State of Knowledge REPORT

South Carolina Coastal Wetland Impoundments

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I. INTRODUCTION

"Despite their abundance and increased pressure for reclamation, little research is presently underway to study the ecological processes of impounded wetlands. The general lack of knowledge concerning saltmarsh impoundments makes this area of marsh ecology a principal data gap." (p.272, Sandifer et al. 1980)

Depending on the subject, it has been 15 – 25 years since coastal wetland impoundments in South Carolina have received a focused review and assessment. If one is looking for a comprehensive treatment of all or most aspects of the science and management of coastal wetland impoundments in one document, it does not exist. The reason for this is that, as noted in the above quote, fundamental questions about the basic and integrative science of coastal wetland impoundments were yet to be asked as recently as the 1980s. The quote specifically mentions saltwater impoundments, however the work from which it is extracted included all wetland impoundments and former impoundments. The knowledge gap existed for them as well. Thus any attempt at science-based policy development and natural resource management was severely handicapped.

The Sandifer et al. (1980) work covered the entire coastal region. The material that was relevant to wetland impoundments was later summarized (Miglarese and Sandifer 1982) and, together with two high-profile court cases of the early 1980s, was the catalyst for a great deal of research and policy activity. The most significant of these initial studies was the massive Coastal Wetland Impoundment Project (CWIP) (DeVoe and Baughman 1987). This project defined the broad themes including issues of ownership, management, policy, and science. For field investigation it narrowed the focus to brackish impoundments in the Santee River delta. Separate but coordinated investigations studied the states and processes within impoundments, compared the results to similar work in adjacent open marshes and tidal creeks, estimated fluxes among components, and assessed the effects of impoundments on more natural systems. Significant though this work was, it "represents the initial stage of investigation on these systems." p. 21 (DeVoe and Baughman 1987).

Later work at other locations looked at natural and anthropogenic features other than just wetlands, but the loss of functions and values supplied by wetland impoundments was one motivating factor. Significant examples include:

The Charleston Harbor Project (OCRM 2000) was a multi-disciplinary effort "to plan for the rapid urban growth projected for Charleston, Berkeley, and Dorchester counties." Project units covered, among other things, a fairly comprehensive array of natural communities and ecosystems, including their current state and potential vulnerability relative to continued expansion of urban development.

The Savannah River estuary, particularly activity related to the Savannah Harbor, has been the subject of a great deal of research and policy discussion for at least 25 years (Kitchens 2003). Harbor deepening, installation of an ecologically damaging tide gate, proposed further harbor deepening, and the impact of severe or repetitive drought have all caused attention to focus on the natural resources of the area, including the coastal impoundments.

The Ashepoo-Combahee-Edisto (ACE) Basin is somewhat unique in that it represents an attempt to prevent, rather than mitigate or retard, widespread degradation and loss of critical ecological resources (CSC 2000). For example, in recognition of its importance to migrating and wintering waterfowl, the ACE Basin was selected a "flagship" project of the North American Waterfowl Management Plan (USFWS 2004). ACE Basin efforts are coordinated by a diverse partnership which, in addition to the SCDNR and USFWS, includes The Nature Conservancy, Ducks Unlimited, and several private entities. There is also a NOAA National Estuarine Research Reserve (NERR) within the ACE Basin.

When studied in detail these examples demonstrate the important role that coastal wetland impoundments play in ecological and economic landscapes at local, regional, and hemispheric scales. Individually, wetland impoundments provide habitat for a variety of flora and fauna. Some of these organisms interact with other components of the estuary or migrate to other continental or inter-continental locations.

Approximately 68% of the impounded and formerly impounded coastal wetlands are in private ownership (Tompkins 1987). The perspective of the ecological and historical importance of these wetlands is gaining broad

acknowledgement even among some private owners (Oswald 1997). But conflicts between resource management and policy (both federal and state) on one side and landowner interests in exerting control over what they can do with their land have been a fact of life in the coastal zone for several decades (DeVoe and Baughman 1987).

What is different today is the 15-20 years of additional information we now have about coastal wetland impoundments. This information has evolved from three broad sources. One is the body of science-based studies within a wide variety of disciplines that took place in South Carolina coastal wetland impoundments. The next section of this report is a subject-based summary of work from studies completed since the mid-1980s that are published or in preparation. Many of these studies were precipitated, at least in part, by recommendations that emerged from earlier studies and syntheses. A summary of the most significant of those, their recommendations, and the current status is in section three.

The other two sources of more recent information are studies in similar wetlands from nearby locations and from the practice of wetland management both individually and in the larger context of landscape and stakeholder concerns. The fourth section of this report is a discussion of the current state of our knowledge about coastal wetland impoundments. The discussion integrates South Carolina based studies with the larger literature that is relevant to coastal wetland impoundments. The discussion also integrates, both directly and indirectly, knowledge and issues about impoundment management and use that are important to consider in the current discussions. Wetland management practices can be difficult to source and learn about. Frequently this knowledge is dispersed in settings where a permanent record may not be developed, such as at professional meetings or among consulting partners. But much can be learned from reading and talking with knowledgeable people and many people have been generous in sharing their experience and ideas.

The fifth section reviews research and related work that is currently active. It also provides a new set of recommendations that follow from the prior synthesis and assessment. The final section of this report is the conclusion.

A word about terminology is necessary. Most of those reading this report are aware of the many variations of names applied to managed and formerly managed tidal wetlands along the coast. The main reason for recent impounding is to establish managed waterfowl habitat. The vast majority of them, however, were once part of the rice industry, either as fields or freshwater holding ponds. For this reason the name "former rice field" or some variation is frequently applied to all of them, regardless of their ontogeny. This report will not attempt to standardize usage. Reference to coastal wetland impoundments, or simply wetland impoundments or coastal impoundments, will mean any current or formerly diked wetland, whatever its past or current use. If specific characteristics are important, such as current salinity conditions or management plan, the term is qualified appropriately.

II. RESEARCH SUMMARY

"If one views the status of coastal wetlands on the global scale, emphasizing areas with emergent vegetation (marshes and swamps), the future of many wetlands appears to be in peril." (p. 28, Baca and Clark 1988)

The following is an annotated listing of work that is published or in preparation that is either about or related to coastal wetland impoundments in South Carolina. This is not a clear distinction in many cases and in the interest of focus I made some judgments. Coastal wetland impoundments occur primarily along the tidally influenced portions of coastal plain and alluvial rivers. These rivers and their estuaries tend to be of interest to researchers and resource managers from many disciplines, such as water quality, sediment toxicology, waterfowl, and fisheries to name a few. Although it is feasible, and in fact likely in many cases, that impoundments exert an influence on a wide range of states and functions of the estuarine and riverine environments, not all the research in these broad disciplines was substantively related to impoundments. So unless a relatively clear connection existed the work was not included in this section.

Also as a matter of judgment this summary includes work from coastal impoundments in Georgia. The Georgia coast has several key similarities with South Carolina, particu-

larly the historical development of rice cultivation made possible by similar coastal geomorphology. So it is likely that Georgia impoundments are ecologically similar if not equivalent to those in South Carolina. Thus research related to Georgia impoundments is directly relevant to understanding Southeast coastal impoundments generally. With the exception of the Savannah River estuary, Georgia-based research is quite sparse due to the less developed coast and concerns related to development. These concerns have been the catalyst for so much of the research and policy activity in South Carolina.

A final parameter that I used for selection was to restrict this section to work that was published from the mid-1980s to the present. The earlier work from South Carolina is summarized in DeVoe and Baughman (1987), Sandifer et al. (1980), and Miglarese and Sandifer (1982). The seminal work of Odum et al. (1984) and Odum (1988), which summarizes still more tidal wetland research, is widely recognized, available, and studied. Some work that would otherwise be included is not, as for example, Wenner and Beatty (1988), which covers work done for the CWIP project and is discussed at length in that report (DeVoe and Baughman 1987).

Note: *The summaries presented here are intended to provide a sense of the dominant objective of the work. They should not be construed as representing all of the significant findings or nuances of the research. As an aid in reading through them, they are organized by subject. It is inevitable, however, that some publications could be placed in more than one subject category.*

Savannah River estuary marsh vegetation studies

Pearlstine et al. (1990, 1993) developed a GIS model of tidal marsh macrophyte community succession to study the effects of a tide gate on the lower Savannah River. The tide gate was constructed in 1977, and significantly increased the upstream extent of salt water, altering marsh communities in the Savannah National Wildlife Refuge (SNWR). The model was developed using measurements of river discharge and tidal stage, along with field sampling of macrophyte community composition and biomass, interstitial salinity and pH, soil organic matter, and site elevation. The model was used to predict the salinity effect of removing the tide gate from operation, and thus the effects on marsh macrophyte community composition. The results were used to justify removal of the tide gate from operation in 1991.

Softstem bulrush is a dominant marsh macrophyte species along a broad environmental gradient in the Savannah River. Latham et al. (1991) studied the spatial patterns of the plant and the extent to which environmental factors alone explain the distribution. Dominance increases as salinity increases, but within-site distributions are caused by a combination of environmental gradients and competitive influences with other macrophyte species.

Latham (1990) and Latham et al. (1994) studied macrophyte species associations along the salinity gradient in the tidal wetland impoundments of the SNWR. They sampled vegetation, soil organic matter, and interstitial water at four locations, from mesohaline to freshwater. Analysis was for both within-site and between-site differences. Vegetation differences between sites followed the salinity gradient. Within-site variability occurred as well, with zonation more distinct in the brackish and saline marsh sites, and more overlap in the freshwater site. One species, *Scirpus validus Vahl*, occurred at all sites, possibly a reflection of its role as a pioneer species.

Bossart (2002) also studied marsh macrophyte community composition along a salinity gradient in the Savannah River estuary. His study interval included the time frame of a significant drought, which allowed evaluation of the effect of this on the marsh communities. The salinity gradient was the dominant environmental forcing function for macrophyte community composition. There was no clear secondary factor, although elevation and sediment composition were contributors.

Dusek (2003) conducted a limited version of the Latham et al. (1994) study to further examine marsh restoration following removal of the tide gate from operation. The marsh macrophyte restoration that was clearly visible in the earlier work was somewhat reversed by the effects of a severe drought that reduced freshwater inflow to the system. The salinity gradient was compressed longitudinally. This study provided an indication of the possible effects of recurring or persistent drought on this system.

Applied Technology & Management (2003) studied the marshes along the fresh to salt gradient of the Savannah

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River. The work was part of a larger effort to forecast possible effects of the proposed deepening of the Savannah Harbor. Water elevation, water quality, salinity, marsh structure, and plant communities were measured, and a GIS model of marsh macrophyte community response to salinity changes was developed. The model will be used for evaluation of various scenarios of post-deepening effects on marsh macrophyte communities.

Loftin et al. (2003) performed change detection on a time sequence of satellite images of the Savannah River marshes from 1986 (before the tide gate opened permanently in 1991) through 2001. They also surveyed vegetation in the marshes to help classify and evaluate newer images. The objective was to determine if marsh recovery to freshwater macrophyte communities was proceeding according to the predictions of an earlier model developed by Pearlstine et al. (1990). At first recovery was fairly quick, but it slowed due to additional harbor modifications and a severe drought; both affected the upstream extent of the salinity wedge.

Wetzel et al. (2004) used reciprocal transplants among marshes along the salinity gradient to assess the rate of macrophyte community change with changes in marsh salinity. They found that with transplants from fresh or oligohaline to more saline marshes the change was fairly rapid compared with transplants along the reverse trajectory. These results suggest a partial explanation for the delayed recovery of Savannah River tidal marshes with removal of the tide gate in the early 1990s, mentioned above.

Aquatic macrophytes – South Carolina other than Savannah River

The labs of B. Joseph Kelley and Richard D. Porcher at The Citadel have studied the macrophyte communities

of the freshwater marshes along the Cooper River for over 25 years. Pickett et al. (1989) studied macrophyte community species composition and above ground biomass in the predominantly intertidal Dean Hall marsh during 1982-83. They found 45 species, with broadleaf species dominating lower elevations near creeks and grasses predominantly in higher elevations away from creeks. Total live biomass peaked in September, although peaks for individual species were more variable. On an annual basis the dominant species in terms of biomass were *Zizaniopsis miliacea* (27.7%), *Pontederia cordata* (16.1%), *Ludwigia uruguayensis* (8.1%), and *Alternanthera philoxeroides* (7.4%). A technique was used for estimating leaf mortality, which increased the total biomass estimates by 60%. Similar work was done after the Santee-Cooper rediversion project was completed (Kelley et al. 1990). Species richness was greater after rediversion, and species biomass distributions and dominance had changed.

In some integrative work, Kelley and Porcher (1995) developed vegetation maps covering an interval from 1982-1994 and proposed a macrophyte successional pattern for the Cooper River marshes. Ecological functions and values change as succession proceeds. A few examples of stage-dependent functions are breeding habitat for game and non-game fish species, waterfowl refuge, and amount and form of primary production. They discussed potential "implications of succession on habitat diversity, ecological function, and recreational opportunities."

Stalter and Baden (1994) compared macrophyte species composition in 1967-68 to 1987-91 in three former rice fields in the Winyah Bay estuary. The fields are now brackish marshes with a range of salinities (Baden et al. 1975). Similarity among fields is high, and composition within fields changed very little except for the presence of the invasive *Phragmites australis*.

Jacobs (1995) studied the spatial and temporal variability in seed banks in open and impounded freshwater marshes in the Samworth Wildlife Management Area near Georgetown. Seed banks were significantly different in 1991 compared to 1990, which he attributed to recovery from Hurricane Hugo. There were also significant differences in managed wetlands versus open marshes. He concluded this was due to differential seed dispersal with regular tidal inundation and management practices that favored vegetative propagation over seedling emergence.

Biogeochemistry

The lab of James T. Morris at the University of South Carolina has conducted several comparative studies over the last 8-10 years dealing with nutrient biogeochemistry in coastal wetlands, including former rice fields along the Cooper River. The primary focus has been on phosphorus, examining several processes as affected by salinity and other factors.

Nietch (2000) compared carbon biogeochemistry in three South Carolina estuaries, two of which (Edisto and Cooper Rivers) included stations in former rice fields. The overall objective of the research was to evaluate the effects of salinity and marsh hydrology (riverine vs. lagoonal) on carbon and nutrient processing. He found that both these factors are associated with significant differences in nutrient availability and carbon mineralization. Pore water nutrients increased with salinity and freshwater discharge, whereas carbon mineralization decreased with increasing salinity.

Paludan and Morris (1999) looked at the speciation and distribution of sediment and porewater phosphorus along salinity and depth gradients. Their study sites were marshes along the Cooper River and at North Inlet. One of the Cooper River marshes was Rice Mill. They found that both sediment and porewater phosphorus decrease as salinity increases. Most of the phosphorus in the freshwater marsh was organic; with the quantity decreasing and proportion of inorganic phosphorus increasing with increasing salinity.

