WATER QUALITY AND ACOUSTIC INVESTIGATION OF SHORTNOSE STURGEON HABITAT IN THE SAVANNAH RIVER

by

LAURA LYNN KNIGHT

(Under the Direction of Thomas Hodler)

ABSTRACT

The Savannah River Estuary (SRE) has historically been challenged to meet water resource demands for multiple, sometimes opposing user groups, such as the global economic engine of the Savannah Port, environmental advocates and the commercial fishing interests within the same stretch of river. Resolution of this conflict is exacerbated when the SRE's most imperiled fish, the endangered shortnose sturgeon (SNS) (*Acipencer brevirostrum*), lacks economic incentives for preservation. Unfortunately, shortnosed sturgeon have no residual commercial value from when they were over-fished to near extinction in the late 1960's for their prized roe, placing them as the first listed species of the Endangered Species Act.

Given the dwindling SNS numbers, recovery requires a plan to protect this species purely for holistic concerns over diminishing bio-diversity within the estuary. The solution, therefore, is necessarily a blend of science and policy to delineate the most threatened habitat where this species is known to exist. Primary shortnose sturgeon habitat in the SRE, however, is located within the busiest section of the port.

This study investigates identified SNS habitat to delineate and draft protective recommendations for the most at risk portions of the lower SRE, plagued by both poor water quality (low DO, high temperature and salinity) and degraded physical habitat. Water quality sampling, mid-range side-scan sonar, high-frequency DIDSON sonar and stakeholder interviews were used to map the key areas of concern. These data reflect the need to investigate and preserve unique habitat features like the single remaining fish hole located in the freshwater-tidal interface. This fish hole provides protection for many species against salinity spikes and thermal stress within the SRE Middle River.

The Georgia Port Authority and United States Army Corps of Engineers plan to expand the Kings Island Turning Basin (KITB) near this unique/rare habitat (the Middle River fish hole). Unmitigated, this expansion may alter river flows, destroying fish hole structural integrity or silting in the rich organic debris lining the bottom. This study employs ArcMap to indicate the most severely degraded habitat, potentially aiding in the prioritization of alternatives identified through the NEPA process of the Savannah Harbor Expansion Project.

INDEX WORDS: Water quality, Sonar, Acoustic, *Acipensar brevirostrum*, Shortnose sturgeon, Savannah River Estuary, Savannah harbor expansion project, Environmental policy

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DEDICATION

This dissertation is dedicated to my parents, John R. Knight (deceased) and Dorothy A. Knight for all their love, patience and unwavering support.

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Georgia Department of Geography's Center For Remote Sensing and Mapping Science, The Georgia Department of Natural Resources, The Georgia Coastal Resources Division, Georgia State University Geology Department, The Georgia Institute of Technology, The National Oceanographic and Atmospheric Administration, The Savannah Harbor Stakeholders Evaluation Group, The Sierra Club, The Center for a Sustainable Coast, The National Fish and Wildlife Service, The South Carolina Department of Natural Resources, The Richmond Hill Fish Hatchery, The Environmental Protection Agency, The Georgia Environmental Protection Division, The City of Savannah, The Savannah Division of the Army Corps of Engineers, United States Coast Guard, The Savannah Riverkeeper, The Altamaha Riverkeeper, The Satilla Riverkeeper, The Georgia Port Authority, and The Georgia Legislature.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

Introduction

The inability for an ecosystem to be sustained under current levels of environmental stress requires policymakers to understand when natural ecosystem tolerances have been breached (or nearly so). The responsibility for maintaining/restoring ecosystem health, therefore, dictates policy to be blended with sound science. Sound science recognizes potentially non-sustainable environmental changes through continuous ecosystem health monitoring regimens (Foyle et al., 2002). The current state-of-the-art monitoring for aquatic environments employs sonar to provide a physical overview of the research area.

Side-scan sonar and state-of-the-art DIDSON sonar will be employed to establish the existence and potential importance of riverine bottom features such as sand ripples, debris fields, rock outcrops, fish holes and seeps. Grounded Theory (see Chapter 3.1) provided the methodological freedom for “real-time” data to include both qualitative and quantitative approaches for analyzing scientific and culturally framed geographic data.

Cultural data were collected through a series of personal interviews with stakeholders in the environmental review process of the proposed Savannah Harbor Expansion Project (SHEP). These stakeholders form a legally recognized entity known collectively as the Stakeholders Evaluation Group (SEG). The interview participants provided cultural context and possible theories to increase the understanding of the appearance of anomalies or gaps in the physical data.

Physical Description of Study Area

The Savannah River, with its headwaters in the north Georgia mountains at the confluence of the Tugaloo and Senaca Rivers, flows some 500 kilometers southeast where it enters the Atlantic Ocean near the city of Savannah, Georgia. Typical of many rivers, the Savannah serves many purposes. First, it serves as the boundary between the states of Georgia and South Carolina where it provides recreational access for many citizens. In its reaches one finds three United States Army Corps of Engineers (ACOE) dams (see Figure 1.1). Second, the river supports shipping, agriculture, industry, and commercial fishing which contribute significantly to Georgia's economy. Third, the river provides habitat for many aquatic flora and fauna. Such uses are not always in harmony with each other and conflicts arise between these uses. Presently, ACOE, The Nature Conservancy (TNC), and others are experimenting with environmental parameters (such as river flow) to determine measures necessary to define what is required to maintain the Savannah River as a sustainable resource in order to serve all uses of the river system.

The Savannah River Estuary (SRE) begins approximately at river kilometer (rk) 72 and continues to rk 0, at the Atlantic Ocean. By the time the river reaches this estuary, it has undergone changes in its physical characteristics and has become a "complex, tidally driven system comprising multiple deltaic channels and habitats" (Duncan & Eudaly, 2003, p. 11) known as the Front, Middle and Back Rivers (see Figure 1.2). The SRE was included in a comprehensive evaluation of Georgia's coastal health,[1] where eighty percent of Georgia's estuarine resources were rated as "fair" (Guadagnoli et al., 2005, p. 4). The Savannah River estuary, however, was listed as an "impaired water" by EPA because of seriously low DO levels that created frequent hypoxic conditions for many native species of fish (see Figure 1.3).

Figure 1.1. The Savannah River. Source: Duncan & Eudaly, 2003.

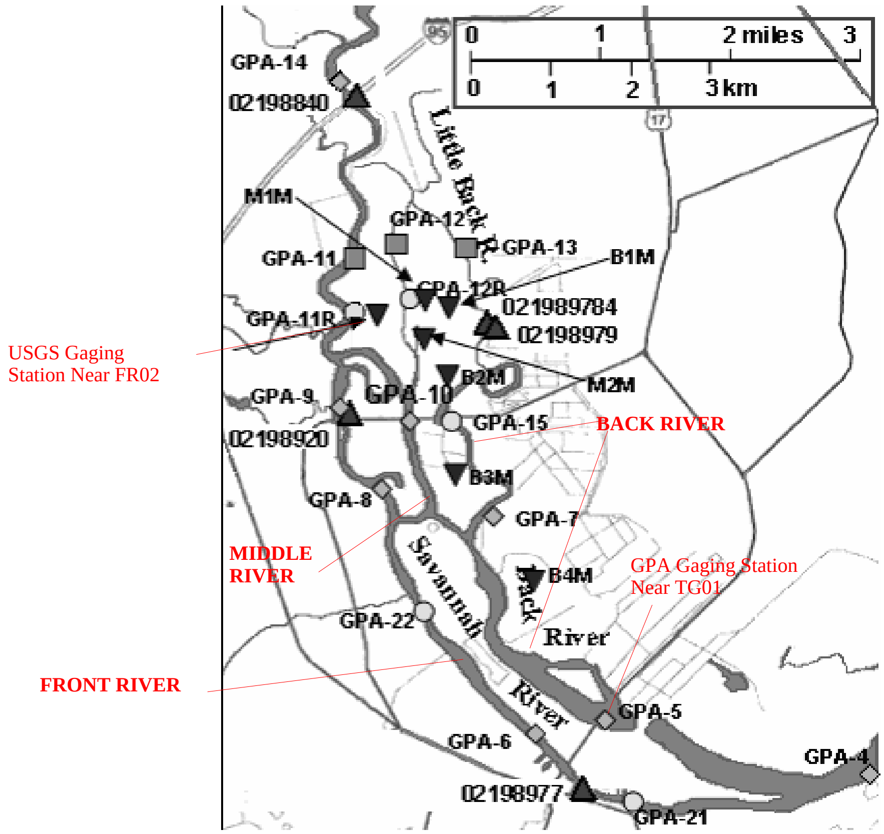


Figure 1.2. United States Geological Survey (USGS) and Georgia Port Authority (GPA) Gaging sites showing Savannah River Front, Middle and Back River Channels. Channels indicated in red. Source: USGS.

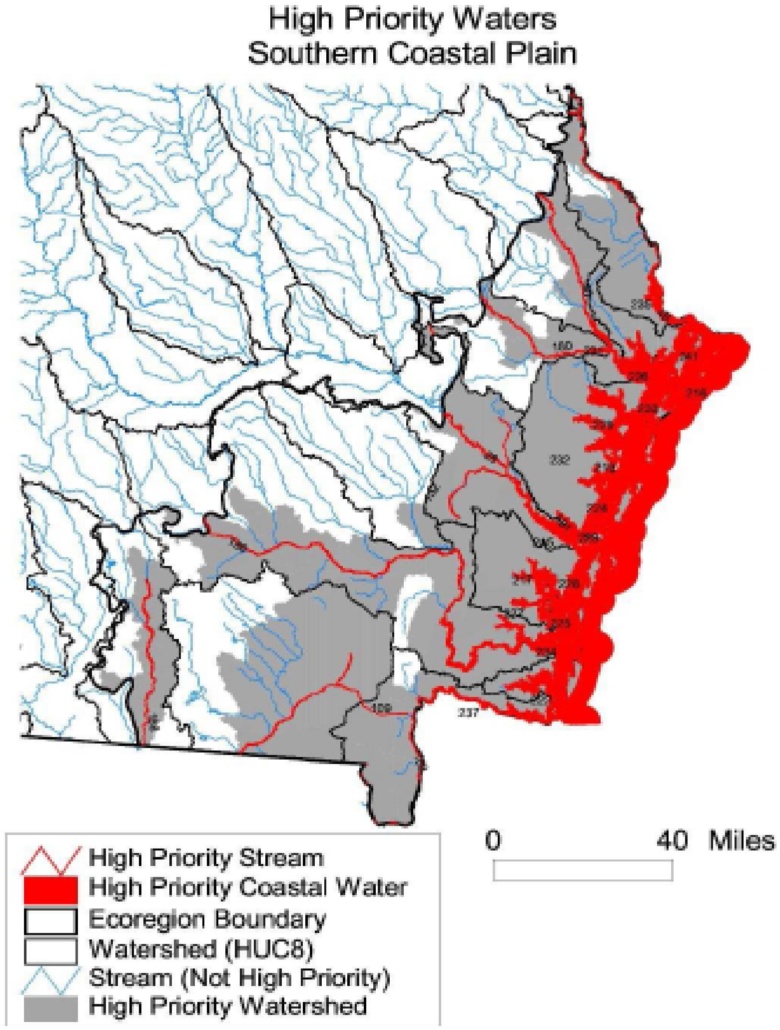


Figure 1.3. High Priority Waters in the Southern Coastal Plain. Source: USGS.

Specific SRE water quality problems were highlighted as problematic for the survival of Striped Bass (SB, *Morone saxatilis*), Atlantic Sturgeon (AS, *Acipenser oxyrhynchus oxyrhynchus*), and Shortnose Sturgeon (SNS, *Acipenser brevirostrom*) among others (Reinert, 2003).

Water quality concerns within the SRE are typically monitored in terms that have been linked directly to species mortality (LC_{50})[2], particularly for the endangered shortnose sturgeon (SNS), where salinity, DO and temperature predict the survival rates of the most vulnerable juvenile populations (Jennings, 2005). Rainfall/river flows must also be considered in evaluating WQ, particularly when evaluating comparisons between drought and non-drought years. River discharge for the Savannah River is estimated to be between 22.7 and 27.3 million liters per minute (lpm) during periods of normal rainfall and is considered to be a high priority waterway within the state.

Background

The SRE and the Georgia coastline are protected by nine major and five minor barrier islands with a characteristically moderate to high tidal range of 2-3 meters. Near the city of Savannah, the wide, shallow and gently sloping continental shelf provides a low energy environment as wave energy dissipates to calm swashing on the leeward side of these barrier islands. The Savannah River has a relatively large freshwater discharge (when compared to Georgia's four other coastal rivers) that is characterized by clay-type sediments, a high carbonate content and relatively high ph (Daamen et al., 2006).

Although anthropogenic activities may substantially contribute to the SRE carbon footprint, the intertidal zone supports a large array of both plant and animal species that are also believed to contribute considerable amounts of organic carbon to the estuary, potentially having a negative impact on the supply of available dissolved oxygen (Odum, 1969). Other natural vegetation may enter the estuary at high tide, adding to the biological oxygen demand (BOD) required to break down such organic material.

Spartina (S*partina alterniflora*) is the most common marsh-grass (*Graminoid*) found in the SRE intertidal mud-flats, although drought and saltwater encroachment are suspected to have caused an unprecedented loss of over 40 hectares of this marsh-grass in the late 1990s (Duncan & Eudaly, 2003). The energy dissipation and resulting sediment deposition on these mud-flats provide critical nutrients for vascular plants, algae and phytoplankton. The transport and subsequent deposition during inundation from high tides, storms and flood events provide a constant food supply for aquatic life. Extreme historic river modifications over the past one hundred-plus years have provided an improved economic return from riverine activities, however, physical modifications such as straightening, damming, deepening, and dredging have created new ecological challenges to maintain the water quality of the Savannah River.

Each anthropogenic physical change in the river may require other activities in order to maintain the ecological balance. For example, the negative effects from dredging in the interior SRE channel increase the importance of maintaining adequate river flow so that aquatic species can maintain access to their upstream nutrient rich habitat (Wrona, 2005, Wrona et al., 2007). Recreational fishing, although economically important to the area, has declined in recent years and generated "special concerns about exacerbating the sciaenid family of spawning stock reductions due to: (1) direct dredging mortality; (2) acoustic disruption of spawning aggregations; or (3) reducing the acceptability to the fish of any presently utilized spawning sites through alterations to the bathymetry, flow characteristics or physical features" (Collins et al., 2000A).

Scientists from The Nature Conservancy (TNC) are currently experimenting with timed and measured flow enhancements via dam release pulses, to balance the Strom-Thurmond Dam impacts on natural flow regimes of the lower Savannah River. Such regimes are used for hydro-electric power generation and navigation with minimum mean base flows ranging from 4000 cfs to 8000 cfs, depending upon rainfall, seasonal ecological demands and aquatic species spawning patterns (Duncan et al., 2003). Savannah River flow rates are also manipulated and designed to include scientifically applied high pulses and floods of an estimated 10,000 - 50,000 cfs on the Savannah River. Maximums are 36,000 cfs during power generation at Strom-Thurmond Dam for two week durations. These extra flows provide striped bass spawning and egg transport and help control oyster and crab parasites. Additionally, higher flows increase flood plain inundation resulting in increased spawning and floodplain habitat for fish (Meyer et al., 2003).

Despite scientific flow models, flow recommendations are difficult to prescribe because the SRE contains a variety of habitats that support a diverse fish population of greater than 92 species. Some of these species, such as the SNS, are very particular about flow velocities and water temperature. The SNS have been negatively impacted by velocities that were too fast for egg fertilization and larval migration to protected habitat, or conversely, too slow to avoid egg "clumping" and fungus growth (National Marine Fisheries Service [NMFS], 1998).

The proposed water flows for the river must consider the life history/stages for each of the selected species, creating tough trade offs for establishing ideal flow regimes between species. For example, changes in flow and salinity tend to favor fecundity recovery for Striped Bass. By contrast, SNS are most affected by dredging operations that cause habitat degradation and low dissolved oxygen (DO) threats to water quality (Duncan & Eudaly, 2003). Similarly, providing adequate flows for American Shad, Striped Bass and Atlantic Sturgeon may have negative or unpredictable consequences for one species and desirable consequences for another. Additionally, river discharge and flow rates are important for flushing contaminates from estuaries, maintaining salinity mixing regimes, balancing sediment load transport of nutrients and providing gravel substrate for spawning habitat further up river.

Despite the attempts to create restorative flows, however, some scientists believe that the degree and frequency of flooding events will not recreate the original habitat and species distribution of pre-dam flows (Meyer et al., 2003). Although river flow is inextricably linked to water quality, the precise mechanisms that provide cause and effect data are not defined and require constant revision in even highly sophisticated water quality models such as those currently proposed by The United States Environmental Protection Agency (USEPA). Given this technical limitation, it is best to proceed with a variety of data inputs to create more realistic models. Water quality data, for example, may be enhanced and given a physical context by adding additional variables such as specific habitat features obtained through sonar or river sediment data (see Chapter 4).

Multi-variate computer models may include elaborate combinations of variables that may consider complex interactions, making analysis of individual statistically significant changes difficult to delineate (e.g., the models are not user friendly and have no lay translation for the public at large). Temperature, salinity and dissolved oxygen (DO), however, are minimally employed to characterize water quality for a snapshot understanding of general conditions. Consideration of only one variable at a time, however, may not necessarily reflect the unpredictable and potentially lethal synergistic combinations that may occur for aquatic species (Flournoy et al., 1992). The critical values of each variable change according to the specific target species and life stage, but general water quality conditions are reliable predictors of fish and other aquatic species' health and mortality within a specified river reach (Jenkins et al., 1993).

Some studies have focused on salinity regimes as a means of categorizing specific species responses to environmental changes. Salinity preferences of many species in the estuary range from tidal freshwater (<1.0 Practical Salinity Units (PSU)) to mesohaline (5.1- 15.0 PSU) (Jennings & Weyers, 2002). Shortnose sturgeon have been reported to suffer stress and higher mortality rates when low DO concentrations are exacerbated by high temperatures (>28 °C) (Flournoy et al., 1992; Rogers & Weber, 1994). Specifically, a synergistic effect was noted in fish stress/mortality when DO concentrations were low (below 3 mg/l), temperatures were high (22 degrees C and higher) and salinity exceeded 15-17.5 PSU (Collins et al., 2000A). Regardless of which SRE flow prescription is implemented, policy decisions require historic water quality data and continually demand new strategies for future water quality monitoring and modeling. Currently, the Georgia Environmental Protection Division (EPD) is focused on the low DO problems within the Savannah River basin extending from Augusta to the Savannah River Estuary. This statewide focus on DO relates to both point and non-point sources[3], including natural and anthropogenic causes for low DO. The scientific community from within the Savannah River Basin must implement a dramatic increase in levels of DO to meet current water quality standards and allow for future wastewater discharge permits or proposed Savannah Harbor improvements (Georgia EPD, 2006).

Purpose of Study

This study explores both quantitative scientific and qualitative cultural data to assess the geographic distribution and cultural significance of a variety of ecosystem features within the Savannah River Estuary that may be linked to overall ecosystem health and sustainability.

Specifically, this study examines original[4] water quality data, SNS habitat data, mid-range frequency side-scan sonar and DIDSON high frequency sonar data to create a more complete picture of which SRE ecosystem functions are either threatened or non-existent as a result of ongoing modifications to the lower Savannah River. Additionally, this study provides water quality data from a normal rainfall period that occurs between time periods of previously published SRE sensitive habitat studies and documented drought years.

Interviews were conducted with Savannah Harbor Expansion Project[5] Stakeholder Evaluation Group (SEG)[6] participants in order to fill in gaps in the data concerning water quality monitoring requests as mentioned in the recent state publications as, "*2006 Coastal Georgia Water and Wastewater Permitting Plan for Managing Salt Water Intrusion*" and "*Draft Statewide Comprehensive Water Management Plan*" (Georgia EPD, 2007). Specifically, findings from these interviews and this dissertation's water quality research provide a geo-spatial analysis of current water quality concerns relating to salinity, low DO and critically impaired habitat for the endangered shortnose sturgeon. These data will be useful in designing future policy decisions relating to optimum placement of proposed SRE navigational improvements as outlined in the environmental impact statement (EIS) mitigation requirement of the National Environmental Policy Act (NEPA) and regulatory requirements promulgated by the Endangered Species Act (ESA). Lastly, this study helps delineate unique SRE habitat features that may require additional attention to retain their sustainable role in SRE ecosystem health. The most salient example concerns the importance of protecting a threatened fish hole in the Middle River that has been documented as critical habitat or nursery areas for the endangered SNS and other threatened species (Collins et al., 2000B).

Objectives

The objectives of this study (see Table 1.1) include the following:

1. Identify and map/highlight problem shortnose sturgeon (SNS) habitat areas.
2. Spatially delineate habitat features possibly related to ecosystem functions.
3. Spatially delineate regions possibly related to cultural heritage within SNS habitat.
4. Determine protective strategy for delineated features.
5. Provide scientific and culturally relevant recommendations.

These objectives are specific to an approximately 27 kilometer stretch of the Savannah River Estuary beginning from the confluence of the Front and Back Rivers near Fort Jackson to the lower reaches of the National Wildlife Refuge near the I-95 Bridge. This area was selected on the basis of previous studies conducted by Collins, Smith, Rogers and others, to determine the presence, location and habitat health of SNS. Since shortnose sturgeon were found to be present in this segment of river almost year round, it represented an excellent location to learn more about their habitat preferences and possible factors contributing to their habitat degradation.

This study provides sonar bank-to-bank investigation of SNS habitat regions identified with poor water quality from past studies and cultural interviews. Additionally, the data collected for this study are featured on maps to delineate geographic hot spots, where water quality is so severely impaired, healthy SNS tolerances are exceeded for early life stages. Sonar identification of physical features that may provide refuge from temperature and salinity spikes is also recorded.

Finally, these data provide sufficient evidence of the need to preserve the rare features in the freshwater tidal interface that offer protection from extreme conditions (temperature and salinity spikes when they occur). These features, such as the Middle River fish hole, are unique

Table 1.1

2003 Water Quality Study Objectives

Objective	Location	Purpose
1. Identify and map/highlight problem SNS habitat locations	Savannah River Estuary	1. Delineate low DO hot spots 2. Map DO and temperature behavior in SRE (see Chapter 4)
2. Spatially delineate habitat features possibly related to ecosystem functions	Savannah River Estuary	1. Identify current location of rare SNS habitat features (e.g.- fish holes) 2. Identify current location of critical characteristics of SNS habitat (e.g.- stumps, logs, gravel, rock outcrops) 3. Identify current location of freshwater seeps or other thermal features (see Chapter 4)
3. Spatially delineate regions possibly related to cultural heritage within SNS habitat	Savannah River Estuary	Identify current location of possible cultural artifacts (e.g.- sunken boat hulls or rice trunks from rice plantation era) (see Chapter 4)
4. Determine protective strategy for delineated features	Savannah River Estuary	Trigger possible habitat protection under NEPA or ESA (see Chapter 5)
5. Provide scientific and culturally relevant recommendations	Designed for inclusion in Tier II Draft EIS	Mitigate potentially negative impacts to SRE ecosystem sustainability, particularly concerning the health of the endangered SNS (see Chapter 5)

to this freshwater tidal interface region of the lower estuary, an area preferred for habitat by the endangered SNS and other sensitive species (Collins & Smith, 1997). The protection of such rare features may augment efforts to restore the seriously dwindling numbers of SNS within this lower Savannah River Estuary population segment. Additionally, sonar surveys (Klein 3000 mid-frequency sonar and DIDSON high-frequency sonar) conducted across the Front, Middle, and Back River portions of the lower SRE provide a quick, cost-effective overview of substrate materials, seeps and other clues to aid in the monitoring of ecosystem health.

Endnotes

[1] *The Condition of Georgia's Estuarine and Coastal Habitat 2000-2001* highlighted the SRE's problems with salinity encroachment and low DO.

[2] LC_{50} refers to the lethal concentration at which fifty percent of the test subjects die when exposed to the test treatment. Generally, water quality regulations implement margins of safety in water quality parameters using this figure.

[3] Recent Savannah River sediment analysis data indicate that overall contamination is lower than pre-regulatory levels, however, this same data also indicate that non-point source trace amounts of DDT and Chromium are migrating deeper into the estuary than ever recorded (Alexander et al., 1997).

[4] The water quality data, sediment data, side-scan sonar and DIDSON sonar data used as the basis of this study were collected by Laura L. Knight with cooperation and assistance from the Georgia Department of Natural Resources from January 2002 through November 2004.

[5] The Savannah Harbor Expansion Project was pre-authorized by Congress under the Water Resources Development Act in 1999. Proposed improvements will deepen the harbor to a proposed maximum of 48 feet and expand some existing features, such as the King's Island Turning Basin. Final approval is contingent upon additional analyses and approvals required in the authorization and the USACOE's Chief of Engineers Report. A Tier II Environmental Impact Statement (EIS) must be completed and the project (and mitigation plan) must be approved by the Secretary of the Interior, Secretary of Commerce, Administrator of the United States Environmental Protection Agency, and the Secretary of the Army before construction can begin (SEG, 2001).

[6] The Stakeholders Evaluation Group was established under the mitigation requirements of the National Environmental Policy Act (NEPA) as part of the pre-approval authorization requirements of federally funded projects.

CHAPTER 2

LITERATURE REVIEW AND CONCEPTUAL SETTING

Overview

This research integrates the multi-disciplined perspectives of Geography, Environmental Policy and Marine Science for its theoretical underpinnings and scientific method. Despite the differences between the analytical approach used to extract conclusions, these disciplines share the common objective of capturing scientific data to support varying degrees of environmental protection for the land and adjacent water bodies within the designated research area, the Savannah River Estuary (SRE). This research is also tasked with providing a deeper understanding of what physical attributes of the SRE are critical to achieve potentially conflicting riverine functions.

The SRE has been physically altered over the past one hundred and seventy-five years, most appreciably, when navigable channels were widened beginning in the late 1820’s from 150’ to 300’ and deepened from depths around 8'-10' to 13'-17' (Propeller Club, 2006). These changes and many to follow have required ongoing modifications in the river sinuosity, main channel depth and width, and a host of specific modifications deemed necessary to support industries and commerce that have been reliant on its maintenance as a navigable waterway. A review of relevant literature reveals hundreds of documents published by the United States Army Corps of Engineers, local government, academia, environmental groups and private industry that reflect a history and outcome of many changes along the way, most notably, the installation (1977), then subsequent removal of a tide gate (1991) (Pearlstine et al., 1993).

The problems identified during the operation of the tide gate invited intensive SRE scrutiny, eventually leading to the closing of New Cut (a former connecting channel between Back River and Middle River) in the first bend of Middle River. The river modifications to the Middle River sinuosity and velocity are potentially responsible for a scour hole in the first bend of the Middle River (Kjerfve et al., 1979; USFWS, 2004; Zingmark, 1978). The earliest maps documenting this hole are dated in the middle 1980s (Personal inspection of maps/T-sheets from NOAA/ Skidaway Institute of Oceanography in Savannah, Georgia and publicly available U.S. Coast Guard maps dating back more than 30 years). The closing of these ACOE projects marked the beginning of the modern SRE configuration (save some additional dredging activities) (see Figure 2.1).

Problems ranged from unacceptable levels of salinity that threatened local populations of striped bass and sturgeon (Howell et al., 1999), to claims that changes in tidal influences were responsible for the rapid decline and projected demise of indigenous marsh grasses and the habitat they supported (Pearlstine et al., 1993). Dieback of tidal freshwater wetlands were also cited in numerous Federal Water Conservation Act reports throughout the 1990s as a result of high salinity levels in the estuary exposed to tidal influences extending approximately to rk 45 (Alber & Flory, 2003). Salinity concerns escalated, despite encouraging signs of wetland and habitat recovery following the tide gate closure because salinity level decreases that promoted wetland recovery were being offset by additional harbor deepening activities overseen by the ACOE (Eudaly, 1999).

Figure 2.1. Aerial Photo of Middle River's Fish Hole in Front of New Cut (now closed). Source: USGS 1999 Topographic Quadrangle.

Additional studies examined drought conditions during 1998-2002. Lack of normal rainfall contributed to salinity extremes that were responsible for a wave of lethal opportunistic dinoflagellate parasites (*Hematodinium perezi*) affecting the Blue Crab population in the SRE and adjacent tidal rivers (Lee and Fischer, 2004). Mosquito larvae numbers exploded by the year 2000, disrupting normal ecological cycles (Kaiser, 2003), leading to one of the toughest seasons for fishermen and tourists. The low flow conditions also exacerbated DO levels and placed the SRE on Georgia's Section 303(d) list for waters that do not comply with current water quality standards (Stakeholders Evaluation Group [SEG], 2006).

The United States Army Corps of Engineers has been tasked with reviewing engineering reports from consultants, government and academia to provide relief to the most DO stressed parts of the estuary, generally identified to exist in portions of Back River and from Front River near Houlihan Bridge (approximate rk 36) to the Atlantic Ocean (SEG, 2006) (see Figure 2.2). Complex experimental hydrology models suggested low DO impacts could be mitigated by injecting dissolved oxygen into the river where greater depths from proposed additional dredging threaten to cause DO levels to deteriorate further (SEG, 2006). Despite the large-scale development of this mitigation effort, critics contended the model data were either invalid, incomplete or biased to favor economic rather than environmental considerations (Kyler, 2003).

The actual validity of the currently proposed DO injection mitigation efforts by the United States Army Corps of Engineers may be irrelevant if alternative mitigation strategies can be co-developed to provide more natural restoration of the river to its "original" state[1] (Wrona, 2005). Findings from several workshops sponsored by The Nature Conservancy suggest restoration of the river's sinuosity in portions of the Savannah River as a more viable solution for the environmental protection of threatened riverine species such as the endangered shortnose

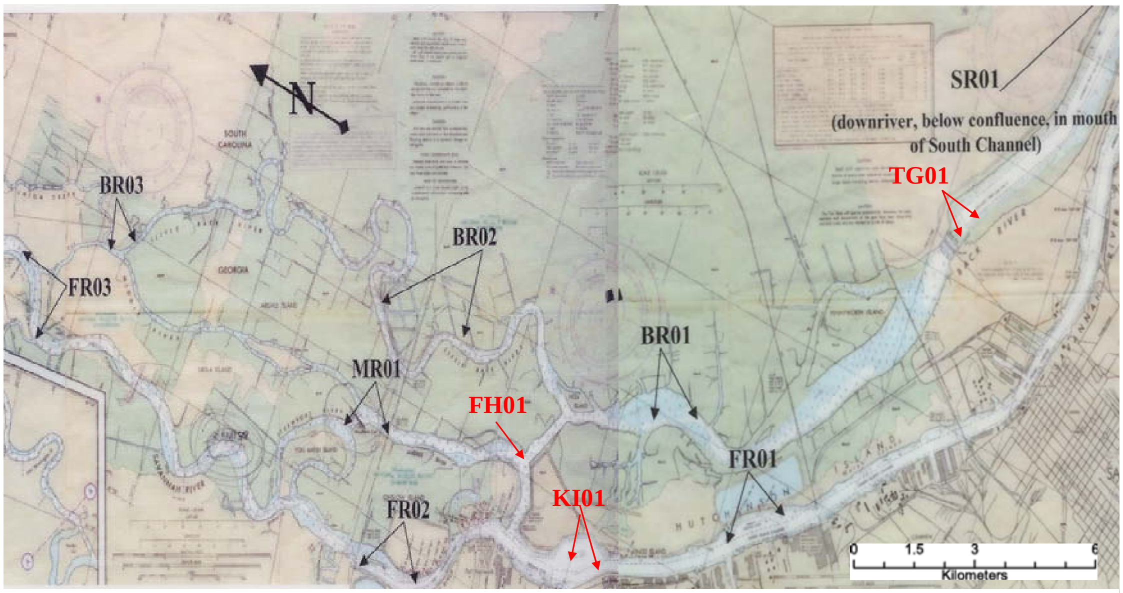


Figure 2.2. Study Research Area. Source: NOAA Nautical Chart 11514
Note: Sample sites shown in red were added in this study to original sample locations used in the Collins, 2000A study.

sturgeon and the recently threatened striped bass (Jennings & Weyers, 2002; Reinert, 2003). Both of these fish have been the focus of efforts to prevent further degradation of water quality or riverine habitat (Howell et al., 1999). The larger issue of protecting water quality, however, underpins concerns to protect certain species such as shortnose sturgeon. Some sturgeon are thought to be a modern day “canary in a coal mine” within specific river reaches, typically because they provide an early alert system about pending serious declines in ecosystem health and the possible loss of genetic diversity from habitat degradation or disruption (Brownell, 2005).

Shortnose Sturgeon in the Savannah River

Wild shortnose sturgeon (SNS) exist in relatively small numbers in the Savannah River (estimated to be fewer than 500 adults) (Collins & Smith, 1997) when compared to the other 19 geographically distinct population segments than run south along the North American east coast from the St. John River in Canada, to the St. John’s River in northern Florida (National Marine Fisheries Service [NMFS], 1998). Although other degraded habitats exist (for example, Cape Fear, N.C.), the Savannah River had been identified for having nursery and spawning grounds for shortnose sturgeon (Hall et al., 1991). Additionally, the Middle River and parts of the Front River have been documented to harbor fish holes, where shortnose sturgeon (*Acipemser brevirostrom*), Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*), American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*) have been either seen or captured (Collins et al., 2000B).

Although the importance of these fish holes has been debated by biologists, general consensus suggests they provide thermal refuge, protection from predation and/or protection from salinity spikes during storm events and prolonged periods of drought (Collins et al., 2002).

It was not clear whether or not the Savannah River fish were still using the fish hole and nursery areas after a succession of maintenance dredging activities, tide gate closure and new cut closure that had taken place by 2000 (Bailey, 2002). The South Carolina Department of Natural Resources was commissioned by the United States Army Corps of Engineers to conduct additional studies to provide guidance about fish population and distribution within the SRE (Collins et al., 2002). This study was designed to investigate the possible destruction of important fish habitat feeding and nursery areas identified in earlier studies (Collins & Smith, 1993, 1997).

Habitat disruption may partially explain why recruitment of juvenile SNS continues to decline, despite massive efforts by the Georgia Department of Natural Resources (GADNR) to replenish local populations using hatchery-reared stock during 1985-1992 (Collins et al., 2000B, Collins et al., 2002). Although fish stocks were determined to be higher than in the late 1980s to mid-1990s, poor recruitment of juveniles confounded a clear picture of what was happening with native SNS (Collins et al., 2000C). Beyond 2000, there were no records of what habitat features still existed in both the Front and Middle Rivers of the SRE. Specifically, the SRE fish (including the endangered SNS) may have moved further up river, abandoning the fish hole they had been identified to occupy in earlier studies (Bailey, 2002). More current studies were required to ascertain both the continued existence and functionality of the fish holes mentioned in previous studies.

Conceptual Framework for Further Study: Grounded Theory

Grounded theorists employ unique and potentially conflicting approaches to conducting scientific inquiry; therefore, it is useful to find a loose theoretical framework to provide unity. Grounded Theory (GT) (Glaser & Strauss, 1967) was selected for use in this research because there were many unknowns regarding what research path would be the most fruitful, given the scope and complexity of the problems to be investigated, such as what was causing the decline in SNS populations in the SRE. Grounded Theory provided a flexible and objective method of research. Specifically, GT differed from traditional scientific inquiry because a “scientific approach” is based upon *a priori* assumptions that are formulated into hypotheses testing for a probabilistic outcome. Grounded Theory, by contrast, “is grounded by the data” (Glaser & Strauss, 1967) irrespective of the probabilistic occurrence of any recorded phenomenon (outliers are not considered non-existent). The scientific underpinnings of GT suggest that theories must be constructed in order to explain or understand phenomena, specifically, well constructed GT is: (1) inductively derived from data; (2) subjected to theoretical elaboration; and (3) judged adequate to its domain with respect to a number of evaluative criteria (Haig, 1995).

Grounded Theory is designed so that collection of data drives discovery and discovery also drives the decision to develop the data in a particular direction, specifically, when a potentially explanatory variable, for example, fish habitat data, is missing or needs further consideration. The reversibility of data collection decisions allows the researcher to explore multiple paths to investigate a phenomenon of interest. A multi-dimensional approach provides “real time” data correction when research paths become blocked or are not helpful in achieving general research objectives. For example, if the general objective is to find out what may be mined of value in a particular location and that location does not produce any relevant data, another location may be explored or a new directive may be created on the fly to gather another type of data than what was originally proposed at that location.

The ability to capture central themes as they change or assert new priorities provides a dynamic framework for building current and culturally relevant theory (Pandit, 1996). Research flexibility is important because of the temporal and transitional quality of real-time data collection. Reworking hypotheses in empirical research, by contrast, may potentially create time lags between events and how they are perceived or recorded for analysis.

In the Savannah River, for example, there may be more serious threats to fish habitat than what is known. Grounded Theory allows a field researcher to adapt exploration efforts in live time to focus on any subject that may be suspected as responsible for habitat decline, regardless of whether the new direction of research is anticipated or not. The applied use of all types of data that may be collected during exploration (qualitative and/or quantitative) are considered equally important as data input. The triangulation of these multiple inputs leads to the development of theory directly from the convergence of data.

Grounded Theory Applied .

Grounded Theory uses concepts as basic units for analysis of data (Strauss & Corbin, 1998). Data consist of the incidents, events and happenings that are analyzed as potential indicators of phenomena, which are thereby given conceptual labels. The conceptual labels outline emerging theories that may justify additional investment of time and resources in a particular direction. For example, the unexpected verification of a fish hole in the Middle River could provide scientific justification to investigate the contents through multiple techniques. The inclusive observation of this river feature may lead to an increased understanding of overall ecosystem function. Traditional scientific methods relegate this type of emergent data to future studies if discoveries do not fit within the pre-selected parameters of what must be investigated. Hypothesis testing in the traditional scientific method has no mechanism to address the immediacy, breadth and significance of unexpected relevant findings in field research .

Grounded Theory was the best theoretical framework because it highlighted the importance of using qualitative and quantitative data. Grounded Theory's self-corrective design was an appropriate choice for multi-disciplined research because it is useful with any mix of data, and it is particularly suited to incorporate contextual qualitative data (Strauss & Corbin, 1998). Grounded Theory allowed flexibility in combining data from interviews with data from empirical studies. The use of one source of data supports the collection of additional data. Salient regional issues expressed by the Stakeholders Evaluation Group (SEG)[2] established a baseline for emergent theories. This Grounded Theory process generated insight into current water quality concerns, specifically, providing a hierarchy of inquiry that eventually led to the decision to investigate habitat management for SNS.

Additional Theoretical Perspectives

The Savannah River Estuary must serve many purposes; economic, recreational and aesthetic. Competing interests on the river demand sustainable ecosystem health, but each use requires varying degrees of ecosystem health. The Clean Water Act (CWA, Section 319(h) of the 1990 re-authorization and amendments of the Coastal Zone Management Act) provides some non-point source (NPS) water quality guidelines under the NEPA process, but the existing best management practices lack a unity in focus, specifically, regarding which ecosystem features and functions must be sustained. The greatest difficulty, however, is deciding what level of functionality should be sustained for a specific site (Bien et al., 2001). Inherently, the development of environmental policy (including for the Savannah River) borrows from established doctrines of Sustainability Theory[3]. Sustainability requires a pragmatic philosophy for mediation between scientific doctrines and ordinary language (Norton, 2005). Mediation is also necessary to forge sustainable compromises between existing user groups and nature preservationists.

Sustainability Theory echoes central themes identified by many early 19th century environmentalists such as Sierra Club founder, John Muir and ecologist, Aldo Leopold. John Muir spent most of his life observing nature and recording his scientific observations in the popular media of the day. Aldo Leopold was scientifically trained, yet his most seminal work, *A Sand County Almanac* (1949), was written in prose and non-technical language to invite non-scientists into the fold of stakeholders as future environmental stewards. Leopold's famous essay, "The Land Ethic" (Leopold, 1949) emphasizes the importance of extending the social conscience from people to land by evaluating holistic systems that hold economic activities accountable for their environmental "costs." Environmental "costs" are not universally defined in the real world (Norton et al., 1998), so stakeholder groups such as the Savannah Harbor SEG create open dialogue. This discourse is designed to develop a list of concerns that will ultimately require editing and weighting to achieve some mutually acceptable level of sustainable ecosystem health.

The weighing of competing interests begins with the extremes (such as no development versus full development) and gradually moves toward the center in sustainable development doctrines. Sustainable development for the United Nations is defined as a polluter pays doctrine (United Nations Report of the World Summit on Sustainable Development, 2002), where economics and environmental integrity are forced to compete. Savannah River Estuary scientists, however, believe there may be no tolerance for weighing critical ecosystem functions, suggesting, for example, that DO impaired waters are not acceptable under any circumstance in the lower Savannah River.

