

Understanding Needs for a Drought Early Warning System: Drought Impacts and Stresses on Coastal Ecosystems

Prepared by

Carolinas Integrated Sciences and Assessments (CISA)
University of South Carolina

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Executive Summary

The objective of this research project is to expand current, limited understanding of drought impacts on coastal ecosystems. An inaugural workshop involved researchers, resource managers, education and outreach providers, and NGOs interested in land and water conservation issues. Participants discussed the current state of knowledge about drought impacts and coastal ecosystems, data and information needs, and recommendations for management improvements. Local leaders were particularly interested in how to balance diverse social and ecological needs. Based on participant recommendations, our first follow-up activity is to write a comprehensive state-of-knowledge report. Collectively, these activities represent a first-step to help inform the National Integrated Drought Information System (NIDIS) efforts to develop an early warning system in the Southeast. Such a system will include monitoring and forecasting tools as well as decision support for coastal resources stakeholders, education and outreach, and networks which facilitate sharing and communicating information among different groups.

Several key themes emerged from this research project:

- Drought impacts coastal resources by affecting water quality (e.g. saltwater intrusion) and water quantity (e.g. reduced streamflow). Impaired hydrological conditions contribute to habitat loss or conversion and subsequent impacts to the ecosystem services upon which various plant and animal species – as well as human systems – depend. Capacity to manage drought events effectively may be limited due to the lack of appropriate data and information related to coastal resources, inadequate understanding about hydrological processes, and limitations of existing systems of water management to balance environmental and human needs.
- The current state of knowledge about drought and coastal ecosystems is minimal to poor. While some short-term impacts to particular organisms or species may be well-understood, researchers lack adequate long-term and site-specific biological and ecological data, as well as models or tools which incorporate human influences on ecological impacts (e.g. socioeconomic data, land use, water allocation and permitting). Basic research may be required to assess the quality and appropriateness of existing data networks and to identify which variables are most important to monitor and assess drought-impacted ecosystems (e.g. chemical, physical, or biological).
- Drought management has been conducted as a “reactive” response to impacts or through “stop-gap” measures. Resource managers report a general lack of knowledge about available drought-related data and information, conditions and impacts, and possible management tools. Cross-agency communication and coordination is limited. Ecosystem issues are currently not well-integrated into other management regimes, including state-level drought response management processes.
- According to education providers, the public and local decision-makers lack interest in and knowledge about drought, broader water supply issues, and the linkages between human uses and ecosystem processes and needs. Part of the challenge is translating scientific data and information into a format or context that meets local interests. Participants recommend using existing networks to distribute drought-related information. Drought would probably not be a stand-alone topic, but part of broader information outreach on climate, coastal hazards, and/or shoreline change.

This document presents details about the various activities conducted as part of this research project and a synthesis of the workshop results. For more information about this research, please contact cisa@sc.edu.

Table of Contents

- Executive Summary..... 2
- Table of Contents..... 3
- Introduction 4
 - Background: Drought in the Carolinas..... 4
 - Research Objectives..... 4
 - Coastal Ecosystems..... 5
 - The National Integrated Drought Information System (NIDIS)..... 5
- Project Design 6
 - Pre-workshop activities..... 6
- The Drought Impacts and Stresses on Coastal Ecosystems Workshop 7
- Project Results 9
 - 1. Drought and coastal ecosystems: impacts, concerns, and vulnerabilities 9
 - Research and Monitoring Group 10
 - Management and Planning Group..... 11
 - Education, Outreach, and Communication Group..... 11
 - 2. Needs and preferences for a drought early warning system..... 11
 - Research and Monitoring Group 12
 - Management and Planning Group..... 12
 - Education, Outreach, and Communication Group..... 13
 - 3. Potential building blocks for the design of a drought early warning and information system 14
 - Research and Monitoring Group 14
 - Management and Planning Group..... 14
 - Education, Outreach, and Communication Group..... 15
- Recommended Actions and Next Steps..... 16
- About CISA 16
- Acknowledgements..... 17
- References 17
- Appendix A. On-line survey results..... 19
- Appendix B. Workshop Agenda 23

Introduction

Background: Drought in the Carolinas

Although the Carolinas normally receive ample annual precipitation, the region is not immune to drought risks. Significant periods of statewide drought occurred in 1925-29, 1930-35, 1950-57, 1965-1971, 1980-82, and 1985-88 (USGS 2002, Weaver 2005). Beginning in 1998, several years of below-normal precipitation contributed to critically low river and reservoir levels which peaked in summer 2002. Many areas experienced record lows for stream flows, ground water levels, and reservoir storage, and at least 60 community water systems were vulnerable to running out of water had the drought continued (NC DENR 2004, Weaver 2005, SC DNR 2003). The 1998-2002 drought severely impacted water systems and numerous water users across the Carolinas. Many sectors experienced substantial economic losses including agriculture (\$357,410,000), forestry (\$1,311,533,243), and hydropower generation (\$38,000,000) (SC DNR 2003). On the Yadkin-Pee Dee River, rapidly declining water supplies necessitated emergency meetings between dam operators, North Carolina and South Carolina state agencies, and water users to manage the limited resource for the duration of the drought.

In 2007-2008 the Carolinas experienced another “drought of record.” This drought’s rapid and intense onset in summer 2007 was exacerbated by above-average temperatures. North Carolina experienced the driest year on record and a record number of days above 90°F, and South Carolina experienced its 5th driest year on record in 2007 (NC DMAC 2008). Below-average rainfall persisted throughout 2008, and streamflow-, reservoir-, and groundwater levels failed to recover as they normally would through the winter and spring months.

