Research Needs for the Sustainable Management of Crustacean Resources in the South Atlantic Bight

April 9-10, 2014

Marine Resources Research Institute

South Carolina Department of Natural Resources

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ACE Basin National Estuarine Research Reserve

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Research Needs for the Sustainable Management of Crustacean Resources in the South Atlantic Bight.

Report from a workshop held at the
Marine Resources Research Institute
Charleston, South Carolina
April 9-10, 2014

Authored by Jeff Brunson, Peter Kingsley-Smith, John Leffler,
Blaik Keppler, Amy Fowler, Larry DeLancey and David Whitaker.
South Carolina Department of Natural Resources

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EXECUTIVE SUMMARY

While the management authority for crustacean fisheries generally resides with individual states, crustacean resources are often interconnected within the region of the South Atlantic Bight. Declines among certain economically-important crustacean fisheries (i.e., blue crabs and shrimp) have been reported for both fishery-dependent and fishery-independent data region-wide since 2000. This workshop provided an opportunity for state resource managers and researchers to discuss issues affecting those fisheries and to attempt to identify approaches and resources for addressing the concerns raised. A secondary goal was to improve communication among the participants to facilitate prioritization of research in the near term and encourage collaboration to most efficiently utilize resources that are available regionally.

The two-day workshop was held at the Marine Resources Research Institute in Charleston, SC on April 9-10, 2014 and opened with a series of presentations highlighting the issues of concern for crustaceans. David Whitaker (South Carolina Department of Natural Resources) presented a broad overview of the different factors impacting crustacean species of concern (i.e., blue crabs, shrimp, horseshoe crabs, and stone crabs). This was followed by overviews of crustacean diseases by Dr. Dick Lee (Skidaway Institute of Oceanography), habitat loss and environmental modification impacts on crustaceans by Dr. Denise Sanger (South Carolina Department of Natural Resources), the impact of climate change on crustaceans by Dr. Dennis Allen (University of South Carolina, Baruch Field Marine Laboratory), and crustacean stock assessments by John Carmichael (South Atlantic Fishery Management Council). PowerPoint presentations of those talks are available at http://www.dnr.sc.gov/marine/NERR/eventsctp.html. During the afternoon of the first day and the morning of the second day, attendees broke out into small groups, determined by species of interest (i.e., blue crabs, shrimp, horseshoe crabs/stone crabs), to discuss how disease, habitat loss, climate change, and stock assessment directly related to each crustacean species or group. The objective was for each breakout session group to discuss the status of the fishery, identify gaps in knowledge about the species, and recommend research studies, approaches, resources, and regional expertise for addressing those gaps. After each breakout group presented their findings to all participants, a panel of state resource managers discussed some of the overarching issues, drawing the workshop to its conclusion.

In summary, while certain crustacean diseases are well known (e.g., reo-like virus and *Hematodinium* for blue crabs, and black gill disease for penaeid shrimp), the potential for expansion of new diseases into crustacean fisheries exists through introductions of exotic species and possible increased virulence of endemic organisms. In many cases, however, diseases are poorly understood, and even for known diseases, such as black gill, questions remain about the spatial and temporal distribution, mode of transmission, vulnerability of animals at different sizes, physiological impacts and sublethal effects of disease, and the influence of environmental factors on disease susceptibility. Harvest techniques (e.g., claw removal with stone crabs and bleeding of horseshoe crabs) could also impact disease susceptibility, but this has not been examined. Established monitoring programs in each state offer resources to monitor the

prevalence of particular diseases, both temporally and spatially, but coordination of these efforts to standardize protocols used to monitor disease will be necessary. In addition, laboratory studies will provide integral information about the impacts and causes of disease, both physiologically and demographically, and will ultimately add to the growing body of literature on crustacean diseases, some of which could be incorporated into future population or stock assessment models.

The effect of predicted climate change requires further study. Changing wind patterns and ocean currents may alter crustacean larval dispersal and distribution patterns, while increasing water temperatures may lead to changes in the ranges of species and species-specific phenology. Some evidence exists for the range expansion for certain species, such as stone crabs. An increase in the occurrence of extreme weather conditions (e.g., atypically cold winters, increased rainfall) is predicted as well, and the influence of these various events on crustacean populations warrants increased investigation. For example, the amount of rainfall, whether drought or high freshwater discharge conditions, is known to affect key life history stages of all crustaceans and, ultimately, therefore impacts fisheries landings. Ocean acidification, characterized by a decrease in ocean pH over an extended period of time, resulting primarily from increased uptake of carbon dioxide from the atmosphere following increased carbon emissions, may also have negative effects on the survival, development, growth, and physiology of crustacean species occurring outside of estuaries. Directed studies on how ocean acidification may impact crustacean species in the South Atlantic Bight are, however, lacking.

A more significant effect of global climate change in estuarine systems, however, is likely to be sea level rise, with consequent changes in habitat quality and availability. An understanding of these effects will require long-term environmental and ecological sampling combined with laboratory experiments, field studies, and modeling efforts (such as those incorporating GIS and/or LIDAR). Habitat degradation and loss due to physical and chemical anthropogenic effects are also occurring, and may be addressed through legislative, legal, and public outreach and education strategies. While all target species could be impacted by sea level rise, a "state of the knowledge" report, followed by a data workshop to collate all fisheries independent data from each state was suggested as a means of improving our understanding of the habitat requirements of economically-important crustaceans, and blue crabs in particular.

In order to understand the status of crustacean fisheries, a reliable stock assessment is important. Traditional fisheries stock assessment models that follow particular year classes through time, however, are not appropriate for annual species such as shrimp and blue crabs, so a new stock assessment technique will likely be necessary. To improve accuracy, more reliable and updated species-specific estimates of natural mortality and recreational landings are needed. In order to determine whether target species should be managed at the state or region level, and to provide information for a stock assessment, larval dispersal and connectivity of crustacean populations should be evaluated using a variety of mark-recapture and population genetics techniques. Collaborations with commercial fishermen across the South Atlantic Bight (e.g., electronic log

book use by commercial shrimpers, observers on board vessels) could further improve assessment models by providing species-specific demographic information.

Many resources for addressing knowledge gaps related to these issues and the effects that they may have on crustaceans were identified in the breakout sessions. Data collected by established monitoring programs of federal, state and county agencies, as well as from academia (e.g., marine laboratories) provide a wealth of accumulated information, and organizations such as Southeast Data, Assessment, and Review (SEDAR) and Southeastern Estuarine Research Society (SEERS) provide approaches for data assessment and forums for presenting findings. Many facilities offer laboratories for gut content analysis, genetic analysis, and bioassays, while long term ecological research (LTER) sites and National Estuarine Research Reserves (NERRs) provide baseline data and continued monitoring of key habitats. The Environmental Protection Agency, state Sea Grants and county agencies are possible funding sources, while NOAA Cooperative Research Programs (CRPs), non-governmental organizations, and commercial enterprises offer potential opportunities for public-private collaborations.

RATIONALE AND OVERVIEW OF WORKSHOP

The South Carolina Department of Natural Resources' Marine Resources Research Institute (MRRI) is responsible for providing support for management decisions of commercially-important crustacean species through reports, advice, and data collected through regular fishery independent monitoring efforts. Fishery-dependent catch and effort data are collected by the SCDNR Office of Fisheries Management, also within the Marine Resources Division. Both fishery-independent and fishery-dependent data, including total landings, over the past decade indicate declines in blue crab catch per unit effort (CPUE). A decade-long decline in the shrimp fishery in South Carolina is due largely to market forces. Recent shrimp diseases and potential impacts from invasive tiger shrimp (*Penaeus monodon*) are also causes for concern. Managers in neighboring southeast Atlantic states are reporting similar trends with these and other commercially-important crustacean species. The northward expansion of the stone crab fishery and the continued harvest of horseshoe crabs (although chelicerates rather than crustaceans) are commercially- and ecologically-important fisheries that require increased attention. In a time of reduced funding for research and monitoring efforts, however, collaboration among management agencies and research organizations has become increasingly important. For collaboration to be effective, it is important to identify research and management activities within the region and to explore ways in which additional collaborations could be developed. A workshop was organized to facilitate discussions of issues concerning commercially-important South Atlantic crustacean species, the status of crustacean research in the region, and approaches and resources for addressing identified research needs. The workshop was envisioned to facilitate communication and collaboration among South Atlantic Bight crustacean researchers and managers. The Marine Resources Division expects to draw on the conclusions from the workshop to set research priorities for the next five years.

