STATE OF THE RIVER REPORT FOR THE LOWER ST. JOHNS RIVER BASIN, FLORIDA: *WATER QUALITY, FISHERIES, AQUATIC LIFE, CONTAMINANTS & AQUATIC TOXICOLOGY*
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Prepared for

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Preface

The State of the River Report is the result of a collaborative effort of a team of academic researchers from Jacksonville University, University of North Florida, Jacksonville, FL, and Valdosta State University, Valdosta, GA. The report was supported by the Environmental Protection Board of the City of Jacksonville and the River Branch Foundation. The purpose of the project is to review various previously collected data and literature about the river and to place it into a format that is informative and readable to the general public. The report consists of three parts---the brochure, the full report, and an appendix. The short brochure provides a brief summary of the status and trends of each item or indicator (i.e. water quality, fisheries, etc.) that was evaluated for the river. The full report and appendix were produced to provide more to those interested. In the development of these documents, many different sources of data were examined, including data from the Florida Department of Environmental Protection, St. Johns River Water Management District, Fish and Wildlife Commission, City of Jacksonville, individual researchers, and others. The researchers reviewed data addressing many different aspects of the Lower St. Johns River. The most statistically rigorous and stringent research available was used to assemble the report. When a draft of all documents was produced, an extensive review process was undertaken to ensure accuracy, balance, and clarity. We are extremely grateful to the following scientists and interested parties who provided invaluable assistance in improving our document.

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We have appreciated the opportunity to work with the environmental community to educate the public about the unique problems of the Lower St. Johns River, and the efforts that are under way to restore our river to a healthy ecosystem.

We would also like to thank the following undergraduate students for their contributions toward the development of this report:

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Executive Summary

The Fifth State of the River Report is a summary and analysis of the health of the Lower St. Johns River Basin (LSJRB). The Report addresses five main areas of river health: water quality, fisheries, aquatic life, and contaminants, and for the first time, aquatic toxicology. Additionally, the water quality section includes a new section on groundwater, the fisheries section contains new analyses of time trends of fish species abundance, and the contaminants section now contains a description of the region's chemical release inventory. Section 1 provides an overview of the Report and the basin, and it describes the basin's landscape, human occupancy, and environmental management spanning the 1800s to 2011.

Section 2 describes water quality in terms of dissolved oxygen, nutrients, turbidity, algal blooms, fecal coliform, and metals. Dissolved oxygen concentrations are within acceptable limits for aquatic life in the main stem of the river but fall below the site-specific minimum standard in several tributaries. Average nutrient levels, for phosphorus and some nitrogen species, have remained stable or have decreased slightly; however, maximum values frequently exceed EPA recommended standards, particularly in the smaller tributaries and creeks. Turbidity levels have remained stable over the past several years. Algal blooms have increased significantly in frequency over the past few years, but recent reductions in nutrient concentrations in some areas of the river, which directly affect algal blooms, are expected to reduce the number and intensity of such events. Trends in fecal coliform have indicated some improvement recently, according to a new analysis of tributary fecal coliform counts. The condition of the main stem is satisfactory. Regarding metal concentrations, a pattern of reduced concentrations has been observed over the past two years, with copper as a notable exception exceeding water quality criteria. Analysis of the region's ground water indicates that ground water supplies are insufficient to meet the future public water supply needs of Northeast and Central Florida.

Section 3 addresses the state of the river's finfish and invertebrate fisheries. A new analysis of fisheries data sets reveals time trends of species abundance by age group from 2001 to 2011. Although consistent quantitative information on fisheries is limited, finfish species do not appear to be overfished at the current time. The incidence of gross external abnormalities in finfish was less than one percent in 2001 to 2010, and mercury levels in several species suggest limited consumption of only 1-8 meals per month. Blue crabs are the dominant invertebrate fishery in the region; it is unclear from current data whether blue crabs are overfished. Other invertebrate fisheries that include Penaeid shrimp and stone crabs, do not appear to be overfished, although stone crabs are currently at their maximum level of harvesting

Section 4 examines the condition of aquatic life, encompassing plants, animals, and wetlands. Submerged aquatic vegetation (SAV), including commonly observed species like tape grass and widgeon grass, has experienced variations caused by drought and increased salinity. In 2008-2011, grass beds north of Palatka showed a declining trend in grass bed parameters; as well, increased salinity was correlated with decreased grass bed cover. Wetlands are vital to the Northeast Florida ecosystem, but trends in wetland acreage over time cannot be accurately established due to insufficient and inconsistent information. Diversity and abundance of macroinvertebrates, such as crabs, clams, snails, worms, insects, and shrimp, vary widely but in general are dominated by the more pollution-tolerant species. Salinity gradients are expected to affect macroinvertebrate communities significantly. Threatened and endangered species, namely the Florida manatee, wood stork, shortnose sturgeon, piping plover, Florida scrub jay, and eastern indigo snake, continue to be vulnerable due to habitat loss, increased boating traffic, drought, and threats to SAV. A total of 64 non-native aquatic species, ranging from microorganisms to animals like the red-eared slider turtle, are documented in the LSJRB.

Section 5 discusses the importance of contaminants in the LSJRB. The release of chemicals into the regional environment by various regional industries is documented for the first time, and the impact of four classes of sediment contaminants to the health of organisms in four regions of the river is examined. The EPA Toxics Release Inventory in 2010 showed that 95% of all chemicals released by regional entities are discharged into the atmosphere and consist largely of acid gases emitted by electric utilities. The portion of chemicals released directly into the waters of the LSJR is dominated by nitrates and manganese from the U.S. Department of Defense and the paper industry. In general, emissions of chemicals to the atmosphere halved between 2000 and 2010 while discharges into surface waters have remained fairly constant. The sediment contaminant classes evaluated include polycyclic aromatic hydrocarbons (PAHs), metals, polychlorinated biphenyls (PCBs), and pesticides that contain chlorine. The analysis was based on comparisons between concentrations reported in sediments and concentrations that cause biological effects in sediment organisms. Currently, metals and PAHs cause the most toxicity to sediment-dwelling organisms in the LSJRB. However, the decline of emissions of metals and PAHs into the regional atmosphere in the last decade may improve conditions. Furthermore, plans are underway for

mercury to be regulated via a statewide or regional TMDL. PCBs are present throughout the LSJRB at concentrations that may harm very sensitive organisms. Older, banned pesticides are found throughout the basin, but they are usually at low levels that do not contribute substantially to the overall toxic stress on the river. The shipping areas of the river show elevated levels of PAHs while urban-industrial Jacksonville has PAH and metal concentrations typical of other urban, industrial rivers. Other areas of concern include several tributaries which contain very high concentrations of multiple contaminants.

Section 6 is a new section describing aquatic toxicology of PAHs, metals, PCBs, and pesticides. PAH toxicity affects reproductive capacity of organisms and causes narcosis in fish. Metals typically cause an organism to undergo a disruption of ion and water balance, leading to death. PCBs have caused reproductive failure in numerous species. Pesticides have also been implicated in reproductive failure as well as neurotoxicity.

The Fifth State of the River Report is available in PDF format at http://www.sjrreport.com, along with a digital archive of cited references posted August 15, 2012, and previous editions of the report.

LIST OF ABBREVIATIONS AND ACRONYMS

AEF American Eagle Foundation
AKA Also Known As
ATSDR Agency for Toxic Substances & Disease Registry
BMAP Basin Management Action Plan
BOD Biochemical Oxygen Demand
CCA Chromated Copper Arsenate
CDC Center for Disease Control
CDOM Colored Dissolved Organic Material
CFR Code of Federal Regulations
COJ City of Jacksonville
CSA Continental Shelf Associates
CWA Clean Water Act
DDD dichlorodiphenyldichloroethane
DDE dichlorodiphenyldichloroethylene
DDT dichlorodiphenyltrichloroethane
DEP Florida Department of Environmental Protection
DO Dissolved Oxygen
DRI Development of Regional Impact
EPA U.S. Environmental Protection Agency
EPB Jacksonville Environmental Protection Board
FDHSMV Florida Department of Highway Safety & Motor Vehicles
FDOH Florida Department of Health
FDOT Florida Department of Transportation
FWC Florida Fish & Wildlife Conservation Commission
FWRI Fish and Wildlife Research Institute
GDNR Georgia Department of Natural Resources
GEA Gross External Abnormalities
GIS Geographic Information System
HAB Harmful Algal Bloom
HSDC Highest Single Day Count (of manatees)
HMW High Molecular Weight
ICW Intracoastal Waterway
JAXPORT Port of Jacksonville, Florida
JU Jacksonville University
LMW Low Molecular Weight
LSJR Lower St. Johns River
LSJRB Lower St. Johns River Basin
MOL Mitsui O.S.K. Lines
MPP Manatee Protection Plan
MS4 Municipal Separate Storm Sewer System
NAP Non-Algal Particulates
NAS Nonindigenous Aquatic Species
NAS JAX Naval Air Station Jacksonville
NMFS National Marine Fisheries Service
NOAA National Oceanic & Atmospheric Administration
NPDES National Pollutant Discharge Elimination Program
NRC National Research Council
NPS National Park Service
PAHs Polyaromatic Hydrocarbons
PCBs Polychlorinated Biphenyls
PEL Probable Effects Level
PLRG Pollutant Load Reduction Goal
OCPs Organochlorine Pesticides
SAV Submerged Aquatic Vegetation
sd standard deviation
SJR St. Johns River
SSAC Site-Specific Alternative Criteria
SJRWMD St. Johns River Water Management District
STORET STOrage and RETrieval (EPA Database)
SWIM Surface Water Improvement and Management
TAC Technical Advisory Committee
TEL Threshold Effects Level
TMDL Total Maximum Daily Load
TNC The Nature Conservancy
TSI Tropic State Index
UDS Ulcerative Disease Syndrome
UNF University of North Florida
USACE U.S. Army Corps of Engineers
USDA U.S. Department of Agriculture
USGS U.S. Geological Survey
USFWS U.S. Fish and Wildlife Service
WBID Water Body Identification Number
WHO World Health Organization
WSEA Jacksonville Water & Sewer Expansion Authority
WWII World War II
WWTF Waste Water Treatment Facility

Table of Contents

1. Background

1.1. Introduction to the River Report

This *State of the River Report for the Lower St. Johns River Basin* was written by a team of academic researchers from Jacksonville University (JU), University of North Florida (UNF) and Valdosta State University (VSU). This report has undergone an extensive review process including local stakeholders and an expert review panel with the expertise and experience in various disciplines to address the multi-faceted nature of the data.

The *State of the River Report* was funded through the Environmental Protection Board (EPB) of the City of Jacksonville, Florida, and the River Branch Foundation. The report comprises one component of a range of far-reaching efforts initiated by Jacksonville Mayors John Delaney and John Peyton and continued by Mayor Alvin Brown and the *River Accord* partners (including the St. Johns River Water Management District (SJRWMD), JEA, Jacksonville Water and Sewer Expansion Authority (WSEA; until 2011), and the Florida Department of Environmental Protection (DEP) to inform and educate the public regarding the status of the Lower St. Johns River Basin (LSJRB), Florida (Figure 1.1).

1.1.1. Purpose

The *State of the River Report's* purpose is to be a single clear, concise document that evaluates the current ecological status of the Lower St. Johns River Basin (LSJRB) based on a vast amount of scientific information.

1.1.2. Goals and Objectives

The overarching goal of the *State of the River Report* is to summarize the status and trends in the health of the LSJRB through comprehensive, unbiased, and scientific methods.

The tangible objectives of the report project include the design, creation, and distribution of a concise, easy-to-understand, and graphically pleasing document for the general public that explains the current health of the LSJRB in terms of water quality, fisheries, aquatic life, and contaminants.

Secondary objectives include the production of a baseline record of the status of the St. Johns River that can serve as a benchmark for the public to compare the future health of the river. This baseline information can be used by the public and policymakers to focus management efforts and resources on areas that need the most improvement first and to gauge the success of current and future management practices.

1.1.3. River Health Indicators and Evaluation

The *State of the River Report* describes the health of the LSJRB based on a number of broad indicators in four major categories:

- WATER QUALITY
  - Dissolved Oxygen (DO)
  - Nutrients (Nitrogen & Phosphorus)
  - Turbidity
  - Algal Blooms
  - Bacteria (Fecal Coliform)
  - Metals
  - Tributaries
  - Groundwater
- FISHERIES
  - Finfish Fisheries
  - Invertebrate Fisheries
- AQUATIC LIFE
  - Submerged Aquatic Vegetation
  - Wetlands
  - Macroinvertebrates
  - Threatened and Endangered Species
  - Non-native Aquatic Species
- CONTAMINANTS
  - Chemical Releases in the LSJR Region
  - Polyaromatic Hydrocarbons (PAHs)
  - Metals
  - Polychlorinated Biphenyls (PCBs)
  - Pesticides
- AQUATIC TOXICOLOGY

The *State of the River Report* is based on the best available data for each river health indicator listed above. How each indicator contributes to, or signals, overall river health is discussed in terms of its 1) *Current Status,* and 2) the *Trend* over time.

The *Current Status* for each indicator is based on the most recent data and is designated as "satisfactory" or "unsatisfactory." In some cases, this designation is defined by whether the indicator meets State and Federal minimum standards and guidelines.

The *Trend* is derived, where possible, from statistical analyses of the best available scientific data for each indicator and reflects historical change over the time period analyzed. The *Trend* ratings for each indicator are designated as "conditions improving," "conditions stable," "conditions worsening," or "uncertain." The *Trend* rating does not consider initiated or planned management efforts that have not yet had a direct impact on the indicator. Statistical tests to indicate trends vary with each indicator and are described in each section.

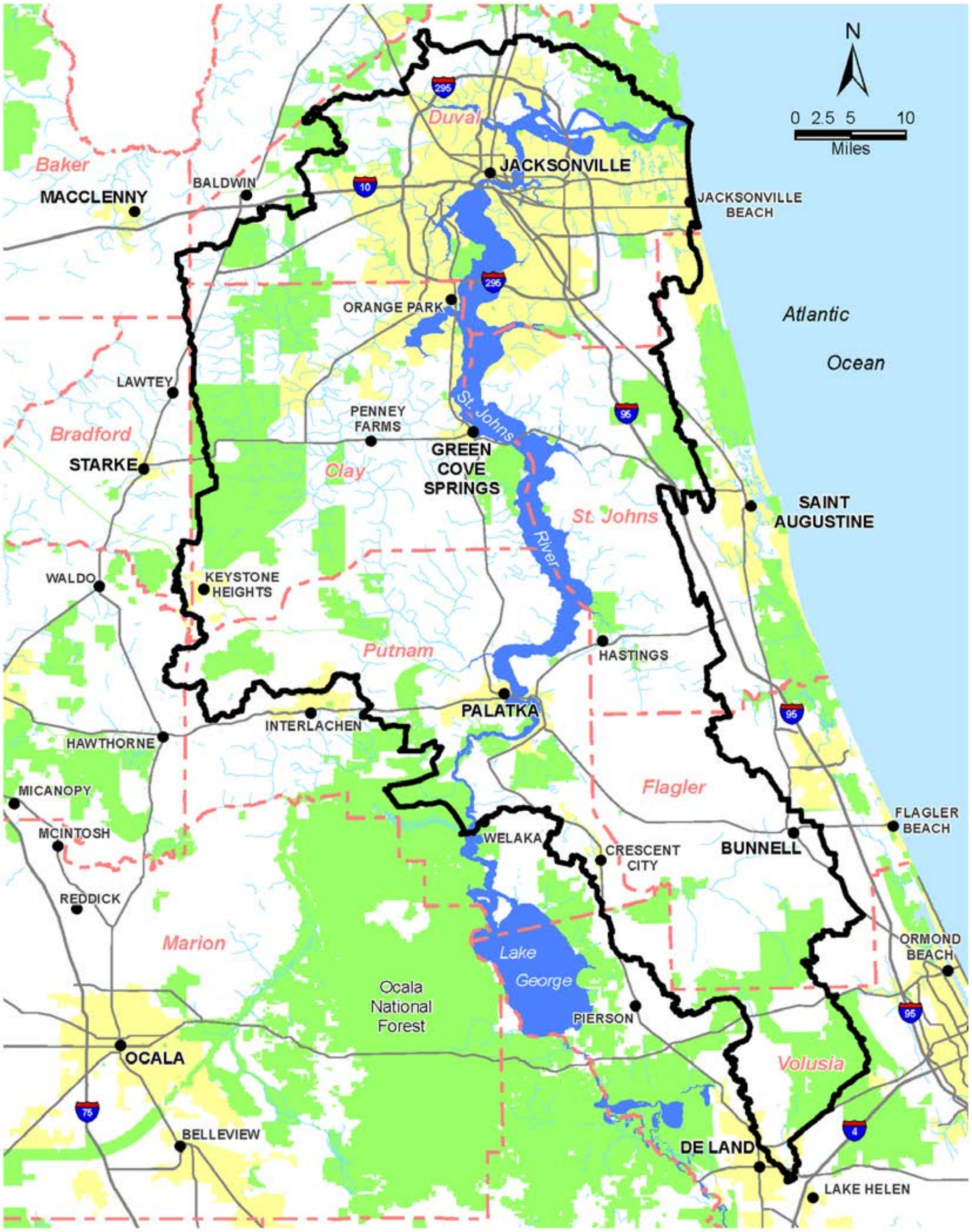


Figure 1.1 Geopolitical Map of the Lower St. Johns River Basin, Florida (outlined in black).

1.2. St. Johns River Basin Landscape

The LSJRB in Northeast Florida has long been recognized as a treasured watershed - providing enormous ecological, recreational, socioeconomic, and aesthetic benefits. However, during recent years, it has also been recognized as a threatened watershed, which is critically in need of resource conservation, water quality improvement, and careful management.

1.2.1. Geopolitical Boundaries

For management purposes, the entire St. Johns River watershed is commonly divided into five basins: the Upper Basin (southern, marshy headwaters in east central Florida), the Middle Basin (the area in central Florida where the river widens, forming Lakes Harney, Jesup, and Monroe), the Lake George Basin (the area between the confluence of the Wekiva River and St. Johns River and that of the Ocklawaha River and the St. Johns River), the Lower Basin (the area in Northeast Florida), and the Ocklawaha River Basin (the primary tributary for the St. Johns River). The LSJRB is the focus of this State of the River Report.

As a constant, this Report defines the LSJRB in accordance with the SJRWMD definition: "the drainage area for the portion of the St. Johns River extending from the confluence of the St. Johns and Ocklawaha rivers near Welaka to the mouth of the St. Johns River at Mayport" (**SJRWMD 2008**; Figure 1.1).

The LSJRB includes portions of nine counties: Clay, Duval, Flagler, Putnam, St. Johns, Volusia, Alachua, Baker, and Bradford (**Brody 1994**). Notable municipalities within the Lower Basin include Jacksonville, Orange Park, Green Cove Springs, and Palatka (Figure 1.1).

The LSJRB covers a 1.8 million-acre drainage area, extends 101 miles in length, and has a surface area of water approximately equal to 115 square miles (**Adamus, et al. 1997**; **Magley and Joyner 2008**).

1.2.2. Existing Land Uses

The LSJRB, including all aquatic and adjoining terrestrial habitats, consists of approximately 68% uplands and 32% wetlands and deepwater habitats (Figure 1.2, see Appendix 1.A. for acres and definitions of categories).

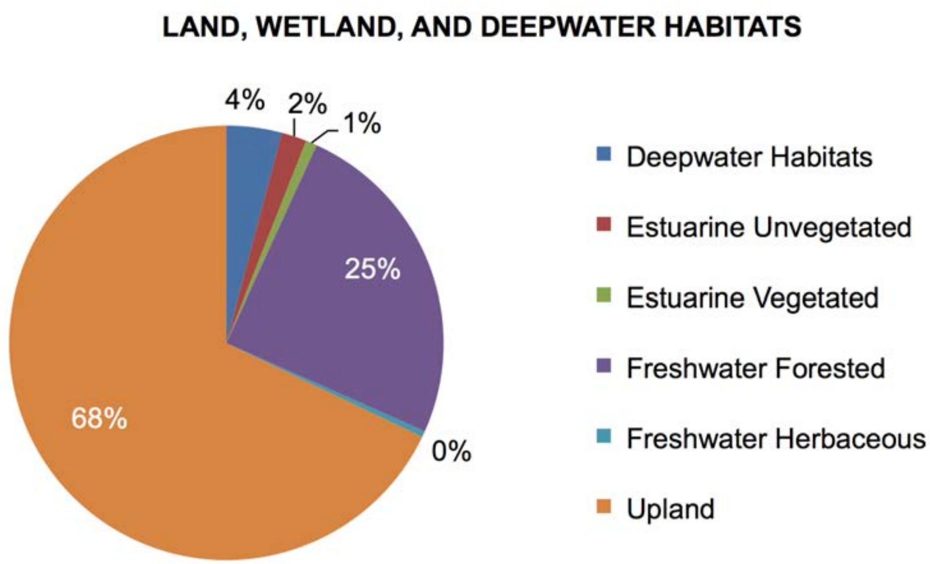


*Figure 1.2 Total percentages for land, wetland, and deepwater habitats within the Lower St. Johns River Basin, Florida. (Source: SJRWMD Wetlands and Deep Water Habitats GIS Maps, 1972-1980; **SJRWMD 2007a**)*

Within the LSJRB in 2004, the dominant land covers were upland forests (35%) and wetlands (24%), and 18% was considered urban and built-up (Figure 1.3). Since the 1970s, the proportion of the total basin designated as upland forests and agriculture has decreased, while the proportion designated as urban and built-up has increased (see Appendix 1.B.; **SJRWMD 2007a**).

1.2.3. Ecological Zones

The LSJRB is commonly divided into three ecological zones based on expected salinity differences (Figure 1.3; **Hendrickson and Konwinski 1998**; **Malecki, et al. 2004**). The ***mesohaline riverine zone*** is the most northern ecological zone in the LSJRB, stretching from the Atlantic Ocean to the Fuller Warren Bridge. The mesohaline riverine zone is typically deeper and well-mixed with an average salinity of 14.5 ppt and a fast flow rate. South of the Fuller Warren Bridge, the St. Johns River widens into a broad, shallow, slow-moving, tidal area called the ***oligohaline lacustrine zone***. This zone extends from the Fuller Warren Bridge to Doctors Lake and has an average salinity of 2.9 ppt. South of Doctors Lake to the confluence of the St. Johns and Ocklawaha rivers near Welaka, the LSJRB transitions into the ***freshwater lacustrine zone***. This zone stretches through the Middle and Upper Basins of the St. Johns River as well. The freshwater lacustrine zone is lake-like, typically not influenced by oceanic tides, and has an average salinity of 0.5 ppt.

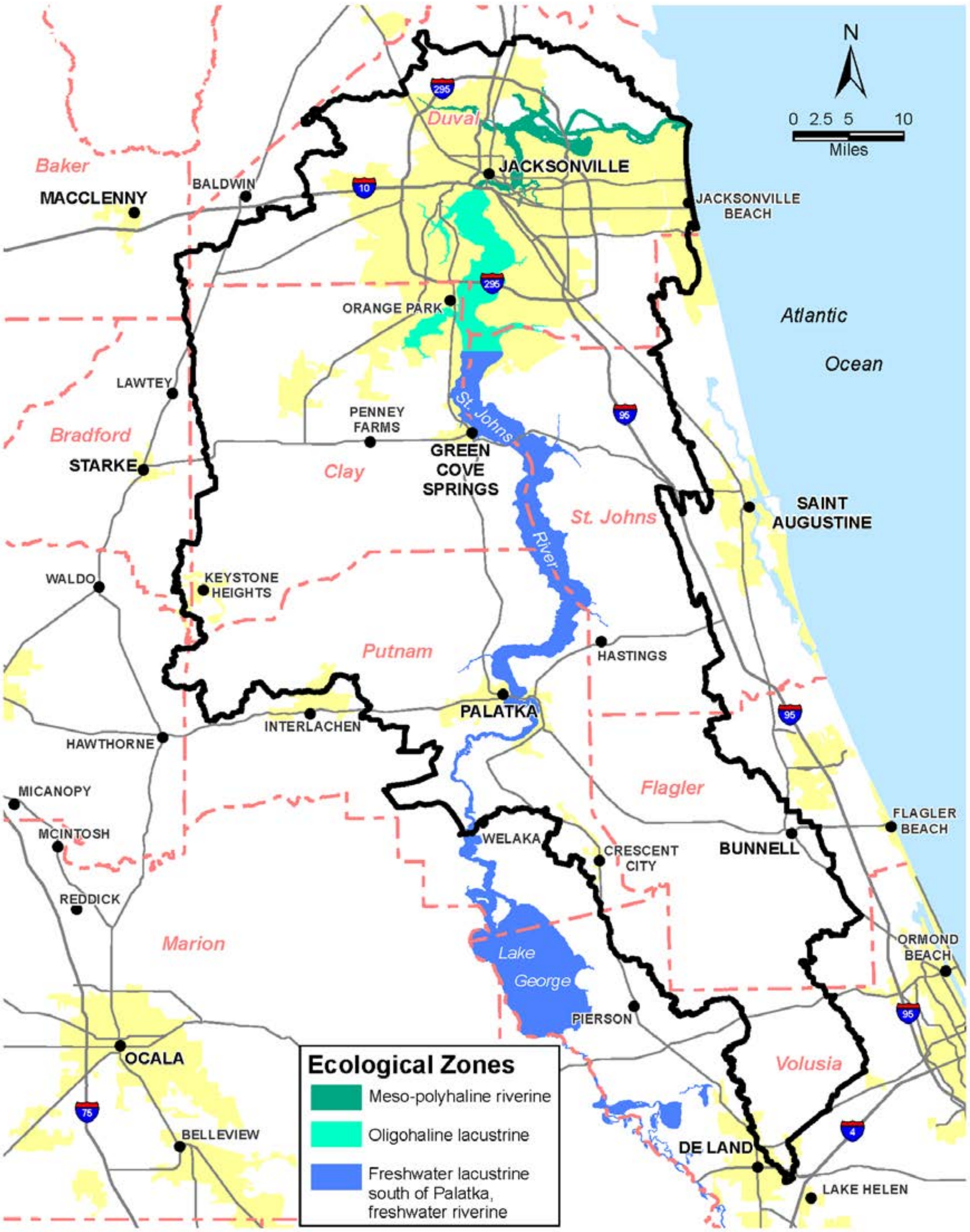


Figure 1.3 Map of the Ecological Zones of the Lower St. Johns River Basin

1.2.4. Unique Physical Features

The St. Johns River is unique and distinctive due to a number of exceptional physical features.

The St. Johns River is the longest river in Florida. Stretching 310 miles and draining approximately 9,430 square miles, this extensive river basin drains about 16% of the total surface area of Florida (**DeMort 1990**; **Morris IV 1995**).

The St. Johns River flows northward. The result of this northward flow is that the *Upper* St. Johns actually lies south of the *Lower* St. Johns (**DeMort 1990**). The St. Johns River is one of the few rivers in North America to flow north.

The St. Johns River is one of the flattest major rivers in North America. The headwaters of the St. Johns River are less than 30 feet above sea level. The river flows downward on a slope ranging from as low as 0.002% (**Benke and Cushing 2005**) to about 1% (**DeMort 1990**). This slope is governed by the exceptionally flat terrain of the drainage basin and most of the decline occurs in the first 100 miles of the river. In fact, the river bottom at the mouth of Lake Harney is below sea level (**Bowman 2009**). This extremely low gradient contributes to a typically slow flow of the St. Johns River. This holds back drainage, slows flushing of pollutants, and intensifies flooding and pooling of water along the river creating numerous lakes and extensive wetlands throughout the drainage basin (**Durako, et al. 1988**). The retention time of the water, and its dissolved and suspended components, in the river is on the order of three to four months (**Benke and Cushing 2005**). High retention times of pollutants have severe impacts on water quality.

The Lower St. Johns River is a broad, shallow system. The average width of the Lower St. Johns River from Lake George to Mayport is one mile, although the flood plain reaches a maximum width of ten miles (**Miller 1998**). The average depth of the river is 11 feet (**Dame, et al. 2000**). The variability in width of the river can result in different water flow patterns and conditions on opposing banks of the river (**Welsh 2008**).

The St. Johns River receives saltwater from springs. Several naturally salty springs feed into the St. Johns River Drainage Basin. The most significant inputs of salty spring water originate from Blue Springs, Salt Springs, Silver Glen Springs, and Croaker Hole Spring (**Campbell 2009**). Inputs from these salty springs cause localized areas of elevated salinity (>5 ppt) in otherwise freshwater sections of the river (**Benke and Cushing 2005**). The amount of flow from springs is highly variable and dramatically affected by droughts (**Campbell 2009**).

The St. Johns River drains into the Atlantic Ocean. The average discharge of water at the mouth of the St. Johns River is 8,300 cubic feet per second (**Miller 1998**) or 5.4 billion gallons per day (**Steinbrecher 2008**). However, this flow rate is dwarfed by the volume of tidal flow at the mouth of the river, which is estimated to be approximately seven times greater than the freshwater discharge volume (**Anderson and Goolsby 1973**). This difference often causes "reverse flow," or a southward flow, up the river. Reverse flow has been detected as far south as Lake Monroe, 160 miles upstream, and is influenced as much by weather conditions as by ocean tides (**Durako, et al. 1988**). Natural water sources for the St. Johns River are direct rainfall, rainfall from runoff, underground aquifers, and springs. Continual input from springs and aquifers supplies the river with water that discharges into the Atlantic Ocean, despite drought periods or seasonal declines in rainfall (**Benke and Cushing 2005**). Water quality depends on the primary sources of water at any given time.