Sundareshwar conducted studies of phosphate in sediments along a salinity gradient in the Cooper River (Sundareshwar and Morris 1999, Sundareshwar 2000, Sundareshwar et al. 2001). They found that sediment phosphate sorption decreased with increasing salinity which they attributed, in part, to differences in sediment mineral composition which influences sorption capacity. They also found that pyrophosphates were as much as 57% of extractable phosphorous from sediments in Cooper River salt marshes. In freshwater marshes the amount was only 4% and in brackish marshes it was 13%. Their study also demonstrated that the presence of pyrophos-

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phate in the sediments was correlated with density of urban development in the immediate watershed.

Huang looked specifically at phosphorus along a macrophyte successional gradient in tidal freshwater marshes of the upper Cooper River (Huang 2002, Huang and Morris 2003, Huang and Morris in press). Sites ranged from no macrophytes to predominantly intertidal habitat. They found that phosphatase activity in sediments increased along the gradient and was highly correlated with sediment organic matter. Inorganic forms of phosphorus decreased along the gradient. This corresponds to bottom elevation increases that help drive changes in habitat suitability and suggest a complex feedback process involving sediment nutrient dynamics, sediment accretion, and macrophyte community succession. They also looked at phosphatase activity along a salinity gradient in the Cooper River marshes and salt marshes at North Inlet, SC and Massachusetts. Pore water pH was the most significant explanatory variable, with salinity and sediment organic matter, organic phosphorus, and clay content also contributing. The highest activity occurred in the intertidal emergent successional stage of freshwater marsh.

Goni et al. (2003) conducted a comprehensive study of organic matter in the Winyah Bay estuary with the intention of determining sources. Their results suggest that the high molecular weight dissolved organic matter (DOM) is primarily from terrigenous sources, as is the particulate organic matter (POM) during winter and early spring. Terrigenous sources are identified as vascular plants, including emergent marsh vegetation. Large extents of former rice fields occur in the Winyah Bay drainage. There was a DOM concentration gradient that decreased along the upstream to downstream axis.

Water and sediment quality

The lab of Hank N. McKellar, Jr., at the University of South Carolina, studied water column nutrient characteristics along the macrophyte successional gradient in rice fields along the Cooper River, in the Goose Creek tributary (Douglas 1995), and within the river itself. Abusam (1999) developed a steady-state conservative box model of inorganic nutrient distribution along the Cooper River from the mouth to the "T" for 1988 and 1993. Inputs included estimates of point source loading and tidal wetland exchanges; the model produced estimates of nonpoint source loading. He concluded that tidal wetlands have a negligible effect on phosphate concentrations in the river. For DIN it ranges from 6 – 15%. This work did not consider the effects of the former rice fields upriver from the model domain. Alford (2000) studied high- and low-tide differences in inorganic nitrogen and phosphorus. Saropraygoi (2001) evaluated seasonal and annual fluxes of inorganic and organic nitrogen and phosphorus in the same fields. McKellar and Bratvold (in prep) recently summarized this and other recent research on nutrient exchanges in tidal wetlands along the US East Coast. They conclude that the general trend is for export of ammonia and or-

ganic nitrogen and import of nitrate, suggesting biotic assimilation of oxidized nitrogen. Several factors influence flux activity, including age of the marsh, elevation, season, vegetation dominants, spring/neap tides, and upland land use.

Conrads et al. (2002) used field data (water quality and meteorological) collected from 1993-95 in a statistical and modeling analysis of dissolved oxygen (DO) concentrations in the Cooper River. They found that rainfall runoff decreased DO and that ebb tidal flow from nearby rice fields caused a large decrease in DO. They conclude the likely cause is organic loading, although they did not explicitly measure it.

The Urbanization and Southeastern Estuarine Systems (USES) project is a long-term, multi-investigator project that conducts extensive field studies to aid in understanding the ecological effects of coastal development on high-salinity estuaries. For several years their comparisons were between the Murrells Inlet (developed) and North Inlet (undeveloped) estuaries. The largest portion of upland at North Inlet is the Hobcaw Barony, a former rice plantation. Several of the studies looked at upland land use effects on hydrology and nutrient export (Corbett et al. 1997, Wahl et al. 1997, Tufford et al. 2003). The Hobcaw Barony site was a rice field that has since regenerated into a coastal forest ecosystem. The site had less flow and nutrient export than the developed site, and the dominant nutrient species exported from the two are different.

A few studies have examined contaminants in biota and sediments (dredge spoil) from the harbor. Some of the spoil is in the SNWR so there is concern for bioavailability, bioaccumulation, and negative effects on fauna that feed in the spoil areas. Winger et al. (1990) looked at contaminants in nine species of fish and fiddler crabs from the Savannah River and SNWR. Metals and hydrocarbons were found in fish, but were generally below levels of concern. Elevated levels of lead were found in the SNWR and the recommendation was made that the source should be identified.

Winger et al. (2000) studied the accumulation of sediment metals in fauna at higher trophic levels.

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They looked at one species each of amphipod and oligochaete, two bird species, and raccoons. Liver analyses indicated that bioaccumulation of metals was occurring in the birds and raccoons. They also found that levels of several metals in raccoons that forage in the spoil areas was significantly greater than those from upland control sites. They suggest their results indicate these species may be at risk from accumulation of the metals.

Water quality problems had been observed in the Savannah River downstream from the discharge from dredge spoil impoundments, resulting in a study of the sediment quality in the ponds in the SNWR (Winger and Lasier 2004). Sediment and pore water toxicity

testing revealed degraded sediment quality. Problems in one pond in particular may be associated with management practices (disking, burning, drying) that increase acidification of the pore water, which promotes mobilization of metals.

Fish

Long et al. (accepted) conducted sampling for a year in two marshes on the Cooper River. One is dominated by intertidal habitat, the other by subtidal habitat. They observed monthly variability within sites as well as differences between sites. The subtidal site contained more estuarine migratory species and had a more stable community. The intertidal site was dominated by Centrarchids. They believe their findings highlight the need for habitat diversity because of its determining role in fish community structure.

Osteen et al. (1989) studied spawning utilization of former rice fields on the Cooper River by Blueback Herring during 1981 and 1982. Several indicators suggested that the field is used by the fish preferentially over the main river channel. These include larval density and spawning consistency, timing, and duration. They expressed some concern that lowering discharge into the river as part of rediversion could negatively affect fish spawning.

Homer (1988) studied the effect of habitat loss on fish populations in an unnamed former rice field on the Upper Cooper River. He measured fish abundance, macrophyte species, and water quality parameters in an area of submersed macrophytes during one year, then sprayed the area with an herbicide and continued measuring for another year. Fish abundance varied directly with submersed macrophyte density. He also noted that DO levels frequently were well below regulatory minimums in the macrophyte areas, getting worse as the growing season progressed. There were no DO excursions after the area had been sprayed and the macrophytes were gone.

Thomas et al. (1992) present the results of a study of spawning by Blueback Herring that is a post-rediversion update to Osteen. They found a significant decline in spawning utilization of Mulberry field compared to the earlier work. They identify possible effects of decreased flows, such as the development of unfavorable environmental conditions and modification to juvenile behavior.

Slack (1991) studied the spatial distribution of Blueback Herring in the Cooper River after rediversion. He found that although adult herring returned to the river immediately after rediversion, the abundance had declined as did the number of eggs and juveniles that were found. The number of eggs also declined substantially from 1996 to 1997. He attributed his findings to reduced flows from Pinopolis Dam.

Malloy (2004) studied the fish use of marshes along a salinity gradient in the Savannah River estuary. She found that biomass, density, and diversity were greatest in the more brackish sites. Freshwater species were not dominant even in freshwater sites. Utilization was greatest at marsh edges versus interiors.

Forest studies

The dominant image that people have of the former rice fields is that they are in a pure or mixed state of sub- or inter-tidal marsh. Many locations, however, have succeeded back to swamp forest. This is especially the situation near the upstream influence of tidal effects. These sites are useful for a variety of forested wetland research activities.

Blood et al. (1989) conducted a study in relatively young pine stands growing in what were once rice fields at Hobcaw Barony. They looked at the effect of the young forest on wet deposition of nutrients, several metals, and other ions. Although the study was not directed explicitly at rice field questions, the results provide a base for comparison of forests of other age and stand composition during successional recovery of former rice fields into forests.

Burke et al. (1999) used a former rice impoundment in the ACE Basin as a forested wetland study site to examine the effect of several environmental parameters on net primary productivity. The site was not chosen based on its historical use, but because of its suitability for

testing the study hypotheses, which required gradients in moisture and nutrient availability.

The lab of William H. Conner at Clemson University's Baruch Institute of Coastal Ecology and Forest Science in Georgetown is studying forest productivity and related issues in floodplain wetland forests, including tidal wetlands that were once used for rice culture. Ozalp (2003) studied water quality, aboveground productivity, and nutrient dynamics in a tidal floodplain forest in the Pee Dee River. Water quality was generally good and floodwater nutrients were reduced during residence in the forest. Litter decomposition studies found that both nitrogen and phosphorus limitation occurred, but that moisture and hydrology were the most important factors influencing decomposition. It is likely the forest was similar to those in the area at the time they were cleared for rice agriculture.

Conner and Inabinette (2003) studied the response of three coastal wetlands at Hobcaw Barony to salt water inundation due to storm surges from Hurricane Hugo. The sites were selected based on the extent of inundation from the storm; no saltwater entered the site furthest from the marsh. Mortality of mature trees depended on species, but ranged from 77% for baldcypress at the site closest to the marsh to 15% at the site furthest form the marsh. Saltwater intrusion limited tree regeneration for 2-3 years beyond the storm event allowing grasses and *Phragmites* to become dominant.

Conner and Inabinette (in press) are studying the possibility of finding baldcypress populations that can survive and grow in saltwater damaged areas. Seeds were collected in 1996 from eight estuarine areas (James River, VA; Cape Fear River, NC; Winyah Bay, SC; Ogeechee River, GA; Ochlockonee River, FL; Mobile Bay, AL; Biloxi River, MS; Chalmette, LA), stratified and planted in the Hobcaw nursery, and seedlings were grown for two years before planting in two abandoned rice fields near Georgetown in 1999. Salinity levels reached 18.5 ppt during 2001 at the peak of the worst drought on record. By 2002, the only seedlings surviving were those from LA, AL, and FL. After five years in the field, LA seedlings were the best performers with a mortality rate of only 27%.

Ratard (2003) studied tree growth and productivity of forested wetlands on the Waccamaw and Pee Dee rivers surrounding Sandy Island. He also analyzed tree rings to look for historical environmental influences on growth. The tidal forested wetlands were intermediate in productivity compared to permanently flooded and intermittently flooded wetlands. He found no correlations with environmental effects and concluded that tidal hydrology was the dominant factor controlling growth.

In 1991 Conner et al. (2004) began a study of forest regeneration in a nine-acre tract of former rice field near Jacksonboro that was planted in baldcypress in 1956. Red maple, black willow, sweetgum, and persimmon also became established. Tree density decreased in study plots during the study, initially due to natural mortality and later to thinning. Regeneration plots were established to follow future growth in portions of the tract that were clear-cut.

Duberstein (2004) examined forest community composition in the tidal freshwater zone of the Savannah River estuary. Using multivariate statistical procedures with soil properties and plant species data, he delineated four communities whose dominats were shrubs, Water Tupelo, Swamp Tupelo/Tag Alder, and Water Oak/Swamp Bay. This study is the only one detailing community composition of tidal freshwater forest swamps along the Georgia/South Carolina coast.

Waterfowl

Gordon et al. (1989) go into a wide-ranging discussion of coastal wetlands, including marshes (salt, brackish, and fresh), remnant impoundments, and tidal forested wetlands. Abbreviated discussions of coastal geology, climate, marsh vegetation, history of rice culture, and hunting precede more detailed summaries of waterfowl ecology and management.

Gordon et al. (1998) studied the winter use of managed impoundments versus natural tidal wetlands by dabbling ducks. The study sites were freshwater wetlands in the Winyah Bay estuary and brackish wetlands in the Santee River Delta. The ducks made greater use of the managed wetlands, which is attributed largely to the greater amount of open water. Comments are made about the manage-

ment implications of these results, including recognition that there are also reasons to favor natural wetlands. They recommend more studies of more locations.

Harrigal and Cely (2004) update the South Carolina species list to definitively include the Black-bellied Whistling-Duck. After several sightings, in 2003 an adult with brood was observed at the Donnelley Wildlife Management Area in the ACE Basin. The preferred breeding habitat of these birds includes marsh areas like the former rice fields.

Wading and shore birds

Dodd and Murphy (1997) summarize a literature review and quantitative survey of nesting colonies of 13 species of wading birds in South Carolina from 1988 to 1996. Colonies are associated with aquatic habitat. Although nesting colonies for some species are found along inland waterways, by far most colonies are along the coast near riverine estuaries. Some species only occur in the coastal estuaries. The number of colonies almost doubled during the study interval. They attribute much or all of this to improved survey techniques, although there were still problems with the surveys of four species.

DeSanto et al. (1997) monitored the activity of radio-tagged breeding White Ibises in Winyah Bay. When feeding their young, the adult birds traveled to freshwater wetlands (rice fields, impoundments) for most of the food. They returned to mostly salt marsh feeding when the young had gone. Since travel to the freshwater wetlands was longer than to salt marshes, they hypothesize that perhaps salt balance considerations in young Ibises motivated the extra energy use.

Petit and Bildstein (1986) studied the development of formation flying in juvenile White Ibises in Winyah Bay, and noted that as the young learned to fly, most went to foraging grounds in freshwater marshes and swamps. These are two of several studies published using the White Ibis breeding colony on Pumpkinseed Island in Winyah Bay as the source of birds and observations. Others examined effects of rainfall variability on foraging success (Bildstein et al. 1990), behavioral development (DeSanto et al. 1990), and sexual size dimorphism (Bildstein 1987). It is frequently noted that successful White Ibis breeding and rearing is dependent upon the freshwater marshes in close proximity to the colony site.

Managed impounded wetlands are credited with providing important habitat for shorebirds as natural habitat declines. Weber and Haig (1997) reported the preference of Lesser Yellowlegs and Short-billed Dowitchers for a particular polychaete at the Yawkey Center and made recommendations about how to maintain high numbers of these worms. Boettcher et al. (1995) studied the significant preference that nonbreeding American Avocets have for the stable water levels in brackish impoundments, also at the Yawkey Center on South Island. There was also a preference for open water areas within an impoundment.

Weber and Haig (1997) also tested hypotheses about migrating shorebird density and prey density in brackish managed wetlands. Shorebird and prey density (patchiness) were positively correlated early in migration and shorebirds were responsible for prey declines. However, reductions in prey density did not result in redistribution of shorebirds, which was predicted, apparently due to high prey abundance and other small scale-habitat factors.