The workshop planning committee quickly recognized that certain issues (diseases, habitat loss, climate change and stock assessment) were common concerns and could be applied to all ecologically-, recreationally-, and commercially-important crustaceans. Those topics were discussed by invited keynote speakers at the beginning of the workshop and were incorporated into the discussions of facilitated, small group breakout sessions. The breakout groups were charged with accomplishing specific objectives: 1) identify important knowledge gaps about commercially-important crustaceans; 2) describe approaches to address those identified gaps; and 3) identify regional expertise and resources to implement suggested approaches. The three commercially-important penaeid shrimp species (white shrimp, *Litopenaeus setiferus*, brown shrimp, *Farfantepenaeus aztecus*, and pink shrimp, *Farfantepenaeus duorarum*) were discussed in a single breakout session, while blue crabs (*Callinectes sapidus*) were discussed in a separate session. A third breakout session was dedicated to discussions of both stone crabs (*Menippe mercenaria* and *Menippe adina*) and horseshoe crabs (*Limulus polyphemus*), due to their more limited commercial role within the South Atlantic Bight. When the entire group reconvened, breakout session group report-outs were followed by a Q & A discussion with a panel of state resource managers.

LIST OF WORKSHOP ATTENDEES

Al Segars	SCDNR	segarsa@dnr.sc.gov
Alyssa Gehman	University of Georgia	gehmana@uga.edu
Amy Fowler	SCDNR	fowlera@dnr.sc.gov
Bethney Ward	NOAA	bethney.ward@noaa.gov
Blaine Griffen	University of South Carolina	bgriffen@biol.sc.edu
Chrissa Waite	NOAA	chrissa.waite@noaa.gov
Dara Wilber	Bowhead Science and Technology	darawilber@gmail.com
David Whitaker	SCDNR	whitakerd@dnr.sc.gov
Denise Sanger	SCDNR	sangerd@dnr.sc.gov
Dennis M. Allen	Baruch Marine Field Laboratory, USC	dallen@belle.baruch.sc.edu
Elizabeth Fly	South Carolina Sea Grant Consortium	elizabeth.fly@scseagrant.org
Geoffrey I. Scott	NOAA/NCCOS CCEHBR	geoff.scott@noaa.gov
Harvey Seim	University of North Carolina at Chapel Hill	hseim@email.unc.edu
J. Antonio Baeza	Clemson University	baeza.antonio@gmail.com
Jeff Brunson	SCDNR	brunsonj@dnr.sc.gov
Jim Page	GADNR	jim.page@gadnr.org
John Carmichael	South Atlantic Fishery Management Council	john.carmichael@safmc.net
John D. Zardus	The Citadel	zardusj1@citadel.edu
John Leffler	SCDNR	lefflerj@dnr.sc.gov
Julia Byrd	SEDAR	julia.byrd@safmc.net
Julie Davis	South Carolina Sea Grant Consortium	julie.davis@scseagrant.org
Karen Burnett	College of Charleston/Grice Marine Laboratory	burnettk@cofc.edu
Larry DeLancey	SCDNR	delanceyl@dnr.sc.gov
Lindsey Parker	University of Georgia MAREX / GA Sea Grant Program	lparker@uga.edu
Liz Duermit	College of Charleston / SCDNR	duermite@gmail.com
Lou Burnett	College of Charleston	burnettl@cofc.edu
Rick DeVoe	South Carolina Sea Grant Consortium	rick.devoe@scseagrant.org
Marc E Frischer	University of Georgia Skidaway Institute of Oceanography	marc.frischer@skio.uga.edu
Marcel Reichert	SCDNR	reichertm@dnr.sc.gov
Mel Bell	SCDNR	bellm@dnr.sc.gov
Michael Childress	Clemson University	mchildr@clemson.edu
Michael Denson	SCDNR	densonm@dnr.sc.gov
Patrick Geer	GADNR	pat.geer@dnr.state.ga.us
Peter Kingsley-Smith	SCDNR	kingsleysmithp@dnr.sc.gov
Richard Lee	University of Georgia Skidaway Institute of Oceanography	dick.lee@skio.uga.edu
Robin Frede	College of Charleston / SCDNR	frederl@g.cofc.edu
Ryan Gandy	Florida Fish and Wildlife Research Institute	ryan.gandy@myfwc.com
Shanna Madsen	Atlantic States Marine Fisheries Commission	smadsen@asmfc.org
Stephanie Robinson	NOAA	steph.robinson@noaa.gov
Stephen D. Taylor	NC Division of Marine Fisheries, Wilmington Office	stephen.taylor@ncdenr.gov
Susan Laramore	Florida Atlantic University (HBOI)	slaramo1@hboi.fau.edu
Tanya Darden	SCDNR	dardent@dnr.sc.gov
Todd Mathes	GADNR	todd.mathes@dnr.state.ga.us
Trish Murphey	NC Division of Marine Fisheries	trish.murphey@ncdenr.gov
Wally Jenkins	SCDNR	jenkinsw@dnr.sc.gov

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WORKSHOP AGENDA

WEDNESDAY APRIL 9TH 2014

8:30 Sign-In begins

SCDNR Marine Resources Research Institute, Main Lobby

9:00 Opening Remarks (MRRI Auditorium)

Dr Michael Denson; Director, MRRI, SC Department of Natural Resources
Dr. Peter Kingsley-Smith; SC Department of Natural Resources

9:15 Issues in Crustacean Management (MRRI Auditorium)

David Whitaker; SC Department of Natural Resources

9:45 Diseases Affecting Commercial Crustacean Resources (MRRI Auditorium)

Dr. Dick Lee; Skidaway Institute of Oceanography

10:15 Break

10:30 Effects of Habitat Loss and Modification (MRRI Auditorium)

Dr. Denise Sanger; SC Department of Natural Resources

11:00 Climate Change Effects on Crustacean Resources (MRRI Auditorium)

Dr. Dennis Allen; University of South Carolina—Baruch Marine Field Laboratory

11:30 Stock Assessment and Population Dynamics

John Carmichael; South Atlantic Fishery Management Council

12:00 Keynote Wrap-Up and Breakout Session Instructions

12:15 Lunch (provided)

1:15 Breakout Sessions

White, Brown, Pink Shrimp (Administration Building Conference Room)

Blue Crab (MRRI Classroom)

Horseshoe Crab, Stone Crab, Other (Marshlands House Classroom)

4:30 Breakout Session Progress Reports (MRRI Auditorium)

5:00 Poster Session and Mixer (SCDNR Outdoor Classroom)

6:00 Dinner (SCDNR Outdoor Classroom)

THURSDAY APRIL 10TH 2014

8:30 Breakout Sessions Continued

10:15 Breakout Group Report-Out and Discussion (MRRI Auditorium)

11:30 Resource Manager Panel

Trish Murphey (NCDMF), Wally Jenkins (SCDNR), Pat Geer (GADNR) & Dr. Ryan Gandy (FFWCC)

12:15 Closing Remarks

Dr. Peter Kingsley-Smith; SC Department of Natural Resources

12:30 Conference Conclusion

IDENTIFICATION OF RESEARCH PRIORITIES

Blue crabs

Disease

The discussion on diseases of blue crabs began by defining disease as any stressor that causes an abnormal pathological condition in an organism. Although it seems clear that not all the major diseases affecting blue crabs are known, it was agreed that the focus should be on *Hematodinium* and reo-like viruses (RLV). Spatial and temporal distribution of these diseases should be studied, with particular focus on areas where the diseases are intense (hot spots), identification of refuges from particular pathogens, and whether such refuges sustain populations. A key knowledge gap is the mechanism by which the diseases are spread (e.g., possibly as a result of crabbers culling diseased crabs and disposing of them overboard). It was suggested that interactions between diseases should be investigated, along with cumulative resilience to disease. Finally, it was concluded that the economic impacts of diseases, such as those on product quality and additional resource investments (e.g., time, fuel and other economic considerations) to ensure returning to docks with a full load, need to be better understood.

