THE NIDIS COASTAL CAROLINAS DEWS PROGRAM

PROGRESS REPORT

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SUBMITTED TO

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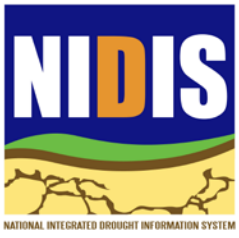

EXECUTIVE SUMMARY

The Coastal Carolinas Drought Early Warning System (DEWS) is one of several National Integrated Drought Information (NIDIS) regional DEWS programs in place across the United States. As different parts of the country are affected by drought in different ways, DEWS provide tools, resources, management strategies, and opportunities for information exchange around salient drought issues at the regional scale. DEWS convene stakeholders and partners from federal and state government agencies, universities, local communities, and a broad range of sectors. Activities include monitoring, forecasting, research, and communications and educations with the goal of facilitating proactive response to and preparedness for drought.

Launched in 2012, the Coastal Carolinas DEWS has focused on 1) improving understanding of the unique vulnerabilities and impacts of drought on coastal ecosystems and 2) developing tools, information, and other resources that will help managers and decision makers integrate drought- and coastal resource management activities. Priority project areas and goals were developed at a stakeholder scoping workshop in summer 2012. Over fifty individuals from federal and state agencies, community agencies, non-profit organizations, and academia contributed to this effort. Coastal Carolinas DEWS priorities and projects have centered on improving of drought impacts reporting and monitoring, evaluating and developing drought indicators appropriate for coastal ecosystems, and facilitating the use of drought forecasts and other products for decision making.

This report highlights project progress through 2015. Notable accomplishments include the following:

- The development of a citizen science condition monitoring network that provides regular reports regarding the effects of rainfall (or lack thereof) on local environments and communities. This on-the-ground information has value for drought monitoring and understanding local drought impacts.
- The establishment and refinement of a Coastal Drought Index (CDI) that uses salinity data to characterize drought conditions in coastal environments. Related work is assessing the ecological response variables that can be used with the CDI to link drought and ecological impacts and thereby inform resource management and planning decisions.
- An assessment of drought indicators for monitoring and managing fire risks in the coastal zone.
- The development of tools and information that allow fisheries managers and crabbers to investigate the connections between climate variability and crab landings.
- Foundational steps to build an “Atlas of Hydroclimate Extremes for the Carolinas.” This web-based tool will provide baseline information about drought duration, frequency, and intensity as requested by decision makers for long-term drought planning.
- Over 50 presentations by project leads and partners at local, regional, and national events.

The Coastal Carolinas DEWS is advancing NIDIS early warning goals centered on improving and integrating public awareness, monitoring and forecasting activities, risk assessment, preparedness, and communications. Through applied research and ongoing engagement with stakeholders and decision makers, the Coastal Carolinas DEWS is building a solid foundation for, and developing new knowledge that can be applied to, a wide variety of drought early warning activities.

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1. INTRODUCTION

This report provides progress to date for the National Integrated Drought Information System (NIDIS) Drought Early Warning System (DEWS) program in North Carolina and South Carolina. Specifically, this DEWS program focuses on the coastal regions of the Carolinas. The program includes efforts to improve understanding of the unique impacts of drought on coastal ecosystems and develop tools and information that will help resource managers and drought decision makers integrate drought and ecological information into drought monitoring, planning, and response activities.

The Carolinas Integrated Sciences and Assessments (CISA) team is collaborating with NIDIS to develop the Coastal Carolinas DEWS. CISA is one of ten NOAA-funded Regional Integrated Sciences and Assessments (RISA) teams. The RISA program supports research teams that help to build the nation's capacity to prepare for and adapt to climate variability and change. The CISA team has worked with a variety of regional partners on drought and related topics since the program's inception in 2003. Agency partners on the Coastal Carolinas DEWS include the North Carolina and South Carolina State Climate Offices, North Carolina Sea Grant, South Carolina Sea Grant Consortium, and the USGS South Atlantic Water Science Center. Projects have addressed needs in each of the DEWS sub system areas education and public awareness, integration of monitoring and forecasting, risk assessment, preparedness, communications, and evaluation and feedback.

The report is organized as follows:

- Section 2 continues with background about the development of the DEWS and program priorities.
- Section 3 discusses NIDIS and Coastal Carolinas program goals.
- Section 4 provides an overview of individual projects and accomplishments to date.
- Section 5 discusses ongoing work and makes recommendations for future work and next steps.
- Appendix A lists the Steering Committee Members for the 2012 NIDIS Carolinas DEWS Stakeholder Scoping Workshop.
- Appendix B consolidates information about the Carolinas DEWS projects into summary tables.
- Appendix C is a bibliography of all written materials, oral and poster presentations, stakeholder engagements, and other outreach activities conducted as part of the Carolinas DEWS program.

2. COASTAL CAROLINA DEWS BACKGROUND

2.1 DROUGHT AND COASTAL ECOSYSTEMS

During the past fifteen years North Carolina and South Carolina have experienced several periods of extended drought. Extreme- to exceptional events occurred in both states in 1998-2002 and 2007-2009. Many locations continued to experience moderate- to severe drought conditions from 2010 to 2013 (See Figure 1). During this time, both states initiated many improvements to drought monitoring and planning and have established active drought response programs. However, the frequent occurrence of drought conditions over the past 15 years, in combination with increasing populations and other demands on water resources, highlights the need to continue to improve drought preparedness.

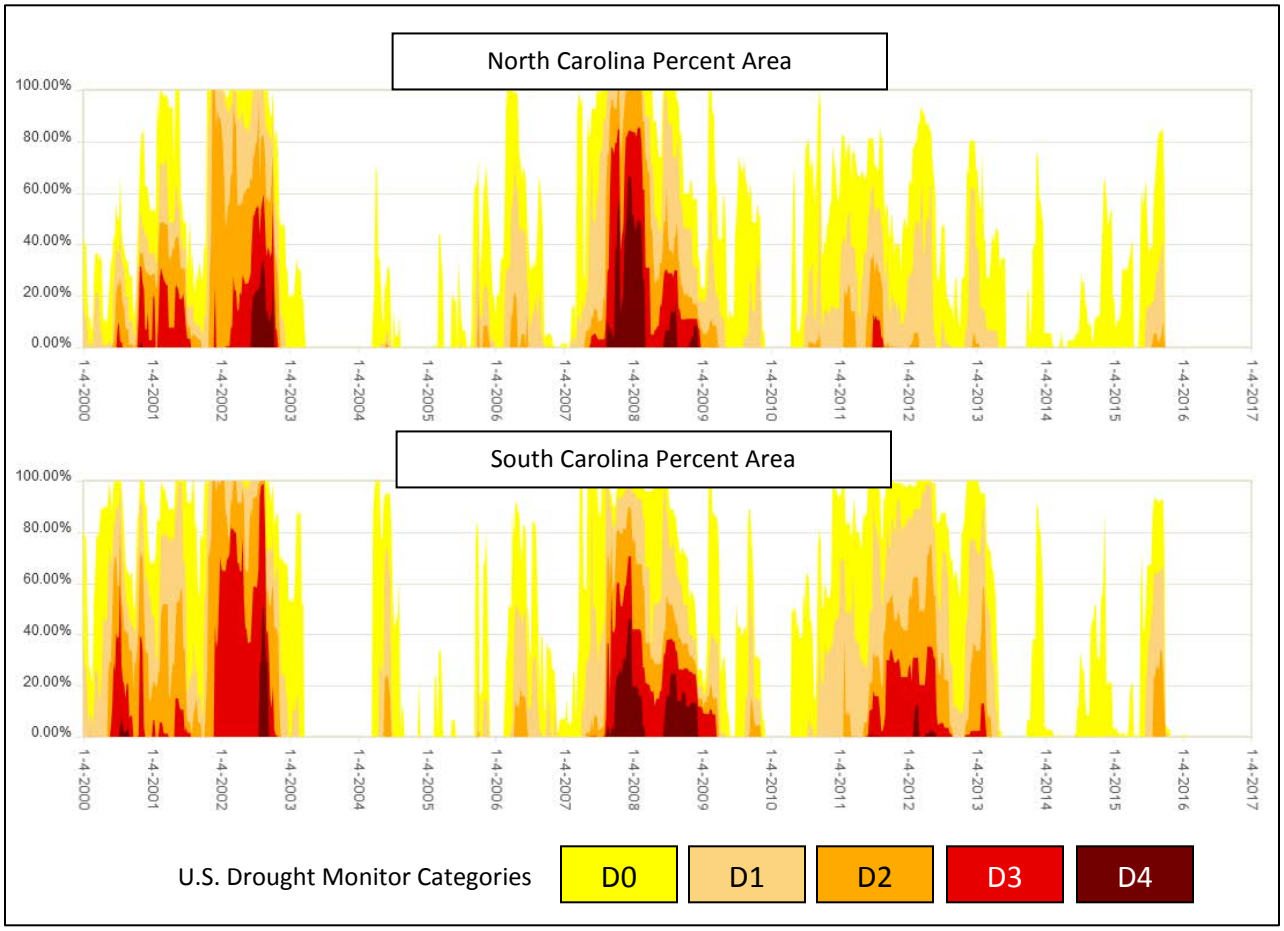

Figure 1. Percent Area of North Carolina and South Carolina in Drought Conditions, 2000-2015
(Source: http://droughtmonitor.unl.edu/MapsAndData/Graph.aspx)

The drought monitoring and planning community is recognizing the need to expand beyond the standard drought categories (i.e., meteorological, agricultural, hydrological, or socioeconomic) and associated sectoral concerns such as agriculture, forestry and fire management, and water supply. "Ecological drought," a water deficiency causing stress to plants, animals, and ecosystems (Lake 2003), has not been systematically investigated or well integrated into existing drought monitoring and management activities (Bond et al. 2008; Donahue and Schirmer 2015). Although considerable research in this area exists, there is not a comprehensive set of information and knowledge about drought and ecosystems (Lake 2011).

Much of the existing research has focused on *coastal* environments and resources. More specific to coastal ecosystems, "coastal drought" refers to water deficiencies and conditions that contribute to changes in 1) water quality conditions, particularly increasing salinity levels and fluctuations and 2) the availability and timing of freshwater to support animals, plants, and habitats (Gilbert et al. 2012). Indeed, a variety of state and federal agencies have recognized drought as a significant stressor to coastal ecosystems (e.g., APNEP 2011; Deaton et al. 2010; NC Ecological Flows SAB 2013; Robinson et al. 2013; SC DNR 2003). In coastal areas, drought conditions are produced not only by a lack of rainfall in the coastal region itself, but also by a lack of freshwater inflow from upstream and interactions with tidal regimes.

