**NOAA Technical Memorandum NOS-NCCOS-CCEHBR-0008**

# Literature Review for a Resource Characterization of Cape Romain National Wildlife Refuge

**Laura M. Kracker**

Charleston, South Carolina
July 2003

**U.S. Department of Commerce**
**NOAA** National Oceanic and Atmospheric Administration
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Phone: 301-713-3020
Fax: 301-713-4353
E-mail: nccos@noaa.gov
Web: www.nccos.noaa.gov

*Cover: Bull Island in Cape Romain National Wildlife Refuge*

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National Centers for Coastal Ocean Science
Center for Coastal Environmental Health and Biomolecular Research
219 Fort Johnson Road
Charleston, South Carolina 29412-9110

Laura M. Kracker

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U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Conrad C. Lautenbacher, Jr., Under Secretary for Oceans and Atmosphere

NATIONAL OCEAN SERVICE
Richard W. Spinrad, Assistant Administrator for Ocean and Coastal Zone Management

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TABLE OF CONTENTS

# EXECUTIVE SUMMARY

Through research aimed at understanding the coastal environment, surveys designed to help manage the resource, and national programs to monitor environmental condition, we see a picture of a dynamic ecosystem that is Cape Romain National Wildlife Refuge (CRNWR). Currently, there are efforts underway to protect threatened species; monitor fish populations; and quantify the biological, physical, and chemical characteristics of this environment. The potential impacts to this system are just now being understood as ecological responses to human modification are observed and explained. As a starting point, this document compiles existing information about Cape Romain NWR in five topic areas and addresses the potential impacts to the Refuge.

This review is intended to serve as a stepping stone to developing a research agenda in support of management of the Refuge. There are various sources of information on which to build a framework for monitoring conditions and detecting change to this environment. For instance, information on basic ecological function in estuarine environments has evolved over several decades. Long-term surveys of Southeast fisheries exist, as well as shellfish and sediment contaminants data from estuaries. Environmental monitoring and biological surveys at the Refuge continue. Recently, studies that examine the impacts to similar coastal habitats have been undertaken. This document puts past studies and ongoing work in context for Refuge managers and researchers.

This report recommends that the next phase of this resource characterization focus on:

- compiling relevant tabular and spatial data, as identified here, into a Geographic Information System (GIS) framework
- assessing the abundance and diversity of fisheries utilizing CRNWR
- delineating additional data layers, such as intertidal habitats and subtidal clam beds, from low-level aerial photography, hard copy maps, and other sources
- continued inventories of plant and animal species dependent on the Refuge
- monitoring physical and chemical environmental parameters using the methodology employed at National Estuarine Research Reserve System (NERRS) and other coastal sites, where appropriate
- further definition of the potential risks to the Refuge and preparing responses to likely impacts.

# I. INTRODUCTION

This document is a review of studies and information related to the resources and potential impacts on those resources at Cape Romain National Wildlife Refuge (CRNWR). This work was conducted by National Oceanic and Atmospheric Administration, National Ocean Service (NOS) in cooperation with US Fish and Wildlife Service (USFWS) Cape Romain NWR and USFWS Coastal Ecosystem Program (CEP). The objective of this task was to synthesize available knowledge from existing literature and ongoing research. This task will contribute to the larger goal of characterizing the resources at the Refuge and determining the best approach to assess and deter impacts to this environment.

The issues facing coastal environments occur around the globe. Therefore, extensive literature exists that is potentially applicable to the Cape Romain area. This effort summarizes information applicable to the function of the Cape Romain ecosystem, including site-specific studies, to assist resource managers in addressing concerns evident at a regional/local scale.

This literature review focuses on descriptive, quantitative, and spatial information on species and resource conditions at Cape Romain in five broad topic areas:

- the intertidal environment,
- sediment characteristics and geomorphology,
- contaminants in air, water, and sediment,
- nearshore and offshore fisheries, and
- inventories of terrestrial plants and animals

A synopsis of relevant literature and available data in each of these areas is provided. Information on potential risks and assessment tools is also included.

The approach used to organize and present this information is outlined here:
I. Identify sources of information about resources and ecological processes at Cape Romain NWR. In each topic area:

- provide a general overview
- summarize the most relevant and/or representative studies
- identify available databases
- give a synopsis of how the available information contributes to a better understanding of the role of the Refuge as an important ecosystem component
- list additional sources of information for evaluating various aspects of environmental condition.

II. Given what is known about the study area, what else needs to be known and what methodologies can be employed to assess potential impacts? This is accomplished by reviewing the literature on potential impacts and methods for quantifying resources and assessing risk. (This task should be further developed in the next phase of the project as objectives and areas for future study are defined by the community).

## A. Processes in Coastal Environments: An Overview

In its simplest form, the primary components of the Cape Romain ecosystem are air, water, biota, sediment, and substrate. The interaction between physical oceanographic tidal processes and organic and inorganic sediments create a complex ecosystem in which biota are uniquely adapted to survive and take advantage of conditions at the land-water interface. The highly productive nature of these systems suggest that they play a unique and dynamic role in coastal and marine environments.

Cape Romain NWR is a complex system of barrier islands, open embayments, and marshes located along the South Carolina coast, from Cape Island at the north end to Bull Island at the south end. The Refuge can be examined in terms of the range of physical and hydrological conditions that define coastal environments. Cape Romain NWR is a tidally influenced coastal environment dominated by salt marsh, barrier islands, and open bays. Tidal inputs to this area are more dominant than freshwater input (Jackson 1993), resulting in relatively high salinity. The tidal creeks that traverse the salt marshes include the Romain River, Harbor River, Five Fathom Creek, and Bull Creek.

The geomorphological processes occurring at the land-water interface drive a dynamic, living process. The barrier islands are continually shifting as sediments accrete and erode from adjacent headlands, beaches, and shelf deposits. In general, the barrier islands migrate southward through a process of erosion at the northern end and deposition at the southern tip. Tides, wind and waves play a major role in reshaping these islands. The alongshore currents are from north to south. The physical characteristics of the islands, bays, inlets, and the type of sediments are indicative of the forces at work here.

The northern half of Cape Romain National Wildlife Refuge is part of the Santee River complex. At one time, this delta complex provided a greater supply of sediments to the barrier islands than is observed today. In 1942, the Santee River was diverted into the Cooper River, reducing flow and sedimentation to this area and accelerating the rate of erosion. This had a pronounced effect on the Santee delta complex (Brown 1977). Although the Santee River was rediverted in 1985, rates of deposition probably remain lower than historic conditions due to the damming of upland waters (Jackson 1993). The degree to which these hydrologic changes have affected the Refuge remains undetermined (Wood pers. comm, Jackson 1993).

*Battle's account of a 1890-1891 survey comments on the influence of the Santee River to this area: "Referring again to the yellow tinge of mud found in all the waters between Sullivan Island and Bull Bay, including the latter, it is a noteworthy fact that as the steamer Fish Hawk proceeded up this coast from Bull Bay to Winyah Bay the water was thick and yellow all along the coast, close to shore, the yellowish tinge growing fainter off shore until it merged gradually and imperceptibly into the green seawater....This was caused by the immense volume of fresh and muddy water discharged through the mouth of the Santee River and through the inlet of Winyah Bay, and which is undoubtedly an important factor in the discoloration of the water for many miles south...(Battle 1892 p.325)."*

An important aspect regarding production and consumption in the marsh-estuarine ecosystem is that primary producers (Spartina) are not directly consumed by grazers but rather decomposed by diverse aerobic and anaerobic bacteria and converted to energy for direct or secondary consumption by higher trophic levels (Pomeroy and Wiegert 1980, Bahr and Lanier 1981). Decomposers provide the link between this primary food source and higher trophic levels. Availability of detritus year round, combined with seasonal primary productivity, supports diverse use by resident and transitory species in the marsh (Vernberg 1996).

The extensive salt marshes protected by the barrier islands; maritime forests responding to salt spray, winds, shifting sands, and extreme meteorological events; and the interplay of tidal creeks, mud flats and benthic organisms make this a complex system.

## B. Spatial Data

Basic information on the features of CRNWR can be mapped and quantified to better understand the physical, biological, and chemical components of this ecosystem. Information about landscape characteristics can be interpreted from low-level aerial photographs recently flown over CRNWR (USFWS CEP). The extent of salt marsh, upland, beaches, and tidal creeks can be delineated according to a variety of standard classification systems (eg. Cowardin et al 1979), a modification of existing systems (eg. South Carolina Department of Natural Resources (SCDNR) - wetlands plus upland classes), or a site-specific classification that addresses habitats and management needs (eg. Florida Department of Environmental Protection (FLDEP) - benthic habitats). General spatial environmental data on characteristics such as bathymetry, wetlands, soils, and land use is available from various federal (eg. National Wetland Inventory (NWI) and US Geological Survey (USGS)), state (eg. South Carolina Department of Health and Environmental Control (SCDHEC), SCDNR) and local agencies. This information is accessible on a regional or state level. Historic images of the landscape captured through aerial photography, charts, and satellite sensors are another potential source of environmental data. Issues of accuracy, time frame, level of detail, as well as data processing and format must be examined for each data layer. Metadata is necessary to manage spatial data and retain information that can address these issues. The classification of color infra red aerial photography, along with the spatial extent of pertinent studies identified in this review, can be incorporated into a Geographic Information System (GIS).

# II. SALT MARSHES AND INTERTIDAL HABITATS

## A. Overview

The ecology of intertidal areas has been described in several relevant works over the last century (Vernberg 1996, Bahr and Lanier 1981, and others are reviewed in this section). By mapping wetlands and intertidal flats, as well as the distribution of organisms that utilize this environment, we can quantify and detect changes in the resource.

The intertidal area of CRNWR is recognized as a highly productive shellfish area (Bahr and Lanier 1981). Efforts to delineate intertidal oyster reefs date back to surveys by Battle in 1892 and were also conducted in the 1980's by SCDNR (Anderson and Cohen pers comm). SCDHEC is responsible for monitoring and classifying harvest growing area waters and maintain these data in a GIS. In addition, the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR) is developing a national database of shellfish classification areas (Shellfish Information Management System (SIMS)) to assess shellfish resources nationally.

## B. Relevant Studies

| Reference | Vernberg 1996 |
|---|---|
| Ecology of Southeastern Salt Marshes | |

Summary: An extensive body of scientific observation exists for a pristine inlet in South Carolina. North Inlet, in Georgetown County, has been the site of numerous studies documenting biological, physical, and chemical processes in an estuarine ecosystem (Vernberg et al. 1996). Vernberg identifies four unique characteristics of **salt marshes**: 1) mudflat-marsh-scrub transition from sea to land 2) low diversity in genera of salt marsh vegetation 3) drainage creeks and rivers that bisect the marsh and 4) the dependence on silt and protection from wave action to allow sedimentation to occur. The balance between sedimentation rates and sea-level rise or inundation is necessary in maintaining coastal marshes. Sediment size and type play a role in determining rates of transport, erosion, accretion, and subsidence; the affinity of chemicals to sediments; and oxygen levels. While rates of sediment deposition and sea level rise are important for marshes to persist, measurements of deposition rates vary greatly given local techniques and the difficulty of measuring fine scale changes in tidal creeks.

Variation in physical factors such as circulation patterns, tides, and winds influences the distribution of biota, chemicals, sediment, temperature, and nutrients. For instance, anomalies in sea-level alter the productivity rates for Spartina and impact related species by increasing habitat and refuge for dependent species (Morris et al. 1990). In marsh ecosystems, phytoplankton, epibenthic algae, attached macrophytes, and vascular plants are the primary producers, with Spartina being the most important in North Inlet, SC. However, "bacterially rich detritus" is probably the most important food source in estuarine systems. Salt marshes are highly productive systems and many oceanic and commercially important species are dependent on estuaries for some portion of their life cycle.

Significance: Information from North Inlet studies that address how the function of undisturbed coastal ecosystems provide a basis for understanding natural variation and the biotic and abiotic factors controlling ecological processes. Impacts to coastal ecosystems can only be understood in the context of how such systems should function.

| Reference | Wenner date unknown |
|---|---|
| The Importance of Estuarine Shallows | |

Summary: This document provides a very good overview of function, use, and components of estuarine systems. These "living spaces"and their functions are described. "Living spaces" in **estuarine shallows** include: 1) oyster bars; 2)intertidal marsh; 3) shallow tidal creeks; 4)intertidal creeks and 5) shallow bays and their mud flats.

Significance: The "living spaces" approach could be useful in delineating intertidal habitats by incorporating functional roles of each unit for classification and spatial analysis.

| Reference | Peterson and Peterson 1979 |
|---|---|
| The Ecology of Intertidal Flats of North Carolina: A Community Profile | |

Summary: Important functions of **intertidal flats** include recycling of nutrients, providing benthic habitat, and acting as a sediment trap as nutrients from other environments are deposited into intertidal areas. Mineralization of detritus is a driving force in intertidal ecosystem function. Estuarine food webs are differentiated from terrestrial food webs by the "variety of top predators which exist at the ends of largely detrital-based food chains on the mud and sand flats of estuarine systems (p 18)." In these intertidal flats, the fauna are dominated by oyster beds and all stages of fishes dependent on intertidal habitat (see also Bahr and Lanier 1981). A list of fish species utilizing North Carolina intertidal flats, as well as fishes and birds that feed on prey utilizing these flats, are included in this document.

