.g. shrimp, crab, menhaden, snapper/grouper)
- Management areas, MPAs, overlap with OA vulnerabilities

- pH of Gray's Reef and Florida reefs
- Qualitative ecosystem model to show vulnerabilities to OA

Breakout Objective 3

- Additional key stakeholder groups should include Federal agencies (e.g. NOAA, USGS), PEW, tourism, and tourism downstream industries
- Engagement should be a two way street. We need to receive input from stakeholders to create a conversation.
- Full list of stakeholders mentioned: citizens, residences, general public, tourists, recreational users, boaters, divers, environmental educators, industry, coral reef users, local seafood groups, county regulators (city council, elected officials, county planners), public interest groups, chambers of commerce, port authorities, county parks, aquariums, coastal beaches and parks, natural resource agencies, environmental quality and health officials, governors and legislative delegates, Sea Grant, Federal Coastal Management (i.e. Sanctuaries), councils and alliances, Fishery Management Councils, Seafood Alliance, Shellfish Association, regional planning bodies, scientists , influential funders
- Some of these were contentious as group members discussed the difference between stakeholders and groups that should are neutral bodies (e.g. NOAA Sea Grant)
- Communicating options for local mitigation and tangible solutions to reduce acidification
- Delivery of message: NOAA Sea Grant, state natural resource agencies, sanctuaries, estuary programs, NEERS, Fishery Management Councils, SECOORA/IOOS, Ocean Conservancy, TNC, aquariums, Coastal Conservation League, Local TV weatherman/meteorologists, chefs, bloggers, social media

Suggested figures to illustrate key points:

- Decalcified organisms
- Before/After images of ecosystems
- Reference the Ocean Conservancy brochure
- Pie diagram of fishery dependence
- Stakeholder tier down graphic, concept map
- "Hot sour and out of breath brochures"
- "Clean and Lean protein from the ocean"
- Marketing products

Appendix 4: References

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