These recent droughts have raised awareness of the need to improve understanding of impacts and planning for such events. While drought impacts on agriculture and water supplies are relatively well-studied, the myriad ways in which drought affects aquatic and terrestrial environmental resources are not well understood. Drought contributes to reduced streamflow, diminished water quantity and quality, which then impacts habitats and limits the resources available to wildlife. Human-induced changes in the environment (e.g. dams, flow regimes, development) may compound drought conditions and exacerbate impacts. However, studies have indicated that “...environmental resources often receive inadequate attention during drought emergencies and in drought planning, not so much because of lack of concern but because of lack of expertise in this arena, lack of adequate financial resources, and sometimes lack of awareness” (NDPC 2000, 29).

Research Objectives

In collaboration with the National Integrated Drought Information System (NIDIS), the Carolinas Integrated Sciences and Assessment (CISA) team organized a workshop among South Carolina coastal management professionals with experience and responsibility for managing natural resources. The primary objectives of this workshop were to:

- Identify and explore drought impacts, concerns, and vulnerabilities on coastal ecosystems,
- Learn about needs and preferences for a drought early warning system, and
- Identify potential building blocks for the design of a drought early warning and information system.

This document reports on the insights resulting from the workshop, as well as pre-workshop activities. The accompanying Appendices provide additional details about this project.

Coastal Ecosystems

Nearshore coastal ecosystems are characterized by a diverse array of estuarine and associated upland, marsh, and wetland habitats. These ecosystems provide several important provisioning, regulatory, supporting, and cultural services to coastal communities (Millennium Ecosystem Assessment 2005). For example, they provide nursery habitat for many fish and shellfish species of commercial and recreational importance, enhance water quality by filtering sediments and absorbing excessive nutrients, protect inland areas from storm surges, and provide many recreation opportunities (Laporte et al. 2010). In the Carolinas, the vast, flat coastal plain supports extensive estuaries dominated by spartina.

Water flow regimes and the physical characteristics of a given watershed and coastal area play a major role in estuarine processes. Water flows may be affected by rainfall events as well as by local and upstream management decisions (Dame et al. 2000). In this context, coastal ecosystems are sensitive to changes in water flows. In South Carolina, the prolonged drought of 1998-2002 produced high salinity conditions that adversely impacted several species (shrimp, crabs, wood storks, wading birds, salamanders) (SC DNR 2003). Such impacts highlight the need to understand the connections between drought, water quality, and water quantity in coastal ecosystems:

Understanding the impacts of freshwater input to estuaries and the resulting changes in salinity regimes may be one of the most important challenges facing coastal scientists and managers. Salinity is a primary indicator of estuarine circulation because of its conservative character; it is also a significant determiner of biological productivity, faunal distributions, and habitat structure (Dame et al. 2000, 798).

The National Integrated Drought Information System (NIDIS)

The National Integrated Drought Information System (NIDIS) is an interagency program that works to improve drought monitoring and management systems on the national level. One goal of NIDIS is to create a comprehensive “drought early warning system,” that provides accurate information and tools to monitor and forecast drought conditions (NIDIS 2010). Such decision support tools facilitate proactive decisions aimed at minimizing the economic, social, and ecosystem losses associated with drought. This type of early warning system supports communication networks, stakeholder partnerships, and education and outreach programs that enable information-sharing among different groups. NIDIS also incorporates interdisciplinary research in order to improve understanding of how to make scientific data useable and accessible to decision-makers and how to incorporate drought information into drought response planning effectively (NIDIS 2007).

NIDIS is currently developing and implementing drought early warning system pilot projects in the Southeast. This research includes engagement with a range of stakeholders to determine their decision-support needs and possible opportunities and regional activities through which NIDIS can support those needs. CISA works with NIDIS and stakeholders to prioritize, develop, and initiate projects

to be included in an early warning system pilot and help to develop ways to transfer tools and information to stakeholders in other regions.

Project Design

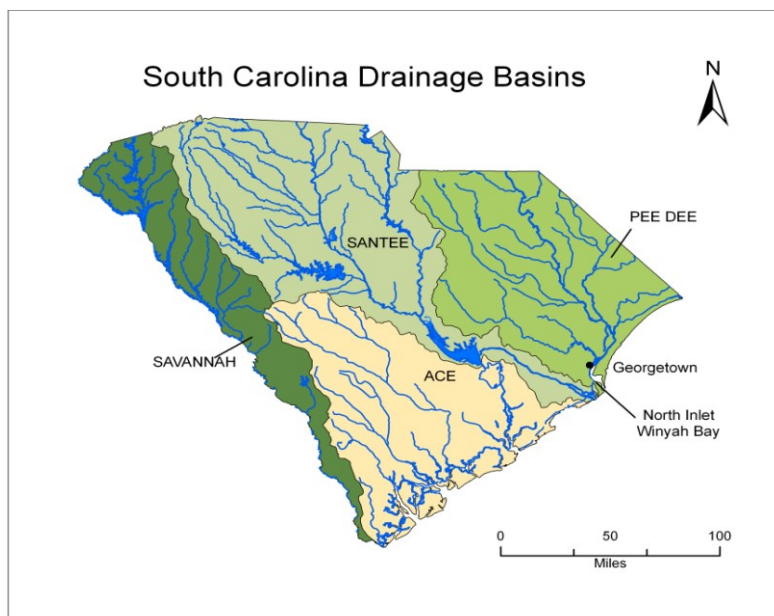
We used a variety of information sources and methods to meet the objectives of this project. The following sections briefly outline the project design. Research activities began in October 2009 to prepare for a stakeholder workshop in March 2010.