Significance: This reference provides an excellent discussion of intertidal flats as habitat. It is based primarily in North Carolina but cites several studies from South Carolina. This information is useful for determining overlap and extent of species utilizing intertidal habitats in the Carolinas and should be studied in conjunction with species distribution from trawl and trap data along the South Carolina coast.

| Reference | Bahr and Lanier 1981 |
|---|---|
| The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile | |

Summary: The oyster reefs of South Carolina are the most extensive reefs along the southeast coast. Hydrography, freshwater inputs, and circulation patterns are important in determining sedimentation patterns, turbidity, temperature, and nutrient conditions. The surface area of substrate is 50 times the areal extent of oyster reefs. This **reef habitat** supports many species of macrofauna. This document provides information on organisms associated with reefs including oyster commensals, insects, mud crabs, mussels, polychaetes, and amphipoda (as reported by Dame 1979). Predation on reefs by other organisms include a diverse community of resident benthic consumers, aquatic organisms that feed during flood times, and terrestrial animals. These include blue crabs, drum, racoons, grackles, and oystercatchers. Physiographic conditions and predation are the most important determinants of distribution of oyster bars. In turn, oyster reefs impact the characteristics of their immediate environment by modifying the velocity of water, thereby affecting sedimentation patterns.

The distribution of reefs within the tidal zone is influenced by wave energy and current regimes within tidal creeks. Reefs often exist at the concave edge of meandering creeks, near tributaries, and at the confluence of streams. An overall decline in oyster reefs is reported for the time period from 1889 to 1977 although the same general location of reefs is noted. In South Carolina, some reasons for decline are suggested, such as natural successional changes in temperature, salinity or sea-level, and anthropogenic causes such as “dredging, waterway construction, pollution, or overharvesting (p. 61).”

From a management perspective, “ because oysters in reefs apparently live close to their stress tolerance threshold, further perturbation by man can easily destroy the entire reef community (p 81).” Destruction of the marsh water interface, dredging or other activities that increase sediment load, and chemical contaminants can be expected to adversely affect oyster reefs.

Significance: This document identifies important ecological characteristics in the context of human-induced threats to oysters. Changes in the actual harvest of oysters and reasons for decline are provided. Basic information is provided on oyster reef ecology that could be incorporated into models that address reef distribution, potential stressors, and suitable areas for restoration.

| Reference | Coen et al 1999 |
|---|---|
| The Role of Oyster Reefs as Essential Fish Habitat: A Review of Current Knowledge and Some New Perspectives | |

Summary: This paper focuses on 1) the **role of oyster reefs** in ecosystem level processes and essential fish habitat, 2) finfish assemblages associated with reefs, and 3) the current state of knowledge and research needs regarding the functional relationships between oyster reefs and other ecosystem components. In addition, parallels with artificial reefs are drawn. Characteristics such as reef height, interstitial spaces, velocity, oxygen levels, and sedimentation rates play a role in the function of reefs and utilization by finfish and crustaceans for feeding, reproduction, and refuge from predators. These characteristics must be considered in restoration and plantings if these ecological services are to be maintained. This study identifies three resident reef fishes, two facultative reef fishes, 30 transient fishes, and seven transient decapod crustaceans at two sites in the Charleston harbor area.

The authors note a recent shift in approach from managing oysters for harvest to managing resources to maintain ecosystem function in molluscan-dominated systems. Establishing reef sanctuaries, testing the value of natural versus artificial reef structures in producing additional fish biomass (as opposed to simply aggregating biomass), testing alternative harvest practices, and coupling research with adaptive management should help in understanding the balance between habitat function and resource extraction.

Significance: This document provides information on the role of oyster reef habitat and the ecological services provided to coastal marine species. These functions are addressed in terms of maintaining ecosystem function and managing fisheries on a broader scale.

| Reference | USFWS 1965 |
|---|---|
| Biological Studies of Price Inlet Area | |

Summary: Studies on the extent and condition of oysters in small tidal creeks between Charleston Harbor and Bulls Bay were conducted in response to potential impacts on fisheries due to changes in salinity predicted by the proposed rediversion of the Santee River through Price Inlet. Acreage of **intertidal oyster grounds**, as well as abundance of fish, crabs, shrimp, and plankton are reported. Salinity of the entire area is relatively high (averaged 30 ppt). When compared to 15 other trawl locations in South Carolina, Price Inlet trawls exhibited higher catch per unit effort (CPUE) of young-of-year (YOY) sea bass than the rest of the state. Spot, the dominant species, was also caught in higher numbers at Price Inlet than at other sites. Utilization by croaker was lower than average CPUE and northern fluke was much higher than average CPUE during the winter. Zooplankton data, compared to other locations in SC, indicate that this area is probably not as important a nursery for blue crab, white shrimp, or croaker; but higher abundance of early stages of brown shrimp and spot were reported here than in other coastal SC sites. Two sites sampled offshore indicate that nearshore assemblages were more similar to offshore coastal waters than brackish waters. The fauna just offshore includes many of the fish and invertebrate species occurring in Price Inlet. Common recreational fish species include channel bass, whiting, and black drum.

Historic catch data are grouped according to salinity range by species and season. This guide is useful in identifying relationships between species and 'preferred' salinity. Based on this relationship, this study predicted that a slight decrease in salinity would increase the CPUE of most species; whereas, a drastic reduction in salinity (below 20ppt) would result in four out of the nine groups studied becoming less abundant.

Significance: Historic use of the Price Inlet area as a nursery is documented for some important species. Comparative analysis illustrates the importance of the area relative to other SC sites and suggests preferred salinity for various species. As in the study of mortality of shellfish associated with hydrologic changes (Burrell 1977), this research was motivated by an expected or measurable change in freshwater flow. Depending on development in surrounding areas, these studies provide insight into how modifications in flow and salinity may affect ecological function and viability of oyster reefs.

| Reference | Judd et al 1992 |
|---|---|
| Remote Sensing of Oyster Reefs | |

Summary: This study compares the accuracy of estimating the extent of oyster reefs from aerial photographs taken at various altitudes. For larger reefs (at least 18 meters in length and width) altitudes lower than 1524 meters do not improve accuracy. Smaller reefs (less than 10 meters) could be measured just as accurately at 762 meters as 381 meters. In addition, measures of reef sizes from aerial photos may be just as accurate as ground surveys. Specific details on interpreting images are provided. The best results were obtained when maximum depth of overlying water did not exceed 50 centimeters.

Significance: Depending on the size of oyster reefs in the Cape Romain region, aerial photography resulting in a scale of 1:24,000 may not be at an appropriate scale for delineation of oyster reefs.

| Reference | Boyd 1996 |
|---|---|
| Using a Personal Computer-Based Geographic Information System for Shellfish Management | |

Summary: Intertidal oyster resources mapped by SCDNR using a classification by strata were last surveyed in 1985. This study updates a section of the 1985 survey on Folly Island to demonstrate the application of GIS for trend analysis and mapping. Issues associated with using GIS and GPS for field surveying and mapping are addressed, including questions of accuracy and time in the field.

Significance: This study illustrates the advantage of

GIS for quantifying shellfish resources. However, field surveys will still require extensive field and personnel time. Options for aerial surveys of oyster resource should be explored. However, applying the SCDNR system of classifying oyster reefs by strata would require extensive field work.

**C. Available Databases**

Several sources of data related to intertidal habitats and the shellfish resource are available. While SCDNR has initiated activities to map the extent of the resource, SCDHEC is responsible for the classification and delineation of shellfish growing waters, based on water quality parameters. SCDNR resource maps of oyster reefs (1:12,000) compiled in the 1980s are available digitally. Features include the extent of the shellfish resource and permit boundaries. Shellfish reefs are classified as intertidal oyster bed, area of several intertidal oyster beds, unharvestable oysters in riprap concentrated washed shell, intertidal oyster flat, and subtidal shellfish bottom. Hard clam maps are hand drawn on mylar and could be digitized.

The classification of shellfish growing waters is maintained by SCDHEC and exists in digital format (1:24,000) going back to 1995. This information is updated as changes in classification occur and is conducive to examining trends in shellfish condition. Both of these sources provide spatial data on the historic status of hard clams and oysters, as well as the condition of growing waters, which may be applicable to the Cape Romain area. Continuation of these efforts and application for managing CRNWR resources should be examined. Additionally, efforts to organize the status of shellfish growing waters at a national level are underway (NOAA/CCEHBR) and would be useful in the comparison of mapping and restoration activities among coastal states. Likewise, efforts to map shellfish acoustically and from remotely sensed imagery show promise.

Efforts to map benthic areas can be used as a model for Cape Romain. For instance, metadata on a mapping effort in Florida is available at: http://www-ocra.nos.noaa.gov/datasets/benthic_habitats/benthic_habitats.htm . The habitat types used to classify this area include coral reefs, hardbottom, bare substrate, seagrass, special modifiers, and unknown.

Environmental parameters such as salinity, water temperature, and oxygen levels may also contribute to defining the characteristics of the refuge, although methods for addressing temporal variability make this a complicated endeavor. However, data collection occurring at National Estuarine Research Reserves (NERR) sites can be used as a model, allowing for comparisons between systems. Information on data collection efforts in the Ace Basin and other NERR sites can be found at: http://inlet.geol.sc.edu/cdmohome.html
Sixty water quality monitoring sites in the Cape Romain area are sampled under the auspices of SCDHEC for the shellfish program and ambient water quality determinations. In addition to the ambient water quality monitoring program, a coastal estuarine monitoring program is underway. SCDNR, SCDHEC, and Marine resources Research Institute (MRRI) will sample a variety of coastal habitats (SCDHEC 1999) in a five year study initiated in 1999. The selected sites will be sampled for water quality parameters (BOD, fecal coliform, Chl a, and nutrients), sediment chemistry (both contaminants and physical characteristics), benthic infauna, fish trawls, and other characteristics. In 1999, three creek sites were located within the refuge boundaries (Du Pre Creek, Five Fathom Creek, and Alligator Creek). The sample design is random in each successive year. This information will be useful in assessing the current condition of these areas, especially in comparison to other estuaries and as suitable habitat. Complete information on the South Carolina water quality monitoring strategy can be found at: http://www.state.sc.us/dhec/eqc/admin/html/eqcpubs.html#wqreports

**D. Synopsis**

The references presented here indicate a basic understanding of complex intertidal habitats. An extensive body of research has been conducted at North Inlet in SC, as well as other coastal estuaries, to advance this knowledge. Selected North Inlet studies that focus on the ecology of oyster reefs and salt marshes have been included in this review and may be applicable to the ecology of CRNWR. To date, apparently little work has been done on the productivity of the Refuge in terms of nutrients and the role of oyster reefs as spawning and nursery habitat. While the importance of the shellfish resource has been noted and select information exists on shellfish areas, additional time and effort would be required to update this information and develop a working definition of shellfish as habitat in relation to management objectives. In addition, mapping and monitoring efforts should be aligned with activities at other coastal locations to allow comparisons. Water quality data from ongoing monitoring efforts by SCDNR and SCDHEC may be useful in supporting these objectives. Additional work in the area of salt marsh ecology and intertidal habitats may further define the characteristics and significance of the intertidal environment, the extent of the shellfish resource, and the issues or threats related to this system.

## III. SEDIMENT CHARACTERISTICS AND GEOMORPHOLOGY

### A. Overview

In 1942, the Santee River was diverted into the Cooper River, reducing flow and sedimentation to the Santee delta area and accelerating the rate of erosion. This had a pronounced effect on the Santee delta complex (Brown 1977). The rediversion of the Santee in 1985 probably did not restore historic rates of deposition due to the damming of upland waters. Jackson (1993) states that flow and deposition has likely changed but the degree to which these hydrologic changes have affected the Refuge remains undetermined (Wood pers. comm., Jackson 1993).

The barrier island system with its underlying geology and marsh/island configuration evident along the South Carolina coast has been evolving since the last glacial period. The current sea level was established four to five thousand years ago (Pilkey and Dixon 1996). The formation and maintenance of these barrier islands are the result of the interaction between sand movement, sea level rise, coastal geology, and wave action (Pilkey and Dixon 1996). They are ever-changing as the islands migrate to the south and landward as waves and winds carry sand to the back side of the islands. On Bull Island, accretion of the island is occurring at the inlet at Price Creek and behind Northeast Point, while erosion occurs at the cape to the south of Northeast point. Based on the known location of the Bull Island lighthouse 100 years ago and the recent finding of its submerged foundation offshore, this point may have eroded at the rate 35 feet per year over the last 100 years (Wood pers comm). To the south, Morris Island eroded 1600 feet in 35 years near the Morris Island Lighthouse (Hayes et al 1979).

Sea level rise and the rate of sedimentation affects the development of coastal wetlands. If sedimentation dominates, coastal wetlands do not flood as much, resulting in formation of upland. When sea level rise overcomes the sedimentation process, coastal wetlands can become permanently flooded.

Comparative analysis of coastal ecosystems based on geomorphological characteristics provides a basic understanding of impacts to ecological function as a result of changing physical features.

### B. Relevant Studies

| Reference | DeVoe 1999 |
|---|---|
| The South Carolina/Georgia Coastal Erosion Study | |

Summary: This cooperative program with USGS is designed to determine the factors and processes that control **coastal sediment movement** within critical areas of erosion along the coast. This study looks at underlying geologic formations and sediment volume and transport perpendicular to shore. Conduits carry significant amounts of sediment offshore. Phase I of this study focused on the Charleston and Folly Beach area. Phase II will expand the study area north and south of Charleston. This study has a GIS component.

Significance: Information on sediment dynamics for CRNWR proposed for Phase II may provide additional insight into the supply of sediment from the Santee and rates of erosion and accretion of the barrier islands to the south.

| Reference | Bury and VanDolah 1995 |
| --- | --- |
| Spatial Analysis of Bottom Habitats and Sand Deposits on the Continental Shelf off South Carolina | |

Summary: This study used **bottom type** data from various sources to estimate likely locations of major offshore sand deposits for use in beach nourishment programs (See also Hansen and Work 1999). This compilation contains information on areas of possible hard bottom, maximum sediment thickness, mean grain size, and percent sand. Information for the CRNWR area is generally sparse. Specific information on bottom type exists for areas at least three miles offshore near Bulls Bay. This study indicates the presence of thick sand deposits offshore of Bulls Bay north to Winyah Bay. Suggestions for mining these sand deposits consider the distance from those beaches in need of renourishment. Most sites that are within 10 miles of shore are >90% sand.

