# The Impact of Drought on Coastal Ecosystems in the Carolinas

**Executive Summary** January 2012

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## About CISA

The Carolinas Integrated Sciences and Assessments (CISA) works with a variety of stakeholders across North Carolina and South Carolina to incorporate climate information into water and coastal management and related decision-making processes. Efforts include working with decision makers on improving drought monitoring and management, linking climate variability to watershed/landuse planning, planning for coastal adaptation, and characterizing climate vulnerability in the region. The program is supported by NOAA's Regional Integrated Sciences and Assessments (RISA) program. Based at the University of South Carolina, CISA researchers collaborate with colleagues at the Southeast Regional Climate Center located at UNC-Chapel Hill, North and South Carolina Sea Grant, North Carolina State Climate Office, and South Carolina State Climate Office.

CISA's core activities encompass five general focus areas: drought, climate and watershed modeling, coastal climate, health, and adaptation. Within each of these areas, we are pursuing several cross-cutting activities that seek to advance scientific understanding of climate and hydrological processes in the Carolinas, improve the assessment of climate-related vulnerabilities and impacts, and provide timely and relevant information and tools for decision-makers.

## I. Introduction

This State of Knowledge Report provides a synthesis and analysis of the peer-reviewed literature regarding drought impacts on coastal ecosystems in the Carolinas. Its objective is to expand current, limited understanding of drought impacts on coastal ecosystems, to identify critical gaps, to inform future research efforts, and to suggest measures to facilitate drought adaptation for ecosystems. The report centers on biological, chemical, and physical impacts and is not meant to address social impacts. While we targeted literature from studies done in the Carolinas, some research from outside the region was included when deemed pertinent. The report focuses on the coastal ecosystems of North and South Carolina but includes portions of the southern Virginia and Georgia coasts with ecological continuity to the Carolinas.

Droughts are a normal part of climate variability that occurs at scales from days to years. Significant periods of widespread drought in the study area occurred in 1925-29, 1930-35, 1950-57, 1965-1971, 1980-82, 1985-88, 1998-2002, (USGS 2002, Weaver 2005) and 2007-2008. Many of the droughts of interest in this report are multi-year droughts or "supra-seasonal" droughts, typified by longer-term rainfall deficits and declines in water availability. Of lesser concern are seasonal droughts that occur as regular periods of low flow.

This executive summary presents the key themes identified from the literature. References are cited where a specific finding or observation is noted. The full report includes a more extensive bibliography.

Section II provides brief syntheses of research findings, organized into the following coastal subsystems: Coastal Marine; Maritime; Estuarine; Tidal Freshwater Riverine, Forested Floodplain and Marsh; Coastal Impoundment; Non-Alluvial Wetlands; and Uplands.

Section III discusses drought-related research themes highlighted by researchers. These themes include the role of anthropogenic stressors, expected hydrological and ecological changes due to climate change, and recommendations for adaptation.

Section IV presents key literature gaps and research needs.

## II. Drought Impacts on Coastal Ecosystems

The research reviewed for this report indicates that drought is discussed primarily in terms of the hydrology-related impacts that affect coastal ecosystems, such as changes to river discharge, freshwater inflows, water level, and water table depth. The severity of these effects depends upon the longevity and recurrence interval of drought event(s) and may be compounded by other anthropogenic stressors on the system. In addition, some drought-related research considers how sea level impacts these ecosystems. Sea level affects the quantity of saline waters delivered to estuarine systems, and, in concert with freshwater precipitation and runoff, influences the resultant salinity levels experienced by these systems. Salinity and flushing of pore water in estuarine marshes affects geochemical processes and productivity, and thereby the distribution and survival of these marshes.

While many aquatic and wetland coastal systems are particularly vulnerable to long-term and recurrent droughts, some potentially beneficial effects of drought were found through the literature review. Such benefits include temporary changes in nutrient input into aquatic systems that may reduce potential for algal blooms and increase water clarity thereby enhancing macrophyte productivity and reducing hypoxia. However, these effects may only be short-term and their beneficial nature is strongly site dependent.