Pre-workshop activities

Several steps were taken to prepare for the workshop. These steps are described below and include selecting a study area, reviewing existing information on drought impacts, identifying workshop participants, and conducting an online survey with workshop registrants.

Stakeholders in and around the Winyah Bay drainage basin (Figure 1) were targeted for several reasons. The region has experienced two exceptional drought events in 1998-2002 and in 2007-2008. These recent events create an opportunity to elicit first-hand accounts of drought impacts. The larger Yadkin-Pee Dee watershed which drains into Winyah Bay has broad regional significance as it stretches from the mountains of North Carolina to the coast, and requires interstate coordination. In addition, CISA researchers are investigating other regional issues of concern, such as salinity intrusion, in the Winyah Bay drainage basin. Furthering our work in this drainage basin will enable the research team to draw upon existing knowledge of this system and advance our understanding of regional specific concerns.

Figure 1. South Carolina Drainage Basins



A literature review, which broadly encompassed peer-reviewed research, technical reports, white papers, newspaper articles, and organization web pages, was conducted to identify significant issues and concerns for the Winyah Bay region and individuals and organizations with experience and/or expertise with “on-the-ground” drought and related management concerns. The need for greater attention to coastal ecological impacts of drought was reflected in the sparse research published on the topic. The peer-reviewed literature on drought and coastal resources in the Southeast is narrowly focused on the impacts of high-salinity on individual species and habitats, e.g. blue crabs (Lee and Frischer 2004), oysters (Power et al. 2006), and salt marsh die-off and associated vegetation changes (White and Alber 2009; Ogburn and Alber 2006; Visser et al. 2002). Ten scoping interviews were then conducted to gather additional information about possible topics of interest and identify other stakeholders to invite to the workshop. Interviewees represented government agencies, non-governmental organizations, and research institutes.

In February 2010 we sent workshop invitations to 67 people. Ultimately, 27 people registered and a survey of these workshop registrants was conducted through Survey Monkey. Questions were designed to obtain background information about the participants and drought-related work responsibilities, key concerns about drought, current use of drought-related data and tools, and the resources, tools, and information necessary to address their primary concern. Appendix A provides the results of this survey.

The Drought Impacts and Stresses on Coastal Ecosystems Workshop

The workshop was held on March 23, 2010, at the Baruch Institute in Georgetown, South Carolina. The twenty-nine attendees included applied researchers, resource managers, and education and advocacy specialists engaged at the federal-, state-, and local levels (Table 1). While most participants work primarily in the Winyah Bay watershed, several attendees participated in the workshop due to their involvement with drought-related issues in other coastal areas.

The workshop involved three central components, with the pre-workshop survey responses used as a guide to develop follow-up and discussion questions. Appendix B provides the workshop agenda. The first session included presentations by staff from CISA and the National Drought Mitigation Center about national- and state-level activities to improve drought preparedness and monitoring (Table 2). The purpose of this session was to inform participants about various drought efforts and to provide a conceptual framework to guide participants’ thinking about drought-related impacts, stresses, information needs in coastal ecosystems.

The second session was a large group discussion of impacts and stresses of greatest concern. Participants were asked to categorize and rank impacts and consider the specific factors that created or contributed to impacts (e.g. length or duration of the drought, severity, human activities). Individuals wrote responses on “sticky notes” and posted them to display boards according to categories derived from the pre-workshop survey responses (Figure 2). The initial themes pertained to water quality, ecosystem impacts (habitat and species), data and information, understanding hydrological processes (e.g. groundwater-surface water interactions), and management capacity.

Table 1. Organizations and agencies represented by workshop facilitators and participants.

American Rivers
Baruch Institute of Coastal Ecology and Forest Science
Baruch Marine Field Laboratory, University of South Carolina
Carolinas Integrated Sciences and Assessments (CISA)
City of Myrtle Beach
Clemson University
Clemson University Cooperative Extension Service
National Drought Mitigation Center
National Estuarine Research Reserve System (NERRS) <ul style="list-style-type: none"> • ACE Basin • North Inlet-Winyah Bay
National Oceanic and Atmospheric Administration (NOAA) <ul style="list-style-type: none"> • Coastal Services Center • National Ocean Service
North Carolina Sea Grant
South Carolina Department of Natural Resources <ul style="list-style-type: none"> • Marine Division • Marine Resources Research Institute • Office of Fisheries Management • State Climatology Office
South Carolina Sea Grant Consortium/
Southeast Indigenous Peoples' Center
The Nature Conservancy
University of South Carolina
U.S. Fish and Wildlife Service (USFWS) <ul style="list-style-type: none"> • South Carolina Lowcountry Refuges Complex • Waccamaw National Wildlife Refuge
Waccamaw Watershed Academy, Coastal Carolina University
Winyah Rivers Foundation, Waccamaw RIVERKEEPER

Table 2. Presentations

<p><i>National Drought Preparedness and Monitoring</i> (Dr. Cody Knutson, National Drought Mitigation Center)</p> <ul style="list-style-type: none"> • National-level efforts to improve drought preparedness and management, focus on need for more information and better understanding of environmental impacts • NIDIS activities in the Apalachicola-Chattahoochee-Flint Basin • Expected contributions of this workshop to help inform other regional projects
<p><i>Drought Preparedness in South Carolina</i> (Dr. Hope Mizzell, South Carolina State Climatologist)</p> <ul style="list-style-type: none"> • State-level activities and preparedness, Drought Response Act • Updates on the Dynamic Drought Index Tool and the South Carolina Surface Water Withdrawal, Permitting, Use, and Reporting Act
<p><i>Drought and Coastal Ecosystems</i> (Dr. Dan Tufford, USC Department of Biology)</p> <ul style="list-style-type: none"> • CISA activities, including report on basin modeling and salinity intrusion projects • Knowns and unknowns about climate variability and southeastern ecology

Third, breakout sessions assembled participants according to their primary drought-related responsibilities: 1) research and monitoring, 2) management and planning, and 3) education, outreach, and communication. The goal was to tap into the collective expertise represented by each sub-group and stimulate in-depth discussion about the drought issues of greatest interest to each group.