Weber and Haig (1996) discuss results of research to test the effectiveness of the integrated shorebird-waterfowl management strategy at the Tom Yawkey Wildlife Center. Migrating shorebirds preferred the managed impoundments over the natural flats at low tide except very early during spring migration. The reason for the overall preference seemed to be greater prey availability. There were 19 species of shorebirds counted during their study. They do not necessarily suggest more impounding, but do recommend integrative management strategies when possible.

As part of the Charleston Harbor Project, OCRM (1998) studied colonial waterbird use of the estuary. During 1994, 28 species and 88 colonies were found. Former rice fields along with mudflats and small creeks are used for foraging at higher densities than other habitats. The report recommends targeting them for "protection from human disturbance," including minimizing boat traffic. Management of currently impounded wetlands should consider maintenance of suitable nesting habitat (e.g. wooded islands, border trees).

Photo | Daniel L. Tufford

Dodd et al. (1999) followed up on the work of Weber and Haig (1996) (summarized above) by trying a new water management strategy (integrated strategy) at the Tom Yawkey Wildlife Center. They kept water at lower levels than in the traditional strategy to see if they could increase wading and shorebird abundance and species richness without negatively impacting waterfowl usage. Overall waterbird abundance increased by about 50% with the integrated strategy, but changes in abundance and richness was variable by group. They conclude that the integrated strategy accomplished their objective and note that there are some potential negative side-effects that must be considered.

Berryman and Webb (2003) analyzed mid-winter waterfowl surveys for the Savannah National Wildlife Refuge. They concluded that waterfowl use has increased as the marshes have recovered after removal of the tide gate in 1991. Several factors influence actual usage from year-to-year; two important ones are salinity and freshwater flow management.

Other birds

Post (2004) summarizes what is known about the American and Least Bitterns in South Carolina. Their decline is attributed to the loss of freshwater wetlands, and they are known to occur in managed coastal impoundments and have been observed in rice fields.

Two studies looked at the use of impounded coastal freshwater marshes as breeding sites. Post and Seals (1991) looked at the population density and productivity of six bird species. Boat-tailed Grackle was the dominant species. They noted that year-to-year variability in productivity seemed to be related to water levels, thus exposure to nest predation. Post (1995) compared breeding success of Boat-tailed Grackles in South

Carolina and Florida. He found few differences, and highlighted the observation that predator avoidance seemed to be the primary factor controlling nesting behavior in both locations.

Peterson et al. (1995) looked at the use of brackish versus freshwater marshes by passerines in the SNWR. They found that generalist species tended to dominate in the brackish marshes, which they attributed to the lower plant and food diversity as well as more discrete zonation of the plant communities. These results may suggest that as freshwater marshes become brackish there will be a decline in avian diversity.

Brush et al. (2003) looked at migratory bird use of Savannah River marshes along a salinity gradient from fresh to salt. Utilization of the freshwater sites was greater than the more brackish and saline sites. They conclude that this indicates the importance of protecting the freshwater marshes in the Savannah River delta.

Somershoe and Chandler (2004) studied neotropical migrant use of oak hammocks at the SNWR. Hammock size was an important factor, with larger hammocks attracting more birds. They conclude that forest protection should focus on larger tracts.

Vector borne disease

The Wedge, a former rice plantation in the Santee River Delta, is a former USC research facility that was a center of vector borne disease research and education up until the mid-1990s. Wallace et al. (1989) discusses field testing a new technique for testing the effectiveness of biocontrol agents on mosquito larvae. Wallace et al. (1990) reports the results of tests of burning as a mosquito control method.

Ortiz (1999) and Ortiz et al. (2001) conducted research into arbovirus occurrence at two Carolina Bays and The Wedge. They found that mosquito species diversity was greater at the Carolina Bays than at the coastal site, and that the coastal site appeared to be an enzootic foci for the Eastern Equine Encephalitis (EEE) virus.

Wozniak et al. (2001) report the results of field surveys for arboviruses that took place from 1996-1998 in 30 South Carolina counties. Arbovirus-positive pools were found in 12 Coastal Plain counties, including Carolina Bays and coastal impoundments.

The Wedge was also used extensively for research into tick-vector diseases, particulary Lyme disease. Durden et al. (1997) mist-netted birds at The Wedge and on St. Catherine's Island in Georgia. They concluded that birds along the coast may be reservoirs for both encephalitis and Lyme disease, and transporting immature ticks during migration may be a dispersal mechanism. Clark et al. (1998) document seasonal activities of the life stages of Ixodid ticks and in the process show that the ticks are "well established in the southern Coastal Zone of South Carolina." In a later study they conclude that Ixodes minor may be the primary vector for Lyme disease in South Carolina (Clark et al. 2001) and that the spirochete agent of Lyme is endemic in South Carolina (Clark et al. 2002).

Oliver et al. (2003) provide a detailed and widespread study of the presence of the Lyme disease agent, host reservoir, and vectors in the southeastern US. Study sites were in Florida, Georgia, and South Carolina. The South Carolina sites included both The Wedge and Hobcaw Barony. Two of the three tick vectors do not normally bite humans, but they are important for maintaining the spirochete in the wild. The authors conclude their results show that there is risk of contracting Lyme disease along the Southeast coast.

Other biota

Wenner et al. (1991) sampled bimonthly at eight stations on the North Edisto River and four stations on the South Edisto River from February 1973 to January 1975. The South Edisto has substantial freshwater flow and thus species occurrence and abundance is controlled by salinity. The greatest diversity was at the downstream sites. The North Edisto has little freshwater flow without a distinct halocline. Species occurrence appears to be determined by substrate. Ten species of fish (>90% abundance) and four species of crustaceans (>94% abundance) dominated. This study did not target former impoundments, but the upstream sampling stations on the South Edisto were adjacent to these features.

Other Georgia–not Savannah River

Cotton (2004) studied the restoration of an impounded marsh along the Ogeechee River in Georgia, sometimes referred to as the Tucker mitigation site. Flapgates were removed and dike breaches left unrepaired to restore normal tidal exchange dynamics. Water quality and vegetation were compared in a before/after context within the restored marsh as well as to a nearby marsh that had been restored several decades earlier. After 2 years water quality had recovered but vegetation had not. Sedimentation rates were high after tidal restoration. The drainage network (interior canals) changed very little in the two year interval. The drainage network in the older restored marsh also did not much resemble a natural marsh, indicating that full restoration at this location is a process that will take over a century.

Higinbotham et al. (2004) used aerial photography and GIS to map aquatic macrophyte communities in tidal marshes along a salinity gradient in the Altamaha and Satilla rivers in Georgia. Four community classifications were identified, and maps constructed using images from 1953, 1974, and 1993. There was no upstream shift in communities during the interval (as has been seen elsewhere), but the mapping did show substantial changes that they attribute to local scale dynamics, such as biophysical disturbance.

Miscellaneous studies

In many situations impounded coastal wetlands are considered degraded forms of natural wetlands, with attendant negative ecological and water quality consequences. There is a significant body of literature and discussion of marsh restoration objectives and techniques. Baca and Kana (1986) discuss their experiences from South Carolina, emphasizing the importance of soils, vegetation, elevation, and hydrology. With these site-specific data hydraulic models can be developed that will assist in evaluating various restoration alternatives on the resulting tidal dynamics and water quality.

Whetstone et al. (1988) review three different methods for utilizing salt marsh impoundments for shrimp aquaculture: co-management with waterfowl, shrimp with recruitment from the wild, and shrimp with purchased stock material. Water quality issues are also discussed. Yields vary as do capital costs and field management schemes. Recruitment from the wild is the least cost-intensive and could easily be done in many of the existing impoundments, although yields are low and dependent on the availability of wild stock. This material is discussed in more detail in Olmi et al. (1988).

Hopkinson (1992) used data collected from a tidal freshwater site along the Altamaha River (GA) as part of a comparative assessment of ecological processes between relatively open and closed wetland ecosystems (two wetlands in each category). The Georgia site was paired with a mature Cypress swamp along the Cache River (IL) as examples of open (or low closure) systems. One objective was to compare observed results to theoretical predictions of productivity and nutrient cycling and retention; there were some significant deviations.

Cockrell (1998) developed a GIS model to assist in prioritizing wetlands based on functions (hydrology, water quality) and risk of loss. The model was tested in the Lower Savannah-Salkehatchie basin. This work did not focus on coastal impoundments, but several were in the area in which the model was tested. Impounded wetlands were rated low in most categories because they are altered systems and not given the same weight in the model. They were rated medium to high for risk of loss, but their overall significance rating was low to medium. The model was biased toward higher rankings for unaltered wetlands.

In similar work in the Edisto River basin, Sharitz et al. (1998) conducted a wetland assessment by scoring each wetland using widely accepted evaluation criteria and indicators, including hydrogeomorphology and wetland functions. The technique scored natural or minimally altered wetlands higher than altered wetlands. This work was part of a larger study of the Edisto River basin that also ranked areas for value as natural areas and fish and wildlife habitat (SCDNR 1996). Impounded and formerly impounded tidal wetlands scored low as natural areas and high as fish and wildlife habitat.

Oswald conducted a survey of Cooper River rice field owners to understand attitudes and other factors (Oswald 1997). He found that owners believe current regulatory

control of what they can do with the fields was too restrictive. Also that field owners were becoming more aware of the ecological and historical significance of the fields, and that they were prepared to work with others to develop and implement a basin-wide management plan.

McKnight tried to get at the issue of a cost/benefit analysis of options for managing the Cooper River wetlands that included some consideration of ecological values (McKnight 2003). She evaluated four options: doing nothing, reimpounding, dredging, and altering the flow regime from Pinopolis Dam. Her work was an initial evaluation and the results are tentative, but do highlight some of the important questions in this discussion.

The effects of sea level rise (SLR) on coastal ecosystems has received a great deal of discussion in the literature in the past couple of decades. Much of the work does not specifically mention coastal impoundments, but the area most vulnerable includes the locations of the greatest density of salt- and brackish-impoundments. For example, Daniels et al. (1992) evaluated four SLR scenarios using USGS topographic data for locations in Horry County and Hilton Head. They point out that effects include permanent and episodic inundation and greater vulnerability due to possible increases in frequency and intensity of coastal storms, particularly hurricanes. Daniels (1993) looked at the potential loss of habitat for threatened and endangered species. He looked at regional vulnerability then at local vulnerability using Cape Romain National Wildlife Refuge as the study site.

Kana et al. (1986) looked specifically at SLR effects on coastal wetlands in the Charleston area. They conclude that although coastal marshes have kept pace with SLR during the last century, this may not continue in the event of accelerated SLR due to sea walls and similar anthropogenic obstructions to the landward migration of coastal marshes. They made several recommendations for further work that included acquiring more accurate elevation data and determining elevations at which vegetation transitions occur. Titus and Richman (2001) developed GIS models to predict the extent of coastal inundation resulting from SLR along the US Atlantic and Gulf coasts.

III. PRIOR RESEARCH AND POLICY RECOMMENDATIONS

Since the mid-1980s there have been several reviews and major reports covering coastal resources in South Carolina (and Georgia). In a few cases wetland impoundments were the primary focus; in others another subject was primary but impoundments were a significant feature of the study. Most of these reports included a section on recommendations for future research or a list of issues that needed resolution. This section briefly summarizes those recommendations to establish context and continuity for the present state of our knowledge.

Miglarese and Sandifer (1982) distilled the then extant knowledge of coastal impoundments from the Sandifer et al. (1980) report into a smaller and more focused document. They divided the subject into freshwater impoundments (mean salinity < 0.5 ppt), saltwater impoundments, and waterfowl management. Specific research needs and knowledge gaps are embedded in the text. The following is a compilation of most of them.

1 | **The nonvascular flora, its associations and population dynamics, of both fresh and saltwater impoundments have not been thoroughly studied.**

Status: This has still not been done in coastal wetland impoundments. Several defensible inferences could be made based on results of studies in tidal marshes and small impoundments at other locations. Research targeted at specific questions of how tidal impoundments differ could then be proposed.

2 | **They reviewed the several studies of productivity and nutrient exchange in saltwater impoundments which revealed a mixed picture; thus they recommended that additional work was needed in the area of "nutrient cycles, total biomass, and primary productivity in estuarine impoundments."**

Status: Some useful work on nutrient dynamics and macrophyte biomass and productivity has been done on the Cooper River (Kelley et al. 1990, Paludan and Morris 1999, Sundareshwar and Morris 1999, Sundareshwar et

al. 2001, McKellar et al. 2002, Huang and Morris 2003, Huang and Morris in press), the Pee Dee River (Ozalp 2003), and in the ACE Basin (Burke et al. 1999). Additional work is currently in progress, but many significant questions still require investigation.

3 | **Studies are needed to understand zooplankton role in food webs of impoundments and their exchanges with the adjacent creeks and rivers. This applies to both salt and freshwater impoundments.**

Status: This has still not been done in coastal wetland impoundments. Several defensible inferences could be made based on results of studies in tidal marshes and small impoundments at other locations. Research targeted at specific questions of how tidal impoundments differ could then be proposed.

4 | **Studies are needed of the benthos, including meiofauna, in saltwater impoundments; also of the insect and herptofauna.**

Status: This has still not been done in coastal wetland impoundments. The few studies of this in tidal marshes at other locations, such as the Gulf and mid-Atlantic coasts, have noted the potential significance of this group of benthic fauna to ecosystem function, e.g. Bolduc and Afton (2003) and Yozzo and Smith (1995). Based on their results they believe more work is needed.

5 | **A better understanding is needed of the relative importance of impoundments to populations of marine and estuarine fishes.**

Status: Some useful work on this has been done on the Cooper River (Osteen et al. 1989, Slack 1991, Thomas et al. 1992, Long et al. accepted) and Savannah River (Malloy 2004). Of these the Cooper River work gets at the "importance" issue for Blueback Herring but a substantial amount of additional work is needed. There is no question that marine and estuarine fish use impoundments, particularly breached impoundments, along the entire salinity gradient. But the extent of the utilization (number of species and proportion of the populations), importance to their life-cycle, and the impact of reimpounding on estuarine population dynamics are unknown.

6 | **The role and magnitude of impact of mammals is not well studied, although with few exceptions it is believed they are not determinants of the overall community dynamics of the marshes.**

Status: This has still not been done in coastal wetland impoundments. Several defensible inferences could be made based on results of studies in tidal marshes and small impoundments at other locations. Research targeted at specific questions of how tidal impoundments differ could then be proposed.

7 | **The benthic invertebrate community in freshwater impoundments has not been studied, which "constitutes a major data gap."**

Status: This remains a major data gap although some indirect work has been done in feeding studies of shorebirds and colonial waterbirds (Bildstein et al. 1990, DeSanto et al. 1997, Weber and Haig 1997, Winger et al. 2000).