Significance: Spatial information on sediment characteristics and bottom habitats will provide basic information related to intertidal communities and contribute to our understanding of ecological processes, species use, and potential offshore replenishment of sand to the barrier islands. Analysis of bottom habitats will be useful in examining nearshore and offshore fisheries data.

| Reference | Hayes et al 1979 |
| --- | --- |
| Beach Erosion in South Carolina | |

Summary: The purpose of this study is to examine **beach erosion trends** and the dynamic processes occurring along the coast. Along the South Carolina coast, tidal increase from north to south results in more frequent inlets, salt marshes, and larger ebb-tidal deltas than in other regions. The barrier islands of Cape Romain NWR, in general, are migrating landward. On Bull Island, sediment movement is to the north and the south with generally stable beaches near Price Inlet, and variable erosion toward the center of the island. Erosion at Cape Romain and Racoon Key is attributed to the decreased sediment supply from damming. Erosion is related to severe wave attack in the open stretches at the northern end of Bull Island and Cape Romain. This document notes the impact of wind direction and velocity in transforming the barrier islands. "Storm surge is the primary agent of geologic change in storms, particularly hurricanes. However, ...although hurricanes are by far the more severe storms, their lower rates of occurrence make them less significant than northeasters in terms of continual shoreline change (p. 24)."

Significance: Graphics based on successive aerial photographs and coastal charts provide insight into long term variability in rates of erosion-deposition at Cape Romain, Racoon Key, and Bull Island.

| Reference | Pilkey et al 1998 |
| --- | --- |
| The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand | |

Summary: This document provides a description of the history, formation, and ephemeral nature of barrier islands. It also documents failures of beach replenishment and shoreline stabilization efforts. In addition, specific information is provided on **evaluating risk** of erosion based on knowledge of underlying geology, behavior of island migration and beach erosion. Assigning levels of risk is based on published data, aerial photographs, and maps, as well as personal communication.

Significance: Parameters for evaluating site specific risks for unconsolidated shorelines is provided. This well-defined method of determining risk zones could be applied to CRNWR to assist in long-term management.

### C. Available Databases

Sediment characteristics are reflective of sand supply, erosional and deposition patterns, wave action, and bathymetry. Detailed information on sediment characteristics for the immediate area of the Refuge would contribute to our understanding of ecological processes, coastal changes, benthic habitats, and potential occurrence of pollutants. Several efforts are underway to describe coastal erosion and sediment characteristics and processes (DeVoe 1999, Hansen 1998, Barton 1998). A compilation of data on bottom habitats and sand deposits on the continental shelf (Bury and VanDolah 1995) indicates that while surveys have been conducted north and south of the Refuge, information is sparse near CRNWR. Geostatistical interpolation techniques that improve the accuracy of estimating sediment characteristics should be applied to the data that does exist.

Shoreline and vegetation surveys have been conducted on Bull Island before and after hurricane Hugo (Wood pers comm). The focus of this work has been on erosional processes (short time scales), resilience of maritime species (live oak and palmettos) to severe storms, and adaptive management approaches that include management, monitoring, and research. The shoreline surveys could be compiled in a GIS; although extensive data processing may be required. This contribution would be significant in documenting shoreline change and understanding the survival of maritime forests through a significant event.

### D. Synopsis

Intertidal environments that are strongly influenced by tide and wind are dominated by coarser sediments with a gradient toward finer sediments moving offshore. Typically, the energy of tidal currents is higher near tidal inlets with turbulence decreasing with increasing distance from the inlet and decreasing water depth. At Bull's Bay, the relation between depth, wind, and fetch, along with available sources of sand, will affect water movement and rates of sedimentation and persistence of the salt marshes. Further study into the modification of water flow through the Santee River and the resultant changes in sediment input would be needed to assess the impact of these hydrologic changes on the Refuge ecosystem.

Given what is known about the dynamic nature of these systems, the probable decrease in sedimentation to the area, and the configuration of freshwater impoundments on Bull Island, the current configuration of these ponds may be in jeopardy. The physical alteration to the marshes and barrier islands of Cape Romain is a result of natural processes that are certain to persist.

## IV. CONTAMINANTS IN AIR, WATER, AND SEDIMENTS

### A. Overview

As a Class I Wilderness Area, impacts to air quality at Cape Romain NWR must be considered whenever activities with a potentially adverse environmental impact are initiated. As a result, three studies exist that examine airborne toxins at Cape Romain (eg. Espey 1983, Davis 1997, Davis 1999). In addition, a body of work on contaminants in estuaries exists for the nation as a whole, with some sites relevant to Cape Romain. Monitoring through the Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP) provides information on contaminants in sediments and tissue, water quality parameters, and indicators of biotic integrity for benthic species. The use of oysters to monitor water quality conditions continues to evolve (Scott and Lawrence 1982).

### B. Relevant Studies

| Reference | Long et al 1995 |
|---|---|
| Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments | |

Summary: Methods for determining ranges of **adverse biological effects** in marine and **estuarine sediments** have been established and implemented by Long et al (1995) among others. This approach is based on data compiled from modeling, laboratory, and field studies. Two guidelines are established that delineate three categories of potential adverse biological effects from chemical concentrations in marine and estuarine sediments. These two guidelines are Effects Low Range (ERL), levels below which adverse effects are rarely observed; and Effects Range Median (ERM), levels above which effects occur frequently. The range between ERL and ERM identifies chemical concentration levels where possible effects would occasionally occur. Adverse biological effects from contaminated sediments may include, for example, mortality and low species richness of amphipods and liver lesions in fish associated with particular chemicals. In this work, ERL and ERM values are calculated for nine trace elements - total PCBs, thirteen individual PAHs, three classes of PAHs, and two pesticides - p,p'-DDE and total DDT. The compilation of contaminant levels effects relies on agreement between modeling studies, spiked sediment bioassays and real-world conditions reflected in field studies and includes multiple taxa.

Significance: These guidelines have become an accepted tool in sediment quality assessments and have been applied to the Broad-Okatee and North-Murrell's Inlet studies as well as Bull's Bay (Scott 1998). To apply the results from these analyses, it is necessary to understand how these effects levels are derived and the variability of national versus regional datasets as explained in the next study.

| Reference | Hyland et al 1999 |
|---|---|
| Predicting Stress in Benthic Communities of Southeastern U.S. Estuaries in Relation to Chemical Contamination of Sediments | |

Summary: Hyland et al applies ERL and ERM to the **Carolinian province EMAP sediment data** for benthic communities in southeast estuaries. A comparative index of biotic integrity is reflective of sediment bioeffects. The results indicate that "...estimates within which adverse effects are expected or not expected to occur are about an order of magnitude lower than those reported by Long et al." This current study of southeast estuaries includes a smaller proportion of urbanized sites than Long et al. yet, where degraded benthos exist, the contaminant levels are a magnitude less than expected.

Significance: Predicting stress on organisms within the Carolinian province should take into account issues associated with applying nationally derived effects levels to the southeast region.

| Reference | Scott et al 1999 |
|---|---|
| Overview of Preliminary Sediment Contaminant Chemistry in Bulls Bay and Cape Romain Wildlife Refuge | |

Summary: This study examined levels of metals, PAHs, pesticides, and PCBs in **sediments in Bulls Bay** and CRNWR during 1999, using ERL, ERM, and Probable effects Level (PEL) indices of adverse effects from contaminants. Samples were collected and analyzed from six sites in CRNWR during September and November of 1998.

Significance: This study provides baseline information on contaminant levels in sediments. Few elevated levels were noted; however, additional interpretation of this data may be warranted. Continued monitoring of these sites would be useful in identifying potential impacts from increased development and public use. This data is available spatially.

| Reference | Jackson 1993 |
|---|---|
| Biogeochemical Studies of the Salt Marsh and a Barrier Island at Cape Romain National Wildlife Refuge, SC | |

Summary: This is an extensive study of baseline **element levels in plants and soils** conducted at CRNWR. Chapter A covers baseline data for Spartina and sediments. Core samples characterize the sediments as uniform throughout, with predominantly silt and an oxidized zone averaging one centimeter. An important aspect of this study is the spatial variability of elements found in sediments and Spartina, which influences the selection of appropriate mapping and sampling scales (3-5 samples within 2.6 $km^2$ grids). Chapter B (also Gough et al 1994) provides baseline information on potential pollutants absorbed through Spanish moss, loblolly pine (to monitor airborne pollutants) and soils. Chapter C addresses baseline values and anthropogenic effects. The author points out the difficulty in determining baseline levels of trace elements in soils and plants; but, states that there does not appear to be any gross contamination of trace elements in Spartina. However, Cu and Pb levels in Spartina may be suspect, as well as possible enrichment of Pb and Ni in Spanish moss. The role of sulfur is also discussed.

Significance: This very extensive study at CRNWR provides baseline information on element levels and spatial variability, with implications for mapping and sampling. Considerations for monitoring for anthropogenic introductions, including detection limits and slight temporal variation, are suggested. Locations of sample sites accompany this extensive data base.

| Reference | Davis 1997, 1999 |
|---|---|
| Evaluation of Ambient Ozone Injury on the Foliage of Vegetation in the Cape Romain National Wildlife Refuge South Carolina | |

Summary: A survey of **ozone injury** was conducted at four general locations (Moore's Landing, Bull Island, Lighthouse Island, and Cape Island. However, there was a lack of indicator species on Cape and Lighthouse Islands). The aim of this study was to determine the extent and severity of damage to vegetation from ozone and establish baseline conditions. Anthropogenic sources and field indications are described for ozone, sulfur dioxide, and fluorides. Ozone is considered the most likely possible phytotoxic pollutant, unless new sources (eg. sulfur dioxide) are allowed. Ozone pollutants are derived from urban precursors and carried downwind. Evidence of ozone injury was found on 24% of grape species, but no injury on other ozone-sensitive species. Overall ozone injury is considered very light. Ambient ozone monitoring by the state and discrepancies with previous studies were noted.

In 1997 and 1998, the Davis study was repeated for Moore's Landing and Bull Island. Comparisons were made over time and with ambient levels of ozone. Of the three years, levels of ambient ozone concentrations monitored near the Refuge were highest in 1997 and the lowest in 1996. In 1998 44% of grape species exhibited ozone injury (similar to 1997; but up from 24% in 1996). This parallels ambient ozone levels and suggests that wild grape is a valuable ozone bioindicator plant (Davis 1998). Further information is needed on ozone effects on Spartina. Results over three years indicate that ozone injury is present.

Significance: The designation of CRNWR as a Class I wildlife area has resulted in several air quality monitoring studies, such as this, that have provided 'baseline' information on injury from ozone and sulfur dioxide emissions. The need for these studies is likely to continue in light of recent requests for variances through the PSD (prevention of significant air quality determinations) process (see Dames and Moore 1985, 1986; SCDHEC 1998) and the environmental impact statement requirements associated with the proposed Daniel Island Marine Cargo Terminal (Eudaly pers comm).

**C. Available Databases**

Contaminants data is available for estuaries throughout the nation through the EMAP program. The Carolinian province data has been analyzed and interpreted. This information provides long term sediment and tissue data on several contaminants. However, only two EMAP sites are near the Refuge. Scott et al (1999) provides current data from sites within the Refuge. In addition, information on airborne pollutants is available in Jackson (1993) and Davis (1997, 1999). These data can be mapped with varying spatial resolution, depending on the sampling interval. The SCDNR coastal estuarine monitoring program (SCDHEC 1999, Mayer pers comm) will provide additional data from sites within the refuge over a five year period. Routine water quality monitoring is conducted by SCDHEC to meet EPA reporting requirements under the Clean Water Act. This monitoring program provides information on dissolved oxygen, fecal coliform bacteria, nutrients (phosphorous and nitrogen), pH, temperature, heavy metals, and macroinvertebrates. In addition, reporting of this information through the EPA Storet program makes it possible to analyze pollution inputs on a watershed basis. For example, the BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) model can be used to assess environmental quality and identify sources of pollution within a watershed.

### D. Synopsis

In these studies, indications of anthropogenic stresses range from negligible (Scott et al 1998) to more severe (Davis 1999). Other sources of potential pollutants should be explored on a watershed and airshed basis using available models. In addition, the relationship between developed areas - especially impervious surfaces- (Vernberg et al 1996) and impacts to estuarine systems should be studied as development occurs in the surrounding areas. Water quality monitoring conducted by SCDHEC should be used as an indicator of ecosystem health and habitat suitability. In addition, Cape Romain NWR would be a suitable location for testing methods that address fecal coliform typing to determine sources of bacterial pollution.

More detailed information on the physical characteristics of sediments within the Refuge may provide insight into the likelihood that contaminated sediments will be a problem. The need for conducting these surveys should be further explored and coordinated with USGS, SC SeaGrant, and NOAA.

## V. NEARSHORE AND OFFSHORE FISHERIES

### A. Overview

Surveys of the nearshore fisheries communities have been conducted by SCDNR through the Southeast Area Monitoring and Assessment Program (SEAMAP) program since 1986. "This survey provides long-term fishery-dependent data on seasonal abundance and biomass of finfish, elasmobrachs, decapod, and stomatopod crustaceans, and cephlapods that are accessible by high-rise trawls (SCDNR 1999)." This effort provides seasonal information on fish community structure, abundance, and biomass in the South Atlantic. Likewise, surveys of the offshore fishery have been conducted through the Marine resources Monitoring, Assessment and Prediction (MARMAP) program since the 1970s. Understanding regional utilization and diversity of fish species may have implications for Cape Romain as a component in both nearshore and offshore fisheries. In addition, fisheries studies conducted in North Inlet (eg. Allen and Barker 1990), Charleston Harbor (SCDHEC 1999) and other coastal areas in the South Atlantic may be applicable. Fisheries surveys and related environmental data on water temperature, salinity, bottom type and bathymetry (based on historic survey tracks from NOAA National Geophysical Data Center) can provide information on potentially suitable habitat.