Approaches to investigating gaps in the knowledge of blue crab diseases include the use of current, ongoing crustacean monitoring programs to take routine samples (e.g., hemolymph) to identify disease distributions, and the archiving of samples for future processing to evaluate spatial or temporal disease patterns. Such an archive could be used to create a ranking system of disease presence throughout the South Atlantic Bight region to identify the areas in most need of attention. This effort would require regional coordination to determine which information each state or project already collects and what is needed to increase sampling effort. Although potentially difficult and time-consuming, inter-state consistency and standardization of data collection and sampling gear will be necessary within the entire South Atlantic Bight, especially if data are going to be compared within the region. Identification of standard disease markers would improve consistency. For example, samples currently collected by Georgia DNR, which monitors 42 fixed stations monthly, South Carolina DNR, through regular sampling cruises conducted by the Crustacean Research and Monitoring Section, MARMAP (Marine Resources Monitoring, Assessment, and Prediction), SCECAP (South Carolina Estuarine and Coastal Assessment Program), and SEAMAP (Southeast Area Monitoring and Assessment Program) could all be better utilized in this regard. It was suggested, however, that the cost of sampling for disease may exceed the current scope of these sampling efforts, depending on whether investigators are interested in a specific causative agent or a suite of potential diseases, as each sample could cost several hundreds of dollars, and diseases are often not detected during routine sampling.

Laboratory studies are another approach to studying the impact of diseases on crab populations (e.g., proportion of populations affected, rates of mortality, mode of transmission). In laboratory settings, multiple stressors, both biological and environmental, can be tested to provide a broader understanding. Environmental parameters routinely monitored during sampling (e.g.,

temperature, salinity, dissolved oxygen) can be informative for designing these experiments. Results from laboratory studies, particularly physiological studies, can then be used to create individual based models and scaled up to generate population dynamics estimates. Those estimates can then be included in a larger fisheries model to partition out the most impactful stressors when a diversity of stressors is present.

A number of resources were identified for laboratory work, regional coordination, data collection, and sources of funding. The Marine Resources Research Institute (MRRI) and Hollings Marine Laboratory in Charleston were offered as resources to conduct laboratory experiments, but the funding sources for such experiments have yet to be determined or secured. It will be important to gather baseline data to identify specific questions to study before seeking funding. Resources for regional coordination and data collection include the Florida Department of Environmental Protection (DEP, FL), Florida Fish and Wildlife Conservation Commission, water management districts, counties, ocean monitoring programs such as SECOORA (Southeast Coastal Ocean Observing Regional Association), CISA (Carolina Integrative Sciences & Assessments) and ASMFC (Atlantic States Marine Fisheries Commission). Information from commercial and recreational crabbers can be useful, but can also be inconsistent and unreliable. It was suggested that coordination between Sea Grant and crabbers to develop improved fishing practices would be helpful. The need for a blue crab working group to improve regional communication was recognized, but how the group might be funded was questioned, particularly since crabs are managed by individual states rather than at a regional level. The Blue Crab Subcommittee of the Gulf Marine Fisheries Commission, which sometimes uses inter-jurisdictional funding, is an example of a possible funding mechanism. Commissioners prioritize these funds, however, and most funds are appropriated for larger finfish species rather than towards crustaceans.

Habitat Condition and Loss

Knowledge gaps with respect to habitat condition and loss were also discussed in the breakout session. For example, understanding the relationship between precipitation levels, associated runoff, and subsequent population estimates could help inform how blue crabs choose nursery sites. In addition, how different environmental conditions within specific habitats influence growth rates, survival rates, and population dynamics need to be studied. Although there is evidence that blue crabs are in general distributed based on water characteristics such as salinity and dissolved oxygen levels, bottom type and quality may also play a role. Research on predator-prey relationships is also needed to more fully understand how blue crab diets in different habitats affect those habitats, but also to better understand the role of blue crabs as prey organisms. Additional work is needed to understand the response of larval crabs to changing water conditions (e.g., position in the water column and prey availability and type), including the effects of pollutants (e.g., methoprene as a mosquito pesticide), which are heavily influenced by anthropogenic forces. Investigating other anthropogenic effects on habitats utilized by blue crabs is also important. In South Carolina a significant yet under-reported winter offshore

harvest occurs, but these offshore blue crab habitats are not well understood in terms of their environmental or community characteristics.

To gain a better understanding of the habitat requirements of blue crabs, it will be important to identify those factors that drive population densities in different habitats. It was suggested, however, that the same attributes that make blue crabs able to thrive in different habitats are the ones that make them difficult to study. Blue crabs are highly mobile generalists. They live in a wide range of habitats and are able to move to more beneficial areas if they experience habitat loss or degradation. This gives them an advantage over more sedentary and sessile species, but can make sampling and the interpretation of results difficult. Nevertheless, evaluating the habitat characteristics that are assumed to be drivers of natural population abundances in laboratory tests may provide a greater understanding of those factors that control differing crab populations within and between habitats. Established monitoring programs (e.g., SEAMAP and SCECAP in South Carolina) can provide information about habitat use by crabs.

This information could be used to create a state of knowledge report (e.g., "Ecology of Blue Crabs in the Southeast") specific to different habitats to serve as a baseline of general knowledge and to identify information of key importance to researchers and managers. Since the number of studies that have documented the impact of habitat change on crustaceans is low, using "snapshots" of previous work and comparing data, such as those provided by current monitoring programs, along a latitudinal gradient could inform researchers on habitat preferences of blue crabs. The SEDAR approach, in which all parties that have available data to contribute are involved in determining how to effectively use those data to inform management decisions, is an example of how efforts might be directed. It was generally agreed that there is a need for a data workshop to discuss the issue and to produce a report.

Available resources identified to address knowledge gaps surrounding blue crab habitat use and loss included opportunities for data mining of historical data where crabs were present, gut content and analysis in laboratories (e.g., University of South Carolina, MARMAP, University of North Carolina-Wilmington), and long-term ecological research (hereafter LTER) sites (e.g., North Inlet and ACE Basin in SC, Sapelo Island in GA). The Coastal Habitat Protection Plan, developed in NC, may be a good model for how to structure recommendations, and Sea Grant could be a good source of funding.

Climate Change

One potential influence of climate change on blue crabs may be related to changes in coastal ocean circulation and resultant impacts upon the recruitment of megalopae. A recent study has indicated that the Gulf Stream Index (GSI; i.e., position of the north wall of the Gulf Stream) is correlated with blue crab abundance in the Carolinas. The GSI is further related to the North Atlantic Oscillation, which is influenced by the global climate, and thus could potentially be impacted by climate change.

A consequence of climate change that will affect habitat availability for blue crabs is sea level rise (SLR). SLR will inundate marshes that are integral to different life stages of the blue crab. The effect of coastal squeeze, where habitats are prevented from migrating landward under scenarios of SLR as a result of the installation of engineered, hardened structures, such as bulkheads and sea walls, will need to be addressed. However, properly managing these marshes in the face of SLR, while at the same time protecting estuarine habitats, will be problematic. Climate change scenarios generally predict an increase in the number of weather extremes, but how those extreme events will affect abiotic conditions (e.g., salinity, temperature, freshwater input) and consequently biotic factors (e.g., reproductive outputs, predator abundance, prey abundance and community interactions) will require further study. The impact of ocean acidification, due to increased CO_2 levels in estuarine environments, on blue crabs needs further study.

In order to better understand the impacts that SLR may have on estuarine habitats, models incorporating GIS work and LIDAR surveys of critical habitat and geomorphological data, as in the ACE Basin NEER, will be necessary to inform decisions about research needs with respect to climate change. NOAA's Coastal Services Center has produced a model to look at rates of SLR along the Atlantic coast, which could be used as a predictor. Sampling in LTERs (e.g., Winyah Bay, SC) allows researchers to observe natural changes as these locations are relatively undisturbed and represent some of the most pristine coastal environments that are regularly monitored. Manipulative field experiments should be conducted to determine whether blue crabs shift habitats in response to SLR. As blue crabs use both oyster beds and marsh grasses for habitat, current research on the shift of oysters and *Spartina* further up the shoreline may prove to be a proxy for information on blue crab habitat movement in response to SLR. Researchers can also manipulate multiple environmental conditions in laboratory studies to determine the effect of different stressors on blue crabs. Michael Childress (Clemson University) is currently working on a spatially-explicit, individual-based population model that examines the impact of climate change on blue crab growth, parasitic infection, and predation as it interacts with current fishing practices.