The salinity of the St. Johns River is heavily affected by seasonal rainfall patterns and episodic storm and drought events. In general, there is a predictable seasonal pattern of freshwater input from rainfall into the Lower St. Johns River, with the majority of rain falling during the wet season from June to October (**Rao, et al. 1989**). However, this seasonal pattern of rainfall can be overridden by less predictable, episodic storm events, i.e., hurricanes, tropical storms, or nor'easters, or drought events, like the droughts of the early 1970s, the early 1980s, 1989-1990, and 1999-2001 (**DEP 2010f**). In turn, surges of freshwater from heavy rainfall tend to reduce salinity levels in the river. Increased salinity occurs during periods of drought, when there is a deficit of fresh rainwater into the river. Thus, rainfall can prompt a chain of events in the river, where changes in salinity lead to impacts on aquatic plants and animals. Simplified examples of several sequenced events are illustrated below (Figure 1.4).

The Lower St. Johns River is a tidal system with an extended estuary. The tidal range at the mouth of the river at Mayport, Florida is about six feet (**McCully 2006**). The Atlantic Ocean's tide heights are large compared to the slope of the St. Johns River, and at times, can produce strong tidal currents and mixing in the northernmost portion of the river. The St. Johns River is typically influenced by tides as far south as Lake George, 106 miles upstream (**Durako, et al. 1988**). During times of drought when little rainwater enters the system or extreme high tides, river flow-reversal can occur as far

south as Lake Monroe, 160 miles upstream (**Durako, et al. 1988**). Tidal reverse flows occur daily in the LSJR, and net reverse flows, as much influenced by winds as by tides, can occur for weeks at a time (**Morris IV 1995**).

The St. Johns River can be influenced by wind direction and wind speed. South winds blowing to the north accelerate the flow of water toward the ocean, if the flow is not opposed by a strong tidal current. Similarly, north winds can push river water back upstream (**Welsh 2008**). Strong sustained north winds from fall nor'easters or summer hurricanes can push saltwater up the river into areas that are usually fresh. Although considered a natural occurrence, reverse flow of the river can impact flora and fauna with low salinity tolerances and cause inland areas to flood.

The St. Johns River is a dark, blackwater river. Southern blackwater rivers are naturally colored by dissolved organic matter derived from their connections to swamps, where plant materials slowly decay and release these organic materials into the water (**Brody 1994**). The Dissolved Organic Matter (DOM) limits light penetration, and therefore photosynthesis, to a very shallow layer near the surface of the river.

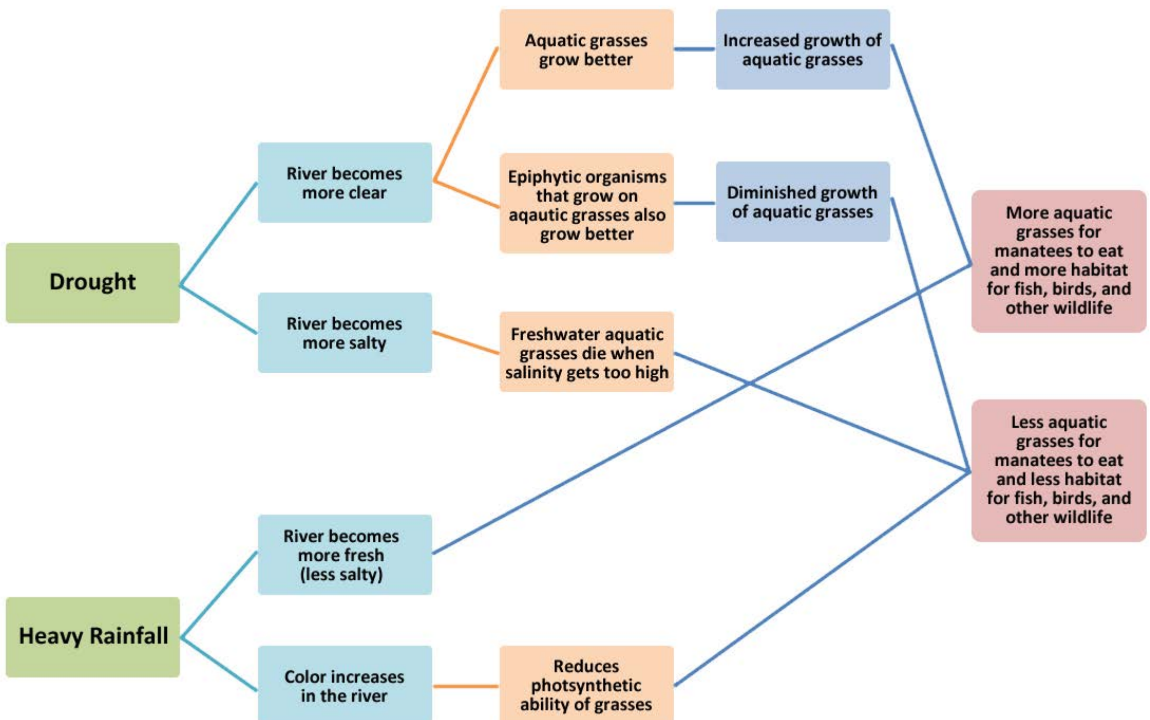


Figure 1.4 Simplified example of sequenced events that can occur in the Lower St. Johns River Basin stimulated by changes in rainfall.

1.3. Human Occupancy of the Region (pre-1800s)

1.3.1. Native Americans

The Lower Basin of the St. Johns River watershed has been occupied, utilized, and modified by humans for over 12,000 years (**Miller 1998**). As the Ice Age ended, the first Floridians were the Paleo Indians. They inhabited a dry, wide Florida hunting and gathering for food and searching for fresh water sources. Gradually, the glaciers melted, sea levels rose, and Florida was transformed. By approximately 3,000 years ago, the region resembled the Florida of today with a wet, mild climate and abundant freshwater lakes, rivers, and springs (**Purdum 2002**). The conditions were favorable for settlement, and early Indians occupied areas throughout the state. In fact, historians estimate that as many as 350,000 Native Americans were thriving in Florida (including 200,000 Timucua Indians in southeast Georgia and northern Florida), when the first French and Spanish explorers arrived in the 1500s (Figure 1.4; **Milanich 1995**; **Milanich 1997**).

The Native Americans that occupied much of the Lower St. Johns River Basin were part of a larger group collectively known as the Timucua Indians. Actually a group of thirty or more chiefdoms sprinkled in villages throughout north Florida and southeastern Georgia, the Timucua Indians were bound to one another linguistically by a common language called Timucua (**Granberry 1956; Granberry 1993**). The Timucua language was spoken throughout the Lower St. Johns River Basin north of Lake George and its tributary the Oklawaha River (**Milanich 1996**). By the 17th-century, the Spaniards

living in the region referred to a distinct group of Timucua known as the Mocama (translates to "the sea") (**Ashley 2010**). The Mocama Indians spoke a unique dialect of the Timucua language called Mocama. They lived near the mouth of the St. Johns River and on the Sea Islands of southeastern Georgia and northeastern Florida (St. Simons, Jekyll, Cumberland and Amelia Islands) as far back as A.D. 1000 (**Worth and Thomas 1995**). Evidence has suggested that the Mocama had extensive trading networks that stretched as far west as the Mississippi River (**Ashley 2010**). Archaeological evidence also suggests that the Mocama became a permanent settlement and cultivated maize for food, in addition to traditional hunting and gathering (**Thunen 2010**). The Timucua Indians did modify the land to their advantage, such as burning and clearing land for agriculture and constructing drainage ditches and large shell middens (**Milanich 1998**). But, by today's standards, these impacts on the landscape were small in scale and spread out over a vast terrain.

The numbers of Native Americans in Florida plummeted during the 16th and 17th centuries, as many were killed by European diseases or conflicts (**Davis and Arsenault 2005**). By the 1700s, the original Timucua population in Florida had vanished (Figure 1.5).

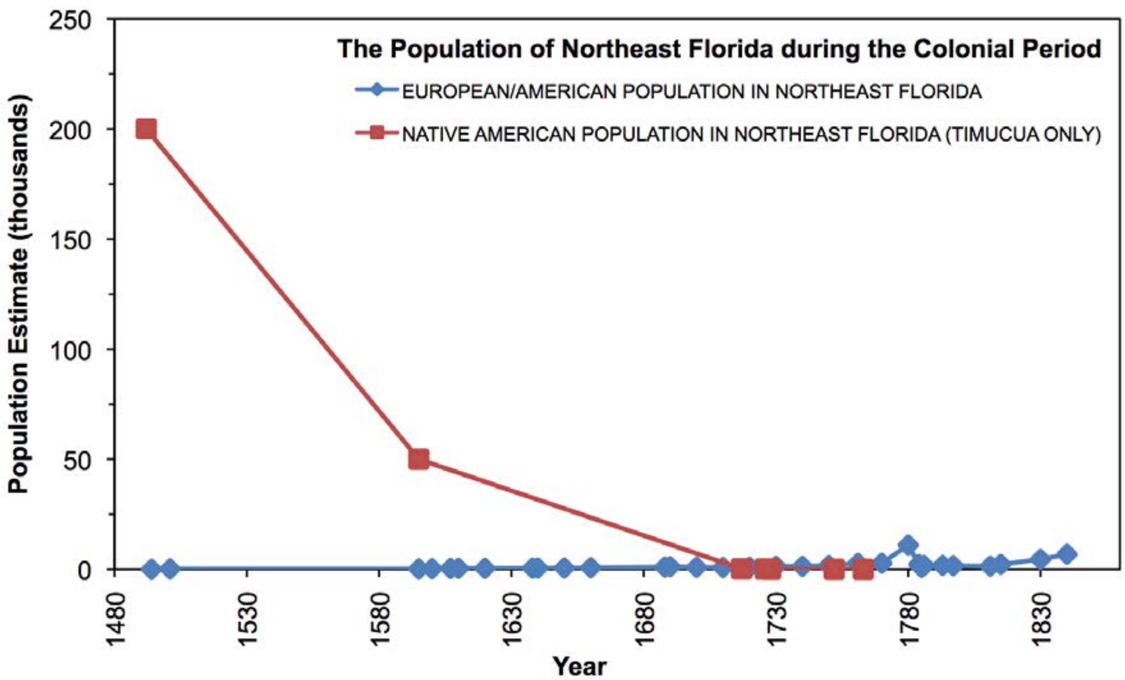


*Figure 1.5 The Population of Northeast Florida during the Colonial Period, 1492 to 1845. (Sources: Population estimates for the Timucua Tribe in Northeast Florida were taken from **Milanich 1997**, and "Northeast Florida" is defined as all lands inhabited by Timucua Indians. Population estimates for European Colonists were taken from **Miller 1998**, and "Northeast Florida" loosely includes settlers in "the basin of the northward-flowing St. Johns River from Lake George to the mouth, as well as the adjacent Atlantic Coast and the intervening coastal plain" (**Miller 1998**). Complete data table provided in Appendix 1.C.*

1.3.2. Europeans

The first permanent European colony in North America was Fort Caroline, founded in 1564 by the French near the mouth of the St. Johns River (**Miller 1998**). One year later, the Spanish conquered the French, and from 1565 to 1763, the still-wild territory of Florida flew the flag of Spain (**Schafer 2007**). The epicenter of the Spanish colony became St. Augustine, and few colonists ventured beyond the walls of the guarded city. In retrospect, the footprint of these Spanish settlers on Florida was light. Apart from introducing non-native citrus, sugarcane, and pigs (the wild boars of today), they altered the environmental landscape very little along the St. Johns River watershed as compared to what was to come (**Warren 2005**; **Schafer 2007**).

In 1763, the British took control of Florida. Two years later, John Bartram, appointed as botanist to His Majesty George III of England, surveyed the natural resources of Florida that were now available for English use and benefit (**Stork 1769**). On this journey, John Bartram was accompanied by his son William, who would later become famous in his own right for discoveries recorded during his solitary travels through the southern colonies in the 1770's (**Bartram 1998**). The writings of this father and son provide evidence that the First Spanish Period left behind a wild and largely untouched land full of untapped resources and potential.

During the 20 years that the British occupied Florida, landscape modifications for colonization and agriculture were intensive. Large tracts of land were cleared for plantations intended for crop exportation, and timber was harvested and exported for the first time (**Miller 1998**). During the American Revolution, Florida became a haven for British loyalists, and the population of Florida ballooned from several thousand to 17,000 (**Milanich 1997**). The Spanish reacquired Florida in 1783, most of the British settlers left the area, and the state population declined again to several thousand (Figure 1.5). The Spanish continued plantation farming within the LSJRB, but did not exploit the land as successfully as the British (**Miller 1998**). Spain held Florida until the region was legally acquired by the United States in 1821. At this time, exploration and exploitation of the St. Johns River Basin began in earnest.

1.4. Early Environmental Management (1800s to 1970s)

The history of environmental management of the St. Johns River watershed, and water resources in Florida in general, is a complex, convoluted, but relatively short history. Major milestones in environmental management in Florida have taken place within just the last century, with much of the story occurring during our living memory (Table 1.1). The story of water management in Florida unfolds as a tale of lessons learned, a shift from reigning to restoring, from consuming to conserving.

Like the tides, management efforts in the watershed have surged and retracted over the last 100 years. Many landmark policies and programs have been initiated in response to environmental changes deemed intolerable by the public and the policymakers who represent them.

Noticeable, but small-scale, changes occurred in the St. Johns River Basin during pre-Columbian times, when Northeast Florida was occupied by the Timucua Indians (**Milanich 1998**). It was not until the Colonial Period, particularly during the British occupation in the late 1700s, that the environment experienced large-scale alterations. Such landscape modifications as the conversion of wetlands to agriculture and the clearing of forests for timber surged again in the mid-1800s after Florida was granted statehood (**Davis and Arsenault 2005**).

Most of the earliest changes to the landscape of the LSJRB were utilitarian in purpose, but the late 1800s and early 1900s were fraught with changes driven by the profitable, even whimsical, tourist industry. Tourists were fascinated with promotional accounts describing this land of eternal summer, filled with wild botanicals and beguiling beasts (**Miller 1998**). The growing village of Jacksonville became the initial portal to Florida, and a thriving tourist industry flourished as steamboats began to shuttle tourists up the St. Johns River. By 1875, Jacksonville was the most important town in Florida (**Blake 1980**). First tourists, and then developers and agricultural interests, were enticed to the rich and largely unexploited resource that was early Florida (**Blake 1980**). By the early 1900s, the population of Northeast Florida was increasing at a slow steady rate (see Figure 1.6).

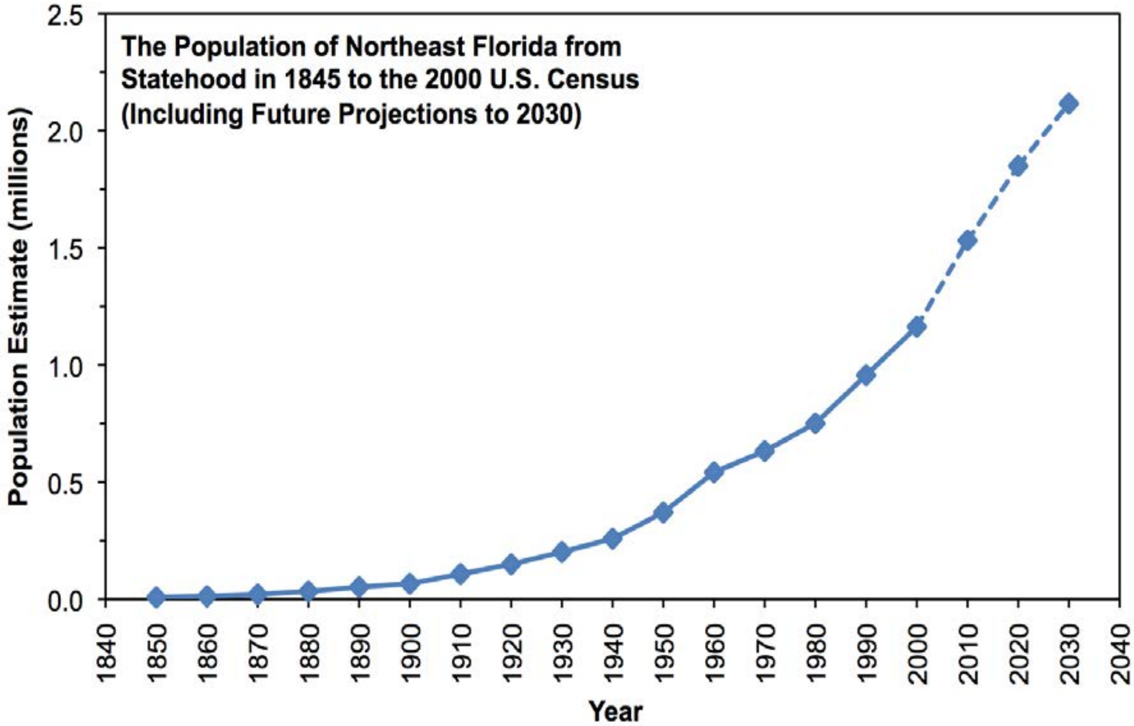


Figure 1.6. The Population of Northeast Florida from the time Florida was granted statehood to the 2000 U.S. Census including Future Population Projections to 2030. ("Northeast Florida" includes population counts from Clay, Duval, Flagler, Putnam, and St. Johns counties. Sources: Population counts for the years 1850-1900 were provided by Miller 1998. Counts from 1900-1990 were extracted from ***Forstall 1995****, and 2000 counts from the* ***USCB 2000****.*
*Note: U.S. Census data was not available for Flagler County in 1900 and 1910.Population estimates for 2010, 2020, and 2030 were extracted from the Demographic Estimating Conference Database (****EDR 2012****), updated August 2007. Complete data table provided in Appendix 1.C.*

Impacts to the environment mirrored the steady population growth during the early 1900s. Entrepreneurs, investors, and government officials in Florida at this time were thoroughly focused on the drainage and redirection of water through engineering works (**Blake 1980**).

The immigration of new settlers was moderate during Florida's first century as a state, because the region still proved inhospitable and rather uninhabitable to the unadventurous. Not only was the region full of irritating, disease-carrying mosquitoes, Florida was just too hot and humid. But, that all changed when air conditioners for residential use became affordable and widespread after WWII (**Davis and Arsenault 2005**). Florida's population exploded around the 1950s and has continued to skyrocket ever since (**USCB 2000**; Figure 1.6).

By the 1960s, a century of topographical tinkering was taking its toll. Ecosystems across Florida were beginning to show signs of stress. Sinkholes emerged in Central Florida (the Upper Basin of the St. Johns River) indicating a serious decline in the water table (**SJRWMD 2010a**). Flooding, particularly during storm events, was destructive and devastating. Loss of wetlands peaked during this time, as wet areas were rapidly converted to agriculture or urban land uses (**Meindl 2005**). Water works, such as the Kissimmee Canal and Cross Florida Barge Canal, continued into the 1960s, but public opposition against such projects was mounting (**Purdum 2002**).

During 1970-71, Florida experienced its worst drought in history, and the attitudes toward water began to shift from control and consumption to conservation (**Purdum 2002**). During 1972, the "Year of the Environment," the Federal and State governments passed a number of significant pieces of environmental legislation (see Table 1.1). The laws of the early 1970s, such as the National Environmental Policy Act, Endangered Species Act, and Clean Water Act, showcased a change in our approach to resource use and our attitudes regarding ecosystem services, nature, and the environment. From this time forward, environmental management began to take a shift towards consideration of the outcomes of our actions.

The Clean Water Act (CWA) and its companion act, the Clean Air Act, have been some of the most enduring and influential pieces of legislation from the 1970s. The CWA addressed key elements that affect the long-term health of the nation's rivers and streams. The CWA requires states to submit a list of their "impaired" (polluted) waters to the U.S.

Environmental Protection Agency (EPA) every two years (or the EPA will develop the list for them). States determine impairment primarily by assessing whether water bodies maintain certain categories of use, e.g. fishable and swimmable. Whether a use is impacted or not is typically based on whether the water body meets specific chemical and biological standards or exhibits safety risks to people. Once a state has an approved or "verified 303(d)" list of impaired waters, it must develop a management plan to address the issues that are causing the impairment. This process of identifying and improving impaired waters through the CWA has played a major role in modern environmental management from the 1980s through the 2000s.

Table 1.1 Timeline of environmental milestones, Lower St. Johns River Basin, Florida: From European colonization to 2000s

DATE	EVENT
1765-1766	During the British occupation of Florida, John Bartram, the "Botanist to the King," and his son William Bartram toured the St. Johns River (**Davis and Arsenault 2005**).
1773-1777	Naturalist William Bartram chronicled his travels up the St. Johns River producing detailed descriptions of pre-statehood, Northeast Florida. "Bartram's observations remain an invaluable tool for environmental planning—restoring paradise—in northeastern Florida" (**Davis and Arsenault 2005**).
1821	Adams-Onis Treaty: United States legally acquired Florida (**Blake 1980**).
1835-1842	Second Seminole War: Many steamboats were first brought to the St. Johns River for combat with the Indians, but continued to operate out of Jacksonville for civilian purposes after the war (**Buker 1992**).
1845	Florida granted statehood.
1850	Swamp and Overflowed Lands Act: stated that Florida could have from the Federal government any swamp or submerged lands that they successfully drained (**Leal and Meiners 2002**).
1868	Florida's first water pollution law established a penalty for degrading springs and water supplies (**SJRWMD 2007a**).
1870-1884	Famed author of *Uncle Tom's Cabin*, Harriet Beecher Stowe, wintered in Mandarin and wrote essays extolling the beauties of the St. Johns River and attracting tourists to Florida (**Blake 1980**).
1870s	Increasing number of tourists visited Florida via steamboats up the St. Johns River.
1875	Jacksonville was the most important city in Florida (**Blake 1980**).
1880	Construction of jetties at the mouth of the St. Johns River was started in order to stabilize the entrance of the shipping channel. They were not finished until 1921 (**Davis 1925**).
1884	Water hyacinth introduced into the St. Johns River near Palatka (**McCann, et al. 1996**).
1895	The Port of Jacksonville shipping channel was deepened to 15-ft (**GLD&D 2001**).
1896	Water hyacinth had spread throughout most the St. Johns River Lower Basin and was hindering steamboat navigation, causing changes in water quality and biotic communities by severely curtailing oxygen and light diffusion, and reducing water movement by 40-95% Palatka (**McCann, et al. 1996**).
1906	The Port of Jacksonville shipping channel was deepened to 24-ft (**GLD&D 2001**).
1912	Intracoastal Waterway from Jacksonville to Miami was completed (**SJRWMD 2007a**).
1916	The Port of Jacksonville shipping channel was deepened to 30-ft (**GLD&D 2001**).
1935	Cross-Florida Barge Canal construction was initiated.
1937	Federal government completed deepening of the St. Johns River to 30 feet deep from the ocean to Jacksonville.
1937	Construction was suspended on Cross-Florida Barge Canal.
1945	River and Harbor Act of 1945 authorized the construction of the Dames Point Fulton Cut. This 34-ft-deep cut-off channel eliminated bends in the shipping channel at Dames Point, Browns Creek and Fulton (St. Johns Bluff). The straightening of the channel shortened the distance between the City of Jacksonville and the ocean by about 1.9 miles.
1950s	Bacteria pollution was first documented in the St. Johns River (largely due to the direct discharge of untreated sewage into the river).
1952	The Port of Jacksonville shipping channel was deepened to 34-ft (**GLD&D 2001**).
1964	Construction continued on Cross-Florida Barge Canal.
1966-1967	Sinkholes occurring in Central Florida (within the Upper Basin of the St. Johns River) indicating a serious drop in the water table (**Purdum 2002**).
Dec. 5, 1967	The City of Jacksonville received a letter from the Florida Air and Water Pollution Control Commission and State Board of Health, who "ordered the City within 90 days to furnish plans and an implementation schedule to end the disposal of 15 million gallons per day of raw sewage into the St. Johns River and its tributaries" (**Crooks 2004**).

1967-1968	Voters approved the consolidation of the Jacksonville and Duval County local governments.
1968	Initial flooding of the Rodman Reservoir. The Rodman Dam was completed and dammed the lower Ocklawaha River.
1970	National Environmental Policy Act: required Federal agencies to consider the environmental impacts and reasonable alternatives of their proposed actions.
1970s	"Cleanup of the St. Johns River was impressive, but many of its tributaries remained heavily polluted; landfills were opened, but indiscriminate littering of wastes continued; polluting power plants and fertilizer factories closed, but other odors remained" (**Crooks 2004**). "Discharges occur to river of primary treated effluent or raw sewage. Periodic blue-green algal blooms and fish kills" (**DEP 2002**).
1970-1971	Florida experiences its worst drought in history (**Purdum 2002**).
1971	Construction stopped on Cross-Florida Barge Canal.
1972	Florida Water Resources Act: established regional water management districts and created a permit system for allocating water use.
1972	Federal Clean Water Act: required that all U.S. waters be swimmable and fishable.
1972	Land Conservation Act: authorized the sale of state bonds to purchase environmentally imperiled lands.
1972	Environmental Land and Water Management Act: initiated the "Development of Regional Impact" program and the "Area of Critical State Concern" program.
1972	Comprehensive Planning Act: called for the development of a state comprehensive plan.
1972	Marine Mammal Protection Act: prohibited the killing or hurting of marine mammals in U.S. waters.
1973	Endangered Species Act: conservation of threatened and endangered plants and animals and their habitats.
Mar. 1973	"Press release announced that the St. Johns River south of the Naval Air Station to the Duval County Line at Julington Creek had been deemed safe for water contact sports" (**Crooks 2004**).
1973-1974	The U.S. Army Corps of Engineers and DEP (then the Dept. of Natural Resources) implemented "maintenance control" of invasive aquatic plants (namely water hyacinth). Maintenance control replaced crisis management and kept water hyacinth populations at the lowest feasible level.
1977	The Federal government funded a shipping terminal on Blount Island (**Crooks 2004**).
1977	Seventy-seven sewage outfalls closed, and the St. Johns River became safe for recreational use again (**Crooks 2004**). Movement to regional wastewater treatment systems providing higher levels of treatment than before.
Jun. 18, 1977	St. Johns River Day Festival marked the completion of the St. Johns River cleanup, and there were reports of some types of aquatic life returning to the river (**Crooks 2004**).
1978	The Port of Jacksonville shipping channel was deepened to 38-ft (**GLD&D 2001**).
Mid - late 1980s	"Outbreak of Ulcerative Disease Syndrome in fish occurs from Lake George to mouth of river. Exhaustive studies are conducted, but specific cause is not determined" (**DEP 2002**).
1987	Surface Water Improvement and Management (SWIM) Act: Recognized the Lower St. Johns River Basin as an area in need of special protection and restoration (**SJRWMD 2007a**).
1988	"The Florida Department of Environmental Regulation delegated authority to permit dredging and filling of wetlands to the St. Johns River Water Management District" (**SJRWMD 2007a**).
1988	"With funding from the SWIM program, the St. Johns River Water Management District began restoration of the Upper Ocklawaha River Basin and the Lower St. Johns River Basin" (**SJRWMD 2007a**).
1989	SJRWMD publishes the first Surface Water Improvement and Management (SWIM) Plan for the LSJRB.
1990s	"Blue-green algal blooms occur in freshwater portion of the river" (**DEP 2002**).
1991	The Florida Times-Union began a monthly series of investigative reports entitled "A River in Decline." This series reported: 17% of septic tanks were failing. In 1990, 47% of tributaries failed to meet appropriate health standards for fecal coliform. In 1990, 50% of privately owned sewage treatment plants violated local regulations. 80% of pollutants in Jacksonville's waterways could be attributed to stormwater runoff (**Crooks 2004**).
Early 1990s	The Florida Department of Environmental Regulation "downgraded formerly pristine areas of Julington and Durbin Creeks in southern Duval County from GOOD to FAIR water quality due to stormwater, sewage, and other runoffs from the rapidly growing suburb of Mandarin." Half of the wetlands in this area were destroyed during this time period (**Crooks 2004**).
Late 1990s	Blooms of an exotic freshwater, toxin-producing, blue-green algae called *Cylindrospermopsis* occurred (**DEP 2002**).
1993	SJRWMD releases first revision of the Surface Water Improvement and Management (SWIM) Plan for the LSJRB.
1997	The Lower St. Johns River Basin Strategic Planning Session (the "River Summit") led to the development of a 5-year "River Agenda" plan.