Moreover, drought interacts with other stressors and processes, and it can be difficult to isolate the contribution of drought to adverse environmental, social, and economic conditions (Lake 2011). Coastal areas, for example, are increasingly facing growing stressors in the form of population growth, urbanization, and increasing sprawl in coastal areas, and the Carolinas are no exception (NOAA 2013; NOEP 2014). Coastal development, land use change, and associated increases in nonpoint source pollution contribute to changes in the physical-chemical environment which can have potentially adverse effects on ecosystems, human populations, and coastal communities (Sanger et al. 2015). The fishing sector, in particular, must often negotiate a wide range of potential threats and opportunities. Deason et al. (2014), for example, discuss the multiple stressors faced by participants in the oyster trade, including changing climate and weather patterns, coastal development, and government policies and regulations.

Given the relatively recent focus on ecological drought, the complexity of the ecosystems, and growing stresses, it is not unexpected that DEWS scoping activities conducted by the CISA team revealed a need for improved integration of these issues into research and management activities.[1] This includes

[1] See Brennan et al. 2012; Gilbert et al. 2012; Lackstrom and Dow 2010; Lackstrom et al. 2011; and Lackstrom et al. 2014.

integrating coastal drought impacts in decision-making, enhancing the tools and approaches used to monitor and communicate drought conditions, improving coordination across sectors, and supporting the long-term monitoring and assessment of drought effects.

In the Carolinas, recognizing and monitoring drought and its effects on coastal ecosystems is important due to the many economic, social, and cultural benefits these ecosystems provide to the region. Coastal ecosystems offer habitat for commercial and recreational fisheries and migratory birds, opportunities for employment and recreation, flooding and storm protection, and water quality benefits (Burkett and Davidson 2012; South Carolina Ocean Planning Work Group 2012). In both states, coastal natural resources support sport fishing, hunting, wildlife viewing, beach going, and other recreational activities. Such activities contribute to the growing proportion of tourism, travel, and recreation income to coastal counties' economies.

In 2008 the economic contributions of natural resources to coastal recreation and tourism equaled approximately $3.5 billion and supported 81,000 jobs in South Carolina (Moore School of Business Division of Research 2009).The estuarine, inshore, and offshore environments also support commercial fishing. These activities are important to the local and regional economies, and to the history of the communities themselves, some of which were established in the 18th century (Burrell 2003; Lourens n.d.; McCay and Cieri 2000). Despite decreasing economic contributions to local communities (including declines in commercial fishing revenue, landings, and employment), fishing remains an important component of the social and cultural fabric of the coastal Carolinas (McInerny and Hadley 2014; Mirabilio 2014; NMFS 2012).

The Coastal Carolinas DEWS was initiated in order to address drought monitoring and management needs and gaps associated with the impacts of drought on coastal ecosystems and resources. Efforts and research projects have been designed to address two overarching goals: 1) to improve understanding and awareness of drought impacts and vulnerabilities in coastal ecosystems and 2) to develop monitoring tools, information, and other resources to improve the integration of drought- and coastal resource management.

2.2 EARLY DEVELOPMENT OF THE COASTAL CAROLINAS DEWS

This section describes the activities conducted to initiate the Carolinas DEWS. CISA has been funded through the Coping with Drought and NIDIS programs to support these efforts since 2010. Figure 2 summarizes the general timeline of CISA's involvement.

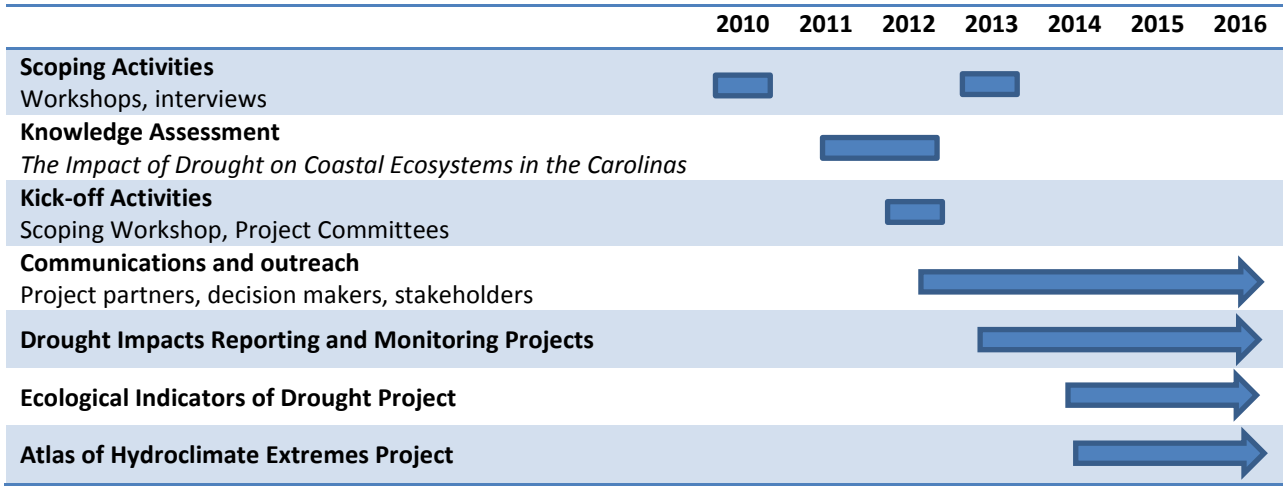

Figure 2. CISA Involvement in the Carolinas DEWS

2.2.1 SCOPING ACTIVITIES: ASSESSING NEEDS AND INTERESTS FOR A DEWS, 2010-2012

In 2010, the CISA team initiated several activities to inform the development of the Coastal Carolinas DEWS. First, CISA conducted interviews with coastal decision makers to assess potential drought early warning needs and to prepare for a "Drought Impacts and Stresses on Coastal Ecosystems" Workshop (conducted in March 2010, in Georgetown, SC). Identified needs included improved understanding of the ecological impacts of drought, the integration of coastal and ecological issues into drought decision making, and the development of information or indices appropriate for monitoring and assessing impacted ecosystems (Lackstrom et al. 2011).

Scoping activities explored the following questions:

What should a drought early warning information system for the coastal Carolinas look like?

What information is needed to cope with drought in coastal ecosystems?

What do we need to learn about drought in coastal ecosystems?

As a follow-up, Gilbert et al. (2012) produced *The Impact of Drought on Coastal Ecosystems in the Carolinas: State of Knowledge Report*. This report synthesized the pertinent literature, identified gaps in understanding, and suggested future research and management activities. The report found that drought is discussed primarily in terms of hydrological effects and changes to river discharge, freshwater inflows, water level, and water table

depth. These changes contribute to increased salinity levels, reduced soil moisture, and other changes to soil and water quality, thereby affecting the productivity, composition, and dynamics of coastal ecological systems. Additional research needs include: identifying ecosystem impacts not covered by existing research, conducting long-term studies to assess causal relationships between drought and ecological effects, and developing indicators with which to monitor ecological changes and impacts.

2.2.2 STAKEHOLDER WORKSHOP, 2012

In 2012, CISA began to work with Lisa Darby of the NIDIS program to develop the Coastal Carolinas DEWS program. The primary activities involved forming a NIDIS Carolinas steering committee and organizing a stakeholder scoping workshop. In May 2012 the steering committee (see Appendix A) met at Fort Johnson, South Carolina, to discuss the region's drought early warning needs and to identify possible project ideas, program objectives, and stakeholders to engage in a scoping workshop. The steering committee also assisted in developing the scoping workshop goals and agenda.

The scoping workshop was held on July 31-August 1, 2012, in Wilmington, North Carolina. Over fifty individuals from federal and state agencies, community agencies, non-profit organizations, and academia participated in the workshop. Through a combination of presentations, large group discussions, and World Café-style sessions, the participants refined regional priorities for the coastal Carolinas DEWS and identified specific projects to pursue as part of the DEWS program (for details, see Brennan et al. 2012). Table 1 shows the priority projects and goals selected to move forward.

Table 1. Coastal Carolinas DEWS Project Priorities and Goals

Drought Impacts Reporting and Monitoring
• Assess ways in which drought impacts might be monitored through stakeholders and citizen science • Investigate ways to improve the communication of coastal ecosystem drought impacts
Evaluation of Drought Indicators and Indices
• Investigate the benefits and feasibility of creating a drought index based on real-time salinity data • Determine which current drought indicators and indices are appropriate for assessing drought in coastal ecosystems
Drought Forecasting for Coastal Ecosystems
• Introduce stakeholders to current products used for drought forecasting • Ascertain which additional drought forecasting products stakeholders need and what time scales are of most interest to them
Seafood Safety Forecasts
▪ Provide an early warning system for commercial, recreational, and subsistence fishermen who harvest drought-sensitive seafood in both fresh and salt waters in the coastal regions of the Carolinas

2.3 IMPLEMENTATION OF THE NIDIS COASTAL CAROLINAS DEWS PROGRAM, 2012-2015

The scoping workshop made substantial progress in identifying key needs and projects to address them. In order to establish concrete steps to move the project ideas forward, planning committees were established for each project. NIDIS and CISA staff led efforts to coordinate the four committees, consisting of participants from the scoping workshop and other identified stakeholders. Conference calls were conducted through fall 2012 in order to refine project tasks and organizational responsibilities.

This process yielded mixed results in capitalizing on momentum from the stakeholder workshop and in identifying leadership for the different project areas. Several projects were initiated where substantial capacity already existed to conduct the work and where opportunities and mechanisms to fund specific projects were available. As the project planning committees reviewed existing work and resources, they found that preliminary investigations of existing datasets and methods were needed in order to fully address researchers' and resource managers' questions and to identify the most effective approaches to integrating coastal drought information into decision making. As a result, many of the projects involved foundational work.

Table 2 lists funded projects and activities, and project team members, for three of the four priorities. Section 4 provides project descriptions and highlights. Several factors constrained the development of the Seafood Safety Forecast priority area. These challenges are discussed in Section 5.2.