### A. Coastal Marine

Very little literature was found on coastal marine systems probably because most drought impacts to the near shore system are likely to be secondary in nature (e.g., drought induced change in estuarine discharges and estuarine habitat for marine species and anadromous fish).

### B. Maritime

Maritime systems occur on barrier islands and contain numerous community types with very different hydrologies; hence the effects of drought will vary significantly depending on community type. Precipitation on barrier islands appears to be the only source of freshwater input and is therefore critical to several of these communities. Consequently, extended or repeated drought will likely cause significant community changes including potential successional community changes. Freshwater ponds, the community type perhaps most sensitive to the effects of drought, often are the only dependable source of water for animals on barrier islands and are critical to their presence there (Bellis, 1995). These animals include frogs, salamanders, water snakes, turtles, aquatic birds, and aquatic mammals.

### C. Estuarine

The estuarine system has by far the greatest literature coverage relative to drought and related freshwater inflow. The report discusses drought effects associated with freshwater inflow, salt marsh dieback, community shifts and productivity, flushing and water quality, and fauna. The majority of ecological effects relate to changes in salinity, productivity, water quality, and circulation.

Documented effects from reduced inflow include: upstream shifts in salinity and the presence of hypersaline conditions, an increasing tidal influence on circulation patterns that may alter stratification and affect bottom water hypoxia, the alteration of freshwater transit time with consequences for the buildup of pollutants and pathogens as well as effects on biogeochemical transformations (e.g., denitrification), changes in estuarine geomorphology due to loss of sediments, and changes to water quality due to changes in the delivery of dissolved and particulate material and in their concentrations in the estuary itself (Alber, 2002). During drought periods, lower freshwater inflow can dramatically lower nutrients and planktonic primary production especially in eutrophic estuaries like the Neuse River in North Carolina (Wetz et al., 2011). Slow or reduced flushing times have been implicated in the outbreak of harmful algal blooms (Alber and Sheldon, 1999; Paerl et al., 1998), and have a potential for higher sediment chemical contamination (Hyland et al., 1999).

Literature on drought effects on salt marshes concentrates in three areas: (1) the dieback of marsh that has occurred in the Southeast (and elsewhere); (2) community shifts in macrophyte composition; and (3) decreased marsh primary productivity as a result of higher pore water salinity. While the evidence for drought being the sole cause of marsh dieback events is still unclear, the literature suggests that high salinities acting in concert with other stressors (e.g., reduced pH, high interstitial salinity, sublethal bioavailable metals, drying) over an extended period could be responsible. Research shows that salt marsh primary production decreases with an increase in pore water salinity (Morris, 2000). Marsh community shifts as a result of salinity changes and freshwater inflow manipulation are also reported, although drought is not discussed as the primary causative agent. White and Alber (2009) observed shifts in marsh composition (*Spartina alterniflora* densities increasing in brackish-dominated *Spartina cynosuroides* marsh zones) during a prolonged drought, and the effects were still evident in a two-year post drought survey. It is difficult to determine if an observed change in vegetation structure and composition is part of natural variation of the system and temporary, or if the change is longer-term.

Estuarine organisms occur within focused salinity ranges, and different stages in their life histories have specific salinity requirements (Alber, 2002). Investigations document how changes in the species composition, distribution, abundance, and health of fish and invertebrate assemblages are attributable to changes in freshwater flow. Changes in river flow are also linked to changes in migration patterns, spawning habitat, and fish recruitment. Prolonged drought can have long-term effects on estuarine trophic system dynamics and the dependent fish community.

**D. Tidal Freshwater**

Tidal freshwater systems[1] occupy the upper ends of estuaries and are composed of tidal marshes, tidal swamps, and associated riverine conveyances (rivers, streams, and headwaters). These wetlands generally receive sufficient freshwater flows to keep surface water salinities less than 0.5[2] (Cowardin et al., 1979). Few ecosystems exist in a more vulnerable location for shifts in salinity and flood regime than tidal freshwater wetlands (Doyle et al., 2007a). Differences in community type, swamp versus marsh, were clearly related to the penetration of saline water into swamps (Hackney et al., 2007). Many existing tidal freshwater marshes in the Carolinas and Georgia are remnants of rice culture clearing of coastal swamps in the 1700s where forest cover is either actively excluded or has not yet regenerated.