Sept. 17, 1998	DEP submitted the 1998 303(d) list of impaired water bodies to the EPA for approval. The 1998 303(d) list included 53 water bodies in the LSJR.
1998	Several Florida environmental groups brought a lawsuit against the U.S. Environmental Protection Agency (EPA) for its failure to enforce the Total Maximum Daily Load (TMDL) provisions in the Federal Clean Water Act (*Florida Wildlife Federation, Inc., et al. v. Browner*, (N.D. Fla. 1998) (No. 4:98CV356).
July 30, 1998	St. Johns River is designated as an American Heritage River (**DEP 2002**).
Nov. 24, 1998	The EPA Region 4 approved the Florida 1998 303(d) list of impaired waters.
1999	Lawsuit against the EPA settled with a Consent Decree, which required the EPA and the Florida Department of Environmental Protection (DEP) to begin implementation of the TMDL provisions of the Clean Water Act. The Consent Decree required EPA to establish TMDLs if the State of Florida does not (13-year schedule to establish TMDLs).
1999	Florida legislature enacted the Watershed Restoration Act (Florida Statute Section 403.067) to provide for the establishment of Total Maximum Daily Loads (TMDLs) for pollutants of impaired waters as required by the Clean Water Act.
1999	DEP formed a local stakeholders group to review the TMDL model inputs.
April 26, 2001	Florida adopted a new science-based methodology to identify impaired waters as c. 62-303, F.A.C. (Identification of Impaired Surface Waters Rule).
June 10, 2002	Following an unsuccessful rule challenge by various individuals and environmental groups (Fla. DOAH case No. 01-1332R), the Impaired Surface Waters Rule (c. 62-303, F.A.C.) became effective.
July 2002	DEP appointed the Lower St. Johns River TMDL Executive Committee to advise the Department on the development of TMDLs and a Basin Management Action Plan (BMAP) for the nutrient impairments in the main stem of the LSJR.
Dec. 3, 2002	Four Florida environmental groups filed suit in federal court against the U. S. EPA for failure of EPA to approve/disapprove Florida's Impaired Waters Rule as being consistent with the Clean Water Act (*Florida Public Interest Research Group Citizen Lobby, Inc., et al., v U.S. EPA et al*.)
2002	The U.S. Army Corps of Engineers began the St. Johns River Harbor Deepening Project (**JAXPORT 2008**). The dredging project deepened "the outer 14 miles of the St. Johns River federal channel from the mouth of the river to Drummond Point" (**GLD&D 2001**). The channel was deepened to 41 ft. in areas where there is a limestone rock bottom. The main shipping channel is maintained at this depth presently.
2002	The hydrodynamic model for the LSJR Main Stem TMDL is completed.
2003	"River Summit 2003" takes place, and the River Agenda is revised.
Sept. 4, 2003	DEP determined that most of the freshwater and estuarine segments of the LSJR were impaired by nutrients, and a verified list of impaired waters for the LSJR was adopted by Secretarial Order.
Sept. 30, 2003	The nutrient TMDL for the LSJR was originally adopted by Florida (Rule 62-304.415, F.A.C.).
April 27, 2004	Florida's nutrient TMDL was initially approved by the EPA Region 4.
Aug. 18, 2004	St. Johns Riverkeeper and Linda Young (Southeast Clean Water Network) filed suit against the EPA on the basis that the targets upon which the TMDL were based were not consistent with the existing Class III marine dissolved oxygen criterion.
Oct. 21, 2004	EPA found that the nutrient TMDL for the LSJR did not implement the applicable water quality standards for dissolved oxygen and rescinded its previous approval of the nutrient TMDL for the LSJR.
May 24, 2005	The Executive Committee identified the water quality credit trading approach for the Basin Management Action Plan (BMAP).
June-July 2005	DEP developed draft TMDL documents for Butcher Pen Creek Fecal Coliform TMDL, Durbin Creek Fecal Coliform TMDL, Cedar River Fecal and Total Coliform TMDL, Goodbys Creek Fecal Coliform TMDL, Hogan Creek Fecal Coliform TMDL, Miramar Creek Fecal Coliform TMDL, Moncrief Creek Fecal and Total Coliform TMDL, Ribault River Fecal Coliform TMDL, Williamson Creek Fecal Coliform and Total Coliform TMDL, Wills Branch Fecal and Total Coliform TMDL.
July 2005	The Tributaries Assessment Team was formed to assess potential sources of fecal coliform in the tributaries.
Early fall 2005	Large clumps of surface scum, caused by the toxic blue-green algae *Microcystis aeruginosa*, bloomed from Lake George to Jacksonville. Some samples exceeded World Health Organization recommended guidelines (**SJRWMD 2007a**).
2005-2008	U.S. Army Corps of Engineers is extending the harbor deepening from Drummond Point to JAXPORT's Talleyrand Marine Terminal from 38 ft. to a maintained depth of 40 ft.
2006	Blooms of algae continue in the St. Johns River. "Algal blooms are caused by a combination of hot, overcast days, calm wind and excessive nutrients in the water, such as fertilizer runoff, stormwater runoff and wastewater" (**SJRWMD 2007a**).
Jan. 23, 2006	EPA established a new nutrient TMDL for the LSJR that would meet the dissolved oxygen criteria.
May 25, 2006	Site-Specific Alternative Criteria (SSAC) for dissolved oxygen in the LSJR (Florida Administrative Code 62-302.800(5)) was adopted by the Florida Environmental Regulation Commission and submitted to the EPA for approval. The SSAC was developed by DEP in cooperation with the SJRWMD.
July 6, 2006	The monitoring plan discussions for the LSJR Main Stem BMAP began.

July 13, 2006	St. Johns Riverkeeper and Clean Water Network filed a suit in Federal Court challenging the EPA's approval of rule 62-302.800 (in effect, the Site-Specific Alternative Criteria). (*St. Johns Riverkeeper, Inc., et al. v. United States Environmental Protection Agency, et al.*, No. 4:2006cv00332 (N.D. Fla.))
July 28, 2006	The Tributaries Technical Working Group was formed to address fecal coliform impairments in 55 LSJR water bodies.
July 2006	The River Accord: A Partnership for the St. Johns established.
Sept. 2006	The project collection process for the LSJR Main Stem BMAP started, which provides the list of efforts that will implement the TMDL reductions and restore the river to water quality standards.
Oct. 10, 2006	EPA approved Site-Specific Alternative Criteria (SSAC) for dissolved oxygen in the marine portion of the St. Johns River.
2007	The U.S. Army Corps started studying the impacts of blasting and dredging to deepen the navigation channel to a maintained 45 feet from the mouth of the river to Talleyrand Terminals (**USACE 2007**). Completion of the study is expected in 2010.
Feb. 1, 2007	The Executive Committee determined the LSJR Main Stem BMAP load allocation approach, which assigned reduction responsibilities to wastewater plants, industries, agriculture, cities and counties with urban stormwater sources, and military bases with stormwater sources.
April 2007	The St. Johns River Water Management District launched the Lower St. Johns River Basin public awareness initiative, "The St. Johns: It's Your River," in order to help the public understand their personal impacts to the river and their responsibility for the river's condition (**SJRWMD 2007a**).
August 2007	Urban stormwater loads were identified and quantified by local jurisdictions for the LSJR Main Stem BMAP.
Sept. 2007	DEP proposed a Plan for Development of a Statewide Total Maximum Daily Load for Mercury (**DEP 2007b**).
Oct. 2007	The first draft of the LSJR Main Stem BMAP was completed and presented to the Executive Committee and Stakeholders Group.
2008	EPA and DEP are expected to develop TMDLs for a number of verified impaired segments of the LSJR Main Stem for several parameters (including nutrients, iron, lead, copper, nickel, cadmium, and silver).
Jan. 17, 2008	EPA approves the LSJR nutrient TMDLs based on the recently adopted Site-Specific Alternative Criteria (SSAC).
April 2, 2008	DEP revised the Surface Water Quality Standards (c. 62-302.530, F.A.C.) to match the EPA approved list of TMDLs for nutrients in the LSJR.
July 17, 2008	Earthjustice (representing the Florida Wildlife Federation, Conservancy of Southwest Florida, Environmental Confederation of Southwest Florida, St. Johns Riverkeeper, and Sierra Club) filed a lawsuit against the EPA "for failing to comply with their nondiscretionary duty to promptly set numeric nutrient criteria for the state of Florida as directed by section 303(c)(4)(B) of the Clean Water Act" (**Earthjustice 2008**; (*Florida Wildlife Federation, Inc., et al. v. Johnson et al.,* 4:2008cv00324 (N.D. Fla.)).
July 27, 2008	The second Anniversary of the River Accord: A Partnership for the St. Johns.
July 30, 2008	The 10th anniversary of the American Heritage River designation for the St. Johns River.
Aug. 6, 2008	The first "State of the River Report for the Lower St. Johns River Basin "was released by researchers at Jacksonville University and the University of North Florida.
August 2008	The Lower St. Johns River Basin Surface Water Improvement and Management (SWIM) Plan Update was released. The plan was prepared by SJRWMD, Wildwood Consulting, Inc., and the Lower St. Johns River Technical Advisory Committee (TAC). The plan outlines milestones, strategies, and objectives to meet goals associated with water quality, biological health, sediment management, toxic contaminants remediation, public education, and intergovernmental coordination.
Sept. 17-18, 2008	SJRWMD held a technical symposium on the preliminary findings of studies examining the cumulative effects of proposed surface water withdrawals on the water resources of the St. Johns and Ocklawaha rivers.
Oct. 8, 2008	The National Research Council agreed to provide technical review of the SJRWMD's assessment of potential cumulative impacts to the St. Johns River from proposed surface water withdrawals (**SJRWMD 2010a**).
Oct. 17, 2008	DEP finalized Lower St. Johns River Nutrients TMDL.
Oct. 27, 2008	The final Basin Management Action Plan (BMAP) for the Implementation of Total Maximum Daily Loads for Nutrients was adopted by the DEP for the Lower St. Johns River Basin Main Stem. The BMAP was developed by the Lower St. Johns River TMDL Executive Committee in cooperation with the DEP, SJRWMD, local industries, cities, counties, environmental groups, and many other stakeholders.
Oct. 29, 2008	DEP released Drafts of the Lower St. Johns River Basin Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the adopted 2004 303(d) master list of impaired waters.
Jan. 16, 2009	EPA issued a formal determination under the Clean Water Act that numeric nutrient water quality criteria are necessary in Florida, and the DEP released plans to accelerate its efforts to adopt numeric nutrient criteria into State regulations. It is expected that proposed numeric nutrient criteria for freshwater lakes and flowing waters will be available within one year, and estuaries and coastal waters within two years.
Jan. 28, 2009	DEP finalized Fecal Coliform TMDLs for ten LSJR water bodies.
March 20, 2009	DEP released revised Drafts of the Lower St. Johns River Basin Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the adopted 2004 303(d) master list of impaired waters.

May 19, 2009	DEP released FINAL Drafts of the Lower St. Johns River Basin Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the adopted 2004 303(d) master list of impaired waters.
June 19, 2009	DEP proposed draft Nutrient, Lead, Fecal Coliform, and/or Dissolved Oxygen TMDLs for ten LSJR water bodies.
Aug. 7, 2009	DEP finalized Fecal Coliform TMDLs for eleven more LSJR water bodies.
Sept. 1, 2009	DEP finalized Fecal Coliform TMDL for one more LSJR water body.
Oct. 19, 2009	DEP finalized Fecal Coliform TMDLs for six more LSJR water bodies.
Dec. 2009	DEP released the Draft Lower St. Johns River Tributaries Basin Management Action Plan (BMAP), which addresses ten fecal coliform TMDLs for Newcastle Creek, Hogan Creek, Butcher Pen Creek, Miller Creek, Miramar Creek, Big Fishweir Creek, Deer Creek, Terrapin Creek, Goodbys Creek, and Open Creek. This plan was developed collaboratively by the City of Jacksonville, JEA, Duval County Health Department, Florida Department of Transportation, Tributary Assessment Team, the community Basin Working Group Stakeholders, and Florida Department of Environmental Protection (Tributary BMAP I - **DEP 2009b**).
Jan. 15, 2010	EPA provided amendments to DEP's FINAL Drafts of the Lower St. Johns River Basin Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the adopted 2004 303(d) master list of impaired waters.
March 10, 2010	DEP proposed draft Fecal Coliform TMDLs for five more LSJR water bodies.
May-December 2010	A major bloom of *Aphanizomenon* and a major fish kill with unusual characteristics occurred in early summer and these events were followed in mid-summer by an additional bloom of *Microcystis* and other cyanobacteria species and a second more typical fish kill. Unusually high dolphin mortalities occurred May-September. Massive drifts of an unusual, persistent foam occurred from mid-summer through the fall.
Aug. 2010	The Lower St. Johns River Tributaries Basin Management Action Plan (BMAP), which addresses fecal coliform TMDLs for fifteen tributaries, was adopted. These fifteen tributaries include Craig Creek, McCoy Creek, Williamson Creek, Fishing Creek, Deep Bottom Creek, Moncrief Creek, Blockhouse Creek, Hopkins Creek, Cormorant Branch, Wills Branch, Sherman Creek, Greenfield Creek, Pottsburg Creek, Upper Trout River, and Lower Trout River. This plan was developed collaboratively by the City of Jacksonville, JEA, Duval County Health Department, Florida Department of Transportation, Tributary Assessment Team, the Basin Working Group Stakeholders, and the Florida Department of Environmental Protection (Tributary BMAP II - **DEP 2010a**).
Nov. 3, 2010	NOAA designated LSJR dolphin mortalities during the summer of 2010 an Unusual Marine Mammal Mortality Event initiating a multi-agency task force to investigate the causes. Investigations are in progress while the event has been declared closed because the unusual number of mortalities has stopped.
Nov. 14, 2010	EPA Administrator Lisa P. Jackson signed final "Water Quality Standards for the State of Florida's Lakes and Flowing Waters" (inland waters rule). The final standards set numeric limits, or criteria, on the amount of nutrient pollution allowed in Florida's lakes, rivers, streams and springs. This rule is set to be effective March 6, 2012.
Feb. 2011	DEP released final TMDLS for Arlington River for nutrients and Mill Creek for dissolved oxygen and nutrients.
Feb. 2011	DEP released the 2010 Progress Report For the Lower St. Johns River Main Stem Basin Management Action Plan (BMAP).
March 2011	DEP released the first progress report on the December 2009 BMAP addressing fecal coliform TMDLs in ten LSJR tributaries.
April 2011	DEP released final TMDLs for lead in Black Creek and Peters Creek.
April 22, 2011	DEP requested EPA to withdraw its January 2009 determination that numeric nutrient criteria are necessary in Florida; to repeal November 2010 rulemaking establishing numeric criteria for inland streams, lakes, and springs; and to refrain from establishing any future numeric criteria.
May 10, 2011	SJRWMD issued to JEA a single consumptive use permit that consolidated 27 individual permits and allows groundwater withdrawals of up to 142 million gallons per day in 2012 and up to 155 million gallons per day in 2031 if key conditions are met.
June 13, 2011	EPA sent an initial response to FDEP's petition (see April 22, 2011 above). In their response, EPA is prepared to withdraw the federal inland standards if FDEP adopts, and EPA approves, their own protective and scientifically sound numeric standards.
March 5, 2012	EPA promulgated an extension of the effective date of the "Water Quality Standards for the State of Florida's Lakes and Flowing Waters" (inland waters rule) by 4 months to July 6, 2012. (The extension does not affect or change the February 4, 2011 date for the site-specific alternative criteria provision.) This extension affords the State additional time to finalize their own rule establishing numeric nutrient criteria for the State and submit it for EPA review.
May 17, 2012	EPA proposed to extend the July 6, 2012 effective date of the "Water Quality Standards for the State of Florida's Lakes and Flowing Waters; Final Rule" (inland waters rule) by three months to October 6, 2012.
July 6, 2012	DEP releases a revised draft of the State of Florida Mercury TMDL (**DEP 2012c**)

1.5. Modern Environmental Management (1980s to 2000s)

The deluge of new environmental legislation in the 1970s caused a backlash during the 1980s from a property rights perspective (**Davis and Arsenault 2005**). At the same time, readily observable symptoms of environmental degradation continued to surface. The St. Johns River began having periodic blooms of blue-green algae, lesions in fish, and fish kills (**DEP 2002**). Each of these conditions was a visible expression of degraded water quality in the river and represented changes that were not acceptable to the public and policymakers.

Since the 1990s, water quality improvements have been achieved in Florida through the seesawing efforts of policymakers and public and private stakeholders (Table 1.1). The policymakers push on the legislative side (via governmental regulatory agencies), while public/private interests push on the judicial side (via lawsuits in the courts). The last two decades have been marked by this oscillation between lawsuits and laws. The result has been incremental and adaptive water quality management.

1.6. Implementation of the Total Maximum Daily Load (TMDL) provisions of the Clean Water Act (CWA)

For years one aspect of the CWA was overlooked until an influential court decision in 1999. Several Florida environmental groups won a significant lawsuit against the EPA, pushing the agency to enforce the Total Maximum Daily Load (TMDL) provisions in the Federal CWA. For many water bodies, including the LSJR, the development and implementation of a TMDL is required by the CWA as a means to reverse water quality degradation. In the TMDL approach, state agencies must determine for each impaired water body: 1) the sources of the pollutants that could contribute to the impairment 2) the capacity of the water body to assimilate the pollutant without degradation and 3) how much pollutant from all possible sources, including future sources, can be allowed while attaining and maintaining compliance with water quality standards. From this information, agency scientists determine how much of a pollutant may be discharged by individual sources, and calculate how much of a load reduction is required by that source (Pollutant Load Reduction Goal or "PLRG"). Once the required load reductions are determined, then a Basin Management Action Plan ("BMAP") must be developed to implement those reductions. Monitoring programs must also be designed to evaluate the effectiveness of load reduction on water quality.

Since 1999, the EPA, DEP, SJRWMD, and numerous public and private stakeholders have been working through this TMDL/BMAP process to reduce pollution into the LSJR and its tributaries (Appendix 1.D). In 2004, the verified 303(d) list of LSJR impairments requiring TMDLs consisted of a total of 153 impairments in 87 water bodies or segments of water bodies (some water bodies have multiple parameters that cause impairment) (Table 1.2; **DEP 2009d**). These impaired statuses were due primarily to unsatisfactory levels of dissolved oxygen, coliforms, nutrients, and metals (Figure 1.7). In May 2009, the DEP released "Final Verified Lists of Impaired Waters and Delist Lists of the Lower St. Johns River Basin Group 2 Cycle 2 Basins – Lower St. Johns River Basin" (dated May 19, 2009). These lists updated the adopted 2004 303(d) master list of impaired waters. The 2009 final verified list of LSJR impairments requiring TMDLs consists of a total of 123 impairments in 97 water bodies or segments of water bodies (Table 1.3; **DEP 2010m**). These impaired statuses are due primarily to unsatisfactory levels of mercury, dissolved oxygen, fecal coliform, and nutrients (Figure 1.8). Amendments to Florida's Impaired Surface Waters Rule (Rule 62-303, F.A.C.) occurred in 2006, 2007, and 2008 (**DEP 2008b**; **DEP 2012b**). These amendments changed the water quality standards and account for some of the changes in both the number of water bodies and impairments on the 2009 final verified list (for complete list, see Appendix 1.D).

In response to these impaired water body designations, several TMDLs have already been adopted in the LSJRB, including those for nutrients in the main stem and fecal coliforms in the tributaries (Table 1.4). Where TMDLs have been adopted, BMAPs are either complete or in development. Typically, BMAPs to restore water quality are developed within 18 to 24 months after TMDLs are established. According to DEP, "the strategies developed in each BMAP are implemented into National Pollutant Discharge Elimination System (NPDES) permits for wastewater facilities and municipal separate storm sewer system (MS4) permits" (**DEP 2008b**). A main stem nutrient BMAP was completed in October 2008. In December 2009, the DEP released the BMAP for fecal coliform in the Lower St. Johns River Tributaries (**DEP 2009b**). This BMAP addressed ten tributaries for which TMDLs had been adopted in 2006 and 2009: Newcastle Creek, Hogan Creek, Butcher Pen Creek, Miller Creek, Miramar Creek, Big Fishweir Creek, Deer Creek, Terrapin Creek, Goodbys Creek, and Open Creek (**DEP 2009b**). In August 2010, DEP released the second BMAP to address fecal coliform in fifteen LSJR tributaries (Tributary BMAP II **DEP 2010a**).

Current and future efforts to improve the health of the LSJR (and other water bodies in Florida) will continue to focus on implementation of the TMDL provisions of the CWA. As this process presses forward, Florida's public and policymakers may continue to find themselves on the litigation-legislation seesaw, as both groups attempt to balance environmental concerns with an exploding population's desire to dwell and prosper in the Sunshine State.

Table 1.2 Summary of the 2004 verified 303(d) list of LSJR impaired water bodies or segments of water bodies requiring TMDLs.

2004 IMPAIRMENT	# WATER BODIES WITH IMPAIRMENT
CADMIUM	1
COPPER	6
DISSOLVED OXYGEN	33
FECAL COLIFORM	54
IRON	11
LEAD	5
MERCURY (FISH)	3
NICKEL	5
NUTRIENTS (CHLOROPHYLL A)	12
NUTRIENTS (HISTORIC CHLOROPHYLL A)	1
NUTRIENTS (TSI)	5
SELENIUM	1
SILVER	1
TOTAL COLIFORMS	15
TOTAL # IMPAIRMENTS = 153	**TOTAL # OF WATER BODIES = 87**

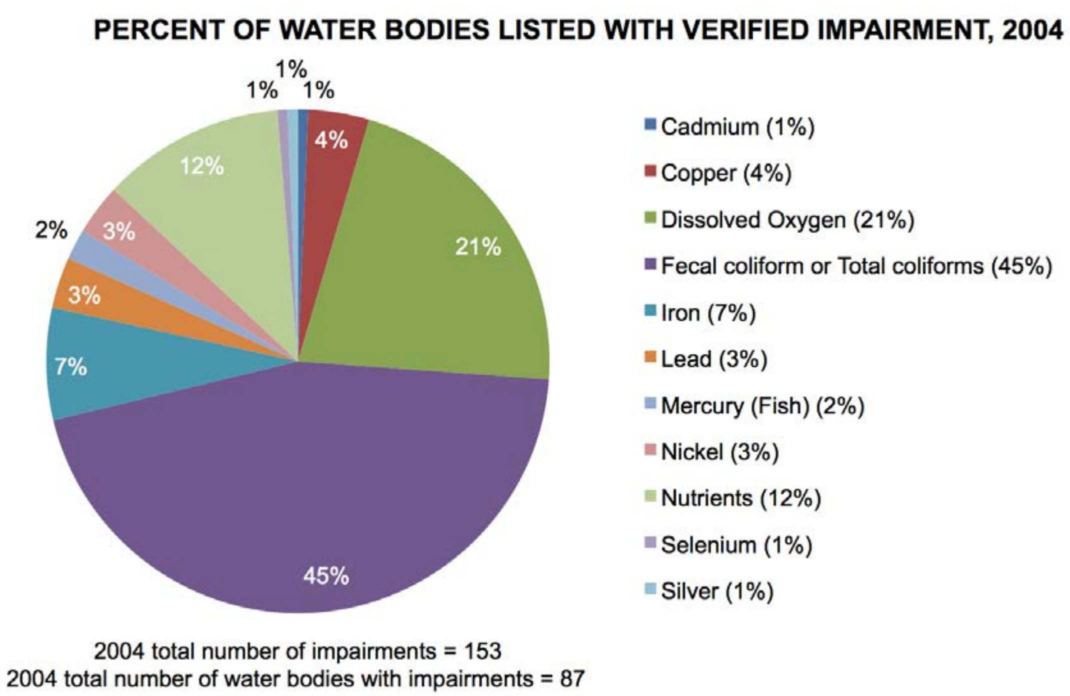


Figure 1.7 Percent of water bodies or segments of water bodies listed with various impairments in the Lower St. Johns River Basin on the 2004 verified list.

Table 1.3 Summary of the 2009 final verified 303(d) list of LSJR impaired water bodies or segments of water bodies requiring TMDLs (as of May 19, 2009). This summary does not include the proposed amendments to the list made by the U.S. EPA on January 15, 2010).

2009 IMPAIRMENT (Final Verified List dated May 19, 2009)	# WATER BODIES WITH IMPAIRMENT
DIOXIN	1
DISSOLVED OXYGEN	25
FECAL COLIFORM	21
IRON	2
LEAD	11
MERCURY (BASED ON FISH CONSUMPTION ADVISORY)	34
NUTRIENTS (CHLOROPHYLL-A)	16
NUTRIENTS (HISTORIC CHLOROPHYLL-A)	6
NUTRIENTS (HISTORIC TSI)	5
NUTRIENTS (TSI)	3
THALLIUM	1
TURBIDITY	1
TOTAL # IMPAIRMENTS = 123	**TOTAL # OF WATER BODIES = 97**

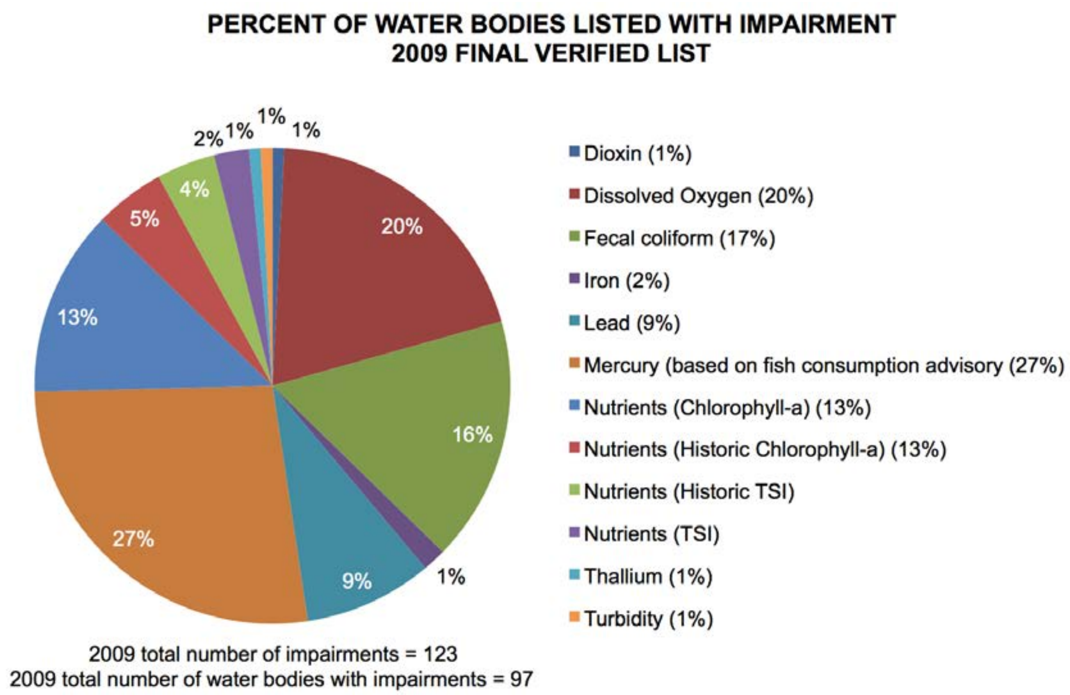


Figure 1.8 Percent of water bodies or segments of water bodies listed with various impairments in the Lower St. Johns River Basin in the proposed 2009 DRAFT verified list (as of May 19, 2009). This summary does not include the proposed amendments to the list made by the U.S. EPA on January 15, 2010).

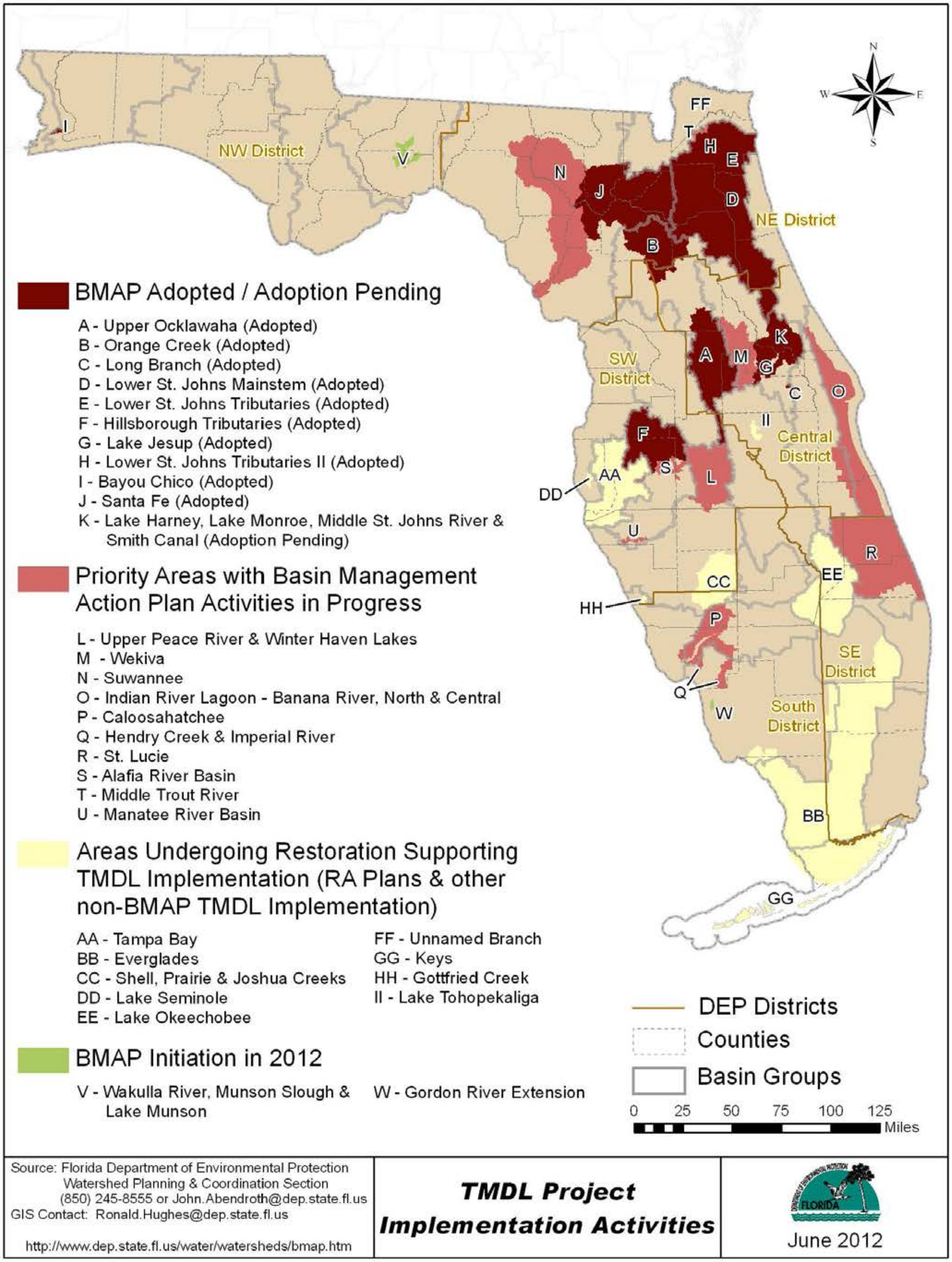


Figure 1.9. TMDL Project Implementation Activities of the DEP as of October 2011 (Source: ***DEP 2012d***

2. Water Quality

2.1. Overview

Water quality, more than any other measure of river health, cannot be reduced to a single factor, much less a single number. For example, some parameters vary as a function of time or tide, others vary by depth, and still others change slowly with the seasons or do not have a consistent pattern of change. Despite these variations, similarities exist in segments of the main stem of the LSJRB as well as among and within each tributary. To identify characteristically similar segments in each separate water body, under the CWA process, DEP has assigned a unique water body identification (WBID) number.