### B. Relevant Studies

| Reference | SCDNR 1999 |
|---|---|
| SEAMAP - SA Annual Report | |

Summary: The **SEAMAP** Shallow Water Trawl Survey has been conducted since 1986. Data collection takes place in the spring, summer, and fall and is summarized annually. Information is available on "species composition, abundance, and biomass, as well as seasonal and regional trends in temperature and salinity."

Significance: Trends in species abundance, composition, and length-frequency will be very useful in determining which species are utilizing waters in the vicinity of Cape Romain NWR. This information, in combination with additional surveys, may provide insight into the role of the Refuge in sustaining the fish populations of the South Atlantic Bight.

| Reference | Sedberry and Machowski 1991 |
|---|---|
| An Analysis of Trawl Catches from Continental Shelf Reef Habitat in the South Atlantic Bight, 1978-1987: A Preliminary Data Report | |

Summary: Offshore surveys have been conducted by SCDNR through the **MARMAP** program to better understand fish community structure, abundance, and biomass of South Atlantic species. Special attention is paid to evaluating populations of hard bottom reefs and commercial fisheries. Like the SEAMAP survey data, this is an extensive dataset that hold great potential for examining trends and patterns of species use both seasonally and temporally.

Significance: Given the extensive oyster reefs and salt marshes of CRNWR, it is likely that the Refuge serves in some capacity to support the offshore fishery. A better understanding of the utilization and diversity of fish species within Cape Romain would help define the role of the refuge for dependent species.

| Reference | Able 1998 |
|---|---|
| Measures of Juvenile Fish Habitat Quality: Examples from a National Estuarine Research Reserve | |

Summary: The approach used at the Jacques Cousteau NERR site is based on the determination of essential fish habitat (EFH). This study addresses not only the distribution and abundance of fish species in estuaries, but also addresses questions of spawning and growth in conjunction with environmental parameters. In this case, the species of interest are flounder and black sea bass. This study also points out the need to expand the scale of observation to examine the dependence of species on both estuarine and shelf habitats. For instance, life history requirements of black sea bass include dependence on both the estuary and inner shelf area for nursery habitat. Also, interannual variability must be addressed to improve estimates of the relationship between fish species and the function of associated habitats. This study illustrates the need to account for interannual variability at broad spatial and temporal scales.

Significance: This paper identifies the need for comparative sampling in the estuary and the adjacent ocean; extensive long-term studies across variable year classes to understand larval supply; better mapping of subtidal habitats; in situ imagery to provide more information on fish behavior; integration of available technologies; and extended observations across varying degrees of human impact. (See further explanation of this study in Impact Assessment Tools).

| Reference | Rubec et al 1998 |
|---|---|
| Suitability Modeling to Delineate Habitat Essential to Sustainable Fisheries | |

Summary: This paper outlines the use of habitat suitability index (HSI) modeling to link fish distribution with environmental parameters. The delineation of essential fish habitat for a given species with known preferred environmental ranges can be mapped using parameters such as water temperature, depth, bottom type, and salinity. Results indicate that HSI modeling can be useful in predicting the geographic distribution of fish.

Significance: This approach may be useful in defining important environmental parameters and suitable habitat for selected fish species at CRNWR.

**C. Available Databases**

The primary source of fisheries data for the Southeast Atlantic Bight are SCDNR surveys of the nearshore and offshore fisheries (SEAMAP and MARMAP). Nearshore fisheries surveys have also been conducted in the area by SCDNR. By analyzing this fisheries data collectively, it will be possible to decipher nearshore to offshore movement of species, seasonal changes in biomass and diversity, and long term trends in the vicinity of CRNWR. From this initial analysis, more directed studies of the inshore area would confirm or reject the use of the refuge by various species for spawning and nursery. Studies conducted in similar estuaries (for example, North Inlet and SCDNR coastal estuarine monitoring program) would provide comparative and supporting information (eg. USFWS 1965). Findings from analysis of this fisheries data can be used in conjunction with fisheries dependent data to track fishing pressure for species that utilize CRNWR.

### D. Synopsis

Several studies conducted at North Inlet may provide insight into the larval and juvenile fishes that characteristically utilize intertidal salt marshes. For instance, Shenker and Dean (1979) examined the abundance, diversity, and temporal variation in intertidal creeks at North Inlet and observed a wide variation in use by larval, juvenile, and adult fishes. (Adult fishes were dominated by Atlantic silversides and bay anchovy; immature fishes were primarily spot, mullet, speckled worm eel, pinfish, flounder and croaker). This study demonstrates the importance of this intertidal salt marsh as critical nursery habitat. Also, numbers of predatory fish were low indicating safe refuge for larval and juvenile fish. Bozeman and Dean (1980) illustrated the importance of the North Inlet estuary as nursery ground for spot, pinfish, and menhaden during the winter. Likewise, Cain and Dean (1976) provided a very good summary of fish use in North Inlet throughout the year. Comparative, historic studies are possible given this summary of most abundant species and species diversity observed throughout the year (p. 374- 377). Interannual variation in larval fish recruitment to estuarine benthic habitats was examined by Allen and Barker (1990) and established that date of arrival could be consistently predicted; larval densities were highest in the summer; and greatest variability occurred with changes in salinity, where low salinities resulted in greater abundance.

Similarly, identification of species utilizing Cape Romain NWR may be gleaned from survey data and ongoing studies, focusing on particular species of concern. As the relationship between ecological function and the distribution of species and habitats at CRNWR becomes better understood, it may be possible to forecast the impact of potential threats to those species and habitats.

## VI. INVENTORIES OF TERRESTRIAL PLANTS AND ANIMALS

### A. Overview

Currently, directed studies are conducted at Cape Romain NWR on various animals including birds (Otis 1999), sea turtles (Hopkins-Murphy 1999) and American alligators (Rhodes 1999). Extensive vegetation surveys have been conducted by Gene Wood (pers comm). Special projects on threatened and endangered species include the recovery of red wolf and potential mink habitat at the Refuge. These studies indicate the importance of the Refuge as a vehicle for research, education, and in the recovery of species. A network of research biologists contribute to inventories of threatened, endangered, and rare species. Inventories of terrestrial plants and animals should be updated digitally and environmental sensitivity index (ESI) maps developed for easy access by Refuge managers.

### B. Relevant Studies

| Reference | Baker 1999 |
|---|---|
| The Status of Mink (*Mustela vison*) in South Carolina 1999 | |

Summary: There is some evidence of historic occurrence of mink in the Cape Romain NWR area and a general decline in mink populations in the Georgia/Carolina coastal plain. Recent sitings of mink include one on Lighthouse Island in 1998 and on Capers Island in recent years. Specimens in the Smithsonian that were collected at the Refuge are dated 1938. Habitat degradation and contaminants may be responsible for declines occurring since the early 1980s. Mercury, PCBs, DDE, and dieldrin are suspected as the cause of this decline. A tri-state study conducted by Clemson University Institute of Wildlife and Environmental Toxicology indicates that levels of dieldrin, PCB, and mercury were significantly higher in mink from the coastal plain than in the Piedmont reference group.

Significance: This document suggests further research areas, including restoration efforts, application of a Habitat Suitability Index model, testing the impact of contaminants on physiology and reproduction, and validating flood tide surveys as an indicator of population density. This study includes maps of sightings compiled through various surveys, charts of harvest efforts, and info on food habitats.

| Reference | Hopkins-Murphy et al 1999 |
|---|---|
| A History of Research and Management of the Loggerhead Turtle (*Caretta caretta*) on the South Carolina Coast | |

Summary: This document provides an island-by-island description of information on loggerhead turtles. Results indicate that "Cape Island, within the Refuge, is the most significant loggerhead nesting beach north of Cape Canaveral with an average 1,000 nests per season (p. 32)." Cape Island has a sea turtle management project that includes moving nests to protect them from predators and erosion. A synopsis of historic surveys is given, including an 1940 manuscript by Baldwin and Lofton and anecdotal information on changes in populations.

Also included are abstracts of other loggerhead research studies and technical guidance that identifies threats to nesting and hatching, along with solutions.

A previous study (Hopkins et al 1978) examines biotic and abiotic nest mortality. Major predation pressure was due to raccoons (*Procyon lotor*), which destroyed 56.1% of the nests. Overall hatch was 6.1%. "The spatial and temporal aspects of nesting and predation, age of nest when depredated, density of nesting, and feeding efficiency of raccoons are discussed as they relate to the number of nests affected by each factor."

Significance: A history of sea turtle research and restoration indicates the importance of this effort in protecting and maintaining this population. Continued efforts and educational opportunities are likely to continue in the future management of the Refuge.

| Reference | Rhodes pers comm |
|---|---|
| Study of American Alligator on Bull Island | |

Summary: Spotlight surveys of American alligator were conducted on Bull Island from 1992 to 1996 and in 1999. Aerial nest surveys were conducted twice a year. Also, research was conducted on the mainland of the Santee Coastal Reserve on the relationship between temperature and sex determination. The Santee study is compiled in a GIS layer and includes approximately ten environmental parameters (eg. hatch success and macro habitat characteristics). The Santee study is fairly reflective, physiologically, of the Bull Island population.

When the Jack's Creek impoundment broke after hurricane Hugo, freshwater ponds became tidal and alligators shifted to other ponds (Ponds 1 and 2 and Summerhouse Pond). They were observed foraging blue crab and mussels in tidal Jack's Pond. The population shifted back to Jack's Creek as it returned to freshwater. The similar scenario occurred on Cape Island, which also had impoundments where alligators resided before Hugo. Now there are only scattered reports of alligators on Cape Island.

Significance: The management of the Refuge will necessarily involve this unique, isolated population, as it was once listed as endangered species and is still federally managed. Current surveys are conducted to meet this management mandate. This species is of great educational value and important for wildlife viewing.

| Reference | Daniels et al 1993 |
|---|---|
| Sea-Level Rise: Destruction of Threatened and Endangered Species Habitat in South Carolina | |

Summary: This study addresses potential impacts on habitats of American alligator, brown pelican, loggerhead sea turtle, and wood stork with potential sea level rise. It also provides a description of threatened and endangered species in South

Carolina dependent on habitat within 3 meters of mean sea level and identifies high risk coastline areas. Model results indicate that the Refuge is vulnerable due to lack of medium sized grain sediment from the north and the presence of storm-induced waves. Changes could be dramatic due to lack of suitable replacement sediment and possible fragmentation of the barrier islands as a result of tidal inundation. Model predictions estimate that by 2100, under a low sea level rise scenario, 51.4% of the current land area could be inundated, adversely affecting loggerhead sea turtle and brown pelican nesting sites and causing a reduction in wood stork and American alligator food supplies.

Significance: Closer examination of model results as they apply specifically to CRNWR would help define risks to threatened and endangered species. (See also Kana et al 1988).

**C. Available Databases**

Compilation of federally listed threatened and endangered species are compiled by the South Carolina Natural Heritage program. Further, low-level aerial photos can be classified according to habitat type and used to conduct a GAP analysis for species of concern to determine where gaps in essential habitat and life history components exist. Likewise, environmental sensitivity indexes can be compiled to identify sensitive species that would be vulnerable to anthropogenic pressures. Vegetation surveys (Wood pers comm.) can be referenced to delineate the extent of various plant species on Bull Island. The convergence of information on the distribution of plant and animal species, along with information on contaminants, sediment type, and other physical parameters (tides, winds, and currents) could be used to conduct spatial analysis in GIS to investigate the relationship between these components.

**D. Synopsis**

The range of species and recovery programs at the refuge point to the importance of this barrier island ecosystem in the maintenance and recovery of coastal species. The identification of focal species and indicators of ecosystem health are the responsibility of all interested parties, including academic and agency researchers, refuge managers, and the community as a whole. Some tools that are applicable for setting those priorities are described in the following section.

## VII. POTENTIAL IMPACTS AND ASSESSMENT TOOLS

**A. Overview**

Impact analysis must go beyond simply complying with existing laws and plans to consideration of broader social goals (Westman 1985). CRNWR is in a position to not simply deter impacts but to set a course for the management and use of this environment, developed in the context of larger social or ecological goals. Westman favors use of the word “impacts” over “risk” in the ecological arena because risk generally refers to human health, whereas impacts generally refer to the natural environment. In addition, risk infers the ability to measure the severity or probability of adverse events (Westman 1985).

The first step in assessing ecological impact is to define the study goals. For CRNWR, goals can range from maintaining the ecological function or self-regulation of communities to allowing the greatest public use without degrading the environment. The end result in each case could be the same, but the strategy could be quite different. A model for assessing ecological impacts is provided in Westman (1985).

**B. Relevant Studies**

| Reference | Westman 1985 |
|---|---|
| Ecology, Impact Assessment, and Environmental Planning | |

Summary: This book addresses impact assessment in an ecological framework. The methodology presented here is useful for defining goals, potential impacts, baseline conditions, and evaluating the outcome of prescribed actions. To identify potential impacts it is necessary to determine the extent (boundaries, organisms); range (direct, ecological, associative effects); and the most significant potential impacts. Next, determining impacts requires the measurement of baseline conditions. Information on baseline conditions includes: populations and fluctuations, dominant or critical species, condition of physical resources, pathways of ecological functions, and existing stresses. Methods for predicting impacts include case studies, bioassay and microcosm studies, field perturbation studies, and theoretical considerations. Finally the findings must be summarized, analyzed, and presented in a form useful to decision makers.