Sonar Use for Mapping Fish Habitat

Although the history of sonar began in 1906 with the discovery of the hydro-phone for locating icebergs (Boyle & Rawlinson, 1928; Richardson, 1912), current sonar technology is largely a reflection of the scale and economic considerations of the intended research. Research conducted over a large area requires long range sonar, but the physical size of the object(s) under investigation determines the required resolution, which may be modified over subsequent iterations of data collection.

The use of sonar in fish studies was virtually undeveloped until the late 1970's , when researchers from Rutgers University and the University of Connecticut teamed up with geologists from USGS to try to provide an integrated approach to mapping fish habitat (Reynolds et al., 2001). They combined visual observation studies with rudimentary sonar data to explore linkages between fish habitat and their geophysical surroundings. The deployment of multi-beam sonar[5] provided both the range and resolution not obtained through Remotely Operated Vehicle (ROV)[6] investigations. Observations were made using ROVs; however, for groundtruthing activities. Although some optical sea floor images were used in the interpretation of the sonar data, the ROV data were both limited in scope and widespread applicability (Reynolds et al., 2001).

One 1991 study, conducted in Monterey Bay, California by the West Coast & Polar Regions Undersea Research Center was particularly instrumental in broadcasting the early success of habitat/species delineation studies. The Monterey Bay study inadvertently stumbled upon examples of commercially targeting species in great numbers in a large canyon filled with a series of rock outcrops sandwiched between smooth layers of mud and gravel. This canyon extended across many kilometers and was discovered as a result of the use of side-scan sonar

(Reynolds et al., 2001). This study revealed new possibilities for providing protection for the highly commercially viable rockfish, now suffering serious declines in nearby over fished straights (Dartnell et al., 2005). Follow-up studies employed low frequency (150 kHz) side-scan sonar[7] to map these refuge regions and provide very specific information about where to perform grab samples[8] to characterize substrate materials. Although groundtruthing was still required by diving expeditions into the region, clear sonar images revealed specific rock outcrops as targets for future studies.

The standardization of habitat schemes is challenging across different research objectives, geography and subject matter, specifically, regarding meaningful comparisons between vastly different research area topography. Despite the difficulty, universal delineation of protocols and techniques were applied across a series of studies performed off the southwestern coast of Nova Scotia to map the benthic habitat of a multitude of species. These studies established five key criteria: substrate type, taxonomic data, habitat complexity (sediment grain size and topography), prevailing currents and depth[9] (Kostylev et al., 2001). Although satellite data were used extensively for monitoring visible changes across the Chesapeake Bay coastal region over a five-year period in the late 1980s through the National Oceanographic Atmospheric Administration's Coastal Change Analysis Project (National Oceanographic Data Center [NODC], 2009), side-scan sonar, grab samples and underwater photography were used to create detailed maps that provided the basis for an official NOAA characterization of marine habitat types (Lucieer, 2008). Maps provide meaningful comparisons of data between studies, easing confusion surrounding the yet non-standardized marine nomenclature for establishing widespread generalization of study findings (Parks, 2002).

Establishing Need for Pilot Study Research

The standardization of habitat types, despite the advantage of comparability, lacks the Best Management Practices (BMPs) approach to establish relevant regional fisheries management solutions. Differences in scale between study regions are subject to temporal discontinuities ranging from short term disruptions, such as salinity intrusion, to long term disruptions that may include the introduction and succession of non-native or invasive species. The temporal scale of the habitat characterization is also subject to dramatic weather events, changes in environmental policy, funding shortfalls and many other potentially devastating obstacles.

To lessen the impact of some unavoidable deterrents (e.g., the SEG was not yet familiar with the forthcoming research), it was logical to begin with a pilot study. Although the pilot study was not intended to delineate physical fish habitat, this early research and qualitative data collection suggested the final dissertation research should include some measurable or spatial scientific analysis that was a product of both physical and temporal scale considerations of the SRE. Chapter 3 reviews the research methodology and participant observation study findings from the pilot study as they established the research design and general objectives for the dissertation research to follow.

Endnotes

[1]"Original" is controversial because it is unlikely that there exists records to indicate the ecosystem details that make such assertions possible. Additionally, the temporal scale for "original" restoration is dynamic and imbued with both natural and manmade modifications. It is reasonable to interpret "original," however, in terms of desirable natural elements (oxbows and substrate) from the past river configurations that existed prior to broad-scale navigational straightening.

[2]The Stakeholder Evaluation Group was set up under the National Environmental Policy Act (NEPA) as a mitigation tool for preventing potentially deleterious environmental impacts among user groups and to provide a direct open public dialogue after the 1999 congressional pre-authorization of the Savannah Harbor Expansion Project (SHEP).

[3]Dr. Bryan Norton has championed concepts of sustainability in his publications since the late 1980s. He broadly defines its' tenants to include: a relationship between economic and ecological systems such that "(a) human life can continue indefinitely; (b) human individuals can flourish; (c) human cultures can develop; but in which (d) effects of human activities remain within bounds so as not to destroy the health/integrity of the environmental context of human activities" (Norton, 2005).

[4]Sonar is an active remote sensing technique that measures the time interval between when an electronic signal (ping) is sent, to when it is received back to the sending unit. This time interval is repeated with varying frequency to produce either short, frequent readings (1.0-1.8 MHz) for targets in close range, or long, less frequent pulses for general reconnaissance (150-500kHz).

[5]Multi-beam sonar uses an array of electronic pulses arranged in accordance to the desired echo characteristics, e.g., wide or narrow angles for target coverage.

[6]ROV are remote controlled robotic submarines that are typically equipped with high-resolution cameras, monitoring instruments and some type of robotic arm or sampling device.

[7]Side-scan sonar is deployed from either a missile-shaped tow-fish suspended from the hull or suspended from a side-mounted pole on a boat. It is so named because the output data shows sonar data from the port and starboard sides of the boat as it drags the suspended tow-fish through the water.

[8]Grab samples are measured samples taken from the substrate. They are typically characterized according to substrate material, faunal composition, sediment size and location.

[9]Depth profiles were completed by multi-beam sensors to provide contour information and other geophysical data about the Scotian shelf.

CHAPTER 3

PILOT STUDY

Purpose

The purpose of the pilot study was to narrow the dissertation research focus and identify the best methods to collect geo-spatial water quality data and qualitative contextual data toward the development of regional water quality public policy. This study included: the evaluation of progressive iterations of relevant qualitative interview data, a video journal of significant findings from participant observation studies, and recommendations for potential alternatives to current environmental policy decision-making. A Naturalism[1]/Ethnomethodology framework was used to evaluate both the content and the social setting of the interview (Gubrium & Holstein, 1997). Additionally, Naturalism captured insights regarding the perceptions of 12 potentially impacted stakeholders in the wider issue, the proposed expansion of the Savannah Harbor. These interviews were subject to IRB approval and the ongoing consent of the research participants.

The relationship between qualitative and quantitative data was examined through the identification of common geographic origins within and across narrowly defined geographic regions, such as the SRE project area as previously defined and investigated in numerous studies by Mark Collins (fisheries biologist with the South Carolina Department of Natural Resources) in conjunction with the ACOE (Collins & Smith, 1997; Collins et al., 2000A; Collins et al., 2000B; Collins et al., 2000C). The widespread exposure of this series of SRE studies enabled the SEG to become reasonably familiar with this stretch of river, improving the probability that some of the cultural context of the water quality data would be captured during the stakeholder interviews from both the pilot study and the dissertation SEG interviews to follow (Western & Wright, 1994). This research, accordingly, was grounded in the relationship between the research study area location and the SEG high profile water quality concerns and related projects. This pilot study also explored potential management strategies for fisheries recovery and sustainability.

Pilot Study Methodology

The initial pilot study research questions were designed to uncover the most current local projects in coastal Georgia that may have potential impact on water quality. The salient issues facing regional stakeholders interviewed during my initial pilot study conducted throughout the South Georgia DNR districts were predominantly related to water quality (see Table 3.1). The SEG was particularly concerned about the potential for further degradation of water quality from the proposed Savannah Harbor Expansion Project and ongoing navigational channel maintenance dredging activities.

The pilot study interview questions (see Table 3.2) were designed to address a subset of these water quality concerns, specifically, concerns related to fisheries recovery, fisheries management objectives, environmental sustainability objectives and the stakeholder identification process. Interview participants from environmental advocacy groups were especially concerned about the dramatic decline in fish populations, such as the endangered SNS, within the lower SRE. This recurrent theme was echoed among other stakeholder groups, providing a clear geographic focus for this dissertation research. The pilot study was designed to identify a wide range of stakeholder concerns to provide a flexible framework for the dissertation to follow. Local representatives of environmental groups and agencies (e.g., Sierra Club, the

Table 3.1

SEG 2003 Topics of Concern

Topic	Location	Concern/Comments
Fish habitat destruction	Lower Savannah Rive Estuary (SRE)	Habitat damage from dredging, poor water quality and over-fishing
Saltwater intrusion	Upper Floridian Aquifer (Miocene layer under Tybee Island)	Exacerbated by negative cone of depression under Savannah
Salinity wedge	Freshwater tidal interface near confluence of Front and Middle River	Moving deeper into Savannah National Wildlife Refuge
Re-release of sediment encapsulated contaminates	Fort Jackson to Houlihan Bridge	Channel maintenance dredging may release buried contaminated sediments or contaminate dredge spoil sediment basins
Low dissolved oxygen	Savannah River mouth at Tybee Island to I-95 bridge in Savannah National Wildlife Refuge	Current water quality standards not met. Problem will be intensified by further harbor deepening activities without mitigation
Bank Stability	Along the sides of the deepened sections of the Savannah River	Deepening may destabilize river banks causing increased erosion and storm event uncertainty
Chloride Distribution	Undetermined	Deepening causes changes in flow velocities and may alter contaminant distribution, potentially changing species distribution
Coastal shoreline impacts	Near Savannah River mouth, along shorelines of adjacent barrier islands (Tybee, Little Tybee, etc)	Changes in velocity of river discharge may alter sediment distribution near river mouth and adjacent barrier islands. Channel deepening may also alter barrier island retreat/accretion patterns.
Sea level rise	Savannah River banks and coastal shoreline	Increase problems from deepening activities

Table 3.1 *continued*

Topic	Location	Concern/Comments
Marsh succession	Undetermined impact areas	Replacement of native plant species by secondary, opportunistic or exotic species because of changes in salinity, water quality, tidal inundation/residence time, and estuary flushing capacity.
Cultural artifacts	CSS Georgia wreck in front of Fort Jackson	Protection of underwater cultural resource potentially threatened by increased velocities, changes in salinity and dredging activities
Exotic species	Multiple locations	Ballast water dumping may introduce exotic species
Dredge spoil disposal	Multiple locations	Leaching of contaminates and introduction of exotic species in dredge spoil areas
Sediment quality	Multiple locations	Increased sediments may impact fish survival, eutrophication from excess runoff, and food web modifications.

Table 3.2

Pilot Study Questions

Question	Category
1. Could you explain the role you see your agency (organization) playing in the mediation of problems associated with over-fishing?	Fisheries Recovery
2. How would you characterize the motivation for your interest in the four H's of fish health: harvesting practices, habitat management, hatchery management, and hydro-electric power environmental management?	Fisheries Management Objectives
3. What specific changes do you think are important to begin more multi-disciplined/integrated and sustainable management of the fishing "tragedy of the commons"?	Sustainability Objectives
4. What organizations or other interested parties do you think should be represented or included in stakeholder discussions and why?	Stakeholder Identification

Department of Natural Resources [DNR], etc.) were interviewed to confine the focus to direct participants in the active debate about water quality and distribution in Georgia. The Stakeholders Evaluation Group (SEG) website was a source of current information for the latest meeting minutes. Although general water quality concerns were addressed during the pilot study, a separate set of more refined categories emerged from the pilot study interviews as a starting point for the dissertation.

Fisheries recovery, for example, evolved into the identification of a specific species, SNS as a research target. Fisheries management evolved into delineating the competing management objectives from specific groups. Sustainability objectives were refined into habitat identification, monitoring and best management practices. Finally, identification of the relevant stakeholder groups created categories and sub-categories for the potentially conflicting uses of a small section of SRE real estate.

The refinements from the pilot study[2] also included minor changes in the way qualitative data collection (interviews) were conducted when respondents were unfamiliar with any of the topics covered by the questions. Respondents were assured that the research was not hampered if they were unable or chose not to answer a question. The dissertation interview respondents were also given the same options.

Interview Structure

The interviews were varied in geographic location, ranging from very formal office settings (Skidaway Institute of Oceanography) to casual conversation over a sandwich at a local restaurant. All interviews began with a presentation of four questions (see Table 3.2), the requisite Human Subjects forms and instructions about what the forms were intended to do. This information was followed with details about the video taping of the interview. After identifying a comfort level for confidentiality of the interview data, the interviews began with a video taped cue for the participant to introduce themselves by name and title.

Interviews proceeded until an interruption or request from the participant led to a pause in the recording process. The interview resumed after the participant was queried about their readiness and comfort with proceeding. Upon interview completion, the participant was thanked and asked if they wished to add any comments of their own or reflect on any of their responses. The interview ended upon the final cue by the participant that they were finished. All participants were thanked again and, if interested, offered copies of transcripts once they were available.

Interview durations were from five minutes to over an hour, given the questions were open ended and the final comments were not limited. In addition to the formal questions, it was often appropriate to ask follow-up questions in response to comments made by the participants. Under some circumstances, the participants were more relaxed when follow-up questions became conversational. The participant controlled the formality and duration of all interviews.

Setting up the Dissertation Study

The pilot study interviews also raised important questions about both the economic and non-tangible costs[3] of potential species loss within the Savannah Harbor, particularly concerning the restoration of fish habitat (and riverine sinuosity), potential loss of tourism revenue and the costs associated with water quality regulatory compliance. Additionally, interviews with several scientists revealed a strong preference to focus on the *real* issues that affected water quality, most notably, the physical characteristics of the water that could be measured and quantified (e.g., dissolved oxygen, salinity levels and temperature) (Lee, 2002).

In addition to studying the unique physical water quality characteristics from past studies of the SRE, three summers were spent observing/participating in data collection activities (see

Table 3.3) of studies performed by DNR, the Marine Extension Service (MAREX), Skidaway Institute of Oceanography, and a handful of non-profit organizations. These participant/observation studies included research conducted on boats, in labs, in fish hatcheries and within regulatory agencies for fisheries management. Direct involvement in laboratory analysis of pH, salinity, dissolved oxygen and a series of other water quality analysis enhanced the understanding of current stresses imposed upon fish population within the lower SRE. The participant/observation studies also provided direct hands-on training for obtaining water quality samples with the YSI 85, obtaining side-scan sonar images with the Klein 3000, collecting sediment grab samples with the Ponar grab sampler, determining turbidity with a secchi disk, and other field activities.

The pilot study was the basis for the design and implementation of a three-year review of the historic, scientific and allegorical data surrounding the SRE decline of endangered SNS. The role of principle investigator in the pilot study was preparation for the coming demands of the follow-up dissertation study. This hands-on training was also augmented with individual instruction, academic classes and independent research. These studies provided the foundation for selecting appropriate scientific parameters in quantitative data collection.

Quantitative Data Selection

Quantitative data variables for the subsequent dissertation research were selected on the basis of the literature review, participation in field experiments and water quality sampling activities that included deployment of a Niskin sampling device, installation of a continuous water quality monitoring datasonde, re-deployment of an autosampler, and obtaining field readings with a YSI 85 water quality measuring device. Dissolved oxygen, salinity, temperature, and depth, emerged as recurrent, meaningful and scientifically credible variables in the

Table 3.3

Data Collection for Participant/Observation Study

Activity	Location	Purpose
Collect WQ Samples	Wilmington River, Altamaha River, Savannah River, Georgia	Improve Riverine/Ecosystem Health
Deploy Datasonde	Sapelo Island Sound, Georgia	Monitor WQ 24/7
Dissect Striped Bass to Examine Otolith	Lake Seminole, Florida	Determine Fish Age (Hydrilla Study)
Cruise with Commercial Fishermen	Altamaha River, Savannah River, Georgia	Fishing
Tag American Shad	Altamaha River, Georgia	Georgia Department of Natural Resources (GADNR) Telemetry Study
Tag Leatherback/Loggerhead Turtles	Bulldog, UGA Research Ship, Brunswick, Georgia	Population/Distribution Estimates
Shock and Net Striped Bass	Ogeechee River, Georgia	Check for Start of Spawning
Log Shortnose Sturgeon (SNS) Location/Clip SNS Fin	Altamaha River, Georgia	DNR Record/DNA Analysis Study
Attend ESRI Workshop	Brunswick, Georgia	GIS Training
Participate in Side-scan Sonar Survey	Chattahoochee River	Cultural Artifact Identification/Removal
Participate in Adopt-A-Stream Program	Brunswick, Georgia	Water Quality Monitoring Training
Observe Striped Bass Egg Removal and Fertilization	Richmond Hill Fish Hatchery, Richmond Hill	GADNR River Stock Enhancement
Collect/Examine Tagged Whelks On Beach	Marine Extension Service, (MAREX), Savannah, Georgia	Track Whelk Movement and Survival
Observe Fidler Crab and Habitat	MAREX, Savannah, Georgia	Observe Soil Changes (Introduces Oxygen)

characterization of water quality throughout the water quality sampling activities and throughout the interviews with marine biologists and scientists from other related disciplines[4]. Despite the recognition and agreement about the most viable and scientific water quality parameters, data observations across different studies were subject to wide fluctuations in analysis as a result of non-standardized sampling protocols and difficulty in capturing real-time data[5]. Stakeholder interviews, photographs and observation studies are examples of qualitative data that may provide contextual and explanatory value to otherwise non-standardized or unexplained quantitative data.

Another quantitative data concern surfaced in The Georgia DNR and South Carolina DNR published reports on the problems associated with large increases in salinity over time (Collins et al., 2000A). Emergent research within the Department of Marine Biology at The University of Georgia[6] questioned some previously unchallenged assumptions about what was happening within the marine waters of coastal Georgia (Alber, 2002). Deep penetration of a salt wedge in the Savannah Wildlife Refuge caused alarm because salinity was introduced into an area that was historically recorded as freshwater exclusively. The prolonged incidence of the high salinity spikes caused a massive die-back of marsh grass and severely impacted many stenohaline[7] species, such as the native tupelo trees. High salinity concerns peaked by the end of a four year drought (1998-2002), causing some disagreement about the role of extreme harbor modifications (closing of the tide gate, closing of new cut, etc.) in the salt wedge intrusion. The identification of reliable scientifically significant data, therefore, seemed equally as vulnerable to attack as qualitative data. The quantitative data (measurements of various physical properties) were presumed to be factual, intentionally devoid of any cultural or contextual bias. The facts, however, were admittedly constrained by technology and funding.

Pilot Study Findings

The first and most meaningful finding from the pilot study was the delineation of relevant water quality research parameters required for subsequent dissertation research (see Table 3.4). The scientific expectations of water quality research were focused upon quantitative evaluation of physical water properties. The second finding, the strained communication and misunderstandings between stakeholders, however, emphasized the need to consider other methods (including qualitative methods) in the creation of comprehensive ecosystem approach. Polar approaches to rooting out the causes for water quality declines primarily existed between institutional scientific researchers and the general public (including some environmental groups with their own scientists). Skidaway Institute of Oceanography scientists preferred not to support claimed causal links with environmental degradation because they were incomplete, and therefore, potentially useless or possibly politically derived to meet some specific objective (Lee, 2002).

Other stakeholder groups believed that altruistic reasons were a strong driving factor for public concern (Jennings, 2001). Environmental advocates maintained it was more reasonable to consider incomplete data to understand possible causal relationships than to ignore the problem entirely (Kyler, 2002). These stakeholders (e.g., Center for a Sustainable Coast, Sierra Club) believed that any information about potential negative effects of a proposed project may offer some important information. Additionally, environmental advocates of the Precautionary Principle[8] acknowledged that science may not be able to adequately predict potential negative impacts in advance, suggesting that there is benefit derived from even incomplete data (Smith, 2000). This belief was consistent throughout the stakeholder interviews, specifically relating to

Table 3.4

Pilot Study Findings

Finding	Purpose
1. Delineate Relevant WQ Variables	Narrow Research Focus
2. Ease Strained SEG Communication	Improve Trust and Working Relationship
3. Remove Language Barriers	Improve Environmental Stewardship
4. Identify Common Objectives	Improve Environmental Cooperation

the unknown causes for the dramatic decline of SNS in the lower SRE over the past several decades.

A third finding was evident after reviewing some of the published scientific literature. A clear language barrier between the public and scientists caused confusion in attempts by lay decision-makers to interpret the recommendations of their scientific colleagues. Individual scientific disciplines may have unique codes, equations and “buzz words”, confounding the relay of important environmental parameters. For example, one potential interview respondent referred other SEG members to examine the proposed 3-D hydrology model presented by one of the Georgia Port Authority consultants (SEG, 2001). While this suggestion was scientifically valid, the majority of stakeholders are not formally trained in hydrology. The findings and recommendations from SEG engineers and scientists are frequently much too complex for typical decision-makers to understand because of discipline-specific vocabulary and complexities. Such vast differences in communication techniques can therefore, widen the communication gap between potential partners for environmental stewardship.

The fourth, and final finding of the pilot study suggested there were inherent problems of trust between stakeholder groups, particularly regarding commercial fishermen and their relationship with “outside” interests. Some fishermen commented about the “window dressing” of the SEG, suggesting additional research and the stakeholder meetings would have little impact on the outcome of the SHEP (Commercial Fisherman, 2002). These beliefs were allegedly rooted in past experiences where some commercial fishermen claimed there were disproportionate costs and benefits bestowed upon the stakeholders with the highest levels of vulnerability to sweeping changes in local environmental policy (Gale, 2001; Miller, 2003).

Despite the reservations any commercial fishermen may express, they frequently work part-time hours with DNR fisheries biologists to provide field data for fish population studies and to supplement their income during the off-season (Gale, 2001). They also may share common thoughts relating to recent declines in fish populations, suggesting that it is possible that such dramatic fish population declines in coastal Georgia may have very little to do with harvesting practices (Gale, 2001; Weller, 2001). Regardless of the cause of dramatic declines in some Georgia fish species (such as robust redhorse, red drum, shortnose sturgeon, etc.), interview participants cumulatively suggest that coastal fisheries management objectives require continual monitoring and revision to reflect a dynamic environment.

This pilot study suggests interdisciplinary studies that incorporate qualitative and quantitative data through shared scientific and local knowledge, provide the best mix for adopting an ecosystem approach to management and sustainability. The next phase of research uses this integrated approach to answer specific questions as they emerge from the targeted lower SRE. Chapter 4, the dissertation study, therefore, identifies relevant water quality variables, examines threatened species habitat, and collects contextual data to geographically delineate the most at-risk portions of the lower SRE.

Endnotes

[1]Naturalism frameworks suggest that data collection is more realistic when the interview participant is in a comfortable and familiar or “natural” environment.

[2]The initial pilot study was performed through a series of casual one-on-one interviews with stakeholder evaluation group (SEG) members identified through the National Environmental Protection Act (NEPA) Tier I Environmental Impact Assessment (EIS) of the Proposed Savannah Harbor Deepening Project. Although this project was pre-authorized by Congress in 1999, there were stipulations that prevented action, pending further investigative review and approval of four Federal Agencies. The pilot study questions are included as Table 3.2., the pilot study interview participants are listed in Appendix C.

[3]The economic and intangible costs of this project were not a focus of the scientific studies identified in my initial collection of data, and were, therefore, not included in this research.

[4]The physical water quality data always included temperature, salinity, dissolved oxygen and pH, minimally. Some data also included turbidity, flow velocity, flow volume and seasonal correction factors. Geographic coordinates of sampling locations were frequently collected for time-series data evaluation and other long-term trend analysis.

[5]Previously published telemetry studies (tagging fish and tracking them) were subject to differing interpretations of fish behavior because data were based on a small sample size when the tags would fall off or the fish would go out of range, possibly introducing sampling errors or incomplete data.

[6]Dr. Meryl Alber questioned the assumption that increased salinity was the “smoking gun” that led to the inevitable decline in water quality in marine waters of coastal Georgia during a 2002 presentation to many of Georgia’s leading water quality scientists.

[7]Stenohaline refers to the narrow salinity tolerances of a species.

[8]The Precautionary Principle has been championed by the Occupational Safety and Health Administration (OSHA) and many other protective government and private institutions. It suggests when we have a reasonable suspicion of harm, and scientific uncertainty about cause and effect, then we have a duty to take action to prevent harm.

CHAPTER 4

DISSERTATION STUDY ASSESSMENT OF WATER QUALITY AND SHORTNOSE STURGEON HABITAT

Introduction

How do scientists determine ecosystem health? What are the indicators of environmental decline in the Savannah River Estuary (SRE)? What actions should be taken to prevent further degradation of SRE water quality and habitat? Traditionally, scientists examine findings from a series of targeted studies to answer such questions. Continuous monitoring provides clues about the long term temporal trends of the SRE ecosystem stability and function (see Figure 4.1). This study examines water quality trends (such as the existence of salinity encroachment in primarily freshwater regimes or unsustainable levels of DO) from past studies and compares them with new water quality data[1]. Additionally, this study explores spatial and cultural dimensions of these trends within the lower Savannah River and its estuary to provide a more comprehensive barometer of the links between water quality and ecosystem health.

Water quality problems within the Savannah River Estuary have been well documented across a long history of dramatic physical changes, both natural and anthropogenic (Hall et al., 1991; Pearlstine et al., 1993; Eudaly, 1999). The combined effect of these changes over time has produced a series of environmental concerns, specifically for the health and habitat of riverine species like endangered shortnose sturgeon[2] (SNS) (*Acipenser brevirostrum*) (see Figure 4.2) and threatened striped bass (*Marone saxatilis*) (Jennings, 2005). Dramatic declines in fish stocks and recruitment bottlenecks have left both species with an uncertain future in a river reach required

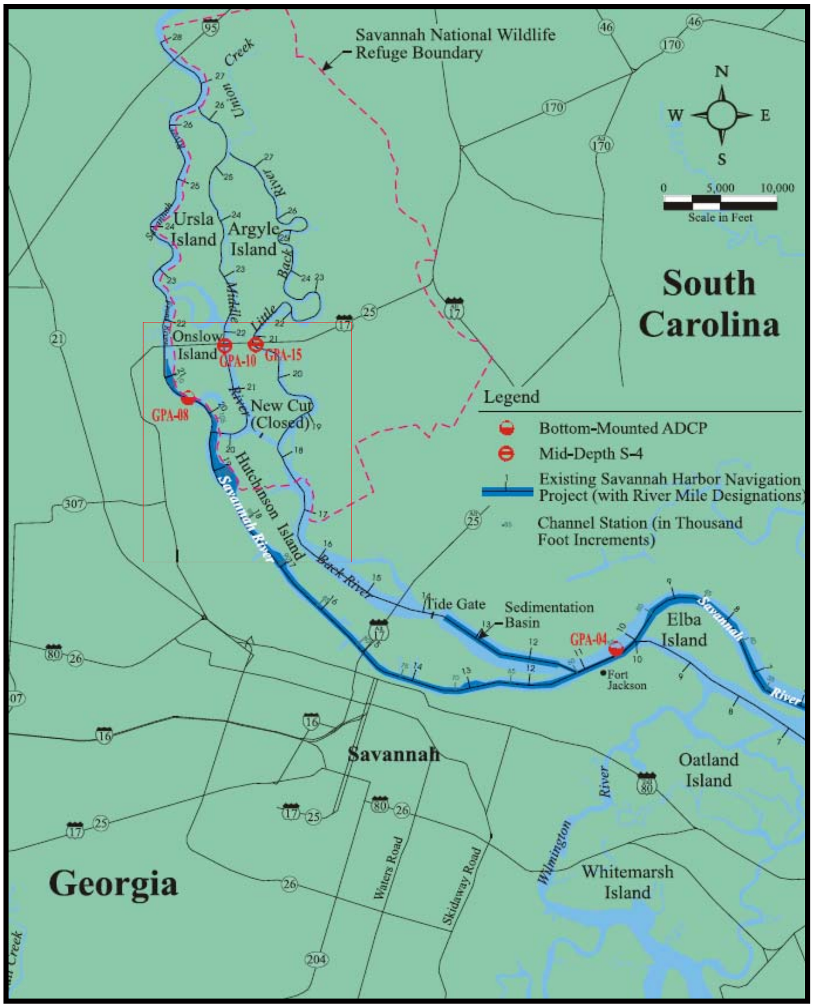


Figure 4.1. Map of the Savannah River Estuary. Source: ATM,1997.

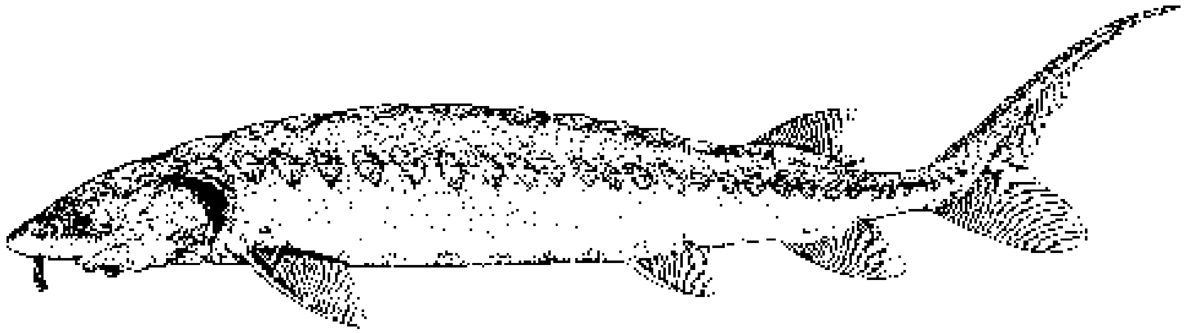


Figure 4.2. The endangered Shortnose Sturgeon. Source: NMFS, 1998.
NOTE: Pursuant to Section 4(f)(1) of the ESA, the NMFS and the FWS are required to develop and implement recovery plans “for the conservation and survival of endangered species and threatened species” unless a recovery plan would not help to promote species conservation.

to maintain water quality suitable for its designation as a recreational fishing zone (Georgia Department of Community Affairs [GDCA], 2005).

Background

The Savannah River has undergone major structural changes that included the 1977 addition of a tide gate, the creation of a drainage canal “New Cut” through Argyle Island (see Figure 4.3), the creation of a sediment basin and the creation of a diversion canal for attempting to supply fresh water to the nearby National Wildlife Refuge (NWR). Navigational demands over the past one hundred years have also led to the straightening of the river channel’s natural meandering. The cumulative impact of these activities caused significant increases in salinity deep within former freshwater areas of the estuary, most notably in the NWR (Alber & Flory, 2003).

The salinity concentrations in the NWR were supposed to be mitigated by the design of engineered river flow conditions but mitigation efforts failed, and much freshwater habitat was converted to saltwater habitat. The saltwater intrusion deep into the estuary caused serious environmental concerns to the managers of the Savannah NWR and private landowners to the south (Eudaly, 1999). The tide gate (see Figure 4.4) and the salt water wedge within the SRE became the nexus of public concern and professional study until the tide gate was later decommissioned because of the significant displacement of the freshwater/saltwater interface (0.5 PSU salt). During low flow conditions, the tide gate caused the freshwater tidal interface to be displaced 4.8 kilometers upstream on the Front River, 5.8 kilometers on the Middle River and 9.3 kilometers on the Back River (Pearlstine et al., 1989) (see Figure 4.5). Flow recommendation studies have been ongoing since the decommissioning of the tide gate (Alber & Flory, 2003).

Figure 4.3. New Cut (see SRE outset in Figure 4.1). **S**ource: ATM, 1997.

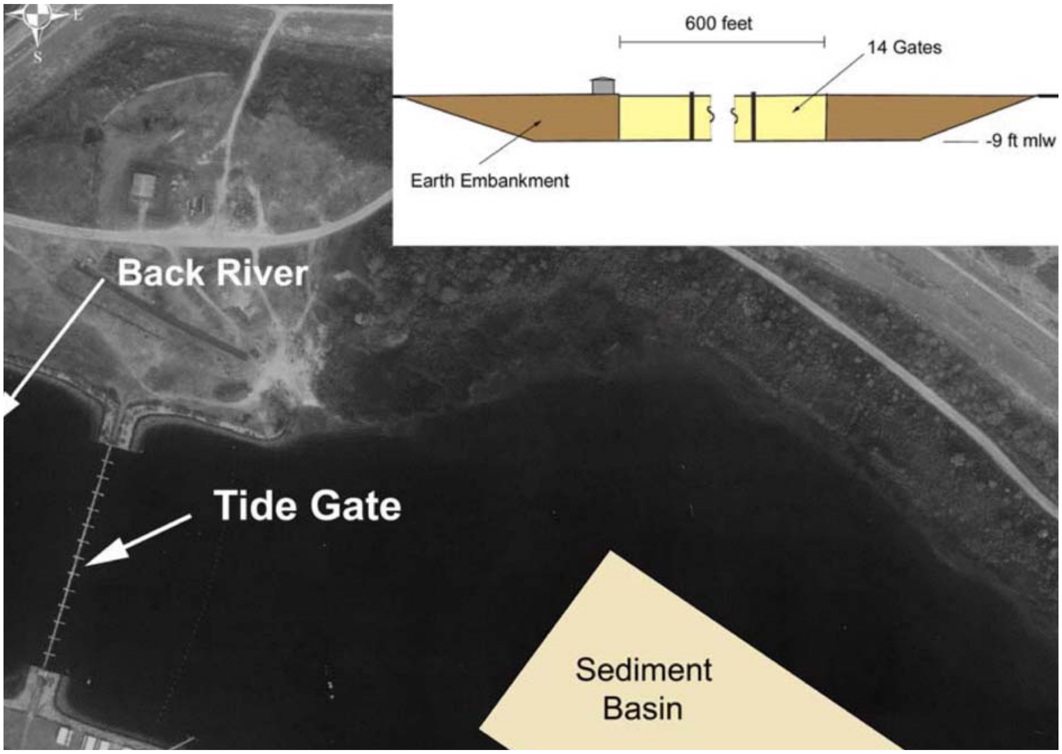


Figure 4.4. The Savannah River Tide Gate (no longer in operation). Source: The United States Army Corps of Engineers, 1997.

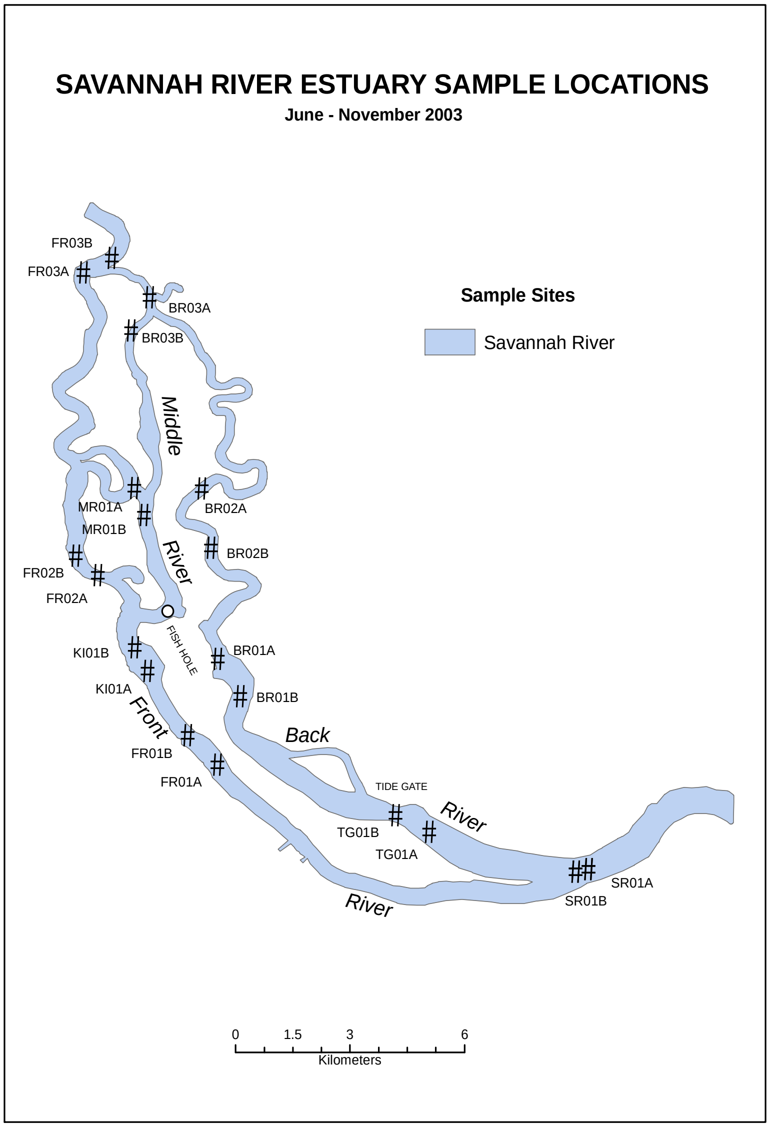


Figure 4.5. Sample Sites on the Savannah River.
NOTE: SR denotes the Savannah River, FR denotes the Front River, MR denotes the Middle River, and BR denotes the Back River, TG denotes Tide Gate, KITB denotes King's Island Turning Basin and FH denotes Fish Hole.

Specifically, The Nature Conservancy has sponsored several workshops for establishing restorative flows through the carefully orchestrated release of large pulses of water during the early spring, when many species depend on “natural” flow levels, water temperature and velocity to assure their continued survival (Wrona et al., 2007).

The lower Savannah River and its estuary have been the topics of diverse environmental investigations ranging from saltwater intrusion (Alber & Flory, 2003) to the decline of specific species such as the native striped bass (Reinert, 2003) and the SNS (Collins & Smith, 1997). Despite the robustness of these previous studies, however, it was not possible to consider all the variables that may be potentially responsible for a general decline in the SRE ecosystem health. The survival of the SNS, alone, represents an unknown cocktail of variables that has led to its endangered status. Synergistic relationships between known aspects of ecosystem decline (such as low DO) have unknown possible geo-spatial links to overall degradation of water quality in the lower Savannah River that need to be explored.

Despite this seemingly daunting task, the SRE is monitored by three of the thirty-three USGS monitoring locations throughout the Savannah River Basin. Additional monitoring can be designed to detect large deviations from established water quality levels, including dramatic changes in total suspended solids (TSS) and the unexpected realignment of sediment deposition patterns (such as displacement from storm events). Such monitoring is already conducted by the Savannah Division of the United States Army Corps of Engineers (SACOEs) for navigation maintenance, but is generally not available to the public (such as sonar data used to select portions of the river that need to be dredged).

The location of SNS within the SRE has been studied since the early sixties during which many major changes have occurred in the river channel and harbor features (e.g., straightening and the now non-operational tide gate). The movement of SNS has been regularly traced as far upstream as rk 280, and as far downstream as the river mouth (rk 0) and into the open ocean (Hall et al., 1991). This wide range of habitat suggests that the SNS need large expanses of unobstructed habitat to carry out natural spawning and other migration cycles (Hall, 2004). The widespread industrial development along this key corridor of SNS habitat, however, constantly threatens the survival of sensitive juveniles and larval stage young with nutrient overloading, chemical contamination, high turbidity, and a myriad of other environmental stressors (Gregory & Bisson, 1997).

The dynamic and competing usages of the Savannah Harbor make it difficult for the scientists studying the SRE to understand how to protect and stabilize the basic functions of fish habitat, specifically, providing adequate flows and water quality for spawning, feeding and overwintering in river reaches at levels that will continue to support biological diversity (Duncan et al., 2003). Given the existing stress on riverine species and sensitive habitat in the Savannah River Estuary, the Tier I Environmental Impact Statement[3] (EIS) of the pre-authorized Savannah Harbor Expansion Project (SHEP) was not sufficient to address the complexities of the potential deleterious effects of planned modifications[4]. Specifically, the water quality model used by the consultants of the Savannah Division of the United States Army Corps of Engineers was rejected because it did not consider all the variables that had already been documented to increase salinity in previously freshwater portions of the estuary (Alber, 2002; Bursen, 2004). Additionally, the excessively vulnerable condition of the SRE (marsh diebacks, saltwater intrusion, increased biological oxygen demand) required more accurate predictive values for mitigating critically low DO levels for both aquatic species and their habitat (Collins et al., 2000A; Eudaly, 2005; Jennings & Weyers, 2002).