WBIDs are unique identifiers that offer an unambiguous method of referencing water bodies within the State of Florida. The CWA process mandates that each water body must be assessed for impairments for its stated uses, and if it is determined to be impaired for those uses, a Total Maximum Daily Load (TMDL) must be established to set maximum allowable levels which should comply with existing standards. The LSJR is a Florida Class III water body, with designated use(s) of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. For assessment purposes, DEP has divided the LSJRB into geographic polygons with a unique WBID for each watershed or stream reach. For example, the main stem of the LSJRB is divided into multiple segments (Figure 2.1).

In certain cases, the type and character of a water body may make it necessary to establish a special criterion for assessing the water quality of that water body. Florida's water quality standards also provide that a Site-Specific Alternative Criterion (SSAC) may be established where that alternative criterion is demonstrated, based on scientific methods, to protect existing and designated uses for a particular water body. As discussed in the background section and below, such a criterion has been established and EPA-approved for dissolved oxygen (DO) in the predominantly marine portion of the LSJRB.

The water quality of each tributary is strongly impacted by both the land use surrounding the tributary and the nature and extent of human impact. Thus, the tributaries of the LSJR vary in water quality impacts from agricultural to industrial and from urban to suburban to rural. Often, different parts of the same tributary will have changes in water quality that reflect changes in land use, industry and population along it. Part of the TMDL analysis is the identification of sources and categories of nutrients or pollutants in the watershed and of the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either "point sources" or "nonpoint sources".

Historically, point sources are defined as discharges that typically have a continuous flow via a specific source such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of point sources. Point sources are registered and permitted under the EPA's National Pollutant Discharge Elimination System (NPDES) program, and the 1987 changes to the Clean Water Act included a redefinition that added storm water and drainage systems, which were previously considered nonpoint sources under the permitted NPDES program.

The term "nonpoint sources" has been used to describe other intermittent, often rainfall-driven, diffuse sources of pollution, including runoff from urban land uses, runoff from agriculture, runoff from tree farming (silviculture), runoff from roads and suburban yards, discharges from failing septic systems, and even atmospheric dust and rain deposition. The Florida Legislature created the Surface Water Improvement and Management program (SWIM) as a way to manage and address nonpoint pollution sources. The program is outlined at **DEP 2008c**.

The required TMDL process for impaired waters considers and can require reductions to both these pollution source types in order to achieve water quality goals. For more about Florida's Watershed Management approach see **DEP 2010n**. In addition, a description of the Basin Management Action Plan (BMAP), which details actions to be taken in a specific basin, can be found at **DEP 2010b**. The status of Northeast District BMAP plans can be found at **DEP 2010j**.

Several aspects of water quality were not addressed in last year's report including, upstream sources, the interaction of living organisms and water quality, the impact of salinity (see section 1.2.4 above) and Trophic State Index (TSI) as a measure of nutrient-induced imbalance in the LSJR ecosystem. Some discussion of TSI can be found below under Dissolved Oxygen (next section) and under the Turbidity section.

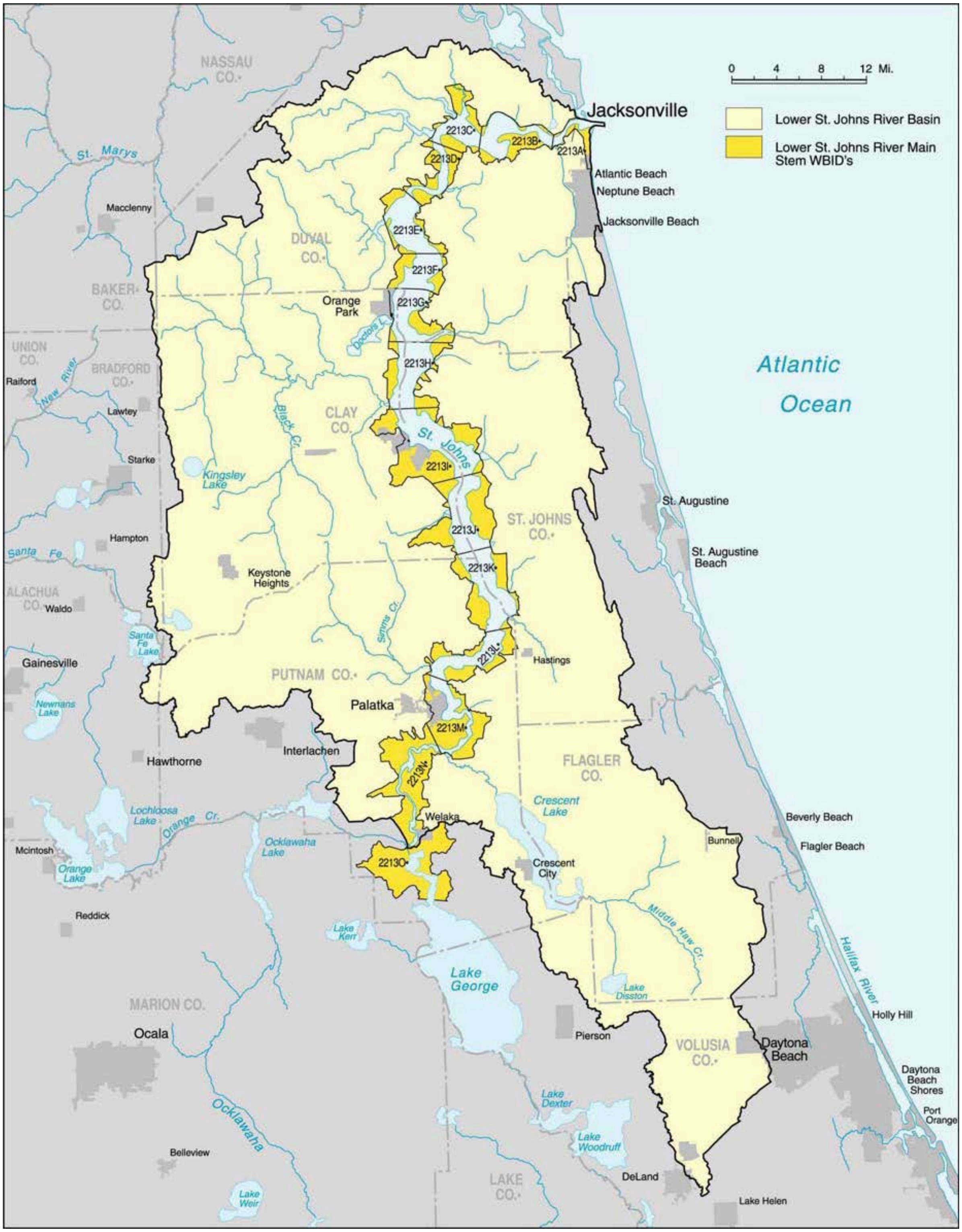


*Figure 2.1 Lower St. Johns River Main Stem Water Body Identification (WBID) Numbers (Figure 3, p5 in **Magley and Joyner 2008**)*

One complicating factor is that many water bodies in Florida are referred to as "blackwater" and may have low DO even without any significant pollutant or excess nutrient; thus, many of these streams and lakes naturally exhibit low DO values. Approximately 30 changes in the "Draft Delist List" of 20 March 2009 are for low DO under Florida's Impaired Waters Rule (IWR), but are being delisted as the "Natural Conditions" of the water body.

Trophic state is an indicator of the productivity and balance of the food chain in an ecosystem. A good discussion of trophic state is found on the website of the Institute of Food and Agricultural Sciences at the University of Florida (**IFAS 2009**). While high TSI values indicate high primary (plant) productivity, often that is part of an unbalanced ecosystem with very high nutrient and a large algal biomass that has large fluctuations in DO. In such a case oxygen is produced in daylight by plant photosynthesis, but used up by bacterial consumption of decaying plant material at night.

Substantially increased continuous real-time data collection efforts are strongly recommended as a top priority over the next decade as the Clean Water Act (CWA) mandated mitigation efforts begin to improve the water quality of the LSJR. However, current fiscal constraints in the state may preclude any immediate improvement. Nonetheless, data resources need to increase rather than continue to decrease during the CWA process. Ultimately, it will be necessary to show that management efforts and funding have produced improvements in LSJRB water quality.

The authors have endeavored to provide a clear and straightforward public presentation of LSJRB water quality. The authors also applaud the efforts at all levels of state and local government, public environmental organizations, and the commitment of the public toward continually improving the water quality of the LSJR.

2.1.1. Overview of Water Quality in Tributaries:

The tributaries of the Lower St. Johns River are varied both in size and water type. Twenty LSJRB tributaries were selected for inclusion in this year's report based on the authors' view of the importance of each tributary to the health of the river and the local community. Section 2.8.1 summarizes general characteristics of each tributary including DO, nutrients, dissolved metals, fecal coliform, chlorophyll-*a*, and turbidity. Several important river health-related characteristics are also discussed in Sections 2.8.2 through 2.8.21.

In the LSJR, many tributaries have failed to meet water quality standards for their designated uses due to indications of excess fecal contamination. The Florida Department of Environmental Protection (DEP) has verified 62 Lower St. Johns River tributaries as impaired for fecal coliform bacteria. While some natural sources exist such as wild birds and mammals, the bulk of the problem has been linked to human sources. Most commonly these sources are from malfunctioning septic systems and sewer problems. There has been a concerted and laudable effort to identify sources of contamination, to prioritize, and to clean up these tributaries. Cooperation between the SJRWMD, the City of Jacksonville (COJ) and its utility providers, and DEP is excellent. The CWA requires states to determine and establish TMDLs for such impairments. To correct these impairments, technical reports are being prepared for each tributary to analyze available data to identify the most probable sources of the fecal coliform impairment. Management actions to correct the impairments are part of the Basin Management Action Plan (BMAP) and are issued as Technical Reports. Current and draft technical reports completed to date are available on the DEP website (**DEP 2010m**). Some specific tributary fecal coliform data are addressed in the Tributary section.

Thirty tributaries of the LSJR have complete and approved TMDL documents (**DEP 2010d**) available on the DEP website:

Big Davis Creek
Big Fishweir Creek
Block House Creek
Butcher Pen Creek
Cedar River
Deep Bottom Creek
Deer Creek
Durbin Creek
Goodbys Creek
Greene Creek
Grog Branch
Hogan Creek
Julington Creek
Little Black Creek
McCoy Creek
Mill Creek
Miller Creek
Miramar Creek
Moncrief Creek
New Castle Creek
Open Creek
Peters Creek
Pottsburg Creek
Ribault River
Sherman Creek
Strawberry Creek
Terrapin Creek
Trout River
Wills Branch
Williamson Creek

Draft TMDLs exist for the following tributaries:

Arlington River	Dog Branch	Ortega River
Black Creek	Fishing Creek	Peters Creek
Cormorant Branch	Greenfield Creek	Sixteen Mile Creek
Craig Creek	Hopkins Creek	Swimming Pen Creek
Doctors Lake	Mill Creek	Trout River

Other water quality issues, such as metal contamination at toxic levels, have been less common, and many originally listed water bodies have been delisted due to decreased levels of silver, thallium, selenium, cadmium, and copper. Widespread excess iron levels still exist. A few areas of high lead, nickel, silver and copper contamination remain.

There is a widespread impairment for specific conductivity, the ability of the water to carry an electric current and related to the total number of ions in the water. There are 91 water bodies in the current draft Verified List with specific conductance samples that exceed 50% above background conductance levels or greater than 1275 micromhos per centimeter (μmhos/cm). There are many natural sources of these ions, such as sea salt from the estuary and raindrop nuclei, mineral deposits near springs and groundwater sources, as well as minerals in the soil that ionize in water. High potassium-to-sodium ratios in the water sample are one indicator that potential human contamination is possible. Potassium is a primary component of fertilizer, which may be an important source.

Even more than last year, the lack of data has limited our assessment. While the reliability and accuracy of available data is improving with time, the quantity of new data samples for many locations is decreasing. This is a concern, as frequent data collection is required in order to determine whether environmental concerns, such as algal blooms, are linked to trends in water quality parameters. Frequent, long-term data are also needed to evaluate the impact of TMDLs and other management strategies. The number of data samples is on an alarming decrease, with real-time data decreasing most rapidly. Only fecal coliform data have increased, and the number of data samples there may not support long-term trend analysis of the impact of the TMDLs and management actions being undertaken. Insignificant trends and insufficient data for trend analysis are reported for the majority of water quality sites by **SJRWMD 2006** as cited in the Basin Management Action Plan for the Main Stem of the LSJR of October 2008 (**DEP 2008a**).

2.2. Dissolved Oxygen

2.2.1. Description and Significance: DO and BOD

Dissolved oxygen (DO) is defined as the concentration of oxygen that is soluble in freshwater at a given altitude and temperature (**Mortimer 1981**). The concentration of oxygen dissolved in water is far less than that in air; therefore, subtle changes may drastically impact the amount of oxygen available to support many aquatic plants and animals. The dynamics of oxygen distribution, particularly in inland waters, are essential to the distribution, growth, and behavior of aquatic organisms (**Wetzel 2001**). Many factors affect the DO in an aquatic system, several of them natural. Temperature, salinity, sediments and organic matter from erosion, runoff from agricultural and industrial sources, wastewater inputs, and excess nutrients from various sources may all potentially impact DO. In general, the more organic matter in a system, the less dissolved oxygen available. DO levels in a water body are dependent on physical, chemical, and biochemical characteristics (**Clesceri 1989**).

As discussed in Section 1, the St. Johns River is classified as a class III water body under the U.S. Environmental Protection Agency (EPA) guidelines. The EPA class III Freshwater Quality Criterion for DO is 5.0 mg/L (62-302.530, F.A.C.; **DEP 2010l**) and requires that normal daily and seasonal fluctuations must be maintained above 5.0 mg/L to protect aquatic wildlife. The predominantly freshwater part of the LSJR extends north from the city of Palatka to the mouth of Julington Creek. In marine waters, the DO average should not be less than 5.0 mg/L in a 24-hour period with a minimum DO concentration of 4.0 mg/L. The Florida Department of Environmental Protection (DEP) has developed a site specific alternative criteria (SSAC) for the predominantly marine portion of the LSJR between Julington Creek and the mouth of the river which requires that DO concentrations not drop below 4.0 mg/L; however, DO concentrations between 4.0 and 5.0 mg/L are considered acceptable over short time periods extending up to 55 days (**DEP 2010c**). For more details on the calculation of the SSAC, please visit the DEP website (**DEP 2010e**).

Biochemical oxygen demand (BOD) is an index of the biodegradable organics in a water body (**Clesceri 1989**). Simply, it is the amount of oxygen used by bacteria to break down detritus and other organic material at a specified temperature and duration. Higher BOD is accompanied by lower dissolved oxygen. The EPA suggests that the BOD not exceed values that cause DO to decrease below the criterion, nor should BOD be great enough to cause nuisance conditions (**DEP 2010l**).

Bacterial growth requires nutrients such as nitrogen, phosphorus, and trace metals. Nutrients, in particular, may contribute to the overgrowth of phytoplankton, periphyton, and macrophytes, which then in turn die. Therefore, nutrient inputs into the river can increase the BOD, thereby decreasing the DO. Phytoplankton population responses to the increased nutrients in a system may be only temporary. However, if nutrient inputs are sustained for long periods, oxygen distribution will change, and the overall productivity of the water body can be altered (**Wetzel 2001**).

2.2.2. Factors that Affect DO and BOD

Warmer temperatures influence DO by decreasing its solubility (**Mortimer 1981**). Increasing temperatures also increase metabolism by causing an increase in respiration in aquatic organisms, which is a process that requires oxygen. Increased metabolism and production of bacteria and phytoplankton contribute to a higher BOD. Therefore, when the temperature increases, the BOD increases in the environment, and DO availability is reduced. Shallow areas and tributaries of the LSJR that are without shade have particularly elevated temperatures in the summer months. Correspondingly, DO concentration decreases during those times. The DO changes are compounded in waters with little movement, so turbulence is also a pertinent parameter in the system. Turbulence causes more water to come in contact with the air and thus more oxygen mixes and diffuses into the water from the atmosphere.

Salinity is another factor that affects DO concentrations in the LSJRB. Salt reduces oxygen solubility causing lower DO in aquatic systems. Normal seawater has about 20% less oxygen than freshwater (**Green and Carritt 1967**; **Weiss 1970**). Factors influencing DO, such as increasing temperatures and BOD, will be compounded in saltwater as compared to freshwater.

Furthermore, productivity and sediment type can also influence the DO concentration. DO usually exhibits a diurnal (24-hour) pattern in eutrophic or highly productive aquatic systems. This pattern is the result of plant photosynthesis during the day, which produces oxygen; such that the maximum DO concentration will be observed following peak productivity, often occurring just prior to sunset. Conversely, at night, plants respire and consume oxygen, resulting in an oxygen minimum, which often occurs just before sunrise (**Laane, et al. 1985**; **Wetzel and Likens 2000**). The LSJR is highly productive; however, it is a blackwater river, thus photosynthesis is limited. In addition to the diurnal DO cycle described, bacterial oxygen demand generally dominates following algal blooms due to decomposition processes, and is present both during the day and the night.

2.2.3. Data Sources

All data used for the DO and BOD analyses were from the FDEP STOrage and RETrieval (STORET) database, except for data used for Figure 2.4, which was from the EPA STORET database. STORET is a computerized environmental data system containing water quality, biological, and physical data. DO and BOD were measured using methods EPA 360.1 and EPA 405.1, respectively. Data points that had a 'V' qualifier (analyte was detected in both the sample and the method blank) were removed from the analyses and values below the detection limit were set to zero. This section examines the data from the entire LSJR basin and not solely the tributaries (discussed in Section 2.8).

Data are presented in box and whisker plots, which consist of a five number summary including: a minimum value; value at the first quartile; the median value; the value at the third quartile; and the maximum value. The size of the box is a measure of the spread of the data with the minimum and maximum values indicated by the whiskers. The median value is the value of the data that splits the data in half and is indicated by the horizontal blue line in the center of the boxes.

2.2.4. Limitations

The time of day in which water quality is measured can strongly influence the result due to the diurnal pattern of DO. Additionally, some of the more historic data lacks pertinent corresponding water quality characteristics, such as tides, which may have impacted the measurements. Also, data used from the EPA STORET database prior to 1998 are of undocumented quality.

2.2.5. Current Status and Trends

Since 1996, the majority of the DO values in the LSJRB were above WQC and therefore within acceptable limits, with the exception of the minimum values, which were well below WQC (Figure 2.2). Yearly data alone can be misleading. A clear seasonal trend is demonstrated in Figures 2.3 and 2.4, with the lowest concentrations observed in the summer months. Seasonal DO fluctuation, although apparent in the main stem of the LSJR (Figure 2.4) is even more problematic in the tributaries and creeks (particularly saltwater), where several DO values were below the site-specific minimum standard of 4.0 mg/L in summer months. Water quality conditions in tributaries will be addressed separately in Section 2.8 because DO concentrations can vary between tributaries, depending on the surrounding land use, water flow, and depth. The majority of the BOD values in the LSJR have been stable since 1997; however, maximum concentrations have fluctuated extensively (Figure 2.5). Unlike with DO, a seasonal pattern of BOD values was not apparent (Figure 2.6). However, trends in BOD may be better observed in individual tributaries of the LSJRB.

2.2.6. Future Outlook

Analysis of available data indicates that the average DO levels in the LSJRB are generally within acceptable limits; however, unacceptable DO concentrations occurred intermittently during every month of the year. Low DO was most problematic during summer months with many of the lowest measurements occurring in tributaries and creeks. DO concentrations below 5.0 mg/L for prolonged periods may be too low to support the many aquatic animals that require oxygen (**EPA 2002a**; **EPA 2002b**). Maintenance above minimum DO levels is critical to the health of the St. Johns River and organisms that depend on it. Nutrient reduction strategies, discussed in the next section, have recently been devised by government agencies and may combat the low DO concentrations observed in the LSJR to some extent. Additionally, monitoring agencies are now making efforts to collect data that better represent the variable DO conditions and to concurrently document other important water quality characteristics for an improved assessment of the river's health.

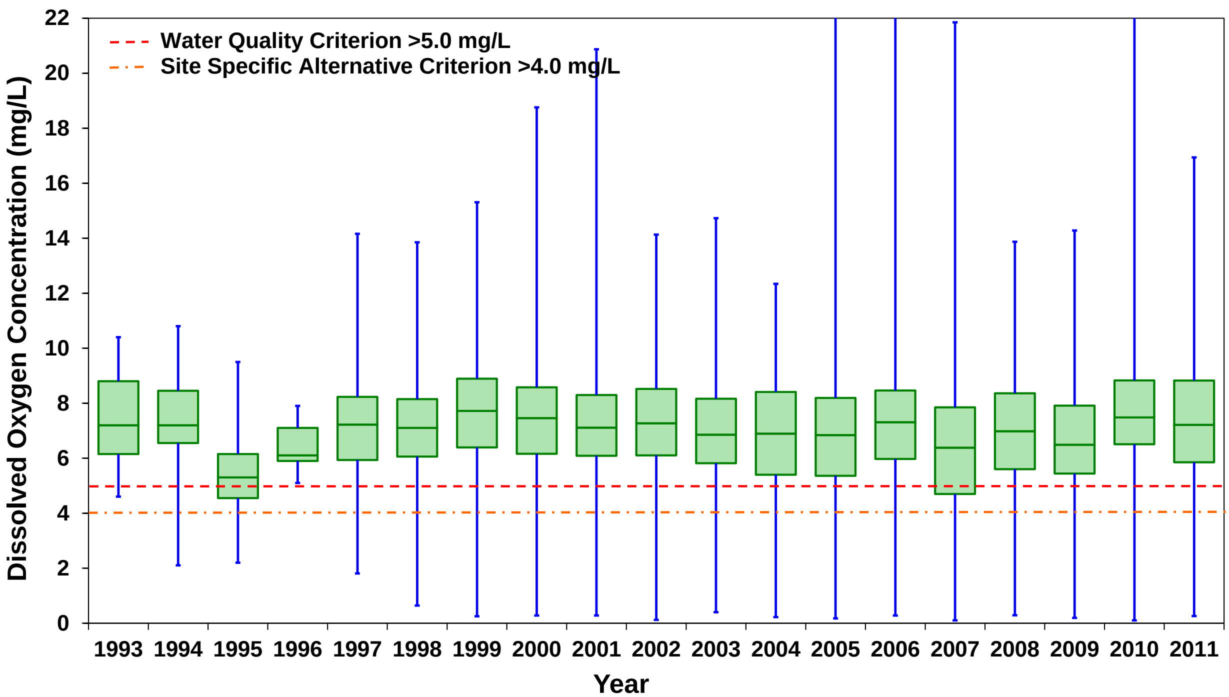


Figure 2.2 Yearly DO from 1993 to 2011 in the LSJRB. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

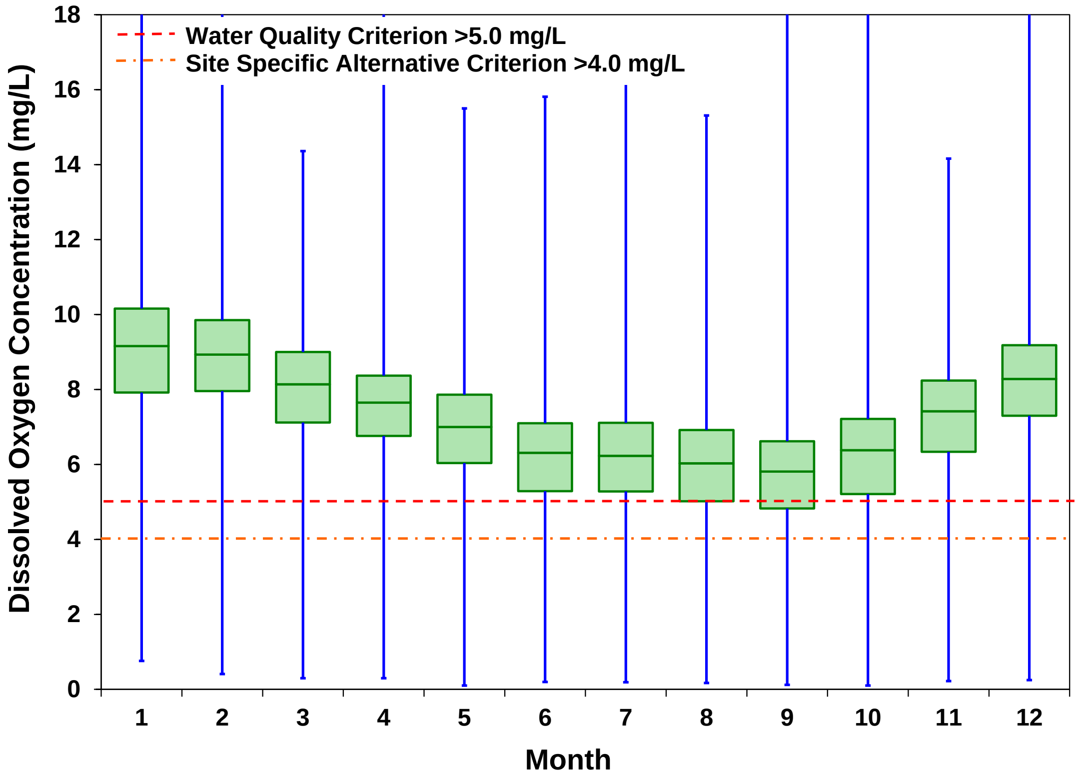


Figure 2.3 Monthly DO concentrations from 1982 to 2011 in the LSJRB. Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

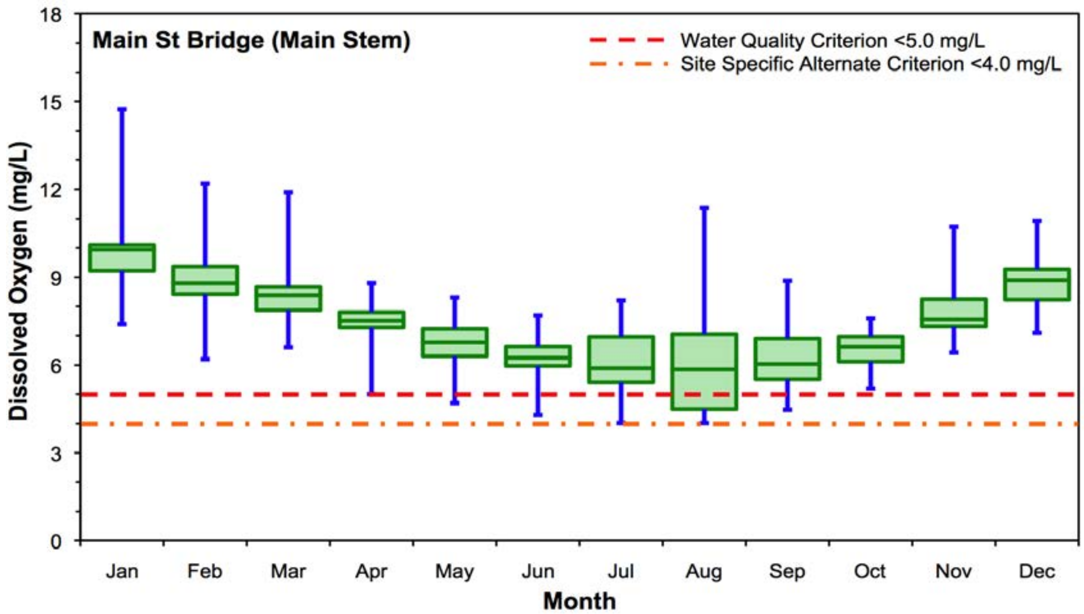


Figure 2.4 Monthly DO concentrations from 1967 to 2007 in the main stem of the LSJR near the Main Street Bridge. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate median values. Blue whiskers indicate the minimum and maximum values in the data set.