Figure 2: Large-group discussion of drought stresses and concerns



Project Results

This section synthesizes insights from the online survey and workshop activities and is organized according to the three research objectives:

1. Identify and explore drought impacts, concerns, and vulnerabilities on coastal ecosystems,
2. Learn about needs and preferences for a drought early warning system, and
3. Identify potential building blocks for the design of a drought early warning and information system.

Results from the online survey and large group session are summarized at the beginning of each section. Because breakout groups expanded upon many of the general themes, their discussions are presented separately.

1. Drought and coastal ecosystems: impacts, concerns, and vulnerabilities

Several broad themes related to impacts, concerns, and vulnerabilities emerged from the survey and large group session. These include: water quality and quantity; impacts to estuarine and river habitat and species; the availability of appropriate information and knowledge; understanding hydrological processes; and management capacity.

- **Water quality and quantity concerns** during drought events involve 1) increased salinity and saltwater intrusion, 2) reduced ability to flush [disperse] or assimilate pollutants, thus exacerbating risks of impairment, and 3) overall water quality changes, particularly in the Waccamaw River.

- **Ecosystem impact concerns** focus on habitat loss or conversion and consequent impacts to species, such as effects on recruitment, distribution and migration patterns, and primary and secondary production. Saltwater intrusion, as well as low streamflows and water levels, contribute to impacts and are attributed to both natural causes (drought) and human actions (e.g. changes in dam releases due to drought).
- Participants cited the **lack of knowledge and understanding** about drought and its impacts on coastal resources as a major concern. Part of this concern stems from the lack of availability of appropriate drought-related data and information. Such data includes not only hydrological and climatological information but also socioeconomic data regarding population growth, land use, and development patterns. Without suitable data and information, an overall lack of understanding about drought limits both the scientific and management realms.
 - One specific concern entailed the **lack of understanding about hydrological processes**. Participants noted that the region lacked a comprehensive view of the system. There is limited knowledge regarding groundwater-surface water interactions, connections between streamflow and water quality characteristics, and how human actions (possible overpumping of groundwater, stormwater practices, development and impervious surfaces) contribute to short-term as well as cumulative impacts during drought events.
 - A second and related concern involves the **ability of existing water management systems to incorporate ecosystem needs and information into drought planning and decision-making**. Participant comments indicated that drought response in the region is often reactive, rather than proactive. Drought conditions and response actions are not necessarily well-communicated to the public, and little coordination occurs across different levels of drought- and water decision-making. Several additional questions relate to these concerns. First, do individual decision-makers have the expertise necessary to consider and use drought data and information? Second, do existing drought management processes have the ability to balance environmental and human needs during drought events? Finally, do existing regional water- and land-management regimes have the capacity to consider drought issues?

Research and Monitoring Group

The Research and Monitoring Group focused on concerns about the current state of information about drought and coastal ecosystems. Participants observed that while some short-term impacts and impacts to specific organisms or species may be well-understood, the understanding of drought impacts at the ecosystem level is substantially less. More specific concerns involved challenges in locating existing data, data quality, and the availability of appropriate data for studying drought-related topics.

Data is often difficult to locate due to a diffusion of data amongst many sources and a lack of published summaries about possible data sources. Participants expressed a low level of confidence in biological and ecological datasets. For example, they questioned data quality when a dataset did not use a widely understood protocol or did not explain quality assurance procedures. Such datasets also exhibit variability in terms of their length and the temporal and spatial scales at which variables are measured, further limiting comparability. Because data collection – and the development of a dataset – often

depends on funding availability and research objectives, participants voiced concerns that the adequate and appropriate data to study drought impacts on coastal ecosystems is unavailable. In short, scientists lack long-term biological and ecological data that is spatially and temporally explicit enough to investigate such impacts. Finally, access to funding to maintain and augment existing monitoring and research activities is a challenge, particularly in light of current budget shortfalls. The funding situation threatens to interrupt or terminate the few existing long-term monitoring stations.

Management and Planning Group

Participants expressed concern that drought management has been conducted as a “reactive” response to impacts or through what one participant characterized as “stopgap” measures. They report lacking knowledge and information about: the various, appropriate management tools that may be available to mitigate impacts; where and how to get data about drought conditions and official drought declarations; and, long-term consequences for resources (e.g. how long does it take resources to recovery, to what extent do they or are they able to recover). Some participants also noted that drought issues are not well integrated into other drought and ecosystem management processes, including state-level drought response management and planning. While upstream decisions influence water quality, habitat, forests, fisheries, reserves, and parks on the coast, cross-agency and cross-jurisdiction communication and coordination is limited.