Objectives and Rationale for New Data Collection

The current Tier II Environmental Assessment is being modified by the United States Army Corps of Engineers to address Tier I EIS concerns with a more sophisticated water quality modeling system designed by the EPA in conjunction with ACOE, but the mitigation requirements of proposed actions have yet to be fully addressed, particularly regarding habitat for the endangered SNS. This dissertation research is designed to answer questions about the geographic extent, current usage and characterization of unique habitat features of the SRE population of SNS (see Chapter 1). This study is also designed to explore the potential role of identified unique habitat features (for example, fish holes, debris, etc.) in overall ecosystem health and stability, specifically regarding threatened or endangered aquatic species. Finally, these data provide the foundation for science-based policy recommendations (Chapter 5) from the collection and analysis of habitat function within the most critical stretch of the SRE, the freshwater tidal interface. This freshwater tidal interface uniquely supports the SNS and other threatened species because of the favorable salinity levels for multiple life stages of these declining species. Specifically, it is most imperative to maintain a delicate balance of salinity, temperature, oxygen and nutrients in this region because it provides life support to the entire ecosystem (see Table 4.1).

Rationale for 2003 Water Quality and Habitat Assessment

Some of the past water quality data for the Savannah River Estuary lacked an integrated context, leaving many potentially useful questions unanswered, such as the interrelationships between variables (Jennings & Weyers, 2002). The actions, elements and purpose of the multi-year collection of several sources of data form an integrated approach to determine and map environmentally challenged portions of the lower Savannah River estuary during a non-drought

Table 4.1

Actions, Elements and Purpose of Study

Actions	Elements	Purpose
Collection and Analysis of Original Water Quality Data	Bi-monthly June - November 2003 records for Dissolved Oxygen, Temperature and Salinity across 22 sample sites in the SRE. WQ analysis also included four months (twice a month) of secchi disk turbidity data.	1. Investigate potentially deleterious impacts to the water quality and habitat of shortnose sturgeon in the lower Savannah River Estuary during a surplus rainfall year (2003) 2. Determine Turbidity in terms of visibility in centimeters.
Sediment Collection	June and November 2003 bottom data for 22 sample sites. Analysis of Sediment type, sediment location, micro fauna presence/absence and particle size analysis.	1. Correlate sediment with habitat delineation. 2. Determine "live" bottom status. 3. Record location of high percentage of "fines". 4. Determine location and main component of coarse fraction. 5. Record location(s) of Polycyclic Aromatic Hydrocarbon (PAH) contamination when present.
Klein 3000 Side-scan Sonar Data Collection	Geo-referenced survey points, benthic habitat features	1. Create geo-spatial inventory of dredging impacts, detritus, fish populations, seeps, thermal refuge features, and cultural artifacts. 2. Record fish response (if any) to sonar.
DIDSON SONAR Data Collection	Real-time (10fps) target investigation.	1. Determine fish usage of target features (fish hole, dock pilings, rice bridges). 2. Identify presence/absence of sturgeon.
Conduct Cultural Interviews	30 Video-taped Stakeholder Evaluation Group Interviews (20 minutes -2.5 hours)	1. Collect integrated information for contextual clues about data anomalies. 2. Establish local "cultural knowledge" database for future collaborative research efforts (such as with DNR and local commercial fishermen).
Create Geo-referenced WQ Maps	12 color-coded maps of WQ sample data	1. Determine location of most sensitive SNS habitat with the lower SRE.
Provide Policy Recommendations for SNS Habitat and WQ Concerns in the SRE	Table of WQ Data from two past data sets compared with new data from three high profile SRE sample sites. Summary DO, Temperature and Salinity data charts from all new sample sites.	1. Provide scientific data for locating least environmentally deleterious site for future lower SRE improvements. 2. Provide SNS data about rarity of SRE features. 3. Provide scientific basis for revisiting cumulative impact provisions under NEPA (further studies of preliminary scientific findings).

year (2003). The maps from this dissertation will depict the areas that are most highly depleted in terms of DO as reported from the dissertation June-November 2003 water quality data and previously identified environmental parameters such as critical fish habitat, nursery areas and wintering areas of the SRE (Collins et al., 2000B). Potential threat regions for some life stages of SNS will also be mapped to illustrate the geographic zones of the SRE that are reaching the brink of their assimilative capacity[5].

Established scientific parameters and emerging high-frequency sonar investigative technologies were blended to identify the habitat and mitigate water quality improvements for the endangered SNS. Investigation of SNS habitat may provide a clearer understanding of the geographic links between relatively healthy and decidedly unhealthy portions of the lower Savannah River that separate Georgia and South Carolina. Water quality data from 2003 was designed to augment the interpretation of new geophysical data collected using state-of-the-art Klein and DIDSON sonars. Sonar data will provide an additional source of information about specific geo-referenced points within the water quality sampling study area. Specifically, the location and presence or absence of physical features such as sandbars, rocks and fish holes will be analyzed with water quality data to map environmentally threatened or unique benthic habitat in portions of the lower Savannah River Estuary.

This research provides updated information about the critical habitat features and related refuge areas of the SNS within the SRE. This information will aid in prioritizing which regions of the Savannah River Estuary must have special provisions for the protection and maintenance of the food web that supports the growth and survival of the SNS and other aquatic species. The unique habitat identification of SNS and other fish species within the estuary provides additional information about current usage patterns, feeding areas, nursery areas and adaptive management capabilities of this declining species. These sonar data also provide baseline monitoring for riverine changes (both natural and anthropocentric) that may potentially prove disruptive to the long-term survival of the endangered SNS.

Methods

The water quality study was conducted over a six month period beginning with early June 2003. Water quality sampling began in the Front River adjacent to Ft. Jackson at a location that geographically corresponds to sample site SR01 (see Figure 4.5) identified in previous studies conducted by the South Carolina Department of Natural Resources (SCDNR). This region reflects one of the known locations of past adult SNS aggregations (Collins et al., 2000B). This region also reflects one of the highest salinity regimes of the selected study area (typically > 15 PSU). Sample sites down river of Ft. Jackson were not included in sample site selection due to the extreme variations in salinity, temperature and river velocity. Such water quality fluctuations are typically not associated with suitable long-term habitat for southern populations of SNS.

Sampling consisted of collecting data at the extremes of 30 meter reaches in each representative halocline regime to create data points A and B for each sample. Sampling activities were primarily limited to daylight hours, although some night sampling was unavoidable as the daylight hours began to diminish in the Fall of 2003. Water quality data were collected at each sample location to minimally include dissolved oxygen (mg/l), salinity (PSU), temperature (ºC), depth (meters) and turbidity (avg cm)[6]. A YSI 85 (see Figure 4.6) water quality sampling instrument was used to collect DO, salinity, and temperature. A 40 cm weighted plastic secchi disk (graduated in decimeters) (see Figure 4.7) was used to determine turbidity, and a depth meter attached to the hull of the research vessel was used to measure depth. Water quality

Figure 4.6. YSI 85 water quality monitoring device.

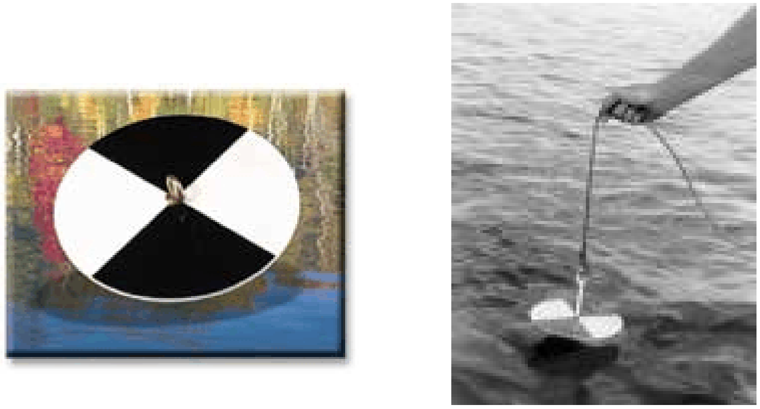


Figure 4.7. A Secchi Disk.

data were collected approximately one meter from the surface and bottom of the water column per protocol from earlier SCDNR studies (Collins & Smith, 1997).

Instrument calibration was conducted in the field at regular intervals (to coincide with powering up the unit and battery replacement) and in the lab. The lab calibration was performed approximately every three weeks of use and consisted of replacing the internal membrane and calibrating the unit using known salinity concentrations. The YSI 85 water quality data were also randomly cross-checked with three known continuous GDNR/USGS water quality monitoring stations within the study region (Ft. Jackson, Tide Gate, and Houlihan Bridge).

A Garmin WAAS-enabled GPSMAP 76 Cx unit was used to determine coordinates within 3 meters of actual sampling location. Water quality and location data were stored onboard a laptop equipped with appropriate GIS software to establish a database for later use with ArcMap. In regions where multiple fish have been known to aggregate, a Klein 3000 side-scan sonar (see Figure 4.8) was deployed at a frequency of approximately 500 kHz to visually record habitat data using sound "images."

The sonar was mounted to the port side of the research vessel suspended on a pole that placed the unit one meter below the surface of the water. Transects of approximately 30 meters provided initial data at a speed of approximately 3 knots. These data were reviewed in live time to determine the presence of any significant bottom features. If unusual bottom features (e.g., seeps, fish holes) were detected, targets were recorded for further investigation using GPS coordinate data. Additional transects were run to provide a bank to bank (approximately 150 meter) coverage of the areas of interest. Areas meeting SNS ideal water quality criteria: low to moderate temperature (e.g., less than 22 degrees Celsius), salinities less than 15 PSU, and DO

Figure 4.8. Klein 3000 Dual Frequency Single Beam Side-scan Sonar. Source: Klein Associates, Inc.

above 5mg/l were also be subject to additional sonar investigation using a proprietary DIDSON high frequency (1.8 MHz) sonar at an average range of about 8 meters.

A Ponar ($0.04m^2$) grab sampler (see Figure 4.9) was used to collect sediment samples at all locations where fish were known (from previous studies) to aggregate to determine potential food sources. A grain size analysis was performed to determine the percentage fines (< 63 micrometers) and the remaining coarse fraction. There was a microscopic inspection to determine presence/absence of foraminifera from samples stored at temperatures between 10-15ºC (to prevent agglutinated (clumped) foraminifera from breaking apart or decaying).

Water Quality Analysis and Findings

Monitoring Water Quality

Water quality concerns within the SRE are typically monitored in terms that have been linked directly to species mortality (LC_{50})[7], particularly for the endangered SNS, where salinity, DO and temperature predict the survival rates of the most vulnerable juvenile populations (Jennings, 2005). Rainfall/river flows must also be considered in evaluating WQ, particularly when evaluating comparisons between drought and non-drought years. River flow measured at the Augusta Shoals station for the Savannah River is estimated to be between 12,000 – 15,000 cfs during periods of normal rainfall and is considered to be a high priority waterway within the state (River Symposium, 2007) (see Figure 4.10).

2003 Rainfall Impacts on WQ Data

Rainfall data from 1998-2002 indicate that a drought occurred in the region followed by a rebound excess in 2003 of 14.5 inches (Georgia Geographic Information System Data Clearinghouse [GGIS], 2003). This El Niño year was different from the past few years because Savannah had been experiencing a drought that started in late1998 and continued into February

Figure 4.9. Wildco Ponar Grab Sampler. Source: Wildlife Supply Company.

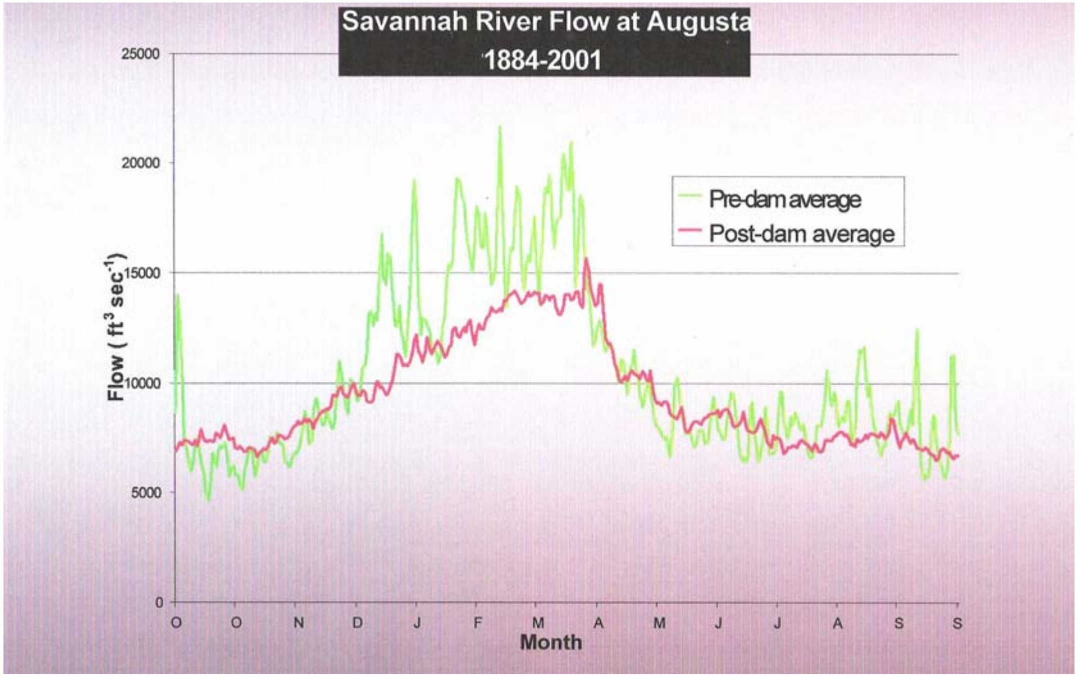


Figure 4.10. Hydrograph of the Savannah River (Augusta Shoals) 2008. Source: Meadows et al., 2008.

of 2003. The previous drought years had been marked with extremely low flows in the Savannah River that contributed to record salinity levels deep within the estuary (Alber, 2002) (see Chapter 1). Additionally, the typically oligohaline (0.0 - 5.0PSU) Middle River, was overly stressed by salinity spikes exceeding the tolerances of most of the resident aquatic species.

This dramatic departure from normal rainfall (see Figure 4.11) caused increases in salinity. It also altered density driven mixing patterns, leading to stratification in the deepest regions of the river (Karim, 1974; Moore, 2008). These factors exacerbated the recovery of the striped bass population and created extended DO stress for a vast portion of the SRE habitat of the endangered shortnose sturgeon (Reinert, 2003). Massive restocking efforts from the early 1990s had not yet had sufficient time to provide the desired effects in population support for both species. The drought also contributed to a widespread marsh dieback, and provided the perfect host environment for a highly salt-tolerant invasive dinoflagellate (*Hematodinium perezi*) parasite that temporarily strained the commercial viability of the blue crab population (Walker, 2002).

The rainfall deficit provided uncharacteristic water quality data for the SRE and became a source of intense scientific scrutiny. The water quality studies conducted by the South Carolina Department of Natural Resources (1999-2000) captured this period of record. The SCDNR study in 2000 was more focused upon salinity instead of DO because DO levels did not drop below undesirable levels (below 5mg/l) for any lifestage of SNS except once in October 2000 (Collins et al., 2000B). By 2003, however, the rainfall was plentiful and river flows were returning to pre-drought flow conditions. The current study began during this period of normal rainfall, beginning in June of 2003. The focus of this study, therefore, was locating the river regions with the most

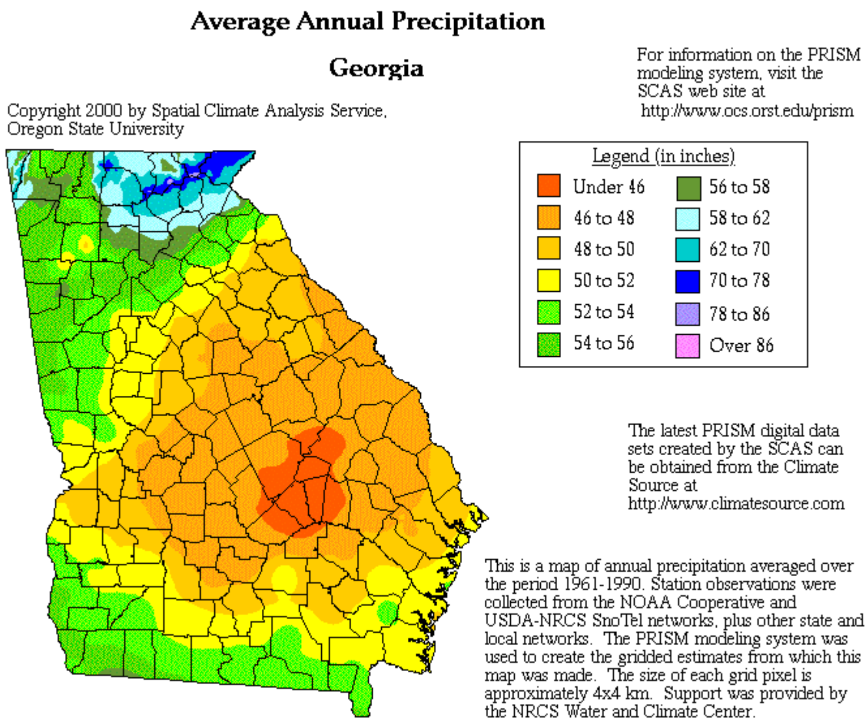


Figure 4.11. Average Annual Precipitation in Georgia. Source: Spatial Climate Analysis. Service, 2000

severe low dissolved oxygen problems. The 2003 data indicated a return to more characteristic[8] water quality measurements within the SRE and marked the decline (but not the end) of salinity "smoking gun" reports (Alber, 2002). Although saltwater intrusion still commanded scientific concern toward the mouth of the SRE, the middle portion of the SRE (rks 17 - 45) required separate water quality investigation to understand the population decline of fish species known to have nursery areas or reproductive migrations within this stretch of river.

Findings from 2003 WQ Data

Because the SCDNR data collected in 2000 represented drought conditions in the SRE, the rainfall excesses of 2003 made direct water quality comparisons between data sets difficult to interpret. This dissertation study, however, uses many of the same sample sites selected in the 1997 Collins and Smith (Collins and Smith, 1997) study for continuity in trend data and to consider the haloclines previously identified in initial characterization of river corridors of interest. Additional studies highlighted Front River and sections of the Middle River as known locations of SNS habitat (Collins et al., 200B), suggesting they were appropriate locations in which to begin data updates and analysis. By August 2003, five additional sample sites (KI01A, KI01B, TG01A, TG01B and FH01, shown in Figure 4.5) were added to capture riverine changes that were not addressed in previous studies. The sonar data (DIDSON and Side-scan) and the added sample sites in this study provide more comprehensive data for discovery of trend analysis for policy development and estuarine monitoring of habitat health.

Salinity Data Findings

The salinity data taken from June through November 2003 (see Tables 4.2 - 4.7) indicated there were only minor concerns with salinity in this section of the estuary during a

Table 4.2

June 2003 Water Quality Data for the Savannah River Estuary

Site	GPS	Tide Stage	STEMP	BTEMP	SSAL	BSAL	SDO	BDO	Date
SR01B	34	slack low	25.8	26.5	2.5	13.8	4.7	3.1	29-Jun-03
FR02B	9	early flood	25.7	25.4	0.3	5.0	4.4	3.3	28-Jun-03
TG01A	43	late flood	27.1	26.4	1.7	10.3	5.3	3.4	29-Jun-03
FR02A	16	early flood	25.1	24.9	0.2	1.5	4.4	4.0	28-Jun-03
BR03B	49	slack low	24.6	24.6	0	0	4.2	4.1	28-Jun-03
BR03A	27	slack low	25.2	24.9	0	0	4.2	4.1	28-Jun-03
FR03A	24	late ebb	24.9	24.4	0	0	4.2	4.1	28-Jun-03
SR01A	33	late ebb	25.7	26.5	3.7	6.3	4.6	4.2	29-Jun-03
FR03B	44	late ebb	24.5	24.4	0	0	4.4	4.3	28-Jun-03
FH01A	19	early flood	25.4	24.6	0.1	0.1	4.9	4.7	29-Jun-03
MR01A	45	middle flood	25.1	24.9	0	0.1	4.8	4.9	29-Jun-03
MR01B	31	middle flood	26.0	25.7	0.1	0.1	5.0	5.1	29-Jun-03
BR02A	35	middle flood	25.5	25.5	0.1	0.1	5.3	5.4	29-Jun-03
MEAN			25.4	25.3	0.7	2.9	4.7	4.2	

Table 4.3

July 2003 Water Quality Data for the Savannah River Estuary

Site	GPS	Tide Stage	STEMP	BTEMP	SSAL	BSAL	SDO	BDO	Date
BR03A	27	early flood	25.4	25.2	0	0	5.5	5.6	16-Jul-03
BR03B	49	early flood	25.7	25.5	0	0	4.9	5.0	16-Jul-03
FR03A	24	slack low	25.2	24.9	0	0	7.9	7.9	16-Jul-03
FR03B	26	slack low	25.2	24.9	0	0	6.1	5.9	16-Jul-03
MR01A	45	middle flood	25.7	25.7	0	0	5.8	5.9	16-Jul-03
MR01B	31	middle flood	25.6	25.6	0	0	5.0	4.9	16-Jul-03
BR01A	48	slack low	26.5	26.3	0	0	4.9	4.9	17-Jul-03
BR01B	38	slack low	26.1	26.2	0	0	4.9	4.7	17-Jul-03
BR02A	35	late ebb	25.6	25.5	0	0	4.5	4.7	17-Jul-03
BR02B	36	late ebb	26	25.8	0	0	4.8	4.7	17-Jul-03
FR01A	42	early flood	25.4	25.3	0	0	4.9	4.2	17-Jul-03
FR01B	42	early flood	25.4	25.4	0	0	4.7	4.8	17-Jul-03
FR02A	16	early flood	25.2	25.1	0	0	5.2	5.2	17-Jul-03
FR02B	9	early flood	25.1	25.1	0	0	5.2	5.2	17-Jul-03
SR01A	33	middle ebb	26.5	25.9	0.8	4	4.7	3.8	17-Jul-03
SR01B	34	middle ebb	25.9	25.9	0.4	2.1	4.8	4.5	17-Jul-03
Mean			25.7	25.5	0.1	0.4	5.2	5.1	

Table 4.4

August 2003 Water Quality Data for the Savannah River Estuary

Site	GPS	Tide Stage	STEMP	BTEMP	SSAL	BSAL	SDO	BDO	Date
FR01B	41	early ebb	27.8	27.4	0.2	15.8	5.3	3.1	17-Aug-03
FR01A	42	early ebb	27.8	27.5	0.5	17.7	5.1	3.3	17-Aug-03
TG01B	21	early ebb	28.6	26.7	1.7	10	5.3	3.4	4-Aug-03
TG01A	43	early ebb	27.8	26.7	2.1	8.7	4.4	3.7	4-Aug-03
FR01B	41	slack high	26.8	26.4	0.2	6.5	4.5	3.8	4-Aug-03
SR01B	34	slack high	27.1	27.1	2.5	14.7	4.2	4.1	4-Aug-03
SR01A	33	slack high	27.2	27	3.6	4.4	4.4	4.1	4-Aug-03
SR01B	34	slack high	27.5	27.8	2.5	24.3	5.1	4.2	17-Aug-03
BR02A	35	middle ebb	27.3	26.4	0.1	0.1	4.8	4.4	3-Aug-03
SR01A	33	slack high	27.7	27.8	3.5	24.2	4.8	4.5	17-Aug-03
BR02B	36	early ebb	26.9	26	0	0.1	4.8	4.6	3-Aug-03
FR02A	16	early ebb	26.7	25.4	0.1	0	4.1	4.6	3-Aug-03
FR01A	42	slack high	26.7	26.4	0.3	6.8	4.1	4.8	4-Aug-03
MR01A	45	middle ebb	26.3	26.2	0.1	0	4.8	4.8	3-Aug-03
BR01A	48	middle ebb	27.1	26.8	0.2	0.3	5.2	4.8	3-Aug-03
BR02A	35	middle ebb	26.4	26.3	0.1	0.1	5.1	4.8	16-Aug-03
FR02B	9	early ebb	26.9	25.4	0	0	4.7	4.9	3-Aug-03
MR01B	31	middle ebb	26.1	26.1	0	0	4.8	4.9	3-Aug-03
BR01B	38	middle ebb	27.4	27	0.2	0.2	5.2	5.0	3-Aug-03
BR02B	36	late ebb	26.4	26.4	0	0.1	5.1	5.1	16-Aug-03
FR02A	16	early ebb	26.1	25.8	0	0	5.6	5.1	16-Aug-03
BR01A	48	late ebb	26.9	26.8	0.1	0.1	5.2	5.2	16-Aug-03
BR03A	27	slack high	25.5	25.3	0	0	5.2	5.3	3-Aug-03
FR03A	24	slack high	25.5	25.3	0	0	5.5	5.3	16-Aug-03
BR01B	38	slack low	26.8	26.8	0.1	0.1	5.2	5.3	16-Aug-03
FR03B	44	slack high	27	25.4	0	0	5.2	5.3	16-Aug-03
BR03B	49	slack high	26.2	25.6	0	0	5.0	5.3	16-Aug-03
FR03B	44	slack high	25.4	25.3	0	0	5.4	5.3	3-Aug-03
MR01B	31	middle ebb	26.6	26.6	0	0.1	5.8	5.4	16-Aug-03
MR01A	45	middle ebb	26.8	26.6	0	0	5.5	5.4	16-Aug-03
BR03B	49	slack high	25.9	25.3	0	0	5.2	5.5	3-Aug-03
KI01A	8	middle ebb	27.9	26.1	0.3	1	5.4	5.7	17-Aug-03
FR02B	9	early ebb	26.1	25.7	0.1	0	5.5	5.7	16-Aug-03
BR03A	27	slack high	26	25.6	0	0	5.9	5.7	16-Aug-03
FR03A	24	slack high	25.9	25.5	0	0	5.2	8.7	3-Aug-03
MEAN			26.8	26.3	0.5	3.9	5.0	4.9	

Table 4.5

September 2003 Water Quality Data for the Savannah River Estuary

Site	GPS	Tide Stage	STEMP	BTEMP	SSAL	BSAL	SDO	BDO	Date
FR01B	41	early ebb	26.3	26.1	7.1	12.4	4.0	3.2	28-Sep-03
KI01B	50	early ebb	26.4	26.1	3.3	9.9	4.9	3.2	28-Sep-03
TG01A	43	early flood	26.3	26.3	6.9	17.3	5.0	3.3	28-Sep-03
FR01A	42	early ebb	26.2	26.2	5.8	13.5	4.2	3.4	28-Sep-03
KI01A	8	early ebb	25.9	26.1	3.5	10	4.5	3.5	28-Sep-03
FR01B	38	early flood	24.5	25.1	1.2	6	5.0	3.7	11-Sep-03
FR01A	42	early flood	24.6	25.1	1.2	5.8	5.1	3.8	11-Sep-03
TG01B	21	middle flood	24.9	25.5	4.5	8.3	5.2	4.0	11-Sep-03
SR01B	34	early flood	25.3	25.6	7.4	13.8	4.8	4.0	11-Sep-03
SR01B	34	early ebb	26.7	26.3	12.2	19.7	4.6	4.1	28-Sep-03
SR01A	33	early ebb	26.6	26.3	17.2	19.6	4.8	4.1	28-Sep-03
TG01B	21	middle flood	26.1	26.5	6.8	12	5.0	4.3	28-Sep-03
BR02A	35	slack low	25.5	25.5	0.3	0.3	4.4	4.4	28-Sep-03
BR02B	36	early flood	25.6	25.6	0.3	0.3	4.6	4.6	28-Sep-03
KI01B	50	early flood	24.6	24.6	0.2	2.2	5.4	4.6	11-Sep-03
TG01A	43	middle flood	24.9	25.4	5.1	7.2	5.0	4.6	11-Sep-03
BR02A	35	slack low	24	23.9	0.1	0.1	4.7	4.7	11-Sep-03
BR02B	36	slack low	24.1	24.1	0.1	0.1	4.8	4.8	11-Sep-03
SR01A	33	early flood	25.3	25.6	7.4	13.7	5.0	4.8	11-Sep-03
BR01B	38	early flood	25.8	25.8	0.6	0.6	5.0	5	28-Sep-03
KI01A	8	early flood	24.5	24.5	0.2	1.1	5.1	5.0	11-Sep-03
BR01A	48	slack low	25.4	24.3	0.4	0.4	5.0	5.0	11-Sep-03
BR01A	48	early flood	25.9	25.8	0.6	0.6	5.1	5.1	28-Sep-03
BR01B	38	slack low	24.4	24.4	0.5	0.5	5.0	5.1	11-Sep-03
MR01B	31	slack low	25	24.4	0.3	0.3	5.3	5.3	11-Sep-03
FR02B	9	late ebb	24.2	24.2	0.5	0.7	5.5	5.4	11-Sep-03
BR03B	49	late ebb	25.9	25.8	0.5	0.5	5.4	5.5	28-Sep-03
MR01A	45	late ebb	24.4	24.4	0.4	0.3	5.7	5.5	11-Sep-03
FR02A	16	middle ebb	24.1	24.1	0.6	0.6	5.4	5.5	11-Sep-03
MR01B	31	slack low	26.1	26.1	0.9	0.9	5.5	5.5	28-Sep-03
BR03A	27	late ebb	25.7	25.7	0.2	0.3	5.5	5.6	28-Sep-03
MR01A	31	slack low	26.2	26.2	0.5	0.6	5.6	5.7	28-Sep-03
FR02A	16	late ebb	25.9	25.8	0.6	0.7	6.0	5.9	28-Sep-03
FR02B	9	slack low	25.8	25.8	0.6	0.6	6.0	6.0	28-Sep-03
FR03A	24	late ebb	25.1	25.1	0	0	5.7	6.0	12-Sep-03
FR03B	44	late ebb	25.2	25.1	0	0	5.8	6.0	12-Sep-03
FR03A	24	middle ebb	25.7	25.6	0.1	0.1	6.0	6.1	28-Sep-03
FR03B	25	middle ebb	25.6	25.5	0.1	0.1	6.2	6.3	28-Sep-03
MEAN			25.4	25.4	2.6	4.9	5.1	4.8	

Table 4.6

October 2003 Water Quality Data for the Savannah River Estuary

Site	GPS	Tide Stage	STEMP	BTEMP	SSAL	BSAL	SDO	BDO	Date
TG01A	43	early flood	22.9	23.4	6.6	17.3	5.0	3.3	11-Oct-03
SR01A	33	slack low	23.4	23.4	6.3	15.9	5.4	4.0	11-Oct-03
SR01B	34	slack low	23.3	23.3	6.7	13.6	4.8	4.0	11-Oct-03
TG01B	21	early flood	23	23.3	6.8	14.3	5.1	4.0	11-Oct-03
FR01A	42	middle flood	22.9	22.3	2.6	10	5.4	4.0	11-Oct-03
FR01B	41	middle flood	23	23.2	2.5	7.6	5.6	4.4	11-Oct-03
KI01B	50	middle flood	22.8	22.2	1	6.6	6.3	4.7	12-Oct-03
KI01A	8	middle flood	22.8	23.2	1.3	4.9	6.0	5.1	12-Oct-03
BR03B	49	early flood	22.4	22.4	0.1	0.1	5.4	5.4	12-Oct-03
BR01B	38	late ebb	22.7	22.7	1.1	2.5	5.9	5.6	12-Oct-03
BR02A	35	late ebb	22.5	22.4	0.3	0.3	5.8	5.8	12-Oct-03
BR03A	27	early flood	22.4	22.4	0.1	0.1	5.4	5.8	12-Oct-03
BR02B	36	late ebb	22.6	22.5	0.4	0.4	5.9	5.9	12-Oct-03
BR01A	48	late ebb	22.7	22.7	1.1	1.1	5.8	5.9	12-Oct-03
MR01A	31	middle ebb	23.2	23	1.4	2.2	6.2	6.1	12-Oct-03
MR01B	31	middle ebb	22.9	22.8	0.8	0.9	6.2	6.1	12-Oct-03
FR02A	16	middle flood	22.5	22.7	0.1	0.2	6.4	6.4	12-Oct-03
FR02B	9	middle flood	22.7	22.7	0.1	0.2	6.5	6.6	12-Oct-03
FR03B	44	early flood	22.4	22.4	0.1	0.1	6.81	6.9	12-Oct-03
FR03A	24	slack low	22.4	22.4	0.1	0.1	7.03	7.0	12-Oct-03
SR01A	33	slack low	21.9	21.7	10	14.9	5.33	4.7	25-Oct-03
TG01A	43	early flood	21.1	21.7	8.3	19.6	6.08	5.0	25-Oct-03
SR01B	34	slack low	21.9	21.6	9.7	15.2	5.13	5.1	25-Oct-03
FR01A	42	early flood	21.4	21.5	3.4	7.5	5.87	5.2	25-Oct-03
FR01B	41	early flood	21.3	21.4	2.8	6.6	5.64	5.2	25-Oct-03
TG01B	21	early flood	21	21.3	7.8	13.4	6.1	5.8	25-Oct-03
KI01A	8	slack low	21.4	21.6	0.8	4.7	7.3	5.9	26-Oct-03
BR03A	27	middle ebb	21.1	21	0.4	1.4	6.7	6.2	26-Oct-03
KI01B	50	slack low	21.5	21.6	1.5	3.2	7.0	6.3	26-Oct-03
MR01A	31	middle ebb	21.7	21.6	2.4	2.6	6.4	6.4	26-Oct-03
FR02A	16	slack low	21.4	21.2	0.2	0.2	6.6	6.5	26-Oct-03
FR03B	44	early ebb	21	20.9	0.3	0.3	6.4	6.6	26-Oct-03
BR03B	49	middle ebb	21.3	21.1	0.9	0.9	6.5	6.6	26-Oct-03
MR01B	31	late ebb	21.9	21.7	1.4	1.4	6.5	6.7	26-Oct-03
FR03A	24	middle ebb	21.1	21	0.6	0.8	6.8	6.7	26-Oct-03
FR02B	9	slack low	21.3	21.2	0.2	0.2	7.8	7.6	26-Oct-03
BR01A	48	middle ebb	21.8	21.7	6.6	9.2	6.3	5.8	27-Oct-03
BR01B	38	middle ebb	21.8	21.8	8.9	9.7	6.0	5.8	27-Oct-03
BR02B	36	early ebb	21.4	21.3	2.5	2.9	6.2	6.1	27-Oct-03
BR02A	35	early ebb	21.5	21.3	2	2.3	5.9	7.0	27-Oct-03
MEAN			22.1	22.1	2.6	5.4	6.1	5.7	

Table 4.7

November 2003 Water Quality Data for the Savannah River Estuary

Site	GPS	Tide Stage	STEMP	BTEMP	SSAL	BSAL	SDO	BDO	Date
KI01A	8	late ebb	20.7	21.2	3.7	9.9	8.4	6.8	11-Nov-03
FR02B	9	middle ebb	19.9	19.9	1.3	1.6	9.3	9.1	11-Nov-03
FR02A	16	late ebb	19.9	19.9	1.1	1.5	9.1	8.8	11-Nov-03
TG01B	21	slack low	19.3	21.4	5.6	15.8	6.4	5.4	10-Nov-03
FR03A	24	middle ebb	19.5	19.4	0.1	0.1	6.5	7.2	11-Nov-03
FR03B	25	middle ebb	19.6	19.3	0.1	0.1	8.7	7.3	11-Nov-03
BR03A	27	early ebb	19.4	19.4	0.1	0.1	7.3	7.0	11-Nov-03
MR01B	31	slack low	19.5	20.4	0.4	2.1	6.9	6.8	10-Nov-03
SR01A	33	early flood	22.2	22.6	7.9	15.6	5.4	5.3	8-Nov-03
SR01A*	33	slack low	21	21.2	10.1	18.8	7.3	7.2	11-Nov-03
SR01B	34	slack low	22.4	22.6	7.7	15.0	5.2	5.2	8-Nov-03
SR01B*	34	slack low	21.2	21.2	9.3	19.4	7.5	7.0	11-Nov-03
BR02A	35	late ebb	18.7	18.7	0.2	0.2	6.5	6.6	10-Nov-03
BR02B	36	late ebb	19	18.9	0.4	0.4	6.6	6.7	10-Nov-03
BR01B	38	middle ebb	19.2	19.1	1.3	2	7.2	6.9	10-Nov-03
FR01B	41	late ebb	20.7	21.5	3.7	12.5	8.6	6.4	11-Nov-03
FR01A	42	slack low	20.7	21.4	4.2	12.7	8.4	6.3	11-Nov-03
TG01A	43	slack low	19.6	22.0	6.3	21.1	6.2	4.8	10-Nov-03
MR01A	45	late ebb	20.5	20.3	1.9	1.8	6.4	6.4	10-Nov-03
BR01A	48	middle ebb	19.2	19.6	2.7	7.2	7.4	6.5	10-Nov-03
BR03B	49	early ebb	19.2	19.0	0.5	0.6	7.3	7.3	11-Nov-03
KI01B	50	late ebb	20.6	21.1	3.1	8.8	8.6	6.9	11-Nov-03
MEAN			20.1	20.5	3.3	7.6	7.3	6.7	

normal rainfall year. Even small increases in salinity, however, are potentially serious because entire salinity regime shifts may cause both phytoplankton and zooplankton to relocate further upstream changing the ecological balance between the *Euryhaline* (wide range of salt tolerance) species and the less adaptable *Stenohaline* (very narrow range of salt tolerance) species. Such salinity regime shifts cause geographic modifications for species up the entire food chain, specifically when deepening activities increase tidal velocities and push greater amounts of highly saline water (> 15PSU) deeper into the estuary.

Shortnose sturgeon have been documented to occupy a wide range of salinity regimes, although southern populations have exhibited a preference toward remaining within the freshwater tidal interface for most of their life-span. The freshwater tidal interface of the SRE may experience salinity surges for short durations, but it predominantly remains stable within a range from 0.5 PSU to 5.0 PSU, such as in the unique habitat of the Middle River. Shortnose sturgeon prefer cool freshwater (< 22 degrees C, 0 - 0.5 PSU), however, when they spawn. Approximately every three years, SRE SNS make spawning runs 250 kilometers upriver to take advantage of freshwater riverine habitat (Hall et al., 1991).

The range of salinity values has seasonal fluctuations that can be observed in long-term continuous monitoring, however, short-term data collection provides meaningful comparisons for specific health criteria of threatened or endangered species. The extreme values of the data represent the first consideration for impacts to specific species or the life-stage impacts within one species. Extreme values are shown in dark red on Tables 4.2-4.7, indicating some possible threshold for stress in adult SNS, depending on duration of exposure and other variables that may be present. Light red indicates levels that may impact very young juveniles or sensitive adult SNS. Green indicates levels deemed generally acceptable for all lifestages of SNS.

Salinity levels for July 2003 data (see Table 4.3) have the lowest mean value (0.1 PSU, surface values) of all months across all points. The highest mean salinity value (7.6 PSU, bottom values) occurred in the cooler month of November (see Table 4.7). A salinity spike (24.3 PSU, bottom salinity) occurred in August, near SR01 (see Table 4.4), the sample site located closest to the river mouth/ocean. Although the lowest mean value (0 PSUs) of salinity data is of little consequence to SNS, the salinity spike of 24.3 PSU may potentially represent a hazardous water quality environment for all SNS lifestages at SR01, FR01 and TG01 because of the synergistic interaction with the concurrently low DO (values that hover between 3 and 4 mg/l), high temperatures (in excess of 27ºC) and poor vertical mixing.

2003 water quality data indicates that although the SRE remains relatively well mixed during June through November, the most southern portions of the estuary near SR01, TG01 and FR01 (see Figure 4.5), show evidence of both vertical and horizontal stratification in the deepest and widest areas near SR01 (see Table 4.4). This stratification was most pronounced during the high temperature months of August and September. Average salinity values across all months (see Figure 4.12) exhibit wild fluctuations, however the mean salinity values were relatively low (mean Surface Salinity (SS) 1.63PSU and mean Bottom Salinity (BS) 4.2PSU) and the data do not indicate the presence of persistent anomalies in any month at any specific location, other than in the lower, more saline portions of the Front River.