Significance: This current task is intended to determine what is known - which species and physical components have been studied - and the relevance of available information. This must be accomplished in conjunction with input from interested parties to set future goals and objectives for resource management and research.

| Reference | Weinstein 1996 |
|---|---|
| Anthropogenic Impacts on Salt Marshes - A Review | |

Summary: This reference provides an overview of **impacts to coastal marshes** as a result of human modification to these ecosystems. Anthropogenic effects from dredging, boating, and urban runoff, as well as chemical contaminants such as PAHs, PCBs, heavy metals, and pesticides are discussed. In coastal marshes, chemical contaminants affect metabolic functions of microbes and perhaps most significantly impact meiofauna that live in the top 5 cm and "graze on detrial aerobic and anerobic bacteria and are preyed upon by shrimp and juvenile fish." The author notes studies that suggest Spartina probably has some resilience to the uptake of chemical contaminants.

The effects, severity, and residence times of oil spills are described. The author notes that both major events and cumulative effects from marinas and recreational boating are concerns.

Significance: This thorough review of potential threats to salt marshes raises several important questions that should be considered for CRNWR regarding the sensitivity, level of risk, and recovery potential for CRNWR. In addition, an understanding of the likelihood of major or minor spills, the cumulative effects of impacts, and those functions most at risk is enhanced in the context of this review.

| Reference | Hoss and Engel 1996 |
|---|---|
| Sustainable Development in the Southeast Coastal Zone: Environmental Impacts on Fisheries | |

Summary: This document identifies **loss of coastal habitats** as a major threat to marine fisheries and suggests these corrective actions: "1) coordinate and enforce municipal, county, and state land use plans; 2) demonstrate to the public the importance of coastal wetland habitat to fisheries; 3) support local, state, federal efforts to limit non-point source runoff; 4) encourage the prudent and safe use of pesticides, herbicides, and fertilizers; and 5) reinforce the concept that people are the source of the fishing, pollution, and habitat degradation problems, and that each of us must be environmentally responsible (p 171)."

Hoss and Engel recognize the correlation between loss of fisheries and increased development but admit the difficulty in quantifying the cause and effect linkages. They call for a better understanding of the functional components of critical fish habitats. Threats to habitats in nearshore waters include loss of marshes, offshore dump sites, oil exploration and production, mining and energy production, riverine inputs, and alteration of freshwater flows. They recognize the need to conduct research that documents the interaction between human activity and fish stocks. They also suggest that multiple insults will have to be dealt with simultaneously; therefore, "risk/hazard assessment techniques, similar to those used in evaluating contaminant-associated impacts, should be developed for fisheries to predict the probabilities of interactive processes and activities affecting fish stocks (p 181)."
Significance: This document prompts the question

of whether or not CRNWR can be used to test risks to fish stocks from increasing pressures from surrounding development. What does this habitat specifically provide in terms of fish production? Emphasis needs to be placed on determining how to best quantify the value of these resources, the risks to the function of that resource, and the ecological and economic costs associated with loss of that function.

| Reference | Gramling et al 1998 |
|---|---|
| Expert Informants and Relative Risks: A Methodology for Modeling Waterways | |

Summary: This paper describes a methodology developed for assessing risk in shipping traffic on the lower Mississippi River. Factors such as amount of shipping traffic, elements that increase or decrease risk, and risks at particular locations are incorporated. This approach takes human and organizational factors into account and is based on input from maritime experts, previous research, and existing databases. Model inputs included risk variables such as traffic (comprised of type of vessel, direction of movement, and commodity); risk factors associated with the river (based on river pilot identification of problematic points along a river - eg. narrow channel, bridges, waterway junctions, etc.); and factors associated with the vessel (eg. direction of travel, load vs. no load). By computing a relative risk per river mile, areas where the probability of spill may be higher can be identified and incorporated into planning and response plans.

Significance: With the likelihood that Atlantic coastal shipping traffic will increase in the future, the potential for shipping related accidents to occur will increase. The model described here could be useful in assessing where shipping traffic risk is highest. This approach should be examined in conjunction with expansion plans for the port terminal on Daniel Island to assess potential impact on Cape Romain NWR.

| Reference | Amrozowicz et al 1997 |
|---|---|
| A Probabilistic Analysis of Tanker Groundings | |

Summary: This paper describes a probabilistic risk assessment of tanker groundings. The method for analyzing risk from tanker groundings focuses on human error, especially passage planning events and piloting events. This analysis is based on predicted rates of human error when performing certain tasks analogous to those studied in the nuclear power plant industry. The authors indicate that critical tasks for navigation are related to checking publications for changes and verifying master plans; accuracy of planning information; reliability of navigation equipment; and piloting tasks such as properly taking fixes and recognizing difference errors. The authors conclude that the maritime system is error-inducing and the system should be further examined to identify areas with the greatest potential for reducing risks.

Significance: The accuracy of charting and navigation information has been identified as a critical factor in error related to tanker groundings. The extent to which regional navigational information is reliable and accurate should be taken into consideration in assessing the potential risk of tanker groundings that could negatively impact the sensitive CRNWR ecosystem.

| Reference | Allen et al 1996 |
|---|---|
| Detection and analysis of unusual events in long-term zooplankton and nekton data sets from North Inlet Estuary, South Carolina, U.S.A. | |

Summary: In addition to long-term trends, ecologists need to understand events that fall outside the range of natural variation. “The Shewhart Control Chart Method is a relatively simple and unique procedure for investigating atypical variation, and its application may be useful for understanding the role of unusual events in determining long-term change in both natural and altered ecosystems (p. 165).”

Significance: Ecological processes in coastal systems occur at a wide range of spatial and temporal scales. An understanding of variation around these processes is crucial to understanding the appropriate scale for studying and detecting change or significant events outside normal limits. The principles presented in this paper should be incorporated into analysis of long-term changes.

| Reference | Sutter et al 2000 |
|---|---|
| NC-CREWS: North Carolina Coastal Region Evaluation of Wetland Significance | |

Summary: NC-CREWS is a GIS-based model of overall wetland functional significance based on water quality, hydrologic, habitat, and risk factor functions as well as replacement and restoration potential. Incorporating the spatial extent of environmental variables (areas of water, proximity to protective habitat and nursery areas, etc.) allows landscape-level elements to be quantified and their ecological function to be analyzed.

Significance: This model can be applied to CRNWR to assess wetland function within the Refuge. Results will indicate the habitat value of component parts of the wetlands to the entire system.

| Reference | Jensen et al 1990 |
|---|---|
| Environmental Sensitivity Index (ESI) Mapping for Oil Spills using Remote Sensing and Geographic Information Systems | |

Summary: This paper demonstrates the use of remotely sensed images that are interpreted and compiled in a relational database to provide improved, easily accessible information on shoreline features and oil-sensitive wildlife to assist in oil spill contingency planning and restoration efforts.

Significance: This method should be applied to CRNWR using the low-level IR aerial photography and updated information on species distributions from databases compiled through this effort.

| Reference | Kana et al 1988 |
|---|---|
| Greenhouse Effect, Sea Level Rise, and Coastal Wetlands | |

Summary: This model of sea level rise for the Charleston area estimates loss of various types of wetlands/marshes/ and transitional zones with high and low sea level rise scenarios and at various levels of protection. The ability of new wetland zones to replace flooded wetlands is taken into account. A shift in wetland zonation is predicted where highland area would be maintained, but transition and high marsh areas would be eliminated by 2075.

Significance: Zonation definitions would be very useful as a guideline for delineating intertidal/coastal landscapes. These zones are highland, transition marsh, high marshes, low marshes, tidal flats, and open water.

| Reference | Murray et al 1999 |
|---|---|
| No-take Reserve Networks: Sustaining Fishery Populations and Marine Ecosystems | |

Summary: The authors present an approach to protecting marine areas that are representative of a biogeographic region as a way to safeguard the ecological benefits of important ecosystem components. A network of no-take reserves serves to limit activities that impact biodiversity and vulnerable habitats, help recover fish populations, provide opportunities for scientific research and environmental education, and allow flexible management designed to test the success of various strategies. Guidelines for developing, designing, and evaluating reserve networks are provided.

Significance: As a National Wildlife Refuge, Cape Romain is already set aside as part of a system "to preserve a national network of lands and waters for the conservation and management of the fish, wildlife, and plant resources and their habitats ... to preserve a natural diversity and abundance of fauna and flora (USFWS )." Cape Romain may play a role in supporting offshore species and environments (eg. Charleston Bump) that utilize nearshore environments. As such, the Refuge has the potential to complement adjacent biologically diverse environments.

| Reference | Howard et al 1985 |
|---|---|
| National Strategy for Beach Preservation | |

Summary: The Second Skidaway Institute of Oceanography Conference on America's Eroding Shoreline held in Savannah, GA, June 1985. Forward by Orrin H. Pilkey, 1997 indicates that this document "is still the most significant US document outlining the needs and means for realistic planning for the future of our retreating shores." This document outlines the problems of responding to eroding shorelines with hard structures. Local defenses to try to harness coastal erosion cause larger changes to occur in adjacent beaches. Immediate local, shoreline problems belie the much greater magnitude of the problems of worldwide sea level rise. A description of a national policy to retreat from the shoreline is given. A list of options for coastal management at the federal, state, local levels is provided.

Significance: The question for CRNWR is how much nearby alteration, such as hard surface retention, mining for or deposition of beach nourishment sands, modification of local circulation or fluvial deposition patterns has occurred or is likely to occur that may impact erosion rates?

**C. Synopsis**

A plethora of assessment tools have been developed based on manufacturing processes (Allen et al 1996), economic value of environmental functions (Gosselink et al 1974), environmental health concerns (eg. EPA's "Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories"), and landscape modeling (eg. GAP analysis, NC-CREWS). An important aspect of assessing impacts are those associated with socio-economic changes. A study is underway to assess perceptions and attitudes toward this resource (Boyles pers comm). In addition, current environmental regulations, local planning documents, build-out projections, and watershed modeling can be employed to predict and direct changes in the surrounding area.

**TABLE OF REFERENCES**

TABLE OF REFERENCES. Additional sources of information for evaluating environmental condition and potential impacts.

| **Topic Area I: Salt Marshes and Intertidal Habitats** | | | **Note: BOLD references indicate focus or site within CRNWR** |
|---|---|---|---|
| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Oyster and Hard Clam Resource Surveys | **Anderson and Cohen pers comm** | SCDNR historic surveys of hard clam and oysters | Potential spatial data available for historic status of hard clams and oysters may be applicable to Cape Romain. Oyster habitat is available in digital form. Hard clam maps are hand drawn on mylar and could be digitized. Provides historic information that could be updated to assess change in resource. |
| | **Anderson et al 1978** | Hard clam resource survey | Historic information shows high clam densities in Bull Island and McClellanville quadrants. Conducted pre-rediversion, which was expected to have a detrimental effect on shellfish due to increased freshwater flow. Notes that 15% or 1,035 acres were closed due to fecal coliform levels in 1977. |
| | **Battle 1892**<br>Dean 1892 | An investigation of the coast waters of South Carolina with reference to oyster culture | Historic survey and qualitative description of SC coastal waters with regard to possibility of oyster plantings. Description of Bull Bay. Extensive maps. Of total coastline, approximately 81,289 acres were surveyed and the area of natural oyster beds estimated as 773 acres. Dean (1892) describes condition of growing characteristics of "racoon" beds and oyster ledges, flats, and islands. |
| | **Lunz 1938**<br>**Lunz 1943** | Study of oyster culture along ICW with regard to dredging and flooding of Santee R.<br>Yield of oysters in SC. | Part-1: A detailed study of oyster beds and adjacent waters before, during, and for a short while following dredging operations to create the Intracoastal Waterway between Charleston and the Santee River, including the Cape Romain area. Indicates no effect on oyster morality. Part-2: The effects of Santee R. flooding had negative impact. 50% of oysters north of Casino Creek and south of Santee R. died due to reduced salinity. |
| | Keith and Gracy 1972 | History of the South Carolina oyster | Overview of historic and recent use of oyster resource. (Notes 1971 SC Marine Resources Dept oyster planting in Alligator creek). Also, notes Alligator Creek to Isle of Palms as most productive area in the state. By 1972, 18% of state shellfish waters closed due to pollution. Notes difficulties within the industry in early 70's "management, conservation, marketing, production, and labor shortage." |

| **Topic Area I: Salt Marshes and Intertidal Habitats** | | | **Note: BOLD references indicate focus or site within CRNWR** |
|---|---|---|---|
| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Intertidal Flats and Salt Marsh Ecology | Peterson and Peterson 1979 | Overview of community profile of NC intertidal flats | Foundational work provides information on basic ecological processes and important ecological role of intertidal flats. These functional roles should be considered when delineating intertidal areas. |
| | Vernberg 1996<br>Pomeroy and Wiegert 1981 | Overview of ecological interactions | Provides a basic understanding of the dynamics of salt marshes and role as source of nutrients to the ecosystem. |
| | Spurrier and Kjerfve 1988 | Study of net flux of nutrients between salt marsh and tidal creek | Examines the tidal and annual variability involved in estimating the net flux of nutrients in North Inlet. Development of statistical models to account for variability due to ebb and flood fluxes. Defines role of salt marshes as sink for nitrates and nitrites. |
| | Gosselink et al 1974 | Overview of value of tidal marsh based on ecological function and economic worth | Provides framework for assessing value to ecological functions of tidal marshes. Review of important functions -primary productivity, export of mineral and organic nutrients, nursery for fish and shellfish. Method for assessing economic value to functions include contribution to dependent fisheries, aquaculture potential, waste treatment, reduction of nitrogen and sulfur in anaerobic muds, buffer during storms. |
| | Stiven and Plotecia 1976 | Salt marsh primary productivity estimates | Contribution of primary productivity and decomposition of marsh vegetation to coastal fisheries. A regression model identifies growing season, temperature range, mean tide, and latitude as most important factors determining productivity. Predictions for other areas can be calculated based on acreage and type of vegetation. This model could be used to determine relative importance of productivity of salt marshes at CRNWR to the open estuary environment and costs if this function was lost. (Compare to more recent methods of determining vegetation index eg. satellite imagery). |