8 | **Colonial waterbird rookeries are frequently, not exclusively, located at or adjacent to freshwater impoundments. The full extent of colonial waterbird rookeries on the Coastal Plain is not known. Also, because waterbirds utilize a variety of wetland habitats (not just impoundments), the consequences of the loss or degradation of a particular habitat is not well understood.**

Status: Some useful work in this regard has been done along the Cooper River (OCRM 1998) and the entire Coastal Plain (Dodd and Murphy 1997). Dodd and Murphy (1995) also assessed the accuracy of various colony nest-counting methods. This is a key question because of variability in individual colony size and the large area over which they may occur. The question of relative importance is less clear, although White Ibises apparently depend on freshwater marshes for feeding young birds (DeSanto et al. 1997). It has also been hypothesized that reduced prey availability in riverine marshes and swamps during drought years can be at least partly responsible for failure to fledge young (Bildstein et al. 1990). Resource managers in South Carolina have found that impoundment water level draw-downs during the late spring can be scheduled so

that it is compatible with waterfowl management and creates high density foraging habitat for Wood Storks that are feeding chicks. Daniels et al. (1993) suggest that loss of coastal wetlands due to sea level rise will have an impact on marsh birds, including Wood Storks.

The Executive Summary (DeVoe and Baughman 1987) of the report of the CWIP summarized the significant research needs that still remained after their work at the brackish impoundment complex on Cat Island. The following is adapted from that text (see pp. 38-41 of the report).

1 | **Work is needed to determine how large systems are influenced by water circulation patterns. In addition, studies should examine the effects of water exchange and periodic flushing/flooding events on water quality inside these larger systems and in adjacent water bodies. These studies should include an examination of the effects of periodic releases of large volumes of water from impoundments on water pH, nutrient levels, and DO concentrations.**

Status: No studies directly assess all these issues. Some work focusing on nutrient exchanges has been done on the Cooper River (McKellar et al. 2002) and more work is in progress that will assess DO. Kelley et al. (in prep) studied macrophyte succession in freshwater rice fields along the Cooper River and hypothesized that internal water circulation patterns determined by morphological factors (elevation, canals, breaches) were a significant determinant of field-specific successional patterns. It is generally accepted that good internal water quality can be maintained in closed fields by ensuring sufficient volume and frequency of tidal exchange, e.g. Olmi et al. (1988). If water is held in the impoundment water quality will deteriorate, e.g. Cotton (2004). Conrads et al. (2002) found that breached impoundments along the East Branch of the Cooper River may be discharging water with low DO concentrations during ebb tide. This result has been corroborated independently, but those data are not published. The Upper Cooper River natural resource management plan (NRMP) recommends a pilot reimpoundment project. The recommendation includes a requirement for before/after monitoring so that water quality issues can be directly assessed (Consensus Solutions 2004).

2 | **Further examinations of primary production should be made for other impoundment systems to determine if they are similar to the Cat Island system. Additional studies of primary production might include the determination of below-ground biomass, turn-over rates, and detritus export.**

Status: This has not been done.

3 | **Impact analyses are needed of various waterfowl management schemes, especially those involving cultivation and/or burning. Their impacts on impoundment productivity and habitat utilization by aquatic species should be investigated. Additional studies on the effects of management schemes to produce other target species, such as shrimp or crawfish, and multi-species management for both waterfowl and shrimp (and wildlife and fisheries resources), would also expand the existing base of knowledge. Other management-related research should include studies to determine the feasibility of double-cropping widgeon grass; delaying the reflood process to produce a later crop of widgeon grass, or using multiple flushing to reduce mosquito production.**

Status: Impact analyses have not been addressed in a comprehensive manner in any published literature. During discussion of work on sediments in tidal freshwater marshes along the Savannah River, Winger and Lasier (2004) hypothesized that management activities such as burning and disking might contribute to the development of acidic conditions that promote mobilization of some contaminants. Impoundment management for target species such as waterfowl utilize well-established techniques that are accepted because they accomplish the specific objective (Gordon et al. 1989, Williams et al. 2002). It is typically stated that these methods do not have detrimental side effects, although resource managers acknowledge this is not based on any rigorous analyses that they are aware of.

4 | **Future research should focus on investigations of methods for improving the amount and timing of water exchange. Studies should determine the optimal number, placement, and design of impoundment water control structures to maintain adequate circulation and water quality. Additionally, the enhancement**

of circulation and drainage in larger impoundments may require crossditching and/or crossdiking. The costs and benefits of these modifications should also be established. Above all, the investigation of management techniques to increase water exchange, both in volume (to maintain adequate water quality) and timing (to provide for the immigration and emigration of marine/aquatic species), is critical for the development of management protocols and the wise use of this valuable wetland resource.

Status: As with the prior recommendation, there apparently are no published reports based on research of these issues, although accepted protocols and construction practices exist, e.g. South Carolina Sea Grant Consortium (1987). Some of these points will be addressed as part of the proposed pilot reimpoundment on the Cooper River (Consensus Solutions 2004).

In another summary of the CWIP findings, DeVoe et al. (1987) discussed several issues that led to the following additional research and science-based policy concerns.

1 | **The duality of the findings with respect to whether or not impoundments have a positive or negative impact on coastal ecosystems highlighted the need for investigations and synthesis of knowledge at scales larger than the local impoundment(s)/creek complex. Meaningful scales for state resource management agencies include the estuary and entire coastal zone. Coordination with federal agencies is necessary to adequately address larger ecological units.**

Status: There remains a need to accomplish this, although the current report is part of a larger project intended to move significantly in that direction. This issue was also discussed at length during development of the Upper Cooper River NRMP; the need to do a larger scale assessment was identified (Consensus Solutions 2004).

2 | **A synthesis is also needed to provide a bridge between knowledge gained from studies of individual systems and principles that are generally applicable to all or many systems.**

Status: The current report is a step in that direction. The most effective way to accomplish this will be as part of a larger multi-disciplinary project to develop landscape models at the estuary and river basin scales.

In the early 1990's the Charleston Harbor Project (CHP) (OCRM 2000) began a 6+ year comprehensive study of the entire estuary. They looked at a complex suite of issues, among which were biological, economic, cultural, water quality, and recreation. A large number of research recommendations and policy and management suggestions emerged from this study. They cover many issues and not all are directly or indirectly relevant to impoundments. The following is a summary of those that are, extracted from the main report (OCRM 2000) and the sub-report specific to rice fields (Kelley and Porcher 1995).

1 | **There is a need to develop a basin-level plan to address rice field succession in the upper Cooper River. The variety of habitat once prevalent appears to be rapidly homogenizing as it undergoes succession toward swamp forest ecosystems. The CHP findings suggest that the estuarine ecosystem is adapted to the former rice field subsystems. Their loss could have negative effects on other aspects of the system.**

Status: The Upper Cooper River NRMP was a major step in this direction (Consensus Solutions 2004). It included several recommendations targeting basin-wide issues and identifying data needs.

2 | **Stabilize Cooper River flows and increase them to the extent possible from January through May. This recommendation is targeted at creating favorable conditions for fish spawning, and includes consideration of the role that the rice fields have in this. This recommendation is interdependent with the first recommendation.**

Status: Cooper River flows are being addressed by the federal relicensing process currently underway for the Santee-Cooper project.

3 | **Measures should be implemented to protect colonial waterbirds. This is also not specific to rice fields**

or impoundments in general, but recognizes that impoundments are foraging and roosting habitat for these birds.

Status: This has not been explicitly addressed except as a consideration in the normal permitting process and environmental impact studies.

4 | **Identify specific functions of succession stages. Continue to track the accelerated process in the Cooper system.**

Status: Work has been done on fish (Long et al. accepted), biogeochemistry (Paludan and Morris 1999, Sundareshwar and Morris 1999, Huang and Morris 2003), water quality (McKellar et al. 2002), primary production (Pickett et al. 1989, Kelley et al. 1990), and mapping and succession (Kelley and Porcher 1995, Kelley et al. in prep). A substantial amount of work has been done in tidal freshwater and brackish marshes along the Savannah River and elsewhere on the mid-Atlantic coast that could be integrated with Cooper River work to document what is known and what still needs to be done to fully address this recommendation.

5 | **Investigate the relationship between plant species/community presence and elevation so that rates of vegetational change can be modeled as a function of elevation change (allows analysis of dynamics of sea level rise, sediment accumulation, and water level management policy).**

Status: A substantial amount of work has been done on this (Kelley and Porcher 1995, Kelley et al. in prep). A field and modeling project currently in progress will address the remainder.

6 | **Develop a legal framework that will allow permitted repairs to strategically located fields with management conditions that accomplish ecological and recreational goals (perhaps through a mitigation banking system).**

Status: A recommendation in the Upper Cooper River NRMP for a pilot reimpoundment identified this as a dependency. Initial planning for that was scheduled to begin in early 2005.

Montague et al. (1987) conducted an extensive literature review to examine the importance of coastal impoundments to overall organic matter and nutrient export to estuaries relative to benefits derived by estuarine fish and shellfish. They acknowledge data gaps that limit conclusions, but their interpretation was that open salt marshes probably have a relatively minor impact on the estuary with regard to assimilable carbon and nutrient availability. Also that saltmarsh impoundments likely have even less, given the reduced exchanges associated with impoundments. They also briefly summarize the several variable ecological effects that impoundments can have on local ecosystems, many of which impact secondary production. Three issues they could not address stand out as future research needs.

1 | **They recommend a top-down approach to studies of the effects of impoundments on estuarine fauna (fish, shellfish). One of the objectives, or secondary uses, of organic carbon and nutrient flux studies are the direct and secondary effects on higher trophic level production. They argue that looking at the use of impoundments by these organisms in a comparative manner with more open systems is a more focused approached.**

Status: With the exception of birds and nekton, little has been done in this regard in coastal impoundments in South Carolina. Miglarese and Sandifer (1982) made several recommendations (discussed earlier in this section) to address community characteristics that would be helpful for addressing this as well.

2 | **There is even less data on fluxes from brackish and freshwater impoundments. They observe that although biophysical differences along a salinity gradient are well documented, the effects of these differences on carbon and nutrient transport are not well known.**

Status: A limited amount of work on organic matter exchange has been done in rice fields along the Cooper River (Saropraygoi 2001) and more is in progress. Comparatively more work has been done looking at inorganic nutrient exchanges along the Cooper River (McKellar et al. 2002) and more is in progress. None of the work has attempted to link the results with downstream productivity.

3 | **Factors other than impoundment salinity, such as frequency and amplitude of water exchange, other management activities, and degree of access by target species, have an unknown effect on biochemical exchanges.**

Status: This has not been addressed.

Gordon et al. (1989) discussed in some detail the coastal wetlands in South Carolina and Georgia, including salt, brackish, and freshwater marshes. Their perspective is the value and use of impoundments by migrating and wintering waterfowl. They discuss primary and alternative management schemes and conclude with several research recommendations.

1 | **They assert that public and regulatory opposition to managed wetlands (as opposed to open wetlands) is largely unsubstantiated with scientific information. A comprehensive understanding is needed of the structure and function of coastal marsh ecosystems (fresh and brackish) so the effects of wetland management can be assessed.**

Status: To the extent that opposition is categorical toward all impoundments and management strategies, it is true that it cannot be substantiated with scientific information. On the other hand, much of what is stated in support of impoundments cannot be substantiated scientifically either. Resource managers readily acknowledge this. What is certain is that impoundments provide habitat that is advantageous for some target bird species, including rare and endangered species. Conversely, there is sound reason to suggest that impoundment structure and management as currently practiced is disadvantageous to other species, mostly fish and benthic invertebrates (DeVoe and Baughman 1987, Bolduc and Afton 2003). What is needed is research across a range of species and impoundment types (salinity, management objective) that will specifically address these issues.

2 | **Substantial information is needed on migrating and wintering waterfowl including habitat requirements, structure, and function across scales.**

Status: There is considerable debate in South Carolina about reasons for the decline in winter duck populations along the coast. This will be discussed in more detail in the next section. It is clear that research is needed to help resolve the questions. Also from a different perspective, from conversations with resource managers and landowners it is clear that winter habitat selection by ducks is not well understood. Specific guidelines to manage an impoundment for ducks are widely accepted, but following them does not guarantee winter ducks will be present. More work is needed on this question.

3 | **A better understanding is needed of the relative importance of various food items (seeds, tubers, invertebrates, etc.) to waterfowl.**

Status: Specific research in the south Atlantic coastal zone is still needed. There has been an apparent decline in waterfowl research along the south Atlantic coast in the last 15-20 years. This may be the reason that some key research questions remain unanswered.

4 | **The ecology and environmental determinants of wetland plants requires more study. Both descriptive and experimental studies are needed including how wetland management practices may impact them.**

Status: One seed bank study was conducted in a tidal freshwater wetland on the Pee Dee River (Jacobs 1995), and a great deal of work has been done in tidal marshes along the Savannah River (Latham 1990, Latham et al. 1994, Bossart 2002, Loftin et al. 2003). Seed bank studies are a substantial part of the body of work from the tidal freshwater and brackish marshes along the mid-Atlantic (Leck and Simpson 1995, Leck 2003, Peterson and Baldwin 2004, Peterson and Baldwin 2004) and Gulf of Mexico coasts (Flynn et al. 1995, Baldwin et al. 1996, Howard and Mendelssohn 1999). These and other studies should be used to help guide future work on this issue.

In other more generalized work, Simpson et al. (1983) summarized existing research on tidal freshwater wetlands, primarily along the mid-Atlantic coast, and Odum (1988) wrote a detailed comparison of tidal

fresh- and salt-water marshes. Both these significant works included research recommendations. The first three are from Simpson et al. (1983); the fourth is from Odum (1988).

1 | **Nutrient flux studies of one year or longer are needed.**

Status: A one year study is currently in progress on the Cooper River which builds upon studies by McKellar et al. (2002). More are needed for longer durations and in a range of impoundments.

2 | **A better understanding is needed of food chain relationships between tidal freshwater marshes and the adjacent estuary.**

Status: This has not been done in South Carolina.

3 | **Additional work on the short- and long-term effects of pollutants (e.g. oil, pesticides, heavy metals) is needed.**

Status: Some useful work on this issue was done in tidal freshwater marshes along the Savannah River (Winger et al. 1990, Winger et al. 2000, Winger and Lasier 2004). They looked at contaminants in sediments and fauna (aquatic and terrestrial) at several locations. Their results were mixed, indicating bioaccumulation in some species but not others.

4 | **Most work in tidal marshes has focused on the fresh and salt end-members of the salinity gradient. Greater understanding of oligohaline and mesohaline marshes is needed.**

Status: Some work with sediment phosphorus (Paludan and Morris 1999, Sundareshwar and Morris 1999, Sundareshwar et al. 2001, Huang and Morris in press) and water column nutrients (Douglas 1995, Alford 2000, Saropraygoi 2001) has been done along a salinity gradient in marshes on the Cooper River. Marsh vegetation has been studied along a salinity gradient in marshes on the Savannah River (Latham 1990, Latham et al. 1994, Bossart 2002, Loftin et al. 2003). A great deal of work has been done in brackish marshes along the mid-Atlantic coast (Baldwin et al. 1996, Perry and Atkinson 1997, Merrill and Cornwell 2000). These and other studies should be used to help guide future work on this issue.