Education, Outreach, and Communication Group

This group discussed their drought-related concerns in the context of broader water supply issues. According to education providers, the public and local decision-makers often lack interest in and knowledge about drought and only recognize the significance of drought when they are directly impacted or when drought is connected to other water and land use planning issues. For example, they noted that the perception on the coast is that ‘there will always be water’. The group identified several challenges related to the lower priority of drought management. The first challenge involves the translation of scientific data and information into a format or context that meets local needs and interests. The public does not necessarily understand science, how it is conducted, and how it is used or could be used in management decisions. It may be difficult to differentiate between decision-making constraints due to political unpopularity and constraints due to lack of expertise or capacity to use scientific information. Second, no comprehensive system exists to monitor or manage who uses water, and the amounts and sources (surface water, groundwater) of that water. Without such a system it is difficult for the public to be aware of the linkages between human uses of that water and ecosystem needs and processes. Third, some had concerns that those who have state or local regulatory authority to implement programs may not prioritize or support them. Educators and outreach specialists traditionally do not have such authority.

2. Needs and preferences for a drought early warning system

Results from the pre-workshop online survey and the large group discussion indicated that participant recommendations for needs and preferences fell into two broad categories: 1) scientific information and tools and 2) resources and techniques to improve management.

Needs for **scientific information and tools** include the acquisition of long-term data sets – and more data – about regional hydrology, climatology, water quality, and drought (including impacts). Participants also discussed the need for science-based models to analyze and link hydrology, ecological impacts, and social-environmental variables; more information regarding climate variability/change impacts on river systems and ecosystems; and, forecasts that indicate how river discharges affect estuarine salt-water gradients and upstream penetration of salt-water.

Management needs identified as having “high importance” include coordination or partnerships with other organizations; public education and outreach; and, online decision-support tools to improve access to information (See Appendix A).

Research and Monitoring Group

This group identified several areas requiring further research. One of the first priorities is to identify which variables are most important to monitor and assess drought-impacted ecosystems (e.g. chemical, physical, or biological) and to determine the appropriate temporal- and spatial scales to study this topic. Such a process will entail assessing the quality and appropriateness of currently available data and establish priorities for collecting additional data if necessary. Researchers highlighted the need for better long-term, fine resolution biological and ecological data; information related to climate variability; and socio-economic data. The variability associated with the El Niño Southern Oscillation (ENSO) has received some attention, but other types of climate information are sometimes difficult to obtain. With coastal areas experiencing increasing development and water demands, understanding and integrating social data (e.g. land use change, water allocation rules, and other socioeconomic processes) into water- and drought management decisions is also critical. Participants discussed a need for better models to analyze the ecological impacts of drought. Such models would have the ability to detect ecological change, incorporate human influences on ecological impacts, or indicate ecological flow needs. This group also indicated a desire to create a central location for data. This tool would be manifest in the form of a drought portal that would provide access to primary data (water quality, hydrology, meteorology, ecology, biology, etc.) as well as a repository for additional and relevant modeling tools and drought studies.

Management and Planning Group

Echoing the Research and Monitoring Group, the Management and Planning Group identified a need for drought-related data and information. Improved understanding of how environmental resources and ecosystem services are affected by drought – and the factors which influence their ability to recover – would be useful for managers as they monitor conditions and try to mitigate impacts. In many cases, drought management plans do not exist. More knowledge about drought impacts on environmental resources is needed to consider such planning.

To improve their capacity to respond to drought, managers cited needs for drought-specific data and information. They are interested in long-term, localized data so they can investigate trends and compare current with past conditions. Groundwater and water quality information may help them to better understand recovery rates and habitat impacts, such as salt marsh dieback due to increased salinity/saltwater intrusion during drought events.

Participants also discussed how existing management systems – and lack of understanding about drought – often constrain their ability to manage resources effectively during drought. For example, many refuges were developed to mitigate the impacts of upstream dams and impoundments on water fowl and other wildlife. During severe drought, however, managers often have limited ability to make water available for these habitats. Managers expressed concern that upstream reservoir managers make minimum releases during drought, thereby decreasing the water available for downstream users, such as the wildlife refuges. Group members identified a need to study, monitor, and improve understanding of how new regulations – the Federal Energy and Regulatory Commission (FERC) licenses and the management provisions for low-flow conditions on the Yadkin-Pee Dee River and South Carolina’s new surface water use and permitting system – will affect ecosystems. A second example concerns fisheries management when drought conditions influence the movement of the freshwater/saltwater line. The movement of this line affects the location and density of species, such as the blue crab, that seek lower salinity conditions. As blue crabs move upstream to more constricted riverine areas, there may be a higher risk of competition and then capture when they return downstream. Existing regulations and management authority are not flexible enough to match the dynamics and variability of the natural system. Empirical data that demonstrates these drought-related impacts could help guide fisheries management and decisions and possibly support changes to the current regulatory framework. While annual data on blue crab abundance is available, additional data regarding water quality characteristics and fluctuations are needed. Salinity intrusion models (e.g. the model described by Dan Tufford in his presentation) that integrate the various factors that affect saltwater intrusion (e.g. rainfall, river discharge) and locate the salt wedge would be a useful tool.

On the regional level, managers would like to know more about:

- Water resources needs and management capacity, e.g. how to maintain both tourist industry and ecosystem needs/services,
- Habitat changes, e.g. shifts in habitat characteristics which will have biggest impact on species that do not migrate or have limited options to move, and
- System connectivities, e.g. relationships between refuge habitats and neighboring land management practices, surface and groundwater, stormwater and water availability.

Education, Outreach, and Communication Group

In order to incorporate drought considerations into decision-making, this group recommended that information and resources link drought to issues that affect people’s lives, interests, and employment. Such issues may include cones of depression associated with pumping, public health considerations of water reuse strategies, and economic value of ecosystem services. They also note the need for greater interagency and interstate coordination and data-collecting/sharing regarding issues such as groundwater extraction and the monitoring of surface water-groundwater interactions.