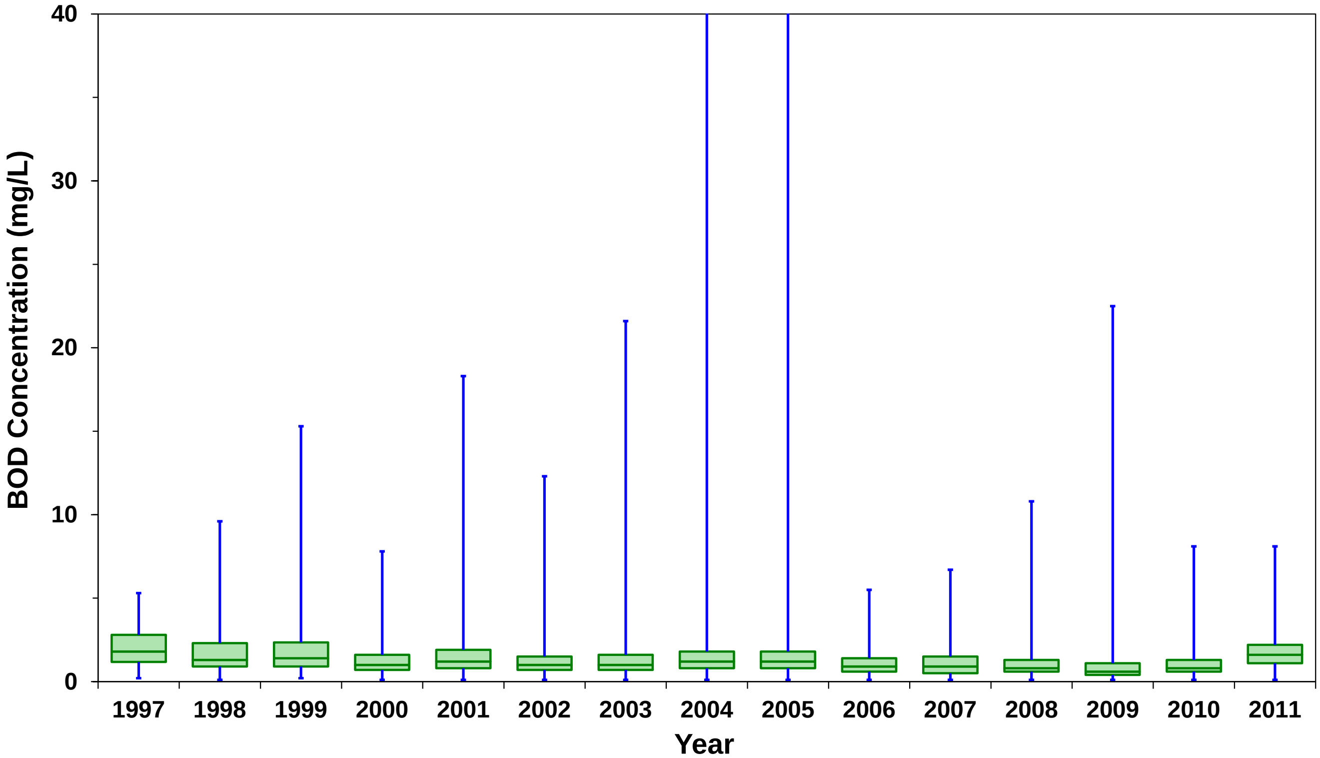


Figure 2.5, Yearly biochemical oxygen demand from 1997 to 2011 in the LSJRB. Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

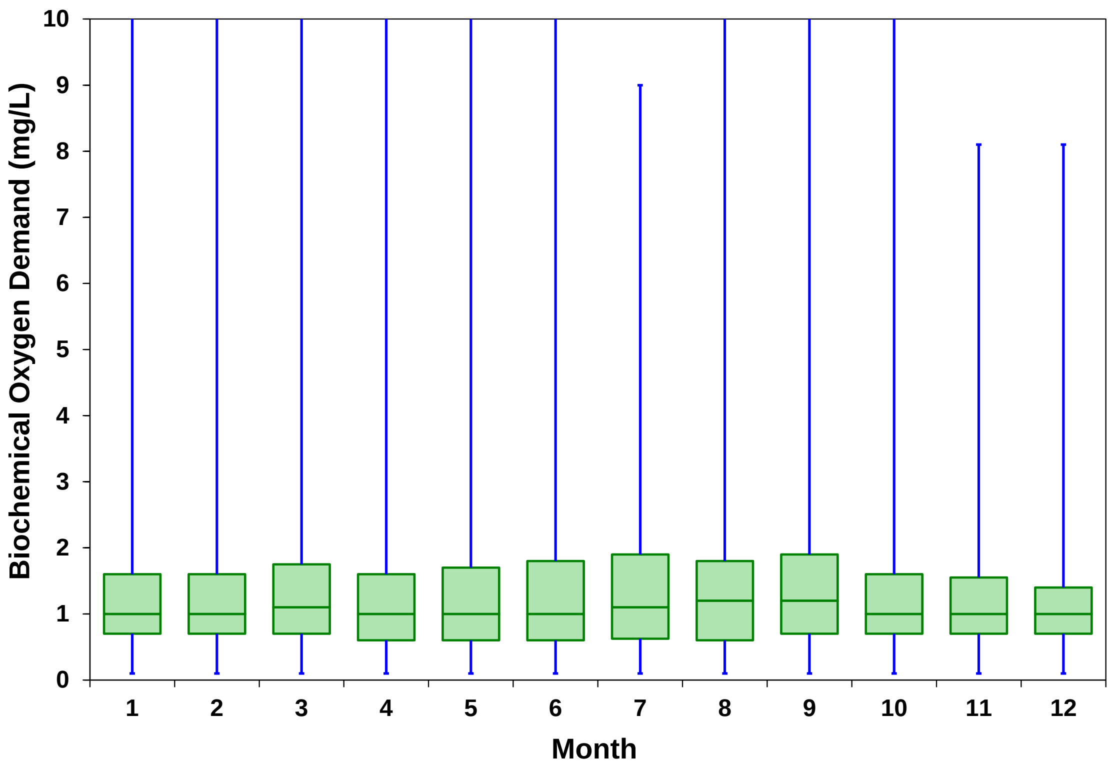


Figure 2.6, Monthly biochemical oxygen demand from 1997 to 2011 in the LSJRB. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

2.3. Nutrients

2.3.1. Description and Significance: Phosphorus

Phosphorus and nitrogen are important and required nutrients for many aquatic organisms, such as phytoplankton (e.g., algae). If all other conditions, such as light, water quality, etc. are sufficient, nutrients stimulate immediate algal growth and alternatively, if absent, can limit algal abundance. In excess, either phosphorus or nitrogen can cause the overgrowth of phytoplankton to nuisance levels. If the nutrient concentration in a system remains high for extended periods of time, eutrophic conditions may result, potentially changing the entire ecosystem by favoring the growth of some organisms and changing the optimal water quality conditions for other organisms. The term "eutrophic" generally signifies a nutrient-rich condition, resulting in a high concentration of phytoplankton (**Naumann 1929**) The more recent definition characterizes eutrophication as an increase in organic matter loading to a system (**Nixon 1995**). Eutrophication is a natural process, predominantly occurring in small, enclosed water bodies like ponds and lakes. However, eutrophication is not a process commonly observed in river systems, like the St. Johns. The presence of eutrophication in these types of river systems is an identifying characteristic of significant anthropogenic (man-made) nutrient inputs.

Phosphorus predominately occurs in natural freshwater areas as organically bound phosphate, within aquatic biota, or adsorbed to particles and dead organic matter (**Clesceri 1989**; **Wetzel 2001**); whereas, the dominant inorganic species, orthophosphate, accounts for about 10% of the total phosphorus in the system (**Clesceri 1989**). Orthophosphate is released by the breakdown of rock and soils and is then quickly used by aquatic biota, particularly bacteria and algae, and incorporated as organic phosphate (**Newbold 1992**; **Kenney, et al. 2002**). Phosphorus can be released from biota by excretion and by the decaying of matter. Several other factors can influence the partitioning of phosphorus in aquatic systems. In oxygen-rich headwater streams of the LSJR, phosphorus may be bound to particulate material; however, as it enters the lakes and slower flowing freshwater parts of the river, sediments generally act as a reservoir for phosphorus (**Brenner, et al. 2001**). Many factors, such as wind, turbulence, DO, water hardness and alkalinity, sulfide concentration, and benthic (bottom-dwelling) organisms may potentially re-mobilize phosphorus into the water column (**Boström, et al. 1988; Boström, et al. 1982; Lamers, et al. 1998; Smolders, et al. 2006; Wetzel 1999**). When reaching the mouth of the river, sulfur may replace phosphorus bound to sediments, thus making it potentially available to aquatic organisms (**Lamers, et al. 1998; Smolders, et al. 2006**). This occurs more commonly in anoxic areas where bacteria reduces sulfate to sulfide as they decompose organic matter (**Lamers, et al. 1998; Smolders, et al. 2006**).

Humans add to the naturally occurring phosphorus in aquatic systems. In Florida, phosphorus is mined quite extensively, and is used in fertilizers, commercial cleaners and detergents, animal feeds, and in water treatment, among other purposes. Runoff can result in the addition of phosphorus into local waterways (**Clesceri 1989**, **Wright and Nebel 2008**). In the past, phosphorus was also often used in laundry detergents. Orthophosphate generally averages 0.010 mg/L whereas total dissolved phosphorus averages about 0.025 mg/L in unpolluted rivers worldwide (**Meybeck 1982**). Orthophosphate concentrations in rivers can increase substantially following a rainwater event to as high as 0.050-0.100 mg/L from agricultural runoff and over 1.0 mg/L from municipal sewage sources (**Meybeck 1982**; **Meybeck 1993**).

The EPA proposed a Water Quality Criterion (WQC) of 0.12 mg/L, for total phosphorus in the St. Johns River (**EPA 2010**). Drainage basins have been shown to largely impact the chemical characteristics of surface waters (**Keup 1968**; **Vollenweider 1968**; **Lal 1998**). The drainage basin for the river consists of agricultural lands, golf courses, and urban areas, all of which add to the phosphorus loading in the river. Those inputs, in addition to inputs from municipal wastewater treatment plants and other point sources may contribute to eutrophic conditions in the LSJR (see Section 1).

Generally, sediments act as a reservoir for phosphorus; however, many factors, such as wind, turbulence, DO, water hardness and alkalinity, and benthic (bottom-dwelling) organisms may potentially re-mobilize phosphorus into the water column (**Boström, et al. 1982**; **Boström, et al. 1988**; **Wetzel 1999**).

2.3.2. Description and Significance: Nitrogen

The atmosphere is the main reservoir for nitrogen, as it contains 78% nitrogen gas by volume. This form of nitrogen is unreactive and unavailable to most organisms. Other forms of nitrogen include nitrate, nitrite, ammonia and organic nitrogen, such as protein and urea, all of which can move freely between organisms and the environment (**Wright and Nebel 2008**). Nitrate is found in the effluent of biological wastewater treatment and nitrite is used as a corrosion inhibitor

in industry and as such is found in industrial effluent (**Clesceri 1989**). Nitrite and nitrate are microbially converted from one to the other, depending on the availability of oxygen and the pH of the environment. Ammonia is a waste product of aquatic organisms and naturally occurs in surface and wastewaters at concentrations ranging from 0.010 mg/L in some natural surface waters and groundwater, to 30 mg/L in some wastewaters (**Clesceri 1989**). Ammonia is interconverted to ammonium ion, depending on the environmental pH. Ammonia is more common in natural waters and more toxic to aquatic organisms because of its ability to cross biological membranes. More ammonium ions are formed when the pH is low. Plants take up inorganic reactive nitrogen and incorporate it into essential organic compounds like proteins. It is then passed up the food chain, during which time nitrogen wastes can be given off, as ammonium compounds. The decay of organisms also liberates nitrogen (**Hutchinson 1944**; **Wetzel 2001**). The EPA recommended WQC for total nitrogen is 1.54 mg/L (**EPA 2010**). The EPA class III WQC for nitrogen, as ammonia is 0.02 mg/L (**DEP 2010l**).

Human processes that produce nitrogen compounds primarily include industrial fixation in the manufacturing of fertilizers, during which nitrogen gas is converted to ammonia, and the combustion of fossil fuels, during which nitrogen from coal and oil is oxidized, liberating nitrogen oxides into the atmosphere. In the first process, nitrogen can pollute waterways from agricultural and urban runoff of fertilizer. In the latter process, nitrogen oxides in the atmosphere are converted to nitric or nitrous acids and brought down to waterways by precipitation. The form of nitrogen that enters a waterway can give an indication of its source. However, in aquatic systems, several abiotic and biotic processes can change the form of nitrogen, so the source may not be as easily identified. Abiotic processes include pH and complexation, and biotic processes include nitrification, denitrification, and nitrogen fixation. Sediments act as a major reservoir of nitrogen, just as they do for phosphorus (**Levine and Schindler 1992**).

Excessive total nitrogen in a system can have severe impacts on the community structure. Nitrogen can markedly alter the community distribution of phytoplankton. Cyanobacteria, for example, are capable of nitrogen fixation (converting inert nitrogen to reactive nitrogen), which allows them to grow rapidly, thus out-competing other species when inorganic nitrogen levels are low (**Smith 1983**). Repetitive nitrogen and phosphorus overloading can be detrimental to aquatic systems.

2.3.3. Data Sources

All data were obtained from the FDEP STORET, except for data in Figure 2.10, which were retrieved from the EPA STORET database. STORET is a computerized environmental data system containing water quality, biological, and physical data. Total fractions (until 2010) and dissolved fractions (2011) of phosphorus, as orthophosphate, and nitrogen, as Kjeldahl, ammonia, and nitrate plus nitrite were measured from surface waters using EPA methods 365.1, 351.2, 350.1, and 353.2, respectively, and used in this data set. Data points that had a 'V' qualifier (analyte was detected in both the sample and the method blank) were removed from the analyses and values below the detection limit were used as zero. Since the nutrient criteria for the state of Florida have not yet been implemented, the EPA's Water Quality Standards for the State of Florida's Lakes and Flowing Waters, Peninsula region (**EPA 2010**) were used for comparison with measured total phosphorus and nitrogen values in the LSJR to assess impairment. The EPA class III WQC for nitrogen, as ammonia was also used (**DEP 2010l**).

Data are presented in box and whisker plots, which consist of a five number summary including: a minimum value, value at the first quartile, the median value, the value at the third quartile, and the maximum value. The size of the box is a measure of the spread of the data with the minimum and maximum values indicated by the whiskers. The median value is the value of the data that splits the data in half and is indicated by the horizontal blue line in the center of the boxes.

2.3.4. Limitations

Data used from the EPA STORET database prior to 1998 are of undocumented quality and no analysis procedure was listed.

2.3.5. Current Status and Trends: Phosphorus

Mean total phosphorus concentrations in the LSJR were generally higher in the 1970s, which largely occurred from the increased use of phosphorus in fertilizers, manure, and laundry detergents (data shown in previous LSJR reports). Even though Florida contains a higher background phosphorus concentration than many states due to its geological

composition (rocks and soils), the anthropogenic inputs of phosphorus in the river have been much more substantial. The use of phosphorus in laundry detergents was banned in Florida, December 31st, 1972 and the use of phosphorus in fertilizers did not considerably increase after 1980. The decreasing use of phosphorus in detergent manufacturing also led to a decrease in the amount of phosphorus in wastewater effluent. Other phosphorus inputs have continued and some of the maximum values measured in the past decade (Figure 2.7) have been greater than those measured in the 1970's.

One of the main objectives of the CWA was to upgrade wastewater treatment plants by implementing technology-based limits, which should have reduced phosphorus and nitrogen, among other things, from wastewater effluent. However, load concurrently increased. Several wastewater treatment plants were upgraded in the 1990s and although tertiary treatment is not required it has been implemented at some wastewater treatment facilities. Median total phosphorus concentrations in the LSJR were fairly stable from 1997 to 2009 and have actually decreased in the past two years, likely reflecting, in part, the point source reduction efforts (Figure 2.7). Over the last decade or so, efforts have been aimed at reducing nonpoint sources of phosphorus, particularly from landscape fertilizer and agricultural rainwater runoff. It is important to note that the median phosphorus data from the entire LSJR may not accurately reflect the phosphorus concentrations in certain areas, such as tributaries, of the river. Currently, maximum levels still exceed the EPA recommended water quality standard of 0.12 mg/L.

In general, lower phosphorus concentrations have been observed in the main stem of the LSJR as compared to several of the creeks and tributaries (see Section 2.8); however, all areas sampled have phosphorus concentrations higher than the EPA recommended water quality standard. The main stem is deeper with more vertical mixing, so the nutrient input is diluted, to some extent.

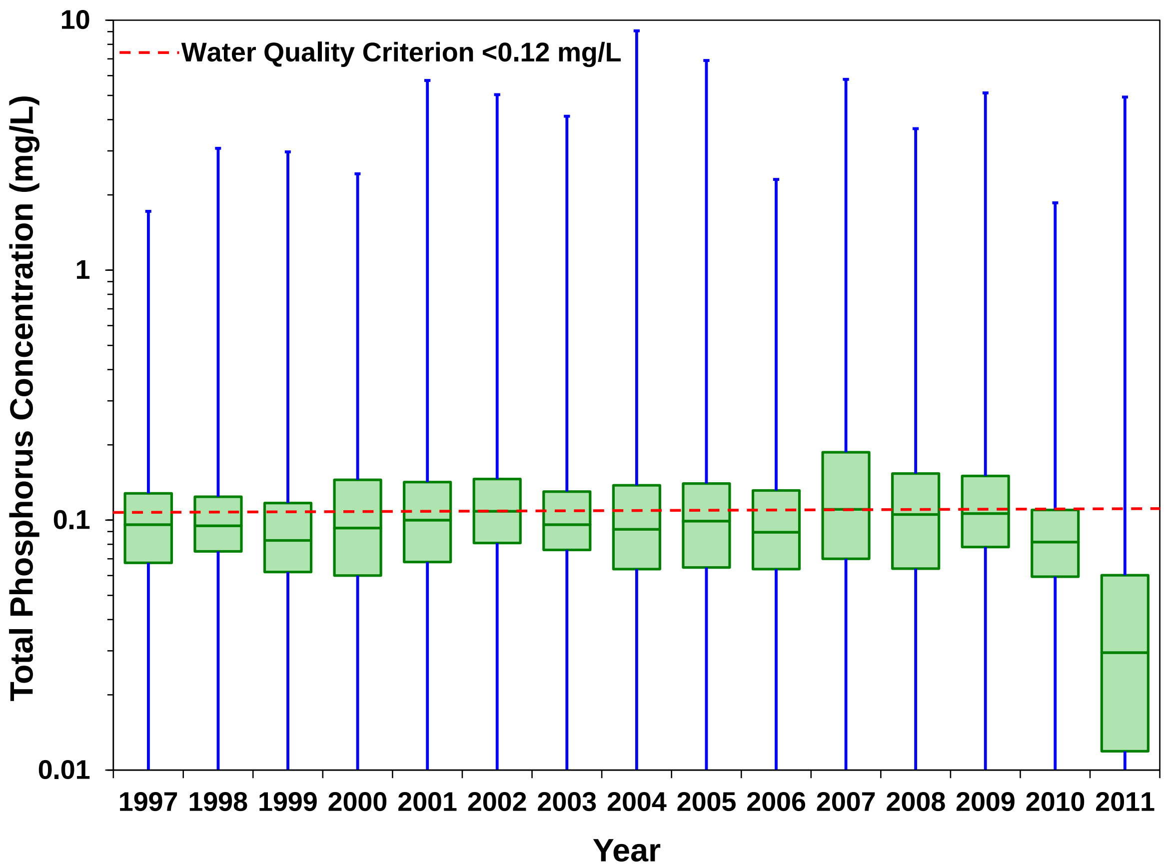


Figure 2.7 Yearly total phosphorus concentrations from 1997 to 2011 in the Lower St. Johns River. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

Slight seasonal increases in phosphorus concentration in the LSJR were observed in summer months (Figure 2.8). Fertilizers containing phosphorus are used on crops primarily during the winter; however, increased stormwater runoff during the summer may liberate phosphorus from the soils resulting in a continuous input into the LSJR. Another

important continuous source of phosphorus is from construction fill materials, which may substantially increase phosphorus additions to waterways, even from soils with no fertilizer.

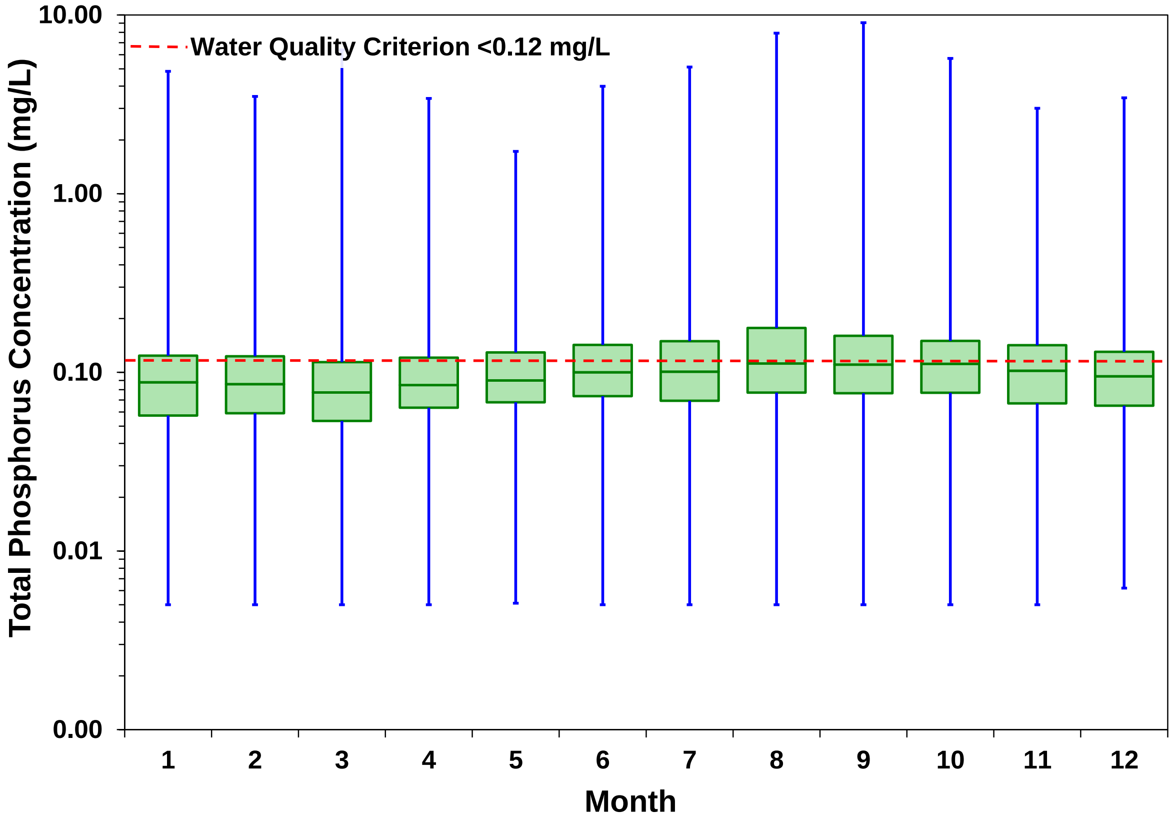


Figure 2.8 Monthly total phosphorus concentrations from 1998 to 2011 in the Lower St. Johns River. Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate the minimum and maximum values in the data set.

2.3.6. Current Status and Trends: Nitrogen

Overall, the yearly median total nitrogen concentrations have been stable since 1997; and the majority of the data has been below the EPA recommended annual mean standard of 1.54 mg/L (Figure 2.9). However, maximum values continue to fluctuate well above acceptable limits. Relatively elevated levels of nitrogen have been frequently observed in several tributaries (see below); as well as specific locations in the main stem of the LSJR, such as the Main St. Bridge, which receives a substantial upstream contribution, city storm drainage inputs and power plant effluent, as well as atmospheric deposition, making it difficult to identify a predominant source.

The yearly median concentrations of nitrogen, as total ammonia (including unionized and ionized forms), have generally decreased from 1968 to 1983 (data shown in previous SJR reports), and with the exception of 2008 have been stable since 1997 (Figure 2.10). The majority of the values exceed the EPA class III WQC for unionized ammonia of 0.02 mg/L (Figure 2.10) and although maximum values were lower from 2006 to 2010, they have again increased in 2011. However, total ammonia can either be in either the ionized or unionized form, depending on the environmental pH, which would in turn determine its toxicity to aquatic organisms.

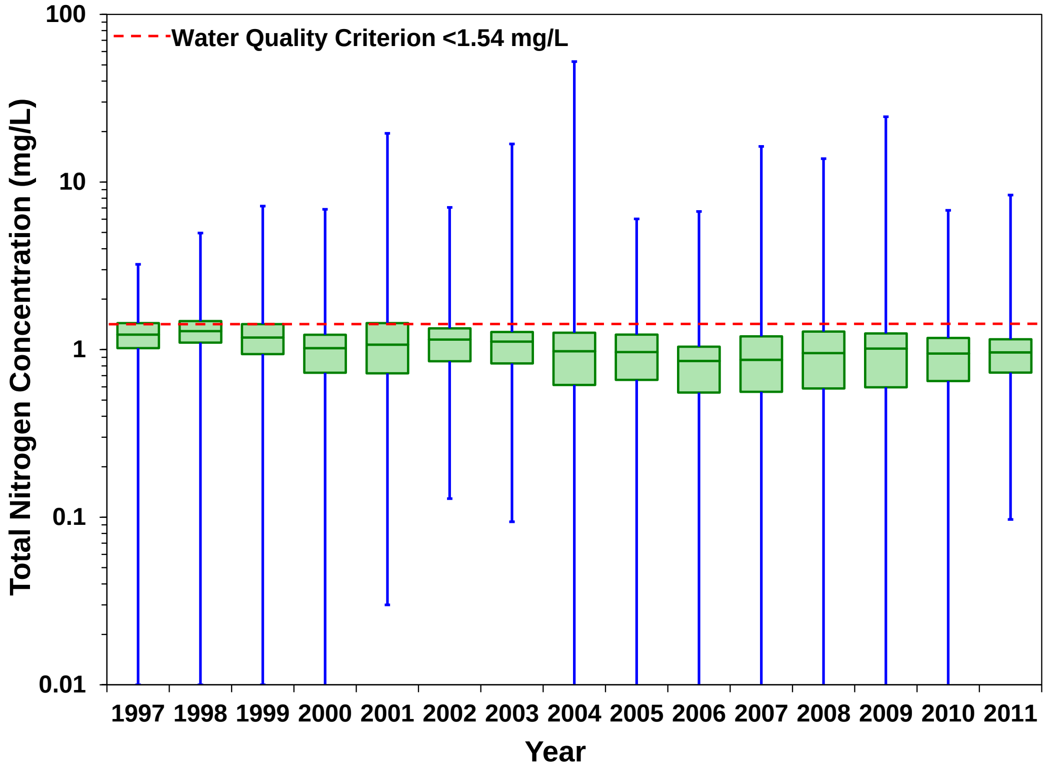


Figure 2.9 Yearly total nitrogen concentrations from 1997to 2011 in the Lower St. Johns River. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

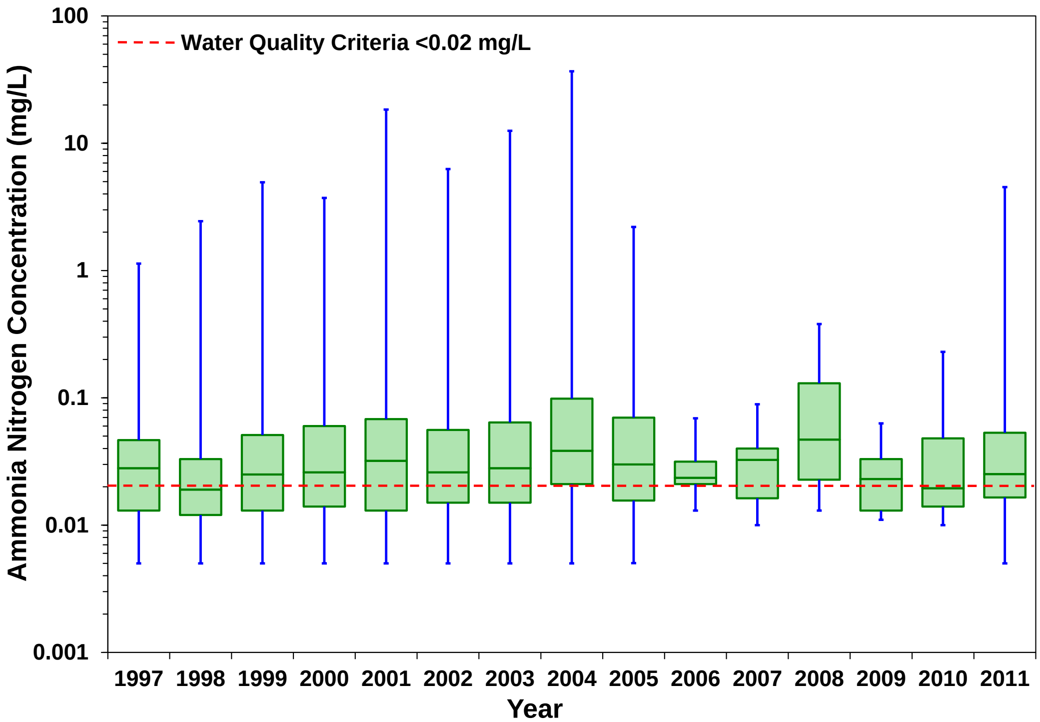


Figure 2.10 Yearly nitrogen concentrations, as total ammonia, from 1997 to 2011 in the Lower St. Johns River. Data are presented as a box-and-whiskers plot with the green boxes indicating the median±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

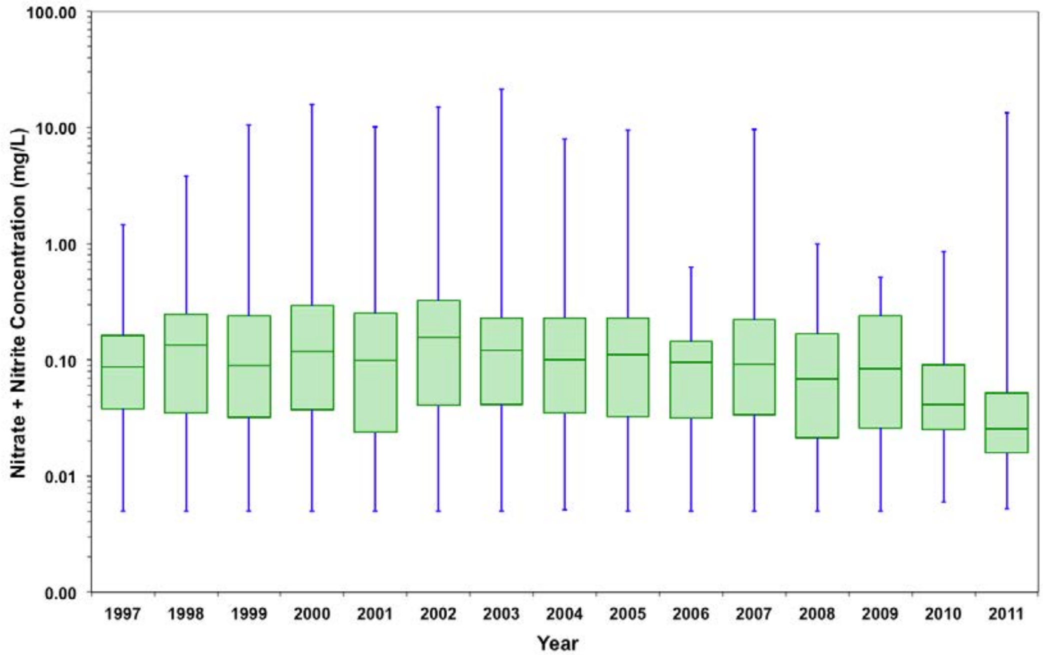


Figure 2.11 Yearly nitrogen concentrations, as nitrate + nitrite, from 1997 to 2011 in the Lower SJR. All data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. In B, the vertical scale has been expanded (compared to A) to more clearly show the acceptable range.