The value that society places on estuaries was also a topic of discussion. Anthropogenic changes to the shorelines, due to hardening and beach renourishment, will likely continue, and mitigation will require time for properly functioning wetlands to develop. It is imperative that society recognizes and supports both blue crab fisheries and the preservation of habitat that will promote not only healthy blue crab populations, but also populations of many ecologically, recreationally, and commercially important vertebrates and invertebrates. Although NOAA has some limited economic and jobs data, more economic studies to quantify the societal value of estuarine habitats, fisheries, and maritime jobs are needed. It was suggested that blue crabs are generally overlooked as agencies believe that other agencies or researchers are paying attention to them. This breakdown in communication seems to suggest that this fishery is in need of a more organized hierarchy, especially when identifying those who are responsible for its management and making sure that the opinions and concerns of the fishermen are heard.

Working with county planners to investigate vulnerabilities and consequences of the effects of SLR on estuarine habitats under various "what-if" scenarios was identified as an important approach. SLR will inevitably require changes in infrastructure (e.g., roads, causeways, etc.), and the public will be required to pay for those changes. Convincing coastal residents that they have a stake in these changes would be helpful. Working with both planners and the public in the initial phases of planning may provide an opportunity for the inclusion of habitat preservation mechanisms in the design phases of plans, particularly if the general public is supportive. Counties also often have funds set aside for environmental work, so approaching them for funding may be an option. It will also be important to develop partnerships with alternate private sources of funding to get people invested in research. Organizations interested in climate change have money for research, but they often do not know who to give their money to, what studies are being done, or what data have already been collected. Communication with these organizations is key, and stronger collaborative efforts among southern states, working as a single unit, will be necessary to secure support.

Although there is an abundance of climate change research being conducted, effective synthesis of the data is lacking, such that accessing the relevant data can be problematic. A regional group such as SEERS could be effective at bringing academic, government, and private sector research contractors, and their resources, together. It was suggested that federal resources tend to be directed towards needs on the west coast because that region is more predisposed to ocean acidification, while the southern coast is more susceptible to SLR. NOAA's Southeast and Caribbean Regional Team (SECART) and the relatively new Governor's South Atlantic Alliance are two bodies that could petition for resources to be directed to the southern region.

Stock Assessment

The stock assessment portion of the blue crab breakout session began with a discussion of what the different states are currently doing. North Carolina conducts a traffic light assessment (an ASMFC-approved, statistically-robust approach for incorporating multiple data sources, both fishery-independent and –dependent, into a single, easily understood metric) through its six monitoring programs and has data going back to 1956. South Carolina has fixed station trawl sampling data going back to the 1960s. Georgia, whose trawl sampling dates back to 1976, is conducting a stock assessment and moving towards a traffic light assessment. Florida is currently conducting a stock assessment using a catch survey analysis (CSA) from standardized data going back to the early 1980s. It was concluded that since each state has a data collection mechanism in place, a coordinated effort to share data would be useful. Consideration might even be given to the development of fishery management plans (FMPs) by individual states, as has been done in North Carolina. Regional data workshops modeled on the SEDAR process, with life history, commercial landings, recreational landings, and fisheries independent data (indices) as components in their approach, could highlight most of the gaps in stock assessment data. In a preliminary workshop, data could be compiled in order to identify missing data and to help focus time and resources.

Several knowledge gaps in regards to stock assessments of blue crabs were identified. Firstly, while blue crabs are managed at the state level, it is currently unclear if South Atlantic Bight blue crabs represent one stock or several stocks; determining effective population size and population structure through genetic techniques will be necessary in order to elucidate how to define "blue crab stock". Such genetics work is ongoing at the Marine Resources Research Institute (MRRI) in Charleston, SC. A better understanding of the relationship between gravid females and larval recruitment to estuaries is needed, and identifying a standardized sampling gear for larval crabs (zoea and megalopae) may be necessary. The need to survey smaller crabs (<50 mm carapace width) to determine recruitment and survival in different habitats was also identified. In an investigation of the distribution of the various blue crab life stages, data on habitat characteristics (e.g., bottom type) may be useful for extrapolating where the different life stages are concentrated along the coast. It must be recognized, however, that blue crab larvae successfully recruit to a wide range of habitats.

Uncertainty in stock assessments is to some degree a result of unreliable estimates of recreational take, discards, and natural mortality. Surveys of recreational crabbers and commercial landings numbers are often inaccurate. Although enumeration of recreationally and commercially deployed crab pots is sometimes undertaken, estimating recreational take by dip nets, seines, drop nets, and other methods is difficult. It was recognized that working with recreational and commercial crabbers can be challenging, but it was suggested that ride-alongs with specific, reliable crabbers to gather discard data could prove useful, though potentially expensive. Furthermore, tag/release studies with blue crabs are often unsuccessful because recapture rates tend to be low. Without reliable natural mortality estimates, the incorporation of such metrics into individual based models can make these models unreliable.

Other knowledge gaps that were identified included the extent of winter harvesting of predominantly female crabs offshore, and the harvest of immature female peeler crabs, in South Carolina and Georgia, and the effects that these harvest methods have on the recruitment of larvae to the population. To more fully understand the impact of the commercial peeler crab harvest, better reporting of mortality from shedding facilities is also needed.

Many resources were identified for blue crab stock assessment assistance. University, state, county, Sea Grant, SEAMAP, and bycatch databases could again be useful for data mining. Southeastern Estuarine Research Society (SEERS) and the Fisheries Workers Associations would be good forums for technical workshops. The ASMFC currently assesses horseshoe crabs, so that effort may be used as leverage when requesting additional blue crab monitoring resources. Some state level funding was recently made available for blue crab research. For example, North Carolina was recently funded to revive programs to sample oyster and crab life history stages. Also, SC Sea Grant Consortium recently funded a project at the MRRI to develop genetic techniques to study blue crab population size and structure, while NOAA and the Cooperative Research Program (CRP) have also funded small scale projects on blue crabs.

These smaller projects often provide opportunities for outreach through engagement with the public and yield public relations benefits.

This session concluded with general agreement that reliable baseline population data are needed before asking more specific questions. Commissioners and funding agencies want hard data on the state of resources rather than predictions. Once baseline assessment data are known, models can be developed using appropriate data provided through experiments.

Penaeid shrimp

At the outset, a decision was made by the penaeid shrimp breakout group to discuss two additional topics, namely: 1) stakeholders, advocates and NGOs (Parker); and 2) commercial fisheries and related issues, with particular attention given to the decline of the trawling industry and support for the industry (Whitaker).

Disease

The discussion of shrimp diseases was generally limited to black gill disease (BGD), although there was recognition that researchers are unaware of all of the potential diseases that are "out there." The question of where the disease originated is often asked by the public and cannot, at this time, be answered. Suggestions were shifts in global distribution of organisms due to climate change, ballast water exchange introducing non-native species, and the use of imported shrimp for bait. Dr. Dick Lee suggested that BGD may have appeared due to increased virulence from an evolved strain, possibly something previously benign, or as the result of environmental triggers. Questions on how the disease is transported, a clear understanding of the life cycle, particularly during times when it is not prevalent in the host shrimp, and the mechanism of virulence also remain unanswered. The causative agent of the disease has generally been hypothesized to be a specific apostome protozoan. Although this ciliate has been shown to be associated with BGD, questions remain about its virulence and global distribution and whether it is opportunistic and secondary in nature, taking advantage of existing gill damage due to stress from another pathogen (e.g., bacteria such as *Vibrio* spp.). It was questioned whether BGD was even caused by a marine parasite. Distribution of the disease regionally was also discussed; BGD is sometimes observed in southern North Carolina and northeast Florida, but is generally ubiquitous in South Carolina and Georgia. If that is the case, research is needed to determine what factors make those states focal locations for BGD.

Other knowledge gaps concerning BGD include the size vulnerability of shrimp, mortality of shrimp in the wild, and sub-lethal effects. It was suggested that although smaller shrimp may be prone to contracting the disease, more frequent molting may make observation of the disease difficult. Mortality of shrimp in the wild is unknown, since dead shrimp are not collected in samples. Susceptibility to predation in weakened shrimp may explain the lack of collection, although it was noted that infected shrimp in captivity are often difficult to catch in aquaria, and that one would expect to see mortality of stressed BGD infected shrimp during trawl sampling. Sublethal effects may include negative effects on reproduction, wherein increased energy

expenditure in excessive molting leads to reduced reproductive potential, thereby affecting recruitment in the following year. Observation of BGD in spawning white shrimp is uncommon, though, based upon frequency of melanized gills in fisheries independent sampling in SC. The ability of shrimp to recover from the disease also remains a question. The group discussed the need for more transmission studies, particularly since work at the Skidaway Institute of Oceanography (Frischer and Lee) suggests that shrimp exposed to infected heads can contract the disease. Based on the theoretical life history of the causative agent of BGD, under natural conditions it is likely that greatest transmission occurs in association with molting.