This group receives requests for drought-related information but does not always have the time to compile data in a meaningful and easy communicable format. The most effective approach is one-on-one and face-to-face work; however it is also incredibly time-consuming and limits their ability to do other activities. They find that they do not have time to stay informed about the most recent scientific

literature although they have science backgrounds. For educators and outreach specialists to be more effective in their roles, they suggest the following. First, they need condensed information with the data source provided, but not necessarily the raw data. Having access to some key facts and interpretations will enable them to apply information to a variety of products and fit the audiences they serve. Second, access to experts or specialists who can provide insights into local situations would also be helpful. Experts may include people with first-hand experiences as well as regional and nationally known scientists or other prominent figures. From their experiences, individual or case study examples tend to be more useful and effective if a local person with hands-on experience talks to another local person. While people want information to be as local as possible, in-depth case studies from other areas may be too locally specific to transfer to another setting. One approach to investigate may be to compare several case studies. A meta-analysis could show how and whether results are robust under different circumstances.

3. Potential building blocks for the design of a drought early warning and information system

Each group addressed activities which could provide a basis for developing a drought early warning system. They identified existing efforts and networks which provide useful services as well as additions and expansions needed to better support early warning goals.

Research and Monitoring Group

One of the more important outcomes of this discussion was the identification of current activities that can be built upon in order to improve the quality and accessibility of drought-related data. One identified activity was testing and modeling to see if existing data are valid and reliable for research on drought, especially to determine the appropriate scale for considering ecosystem impacts. Attendees also expressed a desire to build on data collection and monitoring programs, such as those by the NERRS, the United States Geological Survey (USGS), or the National Climate Data Center (NCDC), that provide specific, consistent, and standardized data and to identify best practices for sharing data (e.g. information portal, webinars).

Management and Planning Group

This group discussed some possible ways in which existing resources could be used to improve drought monitoring and response. First, refuge managers may have drought-related data or information that could contribute to a broader-scale information system, such as the South Carolina Drought Response Committee (SCDRC). Managers of refuges, and similar habitat or wildlife, currently do not participate in a formal process to transfer information to the SCDRC, and they do not have representation on the Committee. Participants suggested that refuge managers, with local- and state-level decision-makers, could investigate 1) whether they have existing information that may be useful to local and state drought decision-making processes and 2) if information was available, identify a process or tool to facilitate information transfer between resource managers and decision-makers (e.g. the SCDRC). It may also be worth investigating whether the SCDRC or State Climatologist's Office has information that is currently available but not in an accessible or useable format for coastal resource managers.

Second, this group noted a need for public education and communication to show how coastal ecosystem services and resource can help to mitigate drought impacts. They recommended using existing and/or emerging networks to integrate drought-related information across organizations and jurisdictions. These networks include NERRs, the SC Coastal Information Network, and the South Atlantic Landscape Conservation Cooperative (a USFWS project working with USGS Water Science Centers).

Finally, this group recommended that managers and decision-makers take advantage of windows of opportunity to address and incorporate drought response and preparedness into other management, planning, and/or research processes. Participants discussed several examples of such processes. The FERC relicensing of hydropower dams in North Carolina helped to increase understanding of the Winyah Bay watershed and a drought response plan was included in new license. The Sea Level Affecting Marshes Model (SLAMM) is used by all refuges to simulate sea-level rise impacts, but the model could be extended to include related drought and salinity issues. Some local planning departments (e.g. Horry County) are starting to consider development impacts on ecosystems. Participants discussed how other local planning activities may be able to incorporate drought management and/or ecosystem needs, e.g. investigations of water intakes and municipal water needs, National Pollutant Discharge Elimination System (NPDES) permitting processes, and stormwater management planning.

Education, Outreach, and Communication Group

This group also noted that existing networks such as NERRS, and the South Carolina Coastal Information Network, a partnership of training providers, may be effective distributors of drought-related information. They see the state-local relationship as complicated. The level of coordination varies among entities and topics. The balance of expertise, authority, and ability to shift the responsibility for decisions to another level all influence the dialogue about coordination. For them, there is a valuable, useful distinction between being science educators and advisers who are separate from the authorities who may require actions. They feel that their lack of regulatory authority allows people to be more open with them.

They also recommend that CISA consider how to incorporate drought concerns into other regional networks and projects. Examples include the Section 208 plan revision process by local agencies and Councils of Government; the Waccamaw River Volunteer Monitoring Project, conducted with Coastal Carolina University and the Waccamaw Riverkeeper; the Clemson Extension Carolina Clear program, which provides water quality and quantity education; and the Waccamaw Stormwater Education Consortium, which consists of stormwater managers, municipalities, and educators. This group's experiences suggest that drought would probably not be a stand-alone topic, but part of broader information outreach on climate, coastal hazards, shoreline change, or combinations of all of the above. Public workshops are not necessarily effective unless the topic ties to a current problem or issue or connects to a civic organization that already is engaged in a related interest.

Recommended Actions and Next Steps

The development of a Southeast early warning system requires a regional approach to understanding drought monitoring and impact assessment needs, gaps in scientific understanding of drought processes, and development of communication strategies useful to a variety of groups involved in drought preparedness and response. This project was a significant first-step in identifying the greatest concerns for coastal Carolina ecosystems and the potential building blocks and priorities for the design of a drought management support system. The workshop was significant in that it convened stakeholders who do not necessarily interact to discuss a topic of common interest in an information-sharing forum.