The yearly median concentrations of nitrogen, as nitrate plus nitrite, were fairly stable from 1997 to 2009 and have since decreased (Figure 2.11). There does appear to be a seasonal trend in the levels of nitrate and nitrite, with the highest concentrations occurring in the winter (Figure 2.12). This may be a result of nitrate liberation from the flood plain in winter months. This pattern has been demonstrated in two Delaware salt marshes (**Aurand and Daiber 1973**); however the data analyzed in this report included freshwater areas of the LSJR as well. Another possible explanation is that in the winter less nitrate and nitrite is taken up as particulate organic matter (POM) (i.e., into algae) because the phytoplankton density is lower.

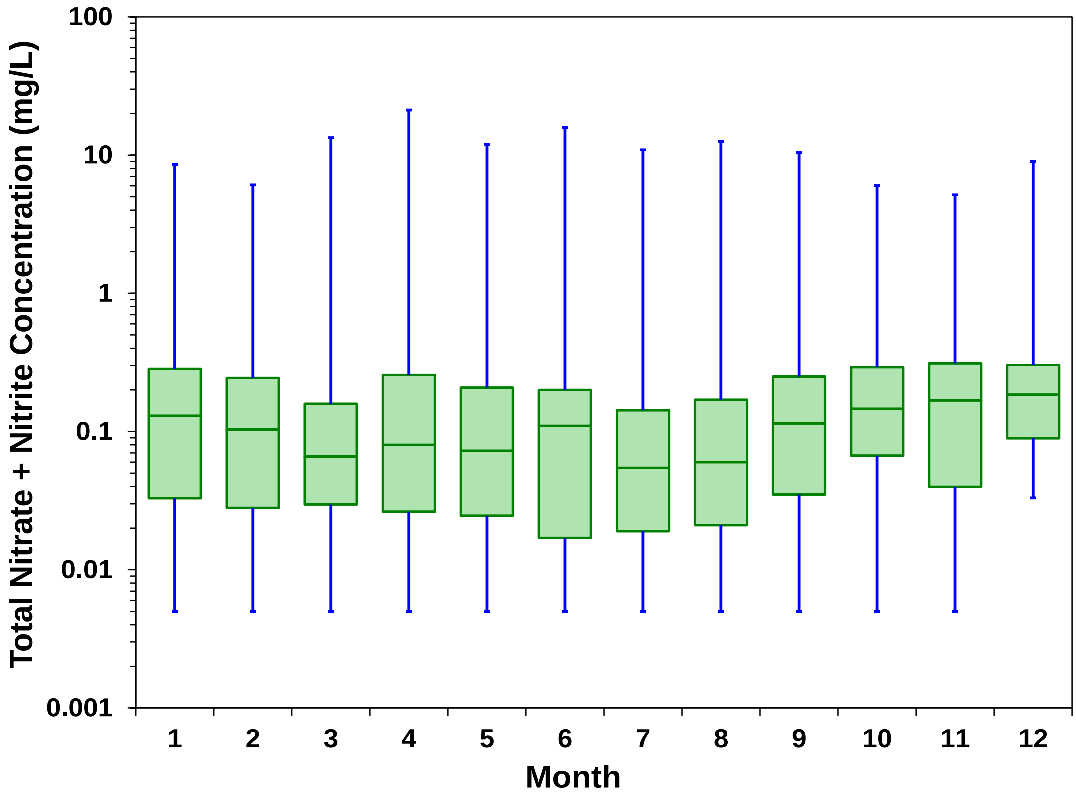


Figure 2.12 Monthly nitrogen concentrations, as nitrate + nitrite, from 1998 to 2011 in the Lower SJR. All data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

2.3.7. *Future Outlook*

Phosphorus and nitrogen inputs from multiple sources should be reduced. Even though the majority of these nutrient concentrations were stable or slightly reduced, maximum concentrations continue to far exceed the EPA recommended standards, particularly in the smaller tributaries and creeks. Like DO, total phosphorus and nitrogen concentrations typically follow a seasonal trend, mostly elevated in summer months. However, nitrogen, as nitrate plus nitrite is higher in the winter months. Monitoring specific chemical species of nitrogen may give some indication of the source. Increases in phosphorus and nitrogen concentrations to eutrophic conditions are highly linked to changes in the relative abundance of phytoplankton, favoring growth of potentially harmful species (**Tilman 1982**; **Smith 1983**; **Kilham and Hecky 1988**; **Kilham 1990**). Decreasing phosphorus loading has been shown to decrease productivity (**Vollenweider 1968**) and may reduce the occurrence of harmful algal and cyanobacteria blooms, particularly in freshwater environments. Further, decreasing nutrient levels would contribute to better water quality in the LSJR, as DO, BOD, and the availability of other contaminants to aquatic organisms, have been associated with nutrient levels.

A final TMDL document was drafted in 2008 by the DEP in efforts to reduce nutrient inputs into the LSJR. A TMDL is a scientific determination of the maximum amount of a given pollutant (i.e. nutrients) that a surface water can absorb and still meet the water quality standards that protect human health and aquatic life (**Magley and Joyner 2008**; see Section 1). The nutrient TMDL indicates the necessary nutrient reduction to meet water quality standards in the LSJR and the restoration strategies required to achieve it. Government agencies are working with municipal and industrial wastewater treatment facilities and NPDES permitted facilities to reduce nutrient loadings from permitted discharges. Also, nutrient-rich waters coming from standard secondary water treatment plants may be recycled. These recycled waters can and have recently been used as a means for irrigation; however, the effluent must not be contaminated with toxic materials. This practice has been recently utilized in Clay County, within the LSJRB as well as other areas of the U.S., such as Bakersfield, California; Clayton County, Georgia; and St. Petersburg, Florida, mostly for irrigation of urban open spaces like parks, residential lawns and golf courses. A similar practice has been used in agriculture.

Local utilities and government agencies have voluntarily made efforts to reduce nutrients since 2000 and a large public outreach campaign is under way to reduce fertilizer use in residential landscapes. Individual homeowners may also introduce excess nutrients into the LSJR through failing septic tanks; therefore the replacement of these septic tanks is one of the actions designated to achieve the proposed TMDL. Government agencies have been working with farming and silviculture operations to implement best management practices to reduce and treat runoff of nutrients. The reduction and treatment of urban stormwater runoff by municipal stormwater programs; improvement of development design and construction by commercial developers and homebuilders; and restoration projects by federal, regional, and state agencies may all influence the attainment of projected future goals of the TMDL program. These methods among others have been included in the DEP Nutrient TMDL (**Magley and Joyner 2008**) and have widespread implications in reducing inputs of nutrients into the St. Johns River, provided government agencies, stakeholders, and the general public contribute efforts to meet this goal. In 2011, a reduction in total phosphorus and some of the nitrogen species was observed, perhaps reflecting the efforts described above (**Magley and Joyner 2008**).

2.4. Turbidity

2.4.1. Description and Significance

In its natural state, the St. Johns River, like other blackwater rivers, swamps and sloughs, has a high concentration of colored dissolved organic material (CDOM) that stains the water a dark brown color. The natural decay of plant materials stain the water to appear somewhat like tea in color. The St. Johns River, in particular, has a varied mix of dark-stained water from rainwater flow through the slow moving backwaters, and nearly clear contributions from large springs such as Blue Spring, De Leon Springs, Silver Springs (through the Ocklawaha River) and others. Heavy rains flush tannin-stained waters out of the slow-moving sloughs, swamps and backwaters and into the tributaries and main stem of the LSJR. Color and turbidity are different properties of water, and both may arise from natural and anthropogenic sources. Turbidity is a reflection of how cloudy a water body appears, unlike the light absorption properties described by color, Turbidity is described on the Florida DEP website as:

> *Turbidity is a measure of the suspended particles in water. Several types of material cause water turbidity, these include: silt or soil particles, tiny floating organisms, and fragments of dead plants. Human activities can be the cause of turbidity as well. Runoff from farm fields, stormwater from construction sites and urban areas, shoreline erosion and heavy boat traffic all contribute to high levels of turbidity in natural waters. These high levels can greatly diminish the health and productivity of estuarine ecosystems. (**DEP 2009g**)*

Turbidity is a measure of the light scattered by particulate materials within the water column that reflect and scatter light. Three types of particles optically scatter light in the water column: suspended solids, particles of bacterial and algal origin, and micron-sized particles of CDOM. All are present in the dominantly freshwater portion of the LSJR (**Gallegos 2005**); however, the turbidity is dominated by both phytoplankton (mostly single-cell plants) and suspended solids from human impact (most often sediment or industrial waste) called non-algal particulates (NAP). NAP comes from such activities as sediment erosion from construction, land clearing and timber harvesting sites; stormwater runoff in urban and industrial areas, dredging, and solids from industrial outfalls (**Gallegos 2005**). During heavy rains, these sources may input a large volume of NAP into tributaries of the river. To address this, Florida has an extensive storm-water permitting program to limit stormwater impact. As discussed above, stormwater and drainage systems once considered non-point sources are now registered and permitted under the National Pollutant Discharge Elimination Program (NPDES) (**DEP 2009f**). In contrast to turbidity in freshwater, in more haline (salty) portions of the LSJR, scattering of light is dominantly from materials which are of larger size such as sediment (**Gallegos 2005**).

Periods of drought and rainfall can significantly affect turbidity. During periods of drought, flow from the tannin-stained backwaters decreases dramatically but the flow from the clear springs diminishes less. When this happens, the water may become significantly clearer and optical absorption by CDOM diminishes to below normal levels. With decreased CDOM and higher light penetration, phytoplankton are able to use the high nutrient concentrations more efficiently and readily undergo accelerated growth. (**Phlips, et al. 2007**) In rainy periods after a drought, the St. Johns River may actually become more darkly stained from CDOM than usual, as rainfall moves the stalled and tannin-stained waters into the main stem of the LSJR again. Under these conditions, CDOM absorption is the most influential optical property in a blackwater system

such as the LSJR (**Phlips, et al. 2000**). In other events, and at specific locations and times, phytoplankton or NAP will dominate light loss in the water column and can be assessed by comparing turbidity levels with chlorophyll-*a* levels, which indicate algal content.

Turbidity levels in tributaries can increase during periods of drought under certain conditions, such as near constant industrial and WWTF output, algal blooms, or, more commonly after episodic rain events. For instance, sediment from construction, land clearing and timber harvesting sites, coupled with stormwater runoff, can be washed into the adjacent waters and overwhelm the other components. The latter should happen much less often with strong enforcement of good engineering practices at work sites and continuing improvements to stormwater practices. Episodic monitoring of work sites specifically after heavy rain events could provide needed help with enforcement. Public vigilance in reporting turbidity events in tributaries will help lessen the total impact of spills and runoff sediment. It is not difficult to spot sediment-laden water due to its appearance, often having a resemblance to "coffee with cream", as shown in Figure 2.13 for example.

Figure 2.13 Turbid water from McCoys Creek entering the LSJR on 17 July 2008. Courtesy of Christopher Ball.

Turbidity and color (light absorption) give a good measure of the amount of sunlight that cannot penetrate the waters to support aquatic photosynthesis. Small plants and plantlike bacteria have evolved to float or suspend themselves in the upper levels of the water column to remain in the sunlight. At high concentration their combined scattering may not pass sufficient light to large plants attached to the bottom, like the river grasses that feed and serve as nursery habitat for juvenile fish and shrimp. Submerged aquatic vegetation (SAV) can suffer from a lack of light resulting from high turbidity and from sediment cover, from shading by smaller plants coating their leaf surfaces, or masking by floating algae. This has a large impact on animals, which depend on the grasses for food and shelter.

Figure 2.14 shows turbidity values in the LSJR since 1993. The box indicates the median +/- 25% of the data points (middle 50%). In several years, the highest value recorded was significantly higher than the interquartile range described by the green box; for those years, the high value is higher than the maximum value on the graph. A background turbidity level in the LSJR varies from single digit values to 12-15 Nephelometric Turbidity Units (NTUs) along the main stem (**Armingeon 2008**), and anything over 29 NTUs above background is considered to exceed Florida state standards (62-302 F.A.C. **DEP 2010l**). While the state criterion for turbidity is 29 NTU above background, background levels vary in the LSJRB; therefore 29 NTU has been used as the threshold in the graphs.

Over this period there have been changes in measurement techniques, spatial sampling changes and many other factors, but clearly since 1993, the median value of turbidity in the LSJR has fallen below the acceptable limit.

Algal blooms (see next section) can dominate turbidity when excess nutrient and sufficient background algal concentrations combine to produce prolific growth of the algal biomass. In this situation, the dominantly planktonic algae can reduce visible depth to less than three feet, affecting the submerged aquatic vegetation anchored to the streambed while producing a green mat of planktonic and filamentous algae at the water body's surface. This is referred to as a hypereutrophic condition. A good discussion of trophic state is found on the website of the Institute of Food and Agricultural Sciences at the University of Florida (**IFAS 2009**). While high trophic state index (TSI) values indicate high primary (plant) productivity, often that is part of an unbalanced ecosystem with very high nutrient and a large algal biomass that has large fluctuations in dissolved oxygen. A reduction in water clarity due to algal blooms is distinguishable from sediment turbidity by a total chlorophyll-*a* measurement greater than 40 micrograms/liter. This is not an optimum, healthy state for the entire ecosystem of the water body. Typical ranges for color in the LSJR are 50 to 200 Platinum Cobalt Units (PCU) in the main stem, and depending on other circumstances (such as a recent rainfall after a drought) can be much higher in specific tributaries.

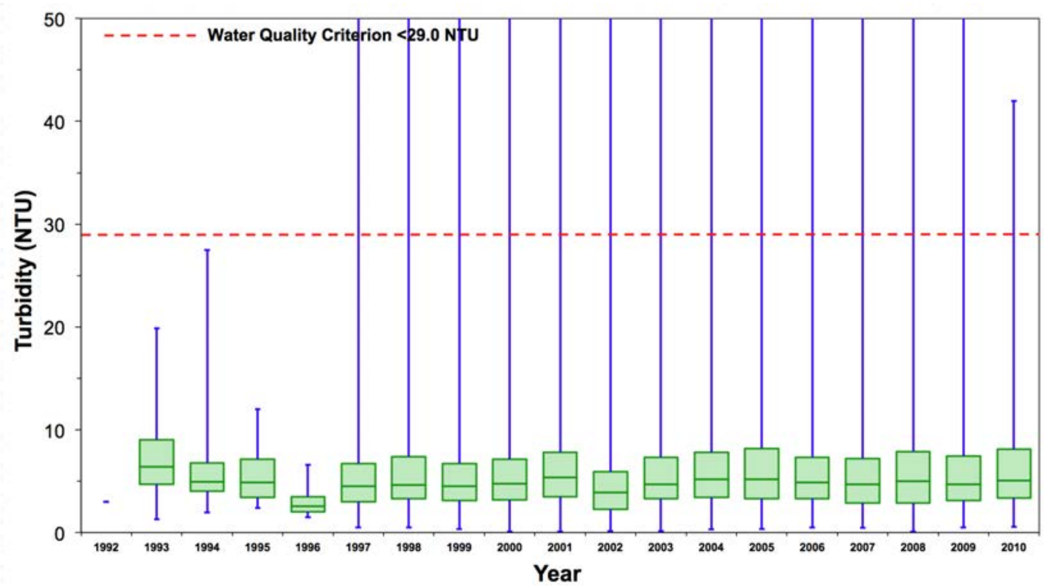


Figure 2.14 Yearly turbidity in the Lower St. Johns River Basin; 1993 - 2010.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median value ±25% (middle 50%of data) and the blue whiskers indicating the minimum and maximum values in the data set.

2.4.2. Data Sources

The primary source for this evaluation is the Florida STORET database and the EPA-mandated reports required by the CWA such as the Florida 303(d) report of impaired waters. These reports become the basis for future water quality management and restoration efforts. These are publicly available online at **DEP 2004** and **DEP 2009d**. Previous versions of this report used EPA STORET data instead of the Florida STORET data used this year.

2.4.3. Limitations

In 1998, under the Florida standards (62-302 F.A.C. **DEP 2010l**), 16 water bodies in the LSRJB were listed as impaired for turbidity. Many of these were urban streams between the city of Jacksonville and Mayport, areas where urban runoff may have been a problem. Many have since been "delisted" in the CWA process. This may truly indicate substantial improvements, but it may also have been partly a function of the sampling timing during pre-hurricane drought conditions in 2004, which greatly reduced runoff and associated turbidity. For example: the earlier 303(d) report listed Cedar River and Goodbys Creek, as well as the main stem of the river above the Dames Point area, at high risk of turbidity impairment. Later sampling in 2004 did not. Additionally, we have chosen to use virtually all the STORET data in spite of changes in methodology, uneven spatial and temporal sampling, and other issues that limit both the validity and generalization of the trend.

2.4.4. Current Conditions

Based on the STORET data available from the current data, turbidity conditions seem to be improving for the main stem of the LSJR. In the tributaries, however, many reported violations of sediment control practices from work sites resulting in high turbidity events still exist, but progress is being made as evidenced by the following.

In May 2009, the following waterbodies were included in the final list of waterbodies proposed for delisting from the Florida 303(d) list: Goodbys Creek (WBID 2326), Cedar River (WBID 2262), Wills Branch (North Prong WBID 2282), Grog Branch (WBID 2407), and Butcher Pen Creek (WBID 2322) (**DEP 2009c**) These five waterbodies had been included in the previous draft delist list.

2.4.5. Trend and Future Outlook

Heightened public awareness and improved engineering sediment control practices are bringing improvements in this area. A few recent finable events and the press they received will help keep the pressure on proper engineering practices, e.g. Figure 2.14. Vigilance in design of retention and detention ponds, sediment fences and public monitoring all can help. Reporting of turbidity events and sediment discharges near land-clearing and construction projects, particularly future Developments of Regional Impact (DRI) and monitoring existing municipal separate storm sewer system (MS4) areas for storm runoff should help ensure the best outcomes for the LSJR. Tributaries are particularly prone to turbidity events after a heavy rainfall.

2.4.6. Recommendation

Model prediction of substantial rainfall is now accurate enough to produce reliable one to two-day forecasts. Scheduling of event-based monitoring of sediment control practices based on forecast rain events is feasible. Rainfall event-based monitoring of turbidity in tributaries near major construction or development should be established in the LSJRB as a standard. Strong enforcement of existing engineering standards for sediment control as well as increased training for crews doing erosion control is recommended.

2.5. Algal Blooms

2.5.1. Description and Significance

Pristine blackwater river systems usually have low levels of planktonic primary producers (as measured by chlorophyll-*a* concentration) since the available nutrient and light levels in black water systems are low. Rapid growth of cyanobacteria (blue-green algae), which are chlorophyll-producing bacteria, has occurred in disturbed blackwater streams in the Carolinas (**Mallin, et al. 2001**) and in the St. Johns River. These organisms can tolerate lower light levels than most other aquatic organisms that conduct photosynthesis and under the right conditions of nutrients and light, can propagate profusely. This rapid planktonic growth event is referred to as a “bloom” (see the DO, Turbidity, and Nutrient sections above).

The St. Johns River and particularly its tributaries are impacted by excess nutrients in runoff and wastewater (see nitrogen and phosphorus section above), with high levels of coliform bacteria, which indicate nutrient sources from human or animal fecal contamination. High levels of nutrients and phytoplankton can lead to eutrophication, in which the ecosystem becomes unbalanced with an increase in organic matter loading to the system (**NRC 2000**). Where these conditions are present in the St. Johns River, high primary productivity of phytoplankton, may dominate the biotic processes in the aquatic ecosystem. “Blue green algae” blooms, in addition to being clearly visible events, often induce high oxygen production during the daylight hours when the cyanobacteria produce oxygen, followed at night by very low oxygen levels due to oxygen consumption from nocturnal respiration and the decay of dead biomass (see Dissolved Oxygen, Turbidity, and Nutrient sections above). This can result in low oxygen levels making it difficult for fish and other animals to thrive. Such blooms can also be so dense as to prevent sunlight from reaching the native submerged aquatic vegetation that are essential for the survival of juvenile fish and other aquatic organisms (see the Turbidity and SAV sections). Algal blooms may have increased after successful eradication efforts to control the water hyacinth, which in the past shaded much of the water column. Reduction in the water hyacinth may have contributed to the change from a floating aquatic plant system to an algal-dominated system in the LSJR (**Hendrickson 2006**; **Hendrickson 2008**).

Some algal species also produce toxins that can reach higher levels in a bloom, and these are collectively known as Harmful Algal Blooms (HAB). Two summary references on HAB by **Steidinger, et al. 1999**, and **Burns Jr 2008** are recommended reading on this subject. There is a valid question about whether harmful algal blooms are even a natural occurrence. Burns has this to say:

> *Although there is little doubt that the phenomenon of cyanobacterial blooms predates human development in Florida, the recent acceleration in population growth and associated changes to surrounding landscapes has contributed to the increased frequency, duration, and intensity of cyanobacterial blooms and precipitated public concern over their possible harmful effects to aquatic ecosystems and human health. Toxic cyanobacterial blooms in Florida waters represent a major threat to water quality, ecosystem stability, surface drinking water supplies, and public health.*

Microcystis species are cyanobacteria with photosynthetic ability and are common in the freshwater portion of the St. Johns River (**Phlips and Cichra 1998**) though only a few produce HAB. In our region, two primary freshwater HAB organisms dominate. *Anabaena circinalis* and *Microcystis aeruginosa* are two of the most widely distributed freshwater cyanobacteria HAB-generating species in Florida. (**Steidinger, et al. 1999**). The World Health Organization (WHO) has set a separate drinking water "provisional consumption" limit of $1\,\mu g/L$ for microcystin-LR, the toxin produced by *Microcystis species* (**WHO 1998**), but up to 12.5 $\mu g/L$ were detected in drinking water samples collected in a 2000 survey (**Burns Jr 2008**). Certain types of HAB organisms may be harmful to human skin and animals. Swimmers and anglers have complained of rashes after coming into contact with a bloom, which often form extensive surface scum in eutrophic waters during calm wind and hot weather conditions. (**Steidinger, et al. 1973**).

Microcystis species have been reported as dominant phytoplankton in the fresh water section of the Lower St. Johns River during all seasons (**Phlips and Cichra 1998**). Some of the other potentially toxic cyanobacteria that are known to bloom in Florida waters, in addition to *Microcystis aeruginosa,* and *Anabaena circinalis,* include *Anabaena flos-aquae, Aphanizomenon flos-aquae, Cylindrospermopsis raciborskii* (reported as a possibly recent invasive species (**Chapman and Schelske 1997**), and *Lyngbya wollei* (**Steidinger, et al. 1999**). Extensive statewide sampling reports showing that *Cylindrospermopsis* accounted for nearly 40% of 88 samples containing cyanotoxins (**Burns Jr 2008**), casts doubt on the recent introduction idea. Other potentially toxic species have been identified, such as the *Pfiesteria*-like *Crytoperidinopsoids* (**Burkholder and Glasgow Jr 1997b**; **Burkholder and Glasgow Jr 1997a**) and *Prorocentrum minimum* (**Phlips, et al. 2000**), and are often in conjunction with fish kills or ulcerative disease syndrome in fish (**Steidinger, et al. 1999**).

An oceanic dinoflagellate, *Karenia brevis*, a common component of "red tides", causes occasional HAB events in the coastal waters offshore but the influence of nutrients from the LSJR and other coastal estuaries on these HAB events is unknown. The saltwater "red tide" has been known to produce respiratory problems in humans who only visited the coast, without direct contact with the water, though it is seldom reported in the LSJR estuary (**Steidinger, et al. 1973**).

Nutrients, which include the same nitrogen- and phosphorus-based chemicals in garden fertilizer, are a common cause of impaired waters in the LSJR and are a crucial contributor to freshwater algal blooms. Much of these nutrients come from leaking septic systems, livestock, industry and runoff during and after heavy rain events. Recent work by **Hendrickson, et al. 2007** indicates that anthropogenic (man-made) nutrient enrichment has tripled the total nitrogen load in the St. Johns River, but even greater increases in the nitrogen components are linked to HAB. The weather also influences HAB, with low flow, or periods of drought increasing the likelihood of algal bloom events, while high flow and hurricane rain events decrease the likelihood (**Phlips, et al. 2007**).

Florida biologists in 1999-2000 collected a total of 167 HAB samples throughout Florida; 88 of these samples, representing 75 individual water bodies, were found to contain potentially toxic cyanobacteria. Most bloom-forming cyanobacteria genera were distributed throughout the state, but water bodies such as Lake Okeechobee, the LSJR, the Caloosahatchee River, Lake George, Crescent Lake, Doctors Lake, and the St. Lucie River (among others) were water bodies that supported extensive cyanobacterial biomass. Seven genera of cyanobacteria were identified in the statewide samples, with *Microcystis* (43.1%), *Cylindrospermopsis* (39.5%), and *Anabaena* (28.7%) the most frequently observed, and in greatest concentration. For the LSJRB the toxic species were 55.5% *Anabaena*, 53.9% *C. raciborskii*, and 47.6% *Microcystis* (**Williams, et al. 2001**; **Burns Jr 2008**).

Chlorophyll-*a* is a light-harvesting pigment molecule that is used as an indicator of algae concentration. Mean chlorophyll-*a* levels for some sections of the LSJR remain at relatively low levels, some as low as 3-6 μg/L (**DEP 2010k**)

compared to the very high levels during HAB events. Current annual mean standards for impairment of Class III water bodies are 11 µg/L for saltwater and generally 20 µg/L for freshwater. The freshwater standard is exceeded during natural algal increases each summer in eutrophic blackwater systems, and greatly exceeded in the HAB events. For the freshwater reach of the LSJR, a target of "40 µg/L chlorophyll-*a* for not more than 40 continuous days" was used as the basis for the TMDL, though it has not been adopted as a SSAC. Figure 2.15 illustrates the trend in chlorophyll-*a* from 1997 to 2011. While mean levels have fallen below the 20 µg/L standard for several years, 2010 marks the first incidence in this time series of exceedance of that level.

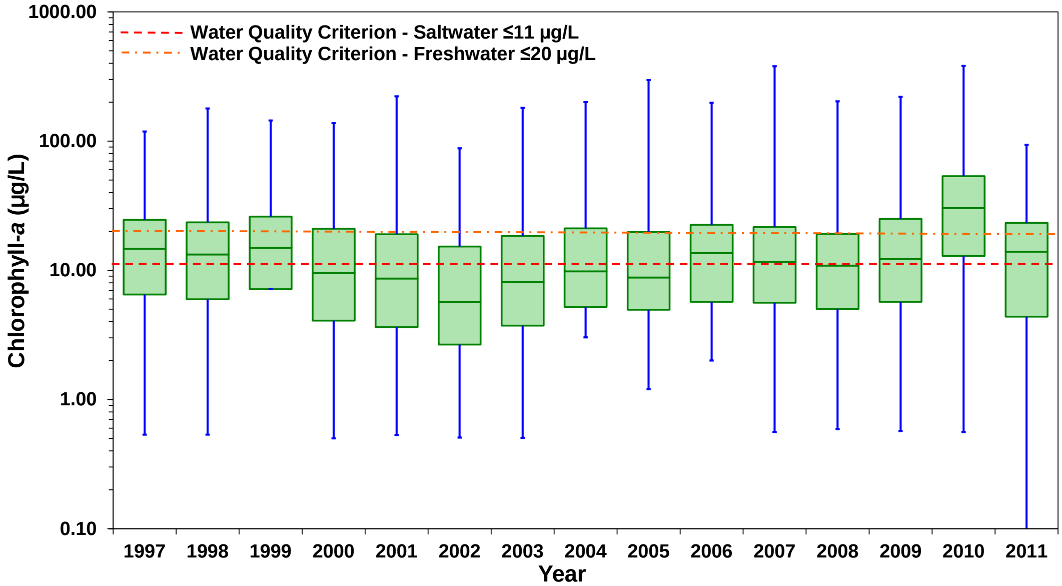


Figure 2.15 Chlorophyll-a data from 1997 to 2011 in the LSJRB.
Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

During cyanobacteria blooms in the LSJR, organisms such as juvenile fish that are unable to escape to deeper offshore, more oxygenated open water (Figure 2.16), may not survive. Typical diurnal DO cycles (over a period of 24 hours) show that DO measurements tend to increase during the day (Figure 2.17) because of photosynthesis by the primary producers (cyanobacters), and diminish at night due to cyanobacterial oxygen depletion by respiration coupled with the additional oxygen consumption by the decaying biomass of the bloom (**Steidinger, et al. 1999**).