A number of approaches were suggested to address these gaps in the knowledge. Development of genetic techniques, such as those currently being developed at Skidaway with funding from GA Sea Grant, may help to determine the origin of BGD. Current sampling programs offer only a snapshot of what is happening, so increases in sampling effort, perhaps weekly, at standard stations from the tidal creeks to the ocean would be useful to better understand the distribution of the disease and rates of infection. If geographical and temporal "hot spots" can be identified, they could be more intensively studied, although this would require a significant commitment of resources. Current temporal and spatial water quality monitoring programs, such as in those in the five National Estuarine Research Reserves (NERRs) in the region, are an available resource to document water quality conditions at the time of BGD outbreaks. Coastal surveys may be able to identify "hot spots". SEAMAP survey data may also be collected at virtually no additional cost, and may provide information on habitat differences. Both Georgia and South Carolina have regular shrimp trawl surveys that could perhaps be used to identify temporal and spatial distributions of the disease. In addition, North Carolina has a juvenile trawl survey (May and June) and the Pamlico Sound survey (June and September). It is important for researchers on sampling cruises to look for the disease, if they are not already.

Collection of daily records from commercial shrimpers should continue, and the use of Cooperative Research Programs (CRPs) should be explored. It was suggested that commercial shrimpers and bait dealers could be recruited to assist in an epidemiological approach, but there was concern about the reliability of fishery-dependent data collection. In a cooperative research project in South Carolina, however, data collected from trawler captains in South Carolina closely mimicked data recorded by DNR biologists who examined frozen samples from those captains. These captains were compensated, and a similar arrangement for compensation would likely be necessary to ensure dependable participation.

In order to conduct proper transmission studies, holding uninfected shrimp to serve as control organisms will be necessary. It may be possible to "clean" wild shrimp, though it was suggested that this technique is unreliable. Use of cultured shrimp would be more effective. Transmission and stress studies could potentially be conducted at the MRRI, and field (caging) studies, though costly, could be conducted throughout the region.

One approach to studying BGD supported by some shrimpers would be to harvest smaller shrimp earlier in the year, before the disease is pervasive, but market forces would likely make that

option much less profitable since larger shrimp typically are much more valuable. It may be more profitable to focus trawling on smaller shrimp if BGD leads to mortality in a significant portion of the larger shrimp, particularly if the current market price for small shrimp is higher than normal.

Shrimpers comment that they worked the sounds for 40-50 years before those sounds were closed to harvest and first observed BGD only recently. They propose a linkage between these observations. Some shrimpers are suggesting that they be allowed to effectively mow or till the sounds to "clean them out", but there is concern among others that stirring up the sediment would release more of the disease and potentially exacerbate the problem. Whether or not the sediments harbor the disease is unknown. Tests on the presence of the disease in sediments could be conducted, but the causative agent must first be positively identified. The question was then asked if BGD is more prevalent in untrawled areas than in trawled areas. In Brunswick County (GA), there is reduced inshore trawling, but BGD is still present. Data mining may provide further answers to questions surrounding these relationships.

The SEDAR workshop in July 2014 was highlighted as a good venue for introducing the need for more data collection related to BGD.

Habitat Condition and Loss

The group discussed what generally constitutes suitable habitat, what the boundaries of that habitat are, and the need for a clear understanding of the overarching habitat needs of various species at different points in their life cycle.

A number of causes of habitat loss, anthropogenic and otherwise, were discussed. Physical anthropogenic impacts discussed were related to development and associated infrastructure needs: dredging, particularly adjacent to wetlands; beach renourishment; sedimentation, often caused by runoff from upland development; causeway construction, resulting in reduced flow rates in affected tidal creeks and possible effects on submerged aquatic vegetation (notable for pink shrimp in NC); upland hardening, which limits migration of wetlands; and marsh impoundments, which though no longer allowed to be constructed, still exist, and are not necessarily managed in the best interest of shrimp populations. Chemical contaminants (e.g., endocrine disrupters, insecticides) may also affect shrimp abundance. A lack of understanding of the effects of fluctuations in freshwater (and potentially temperature) input to wetlands was also discussed, both in terms of increased input from stormwater runoff and also decreased input as upstream freshwater is extracted for anthropogenic uses. An example given was a proposed large-scale potato farm in the upper watershed of the Edisto River (SC) that would extract billions of gallons of water per year. The breakout group also briefly discussed the potentially negative impacts from out-of-basin transfer of water such as proposals to direct Savannah River water to metropolitan Atlanta. Smaller scale issues such as shoreline destabilization due to boat wakes can also have negative impacts on marsh edges, which are known to be important habitats for juvenile shrimp.

To begin to understand what constitutes suitable habitat for shrimp, it is important to characterize habitats in various systems and to attempt to correlate those results with related shrimp abundance and landings. Methods could then be developed to track changes in habitat "health" over time, leading to the development of predictive models for system drivers (e.g., salinity and temperature). Re-evaluating data surveys such as essential fish habitat (EFH), or other critical habitat assessments, based on new and existing data, and relating those to changes in water characteristics (e.g., salinity and temperature) would also be useful. North Carolina is identifying Strategic Habitat Areas (SHAs) by examining abundance data and threats (e.g., storm water) and testing models. Much can be learned from a GIS approach, where data sets are collected and updated, thus enabling creation of new data layers. Legal approaches for habitat protection also exist, and the implementation of critical habitat for loggerhead sea turtles could be a useful model in this regard. Local government interest in stormwater management through retention pond construction and other strategies offers a similar opportunity. Scientists and managers need to educate the public and decision makers so that they understand the critical habitat needs of shrimp.

Many resources are available for consideration. Organizations such as SECOORA (through the Governor's South Atlantic portal), National Oceanographic and Atmospheric Administration Coastal Services Center and ASMFC (with web-based mapping) are sources for GIS data. State programs, National Estuarine Research Reserves (NERRs), and Sea Grant programs are useful for public education and possibly for funding. For example, state saltwater license revenues are currently being used to create "living shorelines" through oyster reef restoration. Funding could also be provided by EPA for habitat restoration projects and through mitigation funds from public projects (e.g., Savannah harbor deepening). NGOs, such as The Nature Conservancy (TNC), the Southeast Aquatic Resource Alliance, and Southeast Landscape Conservation Cooperative, (LCC) also represent potentially valuable resources and collaborators.

Climate Change

The effects of climate change on oceans and estuaries are, in many ways, not well understood, though latitudinal differences are broadly recognized. The changes occurring in the southeastern United States are different from those occurring in the north, and ocean acidification, which may not be an issue in estuaries due to buffering capacity, may have effects offshore. One potential limitation in our future knowledge, largely due to funding, could be the availability of long-term physical (e.g., temperature), chemical, and biological (e.g., ichthyoplankton) data. A trend of significant increases in the intensity of stochastic weather events, and potential effects on rainfall patterns, could have substantial impacts on annual species, especially in nursery habitats, resulting in major impacts on the fisheries. Neither the degree to which stocks will be impacted by the shifts, nor the long-term economic impacts, are known. The potential for shifts in prevailing winds and circulation of coastal waters also exists, and implications for larval migration patterns are unknown. In addition, broad scale changes in ocean currents (e.g., the Gulf Stream) can greatly affect larval distribution. A changing climate could lead to regional

shifts in fisheries, either northward or southward. It was suggested that the main component of shrimp distribution may shift northward in response to climate change. Some species also migrate south to avoid periods of extreme cold during winter, so the possibility of southward shifts also exists. There have been recent southward shifts into Florida (e.g., black sea bass), but the shifts may not be driven solely by temperature. Much about the physiology of shrimp, and how they will respond to these broad scale changes, remains unknown. It will be important to conduct more laboratory and field studies, and then to determine the degree to which laboratory and field data can be correlated. Climate change could also have major impacts on the diseases of shrimp and other crustacean species. Longer summers and/or colder winters may create stressful conditions and lead to disease outbreaks. Disease outbreaks may also result from the introduction of new organisms and parasites.

Finally, the effect of sea level rise on estuarine habitats was discussed. It is unclear whether there will be more or less marsh habitat available, or how crustaceans will cope with these changes. Likely the changes will be good for some species and bad for others.