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"Size does matter; big is different from little, because new properties emerge with an increase in scale." (Odum 2002)

In pre-colonial times most of the current and formerly impounded wetlands along the South Carolina coast were tidal forested wetlands in almost pure stands of Cypress (Mattoon 1915). Of those that are no longer impounded some have regenerated into forest communities (Ratard 2003, Conner et al. 2004), but many remain in earlier successional states, either sub- or inter-tidal emergent marsh (Latham et al. 1994, Kelley and Porcher 1995). Most of those that are currently impounded and managed are kept in a submerged marsh state to support waterfowl populations for hunting or wildlife refuge (Tiner 1977, Gordon et al. 1989).

In the current regulatory and conservation environment it seems unlikely that permits would be issued to clear and impound a large tract of mature tidal riverine forested wetland. Reasons would center around issues of wetland ecosystem functions and values, which include water quality, concerns for the downstream effects of the loss of the forest inputs, and the cumulative impact of habitat loss on local and regional biodiversity. These concerns are based upon sound ecological and conservation science and immediately raise the question of whether the former impoundments are more valuable as forested ecosystems. If so, then sound policy should encourage succession, or at least not manage against it.

An alternative approach is to begin with the baseline condition that whatever the negative effects were of forest clearing and hydrologic alteration during the 17th-19th centuries, the systems have adapted to it and there are now new landscape dynamics in effect. Breached impoundments, dominated by submersed or emergent marsh vegetation, now interact with the larger riverine and estuarine ecosystems. Managed impoundments have roles in species management at scales from regional to inter-continental. In this more complex landscape matrix, management concerns would be more productive if focused on understanding the key features and critical elements of this landscape and managing to ensure those are not lost. Of particular concern in this context is

the ongoing protection of resources from the increasing encroachment of human activities.

There are, of course, many variations and hybrids of these two extremes. But any serious look at these systems, for purposes ranging from restoration of pre-colonial conditions to ongoing manipulation to achieve policy and management objectives at multiple scales, requires an understanding of the critical states, processes, and decision points within ecological, resource management, and sociopolitical contexts. This is not a new observation but restating it reinforces the need to periodically assess current practice and integrate new information. This serves at least two important purposes. One is adaptation of policy and management to newer realities and understanding (Meffe et al. 2002, Olsson et al. 2004). The second is refocusing scarce resources toward research goals that will fill specific gaps in the base of information.

Resource assessments and focusing of research resources has occurred concerning various classes of natural resources within coastal wetland impoundments (see Part II of this report). Brief summaries of recent research and resource management activities since those assessments were presented in Part III. In this section the information is integrated with a larger understanding of similar resources in other locations.

Tidal forested wetlands

Tidal forested wetlands along the Southeast coast occur in the floodplains of larger coastal rivers. The water table is always high as a result of the semi-diurnal tidal inundation. Cypress and subdominant tree species have very low salinity tolerance so these ecosystems are confined to the freshwater reach of the zone of tidal influence (Wharton et al. 1982). Early research in tidal forest wetlands suggested they were a significant source of organic carbon and possibly nutrients to downstream estuaries (reviewed by Wharton et al. 1982).

These wetlands were the dominant land cover that was altered to support rice culture (Mattoon 1915, Doar 1936). It is generally accepted that in the absence of intervention (natural or anthropogenic), a breached impoundment with a compatible salinity regime will eventually return to the mature forest state. Thus one perspective of a discussion on policy toward coastal impoundments is to consider what was lost ecologically as a result of rice culture and assume this will be restored by allowing succession to proceed. It is beyond the scope of this report to attempt a quantitative comparison of current to pre-colonial conditions in the former rice fields, but some useful qualitative observations are possible.

In his literature review of tidal freshwater forests in Georgia and South Carolina Duberstein (2004) could find no other quantitative analyses. Concurrent with Duberstein's work in the Savannah River estuary there were other studies in progress in South Carolina (Ozalp 2003, Ratard 2003), but there remains very little past or current work to aid in understanding these ecosystems. As a consequence, much of the current understanding of freshwater tidal forests is inferred from the large body of research completed on similar systems in the non-tidal floodplains of large Southeastern rivers.

Tidal forested wetlands along the Southeast coast are classified as a type of bottomland hardwood ecosystem (Wharton et al. 1982). A substantial amount of research suggests that these wetlands act as sinks for inorganic nutrients and frequently export organic nutrient forms (Kitchens et al. 1975, Meyer et al. 1997, Conner and Buford 1998, Ozalp 2003, Ratard 2003). Cuffney (1988) estimated that floodplain organic matter input to the Ogeechee River (GA) was approximately 40% of the total flux of riverine organic matter. In another study in the Ogeechee River, Edwards and Meyer (1987) estimated floodplain inputs at 7 times the autochthonous load. The significance of this result is, in part, that it runs counter to the dominant conceptual model of riverine production dynamics and suggests that Coastal Plain rivers may be different in other ways.

Organic material is an important substrate for the microbial loop in downstream ecosystems. Thus floodplain forests are potentially significant contributors of energy and nutrients to estuarine food webs. The contribution of the floodplain to the total organic matter flux would be expected to vary as a result of local morphology and seasonal biotic and hydrologic conditions of the floodplain (Cuffney 1988). Also important is the suspended sediment load in the river. Large loads would increase

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the possibility of burial of floodplain litter rather than mobilization. So for example the expectation would be that the floodplains along the Edisto River make a proportionately greater contribution to the total organic flux than those along the Pee Dee River.

The quantity of organic matter is only one indicator of the relative importance of floodplains to downstream ecosystems. Substantial research in recent years has focused on bioavailability, which can vary seasonally, by source, by molecular size fraction, and along the longitudinal axis of the river (Leff and Meyer 1991, Sabater et al. 1993, Moran et al. 1999, Stepanauskas et al. 1999, Avery et al. 2003). In southeastern Coastal Plain rivers the labile fraction appears to be rapidly utilized with relatively low utilization within the estuary (Leff and Meyer 1991, Moran et al. 1999). Moran et al. (1999) found substantial variability among rivers along the Georgia coast, as well as indications of differences in the photoreactivity of organic matter exported from the rivers. (Photochemical reactions are believed to have a significant role in mineralization of organic matter in some systems [Xie et al. 2004].) They also concluded the dissolved organic carbon (DOC) from Coastal Plain rivers was in general less bioavailable than DOC from other rivers both in the Southeast and elsewhere (Hopkinson et al. 1998). The situation with organic matter is complex and still unfolding, but in general it appears that Coastal Plain rivers export greater quantities of less bioavailable organic matter to estuaries than do alluvial rivers. This suggests that the river dominated estuaries in South Carolina are diverse in terms of the origin of the nutrients and energy that drive ecosystem production.

The prior discussion dealt with the function of floodplain forest nutrient dynamics (transformation, mobilization), energy flow, and food web interactions at the microbial level. Floodplain forests have other ecological roles. Inundation provides a pathway for aquatic invertebrates and their predators to migrate onto the floodplain. In a study on the floodplain of the Ogeechee River, Benke (2001) compared invertebrate biomass among the main channel, snags, and the floodplain, and found that the floodplain and snags alternated as the dominant habitat depending on the specific groups of invertebrates. This result is consistent with related work on the Satilla River (GA) (Benke et al. 1984) and a more generalized understanding of the importance of floodplains to the fauna (invertebrates and their predators) that migrate to them from the main channel (Conner and Buford 1998, Winemiller 2004).

Another significant ecological role of floodplain forested wetlands is their use by migrating and resident avifauna, particularly neotropical migrants. The overall decline in suitable forest habitat has caused concern among conservation biologists (Moore 2000). There are no studies of neotropical bird migration that focus specifically on tidal forested wetlands, perhaps because they are a relatively rare ecosystem. Within the Savannah National Wildlife Refuge, however, Somershoe and Chandler (2004) found that larger oak hammocks within marshes attract more migrants. Based on this finding they suggest that conservation of larger forested tracts will benefit a greater number of migrant species.

Tidal marshes

These systems occur along a salinity gradient from fresh (mean salinity < 0.5 ppt) to saline (salinity around 35 ppt). In the United States most of the tidal marshes are along the Atlantic and Gulf coasts; most freshwater tidal marshes occur along the South Atlantic and Gulf coasts. Floral species occurrence within a marsh is determined by the salinity gradient; species diversity increases as salinity decreases (Nelson 1986, Odum 1988). Species zonation within salt marshes occurs along an elevation gradient, which integrates the effects of tidal hydrology, sediment composition, pore water chemistry, and nutrient availability. Zonation in brackish and, in particular, freshwater marshes is generally considered less distinct although some elevation gradients have been observed (Odum et al. 1984, Odum 1988).

In the most recent review of the literature, Odum (1988) concluded that invertebrate diversity increases with salinity. The pattern of fish communities also appeared to be determined by salinity, with marine and estuarine species dominant at the saline end of the estuary and freshwater species dominant at the inland extent of tidal influence. (This point may seem self-evident but the generalization masks some variability that will be mentioned later.) He noted there was not a great deal of data about invertebrate communities,

particularly in fresh and brackish marshes. Species diversity of land-based vertebrates increases along the gradient from saline to freshwater (Odum 1988).

Most coastal impoundments in South Carolina were originally constructed during the period of tidewater rice production. They were in the tidal freshwater zone or in slightly brackish conditions if freshwater hydrology could be maintained with reservoirs (Hilliard 1975). While many are still in the freshwater zone, a significant number are in brackish and saline conditions due to a combination of changes in river flow, subsidence, and sea level rise. Changes in river flow in South Carolina result from one or more of: hydrologic control (e.g. dams), water withdrawals, impervious surfaces, and altered coastal morphology (e.g. the Intracoastal Waterway).

According to Tompkins (1987), 58% of coastal wetland impoundments are diked (76% of public, 50% of private). A substantial majority of the diked impoundments are managed for waterfowl habitat, with lesser amounts for uses such as aquaculture and row crops. An unknown quantity are managed for multiple purposes, such as wintering waterfowl and waterbirds. Multi-species management is increasingly common (SCDNR 1999, CSC 2000, Williams et al. 2002), a trend that seems likely to continue (Bolen 2000). The trend is driven by many factors, part of which is the need to form diverse partnerships to achieve large scale objectives. Undisturbed ecosystems are "multi-objective" in a sense, so this trend can also claim some legitimacy as a more natural management strategy.

At the other end of the management spectrum are breached impoundments for which water control is not possible. Current policy in South Carolina generally discourages reimpoundment, typically citing the potential for adverse environmental impact and/or concern for access to public waters (OCRM 1995).
As urban development increases pressure on remaining coastal natural resources, the case for active resource management to maintain biodiversity at local and larger scales becomes increasingly compelling, at least on paper. Current policy was not developed in a scientific or public trust vacuum, however, and the legitimate question exists of whether it is better to focus policy attention on protecting natural ecological processes in as undisturbed a state as possible or to actively manage the resources to achieve larger objectives. A hybrid of these approaches is possible and desirable. Although existing policy was formed with the then-available scientific and resource management information, there is new information now that should be integrated into the policy debate.

Marsh vegetation

Vegetation communities and their spatial and temporal dynamics are a primary issue when assessing coastal wetland impoundments. The organizing concepts are community succession and the ecological changes that accompany it. At one extreme is an impoundment managed for waterfowl. In some respects these are analogous to row crop agriculture because the system is permanently maintained in an early successional state. This management plan has an annual cycle with a prescribed sequence of actions, such as drawdown, drying, burning, and flooding to specific depths, all to encourage growth of natural food plants for ducks (Gordon et al. 1989). The analogy with agriculture is more direct for some owners who plant cereal crops such as corn rather than encourage natural foods. This practice is discouraged as not healthy for ducks (Williams et al. 2002), but in South Carolina where duck abundance is relatively low this is known to attract higher numbers of birds.

Another type of succession is caused by salinity change. The most likely causes of salinity change in South Carolina are estuarine manipulation (Pearlstine et al. 1993, Management 2003), upstream hydrologic modification such as dams (Kjerfve and Magill 1990), extended drought (Bossart 2002), and climate change effects such as sea level rise (Daniels et al. 1993, Titus and Richman 2001) and coastal storm frequency and intensity (Michener et al. 1997, Scavia et al. 2002). Increased salinity would be expected to reduce the diversity of marsh vegetation, land based vertebrates (such as birds and mammals), and perhaps aquatic invertebrates that can utilize the wetland. The effect on fish would be an areal increase in the habitat for marine and estuarine fish and a decrease for freshwater fish (Odum 1988, Kitchens 2003).

Stresses resulting from local and regional hydrologic or estuarine modification are the forcing processes that can have relatively immediate yet long-term effects. For exam-

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ple, installation of a tide gate on the Savannah River in the early 1970s caused significant upstream migration of the salt front which caused severe degradation of the habitat value in what were tidal freshwater marshes in the Savannah National Wildlife Refuge (Pearlstine et al. 1993). Marsh recovery after removal of the gate from operation in the early 1990s is still not complete, although this appears to be partly the result of harbor deepening and an extended drought that reduced discharge in the Savannah River (Bossart 2002). A new proposal to further deepen the harbor is receiving a great deal of attention (Management 2003) (see also http://sav-harbor.com) and there is an active process to identify and implement the most effective means for marsh restoration (USFWS 2004). These are in part a response to the earlier problems.

Impounded wetlands may be sheltered from the effects of some causes of salinity change because of their dikes and water control, although owners near the head of tidal influence report that reduced river flows caused by drought can alter the salinity profiles in their impoundments. The dikes may not be effective if the magnitude of change is large, such as has happened twice on the Santee River (Kjerfve and Greer 1978). It may seem unlikely that such a large change to critical river flow could make it through the permitting process today. A smaller flow modification that is one of several effects which together accumulate to a relatively large change is more plausible. Examples of these effects over a longer time horizon include salinity change resulting from climate induced changes such as sea level rise, reduction in river discharge, or coastal storm frequency and intensity.

Salinity change associated with change in sea level in coastal environments is a naturally occurring phenomenon and coastal wetlands can adapt to it both laterally and vertically (Hammar-Klose and Thieler 2001, Morris et al. 2002). Impounded wetlands do not have this option, and unimpounded wetlands may not either if anthropogenic alterations to adjacent land or riparian areas prevent it. These factors suggest that salinity-induced succession will occur to some extent in coastal wetland impoundments in estuaries of both managed and unmanaged rivers, although the time frame is highly variable.