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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Houser and Allen 1996 | North Inlet zooplankton study | Examines temporal variation in densities of copepods and bivalves with tidal, diel, and diurnal cycles. Recurring patterns observed during 48 hr period. Cyclical responses include very high densities of presettlement bivalves on nocturnal flood tide, early settlement bivalves on nocturnal ebb tides, and total copepod densities highest at high tide, likely due to behavioral and reproductive strategies. Contributes to understanding of basic ecological functions. |
| Intertidal Creeks as Habitat | Allen et al 1999 | Site specific fish use and habitat structure | Species richness associated with geomorphologic and hydrographic characteristics. Could be applied to habitat management and restoration. |
| | Wenner (date unknown) | Summary of importance of estuarine shallows | Descriptive summary of function, use, and components of estuarine systems: categorized into "living spaces." Very useful in delineation of intertidal habitat types. |
| | **USFWS 1965** | Price Inlet studies pre-rediversion. | Studies of the extent and condition of oysters in small tidal creeks between Charleston Harbor and Bulls Bay in response to potential changes in fisheries due to changes in salinity predicted by proposed rediversion of Cooper R. through Price Inlet. |
| Oyster Reef Ecology | Bahr and Lanier 1981 | Overview of physical, chemical, and biological aspects of reefs | Very extensive overview of oyster reef ecology. Includes list of man-induced stresses on oysters, community structure of reefs, oyster biology, conceptual models of oyster reef community, and bioenergetics. |
| | Anderson 1979 | Study of oyster growth in saltwater impound-ments versus tidal creeks | Greater oyster production noted in saltwater impoundments (esp. near surface) over tidal creek habitat. Differences in physical parameters noted between the two environments. |
| | Burrell 1977 | Mortality of oysters and hard clams in Santee R. | Above normal flows of freshwater runoff from the Santee River in 1975 resulted in high mortality in oysters. Effect of altered freshwater runoff on shellfish. |
| | Kjerfve and Greer 1978 | Hydrography of Santee R. prior to rediversion | Increased freshwater input from rediversion of Santee R expected to negatively impact hard clam and oyster beds. Effect of altered salinity/freshwater inputs on shellfish. |

| **Topic Area I: Salt Marshes and Intertidal Habitats** | | | **Note: BOLD references indicate focus or site within CRNWR** |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Dame et al 1984<br>Dame 1987<br>Dame et al 1992<br>Dame and Libes 1993<br>Dame et al 1989<br>Dame and Patten 1981<br>Dame 1979 | North Inlet studies on basic ecology of oyster function regarding nutrient fluxes. | Measures of ammonium release; particulate organic carbon removal rates; inorganic sediment; Chl a, oxygen, and ammonium; nutrient retention; C, N, P processing; energy flow; abundance/diversity of macrobenthos. Chl a - maximum uptake in late summer; oxygen - seasonal maximum uptake in summer; ammonium. Demonstrates oyster reef as an important component in processing matter and energy and nutrient retention mechanism. Basic ecological interactions studied here may be applicable to CRNWR. |
| | Kenny et al 1990<br>Michener and Kenny 1991 | North Inlet study-patterns of oyster settlement | Implications for understanding factors controlling settlement rates and survival of oysters. |
| | **Burrell et al 1984** | Comparative analysis of *Perkinsus* in Wando River and Cape Romain tidal and subtidal oysters | Impact of salinity on *Perkinsus* infection in oysters. No relationship between tidal versus subtidal sites and incidences of *Perkinsus*; however; lower incidences at Cape Romain may be associated with higher salinities. |
| | Lenihan et al 1999 | Environmental conditions and susceptibility of oysters to *Perkinsus* | Determined that water flow is a significant factor in the susceptibility of oysters to *Perkinsus* infection. Results suggest that increased susceptibility with reduction in reef height should be a consideration in harvesting methods and restoration of oyster reefs. |
| Oyster Reef as Habitat | Lehnert and Allen 1999 | North Inlet - fish assemblages on reefs | Site specific study of fish assemblage on oyster reefs provides info on most abundant species, seasonality, sampling strategy. “The fish community associated with subtidal oyster shell included small benthic species such as toadfish, blennies, and gobies. Juvenile pigfish and filefish moved into this habitat early in the spring and departed by late summer. Overall, species diversity was consistently high. Useful for examining community structure of subtidal oyster shell habitats.” Compare to fish use at CRNWR |

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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Coen et al 1999 | Summary of current knowledge on ecological role of oyster reefs | Understanding of the ecological services provided to resident and transient fish and crustaceans by oyster reefs. Characteristics such as reef height, interstitial spaces, velocity, oxygen levels, and sedimentation rates play a role in feeding, reproduction and refuge from predators. |
| Mapping of Reefs, Wetlands, Bottom Habitats | Judd et al 1992 | Mapping oyster reefs from aerial infra-red photographs | Accuracy of estimating extent of oyster reefs from aerial photos at various altitudes. Measures of reef sizes from aerial photos may be just as accurate as ground surveys. Specifics on interpreting images are provided. Depending on size of oyster reefs in the Cape Romain region, current aerial photography may not be at an appropriate scale for delineation of oyster reefs. |
| | Boyd 1996 | GIS and shellfish management | Demonstrates the effectiveness of using GIS for trend analysis and mapping. Folly Island site resurveyed and compared to 1985 survey showed an increase in F1 type shellfish beds (based on SCDNR strata classifications). Strata definitions, variations caused by docks, and issues involved in GIS and GPS for field mapping are addressed |
| | **Tiner, Jr. 1977** | Inventory of coastal marshes in SC, classification of marsh types, and description of plant communities | Aerial photos were delineated into beach zone, low salt marsh, high salt marsh, brackish-water marsh, fresh-water marsh, impoundments, and diked disposal areas. Maps bound into atlas. Description of Bulls Bay as a separate wetland unit - mainly low salt marsh (94%) dominated by smooth cordgrass. Classes grouped according to importance to fish and wildlife. Useful in delineating and classifying habitat types and should be considered in subsequent intertidal and wetland mapping efforts. |
| | Kana et al 1988 | Model predictions of sea level rise for coastal wetlands in Charleston area. | Estimates loss of various types of wetlands, marshes, and transitional zones with high and low rise as well as various levels of protection that would affect ability of new wetland zones to replace flooded wetlands. Zonation definitions - highland, transition marsh, high marshes, low marshes, tidal flats, and open water. Very useful as a guideline for delineating and mapping intertidal, coastal landscape zones. |
| | FMRI 1998 | Benthic habitats of the Florida Keys | Can be used as a model for benthic mapping. Habitat types include coral reefs, hardbottom, bare substrate, seagrass, special modifiers, and unknown. Data available at http://www-ocra.nos.noaa.gov/datasets/benthic_habitats/benthic_habitats.htm |

| **Topic Area II: Sediment Characteristics and Geomorphology** | | | **Note: BOLD references indicate focus or site within CRNWR** |
|---|---|---|---|
| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Geomorph-ology and Sediment Dynamics | Pilkey et al 1998<br>Pilkey and Dixon 1996 | Description of history, formation and ephemeral nature of barrier islands | Provides specific information on evaluating risk of erosion based on knowledge of underlying geology, behavior of island migration and beach erosion. Puts long-term management in context. Well-defined method of determining risk zones that could be applied to CRNWR. Also, documents failures of beach replenishment and shoreline stabilization efforts. |
| | **Brown 1977** | Geologic history of formation of barrier islands | Contributes to understanding of formation of islands and processes that maintain and modify these islands. Suggests significant modification of Santee delta due to diversion and rediversion that may have impact on the stability of Cape Island and source of sediments to Refuge. |
| | **Hayes et al 1979** | Beach erosion in SC | Examines beach erosion trends. Implications for long-term management of barrier island beaches and predicting effects/responses to northeasters and hurricanes. |
| | **Kana et al 1988** | Beach erosion in SC | Addresses issues related to beach erosion and defining erosion problems. Highlights differences between SC and other barrier islands. Provides a good description of shoreline processes. |
| | **Stephen et al 1975** | Beach erosion in Charleston County | Study of successive aerial photos to determine amount of erosion, accretion, or degree of stability for coastline. Cape Island - Cape has eroded; spits in north and west accreted. Racoon Key - long term erosion. Bull Is. - north end eroding; south central- alternate erosion and deposition near Price Inlet. Notes changes due to Charleston Harbor jetties and damming of Santee R. |
| | **Sexton 1995** | Recovery of beaches post-Hugo | Summary of changes in shoreline from Capers Island to the Santee Delta three years after Hurricane Hugo. Characterization of transport rates, beach sediments, and shoreline types for CRNWR. (Refs Kana an Knoth 1977, Sexton and Hayes 1991, Moslow 1980, Ruby 1981 for additional info). |
| | **Wood pers comm** | Shifting shoreline of Cape Romain barrier islands | Implications for management of ponds and dependent species. Rapid ecological shift is probably occurring since some recent abiotic processes are severe and occur at shorter temporal scale than biotic processes. Adaptive management techniques. |

| **Topic Area II: Sediment Characteristics and Geomorphology** | | | **Note: BOLD references indicate focus or site within CRNWR** |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Hutchinson et al 1995 | Short term estuary sediment dynamics | Association of seasonal riverine inputs, spring-neap tides, wind, and length of inundation on sediment dynamics at North Inlet, SC. Compare to Cape Romain. |
| | Hansen and Work 1997 | Variability of ebb-tidal deltas | Assessing natural variability of sediment movement as source of beach fill material using methods for determining flux of material. Survey of sediment along SC coast. |
| | DeVoe 1999 | Coastal erosion study | Studying erosion rates, defining geologic framework, and calculating sediment volumes and transport. Currently, this work does not extend to Cape Romain but Phase II offers that possibility and would help to better understand sediment transport. |
| | Kindinger et al 199 | Central SC coastal geological survey | Information may be applicable to the Cape Romain area in terms of understanding geological framework, nearshore physical processes, and shifting shorelines. |
| Shoreline and Sediment Mapping | Barton website | USGS/SC effort to develop GIS inventory of shoreline position, land use, etc. to assess coastal change | As GIS inventories are developed, spatial data can be incorporated into the Refuge management activities. This developing website provides a gateway to currently available and developing spatial data relevant to managing the coast. Spatial data is retrieved from a variety of sources including NGDC (bathymetry), NOAA/CSC (Lidar), and SCDNR GIS clearinghouse for several environmental data layers. http://coastal.er.usgs.gov/national_assessment/scarolina/ |
| | Bury and Van Dolah 1995 | Spatial analysis of existing information on bottom type | Indicates sparse coverage of data. Objective is to examine bottom deposits for beach nourishment. Thick deposits off Cape Romain. Potential implications for barrier islands if mining of these deposits is pursued. |
| | Poppe et al 1999 | A regional database of sediment and bottom characteristics for LI Sound compiled from various sources | Sediment grain size is a basic physical parameter required for environmental, mineral resource, sediment transport, and other assessments and is often indicative of sediments deposited in certain areas. For instance, grain size is indicative of physical mechanisms; characteristics such as permeability, cohesiveness, etc.; community structure; and contaminant adsorption. May be useful as a model. A similar compilation exists for SC (DeVoe 1999). However, not many transects near CRNWR. |

| Topic Area II: Sediment Characteristics and Geomorphology | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Gayes pers comm | Sediment mapping of SC coast | Some nearshore sediment mapping completed near Wrightsville Beach, NC and Folly Beach, Myrtle Beach, and Isle of Palms in SC; but, surveys are lacking near CRNWR |

| Topic Area III: Contaminants in Air, Water, and Sediments | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Sediment Contaminants and Sediment Quality Guidelines | Long et al 1995 | Sediment quality guidelines | For 28 categories of chemicals, defines three ranges of potential adverse biological effects from chemical concentrations in marine and estuarine sediments. Effects low range (ERL) **-** below which adverse effects rarely observed; effects range median (ERM)**-** above which effects occur frequently; between ERL and ERM where effects occasionally occur. |
| | **Hyland 1999** | Sediment quality guidelines applied regionally | Field studies applying ERL and ERM to the Carolinian province EMAP sediment data to benthic communities in southeast estuaries. Calculates index of biotic integrity **-** a comparative index reflective of sediment bioeffects. One site in vicinity of CRNWR |
| | **Scott et al 1999** | Preliminary sediment contaminant study of Bull's Bay and refuge | Uses Long et al ERL, ERM, and PEL as indices of adverse effects from contaminants. Provides baseline information at CRNWR in Sept. and Nov. of 1998. Baseline information indicates few elevated levels. Unpublished data requires additional interpretation. Data is available spatially and will be useful in continued monitoring. |

| Topic Area III: Contaminants in Air, Water, and Sediments | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Long et al 1997 | Sediment toxicity in selected estuaries of SC and GA | Five estuaries, including Winyah Bay and Charleston Harbor were tested for toxicity using a suite of bioassays. http://ccmaserver.nos.noaa.gov/bioeffects/SC%2FGA/ All estuaries showed at least some significant toxicity, with Winyah Bay having the highest levels and greatest extent. Overall, observations indicate that toxicity is somewhat less in this region than in other estuaries and results agreed well with EMAP analyses. For CRNWR, results from EMAP sites near the refuge should be examined. |
| Plant/soils Chemistry | **Gough et al 1994**<br>**Jackson 1993** | Baseline study of element concentrations in soils and plants | Ch. A. Baseline of Spartina and sediments. Core samples characterized sediments as uniform throughout - predominantly silt with oxidized zone averaging one cm. Discusses spatial variability in sediments and Spartina in relation to appropriate mapping and sampling scales (3-5 samples within 2.6km$^2$ grids). Ch B. (also Gough et al 1994) Provides baseline information on potential pollutants absorbed through Spanish moss, loblolly pine and soils. Ch. C. Addresses baseline values and anthropogenic effects. Illustrates difficulty in determining baseline levels of trace elements in soils and plants; but, there does not appear to be any gross contamination of trace elements in Spartina; however Cu and Pb may be suspect. Possible enrichment of Pb and Ni in Spanish moss. Discusses role of sulfur. This very extensive study at CRNWR provides baseline information and locational data on element levels and spatial variability, with implications for mapping and sampling. |
| Air Quality | **Davis 1997**<br>**Davis 1999** | Effects of ozone on vegetation at Cape Romain | Four general locations (Moore's Landing, Bull Island, Lighthouse Island, and Cape Island - however, lack of indicator species on Cape and Lighthouse Island). Suggests ozone is the most likely possible phytotoxic pollutant - derived from urban precursors and carried downwind. However, 1996 observations showed overall ozone injury very light. Anthropogenic sources and field indications are described for ozone, sulfur dioxide, and fluorides. Severity and extent of ozone injury on salt marsh vegetation not determined by Davis in 1996. Noted discrepancies with previous studies. Subsequent studies show higher incidence in 1997 with slight decline in 1998. |