Table 2. Coastal Carolinas DEWS Projects and Project Leads

Projects	Project Leads
Priority: Drought Impacts Reporting and Monitoring	
Drought Impacts Monitoring Working Group	Amanda Brennan, Kirstin Dow, Kirsten Lackstrom ▪ Carolinas Integrated Sciences & Assessments (CISA), University of South Carolina
Citizen Science Condition Monitoring	Amanda Brennan, Kirstin Dow, Kirsten Lackstrom ▪ Carolinas Integrated Sciences & Assessments (CISA), University of South Carolina
Priority: Evaluation of Drought Indicators and Indices	
Development of a Coastal Drought Index	Paul Conrads ▪ USGS South Atlantic Water Science Center
Identification of Ecological Indicators of Drought in Coastal Ecosystems	Dan Tufford ▪ Carolinas Integrated Sciences & Assessments (CISA), University of South Carolina David Chalcraft ▪ East Carolina University
Assessment of Drought Indicators for Coastal Zone Fire Risk	Ryan Boyles, Rebecca Cumbie, Corey Davis ▪ State Climate Office of North Carolina, North Carolina State University
Priority: Drought Forecasting for Coastal Ecosystems	
Stakeholder Interviews	Amanda Brennan, Kirstin Dow, Kirsten Lackstrom ▪ Carolinas Integrated Sciences & Assessments (CISA), University of South Carolina
Forecasting the SC Blue Crab Fishery	Michael Childress ▪ Clemson University
Atlas of Hydroclimate Extremes for the Carolinas	Greg Carbone ▪ Carolinas Integrated Sciences & Assessments (CISA), University of South Carolina Chip Konrad ▪ Southeast Regional Climate Center, University of North Carolina at Chapel Hill, Carolinas Integrated Sciences & Assessments (CISA) Jordan McLeod ▪ Southeast Regional Climate center

3. COASTAL CAROLINAS DEWS: OVERVIEW OF NIDIS AND PROGRAM GOALS

The goal of NIDIS is to improve the country's capacity to proactively respond to, prepare for, and manage drought risks (NIDIS 2007). The *NIDIS Implementation Plan* identifies the development and implementation of a drought early warning system as a key element of the NIDIS strategy to provide accurate, relevant, and timely information to inform drought decisions at multiple spatial scales. Drought early warning systems consist of several components, or sub-systems. These sub-systems center on education and public awareness, integration of monitoring and forecasting, risk assessment, preparedness, communications, and evaluation and feedback (NIDIS 2007).

Coastal Carolinas DEWS projects are addressing and contributing to these sub-system goals in several ways (Table 3). From the earliest efforts to develop the Carolinas DEWS, activities have centered on improving understanding and awareness of drought impacts and vulnerabilities in coastal ecosystems and developing monitoring tools, information, and other resources to improve the integration of drought- and coastal resource management activities. Through applied research and ongoing engagement with stakeholders and decision makers, the Coastal Carolinas DEWS is building a foundation for, and developing knowledge that can be applied to, a drought early warning system. Several projects were designed to collect data and information regarding coastal drought impacts, as well as the use of and needs for coastal drought information. Other projects have addressed specific stakeholder questions regarding hydroclimatological processes and needs for appropriate indicators to monitor coastal drought.

Information about coastal drought has been disseminated through exchanges with interviewees, stakeholder meetings and workshops, and other communications and outreach initiatives such as the Citizen Science Condition Monitoring project. Such engagements have also provided opportunities to discuss approaches to the integration of drought- and coastal management activities with a variety of audiences. For example, the blue crab forecasting project, the Atlas of Hydroclimate Extremes, and assessment of ecological indicators are intended to enhance risk assessment and preparedness activities. The Citizen Science Condition Monitoring project is increasing awareness of drought impacts, serving as a mechanism to communicate and disseminate information about drought conditions, and providing a model for potential use in drought monitoring at multiple scales (local, regional, state, and national). The suite of applied research projects being conducted through the Coastal Carolinas DEWS are contributing to a better understanding of the processes that produce coastal drought and information that can be used to refine monitoring and forecasting tools.

Table 3. Coastal Carolinas DEWS Projects and NIDIS Implementation Goals

Sub-systems	Sub-system Goals	Drought Impacts Monitoring Working Group	Citizen Science Condition Monitoring	Coastal Drought Index	Ecological Indicators of Drought	Drought Indicators for Coastal Zone Fire Risk	Stakeholder interviews	Forecasting the Blue Crab Fishery	Atlas of hydroclimate Extremes for the Carolinas
Education and public awareness	Raise public awareness of drought-related risks and sensitivities		X				X		X
Integrate monitoring and forecasting	Project emerging conditions in the physical environment and contribute to the better understanding of present conditions and past events			X	X	X		X	X
Develop risk assessment	Enable resource and other management authorities to generate risk and impact scenarios			X	X			X	X
Engage preparedness	Inform actions required to reduce the loss and damage expected from an impending hazard event				X		X		X
Communication	Deliver timely information on impending events, potential risk scenarios, and preparedness strategies for at-risk communities		X						
Evaluation and feedback	Refine projects for transferability to similar locations/regions	X	X	X					

4. INDIVIDUAL PROJECT HIGHLIGHTS

This section describes the individual projects that currently constitute the NIDIS Coastal Carolinas DEWS program. The sections are organized according to the priority areas identified at the 2012 stakeholder workshop. Appendix B provides additional information about each of these projects. . Appendix C lists a full bibliography of reports, presentations, and communications products.

4.1 DROUGHT IMPACTS REPORTING AND MONITORING

Scoping workshop participants identified many potential benefits of improving drought impacts reporting, to include building stakeholder awareness and engagement, building linkages between drought indicators and impacts, and addressing the need to improve understanding of the economic benefits of preparedness activities and mitigation and planning strategies. Goals for the specific projects that were developed (described below) included: 1) identifying best practices for monitoring and reporting drought impacts, 2) assessing ways in which drought impacts might be monitored through citizen science and other stakeholder efforts, and 3) investigating how this information might be incorporated into drought planning and response decisions.

The project planning committee suggested that a project also identify what information is needed by the North Carolina Drought Management Advisory Council and the South Carolina Drought Response Committee to improve their drought assessments and to engage with other groups and stakeholders that might benefit from drought impact reporting.

4.1.1 DROUGHT IMPACTS MONITORING WORKING GROUP

Based on a shared interest to better understand the impacts of drought and the potential utility of drought impacts reports as a monitoring tool, CISA team members organized a drought impacts monitoring workshop. The purpose of the workshop was to identify best practices for implementing a drought impacts reporting system and to develop a path forward for addressing or overcoming barriers. CISA worked with other RISAs (CLIMAS, SCIPP, SECC), the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network, the Southwest Climate Science Center, the National Drought Mitigation Center (NDMC), and NIDIS to organize this meeting. The group met in Tucson, AZ, in March 2013, to discuss their knowledge and experiences and to develop a white paper.

PROJECT HIGHLIGHTS

- Findings from this work have been incorporated into the development of the citizen science condition monitoring project (see Section 4.1.2)
- The Missing Piece: Drought Impacts Monitoring report
- “Local Observers Fill in the Details on Drought Impact Reporter Maps” (Smith et al. 2014) published in *Bulletin of the American Meteorological Society*
- Presentations and webinars for multiple stakeholder and research audiences

4.1.2 CITIZEN SCIENCE CONDITION MONITORING

The aim of this project is to further understanding of the usefulness of citizen science engagement as a means to increase drought impacts monitoring and reporting. Building on existing tools developed by CoCoRaHS, CISA engaged target groups in drought impacts reporting, asking volunteers to submit daily precipitation measurements and weekly status reports about the condition of ecosystems and communities in their area. The focus on regular reporting, in contrast to intermittent drought impact reports, is intended to create a baseline for comparison of change through time and to improve understanding of the onset, intensification, and recovery of drought. The CISA team conducted decision-maker interviews to understand how the collected information can be used for drought response decisions. Results from feedback surveys circulated to project volunteers are informing ongoing efforts to engage citizen science volunteers in condition monitoring.

PROJECT HIGHLIGHTS

- CISA initiated this project in 2013, successfully recruiting over 40 volunteers. From September 2013 to December 2015, project volunteers provided over 1,500 condition monitoring reports. The CISA team coded and analyzed these reports using NVivo, a qualitative analysis software package. CISA used this information to develop maps, graphs, and charts to summarize and visualize the report content for interviews with decision makers responsible for drought monitoring and decision making. Interviews indicated that the reports are relevant to and being currently used for drought monitoring.
- Ongoing communications and outreach with project volunteers and drought decision makers
- Presentations to multiple stakeholder and research audiences
- Final project report and manuscripts in progress
- Planning in progress for “Phase 2” of the project. CISA is working with staff from CoCoRaHS, the National Drought Mitigation Center Drought Impact Reporter, and the state climate offices to modify the process through which volunteers provide drought and condition monitoring information and to develop a streamlined process to communicate this information to users.

4.2 EVALUATION OF DROUGHT INDICATORS AND INDICES

Commonly used drought indices were not developed with the unique characteristics of coastal ecosystems in mind. Predicting the onset and intensification of drought, and understanding conditions needed for recovery, could be improved with more knowledge of the most suitable indicators of drought in coastal ecosystems. Two goals were identified for this priority area: 1) investigate the benefits and feasibility of creating a drought index based on real-time salinity data and 2) determine which current indicators and indices are appropriate for assessing drought in coastal ecosystems.

4.2.1 DEVELOPMENT OF A COASTAL DROUGHT INDEX

Salinity is a critical coastal response variable that integrates hydrological and coastal dynamics including streamflow, precipitation, sea level, tidal cycles, winds, and tropical storms. The coastal drought index (CDI) is based on salinity data from USGS gauges located near the freshwater-saltwater interface in coastal rivers. Considerations in the development of this real-time salinity drought index include identification of the appropriate time scale in assessing salinity changes, differentiating aspects of the salinity signal (e.g., periodic, episodic, chronic), and correlating index classes to appropriate environmental responses. Paul Conrads, USGS South Atlantic Water Science Center, leads this project.

PROJECT HIGHLIGHTS

- A coastal drought index (CDI) that uses existing real-time and historical salinity datasets for sites in South Carolina, Georgia, and Florida was developed by using an approach similar to the Standardized Precipitation Index (SPI). CDIs characterizing the 1- to 24-month salinity conditions were developed. Evaluation of the CDI indicates that the index can be used for different estuary types (for example, brackish, oligohaline, or mesohaline estuaries), for regional comparison between estuaries, and as an index for wet conditions (high freshwater inflow) in addition to drought conditions. Due to the limited number of salinity datasets, the project also evaluated the length of record necessary to compute the CDI.
- Manuscript in review
- Stakeholder workshop, *NIDIS Coastal Drought Monitoring Knowledge Assessment Workshop: USGS Real-Time Salinity Drought Index*, held in January 2014 to demonstrate the CDI, discuss potential applications and opportunities for operationalization, and garner additional agency support
- Presentations to multiple stakeholder and research audiences

4.2.2 IDENTIFICATION OF ECOLOGICAL INDICATORS OF DROUGHT IN COASTAL ECOSYSTEMS

This project seeks to improve understanding of coastal resources that are adapted to or dependent upon particular spatial and temporal patterns of precipitation, salinity, or streamflow to determine stress caused by drought. The project is conducted in two phases.

First, a needs assessment was conducted through structured interviews with 30 land managers in the coastal Carolinas. The purpose of the interviews was to identify opportunities for drought early warning and monitoring through the use of existing or potential new indicators or indices as well as needs for additional data and research to effectively understand and monitor drought in coastal ecosystems.

The second component of the project involves collaboration with the USGS to advance the development of the CDI. Utilizing priorities identified through stakeholder interviews, the CDI will be linked to ecological impacts or outcomes in order to further the development of ecological drought indicators and to support adaptation planning for coastal resource managers.