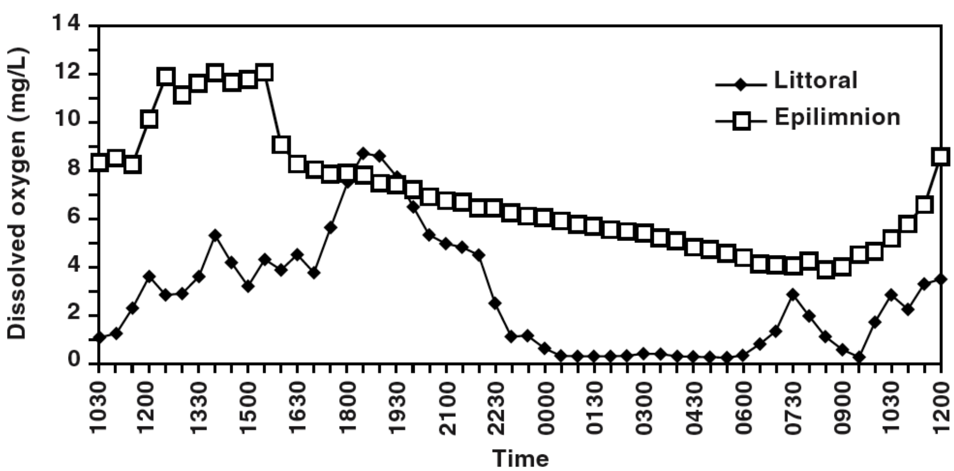


Figure 2.16 Littoral and deeper water Dissolved Oxygen during LSJR HAB event from ***Steidinger, et al. 1999***

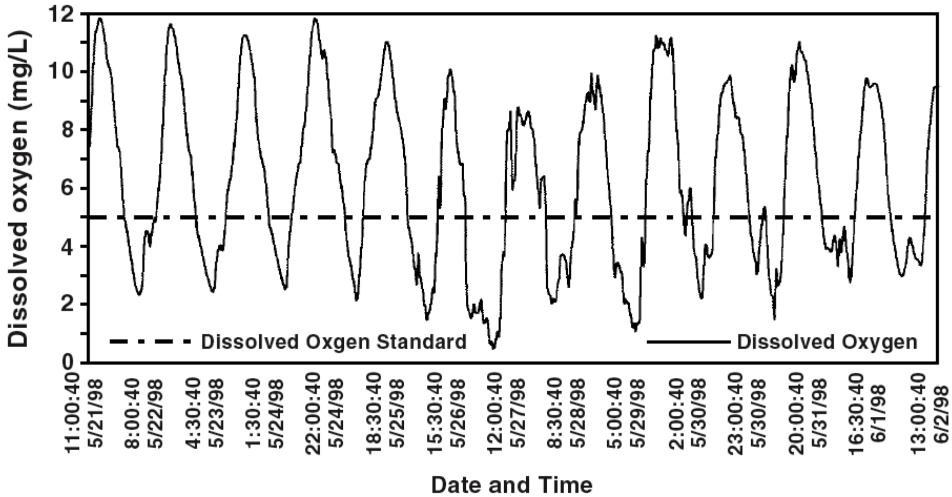


Figure 2.17 Diurnal cycles of Dissolved Oxygen during Doctors Lake HAB event in 1998 from ***Steidinger, et al. 1999*** *page 23.*

2.5.2. Data Sources

The primary source for this evaluation is the Florida STORET database and the EPA-mandated reports required by the CWA such as the Florida 303(d) report of impaired waters. These reports become the basis for future water quality management and restoration efforts. These are publicly available online at **DEP 2004** and **DEP 2009d**. Previous versions of this report used EPA STORET data instead of the Florida STORET data used this year.

2.5.3. Limitations

While there is a long history of chlorophyll-*a* sampling in the LSJR, the data are highly variable. The real-time monitoring of chlorophyll-*a* in the LSJRB proposed by the City of Jacksonville could provide early alerts to potential algal bloom events, and increased sampling could then be triggered to study these events in detail. There are many complex and unanswered questions that would benefit from more data and further research. While we know high levels of nutrients in the river have fostered "blooms" of cyanobacteria, and other algae that can sometimes be toxic to animals and humans, the specifics of toxin production are not well understood. For example, while we know which genes in specific algal species can actually lead to toxin production, there are many genetic questions about when and why toxins are triggered and produced. Similarly, additional near-shore coastal data are required to help us understand how much of the St. Johns River nutrient load may or may not contribute to "red tide" blooms along our beaches.

2.5.4. Current Conditions

High levels of nutrients in the river have contributed to blooms of cyanobacteria and algae, which though native, can sometimes be toxic to animals and humans, and may disrupt the natural balance of the ecosystem. Summer sunlight can further encourage these normally infrequent growth events. The frequency of these toxic events has not been well documented until recently, and no discrimination between HAB and non-HAB events currently is documented on a routine basis.

2.5.5. Trend

While minor algal bloom events, such as might occur near a large bird rookery, have probably occurred since formation of the LSJR, the increases in nutrient concentration over the last few decades have increased the frequency of algal blooms significantly. Recent improvements in nutrient levels since 2000 indicate nutrient reduction progress that needs to be continued.

2.5.6. Future Outlook

Reduction of HAB events is highly linked to continued progress in nutrient reduction. Continued funding of river restoration as specified in the River Accord adopted by the City of Jacksonville and its partners as announced in July 2006 will certainly help. The impact of the nutrient output from the St. Johns and other Northeast Florida rivers on coastal "red

tide" is currently unknown. Likewise, little is known about what triggers toxin production in either the fresh water or salt water HAB species.

2.5.7. Recommendations

Sophisticated DNA studies of the various cyanobacterial genomes previously mentioned, their gene products, and protein structures as well as studies of their toxins are recommended, in order to understand their production of those toxins. A long term study of cyanobacterial growth rates coupled with bioassay studies under varied nutrient loading is essential to understand algal bloom phenomena in the LSJR. Further research into the role of upstream algal seeding, as well as potential estuarine tidal seeding of diatoms is needed to understand the impact of these events on the LSJR HAB cycles.

2.6. Bacteria (Fecal Coliform)

2.6.1. Description and Significance

Fecal coliform bacteria are a natural component of digestive systems of birds and mammals. They aid in digestion, and are not normally considered harmful. Rather, they are used as water quality measures of water contamination by feces, which may indicate potential presence of disease causing organisms such as pathogenic bacteria and viruses. The EPA has set standards (EPA440/5-84-002) for recreational water quality after earlier studies by the Centers for Disease Control and Prevention (CDC) determined that few people become sick with gastroenteritis by accidentally ingesting water with 200 coliform bacteria units per 100 milliliters of water while engaged in recreational activities (**Dufour 1984**). This document can be found at **EPA 1986**.

Florida fecal coliform exceedance criteria standards for recreational contact are as follows:

> *Exceeding 800 colonies/100 milliliters for any single sample and a 30-day geometric mean exceeding 200 colonies/100 milliliters indicates that the water body sampled does not meet recreational water quality standards and contact should be avoided. Exceeding 400 colonies/100 milliliters in 10% of samples taken in a 30 day period indicates that the water body does not meet recreational water quality standards and caution should be exercised (**DEP 2009g**).*

Fecal coliform bacteria reach the river from natural sources such as free-roaming wildlife and birds. Other major sources include domestic animal and pet contamination, human contamination from failing septic tanks, sewer line breaks, and wastewater treatment facility overflows. These latter sources are often called point sources because large amounts of waste can enter the river or tributary at a single point such as an outfall pipe. Non-point sources in contrast, such as wildlife excrement, runoff and agricultural wastes from pasturelands enter the watershed from a broad area.

2.6.2. History

Conceptually, the reuse of sewage wastewater and its recycling by land-based application is not new. Use of human sewage wastes in agriculture to fertilize crops and replenish nutrients from depleted soils has been practiced by the Chinese since ancient times (**Shuval, et al. 1990**). The First Royal Commission on Sewage Disposal in England of 1865 stated "The right way to dispose of town sewage is to apply it continuously to the land and it is by such application that the pollution of the rivers can be avoided."

Modern methods of sewage disposal involve treating human sewage in wastewater treatment plants before discharging it into local waterways or the ocean. Over the last three decades, the standards for sewage treatment have become ever more stringent, particularly with the passage of the CWA in 1977. As the EPA website notes:

> *Growing public awareness and concern for controlling water pollution led to enactment of the Federal Water Pollution Control Act Amendments of 1972. As amended in 1977, this law became commonly known as the Clean Water Act. The Act established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry. The Clean Water Act also continued requirements to set water quality standards for all contaminants in surface waters (**EPA 2008**).*

This law required the nation's publicly owned sewer systems to remove 90% of the solid matter, and to disinfect the effluent (**Shabecoff 1988**), which was usually done with chlorine, to protect streams and rivers. Recently there has been a trend to move from chlorine to other oxidants (such as peroxides, oxygen, or ultraviolet light) because chlorine by-

products may be harmful (**Jolley, et al. 1982**). The City of Jacksonville passed Environmental Protection Board (EPB) Rule 3 to improve water quality in Duval County (1987). This led to a phase-out of the existing but less reliable local wastewater treatment plants (Figure 2.18), many of which were unable to meet the higher standards. Consolidation into larger regional treatment plants helped meet the higher standards.

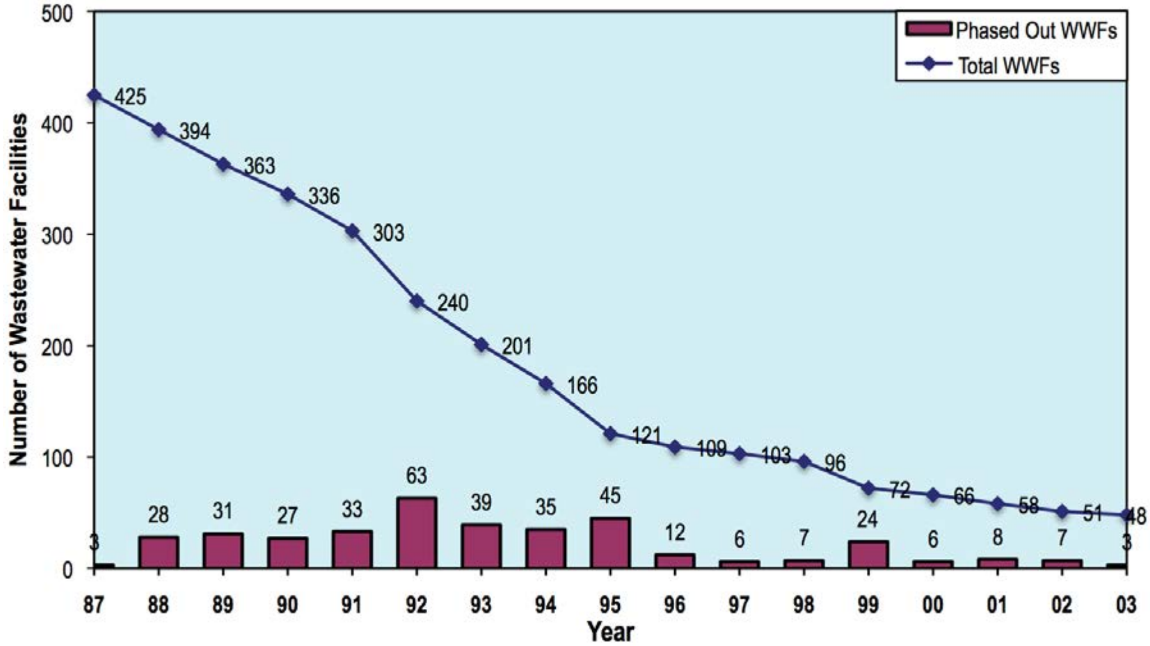


Figure 2.18 Waste Water Treatment Facilities in Duval County by Year. Since the Implementation of EPB Rule 3. Source: ***COJ 2009***

When fecal coliform levels were measured many of the tributaries in the LSJR were out of compliance. Jacksonville made the news when DEP and the St. Johns Riverkeeper noted that "the ocean would be closed to swimmers" at those contamination levels, although actual bathing areas are addressed by different standards and rules. The 50 water bodies that were so listed had measured an average above 400 bacterial colony forming units per 100 milliliters of water. Several sites had count levels in the thousands and a few in tens of thousands. The St. Johns Riverkeeper's website (**St. Johns Riverkeeper 2008**) lists the impaired streams (**DEP 2009d**). Many of these impairments have been traced to leaking or failed septic systems.

2.6.3. TMDL and BMAP Updates

Actions are underway to monitor and correct problems with fecal coliform in LSJR tributaries. At the time of this writing, no current fecal coliform TMDLs are in draft form, but several moved from draft to final form in 2010-2011. These include Cormorant Branch, Craig Creek, Fishing Creek, Greenfield Creek, and Hopkins Creek. The set of 36 tributaries with final fecal coliform TMDLs appears below.

Big Davis Creek	Craig Creek	Greene Creek	Little Black Creek	Newcastle Creek	Sherman Creek
Big Fishweir Creek	Deep Bottom Creek	Greenfield Creek	McCoy Creek	Open Creek	Strawberry Creek
Block House Creek	Deer Creek	Grog Branch	Mill Creek	Ortega River	Terrapin Creek
Butcher Pen Creek	Durbin Creek	Hogan Creek	Miller Creek	Peters Creek	Trout River
Cedar River	Fishing Creek	Hopkins Creek	Miramar Creek	Pottsburg Creek	Wills Branch
Cormorant Branch	Goodbys Creek	Julington Creek	Moncrief Creek	Ribault River	Williamson Creek

A final fecal coliform BMAP was released in August 2010 for 15 LSJR tributaries: Craig Creek, McCoys Creek, Williamson Creek, Fishing Creek, Deep Bottom Creek, Moncrief Creek, Block House Creek, Hopkins Creek, Corporate Branch, Wills Branch, Sherman Creek, Greenfield Creek, Pottsburg Creek, Upper Trout River, and Lower Trout River (**DEP 2010a**). An Annual Progress Report on a previously released BMAP was also released. This Annual Progress Report addresses ten tributaries: Newcastle creek, Hogan Creek, Butcher Pen Creek, Miller Creek, Miramar Creek, Big Fishweir Creek, Deer Creek, Terrapin Creek, Goodbys Creek, and Open Creek (**DEP 2011a**).

2.6.4. Mainstem of the LSJR

The mainstem of the LSJR, as opposed to its tributaries, has been monitored for fecal coliform and other water quality parameters at several sites from Welaka to Arlington (Jacksonville) under the FDEP "River-at-a-Glance" program, and these measurements show that through 2008 the main stem of the LSJR is clearly in compliance for fecal coliform (**DEP 2009h**). Fecal coliform monitoring through "River-at-a-Glance" has been discontinued as of 2009 but is ongoing in other programs.

2.7. Metals

2.7.1. Description and Significance

Naturally occurring trace metals such as copper, zinc, and nickel are essential micronutrients required by all organisms; however in excess these metals can be toxic (**Bryan and Hummerstone 1971**; **Bury, et al. 2003**; **Bielmyer, et al. 2005a**; **Bielmyer, et al. 2006a**). Anthropogenic (man-made) contributions of excess metals in aquatic environments are generally greater than natural contributions (**Eisler 1993**). Human activities lead to increased levels of essential metals, as well as non-essential metals, such as arsenic, cadmium, and silver.

Copper and zinc are two of the most widely used elements in the world and as such are common pollutants found in freshwater and marine ecosystems. Copper enters marine systems through runoff from rivers adjacent to heavy metal mining areas (**Bryan 1976**); through sewage treatment discharge, industrial effluent, anti-fouling paints, refineries, as well as overflow from stormwater ponds (**Guzman and Jimenez 1992**; **Jones 1997**; **Mitchelmore, et al. 2003**). Zinc is a major component of brass, bronze, rubber, and paint and is introduced into water systems via commercialized businesses (smelting, electroplating, fertilizers, wood preservatives, mining, etc.) and rainwater run-off (**Eisler 1993**). Although there are freshwater environments with only a few micrograms of zinc per liter, some industrialized areas may have problematic concentrations of over 1000 μg/L Zn (**Alsop and Wood 2000**). Along with copper and zinc, nickel-containing materials make major contributions to many aspects of modern life. The uses of nickel include applications in buildings and infrastructure such as stainless steel production and electroplating; chemical production, such as production of fertilizers, pesticides and fungicides; energy supply, water treatment, and coin production (Nriagu, 1980; Bryan, 1984; **Hoang, et al. 2004**; Lappalainen et al., 2006). The largest use of nickel alloys and a major use of copper and zinc are in corrosion prevention. Although these applications have provided many benefits, they have resulted in increased environmental concentrations, which may have significant impact on aquatic life (Pane et al., 2003; **Hoang, et al. 2004**). Elevated silver concentrations in aquatic animals occur near sewage outfalls, electroplating plants, mine waste sites, or areas near which clouds have been seeded with silver iodide. The photographic industry has been the major source of anthropogenic silver discharges in the United States (**Eisler 1996**).

Metal concentrations in seawater generally range from 0.003-16 μg/L Zn (**Bruland 1980**; **Bruland 1983**), 0.13-9.5 μg/L Cu (**Kozelka and Bruland 1998**), 0.2 to 130 μg/L Ni (**DETR 1998**; **WHO 1991**), and from 0.001 to 0.1 μg/L Ag (**Campbell, et al. 2000**). The highest metal concentrations reported were measured in estuaries with significant anthropogenic inputs. However, in most cases the concentration of organic ligands, such as humic and fulvic substances, as well as the concentration of inorganic ligands in seawater exceed metal concentrations thereby forming complexes and rendering metals less bioavailable to aquatic organisms (**Campbell 1995**; **Kramer, et al. 2000**; **Stumm and Morgan 1996**; **Turner, et al. 1981**; **Wang and Guo 2000**). Aquatic animals, particularly zooplankton, have been shown to be highly sensitive to these metals (**Bielmyer, et al. 2006a**).

Arsenic and many of its compounds are especially potent poisons, especially to insects, thereby making it well suited for the preservation of wood, which has been its primary historical use. Chromated copper arsenate, also known as CCA or Tanalith has been used worldwide in the treatment of wood; however, its use has been discontinued in several areas because studies have shown that arsenic can leach out of the wood into the soil, potentially causing harmful effects in animals and severe poisoning in humans (**Rahman, et al. 2004**).

All of these metals tend to adsorb to sediments over time (see Contaminants section); however, disturbance of the sediment or changing water conditions can remobilize the contaminants back into the water column where they may exert a toxic effect on aquatic animals.

2.7.2. *Data Sources*

All data were obtained from the FDEP STORET database. STORET is a computerized environmental data system containing water quality, biological, and physical data. Total metal concentrations from surface waters of the LSJR were used in this analysis. EPA methods 200.7, 200.8, and 206.2 were used to measure arsenic; EPA methods 200.7, 200.8, 213.2, and 6010B were used to measure cadmium; EPA methods 200.7, 200.8, 220.2, and 6010B were used to measure copper; EPA methods 200.7, 200.8, 249.2, and 6010B were used to measure nickel; EPA methods 200.7, 200.8, 272.2, and 6010B were used to measure silver; and EPA methods 200.7, 200.8, and 6010B were used to measure zinc. Data points below minimum detection limits were not used in these analyses.

The LSJR varies in salinity, with the main stem predominantly freshwater and some of the tributaries ranging from fresh- to full strength seawater. Salinity may affect the toxicity of some metals to aquatic life therefore the EPA class III Water Quality Criterion (WQC) values may be different for freshwater and marine water. Likewise, for freshwater, hardness, defined as the total concentration of the divalent cations calcium and magnesium, has also been shown to reduce the toxicity of the metals cadmium, copper, nickel, and zinc; therefore the freshwater criterion is based on an equation which incorporates the hardness of the water body. For the hardness dependent metals in this analysis, an average hardness value of 100 mg $CaCO_3$/L was used for generating the freshwater criteria.

The WQC for marine (haline; surface chloride concentration ≥ 1,500 mg/L) waters was also used for all of the metals, except for silver, for which no marine water quality criterion has currently been adopted by the U.S.EPA. Therefore, the current proposed WQC value for silver has been used. It must be pointed out that the freshwater and marine WQC are the same for some metals, like arsenic, for example. However, for other metals, like cadmium, the freshwater WQC is substantially different (0.27 μg/L at 100 mg/L hardness) from the marine criterion of 8.8 μg/L. Therefore, for river segments or water bodies that have no saltwater influence, the potential for environmental impacts of certain metals may vary.

Data are presented in box and whisker plots, which consist of a five number summary including: a minimum value; value at the first quartile; the median value; the value at the third quartile; and the maximum value. The size of the box is a measure of the spread of the data with the minimum and maximum values indicated by the whiskers. The median value is the value of the data that splits the data in half and is indicated by the horizontal blue line in the center of the boxes.

2.7.3. *Limitations*

Data used from the FDEP STORET database are of higher quality but are less abundant than data from the EPA STORET. Also, data points below minimum detection limits were not used in these analyses.

2.7.4. *Current Status and Trends*

In the last two years, a pattern of reduced metal concentrations, particularly the maximum values was observed, as compared to previous years, with a few noted exceptions. This reduction in metal concentration may reflect the recent efforts associated with TMDLs. With all but one exception (elevated maximum value) in 2000, the arsenic minimum, median, and maximum values have been below the WQC of 50 μg/L since 1997 (Figure 2.19). Since 2005, all cadmium concentrations have been below the saltwater criterion of 8.8 μg/L and the majority of the data are now below the acceptable limit in freshwater (Figure 2.20). However, in freshwater areas of the LSJR, cadmium may be problematic, as the maximum values detected in the LSJR have been consistently above the freshwater criterion in all years but 2010 (Figure 2.20). Copper was the most commonly found metal in the LSJR, based on this data set. Through 2009, maximum copper concentrations well exceeded both the saltwater and freshwater criteria of 3.7 μg/L and 9.3 μg/L (Figure 2.21). In 2010, maximum values declined and were near the freshwater criteria; however, maximum copper concentrations in 2011 were again detected above acceptable limits in both freshwater and saltwater. Due to the magnitude of copper elevation above the saltwater criterion, copper may be more problematic in saline parts of the river (Figure 2.21). Similar to copper, maximum nickel concentrations have been consistently elevated above the saltwater and freshwater criteria of 8.3 μg/L and 52 μg/L, respectively. Since 2010, however, all nickel concentrations were below both criteria (Figure 2.22). Median and maximum silver concentrations have generally been substantially elevated above the freshwater criterion of 0.07 μg/L from 1997 through the present time. Maximum silver concentrations decreased below the proposed saltwater criterion of 0.92 μg/L in 2010; however, in 2011, maximum silver concentrations again exceeded the saltwater criterion (Figure 2.23).

Maximum zinc concentrations have fluctuated above the freshwater criterion of 86 µg/L and the saltwater criterion of 120 µg/L from 1997 to 2007 (Figure 2.24). Since then, however, zinc concentrations have declined and are now below both criterion values and within acceptable limits.

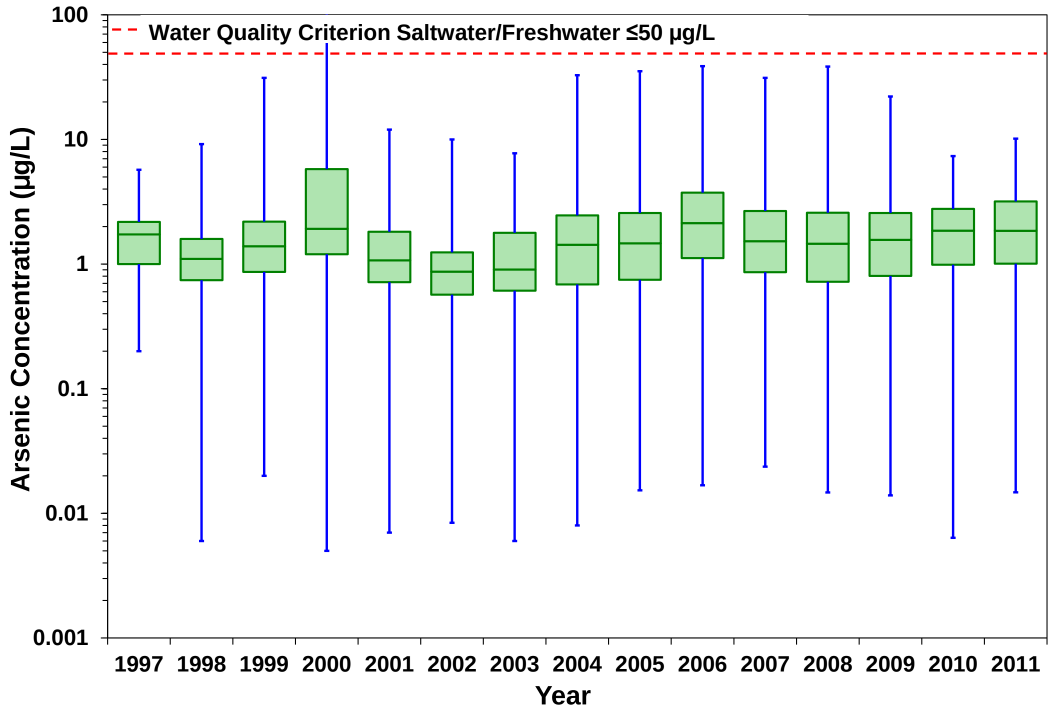


Figure 2.19 Yearly arsenic concentrations (µg/L) from 1997 to 2011 in the Lower SJR.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for both marine waters and freshwaters.

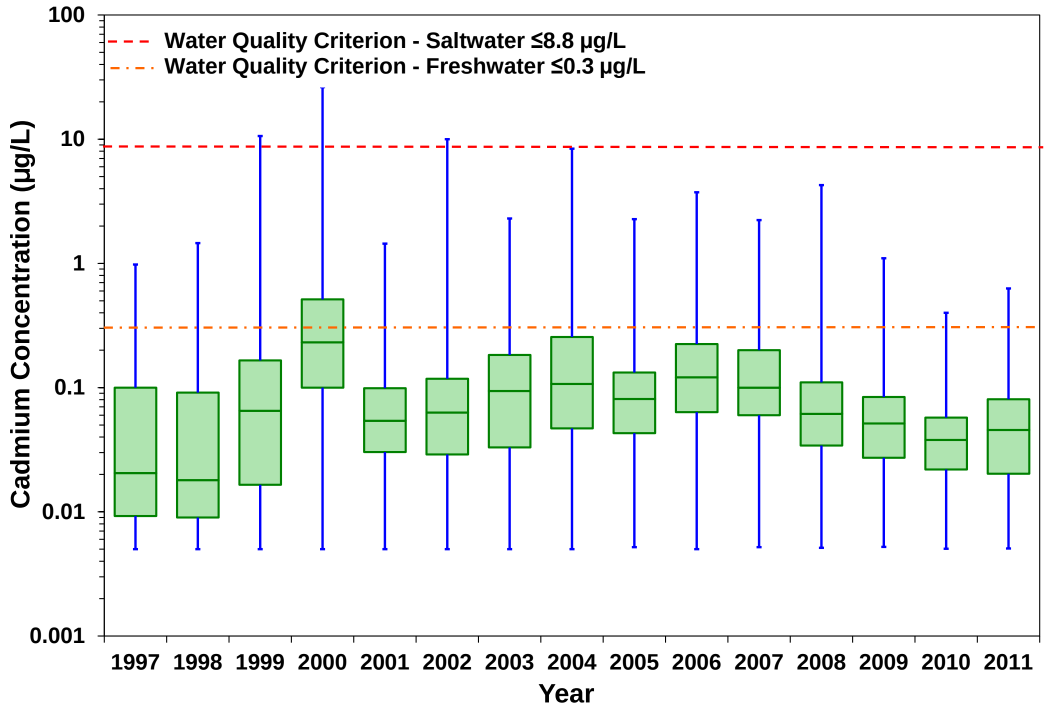


Figure 2.20 Yearly cadmium concentrations (µg/L) from 1997 to 2011 in the Lower SJR.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

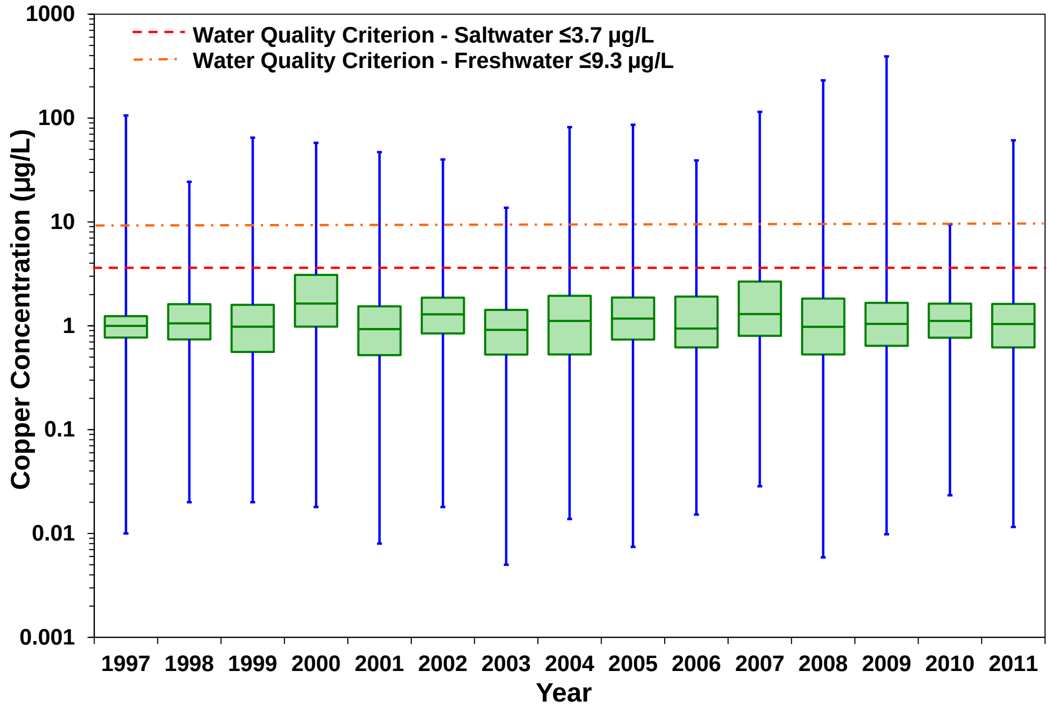


Figure 2.21 Yearly copper concentrations (µg/L) from 1997 to 2011 in the Lower SJR.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

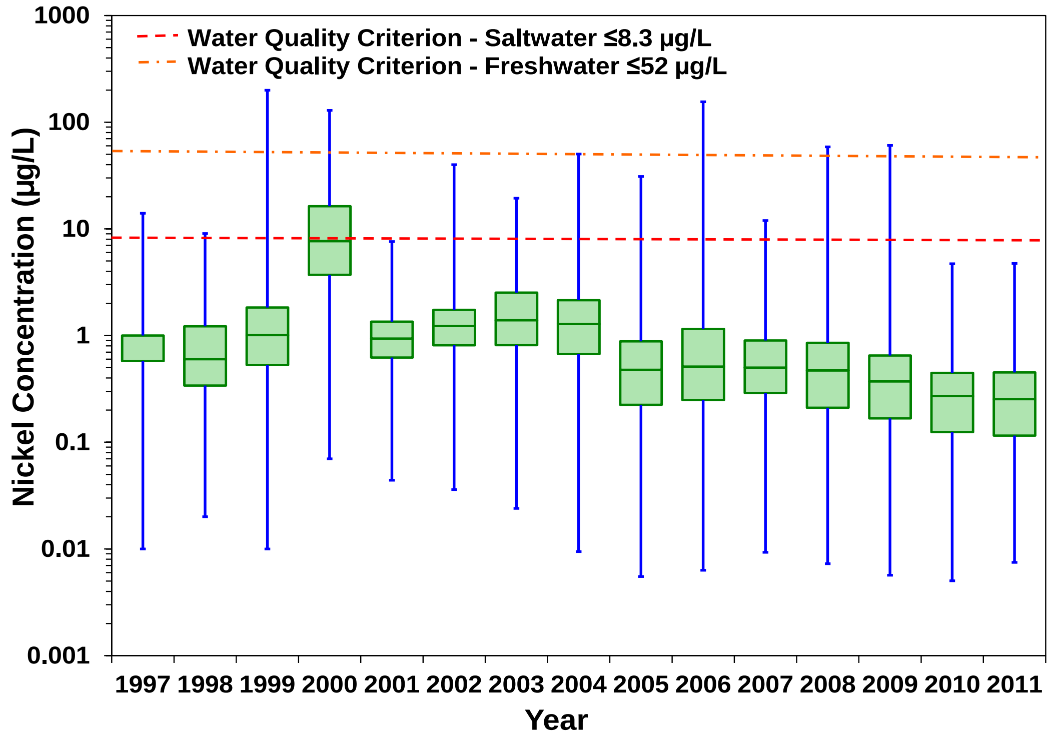


Figure 2.22 Yearly nickel concentrations (µg/L) from 1997 to 2011 in the Lower SJR.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