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| **Topic Area III: Contaminants in Air, Water, and Sediments** | | **Note: BOLD references indicate focus or site within CRNWR** | |
| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | **Zedaker et al 1990** | Effects of ozone on vegetation at Cape Romain | Conducted visible injury survey for ozone damage for 11 indicator species on three islands and established permanent biomonitoring plots in 1989. Suggests damage to Spartina (and four other species) on >50% of individual plants on Bull Island. "Less than ten percent of the extensive survey plants showed pollution symptomology. However, nine of the eleven bioindicator species exhibited ozone injury symptoms." Results indicate that ozone could be adversely impacting vegetation. |
| | **Newman and Hart 1982** | Air quality related values with regard to wildlife at CRNWR | Includes a comprehensive list of birds reported on the Refuge, along with seasonal occurrence and habitat associations; mammals, amphibians, and reptiles, status, and habitat associations. Focuses on ambient air quality and potential effect, especially notes risk to migratory bird species. Suggests biomonitoring programs using resident birds and deer. |
| | **Dames and Moore for Charleston Development Board 1985 - Phase I**<br>**Dames and Moore for Charleston Development Board 1986 - Phase II** | Assessing impact of increasing allowable PSD increments of sulphur dioxide | Delineated six wetland vegetation types and seven upland vegetation types from 1982 IR aerial photos. Qualitative description of plant communities in the refuge. Sulphur dioxide monitored at Cape Romain for 1983 and 1984 and compared to other coastal sites from Georgia to Florida. Provides baseline data of ambient sulphur dioxide. Fernandina Beach, FL and Georgetown, SC selected in Phase I for comparison with Cape Romain in Phase II. |
| | SCDHEC 1998 | Final determination PSD | Prevention of significant deterioration (PSD) in air quality considered (Espey et al 1983) and made in favor of Nucor Steel (SCDHEC 1998) |
| Water Quality | Mallin et al 1999<br>Mallin 1998 | Effect of development on shellfish closures. | Demonstrates association of developed land use, especially impervious surfaces, with elevated levels of fecal coliform, resulting in shellfish closures. |
| | Scott and Lawrence 1982 | Condition index of oysters as pollution indicator | Pollution levels and conditions within intertidal gradient reflected in morphological-health indices. Applicable to quantifying suitable habitat conditions for intertidal oysters. |

| Topic Area III: Contaminants in Air, Water, and Sediments | Note: BOLD references indicate focus or site within CRNWR | | |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Parveen et al 1997 | Association of antibiotic resistence with point and nonpoint sources of *E coli* | Point source *E. coli* isolates are more diverse in resistance to antibiotics than are nonpoint source isolates. This technique may be useful in differentiating source of *E coli* pollution. |
| Contaminants in Oysters/ Birds | **Mathews et al 1979** | Copper and iron concentrations (biologically important) in oysters | Eleven sites include Cape Romain, Bulls Bay, and McClellanville near Bulls Bay (prior to rediversion). Wando River showed higher concentrations of copper; Bulls Bay lowest. Cape Romain and Bulls Bay showed mid-range levels for iron. Iron distribution probably related to environmental variation. |
| | Goldberg et al 1983 | Mussel watch program - a national effort to monitor trace metals and radionuclides in bivalves | US mussel watch program sites in the Carolinian Province near CRNWR can provide long term data on trace metals and radionuclides in bivalves. This paper summarizes results for 1977-1978 on a national scale and suggests that variation in seasonal and annual levels should indicate rate of future monitoring activities. Data from subsequent years should be examined for trends in the CRNWR area |
| | **Blus et al 1974** | Organochlorine residues in Brown Pelican eggs | Study to determine the influence of residues of organochlorine pollutants on reproductive success in the brown pelican. Sample eggs taken from Marsh Island, CRNWR in 1971 and 1972. Data showed strong correlation between DDE and dieldrin in eggs. |

| **Topic Area IV: Nearshore and offshore fisheries** **Note: BOLD references indicate focus or site within CRNWR** | | | |
|---|---|---|---|
| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Nearshore Offshore Fisheries Surveys | **SCDNR 1999** | SEAMAP - seasonal survey of nearshore fishes | Extensive historic dataset from the South Atlantic Bight can be used to examine abundance, seasonal use, and diversity of fish species in the Cape Romain area. |
| | Sedberry and Mach-owski 1991<br>Machowski and Sedberry 1991<br>Wenner et al 1980 | MARMAP - seasonal survey of offshore fishes | Offshore surveys conducted to better understand fish community structure, abundance, biomass, and CPUE. Extensive data on regional utilization and diversity of fish species may have implications for Cape Romain as a component in offshore fisheries. |
| | Barans and Burrell 1976 | Summary of MARMAP data 1973-1975 | Quantifies fish abundance and diversity. Indicates depth range of 18-55 meters may support abundant 'commercially exploitable groundfish stocks' on Southeast continental shelf |
| | Singer et al 1983 | Cape Romain and the Charleston Bump | Hydrographic observations indicate that an area of upwelling and doming waters off Cape Romain coincide with the 200-400m isobath in the area of the Charleston bump. Upwelling of lower salinity, cold waters associated with greatest upward nitrate penetration and highest observed total chlorophyll. Connection between Charleston Bump and CRNWR should be examined. |
| Species Abundance and Diversity in Estuarine Habitats | Cain and Dean 1976 | Seasonal patterns of fish abundance and diversity in intertidal creek | Very good summary of fish use throughout the year at North Inlet. May be valuable in assessing patterns of fish abundance and diversity at the Refuge. Possible basis for comparative, historic studies. |
| | Allen and Barker 1990 | Four year study of larval fish recruitment in North Inlet | Interannual variability of recruitment to estuarine benthic habitats. Date of arrival consistently predicted; larval densities highest in summer; and greatest variability occurred with changes in salinity, with low salinities resulting in greater abundance. May provide insight into the comparative value of Cape Romain as nursery. |

| **Topic Area IV: Nearshore and offshore fisheries** | | | **Note: BOLD references indicate focus or site within CRNWR** |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Shenker and Dean 1979<br>Bozeman and Dean 1980 | North Inlet mid-winter larval and juvenile fish survey | Results indicate high degree of utilization and some differences in night-day use by some species. Importance of intertidal salt marsh as critical nursery habitat |
| | **Miglarese et al 1982** | Study of seasonal use of estuaries by Atlantic croaker | Survey of SC estuaries provides information on basic biology of Atlantic croaker (offshore spawning in fall and winter, onshore Nov to April) and shows positive correlation between salinity and size (greater abundance in mesohaline [ >18%] and increasing size with increasing salinity), includes Cape Romain sites. |
| | McGovern and Wenner 1990 | Larval and juvenile use of salt marsh and impoundments Georgetown, SC | Seasonal species composition and abundance documented for 5 marsh creek and impounded sites indicated seasonal variation in the marsh sites. Access to impoundments due to water management strategies impacted use by fishes in resulting in reduction or absence of some important species. Good info on seasonal recruitment 1983-1984 and implications of impounded tidal creeks. |
| | University of South Carolina (USC) Baruch Institute website | Abundance and life stage information on fishes in North Inlet 1978 to 1998 | North Inlet estuary just north of CRNWR may provide insight into fishes utilizing the Refuge. Organized by abundance, life stage, and season. http://www.geol.sc.edu/baruch/fishsp.html |
| | Able 1998 | Quantification of habitat using Essential Fish Habitat (EFH) model | Demonstrates EFH approach to quantifying fish habitat (flounder, black sea bass). Species of interest and methodology applicable to CRNWR. Interannual variability must be addressed. |
| | Rubec et al 1998 | Model for fisheries habitat suitability | Delineation of essential fish habitat for a given species using known preferred environmental ranges and confirming model output with catch rates. Approach should be applied to select species for the Cape Romain region |

| **Topic Area IV: Nearshore and offshore fisheries** | | | **Note: BOLD references indicate focus or site within CRNWR** |
|---|---|---|---|
| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Peterson et al 1987 | Consequences of alternative fishing gear and methods on benthic habitats | Examined mechanical harvesting of hard clams and the effect on hard clam recruitment, seagrass biomass, and density of benthic macroinvertebrates and bay scallops on a seagrass bed and a sand flat in Back Sound, NC. |
| Shrimp | **Harris and Dean 1998** | King and Spanish mackerel bycatch of shrimp trawlers | Identifies times of vulnerability for king and Spanish mackerel during shrimp trawling season. Age-0 King mackerel vulnerable for at least half of season and Spanish mackerel for most of season in SC. |
| | Porter et al 1997 | Assessing the impact of urbanization on grass shrimp densities | Illustrates use of GIS to combine information on species abundance and spatial distribution with other environmental parameters - in this case, land use. |
| | Low 1990 | Survey of SC shrimp baiting fishery | Creel and mail survey quantifying catch, nets used, effort, socio-economic characteristics, and number of permit holders by region. Successive surveys show trends in shrimp baiting pressure. |
| Fish Species Natural History | Wenner and Archambault | Information booklet on spotted sea trout | Life history and fishing techniques for spotted sea trout. |
| | Marcy and O'Brien-White 1995 | Fishes of the Edisto River Basin | Includes a bibliography (references statewide), location of historic fish sampling by state and federal agencies and lists of species found in the basin. |
| | Nelson et al 1991 | NOAA estuarine living marine resources program | Spatial and temporal distribution and abundance of fishes and invertebrates in estuaries of the southeast, including Winyah Bay, North and South Santee Rivers, and Charleston Harbor. Extensive list of references for southeast. |

| **Topic Area V: Inventories of Terrestrial Plants and Animals** | | | **Note: BOLD references indicate focus or site within CRNWR** |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Threatened and Endangered Species | **Daniels et al 1993**<br>Daniels et al 1992 | Model shows risk to habitat of threatened and endangered (T&E) species with sea level rise | Addresses potential impact on habitats of American alligator, brown pelican, loggerhead sea turtle, and wood stork with potential sea level rise. Provides description of T&E spp in SC with habitat within 3 m of mean sea level, identifies high risk coastline areas. Indicates salt marsh habitat at the Refuge is vulnerable due to lack of medium sized grain sediment from the north and storm-induced waves. |
| Birds | Otis et al website | GAP analysis and compilation of bird lit. | Mapping plant and animal biodiversity using GIS. http://www.clemson.edu/research/SCFW/ecoanaly/5.htm |
| | **Blus et al 1978** | American oystercatcher found at CRNWR | Apparently first record of avian cholera in oystercatcher. Characteristically low levels of organochloride residues reported. |
| | **Blus and Stafford 1980** | Study of black skimmers and gull-billed terns 1969-75 | Documents susceptibility of nests at CRNWR to predation and flooding. Residues of organochlorine pollutants may have impacted reproductive success and eggshell thickness; but overall effect negligible. |
| | **Blus and Prouty 1979** | Pollutants and population status of least tern at CRNWR | Noted no evidence of decline in population since 1940s. Residues of DDE declined over the study period (1971 to 1975). |
| | **Hankla and Rudolf 1968** | Wintering habits of Canada Geese | Documents a substantial increase in wintering populations at CRNWR from 1936 to 1967. |
| | **USFWS 1996**<br>**USFWS 1986**<br>NBS website<br>**Dick 1974**<br>**Chamberlain 1965** | Bird checklist of CRNWR<br>Trend estimation<br>Sightings at CRNWR | Checklist of 277 species of birds observed at the refuge, includes abundance by season.<br>Population trends for SC bird species http://www.mbr.nbs.gov/bbs/trendin.html<br>Sighting of Fork-tailed Flycatcher on Bull's Island<br>Blue-winged teal breeding on Bulls and Cape Islands |
| American Alligator | **Rhodes pers comm** | Studies of American alligator populations | Population counts from CRNWR and temperature-dependent sex determination studies at Santee Coastal Reserve. Potential for education, viewing, research. |

| Topic Area V: Inventories of Terrestrial Plants and Animals | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Mink | **Baker 1999** | Overview of the status of mink, includes summary of studies and reports of sightings | Some evidence of historic occurrence of mink in Cape Romain area. 1998 sighting on Lighthouse Island and on Capers Island in recent years. Smithsonian specimens from Refuge dated 1938. Evidence of declining population; habitat degradation and contaminants (mercury, PCBs, DDE, dieldrin) may be the cause. |
| Turtles | **Hopkins-Murphy et al 1999** | Description of SC coastal loggerhead management and research | "Cape Island, within the refuge, is the most significant loggerhead nesting beach north of Cape Canaveral with an average 1,000 nests per season (p. 32)." Cape Island has a sea turtle management project that includes moving nests from predators and erosion. Technical guidance that identifies threats to nesting and hatching, along with solutions. Implications for the Refuge - continual monitoring of this population. |
| | **Andre and West 1981** | Nesting and management of loggerhead on Cape Island | Nesting mortality rates determined for loggerhead turtles on Cape Island. Noted heavy predation by racoons and detrimental effect of erosion and storms on nesting habitat. Used in conjunction with Hopkins et al 1978 to determine loggerhead productivity. |
| | **Hopkins et al 1978** | Study of Atlantic loggerhead turtle nest mortality on four SC barrier islands | A study of factors affecting mortality of rates for nests of the Atlantic loggerhead (*Caretta caretta*) on 4 South Carolina barrier islands indicates the major predation pressure was due to raccoons (*Procyon lotor*), which destroyed 56.1% of the nests. Overall hatch was 6.1%. "The spatial and temporal aspects of nesting and predation, age of nest when depredated, density of nesting, and feeding efficiency of raccoons are discussed as they relate to the number of nests affected (p. 213)." |
| | **Cobb and Wood 1997** | PCB levels in chlorioallantoic membranes from hatched eggs | Provides information on PCB levels while testing methodology that allows continual monitoring of PCB levels in sea turtle eggs without sacrificing the organism. |
| | **Baldwin and Lofton 1959** | Database for Cape Romain rookery | Presents a database on the Cape Romain rookery for comparative purposes. Details of nest and eggs, their incubation, and hatching are presented. |