CISA PI Dan Tufford leads this project. David Chalcraft (East Carolina University) contributed to the needs assessment. The project commenced in September 2013 and is scheduled to conclude in August 2016.

PROJECT HIGHLIGHTS

- Interviews and needs assessment were completed in 2014. Most interviewees indicated that drought detection was important for resource management efforts, but only 33% were aware of existing drought indicators. Participants agreed on the need for early detection tools and suggested that a coastal drought index focused on freshwater availability and salinity, and connected to ecological parameters, would provide the greatest insight into potential drought impacts.
- In 2015, CISA researchers worked with resource managers to identify and assess ecological datasets with which to apply and refine the CDI. Working to identify correlations between datasets and the Coastal Drought Index is ongoing. Datasets being investigated include the basal area index, litter fall, pore water salinity, and flood depth and frequency in tidal marshes and forests in the Savannah and Waccamaw River drainages.
- Manuscript accepted for publication in *Journal of Coastal Research*
- Presentations to stakeholder and research audiences

4.2.3 ASSESSMENT OF DROUGHT INDICATORS FOR COASTAL ZONE FIRE RISK

Fire plays an integral part in terrestrial ecosystem management across the Carolinas. Controlled burns are used to reduce wildfire risk and to manage species diversity in forest systems. Land managers use drought indices to assess wildfire risk, but traditional indices, such as the Keetch-Byram Drought Index (KBDI), do not provide the spatial resolution needed by land managers nor do they capture moisture in soils with high organic content such as those found in the coastal Carolinas. This project compared commonly used indices with an experimental Estimated Smoldering Potential (ESP) dataset in order to identify better fire risk indicators for coastal areas with organic soils.

This project was conducted by Ryan Boyles, Rebecca Cumbie, and Corey Davis of the State Climate Office of North Carolina.

PROJECT HIGHLIGHTS

- The research team compared several gridded indices including KBDI, daily precipitation, and the Standardized Precipitation Index (SPI) over one- to four-month periods with soil moisture data from an experimental Estimated Smoldering Potential (ESP) dataset. The ESP data were collected intermittently from 2012 to 2014 at three coastal stations in eastern North Carolina. Results showed that all three gridded indices were only weakly correlated with the ESP data, likely because these indices cannot capture the terrain, drainage, and composition of organic soils.
- These findings suggest that no single index based on currently available data is likely to be a consistent indicator of organic fire risk. Additional research is necessary to evaluate which combination of parameters (e.g., surface fuel moisture, soil conditions, and groundwater levels), in conjunction with the development and use of other monitoring tools and networks, will provide more meaningful guidance for fire risk monitoring in areas with organic soils.
- Final report submitted to NIDIS
- Shared information with project partners (NC Forest Service, The Nature Conservancy)

4.3 DROUGHT FORECASTING FOR COASTAL ECOSYSTEMS

Numerous drought, hydrometeorological, and climate products are available to stakeholders in the Carolinas. However, stakeholders may not be aware of all products which are available, may not have the products they need to make decisions (i.e. the regional or temporal scale may not be adequate), or may not know the best way to tailor the products to their region or situation. The goal of this project priority is to facilitate the use of drought forecasting products by decision makers in the coastal Carolinas.

After several meetings of the project planning committee in fall 2012, no firm direction for specific projects had been determined. The group developed a spreadsheet of existing monitoring and forecasting tools as a starting point. It was recommended that as a next step, efforts should work to identify what forecasts and other products are currently being used by stakeholders, their needs for forecasts or other types of information, and the time scales at which information is used and/or needed (e.g., daily, weekly, monthly, seasonally). This information could then be used to develop targeted outreach with, and new resources or products for, specific groups.

4.3.1 STAKEHOLDER INTERVIEWS

In early spring 2013, the CISA team took advantage of persistent (and in some places, worsening) drought conditions to initiate a series of interviews with coastal stakeholders from resource-dependent sectors. The intent of this effort was to collect information that could be used to develop more refined project ideas. The CISA team conducted semi-structured interviews with 50 fishermen, outdoor recreationalists, business owners, and land managers in the Beaufort County, SC, and Carteret County, NC, areas. Although coastal resources users are affected by drought, they reported minimal use of existing drought tools and products. Furthermore, drought is not a stand-alone issue, rather interviewees viewed drought in the context of a range of extremes and climate variability. Many interviewees articulated a need for improved understanding and information about drought impacts and risks within the broader hydroclimate context (both norms and extremes). Moreover, to increase relevance and suitability for decision making, drought information, tools, and resources need to fit locale-specific risks and sector-specific management decision time frames and uses of information.

PROJECT HIGHLIGHTS

- Summary of findings provided in the Proceedings of the 2014 South Carolina Water Resources Conference
- Presentations to multiple stakeholder and research audiences
- Final project report and manuscript in progress

4.3.2 FORECASTING THE SC BLUE CRAB FISHERY

Blue crabs are one of the most important commercial fisheries in the Southeast, but landings have declined during recent droughts. To better understand the complex relationship between crab abundance and freshwater flow, a spatially-explicit, individual-based population model was constructed and parameterized using field observations collected in the Ashepoo-Combahee-Edisto (ACE) Basin National Estuarine Research Reserve (South Carolina). This model is used to examine how the rate of declining flow and the degree of interannual variability might interact to influence crab abundance, commercial landings, and disease prevalence.

Michael Childress received funding from NIDIS to conduct this project.

(Photo Source: Michael Childress)

In 2015, and in collaboration with Michael Childress, CISA PIs Dan Tufford and Greg Carbone began an interconnected project to developing future streamflow forecasts for the Edisto River, a major river in the ACE Basin system. They are using NOAA's Open-source Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT) to identify and examine a range of possible changes in Edisto River discharge between now and 2030. Streamflow projections will be used as input into Childress's blue crab model to provide additional information regarding future SC blue crab landing forecasts.

PROJECT HIGHLIGHTS

- Using the model to develop future projections of crab landings, results showed that when Edisto River annual average discharge remained at or above a critical minimum level (1250 cfs annual average) for three consecutive years, statewide crab landings increased. However, when river discharge dropped below this critical minimum level, crab landings decreased. Statistical models of river discharge trends and climate forecast surface runoff models suggest that the annual river discharge will continue to decrease while the interannual variation in river discharge will remain high. Given these forecasted conditions, future blue crab landings may experience periods (3-5 years in duration) of increase and of decline, but ultimately, if river discharge continues to decrease, crab landings will fall to 50% of the historical commercial landings within the next 15-20 years.
- Final report submitted to NIDIS
- Presentations to multiple stakeholder, decision-maker, and research audiences
- Outreach through a SC Blue Crab Forecast web blog and Facebook page

4.3.3 ATLAS OF HYDROCLIMATE EXTREMES FOR THE CAROLINAS

Through interactions with stakeholders dependent upon coastal resources, CISA identified a need for an improved baseline understanding of information about drought and normal precipitation in the Carolinas. In response, researchers are creating an atlas of hydroclimate extremes for the Carolinas which includes analysis of the temporal and spatial patterns of hydroclimate extremes. In order to further support decision making, the atlas will provide information on related impacts, connecting climate variability to drought management and coping decisions.

In 2014-2015, researchers at the Southeast Regional Climate Center conducted a preliminary set of analyses to develop core material on hydroclimate extremes. Staff based at the University of South Carolina used long-term county-level agriculture statistics to examine corn, cotton, soybean, and wheat yield impacts in North Carolina and South Carolinas from 1950 to 2013.

In 2015-2016, CISA team members at University of South Carolina are continuing to evaluate existing drought data and mapping products for inclusion in the atlas; conduct new analyses to calculate drought duration, frequency, and intensity; and assemble photos, videos, maps, and graphics that depict drought in the Carolinas in the past two decades. The CISA team is developing and testing a website to house the atlas materials and resources.

PROJECT HIGHLIGHTS

- 2014-2015: Analyses of daily PRISM data revealed a marked gradient of summer season precipitation with exceptionally low values along portions of the immediate coastal line, in contrast to very high values 10+ kilometers inland, especially over the South Carolina coastal plain. This pattern has implications with respect to return periods for drought and very heavy rainfall. Analyses of monthly PRISM data (1895-2014) revealed a decreasing mean summer precipitation trend, especially over the western Carolinas and Piedmont region of North Carolina, while a positive trend was identified in mean fall precipitation, especially over the Coastal Plain and Piedmont regions in North Carolina. The drought impact study results indicated that corn and soybean yields were most affected by drought. The best impact indicators were the 3-month SPI (June, July, August) for corn yield and the 3-month SPI (July, August, September) for the soybean yield.
- 2015-2016: Graphics to communicate drought information have been developed, depicting time series and maps of various drought indices for the period of record for climate divisions and individual stations in the Carolinas. Additional analyses have produced probability density functions for precipitation for 135 stations in the Carolinas, intensity-duration-frequency (IDF) curves of 12-month precipitation for those 135 stations, and maps of the Carolinas showing the percent average precipitation for the driest 12-, 24-, 36-, 48, and 72-month periods at 25-, 50-, 100, and 200-year return periods.
- Presentations to stakeholder and research audiences

5. DISCUSSION: ONGOING WORK, NEXT STEPS, AND RECOMMENDATIONS

The following discussion provides a high-level overview of continuing work and progress in current project areas, ongoing needs and suggestions for next steps, and recommendations to consider in the development of the 2016 Carolinas DEWS Strategic Plan.

5.1 ONGOING WORK IN PRIORITY PROJECT AREAS

This section provides brief assessments of progress toward the priority project area goals identified at the 2012 scoping workshop. This section also highlights how projects address decision-making and stakeholder needs for drought information and resources.

5.1.1 DROUGHT IMPACTS MONITORING AND REPORTING

The Citizen Science Condition Monitoring project was designed to expand drought impacts reporting, with the goals of improving the collection of impacts data and informing drought monitoring. The project has garnered considerable positive feedback from citizen scientists and decision makers from the state climate offices, U. S. Drought Monitor authors, and National Weather Service Weather Forecast Offices. Although designed and initiated as a research project, the North Carolina State Climate Office currently uses the information collected through this project on a weekly basis to monitor drought conditions. Phase 2 of the project is currently underway, with the goal of streamlining the reporting process and dissemination of report information to inform drought assessment. CISA is actively collaborating with CoCoRaHS, the National Drought Mitigation Center Drought Impact Reporter, and the state climate offices on this work.