With the absence of the salt stressor, tidal freshwater marshes are significantly more floristically diverse than are downstream brackish or salt marshes. These marshes provide wildlife habitat for numerous species including a diverse assemblage of wading birds, feeding habitat for freshwater fish, and nursery habitat for estuarine organisms and juvenile anadromous species. Similar to salt marshes, tidal freshwater marshes depend on building soil volume to remain in equilibrium with sea level as these systems are sensitive to the accompanying saltwater intrusion.

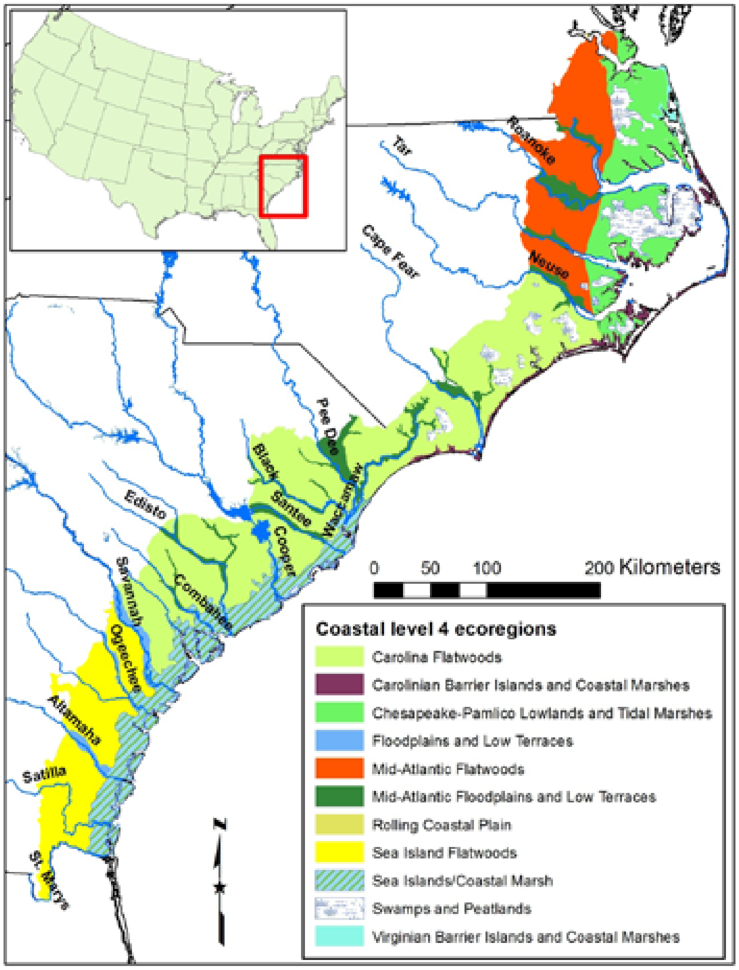
Acute and chronic exposure to even low levels of salinity seriously impact tidal freshwater forests. The combined stress of flooding and salinity compound this threat. Low river discharges also can play a key role in elevating salinities in these systems and may act synergistically with rising sea level, leading to rapid loss and habitat conversion of tidal freshwater marshes (Neubauer and Craft, 2009). Relative sea-level rise of any degree, large or small, in the absence of offsetting accretion or salinity diluting high river flows, will impact tidal freshwater swamps by increasing submergence and salinity over time. Microtopography plays a key role in the ecology of these systems with well-drained hummocks supporting woody forest vegetation and hollows (usually with saturated soils) having bare mud or herbaceous vegetation. Conversion from forest to marsh begins at a salinity of about 2 and is likely caused by a change in soil biochemistry with a switch from methanogenisis to sulfate reduction in the presence of saline pore space water (Hackney et al., 2007). Although drought alone (especially if not chronic) may not be solely responsible for the demise of this system, the cumulative impact of a subsiding coast, rising sea level, recurring hurricanes, and reduced freshwater flow could result in forest dieback and coastal retreat (Doyle et al., 2007b). Although little research was found on drought and tidal freshwater streams and rivers, non-tidal stream literature points to extended droughts having lasting adverse effects on riverine systems (Lake 2003) including destabilization of aquatic communities.