These average salinity data (without considering the synergistic impacts of other WQ parameters) remain within the upper limits of shortnose sturgeon salinity tolerances for adults (< 33 PSUs), however, they exceed ideal levels for juveniles. The salinity levels observed near FR02 and MR01 typically ranged from 0-5 PSUs, suggesting these river sample sites were more hospitable to juvenile nursery areas, confirming findings previously recorded in the Collins 2000

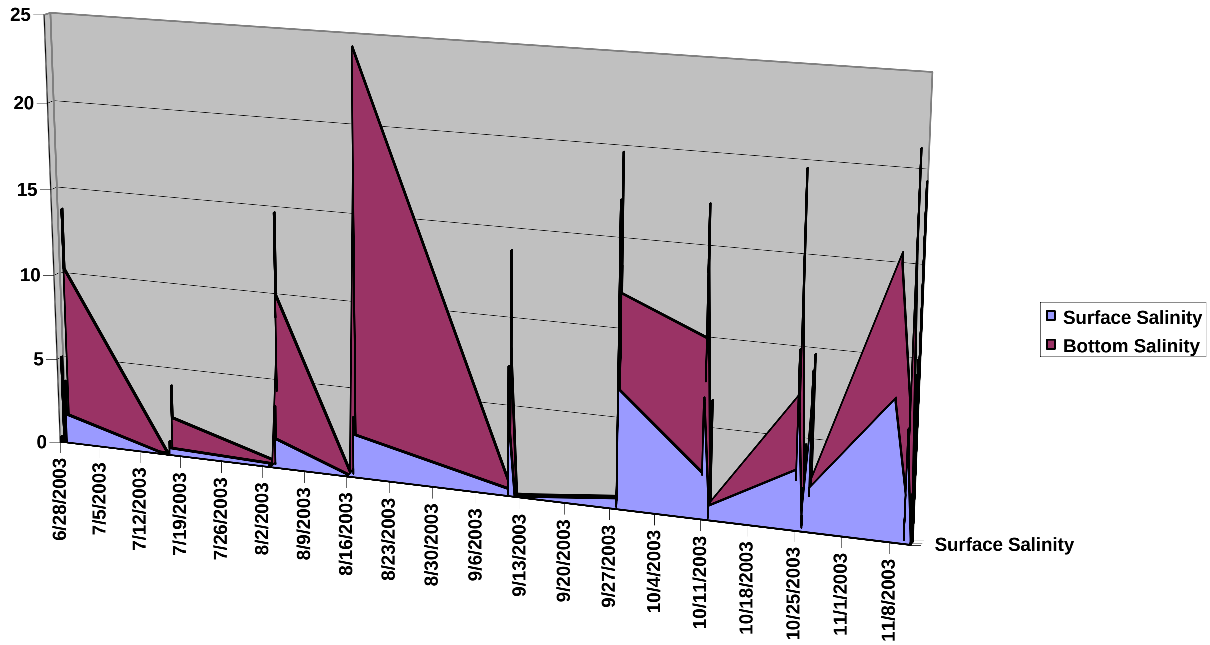


Figure 4.12. June – November 2003 Salinity Data in the Savannah River Estuary.

data. Although the 2003 SRE water quality data confirmed these Front and Middle River locations were still viable SNS nursery sites in terms of salinity, further water quality analysis and physical data were needed to determine if these areas were still able to support the SNS populations identified at these locations in the SCDNR studies. Specifically, the temperature and DO levels had to be re-evaluated to address additional habitat suitability concerns.

Dissolved Oxygen

The regulations for dissolved oxygen content in the Savannah River are established based upon the location and use of the river reach. Some existing guidelines are listed in Table 4.8. Concerns about the low levels of dissolved oxygen in the SRE are documented as early as 1989, when EPD requested more stringent standards for DO because studies performed by Dr. Richard Winn (South Carolina Wildlife and Marine Resources Department) indicated that the DO regulation of 3.0 mg/l needed to be increased to "avoid jeopardizing the recovery of the shortnose sturgeon" (Henwood, 1987, p. 1). The reduced levels of dissolved oxygen were causing high mortality rates in juveniles, altered spawning behaviors and poor survivability of fluctuations in high temperatures (> 26 degrees C) and high salinities (> 15 PSU) within the estuary (Hall et al., 1991). Under established EPA guidelines, there are provisions for localized requests for special concerns, particularly regarding SNS in the Savannah River.

Within the SRE, dissolved oxygen data for 2003 illustrate problems (particularly with bottom DO) throughout the sampled months from June through November (see Figures 4.13 - 4.24). Relatively highly concentrated regions of low DO, however, are known as hot spots. Theses hot spots are evident in data from July through September 2003 (Figures 4.15 - 4.20) in both the highly industrialized Front River and within an undeveloped protected area in the National Wildlife Refuge (BR02). Both areas have been identified as part of the SNS distribution

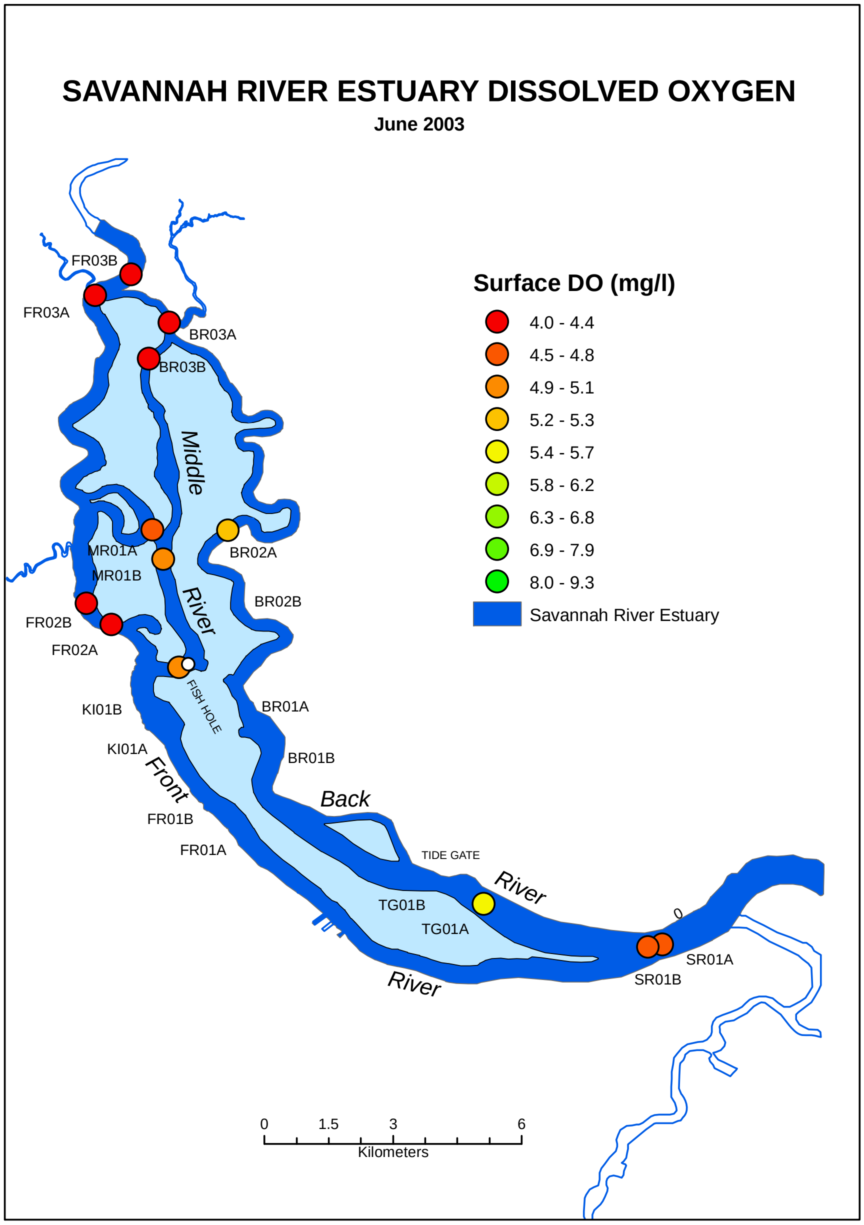


Figure 4.13. June 2003 Surface Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

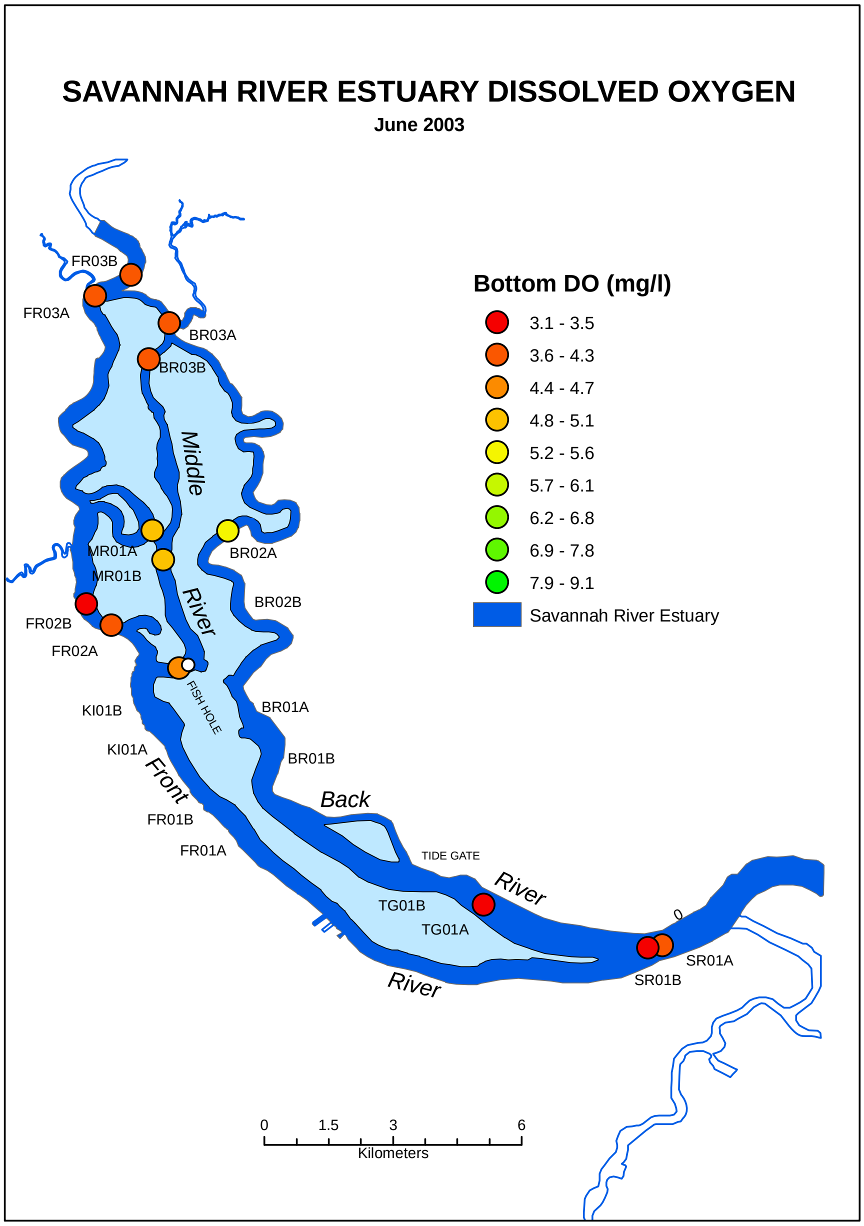


Figure 4.14. June 2003 Bottom Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

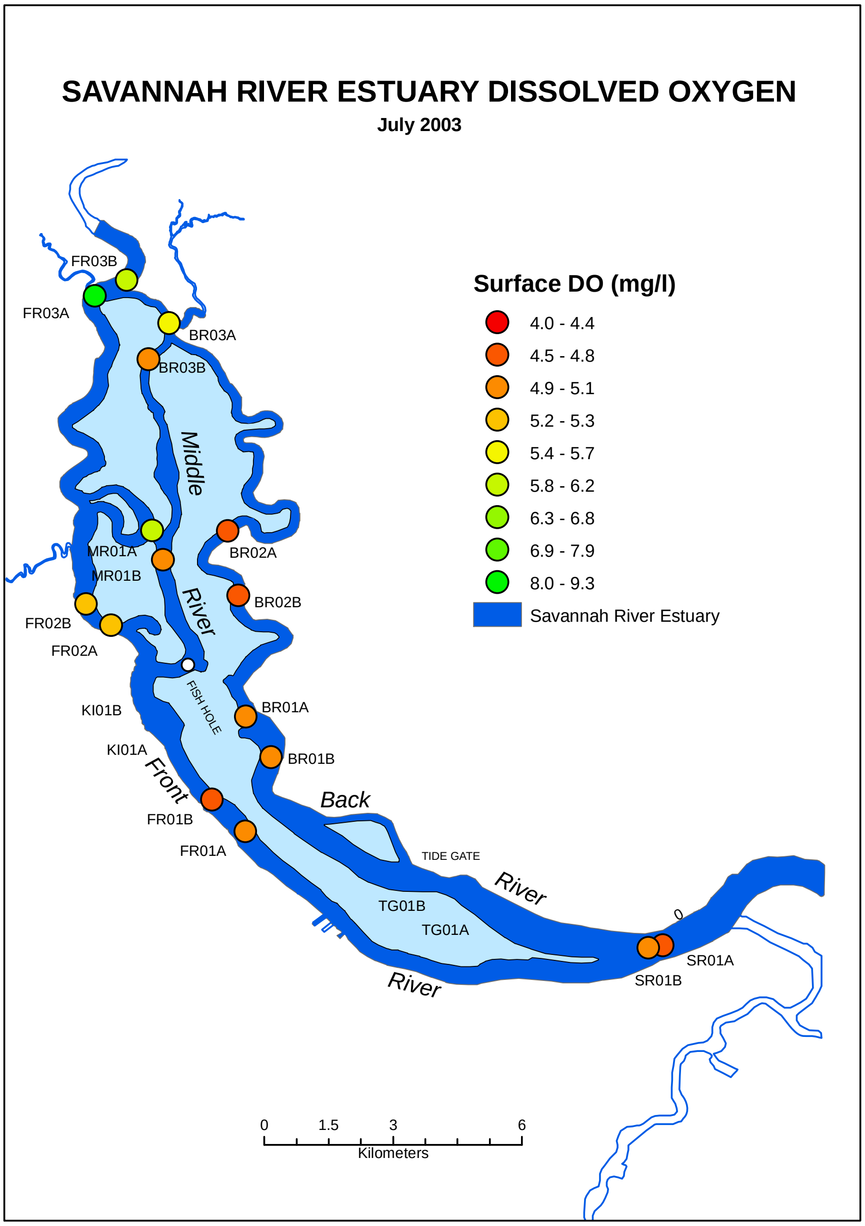


Figure 4.15. July 2003 Surface Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

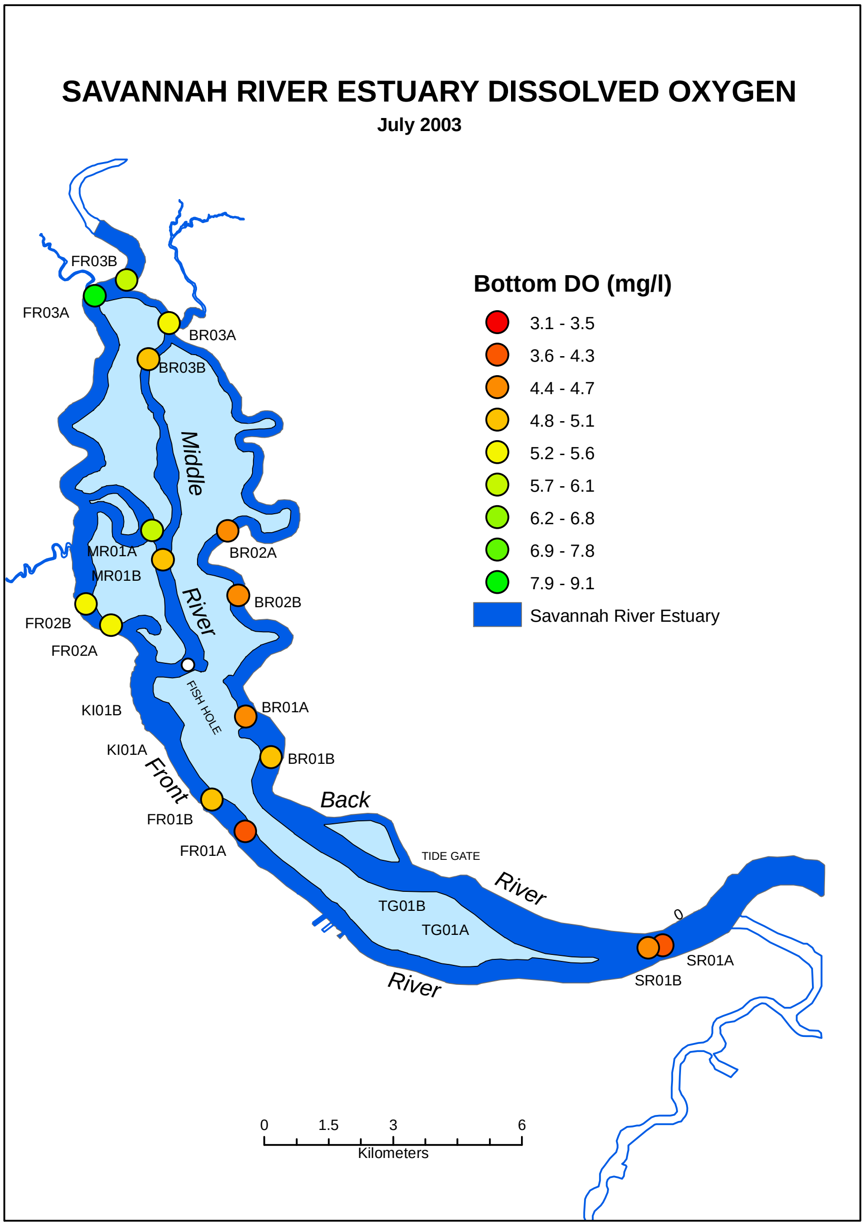


Figure 4.16. July 2003 Bottom Dissolved Oxygen (mg/l) in the Savannah River Estuary.
Note: Unavailable site data depicted without color code.

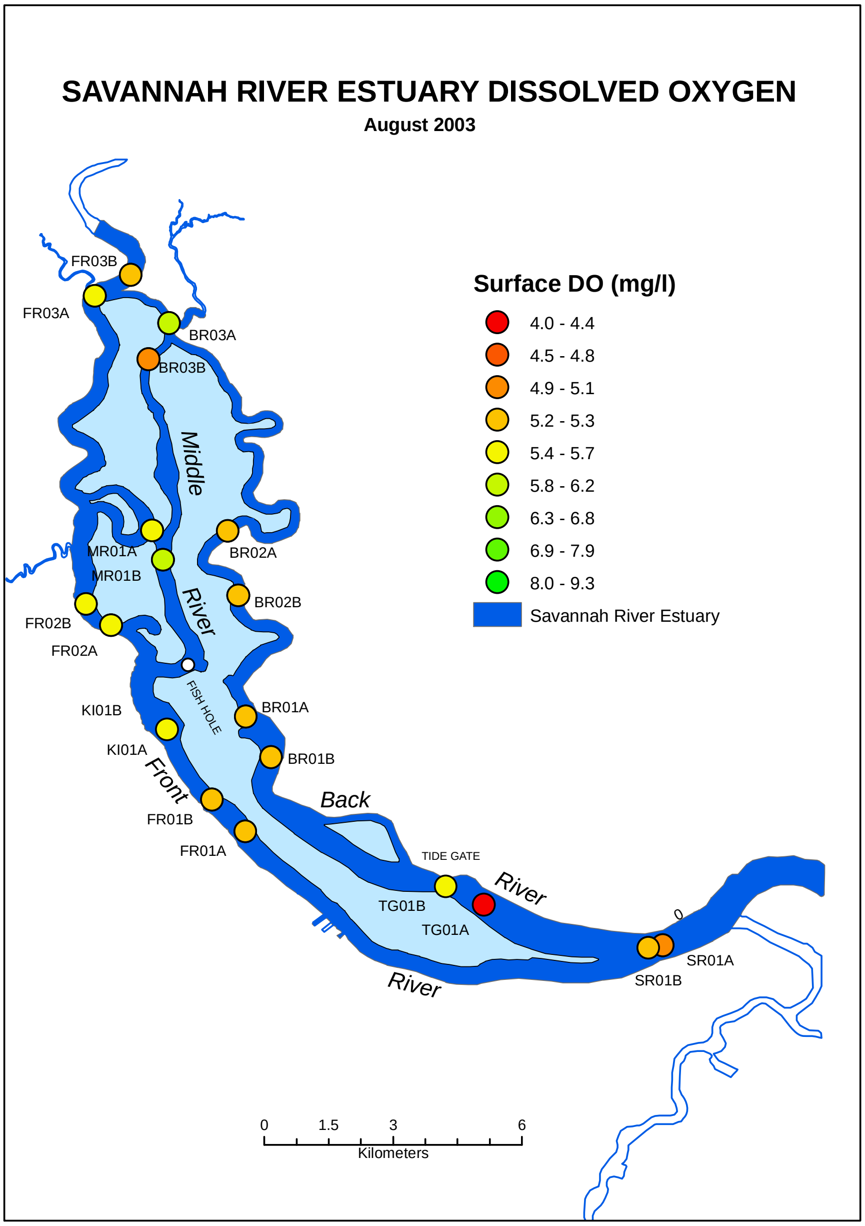


Figure 4.17. August 2003 Surface Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

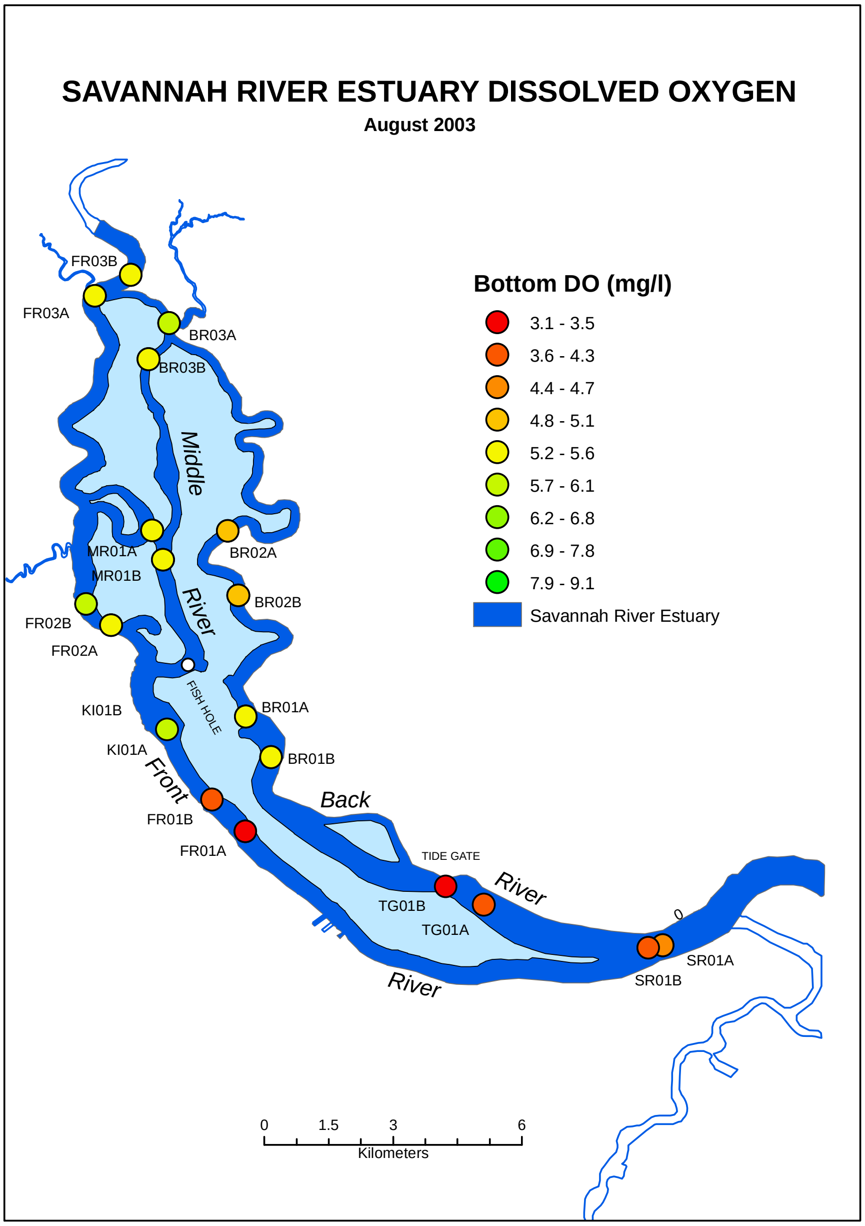


Figure 4.18. August 2003 Bottom Dissolved Oxygen (mg/l) in the Savannah Rivet Estuary. Note: Unavailable site data depicted without color code.

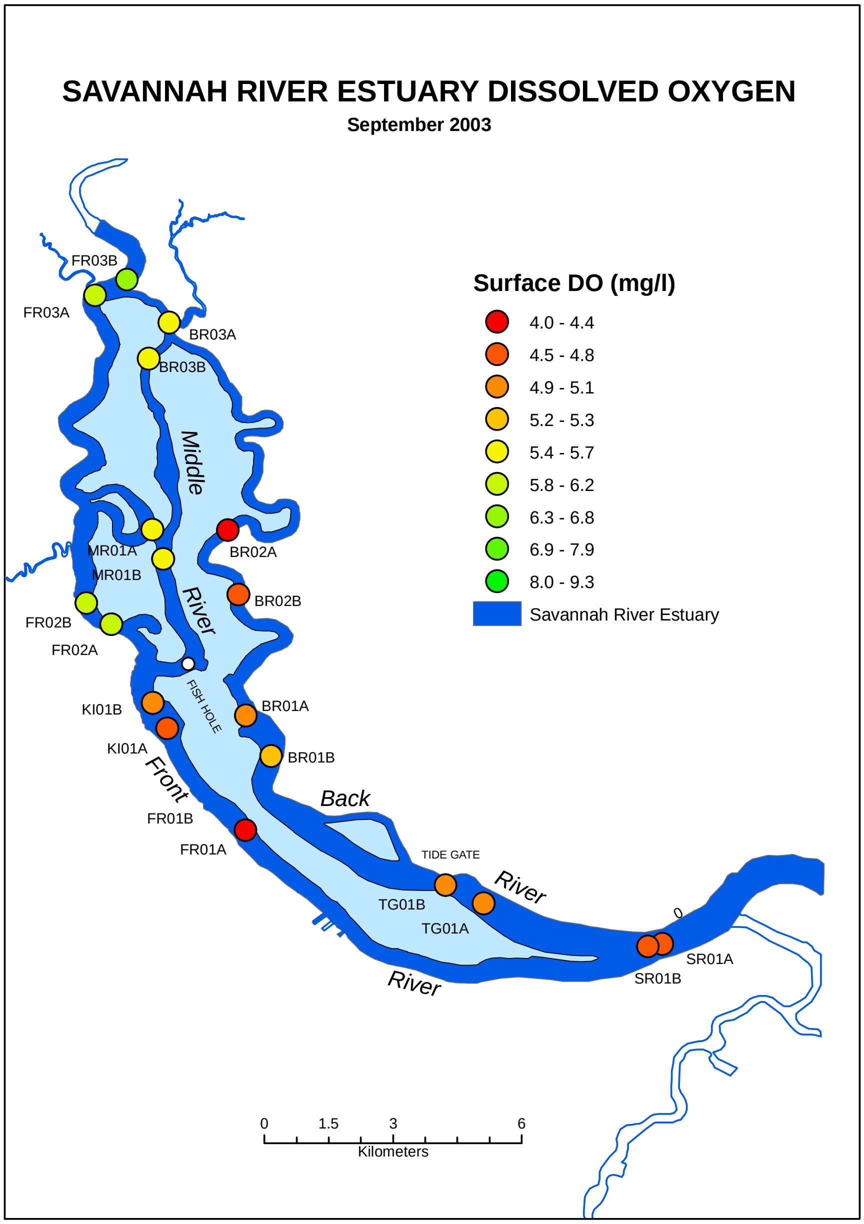


Figure 4.19. September 2003 Surface Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

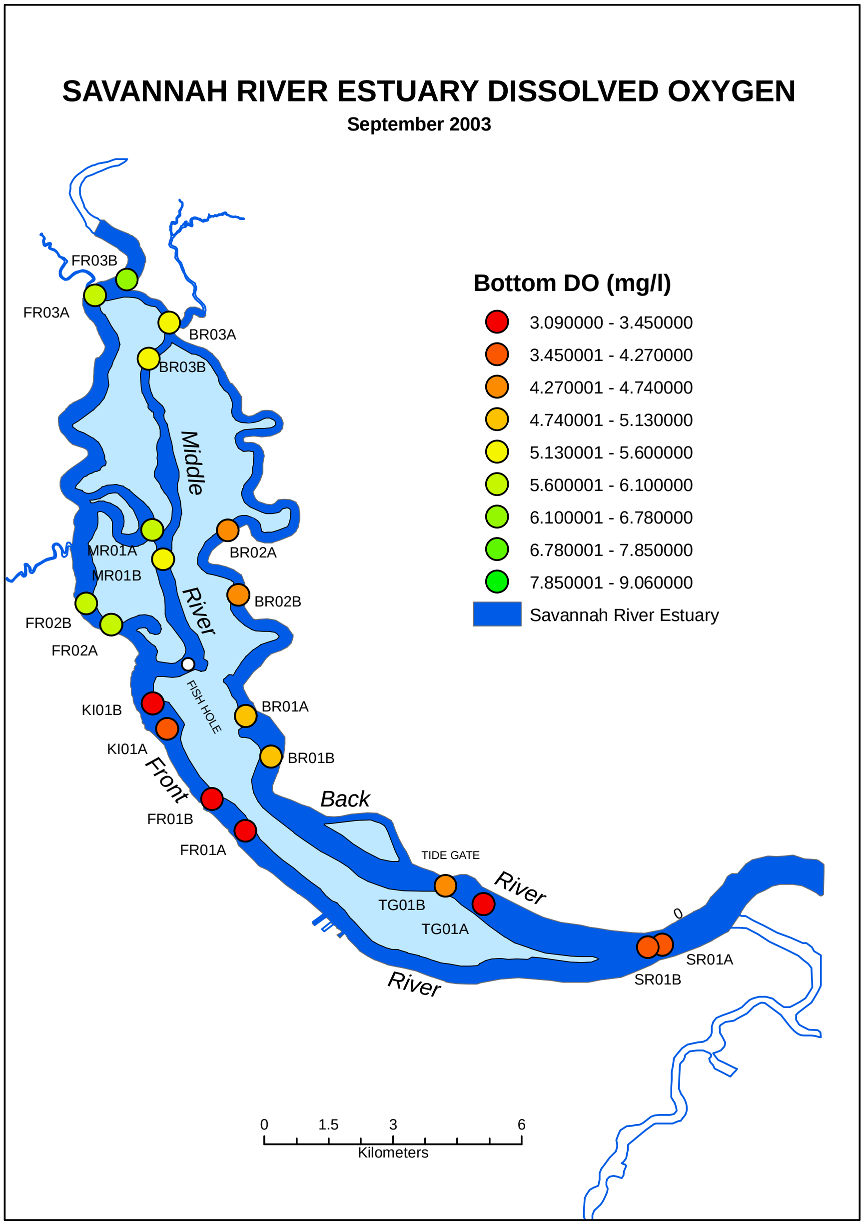


Figure 4.20. September 2003 Bottom Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

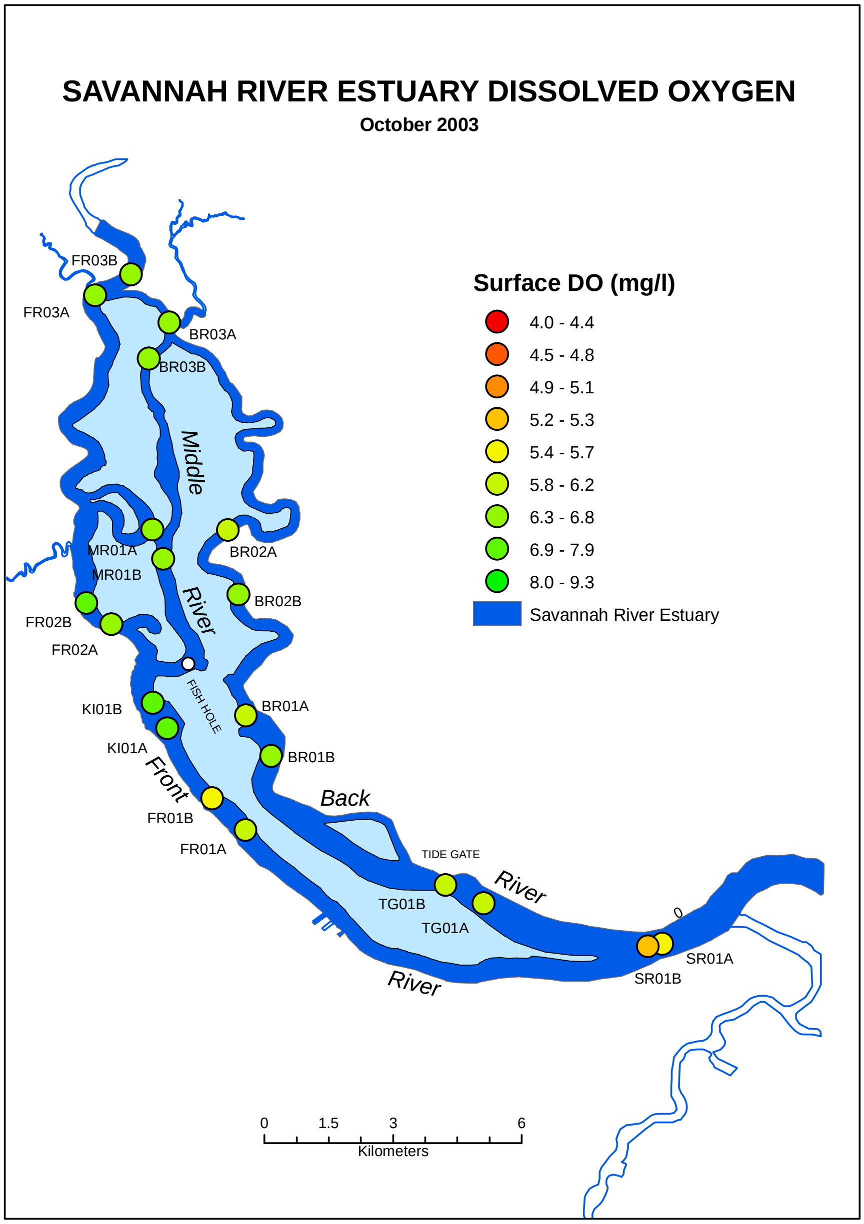


Figure 4.21. October 2003 Surface Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

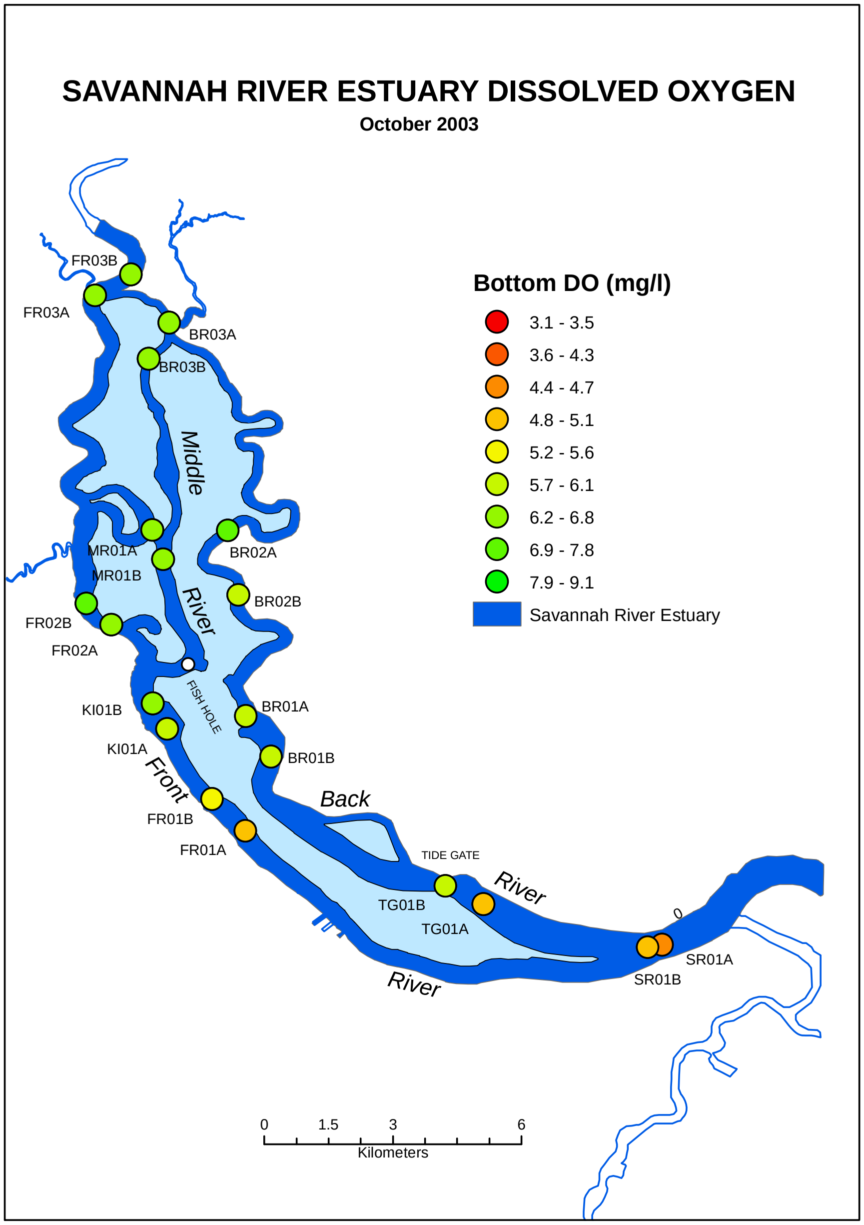


Figure 4.22. October 2003 Bottom Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

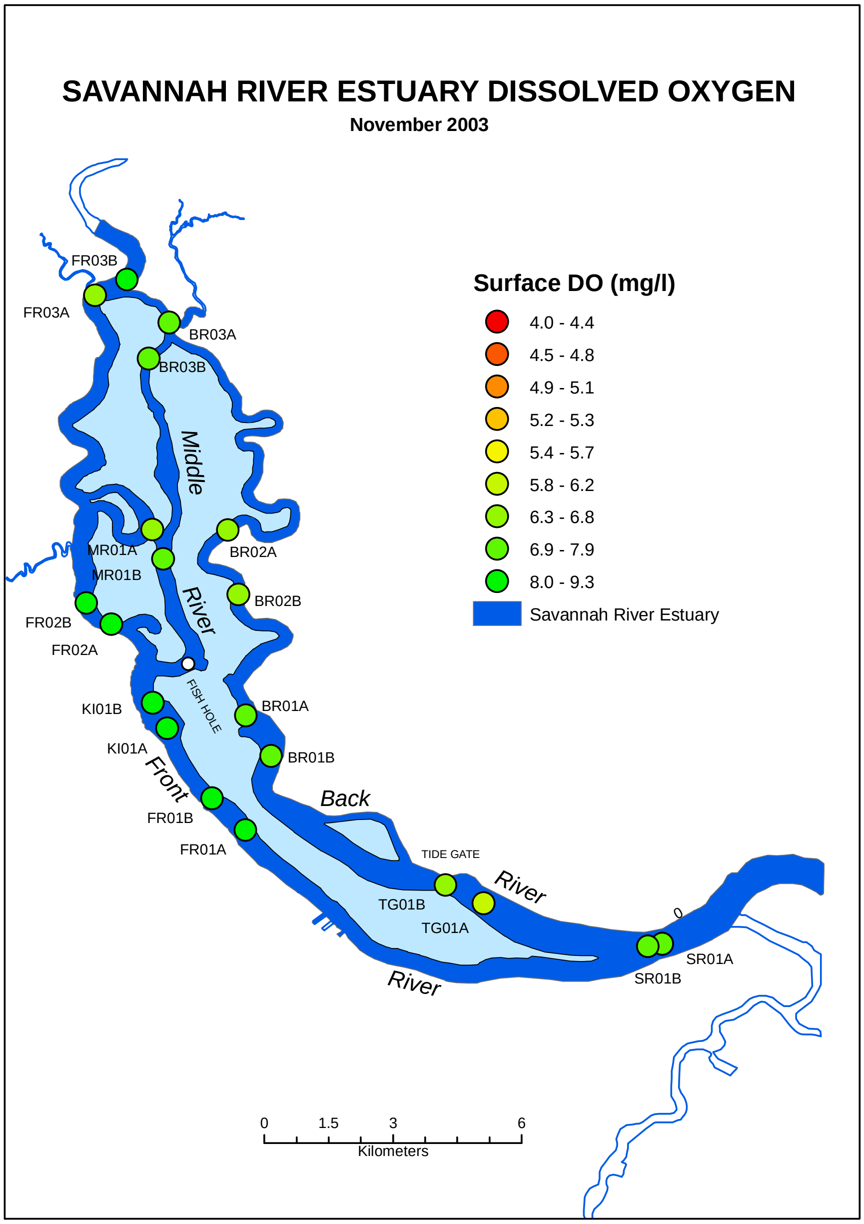


Figure 4.23. November 2003 Surface Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

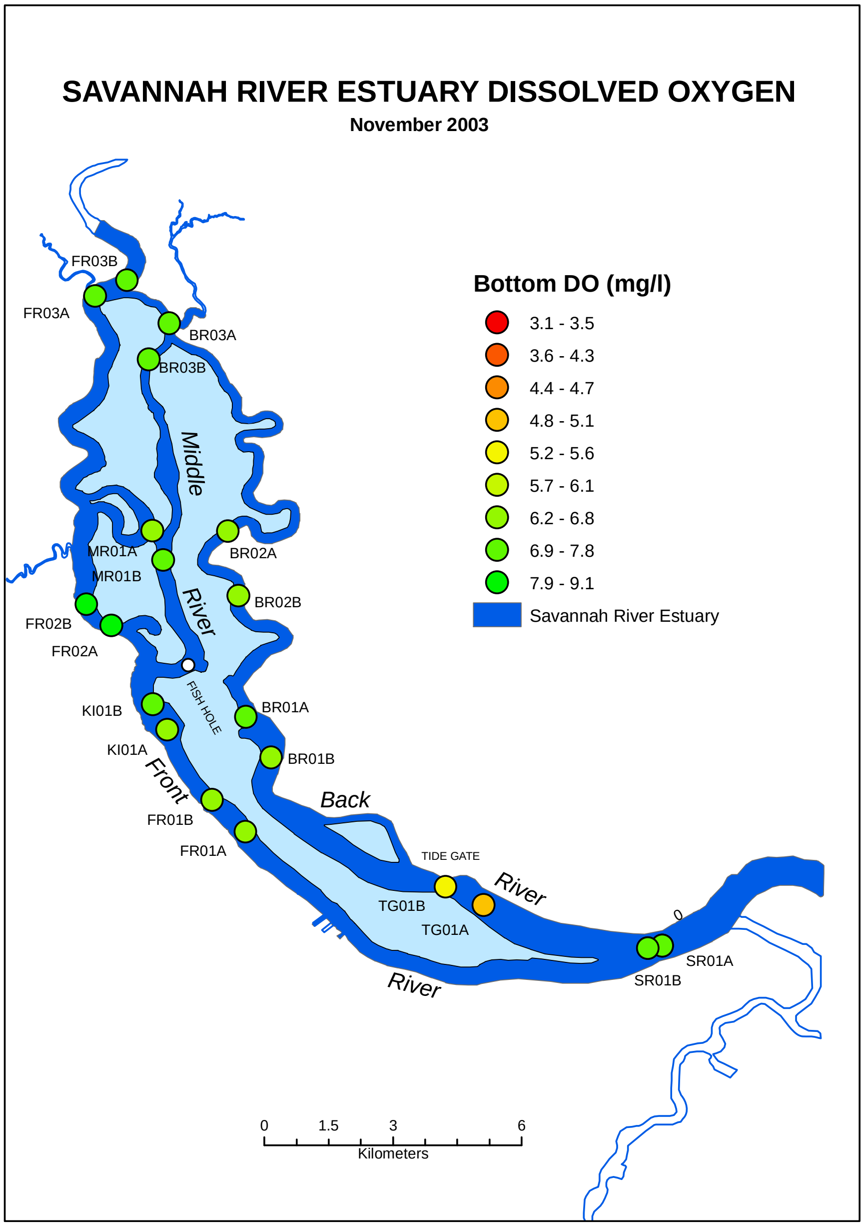


Figure 4.24. November 2003 Bottom Dissolved Oxygen (mg/l) in the Savannah River Estuary. Note: Unavailable site data depicted without color code.

within the SRE (Collins et al., 2000B). Unfortunately, these areas also coincide with low DO concentrations that hover at dangerously low levels for SNS populations during August, when BOD is at its highest. Shortnose sturgeon are well documented to have very specialized DO needs due to their physical inability to quickly regulate changes in oxygen, such as in the presence of riverine hot spots (Birstein, 1993). Hot spots may be natural[9] or man-made, however, it is interesting to note the lowest DO in the Front River reoccurs at exactly the same area over several months of data at TG01, SR01 and FR01. While such an observation is not conclusive, it is possible that a specific location of recurrent hotspot data may pinpoint a sewer outfall, a dredge spoil disposal site or some other anthropogenic activity. The National Wildlife Refuge hot spots are subject to similar concerns, where both natural and manmade[10] causes of low DO are considered.