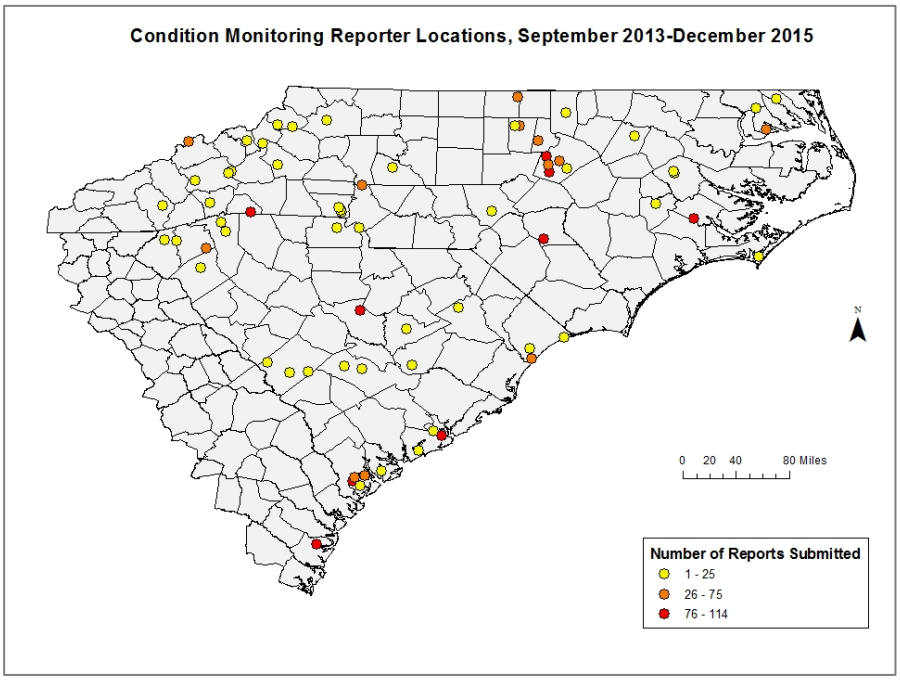

Figure 3. Locations of Condition Monitoring Reporters

Sixty-eight individuals submitted over 1500 reports between September 2013 and December 2015. These reports were submitted through the Community Collaborative Rain, Hail & Snow (CoCoRaHS) Network online form.

5.1.2 EVALUATION OF DROUGHT INDICATORS AND INDICES

The projects in this priority area were developed to fill a need for indices suited to coastal drought monitoring and management.

The Coastal Drought Index (CDI) project has established a methodology for measuring coastal drought and assessed how the tool can be used as an indicator of dry (low freshwater inflow) and wet (high freshwater inflow) conditions. Further efforts to develop the CDI include testing it in different estuary types and comparing conditions between estuaries. Figure 4 shows cases studied and other sites where long-term data sets exist. Application of the CDI is expected to produce more timely and detailed information about drought in coastal areas.

Another key next step in the development of the CDI is occurring through the "Identification of Ecological Indicators of Drought in Coastal Ecosystems" project. This project is ongoing and assessing the datasets and response variables that can be used to link drought and ecological impacts. This investigation is a critical element in linking the CDI to tangible impacts that can be monitored and addressed by resources managers at the operational and planning level. This project has also engaged decision makers to assess needs and educate them about existing drought tools and resources.

The "Assessment of Drought Indicators for Coastal Zone Fire Risk" project laid the foundation for further research on coastal fire risks indicators. The study confirmed that existing indicators and datasets are inappropriate tools for monitoring fire risk in coastal areas and identified further need for additional research and analysis. The project garnered much interest from the fire management community (including state agencies, non-profit and private landowners). These groups should be included in future DEWS activities and product testing.

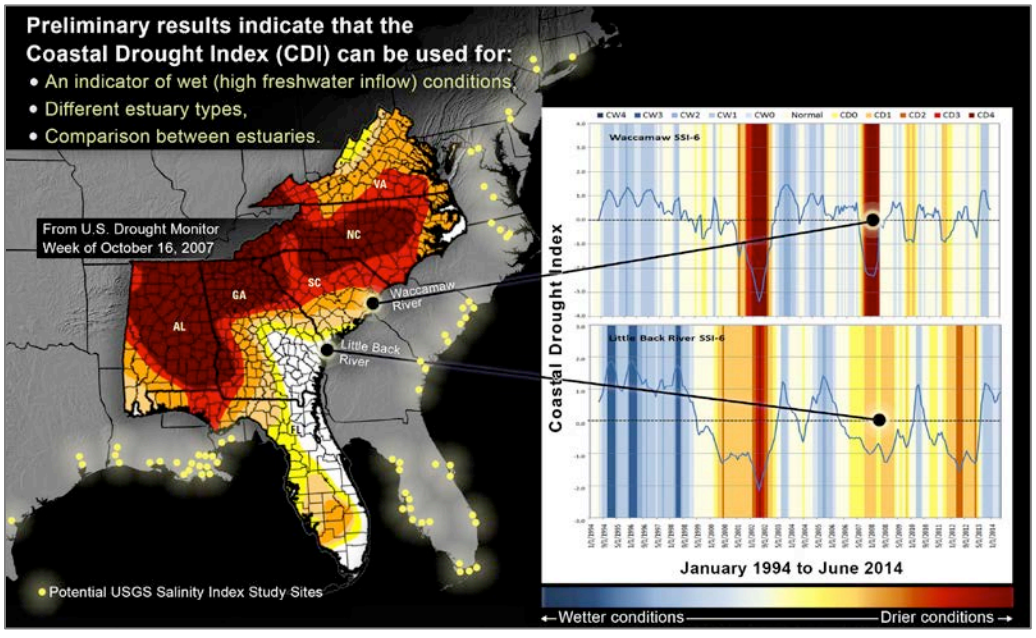

Figure 4. The Coastal Drought Index (Source: Paul Conrads)

5.1.3 DROUGHT FORECASTING FOR COASTAL ECOSYSTEMS

The goals for these projects were to refine understanding of the challenges associated with monitoring and forecasting coastal drought and to develop approaches to address decision maker needs.

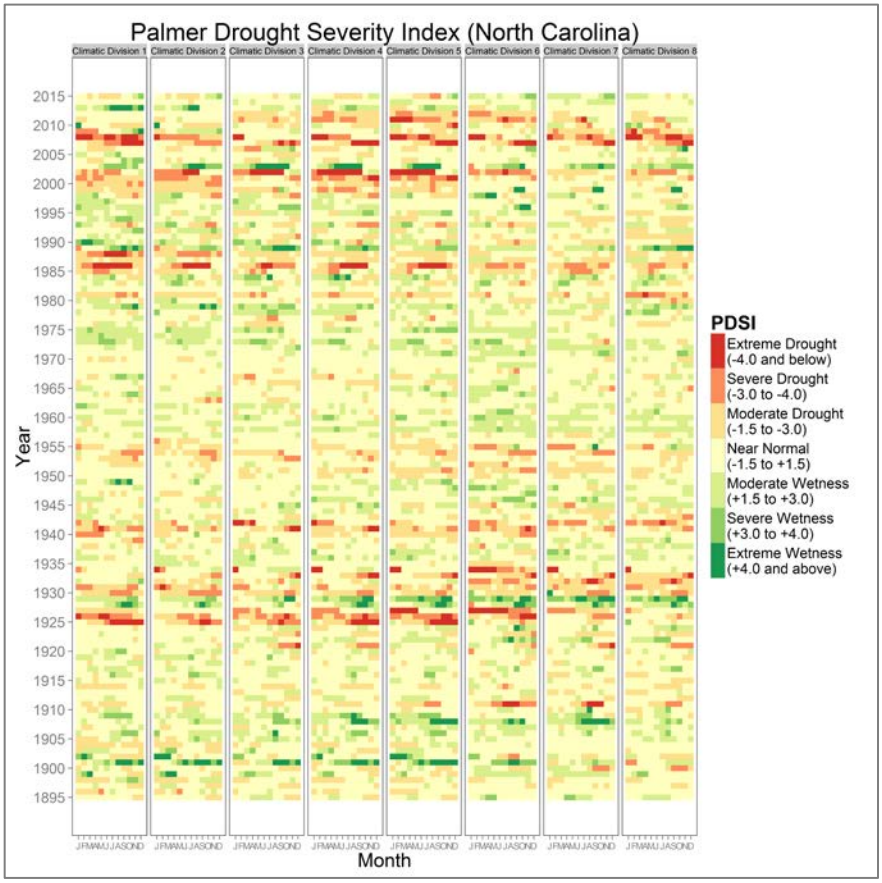

Figure 5. Heat Map of the Palmer Drought Severity Index, North Carolina Climate Divisions, 1895-2015
(Source: Junyu Lu)

Stakeholder interviews revealed that decision makers are interested in drought in the context of the continuum of precipitation events and extremes, not drought alone. Next steps in the Coastal Carolinas DEWS should consider this feedback when developing and integrating information into new tools and products. Interviewees also revealed interest in improved baseline information (see Figure 5, above) about drought and its effects on resources. These findings have already been used to inform directions for the "Atlas of Hydroclimate Extremes for the Carolinas." This project will also provide information regarding drought frequency, intensity, and duration as requested by decision makers. Stakeholder engagements around the tool will occur in 2016. One of the primary tasks will be to provide information about climate variability that can be used to inform management and long-term planning decisions.

The "Forecasting the Blue Crab Fishery" project developed a tool and information for fisheries managers and crabbers to investigate the connections between climate variability and crab landings. Ongoing work is investigating how to apply the CDI to the blue crab forecasting tool and how to develop better projections of future surface water flows for incorporation in the tool.

5.2 NEXT STEPS

The Coastal Carolinas DEWS program has made substantial progress across the array of DEWS sub-systems goals and towards priorities identified by Carolinas stakeholders. Still, given the early stage of development in the area of coastal ecosystem drought management, there is considerable work ahead. Next steps for the Carolinas DEWS should consider the following, broader issues.

First, the "Seafood Safety Forecast" project priority area faced a number of constraints, and a specific project was never developed. During project planning committee calls, members decided that more research was needed to clarify the linkages between drought and seafood safety. It was unclear if the appropriate and necessary data, analyses, and communications capacity existed to support a seafood safety alert system. Unfortunately the committee was unable to identify a project lead with the requisite expertise regarding this topic and capacity to assume a leadership role. Other challenges identified by the planning committee involved 1) addressing fishery sector concerns about publicizing seafood safety risks and 2) the feasibility of implementing and testing a seafood safety forecast in the absence of a drought event. Strategic planning efforts should reconsider this priority.

A second area for further effort focuses on the operationalization of new tools and products and the integration of coastal drought information into different management and monitoring processes. Coastal Carolinas DEWS efforts thus far have shown greatest progress in applied research and outreach activities. Some of the work conducted to date is "foundational" due to the considerable gaps in understanding about, and lack of relevant information regarding, coastal drought. Preliminary work to assess and develop coastal drought indicators, and improve the reporting and communication of impact information, has been a necessary first step in developing the DEWS.