CISA will continue to work with coastal ecosystem stakeholders and follow up on the workshop recommendations:

- The research and monitoring group recommended a state of knowledge report about drought and coastal ecosystem drought impacts; an evaluation of existing monitoring and data collection practices; and a centralized source of drought studies and relevant data. Determining which variables are most important was also viewed as an important step towards developing an effective means to monitor and forecast.
- The planning and management group suggested that the Office of the State Climatologist increase interactions with coastal resource managers and that ecosystem conditions and impacts be better integrated into state-level drought response management processes.
- The education and outreach group advised that local case studies of drought-related impacts and adaptations (e.g. use of grey/recycled water systems or other water conservation strategies) would be most effective in transferring information to local planners and decision-makers.

About CISA

Carolinas Integrated Sciences and Assessments (CISA) integrates climate science into decision-making by developing information, tools, and processes to support water and coastal management and planning processes. CISA is one of 11 Regional Integrated Sciences and Assessments (RISA), a NOAA-sponsored program that seeks to advance scientific understanding of climate variability and change and improve society's ability to respond to climatic events and stresses. A hallmark of the RISA program is the focus on partnerships between scientists and decision-makers to produce usable, useful, and accessible climate information. CISA engages with water and coastal stakeholders to ensure that our activities continually address management and decision-making needs. Current CISA projects encompass drought monitoring and assessment, watershed modeling, and working with communities to identify coastal climate vulnerabilities and adaptation options.

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Appendix A. On-line survey results

DROUGHT IMPACTS AND STRESSES ON COASTAL ECOSYSTEMS

Online Survey Responses, as of 3/19/10 [n = 19 responses from 27 registrants]

BACKGROUND INFORMATION ABOUT PARTICIPANTS

Do you focus on a specific ecosystem or resource?

Yes	11
No	7

If yes, please specify:

fisheries	2
forests	2
shellfish	1
wetlands	5
Other (please specify) <ul style="list-style-type: none"> • Wildlife • Rivers and coastal ocean water quality • North Inlet & Winyah Bay Estuaries • SC Lowcountry National Wildlife Refuges • Watershed as a whole • Coastal focus, aquatic ecosystems (wetlands, estuaries, rivers, coastal ocean) • Freshwater watersheds 	7

Which of the following best represents your current position's role and responsibilities?

education and outreach	5
natural resource management	4
permitting and regulatory enforcement	0
planning	1
program or site management	2
research	7
Other (please specify) <ul style="list-style-type: none"> • Conservation • Advocacy • Tool development, mapping, training, capacity building, stakeholder engagement • NOAA's Southeast and Caribbean Regional Team • Resource monitoring 	6

Drought-related work responsibilities

research: impacts (e.g. saltwater intrusion, forested wetlands, biological monitoring, historical comparative analyses, salt marsh ecosystems, fisheries)	6
research: models and analysis (e.g. minimum streamflows, salinity intrusion, water quality)	3
identify, prioritize, address regional issues as related to drought	2
interest in incorporating drought/climate info into resource management and planning	3
monitor conditions and impacts (e.g. fisheries, water quality, streamflows)	4
education and advocacy (e.g. water quality, water resources, coastal resources)	3

SECTION 1: IMPACTS AND CONCERNS

What specific drought impacts have you observed in relation to your job responsibilities?

habitat impacts, loss, or conversion	8
water quality, pollution	3
lower water level (general)	2
floodplain impacts	3
species (fisheries) impacts	3
reactive responses: awareness and concern about water quality, supply only occurs during drought	2

What are your top 3 concerns about drought impacts or management?

	ONE	TWO	THREE	Total # of responses
ability to balance environmental and human needs ; increased conflict for freshwater resources; equity, fairness of water usage	5	1	2	8
ecosystem impacts (loss or conversion of habitat, estuaries; loss of ecosystem services; species impacts, range shifts)	5	3	4	12
water quality impacts and changes (salinity, saltwater intrusion; reduced dilution, dispersion of pollution; stormwater pollution)	2	6	1	9
planning and management needs : better knowledge and awareness of drought (e.g. monitoring systems, forecasting/prediction, thresholds) and impacts (e.g. from water use, lack of conservation strategies, current management practices)	0	5	6	11
improving coordination, collaboration	1	0	0	1
impacts on freshwater refuge management capabilities	1	0	0	1
water is an undervalued resource	1	0	0	1
water supply	1	0	0	1
water use (drinking, recreation)	0	1	0	1
economic losses (state-level)	0	1	0	1
water conservation measures	0	0	1	1
intense heat waves associated with droughts	0	0	1	1

What resources, tools or techniques are necessary to address your top concern?

	High Importance	Medium Importance	Low Importance	Not Important
Science-based models, e.g. hydrology, ecological impacts, social-environmental carrying capacity	14	3	0	0
More data or basic research about drought, hydrology, climatology, or impacts	11	5	1	0
Coordination or partnerships with other agencies, organizations	10	6	2	0
Public education and outreach	9	7	2	0
Financial resources	8	7	2	0
Decision-support and/or online tools to improve access to information	9	6	3	0
Formal plans to guide actions	8	7	3	0
Monitoring tools	7	8	3	0
Technical training	1	11	6	0
Other: Connecting science to public policy decisions at the local, regional, and state levels to address drought-related impacts in our watershed.	1	1	0	0

SECTION 2: DATA AND INFORMATION

What drought-related information do you use?