Figures 4.17 and 4.18 illustrate the low DO present in August 2003 within the formerly identified SNS nursery area. The areas colored in yellow, orange and red represent low, medium and high impairment respectively. Although sample site KI01 is highlighted in yellow for DO, further analysis is needed to provide evidence that this area may still support SNS nursery habitat.

The 2003 Front River Sample sites (SR01, FR01 and FR02) were most seriously impaired during the warm summer months, frequently exacerbating known SNS DO tolerances (< 5.2 mg/l DO). The location of these poor DO results suggests the presence of pollutants and sediments in this Front River corridor may be partially responsible for the low DO. The Front River sediment samples revealed elevated levels (not quantified) of polycyclic aromatic hydrocarbons (PAHs) in the KI01 and FR02 locations. This finding was supported by the inability of lab sediment samples to be processed because of excessive PAH content in some of the collected samples (Christensen, 2004) and field notes describing the presence of strong odors during July and August 2003 sampling activities.

The high oxygen demand needed to break down the PAHs and other sediments suggest the heavy riverine traffic and industrial activity in this corridor is taxing the ecosystem to the point of impacting the survivability of sensitive species like the endangered shortnose sturgeon (Cavanagh et al., 1998). It is therefore necessary to consider the cumulative impact of additional deepening actions, particularly because this SRE corridor must also support recreational fisheries. Prior to obtaining environmental approval for additional deepening/dredging activities, environmental oversight regulations require provision of physical alternatives to provide similar habitat functionality. In the absence of such substitutions, exacerbated DO trends may render existing fisheries habitat in the SRE Front River corridor incapable of sustaining adequate juvenile recruitment levels.

Geographic analyses of the August 2003 water quality data (see Table 4.4, Figure 4.18) display the river reaches that have consistently exhibited poor water quality, specifically, when low DO, high salinity and high temperatures combine to render the entire Front River corridor (with the possible exception of KI01) inhospitable to SNS. Sections of the lower SRE that exhibit DO, salinity and temperature levels in excess of sensitive population (juvenile SNS) tolerances are highlighted in tables (see Tables 4.2 - 4.7) as either dark red or light red, dependent upon the degree of severity the levels impose through a synergistic relationship

Fish hole data from the Middle River, for example, were monitored in June 2003 (Table 4.2: FH01A Data) to explore the possibility that this location could feasibly provide a means of thermal refuge for sensitive juvenile populations of known indigenous fish species. The combination of a high mean temperature and low mean DO levels (temperatures above 22ºC and

DO below 5.2 m/l) were not listed as suitable for all SNS life stages, so they are highlighted in light red. These data would be highlighted in dark red if they were not suitable to adult SNS water quality standards. Acceptable levels are not highlighted, but ideal levels are shown in green.

The dissolved oxygen levels within the Front River from SR01 to FR02 and TG01 to BR01 (see Figure 4.18) were very questionable as a suitable habitat area for juvenile SNS, with frequent readings dropping below 4mg/l (a survival minimum for sustainable recruitment). Tables 4.2 - 4.6 and Figures 4.18 - 4.23 illustrate extreme DO declines in the summer months, particularly in bottom DO near TG01, SR01, and FR02 in June 2003 (see Table 4.2, Figure 4.19). Sample site BR03 also contained unhealthy low levels of dissolved oxygen (less than 5 mg/l) in a somewhat isolated area in the National Wildlife Refuge during June 2003 (BR03, see Table 4.2). Although other areas in Back River also have bottom DO levels that routinely hover below 5 mg/l, sample site BR03 is far enough upstream from industrial influences to avoid most of the pollution and salinity extremes that are typically characterized with the lower portions of the estuary.

Low dissolved oxygen in this more protected stretch of river could suggest the presence of large amounts of organic material or possible runoff from a sewer outfall within that immediate vicinity. Extended inundation during a high Spring tide may have released organic material into the water column, where, in the shallow water of low tide, the warming of the sun may have created a catalyst for the breakdown of the organic materials. This subsequent increase in BOD, may explain the nearly uniform low DO levels across the vertical gradient in this location.

It is also possible that June 2003 water quality data (see Table 4.2) may be capturing a snapshot of the natural fluctuations in the SRE DO cycle as a result of increased amounts of rainfall during the Spring months of April and May. Rainfall cycles, however, are seldom useful in determining trend data except over continuous long-term water quality monitoring of sample sites. Such multi-decade continuous data does not yet exist for this specific sample location.

Excessive fecal matter from a large population of wild pigs[11] and/or alligators may have also contributed to the highly organic sediment samples taken from this area. Small clamshells, stems, and foraminifera (forams) in varying stages of decay were extracted with a grab sampler from the BR03 and BR02 sites. The presence of newly decayed organic material was noted through visual inspection of the sampled bottom sediments in both Summer and Fall grab sample dates, despite a large fluctuation in temperature (from around 26ºC to 19ºC).

Temperature

Shortnose sturgeon are generally tolerant of temperatures ranging from 17ºC to 26ºC, depending upon their geographic location and their maturity (Jenkins et al., 1993). Juveniles, however, are very susceptible to extreme heat and cold, particularly when they are less than two weeks old and must endure near hypoxic DO conditions (Jenkins et al., 1993). Studies performed by EPA suggest that fish exhibit increasing signs of stress at temperatures as low 20ºC (NOAA, 1998). Extreme heat may also impose similar stress. The higher temperatures recorded during the summer months of 2003 posed a threat to young-of-year SNS when all the sample sites began to exceed 26ºC (see Figure 4.25).

The relatively even distribution of high summer temperatures across all the sample sites (see Table 4.4) suggests that deeper fish holes might be the only possible means of thermal refuge within the freshwater tidal interface of the lower estuary. Side-scan sonar data did not

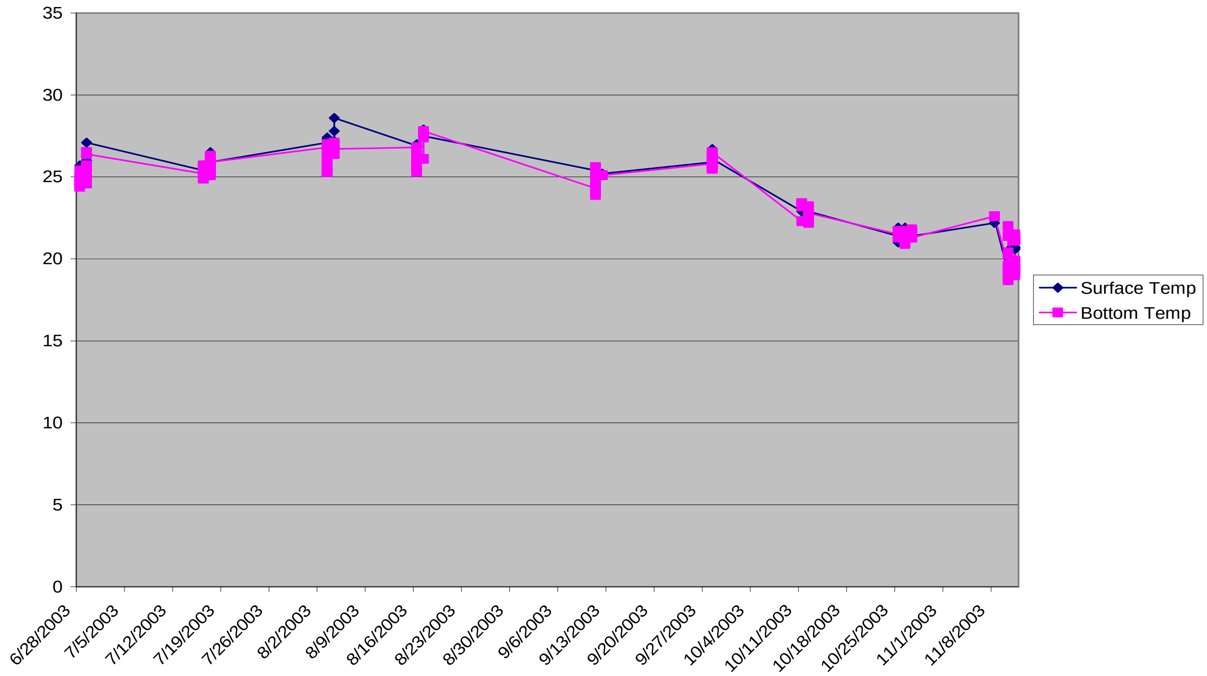


Figure 4.25. June-November 2003 Temperature (ºC) in the Savannah River Estuary.

reveal the presence of a fish hole in the Front River as mentioned in earlier studies (Collins & Smith, 1997; Hall et al., 1991), but the DIDSON sonar data indicated the Middle River did support a very large population of fish within in a fish hole located in the first bend near the confluence of the Front River (see Figure 4.26). The moderate southern climate and the lack of significant changes in food source availability during cooler months (determined by topside observation of presence of flora and fauna) throughout the Middle River and Back River portions of the SRE suggest that temperature is primarily a consideration in the health of SNS only during the extreme heat of the summer months. These summer temperature extremes require SNS to have some temperature refuge or other mitigating factor, such as cool water pockets created by the presence of habitat structures or a topside over-story that may offer shade in shallow portions of the river. It is, therefore, critical to conduct continuous monitoring of all documented riverine physical features to provide a basis for protecting any existing known thermal refuge areas within the river.

Physical Features

This study investigated the geographic distribution of suitable habitat in terms of physical features in addition to water quality. The Collins 2000B study identified the Front River near FR02 and the Middle River near MR01 and FH01 as locations where SNS were captured (see Figure 4.26). Did the physical feature data obtained in the 2003 water quality data demonstrate any changes in the location and use of previously recorded SNS habitat? This question was answered in part with a review of the side-scan sonar data taken in the Front River and Middle River. The bank to bank coverage of the sonar revealed the distinctive cutter-head marks where the United States Army Corps of Engineers had dredged as far upriver as FR02 (Houlihan Bridge).

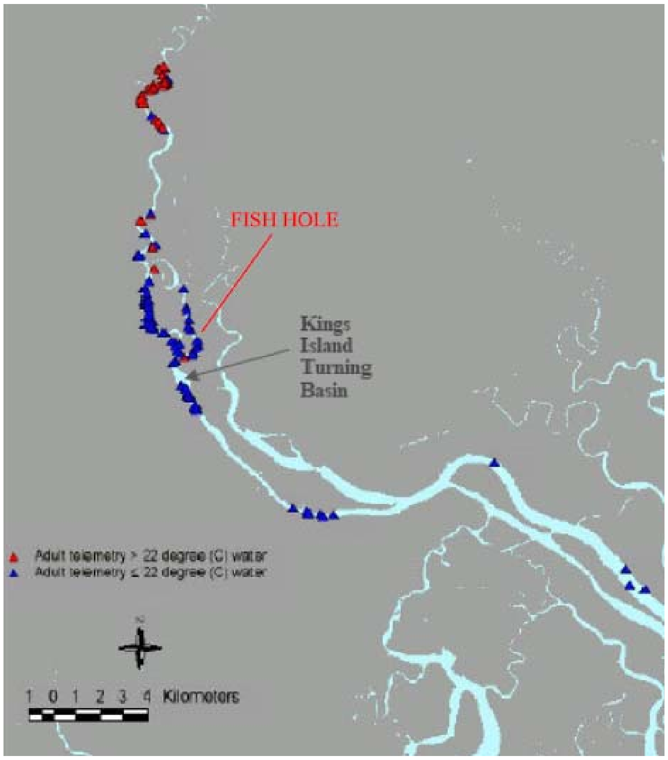
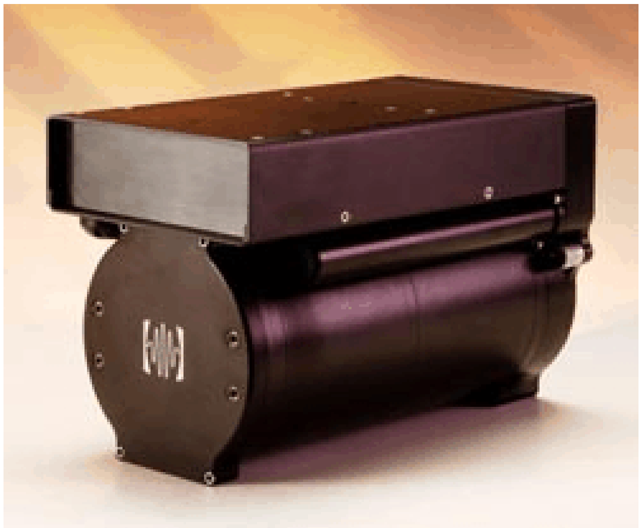


Figure 4.26. Locations of Shortnose Sturgeon Aggregation in the Savannah River Estuary. Source: Collins et al., 2000B.

The 2000B Collins study suggested that there was a nursery area in King's Island Turning Basin. However, this 2003 water quality data, using side-scan sonar data, did not reveal the presence of any aggregation of fish or the presence of fish holes within the Front River, suggesting the fish holes mentioned in previous studies were either scoured away or dredged during SACOE channel maintenance dredging. The side-scan sonar images taken for this 2003 water quality data covered from King's Island Turning Basin to Houlihan Bridge in the Front River, just past the first bend in the Middle River, and across two extended reaches in the Back River, for an approximate coverage area of 17 kilometers. These reaches of the SRE included the areas where the SCDNR had previously identified sturgeon habitat. Although interviews with local fishermen confirmed recent sturgeon sightings and extensive sturgeon bycatch in some of the same previously identified SNS habitat locations (during the 2003 shad fishing season in the SRE), the 2003 Klein side-scan sonar data was not conclusive in determining the presence of specific species within these areas.

The Middle River fish hole, once re-identified with 2003 side-scan sonar, required closer investigation. The investigation began with the collection of water quality data (including temperature data) within the fish hole. This data, however, was difficult to collect in anything but a flat-bottomed skiff, due to the presence of sandbars and areas of very shallow water surrounding the Middle River fish hole sill. This difficulty rendered Middle River FH01 temperature and additional water quality data collection impossible, except on the first date attempted, when the research boat remained stuck on a sandbar adjacent to the fish hole sill until the return of high tide. The constant presence of alligators also discouraged further water quality data collection in this section of Middle River.

Figure 4.27. DIDSON Multi-beam High Frequency Sonar. Source: Sound Metrics Corporation. 2008.



The physical attributes of the fish hole, however, were of particular interest, given the possibility that depth and physical characteristics may have changed significantly since data was last collected in 2000. The fish hole was revisited by boat again when the DIDSON high-frequency sonar (1.6-1.8 MHZ) (see Figure 4.27) further confirmed the depth and captured real time (10f/sec) sonar images of an aggregation of fish of all shapes and sizes. A flat-bottomed skiff was fitted with a pole secured to the bow of the boat from a pivot point. The DIDSON was attached to this pole and lowered directly into the fish hole while a topside computer recorded the fish movements within the hole from the stern of the boat.

The fish were observed hovering, swimming and darting away from the sonar (see Figure 4.8) on occasion. The second attempt for the collection of water quality data within the fish hole was discontinued because additional disturbances in the water negatively impacted the fish in their reaction to the sonar. Additionally, turbidity needed to be kept to a minimum to achieve optimum sonar data clarity. Although SNS could not be specifically identified as present within the fish hole, one of the larger fish sonar images (see Figure 4.28) matched the shape and size of a shortnose sturgeon image that had been observed during a study using the DIDSON sonar in the Fraser River, BC (see Figure 4.29) (Sound Metrics Corporation, 2008). The DIDSON identification of the Fraser River sturgeon was subsequently confirmed during a capture and release.

Significance of 2003 Sonar Findings

The possible identification of a SNS within the Middle River fish hole represents a very powerful argument for protecting it during all proposed expansions of the adjacent Savannah Harbor. Current modifications, as proposed, would extend the King's Island tuning basin an additional 100 feet into the interior portion of Argyle Island that abuts the south-western edge of

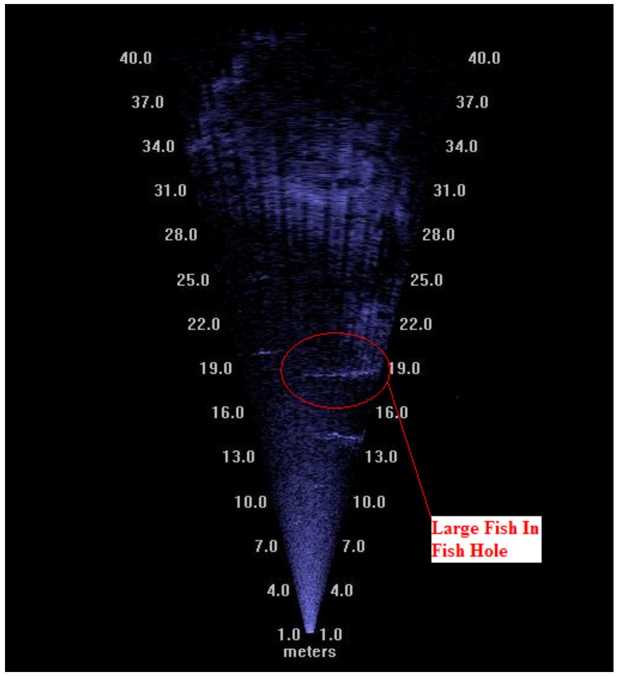


Figure 4.28. Large fish (possible Sturgeon) in the Savannah Middle River Fish Hole.

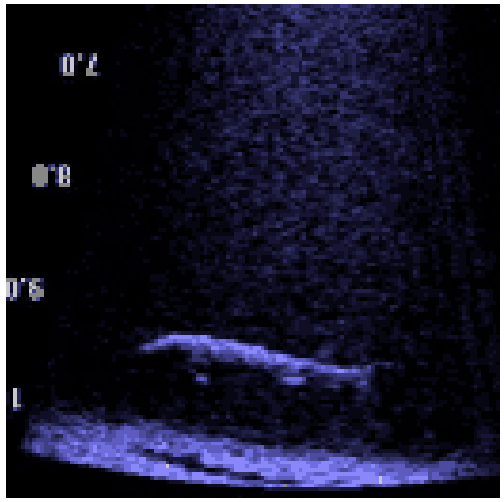


Figure 4.29. Fraser River Shortnose Sturgeon. Source: Sound Metrics Corporation, 2008.

the embankment currently protecting the fish hole. This proposed modification, however, may trigger NEPA protective covenants even without direct confirmation of the presence of SNS habitat in the vicinity of the proposed improvements. Confirmation of the fish hole's unique habitat status within the freshwater tidal interface ecosystem may suffice for demonstrating this region must be protected because it is critical to the survival of many other threatened and endangered species.

Habitat quality is a meaningful measurement of total ecosystem health. Water quality data, alone, from the 2000 Collins study were not predictive of SNS telemetry data from the same study. Shortnose sturgeon aggregated in odd areas and displayed an affinity for river reaches with consistently poor water quality (see Figure 4.26) (Collins et al., 2000B). The Middle River location of the fish hole (FH01) and King's Island Turning Basin (KI01) were both identified in past studies as important habitat for SNS, providing a thermal refuge and a juvenile nursery area respectively, despite their poor condition. An abundance of fish (some assumed to be SNS from SHEP stakeholder claims) were also confirmed present in areas of degraded water quality in 2003 data, suggesting that consistently poor water quality within a specific area may not be enough information to draw conclusions about the habitat preferences of SNS and other indigenous SRE species. Water quality data, however, have had more success and predictive value for determining the expected ability of SNS to function at a benchmarked level of reproductive capacity (predictions for recruitment levels).

Water quality studies interpreted without additional contextual clues have limited predictive value and do not consider other possible SNS habitat features that may explain why water quality data alone, were not necessarily predictive of actual SNS locations in past studies. This study, therefore, considered the rarity or uniqueness of site-specific features as a starting point to discover if the habitat location or a specific feature within a habitat area may be correlated with overall SNS health. Additionally, the rarity of SNS habitat features within sampled reaches of the SRE may provide insight as to whether these areas are providing a unique ecosystem function within the SRE (e.g., increasing food web/primary production).

Habitat Rarity/Unique Feature Findings

The majority of fish monitored in a series of fish telemetry studies conducted by the South Carolina Department of Natural Resources remained demersal and congregated within a deep fish hole in the Middle River (rk 31.5). This fish hole (see Figure 4.30) is believed to provide over-wintering habitat for some SNS that do not move upriver when water temperatures drop below 22ºC (Collins et al., 2000B). The continued presence of this fish hole was determined to be significant in the survivability of SNS because it provides unique habitat within the freshwater tidal interface as mentioned previously and supported by earlier studies and the 1999 aerial quarter quad photo (see Figure 4.31).

The uniqueness of the Middle River fish hole was again confirmed by this study, after review of 2003 side-scan sonar data of the entire study area. The fish hole (see Figure 4.32) is clearly visible in the Klein 3000 side-scan sonar images. The sill of the fish hole is shown as the white area (hard substrate is white) surrounded by a dark area (the actual hole is in shadow because the sound returning to the sonar receiver becomes weaker with sound absorption from soft sediments at depth). The 2003 sonar data confirmed the location of the Middle River fish hole had not changed since mentioned in the 2000 Collins study. Three days of collecting side-scan sonar bank-to-bank data within the navigable SRE study area did not yield any additional locations of a freshwater tidal interface fish hole.

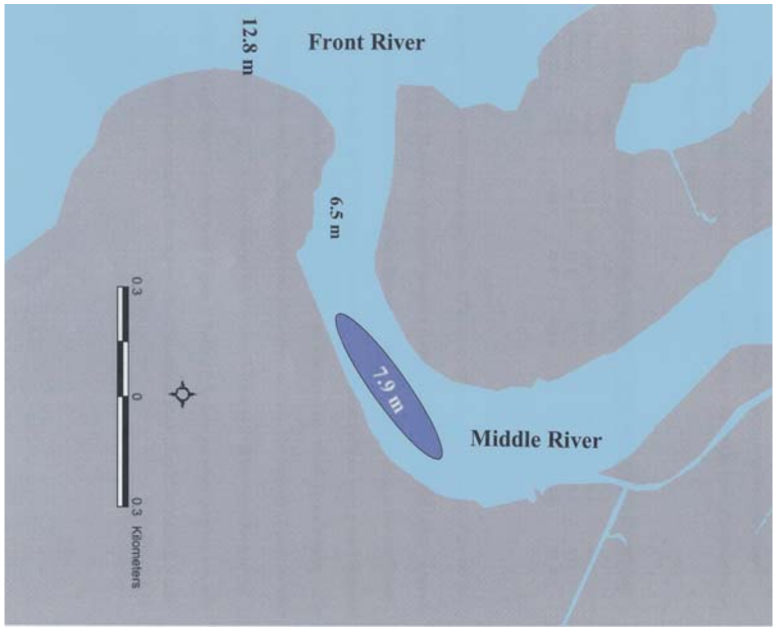


Figure 4.30. Fish Hole In Middle River of the Savannah River Estuary. Source: Collins et al., 2000B.

Figure 4.31. Fish Hole the Savannah River Estuary Middle River. Source: USGS, 1999 Digital Orthographic Quarter-quad (DOQQ).

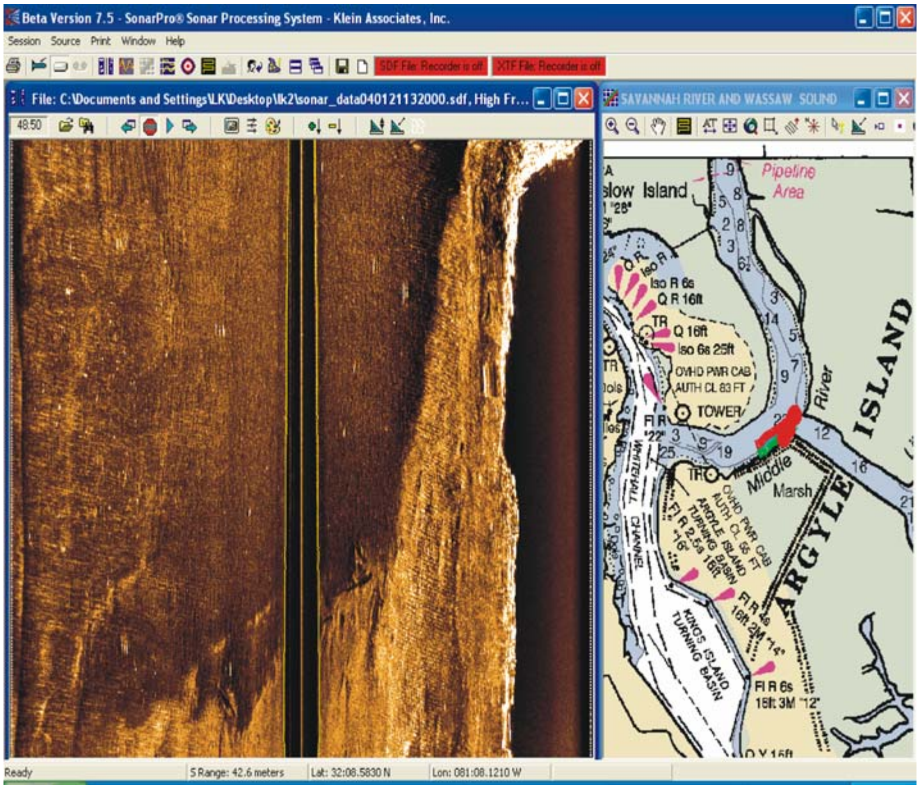


Figure 4.32. The Middle River Fish Hole Using Klein 3000 Mid-frequency Side-scan Sonar.

The fish hole functions (thermal refuge, predation avoidance, feeding ground, protection from salinity spikes) were assumed to be unchanged since the 2000 Collins study (Collins et al., 2000B), given there was little difference in the Middle River fish hole observations between both studies. The Collins study observed SNS toward the bottom of the fish hole and along the rim where temperature, salinity and DO remained within a stable (but not ideal) range for juvenile SNS. This study, by comparison, did not observe any SNS around the sill of the fish hole, but did record many fish swimming at varying depths within the fish hole. Additionally, FH01 water quality data (Table 4.2) confirmed salinity, temperature and DO levels were stable, but still not ideal, as first noted in the Collins study.

Additional Findings: Turbidity, Dredging, Seeps and Debris Fields

Turbidity. Turbidity levels were also observed during the summer of 2003. Secchi disk data revealed that there were few locations within the Front River where visibility exceeded one meter. The presence of heavy sediment causes poor visibility and may have attenuated the light available for photosynthesis, leaving the substrate barren of plant vegetation in areas where high boat traffic and excessive sediment loading/disturbance were present. Grab sample data (taken at sample site KI01 in 2003) did not contain vegetation or indicate the presence of any forams. Instead, the King’s Island turning basin substrate consisted of a thick and fluffy mud. Although previous studies suggested nematodes and other food sources for juvenile SNS were typically found in this type of substrate, the collective 2003 water quality and sonar findings did not confirm or deny whether a SNS nursery area could be supported in the current configuration of the King’s Island Turning Basin, specifically because there was no direct evidence that a food source was present.

Additionally, high turbidity observed throughout the channel was exacerbated on days when dredging operations were noted to be in the sample area. Higher turbidity and increased fine sediments from dredging may clog the gills of sensitive fish and interfere with buoyancy regulation in the SNS *Physostomous* (air/pressure bladder that allows SNS to make adjustments to depth and changes in salinity). The coarse fraction of the sediment samples revealed no organic materials in the sample sites where dredging activities were ongoing for channel maintenance.

Dredging. The ongoing channel maintenance dredging was evidenced by dramatic changes in reported physical features from both the cutter-head marks (sonar live feed) in the area where a fish hole had been identified in 2000, and from a series of unsolicited reports of "dead zones" in front river reaches that had been formerly identified as a nursery area for juvenile SNS (Miller, 2004). The dredging of the front channel was also reflected in the sediment analysis. Specifically, Sedigraph and RoTap analysis of grab samples separated the fine and coarse fraction using a 63 micrometer sieve. The absence of foraminifera in these samples confirmed the "dead zones" or scarcity of food in the recently (within the past six months) dredged riverbed (Christensen, 2004).

Seeps. Freshwater seeps were mentioned by numerous scientists from the stakeholder interviews, however, 2003 sonar data also did not reveal the presence of any fresh water seeps in characteristically cooler portions of the research area, including at depth within the fish hole. This finding was consistent with SHEP stakeholder reports of negative head pressure which effectively capped the ability of historically alleged seeps to be detected or functionally relevant within the study area. The absence of long-term continuous water quality or sonar data, however, did not offer any clues toward the past locations for such features. Hearsay reports from fishermen attested to the existence of many now undiscoverable riverine features (including seeps). Additionally, the historical records from the 1850's described Argyle Island as the past site of two large rice plantations, an intensely demanding use of freshwater that was formerly available in this now partially oligohaline environment.

Debris fields. The present-day fish hole location is on the south-western tip of Argyle Island. Argyle Island rice fields were identified in the side-scan sonar images through the remnant remains of rice trunks, dock posts and large submerged stumps that were formerly plantation shade trees for the land overseers. Detailed accounts of plantation transactions and locations of specific site features were recorded by the Manigaults, absentee owners of the Argyle Island Gowie and East Heritage Rice Plantations that comprised a 650 acre tract in the mid-eighteen hundreds (Clifton, 1978). Some pock-marked stumps, roots and other debris were also visible in the DIDSON sonar Middle River fish hole "images" (see Figures 4.33 and 4.34) with fish of varying sizes scattered throughout the field of view.

This debris field represents a departure from the adjacent Middle River marsh waters, where open areas contain widely disbursed and scattered small debris that does not afford the same level of protection from predation while feeding. The historic record reflects total destruction of the plantation sites during the Civil War, possibly explaining the higher density of debris in an area that contains evidence of boat docks and building sites (historically evidenced by the presence of trees in an area otherwise used for flooded agricultural fields). Topside observations also noted the remains of what appears to have been a hearth within approximately half a kilometer of the Middle River fish hole. Although the hearth remains were located on a mudflat high above the water level during all tidal stages, it is likely that past inundation of this site may have contributed to the density of the submerged debris field in this area.

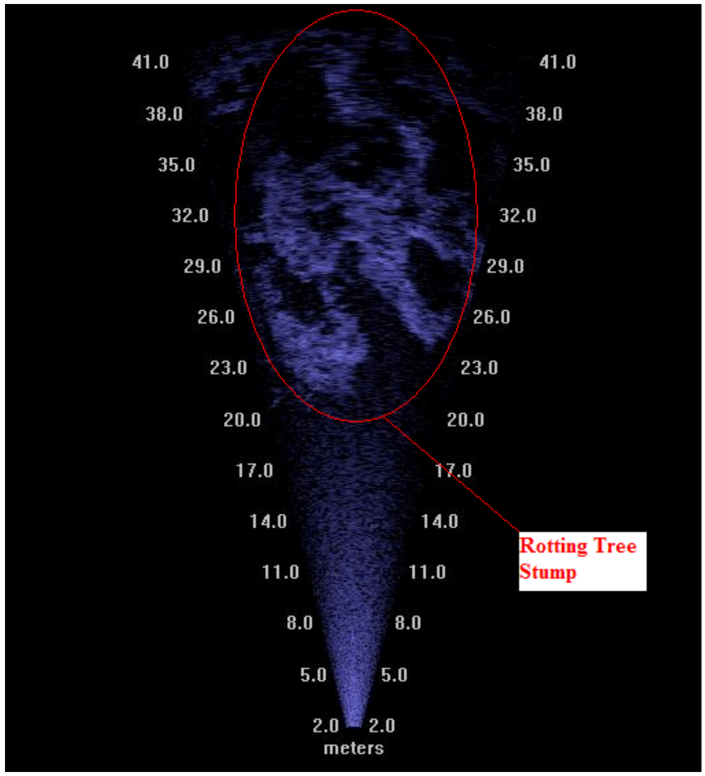


Figure 4.33. DIDSON High-frequency Sonar Image of Rotting Stump in Middle River Fish Hole. Note: Incident angle of DIDSON sonar may alter perspective for visual estimation of size.

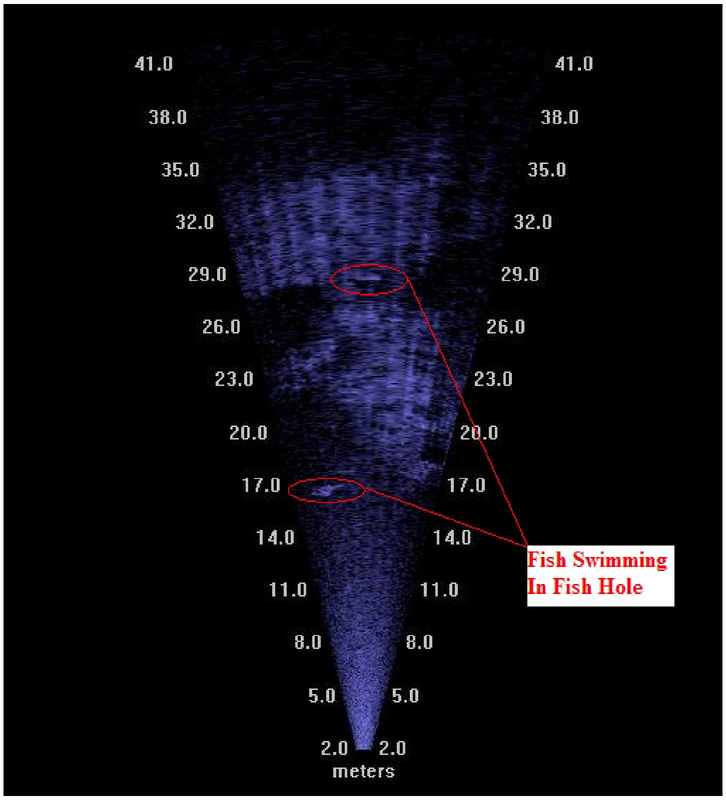


Figure 4.34. High-frequency DIDSON Sonar Image of Fish Hovering in Middle River Fish Hole.

Although the Front River is regularly dredged for maintenance up to Houlihan Bridge (Front River sample site FR02), there is a sloped bank where the dredge cutter-head marks stop. The faint outline of a small wooden boat is barely visible in this scan (see Figure 4.35). A final observation from side-scan sonar data revealed another remnant of the antebellum rice trade. This debris field, however, was located in the Back River near BR02. An old dock and a rice trunk remnant is visible from below and above the waterline (sonar live-feed) (see Figure 4.36). This finding does not seem to be significant relative to SNS habitat, however, because the sonar data did not indicate the presence of an aggregation of fish or other marine animals, and is, therefore, not given further consideration in this study for restrictive regulatory oversight.

Regulatory Oversight for Water Quality Monitoring

Setting Water Quality Tolerance Levels among Different Species

Past EPA studies have struggled with setting tolerances for water quality parameters because, for example, individual aquatic species have different tolerances of DO concentrations. In response to this concern, the United States Fish and Wildlife Service requested the classification of “Industrial/Navigational” be changed to “Coastal Fishery” to consider water quality parameters that were defined based on specific tolerance ranges of some protected or threatened species, including striped bass, the endangered shortnose sturgeon and other indigenous species. Specifically, this decision was made because juvenile SNS exhibit severe stress and mortality over extended exposure to even moderately low levels of DO (levels below 5 mg/l) (EPA, 2003). The indigenous SRE Atlantic sturgeon, however, do not exhibit identical stress responses.