Future work should continue to focus on engaging with drought decision makers and resource managers to determine the most effective mechanisms for integrating new information and tools into existing planning and management processes. A DEWS strategic plan, drawing in new partnerships and resources, will help to facilitate targeted outreach with different sectors and decision making processes, such as river basin planning initiatives, fisheries management, and coastal resources monitoring. These efforts should also engage with the active drought monitoring and management programs in North Carolina and South Carolina. Next steps towards operationalizing DEWS will need to address the significant differences between the state processes and organizations.

For some projects, further work with decision makers to refine the tools and resources for use as early warning indicators will be necessary. For example, there is a need for data (coastal drought response variables), analyses, and participation of management agencies to test and refine the Coastal Drought Index. To advance the Atlas of Hydroclimate Extremes, there will be an ongoing need to interact with decision makers to understand how to most effectively characterize and communicate the hydroclimatic factors that contribute to drought risks. The redesigned NIDIS Drought Portal will be an important asset in enhancing communications, education, and awareness and advancing those sub-system goals. Future efforts should also consider what will be the best "home" for new products, to ensure the seamless integration of new information with existing drought portals in the Carolinas.

5.3 RECOMMENDATIONS FOR A CAROLINAS DEWS STRATEGIC PLAN

In 2016, CISA will work with NIDIS to develop a Carolinas DEWS Strategic Plan. This effort will entail working with existing and new partners to identify ongoing needs for regional drought early warning. This input will be necessary to determine how best to refine and operationalize information, tools, and products that have emerged through the initial work of the Coastal Carolinas DEWS and to recommend specific activities and goals to be addressed moving forward.

Although specific recommendations for future Carolinas DEWS projects will be determined through engagement with partners and stakeholders, CISA proposes the following three "tracks" as we think about who to engage and what types of activities will be feasible and have resonance with a wide range of decision makers. These tracks build on main themes of current Coastal Carolinas DEWS projects.

5.3.1 ADVANCE WORK ON COASTAL DROUGHT AND ECOSYSTEM IMPACTS

These projects would leverage and build on work conducted by Paul Conrads, Dan Tufford, and Michael Childress. Specific activities could include operationalizing and assessing the application of the CDI. This "track" should provide opportunities to involve refuge and land managers in coastal regions (public and private), fisheries agencies, water resources managers, agencies with water quality responsibilities, and the DOI Southeast Climate Science Center. Planning and implementing this work will likely require additional interactions with decision makers to develop strategies to facilitate the integration of the CDI into management decisions.

5.3.2. SUPPORT STATE DROUGHT RESPONSE, MONITORING, AND PLANNING PROGRAMS

Both the North Carolina and South Carolina state climate offices (SCOs) play key roles in each state's drought programs. The Carolinas DEWS could help address drought needs and gaps that are common to both states. Individually, the SC SCO has identified the need to update guidance for local-level drought response, and the NC SCO has identified a need to evaluate some of the drought monitoring products they have developed for use by NC water managers. Projects could leverage ongoing CISA work on the Atlas of Hydroclimate Extremes for the Carolinas and the Condition Monitoring (CoCoRaHS) projects. This "track" provides opportunities to involve the National Weather Service Forecast Offices (interested in the CoCoRaHS project) and other state agencies in the Carolinas (e.g., the NC Division of Water Resources).

5.3.3 ADDRESS LAND MANAGEMENT AND PLANNING NEEDS

This "track" might build on Ryan Boyles' project to assess indicators of fire risk in coastal soils and leverage existing tools (e.g., the Fire Weather Intelligence Portal) produced by the NC SCO. Potential projects could address needs related to short-term condition monitoring and response as well as long-term forest management and planning decisions. This "track" would also provide opportunities to involve the USDA Southeast Regional Climate Hub (SERCH), the South Atlantic LCC, state agencies in the Carolinas (e.g., state forestry commissions), and other organizations responsible for land and fire management decisions (e.g., The Nature Conservancy, private landowners).

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APPENDIX A. STEERING COMMITTEE, 2012 NIDIS CAROLINAS SCOPING WORKSHOP

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USFWS, SC Coastal Program

Ryan Boyles
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Paul Conrads
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Lisa Darby
National Integrated Drought Information System (NIDIS)

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APPENDIX B. COASTAL CAROLINAS DEWS PROJECTS

Drought Impacts Reporting and Monitoring

There are many possible benefits of improving drought impact reporting to include improved drought monitoring, building stakeholder awareness and engagement, and building linkages between drought indicators and impacts. These projects were undertaken in order to assess ways in which drought impacts might be monitored through stakeholders and citizen science. An additional component of the condition monitoring project is to investigate ways to improve the communication of coastal ecosystem drought impacts.

Project Title and Investigators	Funding	Project Background and Goals	NIDIS Implementation Plan Goals	Integration with Drought Decision Making	Activities and Progress To Date
Drought Impacts Monitoring Working Group University of South Carolina • Kirsten Lackstrom • Kirstin Dow • Amanda Brennan	NIDIS, funding to CISA	Based on shared interest to better understand the impacts of drought and the potential utility of drought impacts reports as a monitoring tool, CISA team members worked with other RISAs (CLIMAS, SCIPP, SECC), SW Climate Science Center, NDMC, NIDIS, and CoCoRaHS to begin to identify best practices for implementing a drought impacts reporting system, and to develop a path forward for addressing or overcoming barriers.	• Education and awareness • Integrate monitoring and forecasting • Evaluation and feedback	This evaluation of existing impact data collection and reporting systems was used as a first step in identifying barriers and opportunities for coordination and integration of drought impacts information into decision making across multiple sectors and levels.	• In-person meeting with working group, March 2013 • Workshop report, *The Missing Piece: Drought Impacts Monitoring* • Presentation of findings at multiple conferences
Citizen Science Condition Monitoring University of South Carolina • Amanda Brennan • Kirsten Lackstrom • Kirstin Dow	NIDIS, funding to CISA	CISA is working with citizen science volunteers to report daily precipitation measurements and weekly reports about local conditions to connect weather and climate with on-the-ground drought impacts monitoring and reporting. The reports are intended to create a baseline record of local conditions so that "departures from normal" (i.e. too little or too much rainfall) are more readily identified. The research team is also working to assess the role citizen scientists play in drought impacts monitoring through volunteer feedback surveys.	• Education and awareness • Integrate monitoring and forecasting • Evaluation and feedback	Interviews with drought decision makers will be used to evaluate how condition monitoring might be incorporated into drought monitoring and response planning. Results of the volunteer feedback surveys will be used to inform best practices for drought impacts monitoring and reporting using citizen scientists.	• Volunteer recruitment and education through in-person and webinar trainings, online and printed materials, and continued communication and outreach efforts via a monthly newsletter, blog, webpage, conference calls and thank you notes. • Three feedback surveys circulated to project volunteers over the 1-year project commitment period • Coding and analysis of 1,000+ reports received using NVivo software • Development of maps, graphs and charts to summarize and visualize report content • Interviews with 17 drought decision makers representing the SC and NC SCOs, NDMC, US Drought Monitors, NWS Weather Forecast Offices • Presentations at conferences and workshops • Phase 1 final report in progress

Evaluation of Drought Indicators and Indices					
Many of the commonly used drought indices were not developed with the unique characteristics of coastal ecosystems in mind. There are drought indices and indicators used for agriculture, reservoir management, and water supply, among others, but there is no similar set for coastal ecosystems. Predicting the onset and intensification of drought and understanding conditions needed for recovery could be improved with more knowledge of drought indicators and indices in coastal ecosystems. These projects were developed to fill a need for indices suited to coastal drought management.					
Project Title and Investigators	**Funding**	**Project Background and Goals**	**NIDIS Implementation Plan Goals**	**Integration with Drought Decision Making**	**Activities and Progress To Date**
Development of a Coastal Drought Index (CDI) USGS South Atlantic Water Science Center • Paul Conrads	NIDIS, directly to PI	The location of the freshwater-saltwater interface in surface-water bodies along the coast is an important factor in ecological and socio-economic dynamics. Salinity is a critical response variable that integrates hydrological and coastal dynamics including streamflow, precipitation, sea level, tidal cycles, winds, and tropical storms. The CDI will provide an index for characterizing drought conditions in coastal areas, utilizing real-time salinity data from USGS gauges in coastal riverine systems.	• Integrate monitoring and forecasting • Evaluation and feedback	The CDI will bring more timely and detailed information about drought in coastal ecosystems using localized salinity data. Knowledge gained through the development of the index is anticipated to be transferable to other coastal locations.	• Development of a coastal drought index using salinity data currently at a stage where it could be site-tested • Stakeholder workshop held in January 2014 to gauge interest in applications for the index • Multiple workshop and conference presentations • In 2015, CISA researchers initiated ongoing work with resource managers to identify and assess ecological datasets with which to apply and refine the CDI.
Identification of Ecological Indicators of Drought in Coastal Ecosystems of the Carolinas University of South Carolina • Dan Tufford (PI) East Carolina University • Dave Chalcraft	NOAA, directly to PI	The ability to detect drought onset is important to coastal managers because it enhances preparedness and provides opportunities for mitigation. Existing indicators, however, were designed with agriculture or fire management in mind. This work seeks to determine if existing indicators are adequate for managing coastal resources under threat of drought and, if now, what information would be most useful.	• Integrate monitoring and forecasting • Engage preparedness	Interview findings are guiding the second phase of the project, which includes determining linkages between ecological indicators and varying salinity levels as expressed by the CDI (see above).	• 30 interviews with NC and SC coastal natural resource managers o *Findings*: Participants agreed on the need for early detection tools and suggested that an index focused on freshwater availability and salinity would provide the greatest insight into potential drought impacts. • Manuscript accepted by *Journal of Coastal Research*
Assessment of Drought Indicators for Coastal Zone Fire Risk North Carolina State Climate Office • Ryan Boyles	NIDIS, directly to PI	Land managers use drought indices to assess wildfire risk, but traditional indices, such as the KBDI, do not provide the spatial resolution needed by managers nor do they capture moisture in soils with high organic content such as those found in the coastal Carolinas. This research examined an objective drought index to assess how it represents local fire risk in coastal areas.	• Integrate monitoring and forecasting	With NC Forest Service and The Nature Conservancy partners, these indicators will be compared to local fire event histories to identify those that best represent fire risk in organic soils.	• Calculation of gridded KBDI at ~5km resolution for the continental US • Dataset comparison to assess KBDI as an indicator of fire danger in coastal organic soils