Vegetation community succession can also occur as a result of elevation change caused by sedimentation within a coastal wetland impoundment or by changes in flow. Bottom elevation change by sediment accumulation is a recognized process in aquatic systems (Knighton 1998, Wetzel 2001, Hakanson and Jansson 2002). Vegetation change along elevation gradients in salt marshes is well described (Odum 1988), and although macrophyte community differentiation is not as pronounced in tidal freshwater marshes there is recognition that some degree of separation does occur (Odum et al. 1984). Aquatic macrophyte species are adapted to particular depth ranges due to light availability and other factors (Davis and Brinson 1980). As depth declines due to accumulated sediment, the competitive advantage shifts to different species. Baldwin et al. (2001) found that germination from identical seedbanks in tidal freshwater marshes can vary significantly depending on the extent and timing of flooding.

Kelley et al. (in prep) analyzed a 22-year span of aerial photographs of former rice fields along the upper Cooper River. They concluded there was a significant decline in subtidal habitat and an increase in intertidal habitat, with associated changes in macrophyte community composition. Continuation of this trend will reduce the abundance of fish and other fauna that depend on submersed macrophyte habitats either seasonally or for a stage of their lifecycle (Long et al. accepted). It also increases habitat for land-based vertebrates, such as some birds and mammals.

The end result of succession in freshwater impoundments should be a tidal forest. Since the demise of tidewater rice culture some fields have reverted to forest of varying maturities, but some are also intertidal emergent marsh or shrub and grass habitat (Ozalp 2003, Conner et al. 2004, Kelley et al. in prep). It is possible that the early stages of macrophyte succession have an autocatalytic component, in which an increase in the organic content of sediment results in species shifts that further succession (Barko and Smart 1986, Huang and Morris 2003). Apparently different factors dominate in later stages. As the elevation of the intertidal marsh platform continues to increase, the opportunity for further sediment accumulation decreases as functions of distance from the sediment source and less water cover for shorter periods

of time (Neubauer et al. 2002, Pasternack and Brush 2002), thus slowing physical succession. Tidal action appears to be a significant influence on tree establishment and productivity in these systems (Ratard 2003), but it is likely there are other undetermined factors at some sites.

Invasive aquatic macrophyte species

There is also concern about the increasing dominance of invasive (non-indigenous or nuisance) species in many locations. These plants colonize sites and cause loss of habitat for other biota (flora and fauna), change in site or landscape hydrology or biogeochemistry, cause water quality problems, and impact recreational use of impoundments. The recreational impact and potential for water quality problems are the biggest concerns for South Carolina and the prime motivators for the control program administered by SCDNR. Each year an aquatic plant management plan is developed that, among other things, identifies priority problem areas, the problem species, control strategy, and possible source of funds (SCDNR 2004). Many of the areas identified are former rice fields. Herbicide spraying is the control that is used in former rice fields. Control of existing infestations is focused on keeping boat lanes and other access open. SCDNR works to eliminate initial invasions and has been successful in some situations, such as Water Hyacinth on the Ashepoo River.

SCDNR currently lists 26 nuisance macrophyte species in South Carolina. Many are prevalent throughout the coastal zone; some are currently increasing their range. The top nuisance species in coastal wetland impoundments are Water Hyacinth, Water Primrose, and Hydrilla. All are capable of blocking navigation and other access. Hydrilla and Water Primrose are frequently associated with each other, forming dense stands in the entire water column that increase sediment accumulation rates (Joe Kelley, unpublished data). This may be one cause of accelerated succession in some impoundments. Water Hyacinth is a particular problem because it is a floating plant that can move to new locations with the flow of the river or tidal creek.

Aquatic fauna

The use of tidal marshes by nekton and benthic fauna is dependent on salinity, tidal stage, and perhaps other factors. In a meta-study of oligohaline and freshwater marshes along the East Coast including South Carolina and Georgia, Odum et al. (1988) found that in freshwater marshes 60% of the fish species were freshwater. In oligohaline marshes the percentage declined to 26% (marine and estuarine species made up the difference in both cases). In the marshes along the Savannah River, Malloy (2004) found that even in the freshwater sites most of the species (all nekton) were estuarine or marine. She also found that species richness was greater in the marsh edge over the interior, but overall abundance was greater in the interior.

In a study of nekton in marshes along a salinity gradient in Virginia, Yozzo and Smith (1998) found greater abundance in the salt marsh and greater diversity in the freshwater marsh. Estuarine species were dominant in both sites. Flooding depth and duration were positively correlated with nekton use of the salt marsh surface but not the freshwater marsh surface. They hypothesized that the seasonal presence (freshwater) or absence (salt) of submersed vegetation may affect utilization and other population characteristics.

It is likely that factors other than salinity affect nekton utilization of a marsh. Rozas and Odum (1987) compared overall abundance in the river versus tidal creeks in a freshwater marsh in Virginia. Abundance was greater in the tidal creeks which they attributed to the greater abundance of submersed vegetation. Thorp et al. (1997), working in a tidal freshwater marsh along the Potomac River, found that macroinvertebrate density and diversity were significantly greater in locations with substantial coverage of submersed macrophytes. McIvor and Odum (1988), also working in a tidal freshwater marsh in Virginia, found that fish were more likely to be found along shallow sloping creek banks than along steeper erosional banks. Subsequent work determined this was due to greater abundance of invertebrate prey. Yozzo and Smith (1995) studied microhabitat and seasonality of meiofauna in a tidal freshwater marsh in Virginia and hypothesize on the potential for this group of organisms to be an important link in the trophic structure of intertidal freshwater marshes.

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Photo | Daniel L. Tufford

Along the Cooper River, Long et al. (accepted) conducted monthly sampling at freshwater sites differentiated by the extent of subtidal versus intertidal habitat. Populations at the subtidal site were more stable and contained more estuarine species. A specific example of this is the striped mullet, which was more abundant in the subtidal site. This fish is of recreational and economic significance in South Carolina and is receiving more attention from researchers because it is also important in the estuarine food web (McDonough and Wenner 2003). Homer (1988) looked at fish abundance in a subtidal Cooper River rice field and found that it varied directly with submersed macrophyte density. Slack (1991) and Thomas et al. (1992) found that lowered water levels in the Cooper River significantly altered use of former rice fields by Blueback Herring. They attribute much of the change to loss of subtidal habitat.

The four Cooper River studies all suggest that subtidal habitat with relatively high densities of submersed macrophytes are important parameters for fish utilization in these marshes. This is especially the situation for marine

and estuarine species. When integrated with the more general nekton studies, the affinity for submersed vegetation is probably for both protection and food. The former rice fields along the Cooper River are undergoing succession from subtidal toward intertidal habitat, as discussed earlier, suggesting that over time there will be a significant decline of this important habitat.

The dominant questions concerning the impact of impoundments on nekton and benthic communities relate to the possible loss of habitat, involving both mobility (ingress and egress) and quality (food, spawning, or nursery). To help understand the distinction, an impoundment could be a source of high quality food for a particular species of fish or invertebrate, but if required movements (e.g. tidal or seasonal) are impeded the site is not useful for the larger estuarine population (USEPA 1998).

Few studies directly compare impounded versus natural sites. In South Carolina, Wenner and Beatty (1988) found significant differences in the macrobenthos between a saline impoundment and the adjacent tidal creek. There were also microsite differences between the two locations. McGovern and Wenner (1990) studied recruitment and use by larval and juvenile fish at the same sites as Wenner and Beatty. They found barriers to both ingress and egress and also suggested ways that some of the effect could be mitigated by altering the water management plan. In similar work in Delaware, Stocks and Grassle (2003) report differences between natural and impounded salt marsh sites. They also found reduced abundances and changes in the macrofaunal community during drawdown of the impoundment. They suggest this should be considered if impoundment management objectives include drawdown, such as for shorebird habitat. Rogers et al. (1992) found a significant reduction in marine-transient fish species in impounded sites in Louisiana. In literature reviews it is consistently concluded that water control reduces movement between impounded and open areas (Montague et al. 1987, Rogers et al. 1994, USEPA 1998). Internal habitat may be very favorable for growth of certain organisms, but it does not contribute to the larger population due to lack of mobility. The reviews also note that there is very little data with which to assess this issue.

The mobility issue has been recognized for a long time and partial solutions exist (South Carolina Sea Grant Consortium 1987). Rogers et al. (1992) explicitly address this issue and suggest some site-specific ways to improve management of impoundments for fisheries along the Louisiana coast. They also point out that one complicating problem may be that some marine-transient species are detracted by substantial amounts of submersed vegetation in impoundments. Note the contrast with results reported above for East Coast marshes, suggesting attention to species-specific requirements is needed. The Upper Cooper River Natural Resource Management Plan recommended a demonstration reimpoundment project that includes requirements for, among other things, water control structures that will maintain faunal passage and monitoring so the effects of the project can be assessed (Consensus Solutions 2004).

Avifauna

Most birds in the context of coastal wetland impoundments can be categorized into distinct subcategories based on life history characteristics.

1 | **Land birds**
- *Local residents*
  – breed and/or feed in or near coastal marshes or tidal forests
- *Migrants*
  – mostly passerines that migrate twice annually between neotropical wintering habitat and breed ing grounds in temperate or subarctic locations, using coastal marshes and forests as stopover habitat

2 | **Waterbirds**
- *Waterfowl*
  – permanent residents such as Wood Ducks
  – mostly ducks and geese that winter in coastal marshes
- *Shorebirds and wading birds*
  – Nearctic and Neotropical migrants, some winter here
  – resident colonial waterbirds

Of these categories, the attention of the scientific community and resource managers has focused primarily on waterbirds and Neotropical migrants. Populations of

most species in these groups are declining. Although details of species-specific causes for decline are not known in many cases, anthropogenic habitat degradation or loss is clearly a significant factor. For this reason much of the attention given to birds has been related to understanding physical and biological habitat requirements.

It is worth noting that recognition of the decline in abundance of these birds is not recent. For example, the Savannah National Wildlife Refuge was formed in 1927 as a response to this problem. With the exception of waterfowl, however, little rigorous work was done until recent decades and there is still a large knowledge gap that hinders conservation planning.

Coastal wetland impoundments in South Carolina are significant breeding and feeding habitat for colonial waterbirds (DeSanto et al. 1997, Dodd and Murphy 1997, OCRM 1998) and feeding habitat for some migrating and wintering shorebirds (Boettcher et al. 1995, Weber and Haig 1997). Studies of White Ibises found differential use of coastal wetlands along the salinity gradient. Adults prefer freshwater rice fields and swamps when foraging to feed young birds. Foraging preferences shift to more saline marshes as the young age and eventually fledge (Bildstein et al. 1990, DeSanto et al. 1997). This preference is apparently due to developmental limitations of young birds relative to salt levels in their diet. The preference also may influence breeding success during dry years, when water levels are more impacted in freshwater locations and food supply may be low (Bildstein et al. 1990).

There is evidence that some shorebirds prefer impounded over natural wetlands (Boettcher et al. 1995, Weber and Haig 1996). Reasons include prey availability and consistent water levels. Optimal water level, which varies with species, seems to be especially important. This has critical implications for the management plan, especially since acceptable water level ranges are fairly small (Boettcher et al. 1995, Weber and Haig 1996, Weber and Haig 1997, Collazo et al. 2002). Prey availability is important but the relationship is not clear; more research is needed in this area (Weber and Haig 1997, Weber and Haig 1997). A possible issue is the effects of water level management and circulation on water quality and sediment chemistry. In one study in coastal Louisiana, however, the affected invertebrates were not an important part of the diet of birds feeding in the marshes (Bolduc and Afton 2003).

Marsh bird communities may be sensitive to local land use changes. DeLuca et al. (2004) developed an index of marsh bird community integrity from study sites of varying salinities and land use in the Chesapeake Bay. The index for resident marsh birds suggested they were impacted more by land use at local rather than more distant proximities. This result is interesting in context with GIS models of wetland value along the South Carolina coast described earlier. In those studies intact wetlands near developed land uses were rated higher because of their potential value in reducing the water quality effects of urban runoff (Cockrell 1998, Sharitz et al. 1998). The apparently conflicting result that close proximity of anthropogenic disturbance may increase the importance of wetlands for water quality functions while reducing their importance as habitat for certain avian communities demonstrates both the difficulty of rating natural resources by human values and the importance of wetlands in many positions on the landscape.

Most managed coastal impoundments in South Carolina have winter waterfowl habitat as their primary objective. Many wintering duck species will preferentially utilize managed over unmanaged wetlands (Gordon et al. 1998). The annual cycle of management activities varies depending on the salinities involved (Gordon et al. 1989, SCDNR 1999, Williams et al. 2002). Techniques are well known to manage for both wintering ducks and migrating shorebirds, especially spring migrations. It is frequently stated that impounding can be accomplished in ways that do not negatively impact other biota, particularly fish and macroinvertebrates, but studies thus far suggest otherwise (Rogers et al. 1992, 1994) and the concern is prominently stated by regulatory agencies (USEPA 1998). Bolen (2000) believes that the current trend of managing impoundments for multiple objectives is a trend that will increase in the future, which suggests that more data are needed to help design and implement appropriate plans and structures.

With the population declines of migrating and wintering shorebirds, and the research findings that some species preferentially utilize managed impoundments, a potential justification for reimpounding former rice fields is to provide additional habitat for these birds. Under proper management the impoundments could also be used for wintering waterfowl habitat also. The extent to which the additional habitat would help shorebird populations is unknown and hypothetical at this time, although there is sound reason to infer a benefit of unknown magnitude. The wintering waterfowl habitat justification is problematic because waterfowl populations are depressed in South Carolina and some owners and managers report no ducks in managed impoundments. This suggests that habitat availability is not a constraint for waterfowl in South Carolina. Some owners increase duck usage by planting cereal grains rather than utilizing natural foods. This solution is discouraged for nutritional reasons (Williams et al. 2002).

The larger question exists of just why winter duck populations have declined so significantly in the midwinter waterfowl inventory (MWI) in South Carolina during the last 15-20 years. A frequently heard suggestion is an increasing prevalence of short-stopping along the Atlantic flyway. Short-stopping, which describes the situation of duck migration ending at points north of South Carolina, may have always occurred during warm winters. Some suggest it is increasing because the recent overall moderating trend in winter temperatures results in suitable winter habitat farther north. Short-stopping has been suggested as a cause of altered migration patterns of other bird species along the Atlantic coast (Hestbeck 1995, Viverette et al. 1996), but additional research is needed before the explanation can be accepted.

Another suggestion is that changes in habitat availability throughout the coastal plain have altered patterns of winter residence. Under this explanation there are probably not fewer ducks in South Carolina, but because the MWI counts at the same sites each year, it is not detecting the population redistribution. No one knows for certain what the real situation is, but possible problems with the accuracy of the MWI are not unique to South Carolina. Huesmann (1999) proposed eliminating the MWI along the entire Atlantic flyway because of this concern.