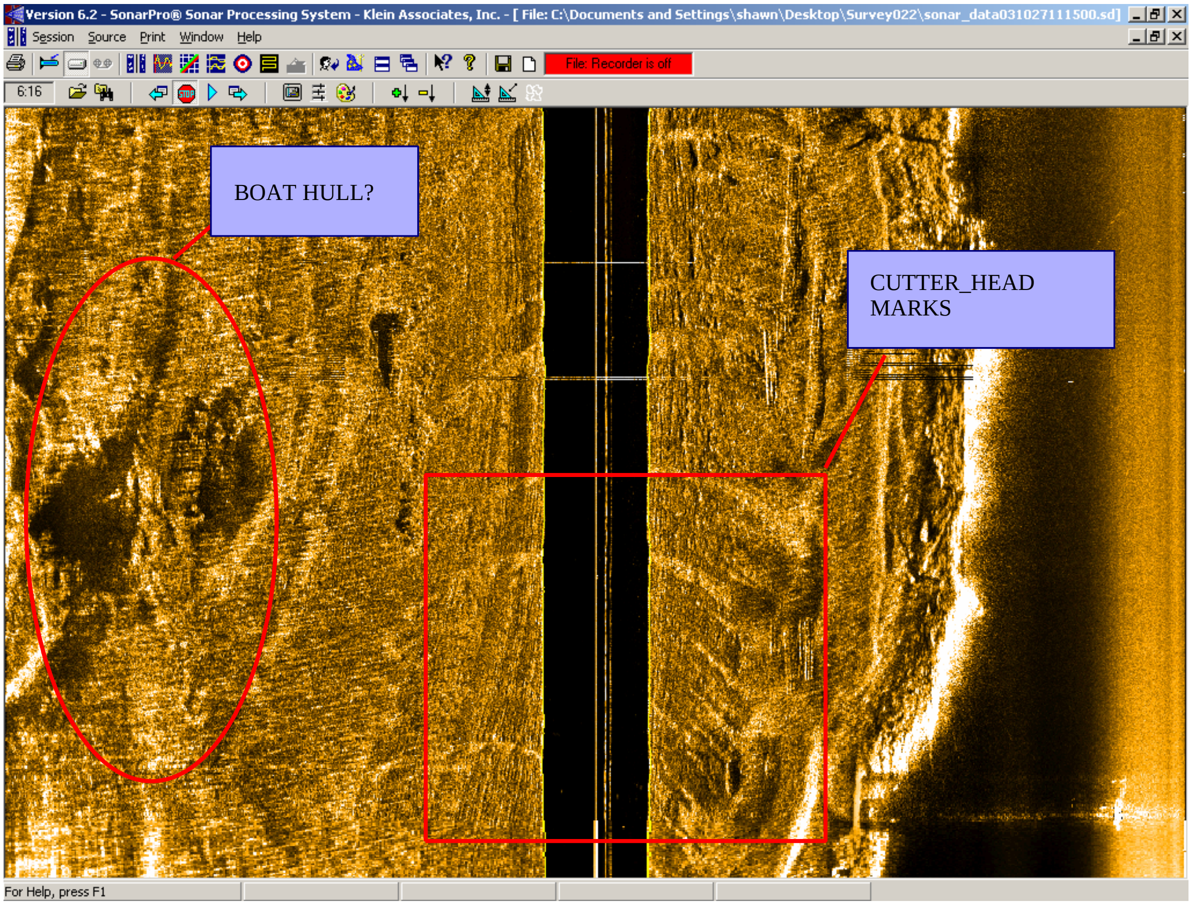


Figure 4.35. Savannah River Dredge Cutter-head Marks and Possible Boat Outline Using Klein 3000 Mid-frequency Side-scan Sonar.

Figure 4.36. Rice Trunk and old dock can be seen in this aerial photo.
Source: FEMA.

Juveniles from different species may exhibit signs of stress at different temperatures and the same DO concentrations (Secor & Niklitschek, 2001). Sensitive populations of both species, however, show inhibited growth due to shifts in metabolic processes that occur when DO concentrations are below 60 percent oxygen saturation at temperatures ranging from 20ºC to 27ºC (Secor & Niklitschek, 2001). Mortality rates decrease as age increases, but very early life stages (less than 17 days) were prone to high mortality in DO concentrations as high as 5 mg/l in the presence of other environmental stress[12] or in exposures over 7 days at 25 degrees C without stress (EPA, 2003).

EPA Response to DO Criteria

The EPA is still struggling with how to handle such species tolerance differences. The debate is over sensitive population regulatory criteria and about whether EPA should take into account DO levels where juveniles begin to exhibit slow growth responses to stressful environments (such as high temperatures or high salinity levels (Campbell & Goodman, 2003; Jenkins et al., 1993).

Lethal Concentration Fifty (LC_{50}) levels for SNS of the sensitive juvenile population suggested water quality parameters needed to be almost two times higher than what adult SNS needed to survive the same conditions (Cambell & Goodman, 2003). The EPA addressed these differences by developing DO water quality standards that were determined by life stage of the target population and duration of exposure. Unfortunately, due to the cryptic nature of the first thirty days of a SNS's life-cycle, the EPA refrained from including this early stage in their DO regulations. State water quality requirements also include bacteria (e.g., fecal coliform <geometric mean of 500 per 100 ml). Numerous toxins/heavy metals were given very stringent compliance levels; however such toxins were not the focus of this study. For all months (see

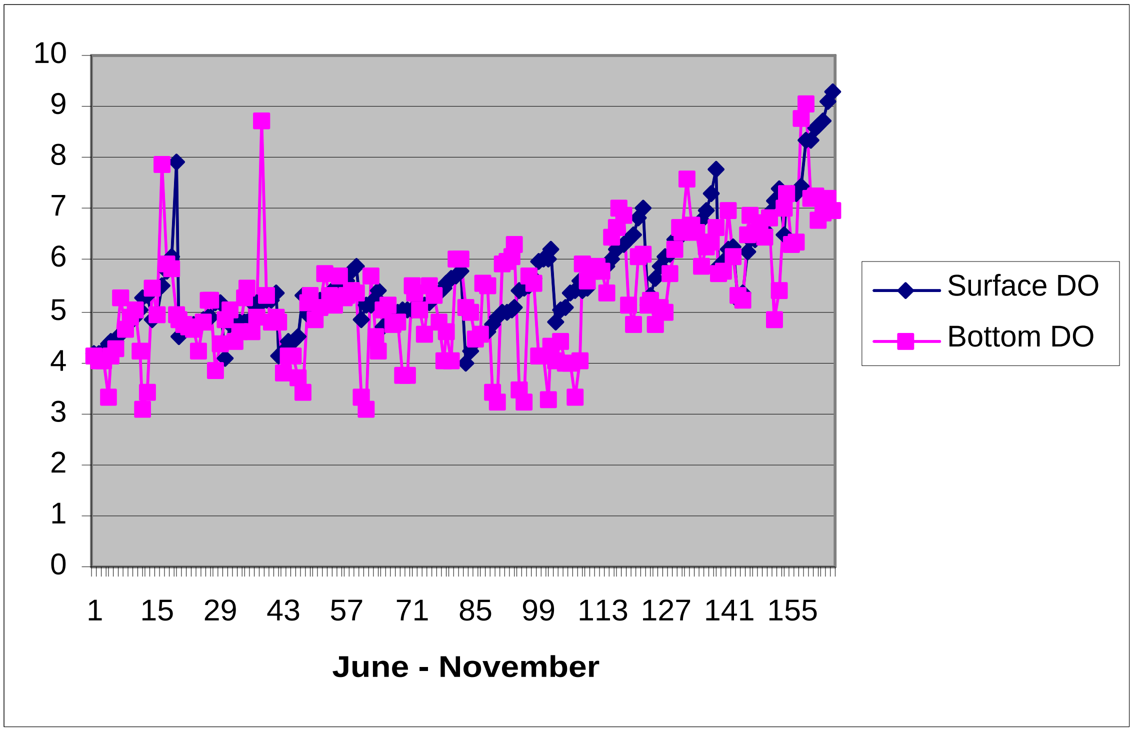


Figure 4.37. June-November 2003 Dissolved Oxygen (mg/l) in the Savannah River Estuary.

Figure 4.37), potentially lethal DO concentrations (below 4 mg/l) were exhibited across approximately half the data, despite the fact that these data were observed during a high rainfall year. Salinity data for this same period (see Figure 4.12) showed no sustained periods of high salinity, but experienced regular periodic spikes, particularly in bottom salinity data.

These findings suggest water quality concerns (salinity spikes) could be more threatening to overall SNS health than the mean salinity data may indicate. Salinity spikes, according to EPA, may be responsible for the current recruitment bottleneck seen with both SNS and striped bass, both of which use passive transport of their eggs to ensure reproduction of the species. The eggs float down river into higher and higher salinities, until the negatively buoyant nature of SNS eggs causes them to sink. Sinking eggs are slightly adhesive (in low turbidity), allowing them to bond with any available hard substrate. In the absence of appropriate (clean and hard) substrate, the egg continues to float into potentially unfavorable conditions for development, specifically, high salinity, high turbidity or low DO concentrations. Salinity spikes may push SNS egg tolerances too high in bottom reaches of river where eggs may settle, causing certain mortality, and a potential recruitment bottleneck, in the event of sustained DO or salinity stress.

Adequate river flows and rates have also been documented to be part of the overall equation for early stage (1-30 days) SNS development. Unfortunately, such flows may become too fast to allow the eggs to attach to the substrate or they may be too slow to allow the eggs to separate, creating lethal clumps (Jennings, 2005). Additionally, the eggs may dry out if they are unable to attach to substrate prior to reaching water with higher salinity.

Summary of Findings

This dissertation includes thirteen findings (see Table 4.9); however, five of these findings portend difficult survival and/or recovery for the endangered SNS. These five findings include the following:

1. DO levels were low enough to cause severe stress in sensitive or juvenile species.
2. DO was not necessarily predictive of movement of SNS.
3. Side-scan sonar data coupled with high-frequency DIDSON sonar data revealed the Middle River fish hole to be in tact with heavy fish utilization.
4. Fish hole and Middle River debris fields are threatened by proposed harbor expansion.
5. Alternatives for protecting SNS rare habitat/features are not yet included in the SHEP Tier II EIS.

The DO remained below established EPA minimum levels of DO (< 4.0 mg/l) for over half the data observations. The SCDNR studies indicated SNS were aggregating in some of the least hospitable waters, potentially affecting the recruitment of juveniles in waters where the synergistic effects of low DO combined with high temperature. This dissertation study, however, indicated that there was not another fish hole within the freshwater tidal interface portion of the lower SRE. The SEG public website has many documents designed to educate the public as the ACOE and the Georgia Port Authority review possible mitigation plans. Currently discussions regarding the possible re-routing of portions of the Middle River are being considered. These proposed plans need to be evaluated in terms of what impacts they may have on the only remaining fish hole in the freshwater tidal interface portion of the lower SRE. The unique status of this riverine feature enhances the importance of preserving habitat that offers thermal refuge, protection from salinity spikes and possible protection from predation. The rarity of the fish hole may also trigger protective measures under EPA and NOAA environmental regulatory requirements through the Endangered Species Act and provisions under NEPA to examine alternatives to mitigate possible negative environmental impacts.

The complete list of findings from this 2003 research are summarized in Table 4.9. They are organized according to the section in which they first appeared, with additional cross-referenced information listed to summarize the significance of individual findings. These findings provided the basis for preliminary recommendations.

Preliminary Recommendations for Development of Physical Habitat Criteria

Despite incomplete life cycle data for the Savannah River SNS population segment, scientists have used data from striped bass populations to extrapolate minimum habitat requirements for larval SNS within the Savannah River (Collins et al., 2000A). Specifically, USFWS supports de-authorization of further harbor modifications from Augusta to Savannah until oxbows and natural debris fields[13] have been returned to portions of the river (Eudaly, 2005). Based upon SNS data from other local rivers, and striped bass data from the Savannah River, protecting physical features such as fish holes, improving substrate material (introduction of gravel, rocks, logs and other debris) and prescribing restorative flow regimes have helped expedite a modest striped bass recovery (USFWS, 2004). It is plausible that similar results may be expected for the SNS once a recovery plan has been given adequate time to develop unimpeded by further degradation of either water quality or physical habitat[14] (Eudaly, 2005). Additional recommendations for improving SNS health will be discussed in greater detail in Chapter 5.

Endnotes

[1] Previous water quality studies established sampling stations based upon salinity regimes and physical proximity to known areas of SNS occupation from telemetry studies (Collins et al., 2000B).

[2] The shortnose sturgeon is a fresh water/marine water (anadromous) fish that has been historically harvested for its delicate roe (fine caviar) and sweet white flesh. The high commercial value of this fish led to a dramatic decline in the population of this fish in its native waters of the eastern coast of North America. The protection of this species under the Endangered Species Act in 1973 stabilized the remaining population until other environmental factors like low dissolved oxygen and dredging were cited as causing the continuing species decline in some geographic regions (Jenkins et al., 1993).

[3] Tier I Environmental Impact Statements are defined in NEPA regulation at 23 CFR 771.117(d)(12) as part of the preliminary investigation of basic impacts and alternatives for a proposed Federal project. Tier II EIS is a more detailed analysis of the environmental, social, cultural and economic impacts. Draft EISs are first reviewed by the public before they may become part of the Record of decision (ROD).

[4] Complexities of modeling dynamic systems include correcting for: time lags, changing water withdrawal levels, energy production flow changes, dramatic weather events, limitations of measurement technology, geological anomalies (SEG, 2006).

[5] EPA defines assimilative capacity as: "The ability of a body of water to cleanse itself; its capacity to receive waste waters or toxic materials without deleterious effects and without damage to aquatic life or humans who consume the water."

[6] Nephelometic Turbidity Units (NTU) are not required for Coastal Fishing designations.

[7] LC_{50} refers to the lethal concentration at which fifty percent of the test subjects die when exposed to the test treatment. Generally, water quality regulations implement margins of safety in water quality parameters using this figure.

[8] Although salinity levels were not as exaggerated in 2003, the salinity concerns of the SRE were not dismissed, rather, they framed other issues as more salient to overall ecosystem health.

[9] Changes from dramatic storm events, rainfall fluctuations, wind currents and other climatic changes effect how much oxygen is introduced or taken out of the environment. Changes that alter salinity also impact circulation patterns because the dense saline water sinks, which ultimately impacts whether upwelling of cold nutrient-filled water occurs and at what rate. The presence or absence of specific nutrients (like nitrogen) also impact the ability of plants to uptake nutrients through their root systems to carry on photosynthesis. If there are too many or not enough of the right nutrients, then plants (and a chain of interrelated species) may die and add organic materials into the estuary at a faster rate than they can be removed. If this pattern persists for extended periods of time, eutrophication results, further exacerbating the problem as more and more species die and the organic overload to the system becomes too high from the increased biological oxygen demand (BOD).

For example, the waterfowl management areas were being affected by changes in the marsh vegetation brought about by eutrophication. Increases in sediment loading also interfered with the ability of some birds to spot their prey in shallow water. As birds lost sources of food and habitat for predation, the birds also died, adding more nutrients to the mix. Nutrient loading decreased photosynthesis, which decreased primary production and increased salinity. The increased salinity killed more marshgrass, putting the ecosystem balance at-risk (Eudaly, 1999).

[10] Water quality in the SRE was listed as impaired by the EPA because concentrations of dissolved oxygen have been lowered significantly by the release of pollutants from a variety of sources (non-point source and point source) including: industrial effluent, run-off from impervious surfaces, agricultural activities, discharge of untreated ship ballast water, nutrient loading from disposal of biological wastes, and increased sediment loading from harbor maintenance dredging activities. NOAA's Coastal Monitoring and Assessment Division conducts analysis of sediments from estuaries (including the Savannah River Estuary) where eutrofication and/or toxicant loading is considered likely from industrial and other anthropocentric activities within the immediate vicinity. NOAA uses results from such studies to create standard protocols and practices and to detect local water quality conditions that may adversely affect aquatic species.

The presence of additional pollutants can overwhelm natural systems because the pollutants remove oxygen from the water to break down chemical bonds such as the conversion of ammonia to nitrite and then nitrate. If too much oxygen is required to break down anthropogenically expelled compounds, then there is not enough remaining available oxygen to sustain fish and other aquatic species. Nutrient total maximum daily loads (TMDLs) were not included because of the dependence upon the scientific question being asked and the difficulty in tracing the exact source of pollutants.

[11] The National Wildlife Refuge has a large population of wild pigs that roam freely within the lower SRE marshes and across many of the Georgia and South Carolina barrier islands. These pigs were observed in high numbers while 2003 water quality data were collected in the Middle River and Back River portions of the study area. Additionally, a wealth of alligators were observed during the warm, sunny days during June, July and August 2003.

[12] Environmental stress may minimally include above average levels of: salinity, temperature, turbidity, pollutants or velocity.

[13]Debris fields provide substrate for egg deposition, escape from predation, and flow modifications that may introduce more oxygen onto the water naturally.

[14]Physical degradation of fish habitat may include dredging, deepening, expansion or reallocation of sediments.

CHAPTER 5

SCIENCE-BASED POLICY DEVELOPMENT FOR SUSTAINABLE FISH HABITAT IN THE SAVANNAH RIVER ESTUARY

Introduction

Current data from this study and the research of prominent Savannah River researchers (Collins et al., 2000A; Eudaly, 2005; Jennings, 2005; Reinert, 2003) suggest the Savannah River Estuary (SRE) is in immanent danger of losing an endangered species of fish, the shortnose sturgeon (*Acipensar brevirostum*). Loss of distinctive and unique population segments are projected because SRE fish habitat has either physically degraded or been exposed to extended periods of poor water quality during low flow periods (Wrona et al., 2007). This research explores the importance and urgency of developing science-based policy to protect and delineate unique fish habitat (including shortnose sturgeon (SNS) habitat) from surrounding proposed navigation improvements of the Savannah Harbor Expansion Project (SHEP). The uniqueness and threatened status of the SNS habitat was evident after water quality monitoring, sonar investigations and physical assessments were performed during non-drought river flow conditions from June-November, 2003.

Poor water quality, such as the unsustainably low DO levels presented in the scientific data (see Chapter 4), supports the necessity for immediate protection of sensitive species (Jennings & Weyers, 2002). Although policy must be developed in keeping with competing economic and environmental interests and in accordance with applicable policy and law, the delay caused by such considerations adds to the urgency for timely evaluation of recommendations prior to their transformation into actions. This chapter begins with the history and general background information relevant to the creation of science-based water quality policy. The review of existing laws, regulations and policy guidelines provides a framework for determining standard environmental practices for stakeholder groups and other participants in water quality stewardship. Secondly, this chapter examines the selection of variables used in the development of science-based policy, specifically relating to past threats to SRE water quality. Finally, this chapter explores water quality protection in Georgia, including the components (e.g., more restrictive access, species recovery, etc.) for establishing the costs and benefits of proposed water resource policy recommendations. These components consider both the intrinsically intangible value and the economic value associated with mitigation of poor water quality to a sustainable level for maintaining ecosystem health within the SRE.

Background of Developing Water Quality Policies for Sustainability

General History of Fisheries Resource Management

Over harvesting of commercially valuable fish has a long history as the focus of problems associated with open access or shared environmental resources. The “tragedy of the commons” (Hardin, 1968) warned of the shortfalls when maximum benefit for the maximum number is not rooted in a sustainable system of checks and balances. The concept of sustainability moved beyond rhetoric as selective harvesting of the most commercially viable fish stocks led to serious declines in species with the most lucrative market values. Such poor management practices, however, were masked in the short term until much of the damage to the target species became evident. This lag-time between cause and effect was revealed through smaller catches and dramatic shifts in indigenous species. The documented decline in species diversity changed the economic productivity of entire regions (Hall, 2002).

The federal government recognized the need to establish specific geographic boundaries and regulations to address the growing concerns over fish stock abundance and health within previously productive near-shore fisheries. The creation of fishing zones defined by International, Federal, and State waters (based on the number of miles from the shoreline) was an early attempt to address fishing resource shortages by limiting the number of fish that could be caught by region. Although these early regulations defined specific jurisdictions for enforcement entities, they did very little to deter unsustainable harvesting practices (Allison, 2002). Despite repeated attempts to compensate for abuse and overuse (restocking, creel limits), open access to fish harvesting areas led to irreversible declines and extinction of many commercially prized species (Collins et al., 1996).

Broader, more stringent guidelines became necessary to harvest even modest catches in heavily fished regions. Scientists from USFWS, NOAA and EPA, in response, generated studies designed to reveal a list of variables that may be linked to ecosystem declines and in some cases, individual fish species population declines. Harvesting practices, habitat management, hatcheries, and hydro-electric power dams (the “four H’s”) were the focus of water quality studies designed to determine what activities were responsible for negative impacts to fish populations (MacGregor, 1970). These studies were conducted primarily in the Pacific Northwest, where the negative impacts from degraded habitat, hydro-electric power dams, non-sustainable harvesting practices and poor hatchery management were well documented, particularly, through the use of sonar.

Published studies by the federal government and concerned fisheries biologists cited cumulative negative impacts for the serious decline of several species of commercially valuable salmon, Coho and Sockeye, however, in the early 1970s, there were insufficient data to differentiate species management objectives (Gregory & Bisson, 1997). The dramatic declines in universal fish stocks across the United States (and much of eastern Canada) from the early 1900's to the 1970's were symptomatic of the need to assign responsibility for maintaining the health of these fisheries. Environmental regulations and management entities were created to begin restoration of the fisheries to their former states of health and production.

Environmental Regulation and Policy

Regulatory control was a second approach used to address declines in fish stocks. In 1969, President Nixon, under pressure from special interest groups to address the growing problems of environmental pollution, signed into law the National Environment Policy Act (NEPA). He further created an agency to enforce the provisions set forth in NEPA by creating the United States Environmental Protection Agency (USEPA) in 1970.

The creation of an enforcement agency was a start, however, in 1970, establishing comprehensive regulatory parameters required obtaining a geo-spatial understanding of what problems were where. Additionally, there was little, if any, research that examined environmental impacts within a real world context of multiple or integrated variables (Jennings & Weyers, 2002). Consequently, there was a long lag time before the EPA had any authoritative power to implement important environmental regulatory controls (Ruckleshaus, 1988).

By the end of the 1970s, the scientific community responded to this lack of information with vigor, publishing many studies designed to address specific threats to fish habitat. These individual studies became the basis for new regulatory guidelines and parameters (Allison, 2002). The narrow focus of these studies, however, provided limited data to legislators, who were charged with defining big-picture parameters to guide their citizenry through a virtual onslaught of newly identified environmental problems. The legislative difficulty of outlining a comprehensive environmental agenda (such as biological integrity) delayed comprehensive ecosystem protection laws until 1990, with the U.S. passage of the Clean Water Act (CWA). This act became necessary when scientific studies linked poor drinking water for humans (and animals) with poor environmental stewardship of what was now recognized as a limited resource base.

The Clean Water Act marked the beginning of a shift from reactive environmental management to preventive environmental management, with laws aimed at preservation, not just conservation (Angermeier & Karr, 1994). The new generalized focus on the preservation of biodiversity seemed to intensify the economic versus environmental debates on the regulatory front. Power companies, mining companies and logging companies were targeted by environmental advocacy groups because of the greater potential threat they posed to burgeoning holistic environmental objectives. These monumental political powers fought for relief from stringent environmental protection laws that were blamed for a myriad economic setbacks (e.g. expensive protections associated with the 1973 passage of the Endangered Species Act[1]). Long-term sustainability and protection of biodiversity were added to the agenda for environmental protection goals, enabling policy-makers to include specialized and regional requirements for mitigation of impacts, ostensibly, to satisfy requirements identified through the NEPA[2] (Norton et al., 1998).

NEPA and the EIS Process

The NEPA scoping process mandates that all federal projects must have an environmental review that includes an environmental impact statement (EIS) and a requirement that all known environmental impacts must be identified and mitigated. This open review process helps decision-makers understand trade-offs associated with balancing economic, political, cultural and environmental benefits. NEPA also requires the scoping process to include meetings with the public and stakeholders.

Through these meetings, problems and alternative strategies must be evaluated in an environmental impact statement. A draft EIS must include mitigation plans for each alternative. If a Final EIS is approved (after public comment period), a Record of Decision (ROD) is issued to complete the NEPA process. The Savannah Harbor Expansion Project (SHEP) was one of the largest federal projects to put the NEPA process to task.

The Savannah Harbor Expansion Project (SHEP)

The environmental problems facing large-scale economic development projects have typically been flushed out prior to congressional approval and the subsequent release of funding. The objective of such cautionary measures has been to put the high cost of environmental regulatory compliance back on the proposing federal/state/local entity. Not all large-scale projects, however, have gone through the same approval process. Preliminary congressional authorization of the 1999 Water Resources Development Act (also known as the Savannah Harbor Expansion Project) proposed extensive harbor expansion and additional dredging activities to allow the Georgia Port Authority to deepen the Savannah Harbor from its current depth of 42 feet to a depth up to 48 feet, subject to stringent project review guidelines established under the National Environmental Protection Act (NEPA) (SEG, 2001).

The concerns over of the deepening of the Savannah Harbor date back over 14 years, but 1999 marked an intensified interest in the limited power of NEPA in Georgia when Congress authorized the Water Resources Development Act, pending satisfactory completion of the NEPA process. Opponents of the proposed Savannah Harbor deepening claimed that the project put the Miocene layer at-risk because the potential dredging activities might punch through this protective layer confining the freshwater of the Floridian Aquifer (Weller, 2002; Will, 2002). Additionally, some NEPA stakeholders (including many marine biologists) suggested that there were risks of irreversible and potentially serious changes in long term water quality for striped bass spawning activities, particularly related to changes in current velocity, salinity and dissolved oxygen as a result of additional deepening (Duncan & Eudaly, 2003).

The potential impacts of these risks were amplified by the threat of rapid further declines in both commercial and endangered fish populations within the Savannah River Estuary. The limited water resources within this port were overtaxed by competition between commercial fishing, tourism/recreational activities and a multi-billion dollar shipping industry run by the Georgia Port Authority (GPA). The NEPA identified Stakeholder's Evaluation Group (SEG) (see Chapter 1) was challenged with protecting the massive economic trade contributions of the GPA, while simultaneously preventing potentially irreversible degradation of Savannah's drinking water and the commercial and recreational fisheries.

The requirements of NEPA, however, do provide stakeholders with a structural hierarchy to meet the conflicting objectives of all interested parties. The United States Army Corps of Engineers, Savannah Division (SACOE) is mandated to provide federal oversight to the lead agency, the Georgia Port Authority, in conjunction with cooperating agencies to meet stringent environmental regulatory guidelines and a host of other environmental, economic and cultural concerns. The SACOE must also address any additional concerns raised by the SEG in the scoping process, as required by the NEPA.

The Stakeholder's Evaluation Group is comprised of representatives from a variety of backgrounds and interests including government agencies (e.g., Federal, State and Local agencies including the United States Corps of Engineers, Georgia Port Authority, Environmental

Protection Division, Georgia Department of Natural Resources, City of Savannah) and special interest groups (e.g., The Sierra Club, Nature Conservancy, Georgia Conservancy, American Fisheries Society). Membership is diverse and also includes commercial and recreational fisherman, shipping companies, Savannah River industries, Trade and Tourism, local Chambers of Commerce and even private citizens. The SEG for the Savannah Harbor Expansion Project opens membership to the potentially impacted public, pending signature and acceptance of legal standing at the outset of environmental mitigation. All meetings are advertised on the SHEP SEG website, where many of the presentations are posted and may be downloaded by the public. The SEG meetings are expected to continue until there has been progress toward creating mitigation strategies for each available alternative and general consensus on solving the most salient issues presented by the SEG.

Stakeholder Process and Outcome

These NEPA identified stakeholders have been meeting for over ten years to bridge extreme opposition between stakeholders with vested economic development interests in harbor expansion and those who fear the environmental, cultural and other unknown consequences of the proposed harbor deepening. The competing interests of all stakeholders are presumed to be given equal weight during the process of reaching an agreement for how to proceed with the proposed project. The mediation process has periodic starts and stops because of competing regional and local interests in economic growth/sustainability. These competing factions, however, have historically had at least one common interest. The recorded minutes from their ongoing meetings revealed they were concerned about the geographic delineation of potential impacts. The United States Fish and Wildlife Service (FWS) has been examining the Back River changes in flow velocities, sediment distribution and the resulting changes in river structure, particularly as a result of the deepening activities and the upriver movement of the head of tide. These and other changes are being included in the development of a SRE FWS habitat model (Eudaly, 1999).

Ecosystem Delineation and Policy Implications for the SRE:

Definition and Monitoring an Ecosystem

Defining an Ecosystem

Savannah River Estuary ecosystem health is monitored by numerous environmental groups from government, private sector and not-for-profit organizations (NPOs). The National Oceanographic and Atmospheric Administration (NOAA), however, is tasked with comprehensive environmental oversight duties:

> On the high seas, NOAA is responsible for U.S. activities related to fishing and any activities that may affect marine mammals or marine species (e.g., marine turtles) that are protected under the Endangered Species Act (ESA)... Moving inland, NOAA has direct management responsibility under the ESA to ensure that federally conducted, funded, or permitted activities do not have significant adverse impacts on threatened or endangered species or the habitats upon which they depend. NOAA also has direct authority under the Magnuson Stevens Fishery Conservation and Management Act, the Federal Power Act, and the Fish and Wildlife Coordination Act to consult with federal agencies to avoid, minimize, or mitigate adverse impacts on managed and anadromous fish species and their habitat. NOAA's National Marine Sanctuary in the Great Lakes also extends NOAA conservation and management responsibilities well inland in the north-central United States. NOAA also has indirect authority through the Coastal Zone Management Act to set policy and provide technical assistance and oversight of state actions under this Federal Act. (NOAA, 2004, p. 7).

NOAA set out to delineate these responsibilities by region, but they were first challenged to derive the definition of an ecosystem and the *scale of an ecosystem*. NOAA defined an ecosystem as “a geographically specified system of organisms, the environment, and the processes that control its dynamics” (NOAA, 2004, p. 8). The scale of an ecosystem is based on the “spatial extent of the ecosystem characteristics and/or dynamic processes that are to be studied or influenced through management” (NOAA, 2004, p. 8).

Although NOAA could define scale, there were still concerns about matching scale to a specific restoration standard, specifically, because problems of scale confound the compilation of a meaningful mosaic of historic research efforts (Meentemeyer, 1989). Issues with scale may relate to the temporal scale of the research, the size of the research subject, the size of the study area, or even the size of the available funding. In 1997, NOAA overcame some difficulties in obtaining a holistic understanding of earth’s many ecosystems by adopting remotely sensed satellite data from SeaWiFS[3] global primary productivity estimates to devise a system comprised of 11 Large Marine Ecosystems (LMEs) (NOAA, 2004).

Since ecosystems, in reality, represent a continuum, NOAA needed to establish some means for delineating ecosystem borders. NOAA set “*ecosystem boundaries* based on discontinuities in the geographic distribution of ecosystem characteristics and based on management jurisdictions” (NOAA, 2004, p. 8). NOAA established four criteria for determining ecosystem characteristics: (1) Bathymetry; (2) Hydrography; (3) Productivity; and (4) Trophic Interactions (NOAA, 2004). The management jurisdictions were constructed from the U.S. Exclusive Economic Zone (EEZ)[4]. The areas extending from the shoreline out to three miles were designated as state controlled waters.

Defining an Ecosystem Management Strategy

A complex cophany of overlapping management jurisdictions exists because of shared regional management objectives throughout each of the 11 LMEs (see Figure 5.1). NOAA defines these shared objectives through a ecosystem approach to management (EAM). The science-based core of this approach is a decision making framework referred to as regional

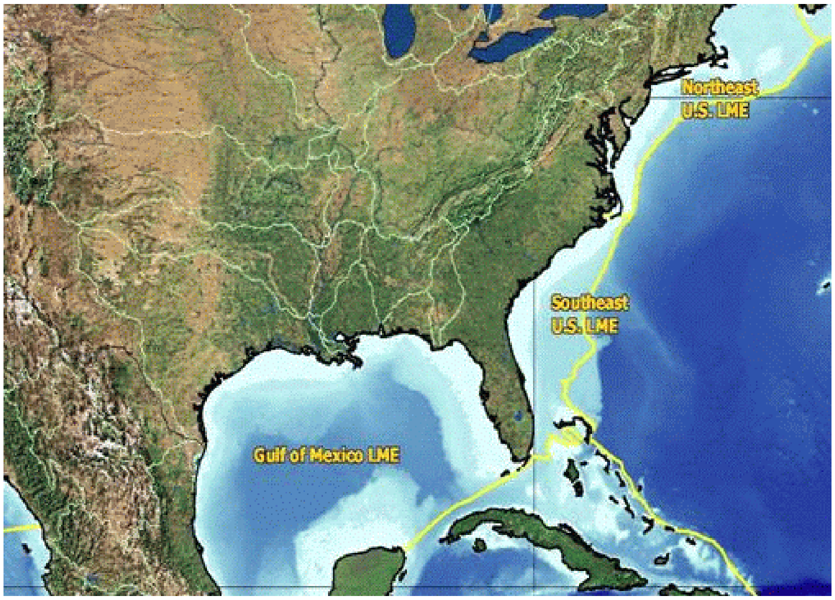


Figure 5.1. Large Marine Ecosystems of the United States. (South Atlantic LME featured)
Source**:** http://www.edc.uri.edu/lme/maps.htm.

marine planning (NOAA, 2005). The tenets of regional marine planning include long term sustainability, increased certainty and long-term security to ocean resource users (NOAA, 2005). The expected outcomes project: “1) healthy ecosystems (including living marine resources and habitat); 2) an increased socio-economic value of marine environment and resources; and 3) ensure the public is well informed and engaged in the assessment and prioritization phase within the regions” (NOAA, 2005, p. 2).

This framework also needed a list of objectives for conflict resolution between local, state, federal and international water ecosystem-based management approaches. Large Marine Ecosystems were established to foster community driven commitments to policy, legal, and institutional reforms for changing the way human activities are conducted within coastal ecosystems. The LME approach involves determining root causes of trans-boundary issues centered on integrated coastal zone management (ICZM), over-fishing, eutrophication and/or nutrient fluxes, habitat destruction, and global climate change” (NOAA, 2004, p. 17).

The Ecosystem Approach to Management (EAM[5]) was designed to be a collaborative and voluntary process. Scientists from NOAA created an integrated and science-based EAM framework of five principles (see Figure 5.2). The application of these principles requires skillful communication and negotiation between potentially polarized stakeholders.

The Ecosystem Approach to Management relegates regulatory decision-making and policy development to state and local levels within the geo-spatial delineation of ecologically connected regions. Cooperation across state and local jurisdictions that share stewardship responsibilities for LMEs is functionally realized in the planning stages of protective legislation. Formal LME jurisdictions, however, are recognized in federal funding of projects regardless of how many state or local jurisdictions are included (see Figure 5.1). EAM guidelines are,

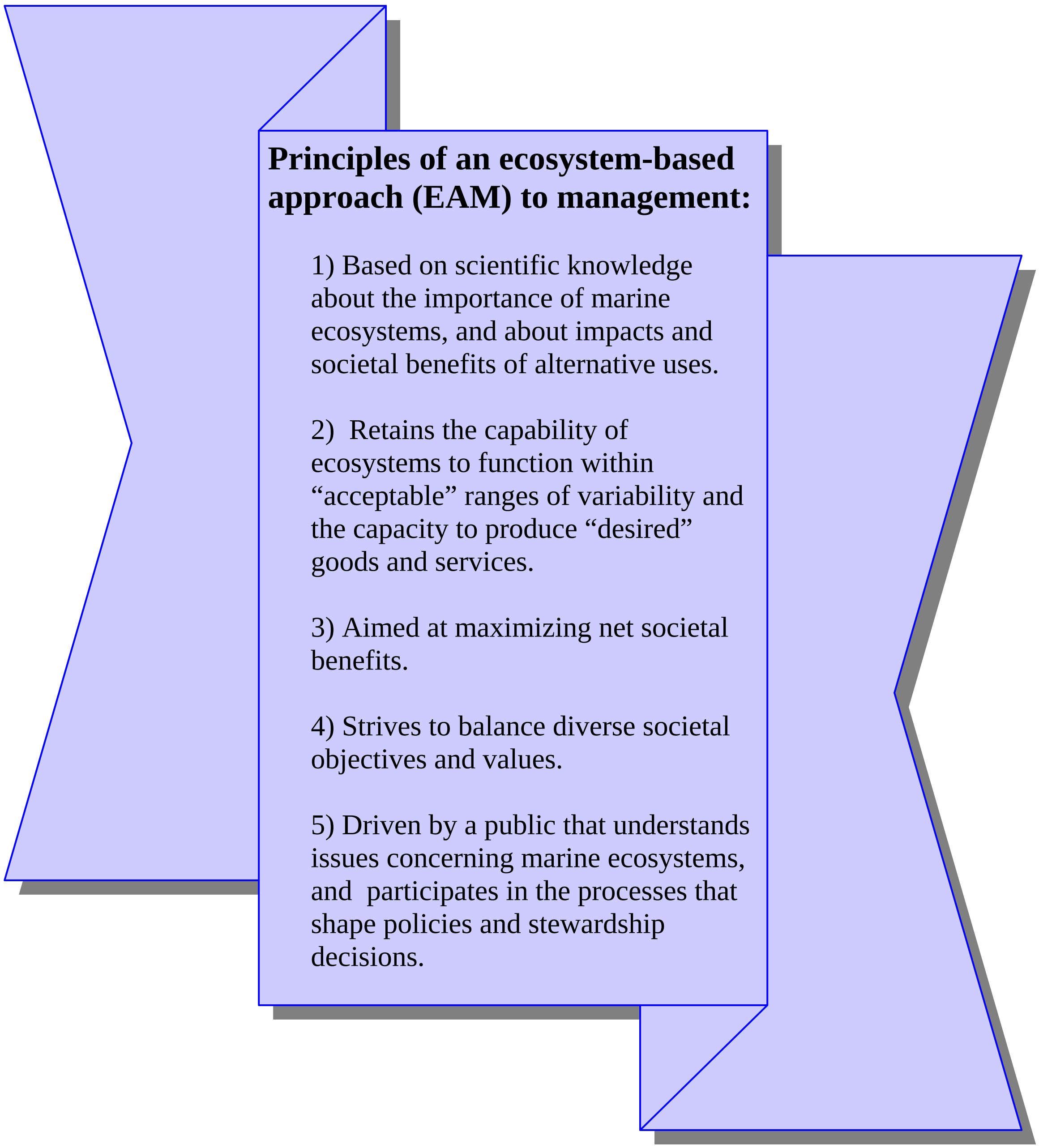


Figure 5.2. Principals of an eco-system approach to management (EAM). Source: NOAA, 2004, p. 17.

however, constantly challenged by decision-makers whom may have a localized agenda in the development of multi-regional policy, suggesting mediation measures may be required before final protective environmental policies may be promulgated within a LME.

Water Resource Management: Water Quality and Habitat Protection Policy Development in Georgia

The development of science-based policy and associated recommendations considers how contextual local data, geographic analysis of water quality data, an inventory of physical components and modifications of an ecosystem must become integrated into a single policy tool. Geographic phenomena associated with 2003 water quality data were integrated with findings from both the Klein and DIDSON sonar "images." The highest priority policy objective was to create specific guidelines for the identification and subsequent protection of at-risk or unique SNS habitat in the SRE.

This study employed side-scan sonar to create baseline data and illustrate the relative ease by which side-scan sonar data may be collected to monitor fisheries habitat with regularly conducted sonar surveys. Such surveys may be used to identify and minimize environmental impacts from competing usages of the Savannah harbor and other locations where physically impaired resources must be shared with competing water resource interests. The sonar data also provides a reliable means of correlating significant habitat changes with the occurrence of stochastic events that may threaten the health of the SNS or their habitat.

The policy recommendations in this study consider the data within the framework of priorities delineated in NOAA's fisheries management objectives, workshops and environmental conferences and Georgia's water quality/aquatic sustainability issues (see Table 5.1) (The Nature Conservancy, 2004). Prior to crafting SRE policy and recommendations from this study, it was

Table 5.1

Sample Discussions from Nature Conservancy Savannah River Restoration Workshop held in 2004

Concern	Location	Concerns/Comments
Marsh/Wetland Inventory	Savannah River Estuary	Marsh Dieback from salinity change: 1. Altered bio-diversity 2. Stressed or killed stenohaline species 3. Interrupted food-chain. productivity
Restoration of River Oxbows	Savannah River Estuary	Straightening from past: 1. reduced fish habitat 2. reduced filtering of contaminates 3. changed distribution of sediment load 4. changed velocity profiles
Regulation of Ballast Water	Savannah River Estuary	Introduction of Exotic Species/Contamination
Flow Regulation	Savannah River Estuary	Low flows stress estuarine species

first necessary to consider and evaluate the blended concerns (and controversy) presented during interviews with stakeholders (such as the SEG, see Table 3.1) and representatives from organized management entities like the South Atlantic Fishery Management Council[6] (see Figure 5.3), whom may share one common objective: to protect (via policy creation) the impaired waters of the Savannah River and adjacent impaired water bodies.