Drought Forecasting for Coastal Ecosystems					
Numerous drought, hydrometeorological and climate products are available to stakeholders in the Carolinas. However, stakeholders may not be aware of all products which are available, may not have the products they need to make decisions (i.e. the regional or temporal scale may not be adequate), or may not know the best way to tailor the products to their region or situation. Additionally, stakeholders are able to identify additional information which may not currently be available that could also provide decision support.					
Project Title and Investigators	**Funding**	**Project Background and Goals**	**NIDIS Implementation Plan Goals**	**Integration with Drought Decision Making**	**Activities and Progress To Date**
Stakeholder Interviews University of South Carolina • Kirsten Lackstrom • Kirstin Dow • Amanda Brennan	NIDIS, funding to CISA	In order to improve understanding of drought impacts and experiences among coastal resources-dependent sectors and needs for drought information, a series of stakeholder interviews was conducted with fishermen, outdoor recreationalists, and land managers in Beaufort County, SC, and Carteret County, NC. These interviews served as a first step in understanding the information and/or actions necessary to better integrate coastal environmental information needs into drought monitoring, planning, and response by identifying gaps in existing knowledge and primary stakeholder concerns.	• Education and awareness • Engage preparedness	The findings from stakeholder interviews have been used to inform future direction for the NIDIS Carolinas DEWS program. Interviewees indicated a need for: better baseline data so they can improve understanding of what is "normal" (e.g., frequency of drought events, recovery periods, and groundwater recharge rates); research and monitoring efforts that would provide better information about ecological indicators of drought (i.e., biological impacts, thresholds and responses to extreme events); continued work with stakeholders to evaluate types of early warning and forecasts that might be useful for season and annual decisions.	• 42 total interviews with 50 individuals located in NC and SC o *Findings:* All groups are affected by drought although impacts vary by sector and are context-dependent; both drought and above normal rainfall are concerns for many industries and decisions; in general, formal sources of drought information are not used for decision making on a regular basis. • Findings provided in the *Proceedings of the 2014 SC Water Resources Conference* • Stakeholder engagement through multiple workshop and conference presentations
Forecasting the SC Blue Crab Fishery Clemson University • Michael Childress	NIDIS, directly to PI	The blue crab fishery is an important commercial fishery, but landings have declined during recent droughts. To understand the complex relationship between crab abundance and freshwater flow, a spatially-explicit, individual-based population model was constructed and parameterized using field observations collected in the ACE Basin NERR. The model is used to examine how the rate of declining flow and interannual variability might interact to influence crab abundance, commercial landings, and disease.	• Integrate monitoring and forecasting	This model will incorporate freshwater flow forecasts with climate envelope hydrological models and be used to forecast future crab landing given a range of future hydrologic and climate scenarios.	• Development, parameterization and sensitivity analysis of an individual-based model (IBM) of SC blue crab estuarine populations (SCBCRABS) • Stakeholder engagement through multiple presentations • Communications and outreach to fisheries managers and fishermen

Atlas of Hydroclimate Extremes for the Carolinas University of North Carolina at Chapel Hill, Southeast Regional Climate Center • Chip Konrad University of South Carolina • Greg Carbone	NIDIS, funding to CISA	Through interactions with stakeholders dependent upon coastal resources, CISA identified a need for an improved baseline understanding of information about drought and normal precipitation in the Carolinas. In response, researchers are working to create an atlas of hydroclimate extremes for the Carolinas which includes analysis of the temporal and spatial patterns of hydroclimate extremes (i.e., spatial variability of annual precipitation across regions, drought recurrence, duration and frequency).	• Integrate monitoring and forecasting • Engage preparedness	Data tools, maps, and information developed for the atlas will be compiled into an online web portal. In order to further support decision making, the atlas will provide information on related impacts, connecting climate variability to drought management and coping decisions.	• Initial steps have included the development of core material on temporal and spatial patterns of hydroclimate extremes. These include maps showing the spatial variability of annual precipitation across the Carolinas, analysis of regional precipitation trends from 1895-2013 and a look at drought onset and recovery for 6 2-year drought periods to identify trends and differences within and across regions of the states. • Initial efforts to analyze drought-related impacts focused on corn and soybean yield in the Carolinas between 1950 and 2013. • Graphics to communicate drought information have been developed, depicting time series and maps of various drought indices for the period of record for climate divisions and individual stations in the Carolinas. This information is being used to develop an online tool for the Carolinas.

APPENDIX C. COASTAL CAROLINAS DEWS BIBLIOGRAPHY

PUBLICATIONS, PRESENTATIONS, STAKEHOLDER ENGAGEMENTS, TRAININGS, AND MEETINGS

NIDIS CAROLINAS DEWS PROGRAM

STAKEHOLDER WORKSHOP

2012 NIDIS Carolinas Drought Early Warning System Scoping Workshop. July 31-August 1, 2012, Wilmington, NC. 53 attendees.

ORAL PRESENTATIONS

2012 Brennan, A. "NIDIS Carolinas Drought Early Warning System Pilot Program." The Climate Connection Workshop Series: Climate Variability and Impacts to South Carolina's Natural Resources, September 13, 2012, Charleston, SC.

2013 Brennan, A. "Understanding Drought in Coastal Ecosystems." Cape Fear Arch Conservation Collaboration Quarterly Meeting, November 12, 2013, Little River, SC.

2014 Darby, L., A. Brennan, K. Dow, K. Lackstrom, and P. Conrads. "What is the National Integrated Drought Information System Doing in the Carolinas?" Carolinas Climate Resilience Conference, April 28-29, 2014, Charlotte, NC.

Lackstrom, K., A. Brennan, P. Conrads, L. Darby, K. Dow, and D. Tufford. "Drought and Coastal Ecosystems: Identifying Impacts and Opportunities to Inform Management." South Carolina Water Resources Conference, October 15-16, 2014, Columbia, SC.

2015 Brennan, A., J. Hartley, and K. Lackstrom. "Climate Interactions with Water Resources in the Carolinas." Water in the World: Interdisciplinary Approaches to Access and Sustainability, November 7, 2015, Winthrop University, Rock Hill, SC.

Brennan, A. "Introduction to CISA & the NIDIS Carolinas DEWS Program." Cape Fear Arch Conservation Collaborative Quarterly Meeting, November 10, 2015, Ocean Isle Beach, NC.

2016 Brennan, A. and K. Lackstrom. "Engaging Stakeholders to Develop a Coastal Carolinas Drought Early Warning System." Social Coast Forum, February 9-11, 2016, Charleston, SC.

POSTER PRESENTATIONS

2012 Brennan, A., L. Darby, K. Dow, K. Lackstrom, and D. Tufford. "NIDIS Carolinas Drought Early Warning Pilot Program." South Carolina Water Resources Annual Conference, October 10-11, 2012, Columbia, SC.

2013 Brennan, A., L. Darby, K. Dow, K. Lackstrom, and D. Tufford. "NIDIS Carolinas Drought Early Warning Pilot Program." North Carolina Water Resources Research Institute Annual Conference, March 20-21, 2013, Raleigh, NC.

Darby, L., K. Dow, K. Lackstrom, A. Brennan, D. Tufford, P. Conrads, R. Pulwarty, R. Webb, J. Verdin, C. McNutt, and V. Deheza. "Developing a NIDIS Drought Early Warning Information System for Coastal Ecosystems in the Carolinas." American Geophysical Union Fall Meeting, December 9-13, 2013, San Francisco, CA.

2015 Brennan, A. and K. Lackstrom. "Developing a Drought Early Warning Information System for Coastal Ecosystems in the Carolinas." 5th Interagency Conference on Research in the Watersheds, March 2-5, 2015, Charleston, SC.

Brennan, A. and K. Lackstrom. "Developing a Drought Early Warning Information System for Coastal Ecosystems in the Carolinas." North Carolina Water Resources Research Institute Annual Conference, March 18-19, 2015, Raleigh, NC.

2016 Lackstrom, K., A. Brennan, P. Conrads, K. Dow, and D. Tufford. Integrating Drought and Ecological Information for Drought Early Warning and Resource Management. North Carolina Water Resources Research Institute Annual Conference, March 17-18, 2015, Raleigh, NC.

DROUGHT IMPACTS REPORTING AND MONITORING

DROUGHT IMPACTS MONITORING WORKING GROUP

JOURNAL ARTICLE

2014 Smith, K. H., M. Svoboda, M. Hayes, H. Reges, N. Doesken, K. Lackstrom, K. Dow, and A. Brennan. Local Observers Fill in the Details on Drought Impact Reporter Maps. *Bulletin of the American Meteorological Society* 95 (11): 1659-1662.

REPORT

2013 Lackstrom, K., A. Brennan, M. Ferguson, L. Crimmins, L. Darby, K. Dow, K. Ingram, A. Meadow, H. Reges, M. Schafer, and K. Smith. 2013. *The Missing Piece: Drought Impacts Monitoring.* Workshop Report. Tucson, AZ. 23 pp.

WORKING GROUP IN-PERSON MEETING

2013 March 5-6, 2013, Tucson, AZ. 11 attendees.

ORAL PRESENTATIONS

2013 Lackstrom, K. "The Missing Piece: Drought Impacts." National Integrated Drought Information System Engaging Preparedness Communities Webinar Series. Web-based presentation, November 6, 2013.

2014 Brennan, A. and K. Lackstrom. "NIDIS Carolinas Drought Impacts Projects & Citizen Science Network." National Drought Information System Engaging Preparedness Communities Webinar Series. Web-based presentation, January 8, 2014.

Dow, K., A. Brennan, K. Lackstrom, and D. Ferguson. "Linking Drought Impacts Information to Decision Making: Identifying Gaps and a Framework for Moving Forward." American Meteorological Society Annual Meeting, February 2-6, 2014, Atlanta, GA.

CITIZEN SCIENCE CONDITION MONITORING

ORAL PRESENTATIONS

2014 Brennan, A., B. Haywood, K. Lackstrom and K. Dow. "Improving Understanding of Drought Impacts in Coastal Ecosystems through Citizen Science." American Meteorological Society Annual Meeting, February 2-6, 2014, Atlanta, GA.

2015 Brennan, A., J. Davis, K. Dow, K. Lackstrom, and S. Selvaraj. "Improving Understanding of Drought Impacts through Citizen Science." NC Water Resources Research Institute Annual Meeting, March 18-19, 2015, Raleigh, NC.

2016 Brennan, A., K. Dow, B. K. Haywood, and K. Lackstrom. "What Can Citizen Scientists Tell Us about Drought? Using the Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) to Improve the Monitoring and Reporting of Drought Impacts." American Meteorological Society Annual Meeting, January 10-14, 2016, New Orleans, LA.

Lackstrom, K., A. Brennan, and K. Dow. "Assessing the Usefulness of Citizen Science Information in Drought-Related Decision Making." American Meteorological Society Annual Meeting, January 10-14, 2016, New Orleans, LA.

POSTER PRESENTATION

2015 Davis, J., S. Selvaraj, A. Brennan, K. Dow, D. Eckhardt, B. Haywood, and K. Lackstrom. "Assessing the Usefulness of Citizen Science to Support Drought-Related Decision Making." 21st International Symposium on Society and Resource Management, June 13-18, 2015, Charleston, SC.