**E. Coastal Impoundments**

Drought impacts on functioning coastal impoundments were not covered to any extent in the literature. However, such impoundments may be able to ameliorate some drought effects (especially those dealing with salinity) by management schemes

[1]Although most literature about tidal freshwater systems includes them as part of the estuary, we have broken this zone out for separate discussion in this report due to its particular sensitivity to drought and concomitant salinity changes.

[2]The Practical Salinity Scale of 1978 defines salinity in terms of a conductivity ratio, so it is unitless.




that selectively preclude or limit exchange during high salinity events in the estuary. These actions may protect, reduce, or simply delay conversion of sensitive tidal freshwater and/or brackish systems to more saline communities. Limiting exchange to manage salinity has its own set of biological and ecological consequences and trade-offs, the nature and detail of which are beyond the scope of this report.

**F. Non-Alluvial Wetlands**

The vulnerability of these wetlands to drought depends, in large part, on the sources of their water supply. Those fed by precipitation are the most vulnerable. Carolina Bays and Pocosins are dependent upon direct precipitation and evaporative water loss can result in the complete drying of shallow bays. Any deviation from normal precipitation will have an impact on their hydropatterns (Sun et al., 2006). Fire plays a large role in the ecology of these systems. The high organic and peat soils burn readily when dry and so the intensity of the fire is related to the depth of the water table (and hence influenced by droughts). Severe burns could result in a shift to a non-pocosin community or even create a lake in a former vegetated area. The widespread installation of drainage ditches for land management (e.g., agriculture, pine plantations, development) has altered the hydrology of these systems. Drainage ditches lower the water table and significantly affect surface runoff (Sharitz and Gibbons, 1982), potentially increasing drought vulnerability.

**G. Coastal Upland Forests**

Several studies in upland pine forests indicate that drought reduces root production and photosynthetic rates. Drought may also affect mast production thereby reducing forage for numerous wildlife species.

## III. Related Research Themes

**A. Anthropogenic Impacts**

Researchers regularly discuss the cumulative effects of drought in relation to other system stressors. The biggest "natural" stressor associated with drought in estuaries is salinity. Effects of drought, most often through the salinity stressor, are compounded by anthropogenic alterations. These alterations include dredging and maintaining navigation channels, development resulting in the proliferation of non-porous surfaces that increase the flashiness of urban runoff, ditching for agricultural and timber production that increases runoff of nutrients and eroded sediments, and conversion of coastal interior wetlands that decreases retention time of nutrients and other pollutants and reduces groundwater recharge opportunities. With most river systems in the Carolinas modified by dam projects, management and operation of these dams affect the timing, duration, and volume of water flows (Richter et al., 2003). During a drought, management of large reservoirs for water supply has the potential to compound instream flow and critical estuarine freshwater inflow problems. Increasing human population densities in the coastal zone are making ever-greater demands on the coastal aquifer and thereby contribute to larger interaction between saline and freshwater aquifers (Dame et al., 2000).

**B. Drought and Climate Change**

In the Southeast, changes in annual and seasonal precipitation patterns are expected to affect the timing and amount of water available and contribute to increased risks of flooding and drought (Karl et al., 2009; Scavia et al., 2002; Committee on Environment and Natural Resources, 2008). Precipitation patterns are projected to be more episodic, with less frequent but more intense storms and longer inter-event droughts (Bates et al. 2008). Predicted warming air temperatures will exacerbate the effects of drought by increasing the rate of evapotranspiration. Drought may play a critical role in compounding the effects of sea level rise by reducing freshwater inputs to estuaries that deliver large quantities of suspended sediments critical to the accretion of wetland soils.

On the other hand, coastal processes are difficult to predict and many other natural factors affect streamflow and produce local and regional variations in drought severity. Factors such as physiographic characteristics and location of the watershed may affect evaporation rates, the influence of sea breezes, or the likelihood that tropical cyclones will provide drought relief.