Coastal wetland impoundments are also utilized by migrating passerines (Peterson et al. 1995, Brush et al. 2003, Somershoe and Chandler 2004). There are utilization differences between freshwater and brackish marshes that may be related to marsh structure as manifested in vegetation zonation (Peterson et al. 1995). Freshwater marshes are preferentially utilized by many species (Brush et al. 2003). Somershoe et al. (2004) also found that oak hammocks are preferentially utilized and the utilization increased as size of the hammock increased. In a review of the broader literature of neotropical migrant selection and use of stopover habitat, Petit (2000) found that although migrating birds will use a variety of habitat types (e.g. forest, shrub, savanna), they are more likely to choose habitat that is similar to their breeding habitat. Since many of these species are forest dwellers, he argues for habitat conservation efforts aimed at protecting forests along migration routes. In total these results suggest that the tidal forested wetlands and forest fragments near tidal freshwater wetlands have particular value as stopover habitat for Neotropical migrants.

Numerous bird and habitat conservation programs exist, ranging from the long-established National Wildlife Refuge system to more recent initiatives such as the North American Waterfowl Management Plan (NAWMP) and the South Atlantic Migratory Bird Initiative (SAMBI), all administered by the US Fish and Wildlife Service. Non-governmental organizations also have significant roles in these programs as well as programs they have the lead role in. Examples are National Audubon Society (Important Bird Areas program), Manomet Center for Conservation Sciences (International Shorebird Survey and Western Hemisphere Shorebird Reserve Network), Ducks Unlimited, and The Nature Conservancy. Many of these have interests that intersect with landscape initiatives such as those of the ACE Basin Task Force. Bird science and conservation is an international effort and one that requires many partners from government, the non-profit sector, and private landowners. To maximize the benefit of research or management activities in South Carolina it is necessary to coordinate the work within these larger partnerships.

IV. DISCUSSION

Biogeochemistry

Water column and sediment chemistry are linked by both physical and biological processes. Physical processes include the tidal cycle and sediment deposition and resuspension. Biological processes include uptake and release by growth, respiration, and death of plants and animals. Substances such as nutrients and some metals are beneficial to biota, while contaminants can degrade or extirpate aquatic populations. Once within biomass, contaminants can move to higher trophic levels and eventually have negative effects on migratory fish and land animals including humans.

Sediment and water column biochemistry is controlled in large part by salinity, pH, sediment properties, temperature, redox potential, and sunlight (Moran et al. 1999, Merrill and Cornwell 2000). A great deal of work in this area has been accomplished in salt marshes but much less so in freshwater and brackish marshes. A limited amount of work has been done in saline impounded wetlands. Generalizations about the effects of impounding on wetlands based on limited studies include increased temperature and salinity, decreased dissolved oxygen and sediment redox potential, and increased mobilization of contaminants, metals, and nutrients (USEPA 1998). These all have potentially negative consequences if the impoundment exchanges water with the adjacent estuary and for animals that feed on impounded communities (Winger et al. 2000, Winger and Lasier 2004).

Research suggests that tidal wetlands along the Cooper River import oxidized inorganic nutrients and export reduced forms (Alford 2000, Saropraygoi 2001). In a model of Cooper River oxygen dynamics, Conrads et al. (2002) found reduced dissolved oxygen levels downstream from rice fields during ebb flow. In longitudinal sampling of the East Branch of the Cooper River during August 2001, depressed dissolved oxygen concentrations were measured adjacent to rice fields (David Whitaker, unpublished data). Together these findings suggest that oxygen is consumed in highly productive rice fields, probably by a combination of respiration and microbial decomposition of detritus and dissolved organic matter. Additional research is currently in progress to further assess this issue.

Studies have been done to evaluate sediment phosphorus dynamics in Cooper River wetlands both along the salinity gradient and within successional stages of tidal freshwater marshes. In sediment from freshwater sites, Huang and Morris (2003) found increasing concentrations of organic matter and decreasing concentrations of phosphate along the sub- to inter-tidal gradient. They concluded most phosphorus needed for macrophyte growth was obtained from desorption of sediment-bound phosphate in the subtidal habitat and by microbial mineralization of sediment organic matter in the intertidal site. They hypothesized a positive feedback loop in which increasing sediment organic content causes successional changes in the plant community that induces further sediment organic accumulation. Sediment organic content as a determinant of habitat suitability for aquatic macrophytes has been observed elsewhere (see Barko and Smart [1986]). Additional work is needed to understand the hydrogeophysical and biochemical determinants of nutrient dynamics in the river/tidal impoundment complexes of South Carolina (Davis and Brinson 1980, Chambers and Odum 1990, Merrill and Cornwell 2000, Madsen and Cedergreen 2002).

Resource management and integrative issues

In its simplest abstraction, natural resource management is a synthesis of science and public policy to create and execute the objectives of the policy. Science is concerned with utilizing protocols and tools to provide objective assessments of natural and human systems. Public policy is concerned with setting broad courses of action for one or more public and/or private institutions. Ideally it integrates science with all other sources of information using a weighting scheme for each source that is dependent on the specific situation.

The discussion thus far has emphasized the various scientific and science-based resource management perspectives that are relevant to coastal wetland impoundments such as salinity regimes, macrophyte communities, and waterfowl management. There is also a strong human factors dimension that can directly influence resource management decisions

and has a role in determining what issues to address with funding for scientific research. Human factors are a broad spectrum of concerns, a short list of which includes personal health, livelihood, educational opportunities, natural resource protection, aesthetics, security, and political and economic influence. One or more of these are manifest in all significant, and many relatively small, decisions about public policy development and/or its implementation. Some consideration of them is necessary, at least to provide examples of how they interact with science and resource management in a discussion of coastal wetland impoundments. The information in this section comes from published sources and conversations with public and private individuals.

Cooper River

The confluence of science, resource management, and human factors is clearly seen in many locations along coastal South Carolina. One example is the recently completed development of a natural resource management plan for the upper Cooper River (Consensus Solutions 2004). The Cooper River has undergone significant hydrologic alteration twice since 1940, with the result that the rice fields along the river are experiencing water levels and hydroperiods completely unlike conditions when they were constructed (Kjerfve and Magill 1990). The Cooper River corridor is also under intense pressure as increased population and industrial development move up the river from Charleston. These factors increase the potential for pollution problems as well as loss of riverine and upland wildlife habitat.

Encouraging regional economic growth while controlling for potential health problems and the loss of natural resources, quality of life, and historical sites led to the initiation of a special area management plan (SAMP) process of which the NRMP is a part. A stakeholder group of business, resource managers, government, scientists, and environmental organizations met for a year to develop the plan. The plan addresses many aspects of the upper Cooper River corridor, including the rice fields as a prominent feature. One of the recommendations of the group was to reimpound a breached field as a demonstration project, which should include substantial before and after monitoring to determine what effect the reimpoundment has on water quality, aquatic fauna, etc. This project reflects the widely held view along the coast that some reimpounding should be permitted.

The Cooper River and greater Charleston Harbor region were the focus of an earlier SAMP that both funded research concerning Cooper River rice fields and made recommendations for further research (OCRM 2000), some of which is currently in progress. The research is motivated by both the need to better understand rice-field ecology and a desire to recognize and protect the historic, recreational, and cultural significance of the fields to the region. One aspect of this is the potential for loss of uplands to urban expansion. During the development of the NRMP (and unrelated to it), a significant tract of land and rice fields was sold. Although it ultimately went to SCDNR, there was concern that it might be sold to a developer. This concern is echoed all along the coast, as population increases fuel the need for more housing and commercial development, which tends to disproportionately go toward rivers and marshes for aesthetic reasons. There is a belief among some people that allowing landowners greater control over the rice fields would be an incentive to prevent development of the adjacent upland, possibly putting it under a conservation easement, rather than sell to the highest bidder, generally a development interest.

For a decade or more the Cooper River has also been the target of efforts to improve dissolved oxygen conditions. Past efforts looked at a subset of known sources of oxygen-demanding material and there were concerns about the simulation models that were used. An effort is currently in progress to develop a new simulation model. The larger project includes significant new sampling, with some sample stations in rice fields. The purpose is to estimate the effect rice fields have on instream oxygen directly with fluxes of dissolved oxygen and over time by fluxes of oxygen-demanding substances such as organic material. This will complement related research conducted by the University of South Carolina and The Citadel to quantify fluxes and estimate the effects of marsh succession on river water quality.

IV. DISCUSSION

Savannah River

Another example is the Savannah River estuary, which has approximately 8000 ac of former rice fields on the South Carolina side of the river (Tompkins 1987). Anthropogenic change to the estuary includes upstream flow modification, harbor deepening, and channel modification. Some of these changes had specific, quantifiable impacts on the tidal freshwater and brackish marsh communities in the estuary that, among other things, caused significant alteration of habitat in the Savannah National Wildlife Refuge (Pearlstine et al. 1993). Many residents and visitors consider these changes negative, as are the prospects of further habitat alteration caused by more dredging (greater salt water intrusion and loss of habitat to dredge spoil areas) and ongoing concerns for potential environmental health problems from dredge spoil sites adjacent to the river (mosquitoes, contaminant mobilization).

As a result of the past habitat alteration, the US Army Corps of Engineers is working with scientists, resource managers, regulators, and environmental organizations "to identify and implement restoration measures in the Savannah River Estuary (USFWS 2004)." Several actions have been identified and prioritized with respect to restoration value and financial constraints. Action is expected toward restoring several meanders and cutoffs in the river and managing upstream impoundment releases to provide optimal seasonal flows, when possible.

The location of dredge spoil areas are determined in part by the cost associated with getting spoil to the site, so they are generally close to the river. This represents loss of habitat along the river and the areas become a breeding ground for particularly noxious species of mosquitoes during the drying phase of spoil management. The increased potential for health problems such as West Nile Virus can be controlled to some extent through spraying, but that increases the quantity of potentially toxic chemicals in the environment. These chemicals as well as contaminants potentially mobilized by dredging and spoil area management increase the likelihood that higher trophic levels will be affected due to bioaccumulation (Winger et al. 2000). Recent analyses of sediments in the Savannah National Wildlife Refuge suggest there also may be some legacy contamination (Winger and Lasier 2004).

There is also a proposal to further deepen the Savannah Harbor. An environmental impact statement is in preparation that is being drafted with the assistance of a diverse stakeholder group. As part of the process a significant body of research is being done that will integrate past studies with new field and modeling work to estimate the ecological effects of the proposal and determine if they can be mitigated. One of the primary concerns is the effect of deepening on the tidal marshes (former rice fields) in the Savannah National Wildlife Refuge.

The Savannah River is also one of the rivers in the Sustainable Rivers Project, a partnership between The Nature Conservancy and the US Army Corps of Engineers (http://nature.org/success/dams.html). Under the project objectives "the two organizations will work together to improve dam operations, helping to restore and protect the health of rivers and surrounding natural areas while continuing to meet human needs for services such as flood control and power generation." It was during work on this project that the need was identified to reestablish optimal flows for, among other things, estuarine marshes.

ACE Basin

A third example is the ACE Basin. As mentioned at the beginning of this report, this is a location where a large part of the focus is on preventing anthropogenic degradation to a relatively undeveloped area rather than mitigating existing problems (CSC 2000). The ACE Basin is under overall administration of SCDNR. The ACE Basin Task Force, however, and the larger group of supporters include members from government at all levels, academia including the extension service, nonprofit organizations, and private landowners. The area includes a National Wildlife Refuge, state Wildlife Management Areas, and a National Estuarine Research Reserve. Total lands protected, primarily by conservation easements, exceed 100,000 ac. Those involved with the ACE Basin say there has been an accumulative effect where the more conservation easements there are, the more attractive the idea becomes for other landowners, which increases their interest in doing the same.

The Edisto River, one of the three forming the ACE Basin, has itself been the subject of a watershed-based

stakeholder planning process (Marshall 1993, SCDNR 1996). Called the Edisto River Basin Project, the effort had sustainable development in the watershed as its explicit goal. Among the activities of the initial project was an inventory of the ecological, recreational, and cultural resources and development of guidelines for promoting development that will not destroy these assets. In the first two examples in this section, the Cooper and Savannah Rivers, upstream modifications were identified as important causes of their present condition. The ACE Basin should be protected from this impact in its main river if the long-term objectives of the Edisto River Basin Project are met.

Importance of scale

These three brief examples clearly demonstrate the variety of contexts that include consideration of coastal wetland impoundments. There are at least four spatial scales that are relevant.

1 | **Site** – Issues are the biotic and abiotic conditions and processes within a given wetland. This depends primarily on whether or not it is diked and managed or open, its target species if managed, its annual management plan, elevation relative to tidal flows, and salinity.

2 | **Estuary** – Issues are the characteristics of wetland exchange with the immediate river and other estuarine subsystems. Exchanges can be either biotic or abiotic and key concerns are magnitude and timing.

3 | **River basin or watershed** – Coastal wetland impoundments are significantly affected by what happens both upstream and in upland areas near the wetland. Abiotic influences such as hydrology and sediment and chemical transport and their impacts on estuarine marshes are the primary concern.

4 | **Regional** – Coastal wetland impoundments serve as nursery, foraging habitat, permanent or seasonal residence, or migration stopover for many species of fish and birds. Issues are habitat suitability, habitat quantity, and multi-species management.

These scales are not discrete. There can be, for example, micro-site questions and "regional" can be anything from the seasonal foraging range of a species up to the entire coastal ocean (fish) or flyway (birds). There are also imbedded temporal scales depending on the species, communities, or ecosystems of concern.

With the exception of birds (waterfowl and neotropical migrants), most of the questions relevant to coastal impoundments in South Carolina that have been studied by the scientific community have focused on site and estuary scales. The few basin scale efforts include work on the Savannah, Cooper, and ACE Basin/Edisto Rivers, but those are largely qualitative with respect to impoundments because of lack of data. Yet it is clear from what is known about the ecological, socioeconomic, and regulatory contexts of impoundment management that larger spatial views are necessary to provide a basis for sound policy and resource management decisions. Large-scale efforts must overcome enormous practical, scientific, and institutional challenges (Imperial and Hennessey 1996, Imperial 1999, Davis 2004), but to accommodate the level of decision-making that is necessary the work must be started.

An alternative spatial delineation is to simply refer to sites and landscapes. Landscape boundaries are typically defined as the area (scale) needed to address the process(es) or phenomena under consideration, with the explicit recognition that it spans multiple ecosystems (Sanderson and Harris 2000). A landscape perspective specifically addresses issues of fluxes and dependencies among ecosystems.

A difficulty with many natural and social science studies is that they are not performed at scales, nor do they measure processes, that make them easily integrable and thus useful for natural resource policy development and management. Vogt et al. (2002) recently summarized the significant hurdles and potential for utilizing a landscape approach for the needed integration in a resource management context. They show that most social systems which are relevant to resource management have scale-dependencies analogous to ecological systems. They then argue that landscape conceptualizations facilitate identifying both compatible scales and scale mismatches among social and ecological systems with respect to critical resource management issues. This provides a structure for putting the appropriate resource (human and research) into problem resolution and decision-making.