The overarching theme in approaching climate change research was the need to bring scientists (state agencies, fisheries managers, academics) together to develop strategic planning for long-term observations, to develop programs to collect relevant data, and to identify what the potential problems are in the southeastern United States. A clear vision of those problems will be necessary to compete for funding with the northeastern United States because impacts in that region are currently more clearly defined. The American Fisheries Society could be a venue for bringing scientists together, possibly with the goal of developing a coastal chapter in the southeastern United States. Historically, shrimp fisheries have been reliable and to some extent therefore have been taken for granted, but in the last 15 years harvests have been more variable. It will be important to enlighten the public, as well as funding sources, that crustaceans are a significant part of the marine food base. A system-wide approach to crustacean research, focused on important ecological interactions (ecosystem services), as well as quality of life issues, have the best chance of success with respect to climate change funding. The key is to connect scientists regionally, and to show that there is concern about the health of crustacean stocks. Although in some cases scientific areas (academic and management) may be fractioned, there is not a shortage of fisheries scientists in the community. That community is variable in space and time (e.g., possible shortage of taxonomists in the region), but researchers now are willing and able to interact to some degree. For example, in South Carolina the academic community has lost most of its fisheries scientists, but that expertise now largely resides within the SCDNR. An opportunity also exists to engage the public sector, and one way to seek funding might be to approach corporations with a vested interest in fisheries (e.g., Pure Fishing, Inc., Columbia, SC), and encourage them to fund endowed chairs (e.g., taxonomists).

To better understand how climate change may affect shrimp populations, a modeling approach in which year classes (cohorts) are studied can be adopted. Those models require long term datasets that incorporate biological and physical/environmental data. Many of those datasets

exist through state surveys, SEAMAP (from the 1980s), NEAMAP (Hatteras to Cape Cod, with sex ratio, length, fecundity, disease, etc., data), NOAA sentinel sites, NERRS, the NSF LTER network, the Long Term Research in Environmental Biology (LTREB) program, and various marine laboratories (e.g., the Baruch Laboratory in South Carolina and the Rutgers Science Collaborative Project) which could provide baselines. Developing an inventory of these various datasets is crucial. NGOs and citizen science groups could also be useful for future data collection.

Stock Assessment

The difficulties in modeling annual crops, such as shrimp, were initially discussed in this session as there is no direct demonstrable relationship between consecutive year classes. By the time managers have the results of a stock assessment, those results are not likely to be indicative of current conditions because of substantial year-to-year variability. Environmental factors play a major role in influencing shrimp populations, so inclusion of relevant environmental data is critically important for an understanding of shrimp population dynamics. These difficulties in modeling of annual species can make appropriately timed management decisions challenging. To begin to develop a model, though, an understanding of the spawning stock is needed. While that is possible with white shrimp, such an assessment of brown shrimp spawning stock is problematic. Many brown shrimp are found in the summer, but it is unclear whether those individuals are indeed the spawning stock. Important research questions are the location of functional spawning stocks, how functional reproductive units are delineated (by sound or by region) and whether there are source or sink populations. For example, it was suggested that the Pamlico Sound (NC) population could be the spawning stock for the south, given that large brown shrimp are typically present in the NC sounds during fall (the believed spawning season), but are less abundant south of North Carolina during fall in inshore waters.

Questions remain about the mechanisms of shrimp larval dispersal and spatial mixing. To better understand migration and dispersal patterns, shrimp mark-recapture and population genetics studies may be valuable. Comprehensive resource studies can also be conducted, possibly using juvenile shrimp as a proxy for larvae, since juvenile shrimp (40-80 mm body length) sampling data correlate fairly well with commercial CPUEs. Population genetic structure studies for shrimp are somewhat lacking, though studies to date suggest good mixing among Atlantic coast populations. It was suggested that shrimp may be entirely different from finfish in terms of genetic analyses. For many finfish stock assessments, bycatch needs to be considered. The effects of bycatch in the fishing industry on shrimp populations are unclear, although studies have suggested that removing certain predators (e.g., snapper) has increased the survival of some species.

Other problems exist which make a useful stock assessment challenging. The degree of recreational harvest of shrimp stocks (e.g., deep-holers) is uncertain and commercial harvest CPUEs of shrimp to be used as bait are inconsistent or lacking. In addition, biological sampling of commercial catch is generally insufficient to provide highly reliable information on size and

species composition, particularly in August and September when both species are landed concurrently. Managers sometimes use fishery-independent sampling as a proxy for speciation of commercial harvest. More detailed reporting of commercial catch and intensification of port sampling are needed. Electronic log books on commercial vessels could be useful to better understand changes in relative abundance, emigration timing and rates, and seasonal distributions. A large portion of the trawl fleet is comprised of small trawlers (including outboard-powered boats), however, making electronic reporting from the boat impractical. Reporting of CPUE is also important, and should be standardized. Some states already have 10-12 years of effort data, and coordination of landings data collection among states will be important.

Development of modeling methods that are appropriate to annual shrimp stocks is necessary, possibly incorporating a spawn-recruitment model, but the challenges with that approach are well recognized. A catch-at-age model using salinity, temperature, and juvenile index may be more informative. Ultimately, ecological and environmental data will need to be added into models (ecosystem based models), since variability and baseline shifts will affect the models. It may be necessary to develop new approaches for how stocks are assessed and a completely new paradigm to properly model shrimp stocks. Finally, proper management policies must be developed, such as reconsidering how shrimp are treated under the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 with regards to defining overfishing.

In discussing available resources to address stock assessment questions, it was suggested that a lack of stock assessment biologists is a significant problem. The Atlantic Coastal Cooperative Statistics Program (ACCSP), however, is a useful resource for understanding the importance of species-based landings data. A recent stock assessment of pink shrimp in the Gulf of Mexico, although raising some questions, may be used as a model for the South Atlantic Bight. Cooperative Research Projects may be a significant resource to provide funding for electronic logbooks, and possibly for sample collection and genetic analyses. It was also suggested that Sea Grant may be the crustacean equivalent to MARFIN (NOAA Marine Fisheries Initiative), and therefore represents a valuable resource for potential funding.

Commercial Fisheries

The shrimp breakout session ended with a discussion of the state of the commercial shrimping industry. Lack of investments, loss of infrastructure, and high fuel prices have led to chronic problems in the industry, with 5-10% reductions in licenses each year. Rather than purchasing new boats, shrimpers are repowering, retrofitting, and renovating boats. Increased regulation and standards in ship building make new boats expensive and purchases unlikely. Questions about the economic viability of the fishery raise the issue of limited entry, which has become a contentious subject. It was asked whether it is better to have 100 people making a good living or to have 400 people in the fishery who are struggling financially. Conflicts also exist between different user groups (e.g., cast netters vs. trawlers) and raise the issue of equal access vs. equal

catchability, but also between market outlets (e.g., people selling shrimp out of coolers on the side of the road). These conflicts lead to questions surrounding the proper management of the fishery, and indeed the proper role of management in helping the industry. In many instances, what states do to manage the fishery is contrary to the Magnuson Act, and underreporting and lack of consistency among states makes management difficult. Although managers can recommend solutions to the industry (e.g., smaller boats, modifying fishing behavior, etc.), those recommendations are often met with resistance from fishermen. Market forces, within the confines of regulatory constraints, will ultimately determine who survives in the industry. Government assistance, however, through various programs (e.g., EPA helping to pay for more efficient engines, similar to "cash for clunkers") may be helpful.

The effect of cultured shrimp on the marketing of domestic shrimp was also discussed. For the viability of the fishery, marketing which puts a high value on domestic, wild-caught shrimp over imported shrimp, is necessary. Most people buy cheaper shrimp, such that niche marketing of wild-caught shrimp is a commonly used method to support higher prices. A recent disease epidemic (Early Mortality Syndrome – EMS) from a mutated form of *Vibrio parahaemolyticus* has led to billions of dollars in economic damage. Such outbreaks may lead to a greater use of antibiotics in cultured shrimp, a practice that may lead to a demand for the expansion of the wild-caught shrimp market. Rather than selling to institutional buyers, some shrimpers are successfully fishing on contract, meaning that they will only harvest what is on order, thus avoiding "random sales." Direct marketing in this manner may become a more common strategy among shrimpers.