| **Topic Area V: Inventories of Terrestrial Plants and Animals** **Note: BOLD references indicate focus or site within CRNWR** | | | |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Waterfowl Management | SCDNR 1999 | Draft management plan for Santee Coastal Reserve (SCR) | Management strategies at the SCR should be considered in assessing the resources and impacts at Cape Romain NWR, especially in the areas of waterfowl management; nuisance species such as phragmites; bald eagle, loggerhead turtle, and wood stork management (disturbance limitations, surveys); and research on American alligator populations and their utilization of impoundments. Also, applicable as a model plan. |
| Maritime Vegetation | **Wood and Mixon website** | Pre and post- Hugo vegetation surveys | Describes ongoing research to investigate response to major climatic event based on historic vegetation and shoreline information. http://www.clemson.edu/research/SCFW/ecoanaly/7.htm |
| | **Wood 1991** | Vegetation survey of Bulls Island | Extensive survey of island divided into five regions provides information on impact of Hurricane Hugo. Extracting and digitizing raw data can provide baseline information for longer term recovery studies. |
| | **Helm et al 1991** | Pre-Hugo survey of Bull Is maritime forests | Provides pre-Hugo data on forest stands in three structural classes - overstory, understory, and herbaceous layer. |
| | **Stalter 1984** | Vegetation of Bull Island | Documents three major plant communities: salt marsh, live oak-laurel oak forest, and sand dune community. List of 268 species provided. Also plant specimens were contributed to the herbarium at The Citadel, Charleston, SC. |
| | Au 1974 | Description of vegetation and ecology of a NC barrier island | Description of soils, wind, vegetation, climate for a barrier island in NC. Useful in comparative analysis. |
| | **Rayner and Batson 1976** | Differentiation of closed vegetated dune systems on SC barrier islands | Indices of species diversity on four islands and one mainland site were calculated, including Bulls Island. Bulls Island and Kiawah Island were most similar, being representative of mature maritime, closed dune systems. Characteristics of other islands represent the range of early successional to mature systems. As a surrogate for changes over time, this study may be useful in investigating ‘successional’ stage (recovery) of Bulls Island post-Hugo and development impacts (Kiawah Island). |

| Topic Area V: Inventories of Terrestrial Plants and Animals | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Impound-ments | DeVoe and Baughman 1987<br>Miglarese and Sandifer 1982<br>Wenner and Beaty 1988<br>McGovern and Wenner 1990 | Characterization of coastal wetland impoundments | Ecological characterization of SC impoundments, including management, status and use. Descriptions of history, management strategies, species, ecological function, nutrient and biomass exchange, and changes to macrobenthic and fish community structure compared to estuary and open coastal habitats. Types of various water management strategies and seasonal use by larval and juvenile fishes are examined. Differences in faunal composition and density observed. For diked ponds at CRNWR, provides information on how managed versus natural systems differ; also, provides indication of changes to ponds as a result of tidal inundation. |

| Topic Area VI: Potential Impacts and Assessment Tools | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Management Strategies Policy | **USFWS 1986**<br>**USFWS 1984** | CRNWR Annual Reports | Summarizes management activities, including air quality monitoring and research on Fox Squirrel. 1986 three major storms. Management of impounded wetlands and plans to rebuild dike at Jacks Pond impoundment. Status of endangered and threatened species - quantifies brown pelican and loggerhead nesting. 1984 continued air quality monitoring, notes study to support a “certificate of no significant adverse impact.” Cattail and bullrush encroachment in impoundments. |
| | Schmitten 1999 | Essential Fish Habitat (EFH) and role of National Marine Fisheries Service (NMFS) | Outlines NOAA commitment to no further loss of habitat quantity and quality. Describes requirements to identify, describe, and map all life stages for each species using GIS. |
| | Sarthou 1999 | An overview of the Magnuson-Stevens Act | Author contends that potential opportunities to protect and manage coastal habitats using EFH ‘guidelines’ may be stifled by lack of authority to require other federal agencies to incorporate habitat conservation measures into projects and lack of funds. |

| Topic Area VI: Potential Impacts and Assessment Tools | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Murray et al 1999 | No-take reserve networks | Guidelines for establishing no-take reserves is presented. Reserves approach may be beneficial in maintaining important ecological functions, protecting key species and habitats, replenishing fish stocks, and scientific research. |
| | Hoss and Engel 1996 | Impact of development on fisheries | Calls for a risk assessment evaluation of fish stocks in coastal environments. Cites degradation of coastal habitats due to increased development as apparent cause of declining fish populations |
| | Auster 1998 | Summary of impacts of fishing activity and gear on fish habitat | Potential impacts associated with gear type. Effects vary with community and complexity of habitat. Concepts may be helpful in predicting outcomes. Advocates adaptive management practices. |
| | **Van Dolah et al 1979** | Effects of dredging and unconfined disposal on macrobenthos | Effects of dredging of ICW at Sewee Bay was detectable at 5 of 13 stations. After dredging community structure had changed and abundance and biomass had decreased. However, recovery was evident within six months. Includes recommendations to minimize adverse effects from unconfined dredge spoil. |
| | SCDNR 1999 | Management plan for Santee Coastal Reserve | This document can be used as a model to define management objectives, summarize what is known about a protected coastal env., and outline management strategies. |
| | Turgeon et al date unknown | Status of harmful algal blooms and a national program | Overview of current knowledge of HABs and effort to expand the scope of research to ecology and oceanography to 'prevent, control, and mitigate blooms and their effects.' |
| Socio-economics | Gosselink et al 1974 | Assigning economic value to tidal function | Describes method for assessing monetary value and loss of ecological function of tidal system. |
| | **Boyles pers comm** | Socio-economic survey by SCDNR | Ongoing study to assess attitudes of local constituents toward the resource. |
| | Weinstein 1996 | Review anthropogenic impacts on coastal environments | Overview of perturbations associated with development in coastal areas. Should be viewed as potential impacts to CRNWR with the likelihood or extent of threat requiring further analysis. |

| Topic Area VI: Potential Impacts and Assessment Tools | | | Note: BOLD references indicate focus or site within CRNWR |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | **Wright 1978** | Cultural resource survey | Survey conducted in response to proposed construction and modification at Moore's Landing Headquarters Complex and Bulls Island Headquarters Complex. Aboriginal materials were widespread at the Moore's Landing Headquarters Complex, and some historic artifacts were found as well. |
| Sustainable Resources & Ecological Characterization | SCDNR 1996<br>Marshall 1993 | Edisto River Basin Project | Provides model for assessing all aspects of environment, ecology, and development; including public participation. Info on species and socio-economic use of Edisto R. Basin. Ecological characterization of land use, wetlands, water quality |
| | NOAA 1996 | Ecological characterization of Otter Is. | Model of environmental factors to be considered in management issues through compilation of an ecological characterization. |
| | Vernberg et al 1996 | Sustainable development in the southeast coastal zone | Compilation of papers from a symposium held in Myrtle Beach, SC 1993 addressing coastal policy, development, and urbanization in the Southeast. Recognizes social aspects, addresses use of GIS, examines changes in biological communities, physical properties, and contaminant levels associated with landscape alterations. |
| | USC and NMFS 1997 | Assessing impacts of coastal development | Urbanization and Southeastern Estuarine Systems (USES) has focused on delineating impact of stresses from urbanization on high-salinity estuaries and developing models for land-use management. Progress in modeling contaminants, bacteriology, toxicology, eutrophication and nutrients, and GIS |
| | SCDHEC website | Charleston Harbor Project | List of projects and abstracts completed under the Charleston Harbor Project. Categorized by topic: Biological Resources, Growth Management, Water Quality Management. Some may be useful for comparative analysis and assessing impacts. http://www.state.sc.us/dhec/eqc/ocrm/html/restopic.html |

| **Topic Area VI: Potential Impacts and Assessment Tools** | | | **Note: BOLD references indicate focus or site within CRNWR** |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| Impact Statements and Transporta-tion Risks | **US Corps of Engineers 1999** | CORPS permit for Moore's Landing | Permit authorization and soil survey for construction of pier at Moore's Landing |
| | Jensen et al 1990 | Environmental Sensitivity Index (ESI) mapping for oil spills using GIS and remote sensing | Approach provides an index of potential damage and recovery plan for environmentally sensitive areas. A review and update of sensitive species and ecosystem functions should be completed for CRNWR using an ESI approach to assess risk of oil spills, etc. |
| | FMRI and research Planning, Inc. website | Environmental sen-sitivity index for fish | Metadata for a compilation of environmentally sensitive fish resources of the St. John's River, FL can be used as a model for CRNWR. http://www.researchplanning.com/metadata/sj/sjfish.html |
| | Gramling et al 1998 | Assessing relative risk for transportation waterways | Includes factors such as amount of shipping traffic and risks at particular locations. This approach takes human and organizational factors into account, based on input from maritime experts, previous research, existing databases. Assess risk to CRNWR |
| | Amrozowicz et al 1997 | Probabilistic risk assessment of tanker groundings | Method of analysis for of risk from tanker groundings - focuses on human error, especially passage planning events and piloting events. |
| Ecological Models | Sutter et al 2000 | Assessing wetland value as habitat | GIS-based model of overall wetland functional significance based on water quality functions, hydrologic functions, habitat functions, and risk factor functions. This model incorporates environmental variables that allow landscape-level elements to be quantified and their ecological function to be analyzed. This model can be applied to Cape Romain to assess wetland function, indicating habitat value of component parts of the ecosystem. |
| Coastal Erosion | Pilkey et al 1998 | Description of erosional processes of barrier islands | Describes methods for determining risk to coastal areas (primarily developed communities) based on geomorphological changes and erosion. |

| **Topic Area VI: Potential Impacts and Assessment Tools** | | | **Note: BOLD references indicate focus or site within CRNWR** |
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| **Aspect** | **Reference** | **Type of Info** | **Implications** |
| | Howard et al 1985 | National strategy for beach preservation | Outlines the problems of responding to eroding shorelines with hard structures and describes a national policy to retreat from the shoreline. A list of options for coastal management at the federal, state, local levels is provided. May be useful for CRNWR to determine if alteration of nearby surfaces, such as hard surface retention, mining for or deposition of beach nourishment sands, modification of local circulation or fluvial deposition patterns have occurred or are likely to occur and impact erosion rates. |
| Statistical Analysis Methods | Allen et al 1996 | Detecting unusual events outside the range of natural variation | Time and frequency of events that are outside of the range of natural variation can be useful in determining significant events over time, as well as determining the independence between physical events (extreme salinity, temperature) and biological responses (abundance). |
| GIS, RS, Mapping Technologies | Campell 1996 | Review of remote sensing principles | Basic info on sources and interpretation of remotely sensed images, including intertidal areas. |
| | Smith pers comm | Seafloor mapping of oyster beds and live bottom | Developing techniques to differentiate bottom types, using equipment that allows enhanced capability to interpret the bottom signal. Currently making this system portable. Setup is time consuming but surveying is rapid. |
| | Raspberry et al 1999 | Mid-Atlantic Gap Project - use of airborne videography to map land cover on barrier islands | Used to identify sites for field visits and groundtruth land cover classification of Landsat Thematic Mapper (TM) imagery for a portion of Maryland barrier islands. NWI maps needed to assist in discrimination of wet and dry vegetation. Resolution limited the separation of some vegetation alliances. |
| Data Management | Ogburn-Matthews 1999 | bibliographic, metadata | Example of data management and metadata for a study site. Facilitates comparative analysis |

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LIST OF ACRONYMS

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| BASINS | Better Assessment Science Integrating Point and Nonpoint Sources |
| CEP | Coastal Ecosystem Program |
| CCEHBR | Center for Coastal Environmental Health and Biomolecular Research |
| CRNWR | Cape Romain National Wildlife Refuge |
| EFH | Essential fish habitat |
| EMAP | Environmental Monitoring and Assessment Program |
| EPA | Environmental Protection Agency |
| FLDEP | Florida Department of Environmental Protection |
| GIS | Geographic information systems |
| HSI | Habitat suitability index |
| MARMAP | Marine Resources Monitoring, Assessment and Prediction |
| MRRI | Marine Resources Research Institute (SC) |
| NERRS | National Estuarine Research Reserve System |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NOS | National Ocean Service |
| NWI | National Wetland Inventory |
| OCRM | Office of Ocean and Coastal Resource Management |
| SCDHEC | South Carolina Department of Health and Environmental Control |
| SCDNR | South Carolina Department of Natural Resources |
| SEAMAP | Southeast Area Monitoring and Assessment Program |
| SIMS | Shellfish Information Management System |
| USC | University of South Carolina |
| USFWS | US Fish and Wildlife Service |
| USGS | US Geological Survey |

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U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
National Centers for Coastal Ocean Science
1305 East West Highway, Room 13601
Silver Spring, Maryland 20910