Controversy in the Creation of Policy and Recommendation Objectives

The blended mitigation recommendation process is exacerbated by opposing political factions tasked with protecting Georgia's impaired waters amidst a water crisis of unprecedented magnitude in the past 100 years. The consideration of multiple recommendations from scientists who have recognized the holistic relationship of their research to the entire water resource management issues of the region (similar to policies created within and beyond LMEs) was echoed as the only appropriate mitigation strategy among interviewed stakeholders.

The objective of LME-type policies is to provide a scientifically peer-reviewed process for the restoration of ecosystem functionality as a healthy and interconnected entity within a continuum that has creativity to adapt to natural stochastic events (Norton & Ulanowicz, 1996). Under such policies, dispute resolution among competing interests is carried out in a democratic peer-reviewed forum and involves parties that have legal standing within a court of law (under the protective laws of the ESA and NEPA environmental review criteria).

The implicit advantages to this type of system are considered in the regionally distinct, but interconnected regional water planning councils, as discussed in Georgia's new Water Resource Management Plan (Georgia EPD, 2007). This ecosystem-based approach examines regional environmental stress factors at multiple scales in an attempt to balance extirpation pressures for endangered species, industrial or agricultural pressures for greater productivity, and

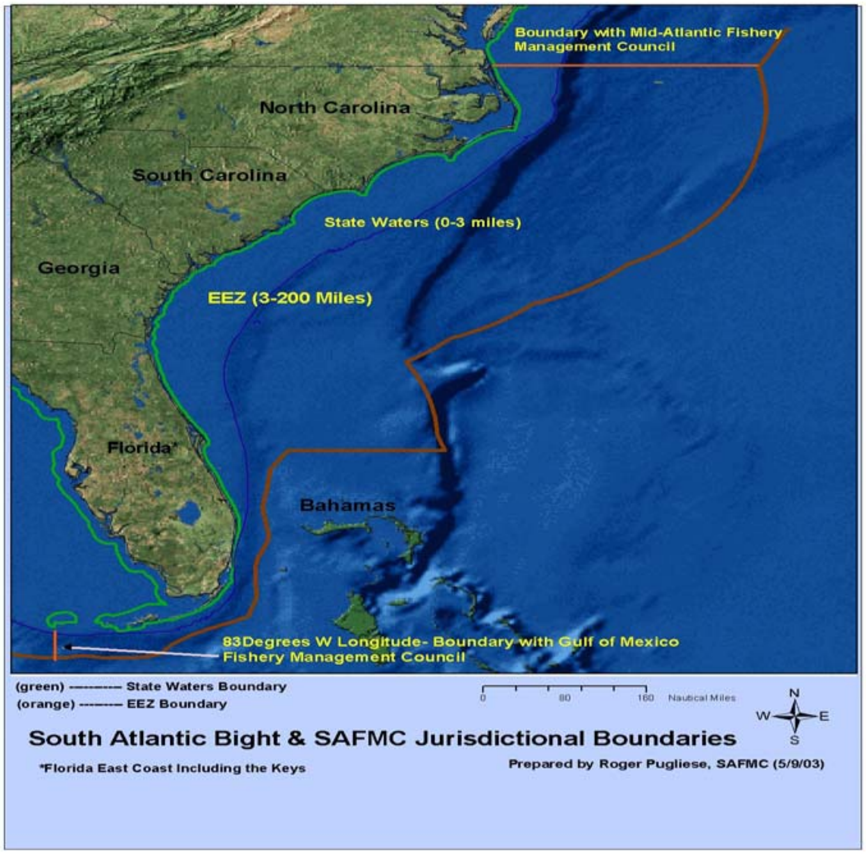


Figure 5.3. South Atlantic Fishery Management Council.
Source: NOAA, 2004.

developmental pressures for protection of dwindling drinking water availability. Ultimately, however, the 2008 Georgia Legislature passed SB352 in both houses to oversee and potentially mitigate the recommendations set forth by these councils. This bill was proposed as an additional check and balance system to insure political pressures do not culminate in the concentration of power in one region over another in the Georgia Environmental Protection Division's approval of council recommendations regarding water allocation decisions.

Georgia Department of Natural Resources' Environmental Protection Division is interested in securing future water resources where current allocation demands predict there will be none available, even if new technologies like desalinization are the only viable alternative. The recommendations of this 2003 water quality data, as a result, focus on the environmental outcomes, not the resource scarcity, distribution and costs for securing adequate water flows within the SRE. These considerations, though not reflected directly in this study's policy recommendations, are discussed briefly to provide context for the political and private sector influences in future water resource policy development.

Consideration of Water Resource Cost, Availability, and Allocation in Policy Development

The costs for securing future adequate water flows within the SRE and other impaired waters came up repeatedly during stakeholder interviews as the most salient water quality concern. In the summer of 2006, Carol Couch, Director of Georgia's Environmental Protection Division (EPD) of the Georgia Department of Natural Resources (GADNR) heard presentations from General Electric and others about the viability of building a reverse osmosis[7] (RO) desalinization plant in coastal Georgia. The stated purpose of considering such an unusual proposal was to help ease some of the developmental pressures placed upon the Savannah River to provide a continued source of freshwater withdrawal. The cost of building such a facility was defined as a private sector cost, noting however, that the facility would provide water as a public benefit, with the right to sell the water it purified to any interested party.

Some opponents objected to this proposal because they suggested that once the Savannah River flows were augmented through the use of such technologies, Savannah River water could be piped to the Chattahoochee River (interbasin transfer), to fuel the continued growth of Atlanta and other metropolitan cities in the northern part of the state. Regardless of the eventual outcome of RO technology in Georgia, the GADNR and several attending members of the Georgia legislature saw no reason to prevent the start of the permitting process of such a facility, assuming it met environmental criteria for returning highly concentrated flows of saltwater back into the ocean (Georgia EPD, 2006). The Georgia Department of Natural Resources unofficially accepted desalinization as a new technology with the potential to be a small part of the solution to anticipated freshwater resource shortages in the future.

Protecting the Lower Savannah River Drinking Water

The creation of water resource policy in the Lower Floridian Aquifer has been at the forefront of studies since the 1970s, when scientists first realized the severe groundwater draw-down that was caused by industrial pumping of groundwater for Savannah's burgeoning industries. The resulting cone of depression directly beneath the City of Savannah exacerbated natural leeching of saltwater from the thin or punctured surficial aquifer to the Lower Floridian Aquifer (Hall & Peck, 2007). The increased salinity within the groundwater of several locations in and around Savannah have been monitored by USGS through a series of wells.

Specifically, monitoring of twelve wells in Vernonburg, Georgia (located in Chatham County slightly southeast of the City of Savannah) has indicated the rate (but not the area) of saltwater contamination has increased over time (Hall & Peck, 2007). The salinity encroachment in the lower Savannah River and its adjacent water bodies (like Vernonburg's Vernon River) is the subject of current water quality studies aimed at providing planning goals for expected growth and development in Chatham County over the next 20 years. The City of Vernonburg has taken issue with Savannah's responsibility to protect limited regional drinking water supplies, regardless of other competing demands. Additionally, Vernonburg's recreational fishing/tourism interests were also cited as being impacted by the poor water quality (low DO) of the lower Savannah River (Jordan, 2005). The creation of integrated water quality monitoring networks throughout the coastal southeast has been suggested as a critical next step in regional planning by environmental advocates ranging from the Center for a Sustainable Coast to the Sierra Club (Kyler, 2005).

Recommendations for Achieving Water Quality Policy Objectives in the Savannah River Estuary

Interviews with recreational fishermen suggested the proposed Savannah Harbor Expansion Plan (SHEP) to dredge deeper into the thinning protective Miocene layer by Tybee Island would increase the need to network inshore monitoring sites both within the estuary and its adjacent waters (Jordan, 2005). Currently, NOAA oversees an established offshore network of water quality monitoring platforms on the Southeastern continental shelf. The South Atlantic Bight Synoptic Offshore Observational Network (SABSOON)[8] provides real-time synoptic observations of large-scale oceanographic processes (see Figure 5.4). Real-time water quality data from an ecosystem-wide integrated monitoring program could assess the effect of flow variations on riverine species survival. Specifically, iterative long-term monitoring may provide the knowledge base and resulting scientific linkages to establish "adaptive management" objectives such as those expressed by The Nature Conservancy (Wrona et al., 2007, p. 3).

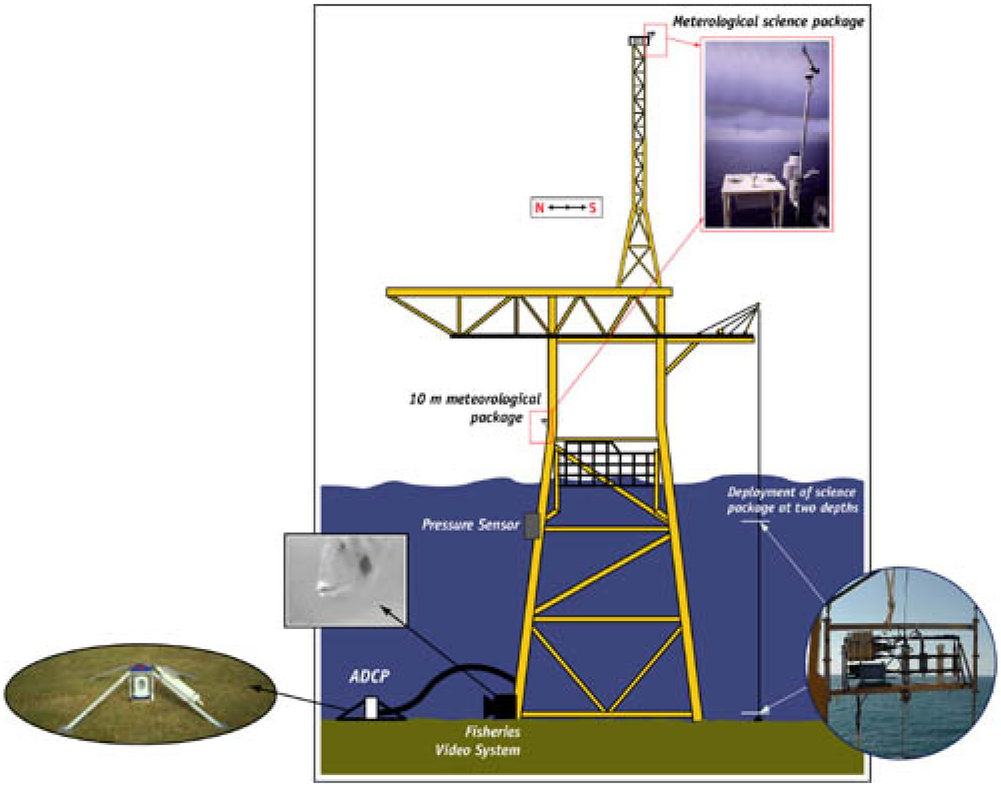


Figure 5.4. SABSOON monitoring platform.
Source: Skidaway Institute of Oceanography (SKIO).
Online: http://www.skio.usg.edu/Skioresearch/physical/sabsoon/system/.

Recommendation 1

The first recommendation is to **establish Inshore/Offshore Continuous WQ and Physical Habitat SRE Monitoring**. The National Oceanic and Atmospheric Administration (NOAA) developed a framework for establishing monitoring plans under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457) in their October 2003 release of "Science-Based Restoration Monitoring of Coastal Habitats." This manual establishes protocols and standards while recognizing the need for region-specific responses to ecosystem threats (Thayer et al., 2003). Additionally, the recent creation of the Georgia Coastal Research Council (November, 2002) provided "mechanisms for improved scientific exchange between coastal scientists and decision makers in the State of Georgia and to promote the incorporation of best available scientific information into State and local resource management" (Alber & Flory, 2003, p.1). The general benefits to establishing a large-scale integrated monitoring network are numerous (see Table 5.2), but begin with increasing the availability of research funding initiatives and cost-efficient technology to improve public recognition of sustainable benefits.

Research funding initiatives. Funding initiatives for the creation of integrated inshore and offshore monitoring programs have been available through EPA, NOAA and Sea Grant as well as some not-for-profit organizations interested in sharing resources, time and data. MySound, a Long Island Sound monitoring network in New York, is an example of a successful real-time integrated monitoring network funded by EPA to cross-reference changes in the harbor water quality with nearby oceanographic water quality data. New York's Indian Harbor Yacht Club hosts an oceanographic monitoring buoy that is part of a network of marine environmental monitoring stations established by the EPA's Long Island Sound Office and the University of Connecticut. The EPA's Environmental Monitoring for Public Access and Community Tracking

Table 5.2

Benefits of Establishing Inshore/Offshore Integrated Monitoring Networks

Benefit	Location	Purpose/Comments
Potential Funding Initiatives	SRE + SABSOON (Savannah River Estuary + Georgia's Offshore Monitoring Network)	NOAA's SeaGrant Program or EPA's EMPACT Program (although currently unfunded) may provide incentives for building database support and detailed studies in areas where data is missing or insufficient to draw scientific conclusions
Efficient techniques: Side-scan sonar data and water quality data	SRE + Shipping Channel out to the Atlantic Ocean	Sonar is: 1. Fast 2. Cost-effective 3. Readily available technology for assessing habitat, physical harbor modifications and detecting changes in sediment distributions
United States Army Corps of Engineers, Savannah Division benefits from Inshore/Offshore Monitoring	SRE + Shipping Channel out to the Atlantic Ocean	Provides the basis of SHEP corrective action design.
Improve Contextual Understanding of Anomalies	SRE + Shipping Channel out to the Atlantic Ocean	Provides Real-time explanation of stochastic events (e.g., the re-suspension of sediments
Improved Predictive Modeling Accuracy	SRE + Shipping Channel out to the Atlantic Ocean	Provides trend data, enhanced flow models and the location/movement of unique habitat features over time
Improved Notification for Presence of Endangered Species	SRE + Shipping Channel out to the Atlantic Ocean	Provides real-time tracking and notification for protecting threatened or endangered species (e.g., the right whale or manatees)

program (EMPACT, although currently unfunded) funded the MYSound (for Monitoring Your Sound) project.

Georgia's South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) is already established as a beginning to a fully integrated offshore monitoring system that may be expanded to host future inshore buoys within the SRE. The SABSOON monitoring program was designed to support the addition of other monitoring networks, including inshore areas like the SRE and other nearby cities (like Vernonburg) that may wish to cross reference local data with the larger ecosystem data. The SABSOON program may also be expanded to include other offshore networks up to a global scale (the Global Ocean Observing System or GOOS) (GOOS, 2008).

The economic viability of expanding an existing monitoring network is additionally enhanced when technical manuals and potential funding initiatives are already available. NOAA, the Skidaway Institute of Oceanography (SKIO), NGOs and academic partners have collaborated in past monitoring initiatives for datasonde and remote sensing data exchanges.

An example of such a program is the Southeast Coastal Ocean Observing Regional Association (SECOORA). SECOORA took over the Southeastern Coastal Ocean Observation System (SECOOS) monitoring program with greater funding and added assets (see Figure 5.5). SECOORA is a non-profit organization which "designs, implements, operates, and improves the provision of data, information, and products for marine and estuarine systems deemed necessary for common uses according to sound scientific practice" (SECOORA, 2009). Organizations like SECOORA are interested in embracing new techniques to accomplish objectives as efficiently as possible, particularly during tough economic times when success or failure may be a product of available funding.

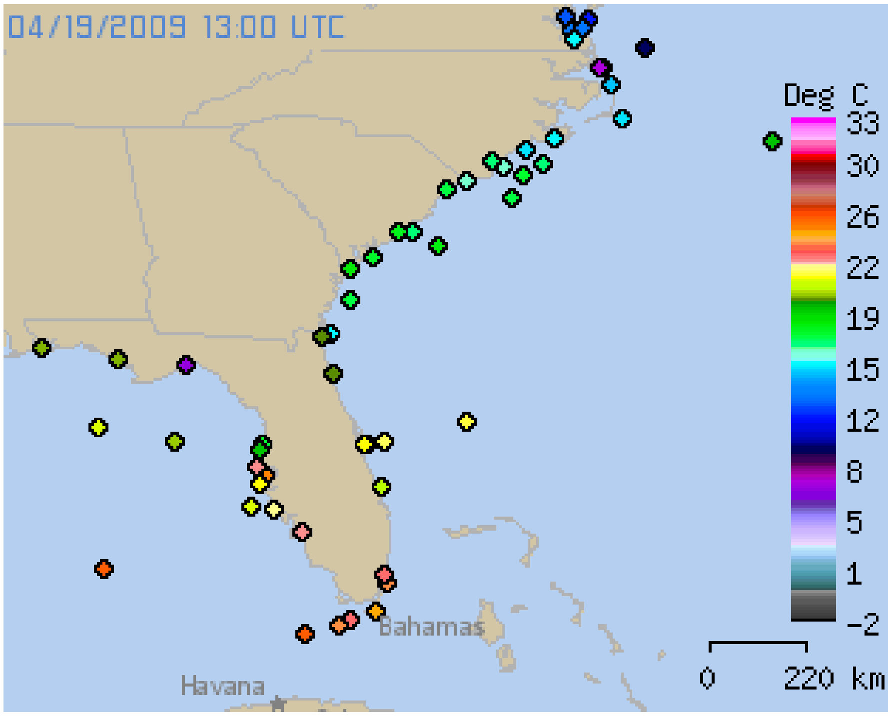


Figure 5.5. SECOORA observation sites. The SECOORA Near Real-time Observations Maps are created hourly from SECOORA member data and ancillary regional datasets. Data include In-situ sea surface temperature, water level, and winds; radar-sensed surface currents; drifter trajectories; and satellite-sensed sea surface temperature, winds, and color.
Source: SECOORA, 2009.

Techniques for establishing long-term SRE monitoring programs. The use of sonar (side-scan mid-frequency and DIDSON high-frequency (500kHz - 1.8 MHZ) sonar data has proven to be a fast, cost-effective and readily available technology for assessing habitat, physical harbor modifications and detecting changes in sediment distributions. Sonar monitoring can be employed in both riverine and pelagic environments as one of several data collection techniques used to provide baseline time-series data for adaptive management decision matrices. Sonar data reveals seeps, distinctive sand ripples and waves, dredging impacts, changes in bathymetry, the presence of debris fields, and the existence of cultural resources that may require further investigation (for example, Front River (FR02) side-scan sonar images revealed the possible outline of a previously uncharted rice barge from the 1800's).

Specific benefits of establishing long-term continuous monitoring networks (including sonar) (see Table 5.2). These benefits include special COE Benefits to Inshore/Offshore Monitoring, Improved Contextual Understanding of Anomalies, Improved Predictive Modeling Accuracy, and Improved Notification for Presence of Endangered Species.

United States Army Corps of Engineers, Savannah Division, benefits to inshore/offshore monitoring. The United States Army Corps of Engineers, Savannah Division, announced a proposal to introduce DO back into the SRE through a massive bubbler or injection system (Seaman, 2007). This water quality mitigation effort will be designed to offset the low DO problems exacerbated in the SRE from additional deepening activities. If this proposed mitigation strategy is approved, the establishment of an inshore/offshore integrated water quality monitoring network will be required throughout the SRE before such an expense could be justified. The real-time data could then be compared to the predictive accuracy of the hydrodynamic models used as the basis of corrective action design.

Improved contextual understanding of anomalies. Geo-referenced sonar data can be correlated through time with both anthropogenic and natural events recorded within the harbor. Regularly scheduled sonar monitoring of regions with ongoing collection of real-time water quality data may provide an enhanced contextual understanding of the processes responsible for dramatic changes in the environment. The resuspension of sediment, for example, may be evident from water quality data, but sonar monitoring could provide real-time answers to how and where sediment is transported and/or redeposited during certain types of prevailing currents or wind events. Specifically, the frame by frame review of this study's side-scan sonar data from the SRE provided updated information on the location of exposed sandbars after storm events, offering explanatory value to data anomalies and saving more than a few wrecked research boat propellers.

Improved predictive modeling accuracy. The cross-correlation of sonar and water-quality monitoring may provide trend data, enhanced flow models and the location/movement of unique habitat features over time. Weekly sonar sweeps, maintenance of inshore/offshore datasondes and bi-weekly grab sampling may provide predictive models of sediment distribution/redistribution, spawning behaviors, species migration, nutrient mixing, and a variety of other currently unknown relationships that make prescribing restorative flows for any specific outcome unlikely under current monitoring regimes.

Although USGS and the Georgia Port Authority inshore SRE monitoring is already in place (USGS water quality monitoring stations currently corresponding to sample sites TG01, KI01, FR02 and side-scan sonar imaging for COE maintenance dredging), this data is not typically integrated to provide a holistic understanding of the ongoing processes within the waters of the Savannah Harbor. Additionally, many of the current inshore sampling stations no longer are maintained to report anything other than flow data.

Improved notification for presence of endangered species. Specialized high-frequency sonar (DIDSON) also may be placed in stationary locations where there is a high potential for entrainment of endangered sturgeon and right whales, dolphins, sharks and manatees. Real-time sonar could easily detect the presence of foreign bodies in sensitive areas such as water intakes for power generation facilities or turning basins for large ships. The national security benefits of ongoing or regularly scheduled sonar monitoring are also apparent.

Recommendation 2

The second recommendation is to **Establish Geo-referenced Threatened/Endangered Species Habitat Risk Maps** to evaluate multiple risks present within the same geographic region. Regardless of which variables are selected in the initial establishment of real-time monitoring networks, it is likely the collection and analysis of additional data will provide new insight into prioritization of corrective actions for improved ecosystem health or prevention of species extirpation. Although poorly chosen or improperly weighted variables may still provide a meaningful iteration in the adaptive management process, it may be prudent to conduct discovery for available data within the most at-risk or "impaired waters." This study (see Chapter 4) highlights some of the most severely impacted areas within the SRE for determining which regions of the SRE may be in most urgent need of prioritized assessment. The focus on these extremely stressed portions of the SRE may provide a modest temporal advantage for development of science-based water resource policy and management within the State of Georgia, given the current developmental status of the statewide water plan.

It is reasonable to request the Georgia Port Authority's proposed harbor improvements consider these at-risk regions in decisions about where to expand the width of the harbor turning basins to accommodate their new Post-Panamax ships. For example, the King's Island Turning Basin expansion would require specialized environmental assessment for sensitive species because it provides unique habitat for SNS and is adjacent to what has been recorded to be a rare physical feature within the SNS habitat (the Middle River fish hole). Additionally, the destruction of sensitive habitat in this proximity may threaten or exacerbate the adjacent fish hole functions in the protection of other sensitive species (e.g., protection from salinity spikes).

Additional concerns surround construction blasting within the area because rapid changes in pressure may rupture the delicate *Physostomous* of the sturgeon present within the estuary for a large range of distances from the expansion site. This construction site may also release fine silts in densities beyond the capabilities of fish to allow adequate respiration. Even modest increases in turbidity throughout the proposed modification construction site may have long-term impacts on overall species fecundity (Buckley & Kynard, 1985, Collins et al., 2000B).

Recommendation 3

The third recommendation is to **Create a Unique Habitat Risk Minimization Plan** that requires delineation of unique or critical habitat specific to Shortnose Sturgeon. The Savannah River Estuary has an existing Shortnose Sturgeon Recovery Plan (NMFS, 1998) per ESA requirements. There is not, however, a plan for minimizing the risk for the potential destruction of unique SNS estuarine habitat areas or features unless they are geographically identified and legally linked to an endangered species recovery plan, a Habitat Area of Particular Concern (HAPC), a threatened species or some other species-dependant regulatory protection. Generic wetland or marsh protection standards may be used for minimal protection for some unique habitat, but such protections do not guarantee the preservation of the integrity of specific features.

For example, the Georgia Port Authority suggested they lacked proof of any existence of SNS within the Savannah Harbor since 1993. This allegation was given publicly by the Georgia Port Authority at a stakeholder meeting held on August 3, 1999. Despite the fact that the continued existence of SNS in the Savannah Harbor had neither been proved or disproved, the Georgia Port Authority used the absence of data as justification for refusing to address stakeholder mitigation concerns surrounding the impact to unique habitat (such as the fish hole in Middle River).

The ESA was insufficient to provide protection of rare habitat features, however, even upon providing scientific proof that the unique habitat area/feature of concern was used by SNS and other fish. The protection of unique habitat is not promulgated under the ESA unless the presence of the SNS (or other endangered species) in the SRE could be verified and the function and location of the unique habitat could be scientifically linked to SNS survival (not conservation) and/or designated as part of SNS critical habitat.

Mark Collins, Fisheries Biologist for the SCDNR, published his 1999-2000 SRE telemetry study that pinpointed sample locations within the SRE where telemetry data had established population estimates for shortnose sturgeon in that same year (Collins et al., 2000B). If a mandate or protocol for discovery had existed prior to the development of the SHEP Phase One EIS, mitigation directives for impacts to SNS and/or habitat would have been in place under ESA protections promulgated through NEPA. However, because there was not a specific directive forcing the Georgia Port Authority to consider in-progress data collection concerning the existence of SNS or protected SNS habitat within the SRE (the proposed project area), the

Georgia Port Authority decided that SNS mitigation action was not required at that time under existing law.

By 2003, this study became part of the research required to establish protection protocols for SNS in the SRE SHEP. In addition to the collection of sonar and water quality data, these efforts included the commencement of SNS stakeholder interviews, review of related additional studies and the introduction of DNR (by DNR personnel and commercial fishermen in the presence of DNR personnel) SNS sightings and by catch during shad tagging and seasonal fishing activities (Gale, 2003) into the public record. The Stakeholder Evaluation Group (SEG) continued to insist upon mitigation measures for potential impacts to SNS and their estuarine habitat (Jennings, 2005). SEG meeting minutes documented multiple examples of SEG concerns raised over this issue.

After reviewing the United States Army Corps of Engineers (COE) sponsored Collins data, multiple SEG presentations (including two that highlighted some data from this study), and the rejection concerns of the Phase I Environmental Impact Statement (EIS) by members of the federal oversight committee, the Georgia Port Authority finally agreed to include SNS and possible protection of SNS habitat in their next round of mitigation plans as required under NEPA. The Phase II EIS is currently in progress, however, habitat protection criteria for SNS are not yet legally established except through the periodic revision of the Shortnose Sturgeon Recovery Plan. This plan lacks the spatially defined details necessary to mitigate the recruitment/fecundity concerns present within the freshwater tidal interface of the SRE. The SEG problems of the past are also further strained as a result of the Georgia Port Authority’s recent acquisition of the much larger Post-Panamax cranes that are scheduled to accommodate the expected fleet of Post-Panamax ships.

The introduction of SRE habitat risk minimization plans, however, is not without some inherent risks and controversy. Such risks include the possibility of signaling to potential SRE developers that any regions outside delineated habitat areas are open to any and all development . Additionally, some interview respondents suggested there were few restrictions that could be enforced, given current budget shortfalls among the agencies in charge of environmental oversight. The controversy surrounding plans to delineate critical habitat is historic, yet it is still relevant today.

Controversy over mitigation plans to delineate critical habitat. The creation of a Habitat Risk Minimization Plan, although needed in the SRE, has been controversial in the initial phase of establishing habitat boundaries to meet the legal protections that may result from following The National Environmental Policy Act (NEPA) guidelines. The National Environmental Policy Act requires evaluation of all mitigation alternatives. In the absence of the delineation of specific geographic regions where environmental stress is legally designated as critical, impaired or at-risk, no special consideration is given to the extreme sensitivity or uniqueness of the area. This fact alone, provided the basis for an ongoing “flood of critical habitat litigation filed by environmental groups in the 1990’s to beat the statute of limitations clock. . . ” (Parenteau, 2005, p. 7).

The historic debate in Congress over the designation of critical habitat at the time of species listing was held by the United States Fish and Wildlife Service (FWS) during the first part of the Bush administration. The FWS insisted that critical habitat designation did not provide any additional protections that were not already part of those offered under the Endangered Species Act (ESA). The National Marine Fisheries Service (NMFS- in charge of managing listed marine species), by contrast, preferred to align their thinking with conservation groups that disputed such claims and offered case studies of successful habitat restoration under a delineated critical habitat protected status (Parenteau, 2005).

Current critical habitat delineation status. The designation of critical habitat is currently at its lowest point since its inception. The identification of at-risk science-based riverine habitat (using GPS registered sonar and water quality data); however, is an effective new tool for insuring such regions get special attention under mitigation alternatives assessment of the NEPA process. NEPA requires the at-risk region to be identified in terms of potential damages and to be identified as contained either partially or wholly within the proposed federal project area.

Proof of diminished eco-system function or rarity of habitat could be enough to mandate the mitigation of potential impacts under NEPA. These threatened areas, however, once delineated in terms of critical habitat and/or water quality degradation, may become eligible for an additional avenue for restoration or mitigation of potential habitat impacts under existing environmental laws (such as the ESA). The Middle River fish hole may be a possible example within the SRE.

Recommendation 4

The fourth recommendation is to **Establish Real-time Reporting and Evaluation of Data, Expedited or Priority Regulatory Review Process for at-risk Species/Habitat, and Best Available Technology Requirement for Proposed At-risk Species/habitat Mitigation Strategies.** The development of clear and timely reporting of increased risks (such as a hazardous material spill) to threatened species may provide adequate time to minimize species mortality when best available technology is immediately deployed to the most geographically sensitive area first (within the spill zone).

Establish real-time reporting and evaluation of data. Protection of sensitive habitat, once delineated (established as at-risk, unique, rare or critical habitat) includes inherent challenges. These challenges range from delegating responsibility for reporting and data evaluation to responding with a pre-authorized mitigation plan for a plethora of potentially disruptive events. The inability to respond to live data monitoring increases the probability of species/habitat loss in the event of a disturbance. This loss of response time currently contributes to the potentially species-devastating impacts of regulatory time lags. Specifically, the time between scientific discovery and the development of a mitigating response may mean extirpation of species or other potentially irreversible environmental consequences. This time loss, regardless of duration, also represents a loss of revenue (such as when damage is done to a commercial fishery), a loss of natural capital (such as clear water and scenic vistas) and/or an opportunity cost associated with the time and money lost as a result of not mitigating negative impacts in a timely manner. These costs may be minimized through proper prioritization of potential deleterious impacts.

Establish expedited or priority regulatory review process for at-risk species/habitat. The development of a triage process for prioritizing at-risk habitat or water quality emergencies in the SRE could prevent cumulative irreversible impacts within the ecosystem. For example, during the 1999 drought, the marsh die-back had already begun as a result of the penetration of high salinity deep within the estuary from the past operation of the tide gate. The inability, however, of the ecosystem to absorb additional salinity had been breeched by the time the tide gate was removed (Eudaly, 2005). Prioritizing the most severely impacted reaches of the SRE for immediate mitigation efforts may have prevented some of the marsh loss (and subsequent demise of some SRE stenohaline species) during the lag-time between the identification of the problem area and the subsequent implementation of the proposed mitigation action.

The EPA and NOAA currently use ranking systems to prioritize everything from hazardous site clean-up to species status. The localized adaptation of “water quality policy express lanes” are encouraged and funded by EPA’s Clean Water State Revolving Program promulgated as part of the CWA. Mitigation efforts could be tweaked over time to incorporate the most critical variables in proposed site-specific corrective action plans.

Create geo-referenced habitat database for specific SRE species. Tweaked mitigation efforts may include the development of a SRE cross-referenced species-specific mitigation database. This data may be geo-referenced to increase the speed of future mitigation responses. Additionally, the data may be setup to be available via a password over the internet as a guide to handling similar mitigation problems in the future. Such database guidance may have some potential risk, however. Specifically, the use of pre-existing data may be interpreted as a “cookbook” for finding solutions, rather than merely as a reference tool. Such an interpretation could increase the probability of miscalculations in mitigated water resource management decisions (such as dredging too deeply, puncturing the Miocene layer protecting an aquifer while doing geological testing or failing to contain a spill of a hazardous substance(s). A record of past data interpretation problems, however, could also be included in the database. Regardless of the comprehensiveness of such a database, it may become an indispensable tool to significantly reduce the lag-time between discovery and response.

Some lag-times in preparing site-specific mitigation plans, however, are unavoidable. Ironically, regulatory policy may delay the protection of the specific species the regulations are designed to protect. For example, fulfilling the requirement to have federal approval before handling any endangered species may take from two to three years because of the time required to obtain the necessary permit. Such long-term lag times prevent timely scientific groundtruthing of sonar and other remotely sensed data. Telemetry studies are similarly unsatisfactory without the associated permits to capture and record fish stress responses, not only as a result of poor water quality, but from the fish responses to the telemetry transmitters themselves.

Improve telemetry techniques. The expense and scale of most telemetry studies represents a potential timing constraint prior to considering the additional delays imposed by obtaining ESA species handling permits. The development of improved tagging and monitoring techniques, however, would not cause the same physical stress upon the endangered fish. Diminished invasiveness of tracking techniques would lower the profound negative consequences (in terms of fish mortality or data loss) of delaying protective action in the absence of continuous and more comprehensive monitoring studies.

Recent nano technology breakthroughs with neural sensors and transducers (Kong et al., 2004) and the diminishing bulk of transmitters used in telemetry studies suggests the application of this technology may lead to reduced lag times between when research is designed, conducted and transformed into science-based policy. Such time lags still exist currently, however, increasing mortality and limiting recovery of sensitive species or habitat. Improving technology and the immediacy of communicating and securing restricted access to threatened species or habitat could translate into improved and more timely ecosystem restoration.

Improve communication in partner relationships. The real-time water quality/habitat monitoring advantage is lost if responder communication networks are not maintained or updated with the latest communication equipment. The immediate response to a developing problem saves money, species, habitat and potentially, human lives. Although response delays are sometimes unavoidable, a well-networked communication plan provides additional back-up personnel. Additionally, the immediacy of daily reporting across networks (with networked partners) improves the effectiveness of managing large, otherwise unmanageable ecosystems.

An example of the immediate effectiveness of science-based ecosystem management is documented in creel limits that are imposed based upon frequent (if not daily) population assessments of the targeted species. The timeliness of robust scientific documentation of degraded habitat or a threatened status is key to securing the immediate protection of that habitat or species. The preservation of a single species may have significant implications to overall ecosystem function, particularly when that species is unique to a predator-prey relationship within that region. Additionally, some commercial fishing industries hinge their entire economic viability upon the abundance and health of only a few critical species.

Economic viability of best available species management criteria. The best available species management criteria refer to the need for commercial fishermen to have flexibility in the selection of their target species. If a fisherman over-harvests a species to extinction, neither the fisherman of the species will benefit in the end. When best available species, however, becomes an acceptable operating practice to preserve over-fished species or habitats, there is room to make adjustments when ideal conditions are not present.

For example, the economic value of Georgia's recreational and commercial fishing interests is estimated to contribute more than a billion dollars annually to Georgia's bottom line (Kyler, 2005). The indirect fishery-related contributions to tourism are also significant in coastal resort areas like Savannah. One of the most historically profitable fishing industries has been the harvesting and sale of Georgia's shrimp and Blue Crab (Walker, 2006).

The quaintness of the shrimp boats outlined in the harbor against a setting sun have sold many margaritas to the patrons of dockside eateries and waterfront hotels (Kyler, 2005).

Additionally, there have been greater numbers of tourists and locals alike flocking to the shrimp compounds that prepare the day's catch for sale within minutes of the shrimpers arriving at the dock. This shrimp industry, however, is in peril because of rising fuel costs and the dwindling commercially harvested catch (Gale, 2002). The local scientific response to this concern has been to encourage these fishermen to expand their ability to find the economic value in harvesting different species. Some fishermen have also been encouraged to help create a new infrastructure to retain more economic control when water quality or habitat degradation threatens the economic viability of their livelihood. The ability to switch to a better or more available species as environmental conditions dictate has been loosely dubbed "best available species management" by commercial fishermen. The current trend in this management style is to consider the commercial viability of aquaculture in Georgia.

Despite the potential for the development of aquaculture in Georgia, there has been limited interest in the creation of the infrastructure that could support the reality of economically viable aquaculture. The water quality concerns (salinity encroachment, drought and low DO) of the past few years have driven commercial fisherman out of the shrimping and blue crab industries in favor of more promising returns (landings worth $614,090 in 2005) from a robust and growing hard clam (*Mercenaria mercenaria*) Georgia aquaculture (Power, 2003). Additionally, Georgia scientists are investigating the viability of Eastern Oyster aquaculture (SeaGrant, 2007).

The establishment of aquaculture management objectives, however, is dependant upon the ability of the public to recognize the long-term benefits of embracing the required behavioral changes to ensure the success of such programs. The outreach component of establishing management objectives becomes critical in the developmental stages of establishing aquaculture infrastructure. An example of the potential difficulty in creating behavior modification of the public is evident in early attempts at getting Savannah seafood restaurants to collect the used oyster shells from the plates of departed diners.

During the summer of 2002, The University of Georgia Marine Extension Service (MAREX) was involved in an education campaign to let the public know the importance of recycling used oyster shells. The restaurant owners were informed about the environmental benefits derived from returning the oyster shells back into potentially productive waters where oyster spat could find suitable hard substrate on which to adhere and restart the process. Despite the obvious logic of this process, few restaurants were initially willing to undertake this minor behavioral modification, despite the stated understanding that pick up of the oyster shells was provided and would be timely and without associated costs (MAREX, 2002).

The MAREX is continuing their efforts to inform the public of the current most salient constraint to developing the eastern oyster industry. Public education and grant applications alike are identifying the infrastructure barrier to a viable oyster market. Specifically, the lack of suitable substrate for spat development has led to oyster reefs that have oyster spat densities beyond what is commercially viable for harvesting. The soft mud of otherwise suitable intertidal zones does not provide enough hard substrate to support an oyster industry. Commercial harvesting techniques from around the world are currently being tested in pilot studies by scientists and commercial fishermen alike, creating a common interest in developing protective water quality policies in coastal Georgia.

The delineation and protection of suitable oyster habitat is the next step of the developmental process, however continued evidence of the economic viability of oyster aquaculture will likely drive the development of the required water resource management objectives and policy. For example, the same restaurants that choose not to participate in volunteer oyster shell recycling programs may be more than willing to consider recycling oyster shells when there is an tangible economic value attached to their participation (such as with the recycling of aluminum cans). The economic viability of water resource policy can be expressed as either a benefit or cost, depending upon the public's willingness to accept the behavioral modifications that may be required to achieve resource management objectives, whether the resource is a public good (like water) or a commercial harvest (like oysters).

Table 5.2 lists several benefits that are equally as likely to be construed as a cost to different user groups. This market ambiguity provides the basis for seemingly conflicting policy recommendations for the protection of individual species and their associated habitat. Since SNS are no longer a market commodity with perceived economic value, it is useful to provide policy recommendations that provide a link to the economic importance of protecting endangered or non-commercial species like SNS and/or its habitat.

The clearest path to attaching economic value to SNS is through its value as a measurement tool for achieving water quality objectives. The protection and sustained population of SNS in the SRE represents the ability of water resource managers to point to tangible results of their success in managing a scarce resource. The establishment of public trust through their proven managerial capabilities results in increased freedom to persuade the public to accept potentially uncomfortable behavioral modifications toward the establishment or maintenance of economically viable markets.

In addition to the intrinsic value of non-commercial species/habitat protection, intangible benefits are derived through the iterative process of developing sustainable policy for the more general protection of water quality. The water quality monitoring networks that indicate DO and salinity are too high to sustain adequate recruitment for SNS or striped bass populations are also responsible for alerting scientists and decision makers about forthcoming potentially lethal system failures. For example, sudden or dramatic fish kills may point to necessary changes required to maintain adequate supplies of drinking water or water for the protection of the economic sustainability of a key industry. The “canary in the coal mine” effect of protecting sensitive species is not only economically viable, but critical in this modern era where terrorism and national security interests must pervade the planning for even mundane events.

Recommendation 5

The fifth recommendation is to **Impose Immediate Restrictions Upon Further Access or Development in At-risk Regions Within the SRE**. Any proposed restrictions, regardless of scope, may be subject to economic cost-benefit analysis because of the competing demands of maintaining commerce and the recreational use designation. Upon securing the parameters of these at-risk areas (with the exception of GPA shipping traffic), a targeted monitoring program may be established to ensure threatened habitat will assume a positive restorative correlation with science-based policy development. Given monitoring in the SRE has been conducted at some level since 1968 (GPA, EPD and USGS) (see Figure 1.2), there is a need to consolidate these data into a comprehensive document that shows trends in the decline of water quality and fish habitat across overlapping monitoring sites. More recent data may include sonar images of significant changes in habitat by region. These data may form the basis for setting original restrictive policies. Restrictive policies may be re-assessed or eased once restoration goals have been achieved.