Horseshoe crabs

Disease

Although work has been conducted in New England on epizoites of horseshoe crabs (hereafter HSCs), not much is known about what species of epizoites occur on HSCs in the southern United States, nor about their effects on HSCs. Since three species of Asian HSCs are imported (dead) for bait, the question was raised about potential disease transmission to native organisms and the potential physiological impacts. Information about the relationship between flatworms and HSCs is also lacking, with some reporting this as a commensal relationship while others stating it as parasitic in nature. Approaches to investigating epizoites (both native and introduced) include conducting thorough life history surveys, a graduate student project to compare current and introduced epizoites, and a population genetics study of epizoites. Potential resources are John Zardus (genetic studies of epizoites), the SCDNR Genetics Group (for population genetics work), and the Southeast Regional Taxonomic Center (SERTC) in Charleston (MRRI).

Habitat Condition and Loss

The effect of habitat loss (e.g., from beach renourishment, channel dredging, development/shoreline loss) on reproductive performance (i.e., suitable nesting sites) was raised as a concern. Studies in the north (e.g., Delaware Bay) have determined that large numbers of

HSCs are found in channels, such that mortality can occur during dredging operations. Many aspects of habitat utility are still unknown for South Carolina's HSC population, such as habitat use by non-breeding adults and juveniles and the degree of site fidelity among breeding adults. Answers to these questions would be relevant to ASMFC and the individual states' management of HSCs. Identifying suitable habitats might be possible using aerial photos, GIS surveys, side scan sonar, and/or satellite tags. It is important to identify critical habitat for all life stages. With funding from Endosafe, a commercial HSC biomedical bleeding operation, the SCDNR is currently looking at HSC nesting abundances on beaches in Beaufort County and collecting core samples from nesting sites to determine egg production from area beaches. Additional funding from Endosafe or the Army Corps of Engineers may be available in 2015-2016. The SCDNR also has seasonal helicopter flights and benthic GIS maps available. A paper by Mark Thompson and Betty Wenner quantified nesting of juvenile HSCs in South Carolina in 2001 (Wenner *et al.*, 2002, "Evaluation of an alternative harvesting methodology for horseshoe crabs and determination of juvenile life history parameters in a nursery habitat." NMFS/NOAA S-K Grant NA07FD0174 Final Report).

Climate Change

The effects of climate change on HSCs are also of concern. The potential effects of sea level rise (SLR) and increased storm dynamics (leading to strandings and egg washout) on nesting beaches remain important questions to be addressed. The effect of ocean acidification on the physiology of both adults and juveniles and the role of temperature extremes on phenology (e.g., time of mating) and prey distribution are further gaps in the knowledge. HSCs are known to feed on a particular clam in the north (e.g., Delaware Bay), but what they feed on in southern waters is not well understood. Researchers could use stable isotope analyses of diets and DNA techniques to address these gaps. Laboratory-based studies could help answer questions about the effects of ocean acidification on physiology, while modeling studies could be used to study the effects of projected SLR on nesting beaches. Researchers could also look at replenished beaches to study the potential creation of new beaches under different scenarios of SLR. Research in Delaware Bay (e.g., by M. Botton), NOAA SLR modeling, and federal replenishment projects in the northeast due to Hurricane Sandy (funded by NOAA and Army Corp of Engineers) could provide additional useful information in answering these questions.

Stock Assessment

With regard to HSC stock assessments, questions remain on the status of the stocks, where those stocks divide, and how individuals move between areas. These lead to questions about gene flow and habitat use. Further questions about effective population size (i.e., the number of breeding adults contributing to the population), population genetic structure, and the genetic diversity of juveniles and adults also remain. Data on female fecundity (e.g., number of eggs per spawn, multiple clutches per season), growth and age at size, and mortality as a result of bycatch in trawls are also lacking. It was suggested that modifications to turtle excluder devices (TEDs) may reduce bycatch mortality. The effects of bleeding on female fecundity are also unknown.

Field sampling (e.g., size, sex, abundance) and mark-recapture studies are needed, although the recapture rate is fairly low (4% according to Larry DeLancey, 2010 study). Sonic tagging combined with population genetics work using microsatellites also shows promise. Use of existing datasets (e.g., SEAMAP, GADNR, SCDNR) may be informative. Mark-recapture data from SCDNR, as well as data from the USFWS HSC tagging program, GADNR surveys, SEAMAP, SCDNR Inshore Fisheries, the State Wildlife Action Plan, and funding from Endosafe are valuable resources. Students could also be enlisted to assist with all future studies.

Fishery and Industry Practices

The topics of the commercial fishery and industry practices were added to the agenda and discussed. Most of that discussion focused on better reporting of harvest data (e.g., location of harvest, number harvested, effort), where the dealers return bled HSCs, and the fate of individuals after bleeding (e.g., fecundity, growth rate, behavior, physiology, immunology, spawning and reproduction). Questions remain about the effect of male-only harvest, ways to reduce mortality during transport, and the impact of the shrimp trawl bycatch. Additional work is needed on handling mortality, bleeding mortality, post-rejection mortality, and tracking of animals after handling. It was suggested that a prohibition of the harvesting of females until after they have spawned is a possible approach (see Wenner *et al*., 2002 referenced above) to protect this resource. Previous work by Watson *et al.* and Wenner, volunteers, observers (for bycatch data), funding from Endosafe and SCDNR Office of Fisheries Management, as well as student research, were offered as resources.

Stone crabs

Hybrids

Two species of stone crabs that may hybridize occur in the southeastern United States, and these two species, and potential hybrids, use different habitats. A better understanding of how the species and hybrids interact with one another is needed. So in considering the following subjects, it is important to consider how hybrids and individual species are affected and how they relate to one another.

Disease

Questions remain about whether stone crabs can contract black gill disease (or if they are carriers/reservoirs) or blue crab diseases (e.g., *Hematodinium*), the causes of the infection that can turn their exoskeleton black (e.g., chitinoclastic bacteria, water quality), and the effects of epizoites (e.g., barnacles) and parasites (e.g., rhizocephalans). It is also important to study the potential for infection following claw removal. Histological and PCR/qPCR approaches were suggested to look at diseases, as were laboratory studies on claw removal with subsequent blood analysis. A literature review of relevant disease topics specific to stone crabs is needed. Available laboratory resources include the Hollings Marine Laboratory for PCR/qPCR analysis, the SCDNR Marine Resources Research Institute (Dr. Amy Fowler), the Skidaway Oceanographic Institute (Dr. Dick Lee), the University of South Carolina (Dr. Blaine Griffin),

the USC Baruch Marine Lab, the NOAA Oxford Laboratory, the Virginia Institute of Marine Science (Dr. Jeff Shields) and the College of Charleston (Dr. Isaure de Buron).

Habitat Condition and Loss

In South Carolina, stone crabs prefer oyster reefs and live on sandy/shell hard bottom. They can survive intertidally, but prefer subtidal habitats. It is important to better characterize their habitat preferences, however, both spatially and temporally for possible differences in size, age, morphology, hybrid identification, and sex. It is also important to better understand the impacts of dredging and beach replenishment on preferred stone crab habitat. To better understand habitat preferences and requirements on a large scale, researchers could use side scan sonar, DIDSON imagery, sonic and/or satellite tags, and mark-recapture studies. Elizabeth Duermit (College of Charleston graduate student) is currently conducting such a study in the Stono River. Other resources include USACE (Army Corps of Engineers), the SCDNR (bottom type mapping), and the College of Charleston Geology Department (Dr. Scott Harris).

Climate Change

It was asked whether climate change could benefit stone crabs. The range of stone crabs may be expanding northward with increasing temperature, and this increase in water temperature may have positive effects on fecundity, mating, and molting. The effect of ocean acidification on stone crabs and their bivalve prey, and what secondary effects climate change may have on critical oyster reef habitat are other important questions to be answered. Also important to study are the effects of sea level rise on habitat suitability and how salinity changes (from increased fresh water flow or drought conditions) affect their distribution, movement, and survival. A long term sampling program of different habitats to determine how stone crabs respond to environmental changes, such as salinity gradient, over time is needed. Thermal tolerance studies, modeling of environmental stressors, laboratory studies of the impacts of ocean acidification, and comparisons of species and hybrid physiology (e.g., temperature and salinity tolerances impacting molting and reproduction) were suggested as approaches to fill gaps in the state of the knowledge, with Sea Grant identified as a potential resource.