VOLUNTEER TRAININGS (IN-PERSON)

2013 LowCountry Master Naturalists, Sea Island, SC, August 28, 2013. 26 attendees.

Coastal Master Naturalists, Caw Caw Interpretive Center, Ravenel, SC, November 13, 2013. 6 attendees

2014 Winyah Master Naturalists, April 11, 2014. 8 attendees.

VOLUNTEER TRAININGS (WEBINARS)

2013 Current SC CoCoRaHS observers, November 7, 2013. 14 attendees.

2014 Current NC CoCoRaHS observers, February 21, 2014. 13 attendees.

SC Master Gardeners and Master Naturalists, June 3, 2014. 22 attendees.

COMMUNICATIONS AND OUTREACH

2013 CISA & CoCoRaHS Citizen Science Condition Monitoring Project Training Materials, http://www.cisa.sc.edu/cocorahs.html

- Information Sheet, 2 pages
- Reporting Instructions, 1 page
- Training Slideshow
- Volunteer Notebook, 9 pages

2014 Brennan, A., K. Dow, B. Haywood, K. Lackstrom, and D. Tufford. Citizens contribute input for better study of impacts. 2014 *Dry Times* 4 (1): 11.

Observer Conference Call, July 22, 2014. 8 attendees.

2015 Observer Conference Call, February 12, 2015. 10 attendees.

Observer Conference Call, July 8, 2015. 4 attendees.
Observer Conference Call, October 29, 2015, 7 attendees.

Ongoing

"Cuckoo for CoCoRaHS in the Carolinas" blog, http://carolinascocorahs.blogspot.com/

CISA & CoCoRaHS Condition Monitoring Newsletter, circulated monthly via e-mail beginning January 2014

EVALUATION OF DROUGHT INDICATORS AND INDICES

DEVELOPMENT OF A COASTAL DROUGHT INDEX

MANUSCRIPT

2015 Conrads, P. Development of a Coastal Drought Index using Salinity Data. Manuscript in review.

ORAL PRESENTATIONS

2014 Conrads, P. "Overview of the Development of the USGS Real-time Salinity Drought Index." Coastal Drought Monitoring Knowledge Assessment Workshop, January 7, 2014, Charleston, SC.

Conrads, P. and L. Darby. "Development of a Real-Time Coastal Drought Index." USGS National Water Data Conference, September 14-17, 2014, Jacksonville, FL.

Conrads, P. and L. Darby. "Development of a Real-Time Coastal Drought Index." South Carolina Water Resources Annual Conference, October 15-16, 2014, Columbia, SC.

2015 Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." American Meteorological Society Annual Meeting, January 4-9, 2015, Phoenix, AZ.

Conrads, P. "Development of a Coastal Drought Index using Salinity Data." USGS National Research Program Weekly Science Seminar Series. Web-based presentation, February 18, 2015, Reston, VA.

Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." 5th Interagency Conference on Research in the Watersheds, March 2-5, 2015, Charleston, SC.

Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." North Carolina Water Resources Research Institute Annual Conference, March 18-19, 2015, Raleigh, NC.

Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." Greater Everglades Ecosystem Restoration Conference, April 21-23, 2015, Coral Springs, FL.

Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." Georgia Water Resources Conference, April 28-29, 2015, Athens, GA.

Conrads, P. "Development of a Coastal Drought Index." Cape Fear Arch Conservation Collaborative Quarterly Meeting, November 10, 2015, Ocean Isle Beach, NC.

Conrads, P. "Critical Aspects of the Coastal Drought Index: Length of Salinity Data Record and Ecological Response Data." American Geophysical Union Fall Meeting, December 14-18, 2015, San Francisco, CA.

2016 Conrads, P., D. L. Tufford, and L. S. Darby. "Critical Aspects of the Coastal Drought Index: Length of Salinity Data Record and Ecological Response Data." American Meteorological Society Annual Meeting, January 10-14, 2016, New Orleans, LA.

POSTER PRESENTATIONS

2014 Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." American Geophysical Union Fall Meeting, December 15-19, 2014, San Francisco, CA.

2015 Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." Water Environment Federation Technical and Exhibition Conference (WEFTEC), September 28-30, 2015, Chicago, IL.

Conrads, P. and L. Darby. "Development of a Coastal Drought Index using Salinity Data." Southeast Climate Consortium Fall Meeting, October 19-20, 2015, Athens, GA.

STAKEHOLDER WORKSHOP

2014 Coastal Drought Monitoring Knowledge Assessment Workshop, January 7, 2014, Charleston, SC. 40 attendees.

COMMUNICATIONS AND OUTREACH

2014 Conrads, P. Update to the Coastal Drought Index Advisory Committee. Webinar, July 17, 2014.

Conrads, P. Seeking salinity's role in drought. *Dry Times* 4 (1): 10-11.

2015 Conrads, P. Tracking salinity and ecological response data on the coast. *Dry Times* 5 (2): 9-10.

IDENTIFICATION OF ECOLOGICAL INDICATORS OF DROUGHT IN COASTAL ECOSYSTEMS OF THE CAROLINAS

MANUSCRIPT

2015 Nolan, C. B., D. L. Tufford, and D. Chalcraft. Needs Assessment of Coastal Land Managers for Drought Onset Indicators in the Southeastern U.S. *Journal of Coastal Research* (accepted).

ORAL PRESENTATIONS

2014 Tufford, D. "Connecting Ecological Linkages to the USGS Real-time Salinity Drought Index." Coastal Drought Monitoring Knowledge Assessment Workshop, January 7, 2014, Charleston, SC.

2015 Nolan, C., D. Tufford, and D. Chalcraft. "Needs Assessment of Coastal Land Managers for Drought Indicators in the Southeastern U.S." NC Water Resources Research Institute Annual Conference, March 18-19, 2015, Raleigh, NC.

Nolan, C. "Ecological Indicators of Drought in Coastal Ecosystems." Cape Fear Arch Conservation Collaborative Quarterly Meeting, November 10, 2015, Ocean Isle Beach, NC.

ASSESSMENT OF INDICATORS FOR COASTAL ZONE FIRE RISK

REPORT

2015 Davis, C., R. Cumbie, and R. Boyles. *Assessment of Indicators for Coastal Zone Fire Risk*. Final Report submitted to NIDIS.

ORAL PRESENTATION

2015 Davis, C. "Fire Weather Monitoring and Coastal Fire Risk Assessment in North Carolina." CISA Full Team Monthly Webinar, October 2, 2015.

COMMUNICATIONS AND OUTREACH

2015 Davis, C., R. Cumbie, and R. Boyles. Assessment of indicators for coastal zone fire risk. *Dry Times* 5 (2): 7-8.

DROUGHT FORECASTING FOR COASTAL ECOSYSTEMS

STAKEHOLDER INTERVIEWS

REPORT

2014 Lackstrom, K., B. Haywood, A. Brennan, J. Davis and K. Dow. *Drought and Coastal Ecosystems: Identifying Impacts and Opportunities to Inform Management*. Proceedings of the 2014 South Carolina Water Resources Conference, held October 15-16, 2014, Columbia, SC.

ORAL PRESENTATIONS

2013 Lackstrom, K., A. Brennan, J. Davis, K. Dow, B. Haywood, A. Patel. "Local Actors' Perspectives about the Impacts of Drought on Coastal Resources and Communities." Southeast Division of the Association of American Geographers Annual Meeting. November 24-26, 2013, Roanoke, VA.

2014 Brennan, A., B. Haywood, K. Lackstrom, and K. Dow. "Improving Understanding of Drought Impacts in Coastal Ecosystems." NC Water Resources Research Institute Annual Meeting, March 20, 2014.

Lackstrom, K., A. Brennan, B. Haywood, and K. Dow. "Improving Understanding of Drought Impacts in Coastal Ecosystems." American Meteorological Society Annual Meeting, February 2-6, 2014, Atlanta, GA.

2015 Lackstrom, K., A. Brennan, and K. Dow. "Drought and Coastal Ecosystems: An Assessment of Decision Maker Needs for Information." 5th Interagency Conference on Research in the Watersheds, March 2-5, 2015, North Charleston, SC.

FORECASTING THE SC BLUE CRAB FISHERY

REPORTS

2014 Childress, M. *Going with the flow: Forecasting the impact of climate change on blue crabs*. Proceedings of the 2014 South Carolina Water Resources Conference, held October 15-16, 2014, Columbia, SC.

2015 Childress, M. *Forecasting the South Carolina Blue Crab Fishery Using Real-Time Freshwater Flow Data.* Final Report submitted to NIDIS.

ORAL PRESENTATIONS

2014 Childress, M. "Forecasting Blue Crab Distributions using an Individual-based Population Model." Coastal Drought Monitoring Knowledge Assessment Workshop, January 7, 2014, Charleston, SC.

Childress, M. "Dying of thirst: Forecasting the impact of drought on blue crabs." Benthic Ecology Meeting, March 19-22, 2014, Jacksonville, FL.

Childress, M. "Going with the Flow: Forecasting the Impact of Climate Change on Blue Crabs." South Carolina Water Resources Annual Conference, October 15-16, 2014, Columbia, SC.

2015 Childress, M. "Integrating field data, individual-based models and climate forecasts to predict blue crab landings." American Fisheries Society Meeting, Crustacean Fisheries Symposium, August 16-20, 2015, Portland OR.

Tufford, D., G. Carbone, J. Lu, and M. Childress. "Forecasts of Future Streamflow in a Coastal Plain River Using OpenNSPECT." 2015 AWRA Annual Water Resources Conference, November 16-19, 2015, Denver, CO.

POSTER PRESENTATION

2015 Childress, M. "Forecasting the Impact of climate change on South Carolina Blue Crabs." South Carolina Department of Natural Resources Crustacean Resources Workshop, April 2015, Charleston, SC.

COMMUNICATIONS AND OUTREACH

2015 Childress, M. Forecasting a crab fishery using real-time freshwater flow data. *Dry Times* 5 (2): 5-6.

Childress, M. “South Carolina blue crab forecast.” Blue Crab Workgroup. South Carolina Sea Grant Consortium Webinar. June 2015.

SC Blue Crab Forecast Website. http://scbcrabs.blogspot.com/

Facebook Group – SC Blue Crab Forecast. https://www.facebook.com/groups/957395250994282/

ATLAS OF HYDROCLIMATE EXTREMES FOR THE CAROLINAS

ORAL PRESENTATIONS

2015 Konrad, C. and J. McLeod. “Determining Climatological Patterns of Wetness and Drought at a Regional to Local Scale across the Carolinas.” Climate Prediction Applications Science Workshop, March 24-26, 2015, Las Cruces, NM.

Lu, J. and G. Carbone. 2015. “Understanding the Impact of Drought on Crop Yield in South and North Carolina.” Association of American Geographers Annual Meeting, April 21-25, 2015, Chicago, IL.

McLeod, J. and C. Konrad. “Determining Climatological Patterns of Dryness and Drought at a Regional to Local Scale across the Carolinas.” NC Water Resources Research Institute Annual Conference, March 18-19, 2015, Raleigh, NC.