**C. Drought Adaptation**

Discussions of adaptation measures are somewhat general in nature and intended to promote ecosystem resilience and adaptability. They fall primarily in the categories of water and/or land planning and management. The interaction of the two main stressors for drought impacts (altered precipitation patterns and water management) can act synergistically to create cumulative impacts or act "commensally" whereby water management can to some degree ameliorate the adverse effects of climate-related droughts. This capacity is a key resource for the development of drought adaptation measures for ecosystems. Among the key elements is water basin planning that includes developing knowledge of adequate flows to maintain river and stream system ecological functions with minimal degradation. This would enable informed decision-making for basinwide water allocation planning purposes during prolonged drought situations.

## IV. Literature Gaps and Research Needs

The most critical needs include examining drought impacts in ecosystems not studied by existing research, implementing long-term studies to identify and examine causal relationships, and developing a set of indicators with which to monitor ecological change and impacts during drought.

There is relatively little literature on the following systems relative to drought impacts: coastal upland forests (particularly from an ecological impact perspective), freshwater stream tributaries of tidal rivers, pocosins and other non-riverine wetlands, savannahs, maritime (barrier island) systems, nearshore ocean, and estuarine high marshes. Additional work on tidal freshwater marshes in the southeast appears warranted, as is research related to drought effects on seagrass beds, organism disease vectors (e.g., Perkinsus infection of oysters), and invasive floral and faunal species.

Long-term or time series studies capturing multi-year and repeated drought events are needed to understand drought impacts, especially for ecosystem processes. At the levels of populations and communities, short-term studies may enable some generalizations about the biotic responses to drought, but more long-term studies are required to understand impacts on ecosystem processes (Lake, 2003). While many of these are covered in the report, long-term studies controlling for outside stressors to scientifically define cause-effect relationships would be valuable in impact analysis and remediation. It would be beneficial to take advantage of available sites with already established long-term data sets for different coastal ecosystem types. Long Term Ecological Research sites, National Estuarine Research Reserves, National Estuary Program Sites, State and Federal Refuges, etc. would be ideal places for such research. An intensive and continuous monitoring program that builds on these resources would require an organized and coordinated, multi-state, multi-institutional approach.

The literature revealed use of existing drought indexes (e.g. PDSI, PHDI), computer modeling, and integration of data sets as useful tools for investigating the effects of drought. However, innovation in tools for discerning conclusive cause and effect relationships were somewhat limited. There is a need to improve understanding of key monitoring variables and to develop a set of indicators of ecological change that may be caused by drought. A search for leading indicators, and including those dependent on a particular ecosystem service that could be degraded or destroyed by drought, will be most helpful to resource managers. Indicator species sensitive to drought-induced changes should be selected for coastal ecosystem communities and studied long-term to develop baseline conditions for comparison with continued sampling during long-term or repeated drought situations. Many data sets of great utility may already exist and can be used with new or continued sampling during droughts to better determine cause and affect relationships. More research and information is needed regarding:

- Groundwater resources in the study area and resulting drought impacts on groundwater dependent ecosystems and baseflow in streams.
- The importance of droughts during different seasons. While numerous studies mention the importance of seasonal flows to support aquatic organism needs in estuaries, more work is needed, particularly in tidal freshwater systems.
- The longevity of droughts in relation to long-term impacts and/or length of recovery. This will enable better decision making for water management during drought periods, allowing more informed impact analysis to balance instream flow with other water needs.
- Potential responses to salinity pulsing, given the expected changes in sea level rise, hydrologic changes, and more frequent and severe saltwater intrusion events due to climate change. The results of ongoing or new studies on coastal impoundment efforts at controlling salinity in tidal freshwater communities (if these exist) would be very informative. Such studies should focus on the long-term ability to provide a controlled salinity regime while minimizing the impacts of reduced connections and exchange with the estuary. Many impoundments, particularly those in National Wildlife Refuges, are managed for particular biotic communities with specific salinity tolerances. Maps that provide Refuge managers with horizontal and vertical detail about projected changes in salinity are needed to help them plan relocation or other adaptive measures. This also necessitates a habitat modeling capability as an essential planning tool.

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