It is not a concern here whether or not this or another model is adopted. The critical thought is that coastal wetland impoundments are not isolated ecological entities. They constitute a complex resource management issue that is best approached within a multi-scale ecological and social decision-making conceptual framework. There are several potential approaches; the important thing is to get started.

V. SUMMARY OF ACTIVE RESEARCH AND NEW RECOMMENDATIONS

"Few politicians, planners, or scientists have been trained with, or have developed, a truly holistic perspective." (*Odum 1982*)

One objective of this report was to provide a sound basis for understanding the current state of our knowledge of coastal wetland impoundments in South Carolina. It started from a baseline of the major work from the early- to mid-1980s, including the tidal marsh reports of Odum et al. (1984), Odum (1988), and the Cat Island work at the Santee Coastal Reserve (DeVoe and Baughman 1987, 1987). In Section II the report summarized research completed since the mid-1980s in coastal wetland impoundments in South Carolina and Georgia. In Section III the report summarized prior research recommendations and provided a sense of the status of work relative to those recommendations. Then in Section IV the report integrated the South Carolina and Georgia research with the larger body of research in tidal marshes along the mid-Atlantic and Gulf coasts. It also provided some context for how these resources fit into the sociopolitical landscape.

Science and resource management are not static disciplines. There is nearly always activity on some aspect that looks either directly or indirectly at coastal wetland impoundments. This section will provide a brief summary of that work. Knowing what has been done and work that is currently in progress will provide context from which to make recommendations for future work. The first several projects are taking place in a single estuary. The rest are broad in scope in the sense that their study sites are in more than one estuary. This list is compiled primarily from conversations with researchers and may not be complete. Following the summary of current research are recommendations for future projects in research, resource management, and outreach.

Current research activities

Some judgment enters into the decision of what constitutes "indirect" research. As one example, an ambient water quality monitoring station in a coastal river or tidal creek downstream from some impoundments is an important research resource because the data may one day be useful in various studies, such as the integrated effects of several impoundment management options. In most cases that is not the reason the station was placed there and so it is not included here.

Ogeechee River, GA – Clark Alexander's team at the Skidaway Institute of Oceanography is still monitoring the Tucker mitigation site for water quality and vegetation dynamics. This is a 10-year study (1996-2004 so far), from which they hope to be able to address the character and rate of natural recovery of diked systems. Initial results were summarized earlier in this report (Cotton 2004).

Savannah River – There are continuing studies of marsh macrophyte communities along the salinity gradient. The work is being coordinated by Wiley Kitchens with the Cooperative Fish and Wildlife Research Unit at the University of Florida. Specific activities include competition studies, marsh succession modeling, and continuous monitoring. Reports and publications based on this work were summarized earlier in this report. Some of the data collected for this work are being used by Paul Conrads (USGS, Columbia) to develop and test a model that predicts salinity and water level in marshes in the SNWR based on predicted flows and salinity in the Savannah River. The river prediction model is being developed as part of work on a TMDL for dissolved oxygen. Finally, The Nature Conservancy and the Army Corps of Engineers are continuing to work on options for marsh restoration. They recently developed a list of ecological indicators that will be used to monitor marsh ecosystem health.

Combahee River – The Nemours Wildlife Foundation owns approximately 2500 ac of former rice fields, both

managed and breached. Ernie Wiggers will soon begin work on a 2-year study to compare Clapper Rail nesting success between the two types of marshes. Study sites are at the Foundation and the ACE Basin NWR.

Cooper River – Joe Kelley at The Citadel is obtaining field measurements of sediment accumulation rates in the major vegetation/elevation successional states, including within-community variability. A team at the University of South Carolina led by Dan Tufford is collecting water quality and related data in three rice fields which will be used to assess site-specific and successional state exchanges with the river. The sediment accumulation and water quality data will also be utilized to develop a simulation model of marsh succession that will provide estimates of the effects of ongoing succession on river exchanges. Tetra Tech, Inc. is collecting field data to support development of a water quality model of the Cooper River as part of the implementation of a TMDL for dissolved oxygen. There will be a marsh exchange component in the model. The Upper Cooper River NRMP includes a recommendation for a pilot marsh reimpoundment project. Initial planning was scheduled to begin in early 2005. There is also a federal relicensing process underway for the Santee-Cooper project at Lakes Moultrie and Marion. Consideration of flows in the Cooper River is part of the process.

Santee River – The Nature Conservancy is nearly complete with a project looking at vegetation change analysis of the tidal marshes in the Santee River delta from 1942 to present. This is the interval during which the salinity front moved well upriver as a result of flow reductions caused by completion of Wilson Dam forming Lake Marion. This study is being done to provide information for the Santee-Cooper relicensing process.

Winyah Bay – John Baden and Richard Stalter are continuing to monitor vegetation along transects in three former rice fields at Hobcaw Barony. They currently have a 35-year record; monitoring occurs 3-4 times per year.

Joe Kelley – Joe is working on a synoptic view of the current successional status of all former rice fields on the South Carolina coast. He is using USGS NAPP and low-altitude photographs to map the wetlands, including the dominant vegetation communities and whether they are managed or open. The goal is to quantitatively estimate ecological functions for all fields, rivers, and estuaries.

William Conner – William has a joint project with USGS examining impacts of disturbance (sea level rise, hurricanes, etc.) on ecological processes of tidal freshwater wetlands in SC and LA. Sites are being established along the Waccamaw, Pee Dee, Savannah, and Sampit Rivers to measure long-term (via tree rings) and short term (via tree bands) tree growth responses, litterfall production, nutrient cycling, hydrology, and salinity. With Clemson support he is continuing the tree growth studies begun by Ratard (2003) and Ozalp (2003), as well as continuing to follow up on the salinity tolerance of seed sources from various areas along the Atlantic and Gulf coasts.

International shorebird survey – This survey has been continuous since 1974 at some locations. Currently part of The Manomet Center for Conservation Sciences, survey sites include 23 along the South Carolina and Georgia coast, many of which are former rice fields. The survey has documented significant declines in the populations of many shorebird species. Brian Harrington is currently obtaining expert opinion to identify the research needs concerning causes of the decline and possible mitigation.

Other bird surveys – Other surveys are the North American Breeding Bird Survey (48 years; http://www.mbr-pwrc.usgs.gov/bbs/bbs.html) and the Christmas Bird Count (104 years; http://www.mbr-pwrc.usgs.gov/bbs/cbc.html). Their domains include coastal wetland impoundments in South Carolina and Georgia. Some scientists are skeptical about using data collected by amateur birders with few if any controls over technique or quality. There is a growing literature, however, on techniques for dealing with these problems. The USGS Patuxent Wildlife Research Center uses these data as one source of information about avian population trends.

Recommendations for future research, resource management, and outreach projects

A substantial amount of research has been done in the last 15-20 years and there is now a great deal more accumulated experience among those who work with some aspect of impoundments. What follows is a list of themes to focus on with future research. It is a distillation of what

V. SUMMARY OF ACTIVE RESEARCH AND NEW RECOMMENDATIONS

has appeared earlier in this report and comments received during conversations with many people, mostly specialists, over the course of the project. The list is at a relatively high level, leaving details of ideas for specific projects to subject-matter experts. Many of these research items are still outstanding from prior recommendations.

1 | There remains a great deal that is unknown about community composition, dynamics, and ecosystem exchange, especially in wetlands at the fresh (including tidal forests) and oligohaline end of the salinity gradient. These issues typically have strong spatial and temporal variability that must be included in study design. The list includes:

- Primary and secondary productivity of phytoplankton and zooplankton, meiofauna and macro invertebrate community composition, and contribution to the impoundment food web
- Fish communities and utilization dynamics
- The effects of invasive macrophyte species on community composition and ecosystem dynamics
- Comparative studies of managed and unmanaged rice fields in the same location

2 | A substantial amount of work has been done with respect to biogeochemical processes and water chemistry, but significant questions are still unanswered. The following are examples of work that is needed especially in fresh and oligohaline wetlands.

- There is a significant body of literature that suggests that some species of submersed aquatic macrophytes can obtain much of their nutrient requirements by transfer across leaf and stem surfaces in addition to root uptake. Knowing the extent to which this occurs and by what species would lead to a better understanding of the interactive effects of water quality, sediment exchanges, nutrient limitation, and macrophyte community composition
- The importance of spatially and temporally variable biochemical exchanges (e.g. inorganic nutrients, dissolved organic matter) to ecosystem functions of the impoundment itself and down stream systems is still largely unknown
- Work is needed to understand the wetland response to interannual variability in climate-related forcing functions such as temperature and streamflow.

3 | A high priority should be a project to develop a quantitative landscape model of estuarine ecosystems. Initial work on the model should focus on functions, values, and exchanges among subsystems. The data requirements for this model can be used to help identify critical research activities in specific subsystems. The model should be designed to address the overarching questions in many discussions of coastal wetland impoundments, which include:

- Their actual ecological value to the larger estuarine system
- The impact of various impoundment manage ment strategies on the functions of the larger estuarine system
- If a management plan is used to enhance the value for one set of target species or functions, what will be lost
- What would the impact be if more freshwater tidal marshes reverted to tidal forests
- What are the thresholds for functional degradation within a coastal wetland impoundment that will cause loss of larger estuarine function or value
- What might be the long term effects of persistent global warming (e.g. different temperature patterns, more invasive plants and animals)

4 | The mapping work currently in progress should be fully integrated into a GIS that includes elevation relative to sea level and other land use/land cover features. This will facilitate its use as a base map for the landscape models and the evaluation of questions such as the effect of urban development and sea-level rise on estuarine functions and values. It is likely this work would benefit from collaborations with existing mapping efforts, for example NERRs, The Nature Conservancy, and C-CAP (http://www.csc.noaa.gov/crs/lca/ccap.html).

5 | Impounded wetland construction and management generate unique questions that require attention. Many impoundment design (e.g. how many trunks and where) and management practices (e.g. related to water exchange rate and timing) are known to be beneficial to target species. There are other aspects of impoundment management about which there is a range of opinion. Some opinions are based on the long experience of expert resource managers and some are not. All need a

more rigorous evaluation. It is possible some of these can be included in related research mentioned in prior recommendations, but if not then targeted projects are needed. Examples include:

- The effects of various management plans on water quality within the impoundment and during exchanges with the river/tidal creek
- The effects of limited ingress/egress for aquatic species on estuarine community dynamics
- Whether or not a trunk that allows full water column exchange and water level control can be designed and effectively implemented
- Whether or not mosquito control protocols can be integrated into all water management plans

6 | There are also some specific questions related to waterbird utilization of coastal wetland impoundments. These are particularly important either for economic reasons or their potential impact on endangered or declining species. Examples are:

- Why winter waterfowl utilization of coastal wetland impoundments has decreased in the last 15-20 years
- To what extent are coastal wetland impoundments a critical habitat for migrating shorebirds
- Would an increase in the number of impoundments managed for waterbirds (especially colonial waterbirds and shorebirds) benefit those populations
- What are the site and landscape determinants of waterfowl utilization of a coastal wetland impoundment

7 | Coastal wetland impoundments, particularly rice era sites, have a strong link to local and state culture and history. There are several things that can be done so that as the living link further separates, the heritage is preserved. Among them are:

- The link is in the memories of people who have family or personal connections to the rice era. Work is being done to collect oral and written histories; this should be encouraged and supported to the greatest extent possible.
- Part of the culture that is embedded in former rice fields is the connection to life on the rural coast. As development encroaches the rural aspect is being lost. Conservation easements are the dominant method for ensuring land protection while maintaining private ownership. Outreach efforts need to continue raising awareness of easements as well as determine if current objections to easements on the part of some landowners can be addressed legislatively or in some other way.
- Also in recognition of the historical and cultural significance of the rice era, restoration of a working rice plantation, even if on a small scale, should be a high priority. A natural choice for this is Brookgreen Gardens; there may be a justification for additional sites further south.

VI. CONCLUSION

"I have tried to preserve, through my paintings and the simple, straight-forward account of one who knew it well, a phase of daily human endeavor —the life of a rice plantation of the Fifties."
(p. xii, Smith and Sas 1936)

The overarching objective of this report was to assist with the construction of a framework for assessing policy and management questions concerning coastal wetland impoundments in South Carolina. A great deal more is known today than when this issue was last addressed almost 20 years ago. Coastal wetland impoundments are significant features of the coastal landscape, which raises many questions about their ecology and management that are an important part of this assessment. This report has developed several conceptual themes about features that coastal wetland impoundments share and significant differences among them. Commonalities include:

- Most are in or near the estuary of large coastal rivers,
- Most were originally constructed for agricultural planting or as freshwater reservoirs for agricultural fields,
- Of those not constructed for agricultural purposes, most were constructed as habitat for migrating and wintering waterfowl,
- They occur along salinity and hydrologic gradients that determine habitat suitability for individual species and biotic communities,
- The habitats and habitat utilization are dynamic both seasonally and over longer temporal scales as a result of natural and anthropogenic forces, and
- Most coastal wetland impoundments figure prominently in the historic, socioeconomic, and natural landscapes in which they occur.

As an integrated whole these statements lead immediately to recognition of the potential for differences. Among these differences are:

- The hydrography and hydrology are different for each coastal river system, which causes differences in hydrologic and biogeochemical zonation that affect coastal wetland impoundments,
- Each estuary is different due to variations in coastal morphology and freshwater input,
- The proportion of open versus closed impoundments, the total areal extent, and extents along the salinity gradient vary among rivers, which means the dynamic relationship is also different,
- Historical anthropogenic alteration and current stresses vary among systems.

Commonalities tend to make policy development more straightforward. They support a single solution approach to managing a resource. The approach has the sociopolitical benefit of appearing to treat everyone the same during permitting decisions. In the present context this perspective tends to minimize the policy-relevance of substantive local and landscape level differences among sites. Differences tend to complicate policy development because they suggest that a sound decision in one location may not be good for another. Several resource managers have directly or indirectly emphasized that there are differences in various impoundment management strategies that are not easy to discern. The research behind this report supports that assertion. This suggests that flexibility is needed as regulatory agencies think about how to manage these resources. Also that research to find answers to critical questions should be a high priority. There are analogous issues with respect to breached former impoundments, including the most basic question of whether they should be managed at all.

It is certain that coastal wetland impoundments are important ecosystems for many organisms, small and large, with implications that range from local recreation to species survival on an inter-continental scale. Relevant time scales are seasonal, annual, and more, but beyond annual they do not fit neatly into human perspectives. The human perspective about which we are certain is that coastal wetland impoundments have an important place in both the cultural history and current economy of South Carolina. This means that policy decisions will be about much more than just ecology. It also means that both policy development and resource management should be adaptive, which requires an ongoing commitment to a greater understanding of the ecological processes, values, and functions of these resources.

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