	I am very familiar with this and use it regularly.	I am familiar with this and have used it.	I am aware of this but have not used it.	I am not aware of this.	I would like to learn more about this.
USGS SC Water Science Center (streamflow, groundwater, water quality data)	5	6	2	2	3
National Weather Service	4	11	1	0	1
SE River Forecast Center	2	2	3	9	2
SC State Climatology Office Current Drought Status	2	7	4	3	2
U.S. Drought Monitor	1	6	7	2	1
U.S. Drought Portal (drought.gov)	1	5	5	5	2
U.S. Seasonal Drought Outlook (NOAA Climate Prediction Center (CPC))	1	5	7	3	1
ENSO forecasts (aka, NOAA CPC Long-lead forecasts)	3	2	6	5	1
Drought Indices	0	2	9	4	3
If you use a drought index (above), please specify which index: Palmer Drought Severity Index					

Are current data and information sufficient for your needs?

Yes	3
No	9
If no, what data and information is most needed?	
More continuous collection sites of water quality and hydrology.	
Drought is important but is tangential to other high priority topics that I work on. I don't focus strictly on drought issues, though I may in the future based on the informational needs and priorities of our local community and local decision makers.	
Additional information linking drought condition with habitats and species (secondary impacts), information on recovery, long-term condition changes	
Unfortunately I am not aware of all the available data and where some of it may be compiled to indicate trends and provide scientific information for public policy decision making.	
Need to learn more about how climate change will affect river systems, wetlands, forests, etc.	
Free access to regional rainfall data in historic and current measurements in spreadsheet summaries.	
A formal El Nino 1 and 2 index. I am familiar with El Nino index 3.4, but investigators have found that the position of the El Nino at 1 and 2 (an eastern position - not the center of the Pacific) better correlates with the SE's precipitation and river flow.	
Need to stabilize funding for USGS stream gages	
Improved SLAMM model(s) with better local data sets and improved elevation data.	
Long-term data sets to see how and when events have occurred and to match with data sets collected over the years.	
Ability to forecast how changes in river discharge will affect estuarine salt-water gradients and upstream penetration of salt-water. Associated with that, ability to forecast long-term changes in river discharge itself.	

SECTION 3: MANAGEMENT PLANS

Does your agency or organization have a formal drought management plan?

Yes	1
No, but we have an informal plan.	2
No, but we are considering a plan.	1
No, we are not considering a plan at this time.	3
Not Applicable	8
If yes, what factors, conditions, or indicators trigger management actions?	2
NOAA works with a number of state and local entities on drought management plans.	
I do not directly work with the drought experts, but they use the usual: rainfall, streamflow, soil moisture, reservoir capacity, monitoring wells.	

Appendix B. Workshop Agenda

Workshop Agenda
Drought Impacts and Stresses on Coastal Ecosystems
23 March 2010, 9:45 a.m. – 3:00 p.m.
Kimbel Lodge, Baruch Institute, Georgetown, SC

- 9:45 a.m.** **Registration, Light Refreshments**
- 10:00 a.m.** **Welcome, Introductions, Workshop Overview and Objectives**
Kirstin Dow, CISA and USC, Department of Geography
- 10:20 a.m.** **Session 1: Presentations**
- National Drought Preparedness and Monitoring
Cody Knutson, National Drought Mitigation Center
- Drought Preparedness in South Carolina
Hope Mizzell, CISA and SC State Climatologist
- Drought and Coastal Ecosystems
Dan Tufford, CISA and USC, Department of Biology
- 11:05 a.m.** **Session 2: Large Group Discussion**
Impacts and Stresses of Greatest Concern for Coastal Ecosystems
Facilitator: Kirstin Dow
- Follow-up to online survey responses
- What are specific examples of drought impacts you have experienced?
 - What are your major concerns about drought?
- 12:15 p.m.** **Lunch**
- 1:00 p.m.** **Session 3: Introduction to Breakout Group Tasks**
Data, Information, and Research Needs
Priorities for an Early Warning and Management Support System
- Online survey responses
- What drought-related information do you use?
 - Are current data and information sufficient for your needs? If no, what data and information is most needed?
 - Do you have or use a formal management plan? If yes, what factors, conditions, or indicators trigger management actions?
 - What resources, tools or techniques are necessary to address concerns?

1:20 p.m. Session 4: Small Group Discussions

Breakout Group 1: Education and Communication

Facilitators: Kirstin Dow, Jess Whitehead

1. To what extent is drought response integrated across stakeholders?
2. How can information-sharing best be coordinated?
3. How could we improve and coordinate the flow of drought planning and preparedness across federal, state, tribal, local, and private entities? Recommendations for specific actions?
4. Which mediums of communication (web, conference calls, seminars, etc.) are most effective for reaching different groups and purposes?
5. What current activities can we build upon?

Breakout Group 2: Management and Planning

Facilitators: Cody Knutson, Kirsten Lackstrom

1. What responses or management actions worked well (or not) during recent drought? What were the gaps and shortcomings – how could you have managed better?
2. To what extent is drought response integrated across stakeholders?
3. What tools or techniques would benefit coastal ecosystem management during drought? Are there specific elements of an “early warning system” which would help address drought planning and management needs?
4. What types of communication are best for making information available to managers?
5. What current activities can we build upon?

Breakout Group 3: Impacts Research and Monitoring

Facilitators: Dan Tufford, Nate Kettle

1. What is current state of knowledge about drought and coastal ecosystems?
2. What information is needed about ecological impacts to determine ecological flow needs?
3. Where do you see gaps in data and information?
4. Which data sources do you have the most confidence in? Least confidence?
5. What current activities (e.g. climate, hydrology, ecology) can we build upon?
6. What approaches would you recommend to best share research and monitoring data?

2:30 p.m. Session 5: Breakout Group Reports

2:45 p.m. Concluding Discussion: Summary of Emerging Themes, Next Steps

3:00 p.m. Workshop Adjourns