Setting restrictions (even temporarily) gives species time to recover to “normalized” levels if damage is not deemed irreversible. Minimally, such restrictions may prevent species extirpation within a genetically distinct population segment. Restricted access, however helpful in preventing additional damage within a stressed region, requires a complementing restoration proposal. A site-specific document may be designed to protect, nurture and minimize future threats to maintaining good water quality and unique habitat features and functions. This 2003 water quality data provides an example of how an integrated approach (that includes mapping) may provide a quick visual understanding for prioritization in response to a variety of environmental threats. These collective findings and recommendations are summarized in Chapter 6.

Endnotes

[1]The establishment of the Endangered Species Act or ESA made it illegal to damage or even threaten habitat of specific listed endangered species. The Endangered Species Act redefined environmental policies to include provisions for protection of species biodiversity and other more holistic concepts that had been initially penned by prominent human ecologists like Garrett Hardin (Professor Emeritus of Human Ecology at the University of California in Santa Barbara).

[2]The NEPA scoping process created a legally recognized entity, the Stakeholder's Evaluation Group (SEG) to identify, assess and compare among alternative strategies for completing the Savannah Harbor Deepening (expansion) project. This project was authorized by Congress in 1999, subject to specific guidelines for Federal oversight of the Georgia Port Authority findings by the Corp of Engineers. Additionally, Congress stipulated the project must be approved by the Secretary of the Interior, the Administrator of EPA and is subject to consensus findings published by the SEG at the end of the NEPA scoping process.

[3]SeaWiFS is a Sea-viewing Wide Field-of-view Sensor launched into space by NASA and a private contractor (Orbital Sciences Corporation) in 1997. It is designed to provide quantitative estimates of primary production based on the concentration of microscopic marine plants (phytoplankton). It continuously monitors subtle changes in ocean color across the visible light region (wavelengths of 400-700 mm) that signify various types and quantities of marine phytoplankton. The depth of the color varies with the concentration of chlorophyll and other plant pigments present in the water. (http://seawifs.gsfc.nasa.gov/SEAWIFS.html, 2007)

[4]The EEZ was originally established by The Magnuson Fishery Conservation and Management Act of 1976, (renamed the Magnuson-Stevens Fishery Conservation and Management Act when amended on October 11, 1996). The U.S. Exclusive Economic Zone extends from 3 to 200 miles offshore. This region is managed by eight regional fishery councils, with Georgia waters under the jurisdiction of the South Atlantic Fisheries Management Council (see Figure 5.2) (NOAA South Atlantic Fisheries Management Website).

[5]An example of the coordinated EAM approach is seen in SEG representatives from South Carolina and Georgia working collaboratively on the management of the Savannah River since neither state contains the entire river.

[6]The South Atlantic Fishery Management Council is one of eight regional fishery management councils established under the original 1976 Magneson Act. The act was reauthorized most recently on January 12, 2007.

[7]Reverse Osmosis is one type of desalinization that removes salt from seawater using osmotic pressure to diffuse water through a semi-permeable membrane (Pankratz & Tonner, 2003).

[8]SABSOON is a real-time observational network on the U.S. Continental shelf. Eight large platforms, currently operated by the U.S. Navy for flight training, are being instrumented to provide a range of oceanographic and meteorological observations on a continuous basis. Online: http://www.skio.usg.edu/Skioresearch/physical/sabsoon/system/

CHAPTER 6

SUMMARY AND FINDINGS

Background

The concept of science-based policy has been developed from the need to integrate decision-making with an understanding of available alternatives. Ideally, science may suggest some alternatives which are more eco-friendly than others, while policy may reflect the economic considerations associated with each alternative. Unfortunately, the political agenda may supersede science and policy considerations, even in ideal circumstances. Politics, however, are the only basis for decision-making in the absence of other relevant data. Filling data gaps, therefore, is the primary objective in creating science-based policy.

The highly politicized Georgia water resource policy agenda is fraught with data gaps that may render good decision-making an impossibility in certain regions. One of these regions is the Savannah River Estuary, where great amounts of data exist, but not in a continuum distributed across some of the most environmentally vulnerable areas. While it may be an inconvenient truth that the Savannah River Estuary is environmentally challenged, there are burgeoning remedies where science and policy may find commonality. Specifically, the research of this study supports five detailed recommendations (based upon thirteen findings) to improve future decision-making regarding the identification and protection of unique shortnose sturgeon habitat and the monitoring of water quality within the Savannah River Estuary.

The irreversibility of species decline is already evident through review of the Savannah River's history. Specifically, the shift in salinity within the middle estuary has been dramatic enough to cause extensive marsh-dieback, destruction of the native tupelo and cypress trees, and the redistribution of salt-sensitive species deeper into the estuary (Duncan & Eudaly, 2003). These facts, however, represent only a fraction of the changes occurring in the port area of the estuary.

The endangered shortnose sturgeon and right whale (*Eubalaena* glacialis)[1], the threatened striped bass and many other fish species have seen dramatic declines within the SRE (and surrounding waters) over the past forty years as a result of Savannah Harbor expansion and deepening, habitat destruction, hydro-electric power dams, improper harvesting practices and inadequate hatchery practices. The water quality and habitat degradation that has resulted from these threats to fish health are examined within the geographic boundaries of the lower Savannah River Estuary from Fort Jackson (rk 16.1/rm 10) to several kilometers north into The National Wildlife Refuge of the middle estuary (rk 44.1/rm 27.4) (see Figure 4.5).

Additionally, contextual data for the study area have been collected through a series of over thirty interviews with multi-disciplined stakeholders. These diverse participants are collectively identified in the Savannah Harbor Expansion Project (SHEP) legal records as the Stakeholders Evaluation Group (SEG) under the NEPA federal oversight requirements. NEPA requires input from the affected community through the regular stakeholder meetings held several times a year[2]. Although the meetings include scientific studies and reports, the community at large is given an opportunity to voice opposition to any findings or facts presented by other members. The SEG may elect to voice concerns that require regulatory investigation, however, such as those expressed surrounding the protection of endangered species. This study was intended to not only highlight the scientific basis for conducting future in-depth studies about the protection of the endangered shortnose sturgeon habitat, but also was designed to provide a prototype for intensified mapping and monitoring of regions within the SRE where poor water quality may also threaten the future of Savannah's drinking water supply (SEG, 2001).

Objectives, Conclusions, and Recommendations

The Sequence of Satisfying Objectives

The five objectives of this study were met through the synthesis of the 13 findings into four conclusions (see Table 6.1). The conclusions provided the basis for the recommendations previously discussed in Chapter 5. The objectives as originally stated and discussed in Chapter 1 are:

1. Identify and map/highlight problem shortnose sturgeon habitat areas.
2. Spatially delineate habitat features possibly related to ecosystem functions.
3. Spatially delineate regions possibly related to cultural heritage within shortnose sturgeon habitat.
4. Determine protective strategy for delineated features.
5. Provide scientific and culturally relevant recommendations.

Discussion of Synthesis from Objectives to Findings and Conclusions

Objective 1: Identify and map/highlight problem shortnose sturgeon habitat areas.

The five primary objectives of this study were accomplished through research and analysis conducted from the summer of 2001 through fall 2008. Meeting these objectives first required a six month investigation of water quality within the SNS habitat region identified in earlier studies (Collins et al., 2000B). Additionally, the use of two types of sonar were employed to understand the range of possible SNS habitat features present, notwithstanding, the visible

Table 6.1

Summary Objectives, Findings and Recommendations

Objective	Finding	Recommendation
1. Identify and map/highlight problem shortnose sturgeon habitat locations	1. DO levels were low enough to cause severe stress in sensitive or juvenile species, particularly near SR01, FR01 and TG01 2. Low DO was not necessarily predictive of shortnose sturgeon habitat, because of rarity of fish holes and other desirable habitat (including food/nursery areas). 3. Mean salinity levels were lower in 2003 than the previous 4 drought years 4. Salinity levels were not maintained at high levels but did exhibit potentially lethal spikes for sensitive shortnose sturgeon life-stages or other vulnerable species. 5. Temperatures were normal, but exacerbated the effects of low DO levels during the summer months, particularly at SR01, FR01, FR02, TG01, and BR01.	1. Expand monitoring network to include repeatedly stressed zones (hot spots) and unique habitat areas
2. Spatially delineate habitat features possibly related to ecosystem functions	6. No seeps or rock outcrops were identified in the study area. 7. Side-scan sonar revealed the Front River fish hole (identified in previous studies) was dredged 8. Side-scan sonar revealed the Middle River fish hole was intact and served as the main freshwater tidal interface protective zone. 9. Food sources were not found in the former King's Island nursery area.	2. Establish geo-referenced threatened/endangered species habitat risk maps to provide protection for unique habitat features under NEPA or ESA.
3. Spatially delineate regions possibly related to cultural heritage within shortnose sturgeon habitat	10. Debris fields were most concentrated in the Middle River, but some debris was also seen outside shortnose sturgeon delineated habitat in portions of the Back River near BR02 and in the Front River near FR02.	3. Create a unique habitat risk minimization plan that requires delineation of unique or critical habitat specific to shortnose sturgeon.

Table 6.1 *continued*

Objective	Finding	Recommendation
4. Determine protective strategy for delineated features	11. DIDSON sonar revealed that the Middle River fish hole contained many fish, possibly including shortnose sturgeon. 12. Fish hole and debris fields are threatened by proposed harbor deepening/expansion.	4. Establish: a. Real-time reporting and evaluation of unique or at-risk species/habitat water quality data b. Expedited or priority at-risk species/habitat regulatory review process c. Best Available Technology requirement for protecting at-risk species/habitat
5. Provide scientific and culturally relevant recommendations	13. Alternatives for protecting unique shortnose sturgeon habitat/features are not yet included in the SHEP Tier II Environmental Impact Statement.	5. Impose immediate restrictions upon further access or development in unique or highly at-risk regions within the SRE until additional studies provide alternate locations/strategies for harbor expansion.

impacts of continual Savannah Harbor maintenance dredging. A grab sampler was also used at each sample site to identify the presence/absence of probable food sources for SNS.

The water quality data revealed the SNS do not have many areas within the lower SRE where conditions are ideal year-round. Instead, the extremely low DO across the Front River (from Fort Jackson to Houlihan Bridge) data illustrated stressful environmental conditions for sensitive species. Low DO, high temperatures, and high salinity were observed in the Front River throughout the warm summer months, particularly at SR01, FR01 and TG01.

The data did not indicate a discernable pattern across the bottom DO values based on the semi-diurnal tides, however, the salinity spikes were somewhat correlated with low bottom DO levels near Ft. Jackson (SR01). DO values were low throughout the lower estuary during June, July and August, but became normal upon reaching the Middle River and northward, where they did not exhibit the same dramatic fluctuations, except in an isolated spot within the National Wildlife Refuge (see Figures 4.17-4.20). Such water quality stress has been reported to impact sensitive species fecundity and reproductive health, possibly explaining the recruitment bottleneck currently plaguing striped bass and shortnose sturgeon (Reinert, 2003).

The expansion of monitoring sites is recommended to provide a more holistic understanding of the inshore and offshore ecosystem processes. Although the SABSOON monitoring network is currently in place, there has been little focus upon expanding the network to newly prioritized sites inshore and offshore due to funding constraints. The United States Environmental Protection Agency (USEPA) has historically sponsored the Environmental Monitoring For Public Access and Community Tracking (EMPACT) to assist communities in providing public access to timely, accurate and understandable environmental monitoring information (USEPA, 1999). This funding initiative, although unfunded during the Bush administration, may become available again as one of several possible programs to provide a jump start to improving the integration of science (monitoring data) with the public and relevant decision-makers.

Georgia Sea Grant, may also be a potential source for additional research capital to repair, expand and maintain the SABSOON network. Data monitoring system maintenance is expensive, however, so it is important to selectively fund continuous monitoring for the most critical habitat to ecosystem functions and sensitive species, unless a private or not-for-profit group offers to sponsor one or more monitoring stations within their region of interest.

Objective 2: Spatially delineate habitat features possibly related to ecosystem functions. The salinity spikes observed in these data (see Figure 4.12) highlight the importance of identifying and preserving the relatively few intact freshwater tidal interface thermal or salinity refuge features. Examples of such features include the Middle River fish hole (see Figures 4.30-4.32) and some stretches of Back River near sample site BR02. The Middle River fish hole and portions of the Back River also provided evidence of multiple food sources among the rich organic debris identified with both sonar and grab samples.

The absence of organic material and the presence of PAH-laced sediments in the grab samples suggested there was an absence of food in the King's Island turning basin (Christensen, 2004). These 2003 data, combined with the observed presence of strong odors, indicated that King's Island Turning Basin was no longer a viable nursery habitat, as thought from earlier studies (Hall et al., 1991). Review of the regional DO risks in this area were also displayed on the isopleth maps from Chapter 4.

The isopleth maps from Chapter 4 (see Figures 4.13-4.24) are the prototype for geo-referenced water quality risk maps. They are a prototype only because they require more extensive monitoring to capture more than a snapshot from 2003. These regional risk maps may serve as the interface between science and policy development once they reflect the dynamic environment of the SRE through regular updates. They provide a quick reference for delineating unique or critical SNS habitat; however, they may also provide guidance for prioritizing the location of additional monitoring stations.

Objective 3: Spatially delineate regions possibly related to cultural heritage within shortnose sturgeon habitat. The debris field in the Middle River near the confluence of the Back River was filled with old dock posts, boat hull remains, hollowed-out tree stumps, remnants of rice trunks and miscellaneous surface features leftover from the old plantations and the booming 1850's rice trade. While much has been written about the possible history of this site, there have been little efforts to preserve what remains on the inter-tidal mud-flats or subsurface. Presumably, the large-scale projects like the CSS Georgia (civil war era ironclad) and the now harbor entombed remnants of the Mary Musgrove Trading Post garnered National attention and funding. The less obvious relics of the past; however, once recorded, have continued to degrade (Georgia Battlefields, 2002).

The cultural artifact remains that fall within the previously identified SNS habitat, however, represent a two-for-one bonus. Securing protection for the fish functionality of the debris would also provide a reprieve against the erasure of history. It is possible that undocumented artifacts may come to the surface (or near so) under the natural forces of erosion and wave friction. Inundation of this region during storms has also revealed new cultural data upon the retreat of the surge.

An unidentified cultural artifact (the possible remnant of a boat hull) was seen near FR02 (see Figure 4.35). Although this area is not representative of unique SNS habitat, regular monitoring with sonar may delineate this region for cultural preservation and subsequently prevent irreversible damage from deeper planned maintenance dredging. The removal of additional sediment may uncover a new large-scale cultural artifact, but it may also demolish the remains in the process. Protection of either unique SNS habitat or artifact-rich regions may require a specific risk minimization plan to address the value from both cultural and environmental perspectives.

Objective 4: Determine protective strategy for delineated features. The plethora of current monitoring stations within the SRE is still incomplete. Many of the existing Georgia Port Authority and USGS stations were established under funding from projects that have long-since been finalized or abandoned. As a result, many of the datasondes have gone offline or have fouled sensors due to lack of funding for proper maintenance. Additionally, the technological improvements in current monitoring equipment make it more economically feasible to integrate the data collection process and upgrade the reporting software.

The immediacy of data collection aids the evaluation and response time, minimizing potential deleterious impacts from radical changes in water quality (such as during a hazardous spill). Once the monitoring is expanded to critical habitat areas, elevated levels of any undesirable substance may be detected before they reach the maximum ecosystem (or species) assimilative capacity. There are obvious security benefits as well.

Expedited or priority at-risk species/habitat regulatory review process. The benefits of real-time reporting and evaluation of water quality hazards are greatly diminished when regulatory process is not expedited through *apriori* guidelines. A triage-type response may be required to secure funding and associated action for the most critical habitat disruptions. A consistent protective strategy requires ranking the ability to achieve desirable and expected (repeatable) outcomes.

The regulations protecting sensitive areas for SNS are not stringent, and require a higher and more immediate level of response than currently available. Such ranking is obvious when human life is threatened, however it is less obvious upon consideration of fish survival. Subsequently, the use of Best Available Technology (BAT) will mandate the best response in the shortest amount of time.

Best available technology requirement for protecting at-risk species/habitat. There is often controversy over using BAT to mitigate non-human environmental impacts. The use of sonar, for example, to detect changes in fish habitat may sound extravagant. In reality, however, sonar is a very cost effective means to detect multiple types of change simultaneously, including those that directly impact human safety (such as detecting the presence of sandbars, large sea mammals or even security threats).

Despite the cost-effective use of sonars, current monitoring efforts in the SRE do not include regular sonar monitoring except for privately held channel maintenance purposes. The requirement to use sonar and other BAT in mitigating fish habitat disturbance will provide an immediate link to understanding ecosystem processes (like sediment redistribution) and provide a critical first step toward expanding the current SABSOON monitoring network. The immediacy of this data will provide regular updates to outdated regulatory policies as soon as it is reported as feasible. Such updates will ease the economic pain of stringent/highly restrictive fishing zones or overprotective creel limits that may be in place throughout an extended period of time in the absence of data.

Objective 5: Provide scientific and culturally relevant recommendations. The science of this study suggests that the Savannah River Estuary is seriously impaired due to poor water quality, particularly in the Front River corridor near the city of Savannah and the associated industry. The culturally relevant data collected from stakeholders suggests the SRE needs immediate action to protect the most critically impaired regions, both for environmental and economic reasons (potential contamination of Savannah's drinking water). Given the unavailability of data regarding universally acceptable environmental and economic alternatives to the proposed harbor deepening, the stakeholders are requesting a moratorium on expansion activity in the port. This study's findings echo that conclusion, particularly regarding the expansion of the King's Island turning basin because of its proximity to the unique SNS habitat of the Middle River.

The logical summary recommendation is to restrict access to the most sensitive portions of the SNS habitat until additional studies/monitoring identify suitable replacement habitat or restore and protect the existing habitat. The United States Army Corps of Engineers are currently investigating a giant DO injection system (bubbler) to mitigate the negative impacts to harbor deepening activities (SEG, 2001). The Nature Conservancy is investigating flow management strategies to offset salinity concerns and fish passage for spawning (Wrona et al., 2007). If Best Available Technology mediation remedies are employed, new options may be less restrictive.

Discussion of Conclusions

Conclusion 1: The Savannah River Estuary, particularly in the Front River corridor as it passes by the city of Savannah, has severe water quality problems throughout most of the warm summer months, especially regarding the extremely low values recorded for bottom dissolved oxygen.

The drought of the previous four years before 2003 exacerbated the salinity concerns within some parts of the estuary where salinity had never been recorded (in The National Wildlife Refuge). Salinity spikes (not mean values) were still a concern in the non-drought 2003 data. These and other water quality concerns (turbidity) suggested the fish were not the only species being negatively impacted (serious declines in recruitment of wild species) by the poor water quality during the hot summer temperatures where temperatures throughout the water column frequently exceeded mean values greater than 26ºC.

Conclusion 2: The presence of unique fish habitat features (debris fields and a fish hole) in the Middle River was confirmed with two types of sonar.

The data also suggests the Middle River fish hole harbors many fish during the warm summer months. Some of these fish were captured by the high-frequency DIDSON sonar as a large and slender species with a pointed head, possibly either the endangered shortnose sturgeon or the threatened atlantic sturgeon. The debris provided hiding locations against fish predation and a possible food source for foraging species.

Conclusion 3: The endangered shortnose sturgeon may be offered greater (but limited protection) through the creation of "no-access zones" based upon delineated regional risk maps reflecting water quality trends.

"No-access" zones should be off-limits for any traffic other than emergency responders and permitted scientific researchers for SRS regions outside the Georgia Port Authority shipping lanes. Maps highlighting these zones should be updated weekly/monthly to reflect serious changes in ecosystem health. Although controversial, Shad fishing SNS by-catch should be prevented by closing the sections of the SRE with fisheries known to contain either shortnose sturgeon or any other threatened species. Commercial fisherman may avoid some financial losses by adapting to the market viability of a more sustainable species.

Conclusion 4: Additional prioritized regional investigation/monitoring of water quality and fish habitat in the SRE is needed to slow or prevent further degradation of the remaining freshwater interface habitat of the endangered shortnose sturgeon.

Associated Finding(s): Although reports of increased survival for hatchery stocked shortnose sturgeon may appear encouraging, the severe degradation of available habitat suggests any gains may not be sustainable. Projected development and population growth of the City of Savannah creates a greater sense of urgency to prevent total species extirpation of any geographically unique species population segments. The expansion of current inshore/offshore monitoring networks may provide more insight into available options for the future.

Research Value

Regional Risk Map Value

This dissertation research puts many types of data together in one place, providing scientific, environmental, economic and cultural perspectives for prioritization of water quality mitigation efforts on a spatial scale. The maps from this 2003 water quality research also provide a prototype for developing subscription series regional risk maps to answer specific regional questions. Although there are many competing user interests in SRE water quality, these risk maps may be regularly reviewed to create a check and balance system for portions of the Savannah River where overall sensitivity is determined to be the highest.

The regional risk maps will change the standard lag time between science and mitigation action if multi-faceted continuous monitoring data is processed and published at frequent intervals using subscription GIS (downloadable) maps on demand. These maps may also improve the equity of scarce resource use if one user group's actions are regularly monitored and tied to a range of known outcomes and published in an online database (expedited modeling prioritized by region).

Regional risk maps may also provide a means for immediately correcting mitigation efforts when possible. If the data is made available in real time to academic institutions as well as government agencies through the GIS clearinghouse or some other service, errors from previously insufficient data may be corrected before resources are allocated in an area that is not a high priority for ecosystem management or survival for a stressed species.

Habitat Classification Refinements with Hydrology Models, Regional Risk Maps and Unique Features

Efforts to discover the "ideal" estuary model is currently being made through the integration of inputs from two previous SRE hydrology models, the marsh succession model (MSM) and the three-dimensional hydrodynamic model (3DM). The new model being tried for the SRE Tier II EIS is called the Artificial Neural Network (ANN) model (Daamen et al., 2006). Additionally, there have been specific recommendations from TNC workshops and water resource conferences over the past ten plus years of SRE study. Examples of some recommendations from these efforts may include: increasing river flow from upstream dams and reservoirs (The Nature Conservancy [TNC], 2004), adding DO back into the most threatened parts of the Savannah River (SEG, 2006), and closing Shad fishing in some areas (Gale, 2001).

Although all of these efforts are currently under consideration, there is little understanding about how one action may impact another within a specified area. The triangulation of quantitative water quality data, mid-range and high frequency sonar data with qualitative interview data resulted in the creation of region-specific risk maps. This study's regional risk map prototype is an example of how scientific data may become user-friendly for policy decision-making across multiple perspectives. The addition of sonar data also demonstrated an efficient way to improve the coordination and tracking of stochastic events and past mitigation results by region.

The USGS and several entities currently monitor the SRE for different reasons, however, this data network is not integrated with all available sources for data (e.g., two types of sonar, cultural and historic records) and simultaneously tied to specific geographic areas. Dynamic integrated GIS maps may be used to route ships around storms, locate channel hazards (e.g., sandbars) and sensitive ecosystems (e.g., spawning runs within fisheries) at the same time. Future multi-source integrated inshore/offshore monitoring data could be converted into regional risk maps for widespread distribution and may be layered to monitor geographically linked phenomenon.

Contributions to the Scientific Literature

This research demonstrated the usefulness of state-of-the-art high resolution, high-frequency sonar (DIDSON) in identifying substrate materials, indicating details about the location, shape and size of mid-range sonar targets, determining animal usage patterns of target features, and identifying cultural or habitat features. Additionally, this study confirmed research findings from previous studies (e.g., the King's Island Turning Basin is no longer viable as SNS nursery area). Finally, this study illustrated the explanatory value offered by integrating multiple types of research perspectives, specifically, through the seamless combination of qualitative and spatially defined quantitative data.

Importance to Shortnose Sturgeon/SRE Ecosystem Health

There are many ways this research may positively impact the recovery of the shortnose sturgeon and health of the SRE. Three specific benefits include:

1. Raising awareness about the need to share data across multiple fields to garner a richer understanding of the holistic interactions between research targets and their environment.
2. Adding the value of isopleth regional risk maps (see Figures 4.13 – 4.25) in delineating the most seriously impaired portions of the SRE for prioritization in protection, given limited funding availability.
3. Documenting the presence of unique/rare ecosystems features (e.g., the Middle River fish hole) and providing non-drought year SRE water quality data.

This dissertation research may potentially trigger the legal mandates under NEPA to include alternatives to the proposed KITB expansion that mitigate impact to the Middle river fish hole[3.] The inclusion of alternatives may afford protection for the fish hole and its aquatic residents or provide new technology. The NEPA induced studies may identify sensitive species habitat mitigation of potential harbor modification disruptions in future fish/ecosystem health.

The Middle River fish hole may be given protected status and lead to many more regional studies that further define the SNS health linkages to their habitat. If such studies suggest a pro-active approach to preserving native species and habitat, the wild SNS may increase their population size within the SRE, rather than just merely survive.

Future Directions

Regional Risk Maps In the Future

The widespread use of Geographic Information System maps has greatly enhanced the availability of spatially accurate data for decision-makers. These maps provide a user-friendly interface to access scientific information. Specifically, the use of regional risk maps (see Figures 4.13-4.24) improves awareness and public response time to potentially negative environmental impacts to aquatic life. Such maps may also aid in the prioritization of potentially impacted areas.

Monthly maps delineating regions of interest (based upon a live feed from a continuous monitoring network and cross referenced with sonar data) may be acted upon to commercial advantage when real-time data prevents an undesirable or irreversible environmental impact. For example, future developers of bi-valve aquaculture may require continuous monitoring data to provide updated maps of suitable habitat, both from sonar investigation and in terms of water quality. Multiple sites can be shown on the maps in various stages of development for aggregation of suitable hard substrate. Such maps may reflect the storm destruction of a previously suitable region, saving time and money in the allocation of future limited resources for cultivation and harvesting.

A continuous monitoring inshore/offshore network is in its developmental infancy (when considering the possible expansion into the Global Ocean Observation system or GOOs) off the coast of Georgia and in the SRE (GOOS, 2008). The use of regionally delineated GIS maps (via cell phones and other GPS electronics) is already well received by the public. Integrating these devices with the geo-referenced data from real-time water quality monitoring networks (including inshore/offshore sonar investigation with custom delineation parameters by region) through publicly available map subscriptions, may bring science and policy a step closer together in the decision-making future.

Future Fish-kill Studies and Maps

A final future consideration regards the exploration of synergistic relationships that exist between temperature, DO and salinity in terms of SNS stress, recruitment and mortality. Although tolerances have been explored for salinity and temperature and other water quality combinations, there is evidence suggesting SNS tolerances may be tied to acclimation temperatures (Zeigewied et al., 2007), in addition to species maturity (Zeigewied et al., 2008, Jenkins et al., 1993). These recent findings suggests that SNS habitat requires additional study before predictive mortality rates may be determined at margins that may be considered “safe” in the presence of multiple indicators of poor water quality.

This dissertation research provides a prototype map for relaying geographic linkages to species survival as they may be explored at different water quality tolerances. Geographic identification of at-risk regions for fish kills may be determined through the iterative testing of values for water quality tolerances within a target species at a specific location. Such events may be predicted and distributed as user-friendly maps. Species-specific water quality tolerances within specific riverine reaches may also aid in the promulgation of region-specific water quality regulations for protection of indigenous species.

An example of a geo-referenced output map for the intersection of multiple water quality parameters expressed as a possible combination of SNS tolerances for predicting fish stress, poor recruitment or possible mortality (DO < 5.2mg/l, Temperature > 26 degrees C, and Salinity < 0.05PSU within the SRE) is shown in Figure 6.1. Future studies may test these selected values for refinement of the unique SNS tolerances of species geographically linked to the SRE.

Regardless of which tolerances may be found to most accurately reflect these linkages, it is critically important to provide timely, integrated multi-variable and habitat-specific SNS mortality data for their continued survival in the SRE (SEG, 2001). The susceptibility of SNS to higher mortality with increased temperature (particularly with low DO) specifically highlights the importance of protecting known thermal refuge areas (such as the SRE Middle River fish hole) within SNS habitat (Ziegewied et al., 2007).

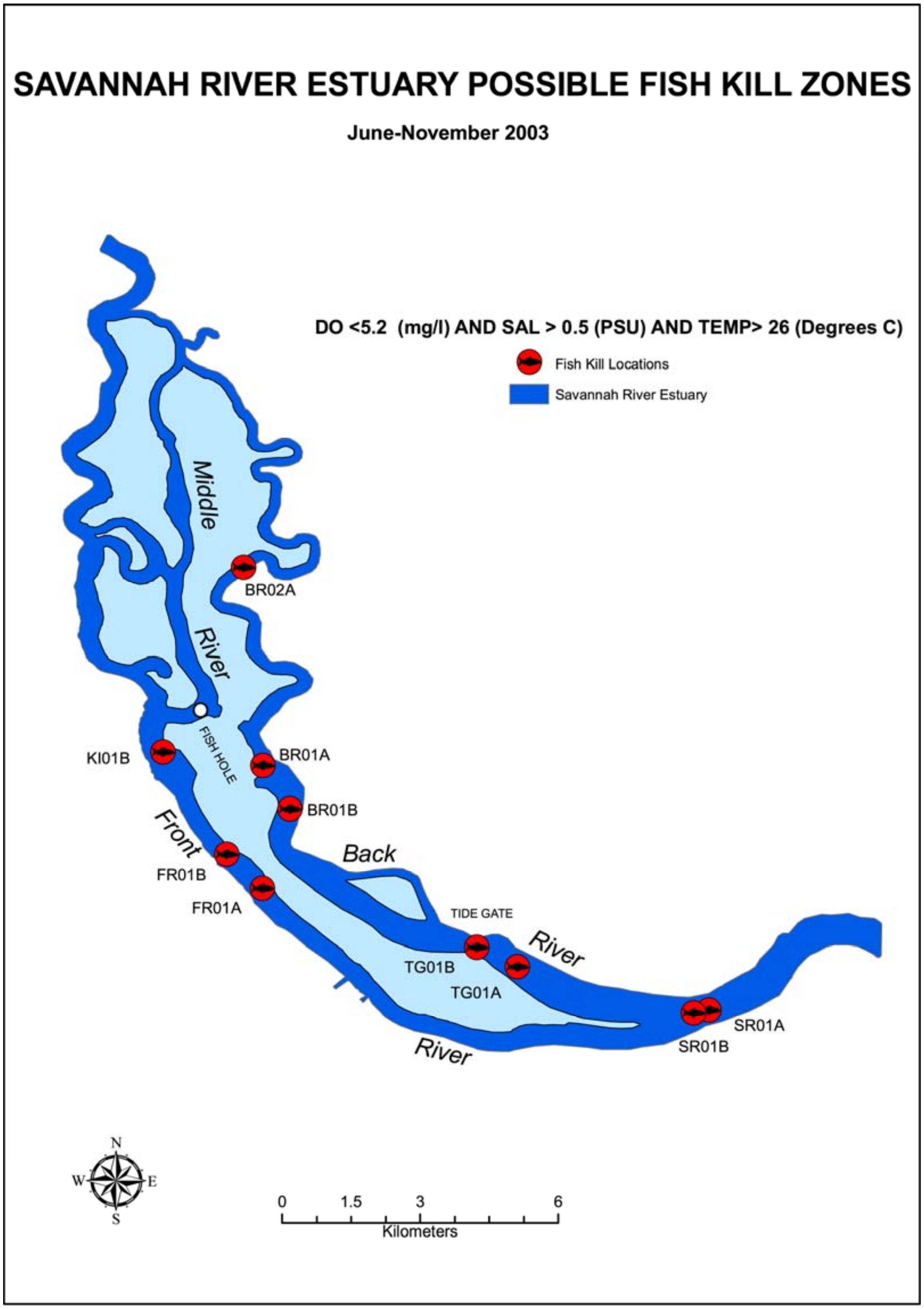


Figure 6.1. Potential Fish-kill Sites in the SRE.

Future Refinements in Fish Habitat Classification

Future studies may also consider refinements in the classification system used to determine habitat status. Although the commonly used Van Dolah model equally weights water quality, sediment quality and benthic IBI scores (Van Dolah et al., 2004), and it offers multiple perspectives for assessing habitat, the rarity or uniqueness of habitat features within a specific geographic region, may be an appropriate addition to these equally weighted variables. Consideration of weighting this variable equally among the existing measurement parameters may be prudent based upon the possibility that the removal or destruction of such features may cause direct impacts on the survival of a specific species or the sustainability of an ecosystem. For example, future studies in the SRE might investigate the specific importance and functionality of the Middle River fish hole in the preservation of SNS and other potentially stressed species.

Endnotes

[1]Right whales have been seen within the lower part of the SRE near the mouth of the Savannah River where it joins the Atlantic Ocean. The GADNR Coastal Resources Division has made efforts to warn ships of their possible presence in the shipping lanes (Shipman, 2007).

[2]These stakeholder meetings give individuals and concerned community leaders legal status and require the Georgia Port Authority to consider or discuss concerns raised during the meetings. The meeting minutes are available to the public and posted on the stakeholder website.

[3]ACOE planned KITB expansion is less than half a kilometer away from the fish hole.

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APPENDIX A

INTERVIEW QUESTIONS

1. Have you or you organization ever been involved with any research concerning shortnose sturgeon in the Savannah River or any other southeastern river? If so, when? What were the results of your research?

2. Do you know the difference between Atlantic and Shortnose sturgeon? If so, would you describe your method for telling them apart?

3. Have you or your organization ever caught any fish in the Savannah River? If so, have you ever caught any shortnose sturgeon as bycatch (caught then immediately released)? If so, where did you catch the shortnose sturgeon?

4. Have you or your organization ever studied or otherwise observed fish habitat in the Savannah River? If so, when and where? Would you describe the habitat you or your organization studied/observed?

5. Are you or your organization familiar with sonar technology? If so, have you or your organization ever observed any acoustic imaging of fish or fish habitat? If so, when and where? Would you please describe your experience?

6. Are you or your organization interested in the water quality and/or habitat of shortnose sturgeon? Would you please describe the context (please include specific geographic location) and extent of you or your organization's interest?

7. Have you or your organization invested any resources toward the preservation of fish or fish habitat in any southeastern river? If so, would you please describe the location and extent of your or your organization's interest in that specific location (please include specific species)?

8. Do you or your organization have any information on current or proposed changes in the lower reaches of the Savannah River? If so, would you please describe the nature or extent of these changes?

9. How would you characterize you or your organization's interest in the proposed Savannah Harbor Expansion Project?

10. Are you or your organization familiar with the National Environmental Policy Act (NEPA)? If so, would you please describe the extent and context of your familiarity?

11. Are you or your organization familiar with the Endangered Species Act? If so, would you please describe the nature and context of your familiarity?

12. Would you or your organization be interested in participating in or funding future water quality and/or acoustic imaging studies of fish or fish habitat in any southeastern rivers? Why or why not?

13. Could you or your organization suggest any other individuals or groups who may wish to participate in water quality or acoustic sampling in southeastern rivers? If so, please identify the individual or group and the river(s).

14. Do you or your organization wish to be included in future discussions about water quality/fish habitat issues of the Savannah River? Why or why not?

APPENDIX B

CONSENT FORM

I, ______________________, agree to take part in a research study titled "__________", which is being conducted by ________, Department of _________ (---) -------- under the direction of _________, Department of ________, (---) --------. I understand I do not have to take part in this study; I can stop taking part at any time without giving any reason, and without penalty. I can ask to have information related to me returned to me, removed from the research records, or destroyed.

PURPOSE

The purpose of the study is to:____.

It is my intention to ____

BENEFITS

I will/will not benefit directly from this research. However, my participation in this research may lead to: ____.

WHAT IS INVOLVED

If I volunteer to take part in this study, I agree to the following:

I will participate in a video-taped, voice-recorded, or manually transcripted interview, with the choice of format being selected according to my (the participant) comfort level:

I understand that I may request to stop taping at any time during the interview, even if I have agreed I am comfortable with my chosen format. I also am aware that, should I agree to be video-taped or voice-recorded, my interview may be used as part of a documentary at a later time. I retain the right, however, to withhold my express consent for publication of the contents of any portion of my statements, my identity or any issues regarding a breech of my privacy.

I understand that any use of my statements will be within the context of research or a research-based documentary on the subject of ____________________________

I understand that I may be asked open-ended questions for a duration ranging from a few minutes to a series of interviews over several days, at a mutually acceptable location, and according to my willingness to provide my time and input. The questions will be identical or very similar to the questions below:

ADD questions here:

DISCOMFORT OR RISK

I do/do not anticipate any discomfort or risk as a participant of this study.
I understand that I have the right to stop at any time without penalty, should my comfort level or perception of risk change for any reason.
I understand that the researcher may, at any time, without my consent, discontinue this interview, should my participation create undo stress to either her or any other party. CONFIDENTIALITY

*Check on*e:
I understand that I have full control over the level of confidentiality: (Please initial the appropriate line)
_____ I want full confidentiality . This means that any information that is obtained in connection with this study and that can be identified with me will remain confidential and will be disclosed only with my permission or as required by law.
OR
_____ I do not mind having my identity and/or comments quoted directly in the research findings and discussion and/or documentary. This means that interviews or excerpts of interviews may be viewed by parties outside the research team (including the public) with my full consent.

FURTHER QUESTIONS

I understand the researcher (*state name*) will answer any further questions about the research, now or during the course of the project, and can be reached by telephone at: (---) ---------.

CONSENT SIGNATURE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____________________ ____________________
Signature of Researcher Date

____________________ ____________________
Signature of Participant Date

HUMAN SUBJECTS OVERSIGHT
For questions or problems about your rights please call or write: ______________ Research Center Location_________; Telephone (---) _____ E-Mail Address _____

APPENDIX C

INTERVIEW PARTICIPANTS

Pilot Study Participants*

Dick Lee	Skidaway Institute of Oceanography	2002
Robert Weller	Georgia Department of Natural Resources	2002
Craig Robbins	Georgia Department of Natural Resources	2002
Randal Walker	Marine Extension Service	2002
Keith Gates	Marine Extension Service	2002
Dave Kyler	Center for a Sustainable Coast	2002
Darwin Gale	Commercial Fisherman	2002
Tom Reinert	Warnell School of Forest Resources	2002
Cecil Jennings	Warnell School of Forest Resources	2002
Ted Will	Richmond Hill Fishery	2002
Carl Hall	Richmond Hill Hatchery	2002

*Incomplete data indicates Human Subjects confidentiality/limited information disclosure.

Dissertation Study Video Interview Participants*

James Woods	Altamaha Riverkeeper	2003
Tom Reinert	Warnell School of Forest Resources	2003
Cecil Jennings	Warnell School of Forest Resources	2003, 2005
	Commercial Fisherman	2003
Gordon Rogers	Satilla Riverkeeper	April 17, 2003
Bobby Wynn	Commercial Fisherman	January 21, 2004
Judy Jennings	Sierra Club	May 11, 20034
Ed Eudaly	Fish and Wildlife	May 19, 2004
Will Bursen	Georgia Nature Conservancy	May 29, 2004
Dave Kyler	Center for a Sustainable Coast	July 20, 20004
John Robinette	Fish and Wildlife	July 22, 2004
Carl Hall	Retired Fisheries Biologist	July 22, 2004
Bob Scanlon	Savannah City Engineer	July 23, 2004
Henry "Red" Miller	Commercial Fisherman	August 30, 2004
Shawn Jordan	Georgia Coastal Resources	February 17, 2005
Prescott Brownell	NOAA	September 28, 2005
Wiley Kitchens	University of Florida	February 21, 2006
Paul Christian	Marine Extension Service	February 22, 2006
Brooks Warnell	Former Bryan County Commissioner	February 22, 2006
Alan Power	Marine Extension Service	March 15, 2006
Henry Len Jordan	Recreation Boating Dealership Owner	March 16, 2006
Amanda Wrona	Nature Conservancy	March 16, 2006
The Honorable Eric Johnson	Georgia Legislature	June 2006
Representative	Savannah Chamber of Commerce	June 2006
Frank Carl	Savannah Riverkeeper	August 14, 2006
Susan Shipman	Georgia Coastal Resources	Email Response

*Incomplete data indicates Human Subjects confidentiality/limited information disclosure.