Stock Assessment

A regional assessment of the status of stone crab stocks was identified as a knowledge gap, particularly with respect to population size outside of Florida; improved fishery independent data would improve that knowledge. By incorporating fishery dependent and fishery independent data, the Florida model of assessment could be used. An analysis of population genetic structure might inform researchers about the degree to which populations are connected. For example, recent work in Florida on microsatellites suggests that there is no "hybrid zone" and it has been hypothesized that the coloration differences that have been used to visually identify hybrids are simply phenotypic plasticity in response to habitat. It was suggested that in Florida stone crabs are being "fished down" in high density areas, which are then repopulated by crabs from lower density, unfished areas. Better information on fishing pressure in Florida is needed, while in

South Carolina, researchers need a way to distinguish the catch per unit effort for stone crabs only, as many fishermen use the same trap for both stone crabs and blue crabs. Reliable aging techniques are lacking, although aging using rings on eyestalks and examination of plates within claws were suggested as possible approaches. Knowledge gaps exist for post claw removal fecundity of adults (some doubt was expressed about regeneration of claws), as well as a way to quantify annual recruitment success. Perhaps fouling plates, multi panel condos on coral reefs, and/or juvenile collectors made of oyster bags could provide an index of juvenile abundance and identification of suitable juvenile habitat. A general lack of knowledge about the biology of stone crabs in the Carolinas exists (e.g., size at maturity throughout the range, especially in North Carolina).

Dr. Ryan Gandy at FWC was identified as a source of information on stone crabs, as well as a resource for genetic analyses. Another resource identified was funding from the State Wildlife Grants program, since oyster reefs are considered priority habitats (at least in South Carolina).

Fishery Practices

Questions on stone crab fishery practices were generally concerned with proper trap types, proper declawing techniques, and the size and sex structure of allowed harvest. Loss of plastic traps in Florida leads to ecosystem damage such that it was suggested that harvest be allowed with wire traps (e.g., blue crab traps) only. Such gear modifications would reduce bycatch mortality. The effect of removal of 1 versus 2 claws on direct and indirect survival, growth, feeding ability, fecundity, and the ability to regenerate claws and re-enter the fishery is unknown and should be investigated for both species and hybrids. Fisheries practices issues to be considered in the future included the following: male only, crusher claw only, slot limits for claw size (minimum 2 ¾ inches), and fishery closure during peak spawning periods (May - September). Approaches to fill in research gaps included education and outreach to fishermen and the public to promote best practices for declawing, a census of commercial vendors for declawing technique and species harvested, and controlled laboratory and field studies. Potential funding resources are state agency funding, Sea Grant, NOAA, and trade organizations (e.g., SC Seafood Alliance).

RESOURCE MANAGER PANEL SUMMARY

The workshop concluded with a question and answer session with a panel of state resource managers: Trish Murphey (North Carolina Division of Marine Fisheries), Wally Jenkins (South Carolina Department of Natural Resources), Pat Geer (Georgia Department of Natural Resources) and Dr. Ryan Gandy (Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute).

The panel initially discussed whether the agencies receive feedback from researchers after the agencies provide data. Pat Geer does sometimes receive graduate research theses, but sometimes never hears anything back. He expressed concern that younger researchers simply want to take data from the internet, and do not properly coordinate with those who collected the data to learn the context, and therefore how the data should be used. Ryan Gandy stated that his agency is happy to provide data, but requests should be made in the correct way. It is important to work collaboratively, rather than just asking for the data. That cooperation is important in order to justify sharing data that the agency has invested resources and time in gathering. Wally Jenkins recognized the positive relationship that the SCDNR has with other researchers due to close proximity, with many researchers located on the Marine Resources Center campus in Charleston. He did suggest, however, that it may be the responsibility of managers to keep current on the literature, though the large number of species that are managed makes it difficult to do so. Trish Murphey stated that research facilities in North Carolina have a good system for collaboration, with many agencies geographically located within the same counties. Agencies in North Carolina try to help the counties understand the ways in which the data can be used. She recognized, too, that some researchers simply want all of the data, whereas others do keep in contact and give proper credit to the people who collected the data.

The discussion then turned to communication between state resource management agencies and state Sea Grants. Rick DeVoe (Executive Director, SC Sea Grant Consortium) stated that Sea Grant proposals require provisions for how results from research will be used to educate the public. In North Carolina, there is good collaboration with Sea Grant, including cooperative efforts between academia and fishermen. Agency Fisheries Management Plans and associated research priorities, including the top five research needs for each species, are provided to Sea Grant. The Georgia Coastal Research Council sponsors a colloquium once every two years so that researchers get the opportunity to introduce themselves and explain the research that is needed from their point of view. Pat Geer suggested that the funding agencies themselves need to say what specific research is of concern to them. David Whitaker (moderator) and Rick DeVoe have discussed holding a combined colloquium for both Georgia and South Carolina.

It was suggested that changes in crustacean resources may be underway, with shrimp populations moving northward and blue crab populations declining. A discussion occurred on the expected state of these crustacean fisheries, and how they might be managed in the next 10 to 20 years, as well as whether there is a compelling need for limited entry. Georgia has had limited entry since 1998, but the crabbers want the number to be reduced. Competition from imported lump crab

meat has led to the closure of domestic picking houses and has caused shifts in the market, so crabbers are targeting high priced specimens (e.g. large males). Geer suggested that it is difficult to predict what will happen in response to declines in catch of shrimp. In South Carolina, crabbers have asked for limited entry, but lack of support in the state legislature has prevented that approach. Wally Jenkins suggested that continuing with current harvest practices and harvesting year round (365 days) is irresponsible, but more public and political support is necessary before changes can be implemented. David Whitaker further suggested that since crabbers can now make money on five crabs per trap, they may be fishing the population down. Dr. Ryan Gandy stated that fisheries managers do not have the capacity to be predictive due to the various uncertainties that surround these fisheries, and that liability prevents them from making predictions that would potentially affect fishermen who rely on those predictions. Managers will therefore always be reactive and are always "working in and out of overfishing." Managers instead monitor and make decisions as close to real time as possible, but it will never be perfect. He also suggested that economics and self-imposed limits (e.g., due to the high cost of diesel fuel) are more important drivers of commercial effort than the abundance of crustaceans. Competition in the lobster market is an economic driver in south Florida.

The managers panel concluded with a discussion of the possibility of global management to affect sustainable fishing and how best to disseminate good information. While the International Fishery Certification attempts to accomplish that goal, it does not really affect the cost of doing business. For example, companies can move from fishery to fishery to supply lump crab meat on the international market at a price that drives some crabbers out of the market. Wally Jenkins stated that SCDNR will support research however it can, since managers need as much information as they can get to support decisions that they make. Managers regularly talk to reporters and organizations such as the Audubon Society, so the more correct information that is available, the better. Trish Murphey suggested that it is important to fight passionate misinformation with passionate informed information. Too much time is spent correcting information. Dr. Ryan Gandy suggested it is important to get the correct information out on the "front end," because once a story gets out, that misinformation will continue to spread.

AREAS OF EXPERTISE OF WORKSHOP ATTENDEES

	Disease	**Habitat Loss**	**Climate Change**	**Stock Assessment**	**Population Genetics**	**Population Ecology**	**Ecosystem/ Community Ecology**	**Physiology**	**Monitoring**	**Policy Development/ Management**
Allen			X			X	X		X	
Baeza					X	X				
Bell										X
Brunson						X			X	
Burnett, Lou	X		X					X		
Burnett, Karen	X		X					X		
Byrd				X						
Carmichael				X						
Childress	X		X			X				
Darden					X	X				
Davis			X							X
DeLancey				X		X			X	
Denson				X	X	X			X	
DeVoe										X
Duermit						X				
Fly			X							X
Fowler				X		X			X	
Frede	X							X		
Frischer	X				X		X			
Gandy				X	X	X			X	X
Geer	X			X		X			X	X
Gehman	X						X			
Griffen		X	X			X	X	X		X
Jenkins				X		X			X	X
Kingsley-Smith		X					X		X	
Laramore	X									
Lee	X									
Leffler		X	X			X	X			
Madsen							X			
Mathes						X			X	X
Murphey		X							X	X
Page									X	
Parker									X	X
Reichert				X		X	X		X	X
Sanger		X	X				X		X	
Scott	X		X				X			
Segars	X	X	X				X			
Seim			X							
Taylor									X	X
Whitaker				X		X			X	X
Wilber		X				X				
Zardus					X	X				

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