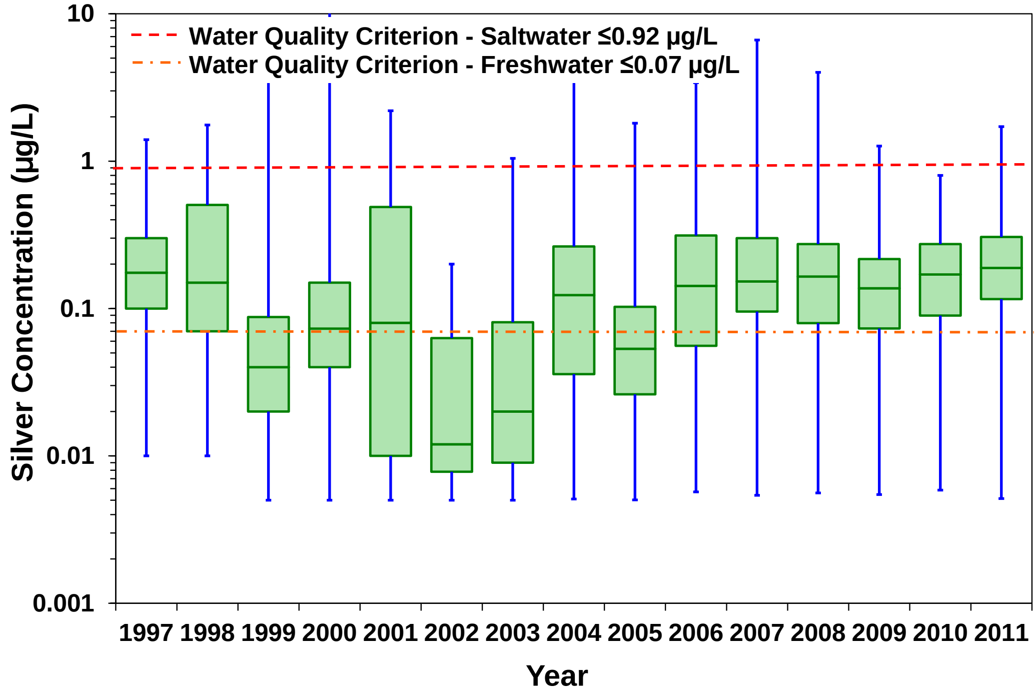


Figure 2.23 Yearly silver concentrations (µg/L) from 1997 to 2011 in the Lower SJR.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

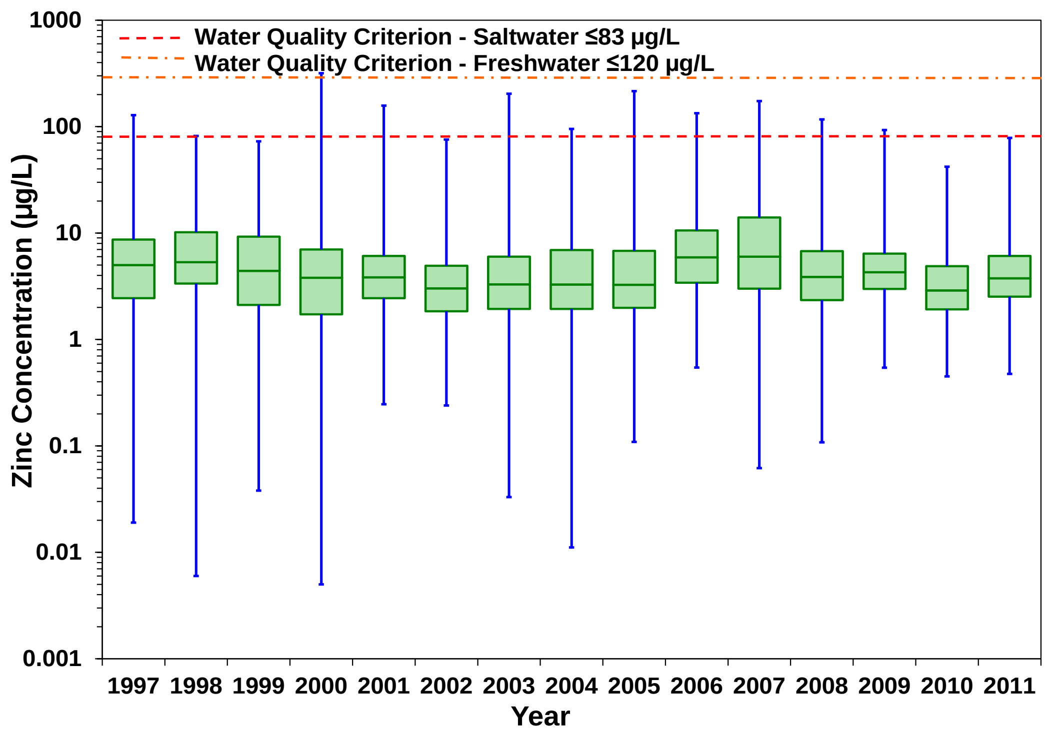


Figure 2.24 Yearly zinc concentrations (µg/L) from 1997 to 2011 in the Lower SJR.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set. The dotted red horizontal line indicates the class III water quality criterion for predominantly marine waters and the dashed orange line indicates the criterion for mostly freshwaters.

2.7.5. *Future Outlook*

The metals analyzed in this report are widely used and therefore continue to enter the LSJR through point and nonpoint sources. However, with the exception of copper, the majority of the metal concentrations detected in the water column

were at or below WQC the last three years. It should be noted that sediments act as a reservoir and may still contain high metal concentrations (see contaminant section). If sediments are disturbed, metals may be remobilized into the water column and may negatively impact aquatic life in the LSJR (see toxicology section). The magnitude of potential impact is dependent on many concurring abiotic and biotic factors.

2.8. Tributaries

2.8.1. About the Tributaries

Water quality data were examined in detail for twenty-three tributaries in the LSJRB. Their selection was based upon several factors. First, the basin was divided into the eleven Planning Units that were initially established by the SJRWMD and subsequently adopted by DEP (**DEP 2002**). These Planning Units include Crescent Lake, Etonia Creek, Black Creek, Deep Creek, Sixmile Creek, Julington Creek, the Ortega River, the Trout River, the Intracoastal Waterway, the north main stem, and the south main stem. Each Planning Unit is made up of several waterbodies (parts of the river system) referred to by their water body identifiers (WBIDs). Then, each Planning Unit was reviewed, in order to choose WBIDs for analysis. A WBID was selected for analysis if it had enough sampling sites at which data had been collected. Often, if a WBID was on the verified impaired list in 2004 or 2009, it was selected for analysis. Some unimpaired WBIDs were chosen because they are historically important or used frequently for recreation.

For each of these twenty-three tributaries, data were extracted (by characteristic) from FL STORET and organized by WBID. The datasets were filtered to remove data that was deemed to be "invalid" for one or more of the following reasons.

- FDEP Value Qualifier of K, L, O, Q, T, Y, ?, or * (indicates a problem with the analysis)
- Data points that were recorded as "Not Detected"
  (However, points where the value in the comments was lower than the PQL but greater than the MDL were included)
- Data points that had comments indicating the reliability of the data was in question
- Data points where the "value" reported was below the minimum detection limit (MDL)

The number of sampling sites and the number of measurements of each water quality characteristic available at each sampling site were assessed. For a given water quality characteristic, if a tributary had a minimum of four sampling sites with ten data points, the sampling sites were graphed on an downstream-to-upstream basis; these graphs appear in each individual tributary's section of this report. The data on each of the tributaries, including those that did not have a minimum of four sampling sites with ten data points for a given water quality characteristic, were averaged and reduced to a single point on a graph of all the tributaries' values for that water quality characteristic; these graphs appear in Sections 2.2 through 2.7.

Figures 2.26 through 2.37 are included to allow the reader a visual comparison of dissolved oxygen, nutrients, dissolved metals, fecal coliform, turbidity, and metals across the different tributaries (based on available valid data – see above - for each tributary 1997-2011).

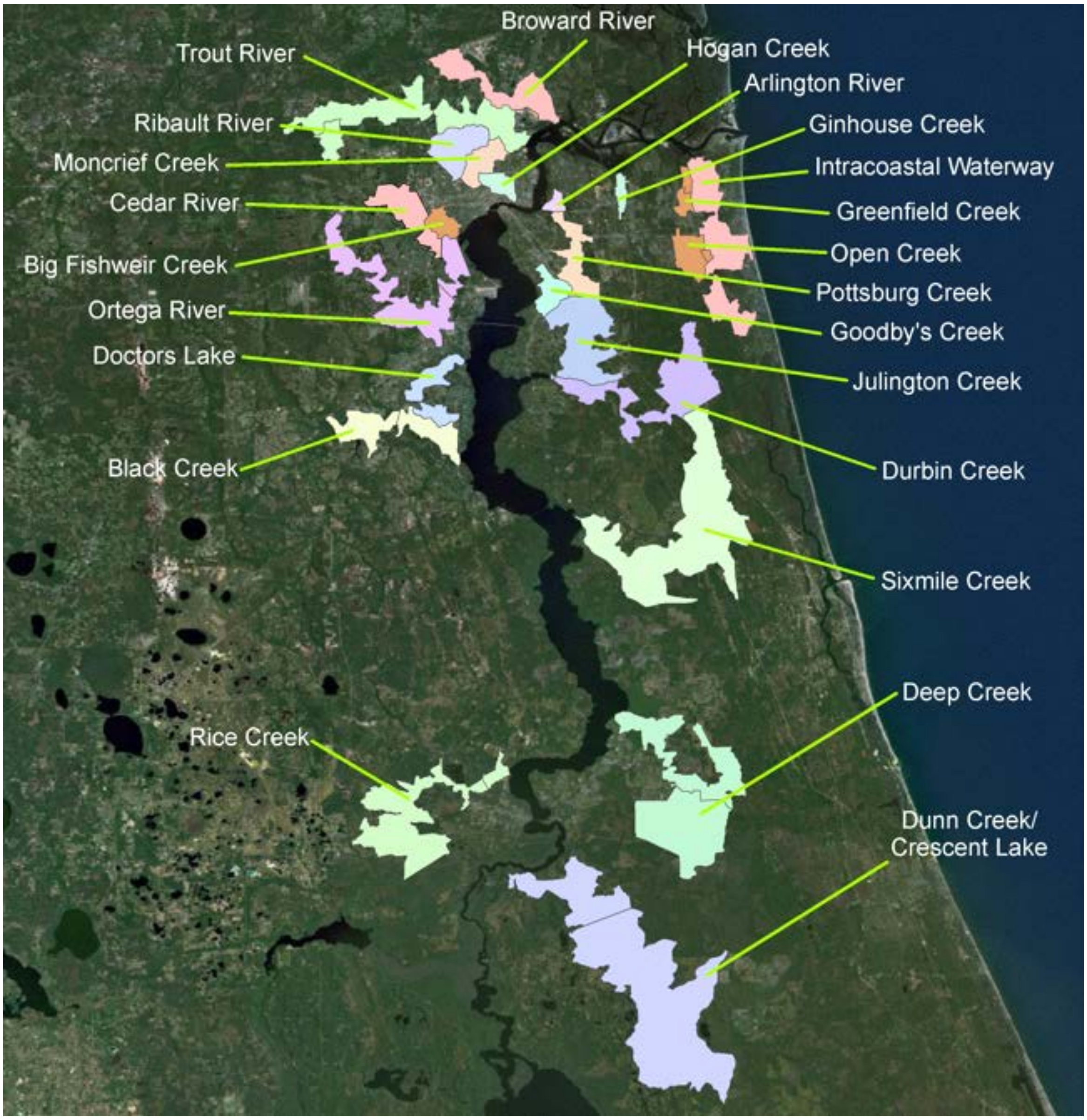


Figure 2.25 Tributaries of the Lower St. Johns River Basin (LSJRB)

Tributary Comparison Key

ARL – Arlington River	**DOC – Doctors Lake**	**HOG – Hogan Creek**	**POT – Pottsburg Creek**
BIG – Big Fishweir Creek	**DUN – Dunns Creek**	**INT – Intracoastal Waterway**	**RIB – Ribault River**
BLA – Black Creek	**DUR – Durbin Creek**	**JUL – Julington Creek**	**RIC – Rice Creek**
BRO – Broward River	**GIN – Ginhouse Creek**	**MON – Moncrief Creek**	**SIX – Sixmile Creek**
CED – Cedar River	**GOO – Goodbys Creek**	**OPN – Open Creek**	**TRO – Trout River**
DEE – Deep Creek	**GRN – Greenfield Creek**	**ORT – Ortega River**	

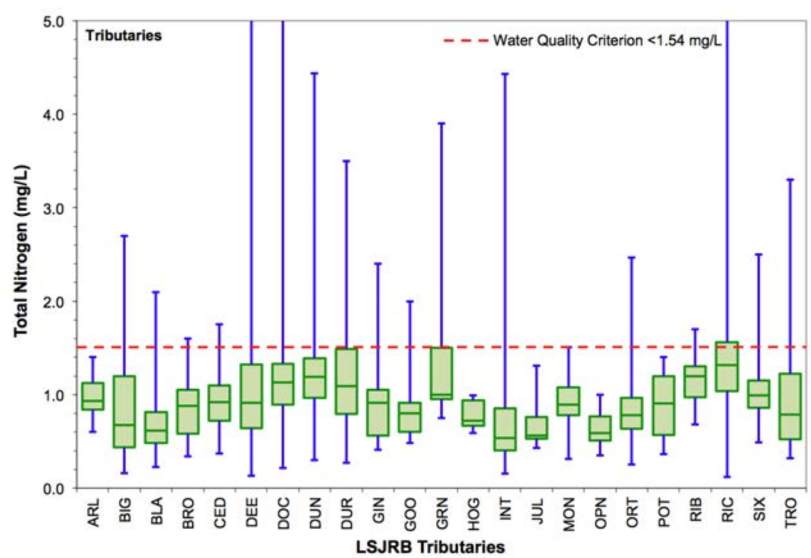


Figure 2.26 Total Nitrogen variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

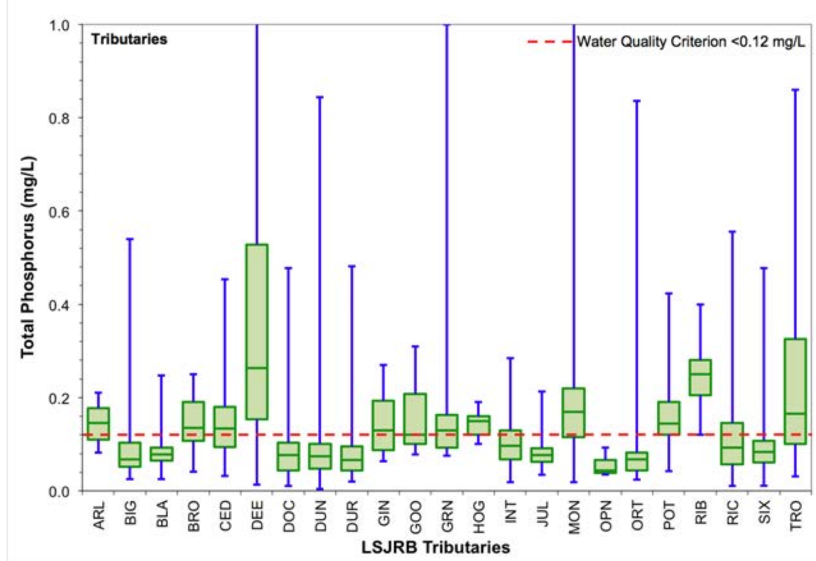


Figure 2.27 Total Phosphorus variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

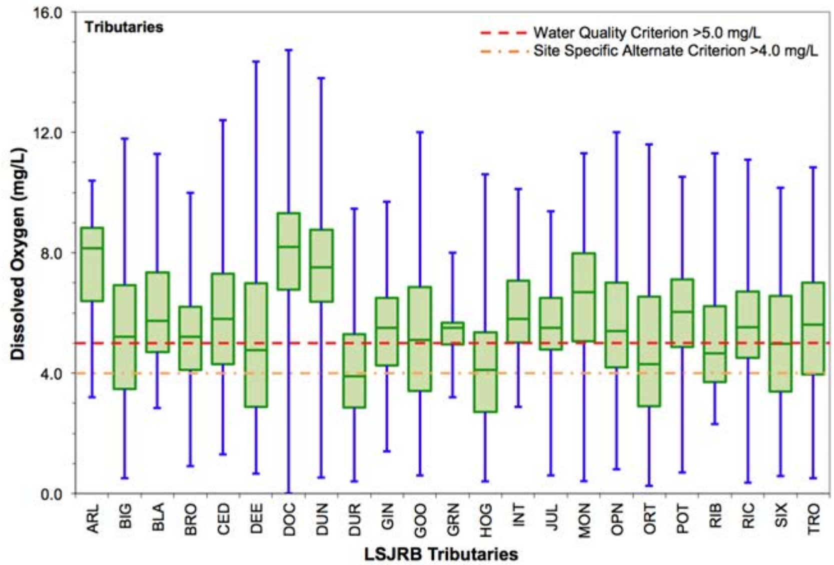


Figure 2.28 Dissolved Oxygen variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

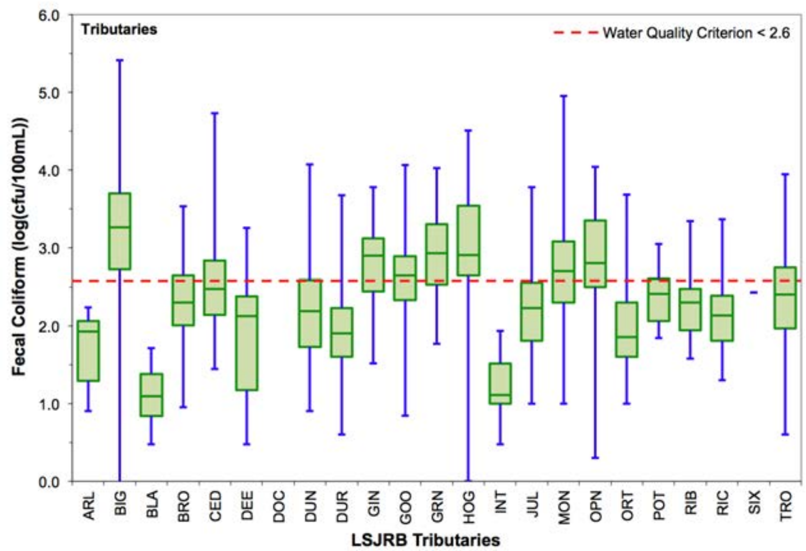


Figure 2.29 Fecal coliform variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

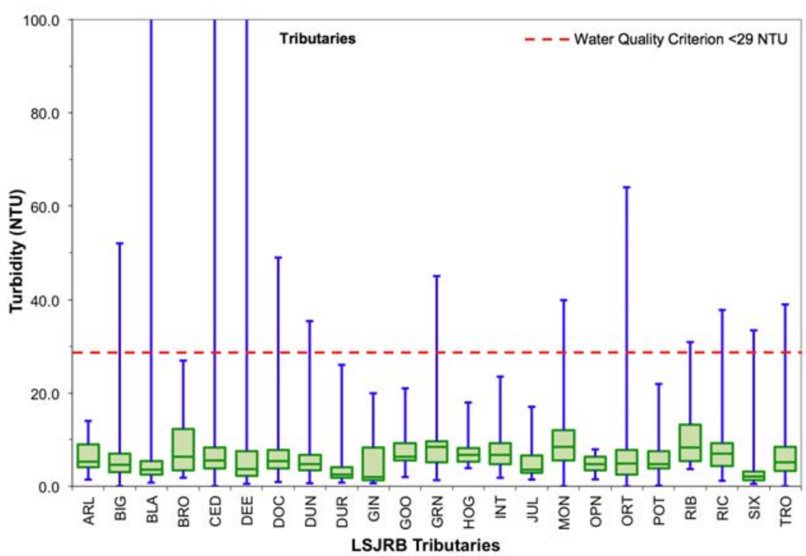


Figure 2.30 Turbidity variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

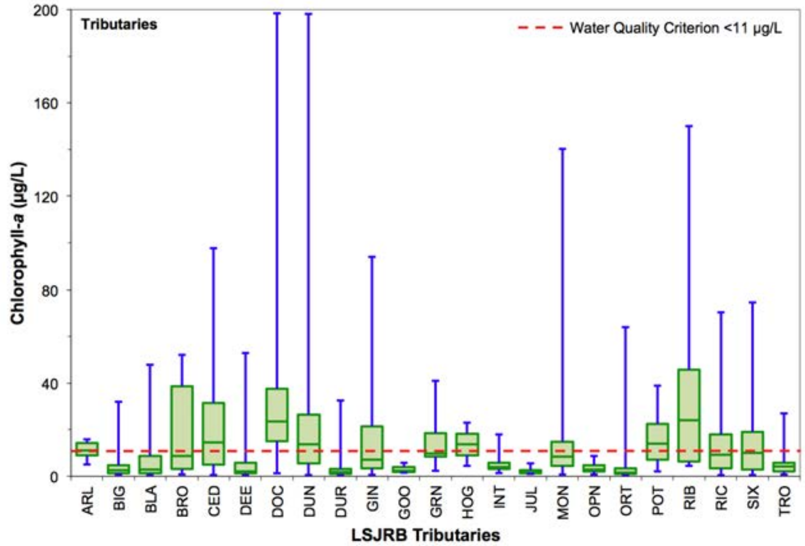


Figure 2.31 Chlorophyll-a variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

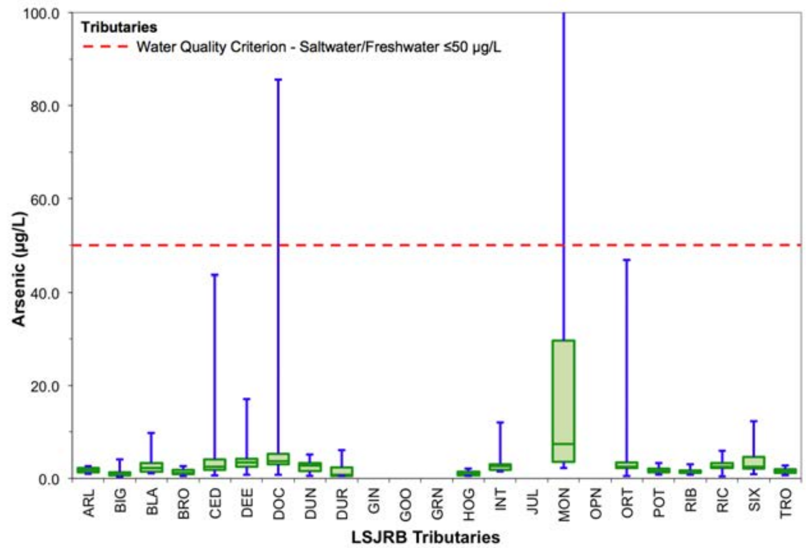


Figure 2.32 Water column arsenic variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

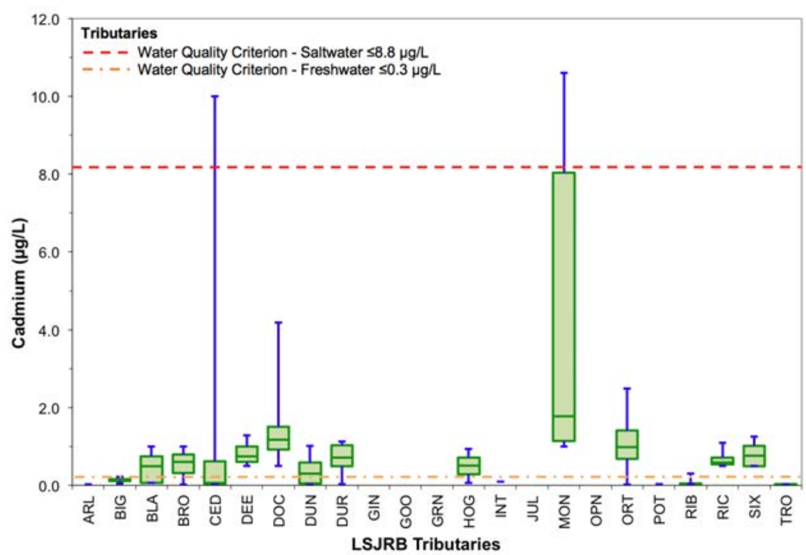


Figure 2.33 Water column cadmium variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

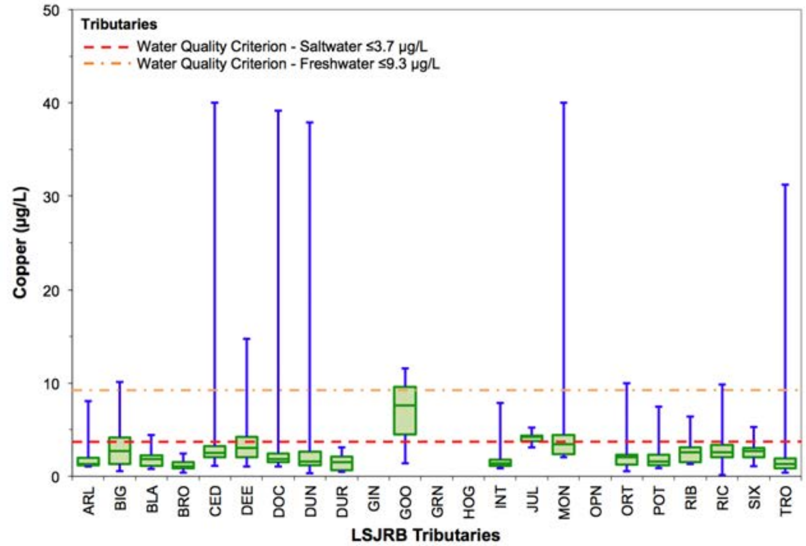


Figure 2.34 Water column copper variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

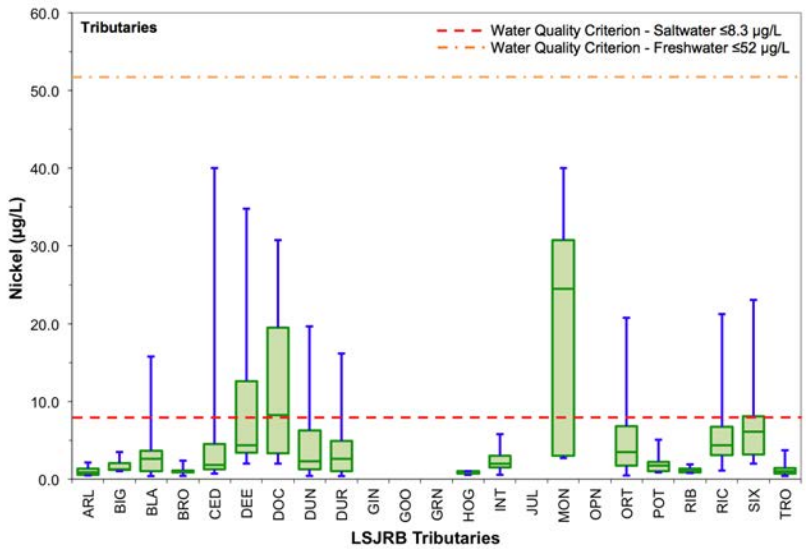


Figure 2.35 Water column nickel variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

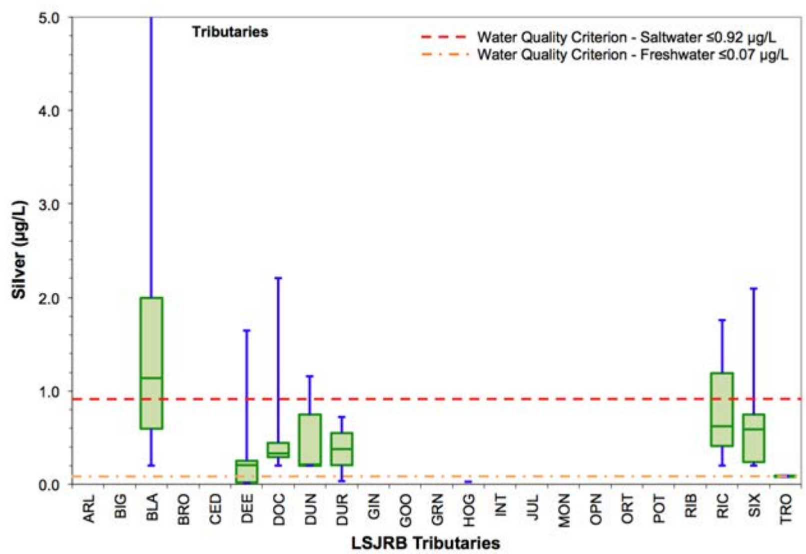


Figure 2.36 Water column silver variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

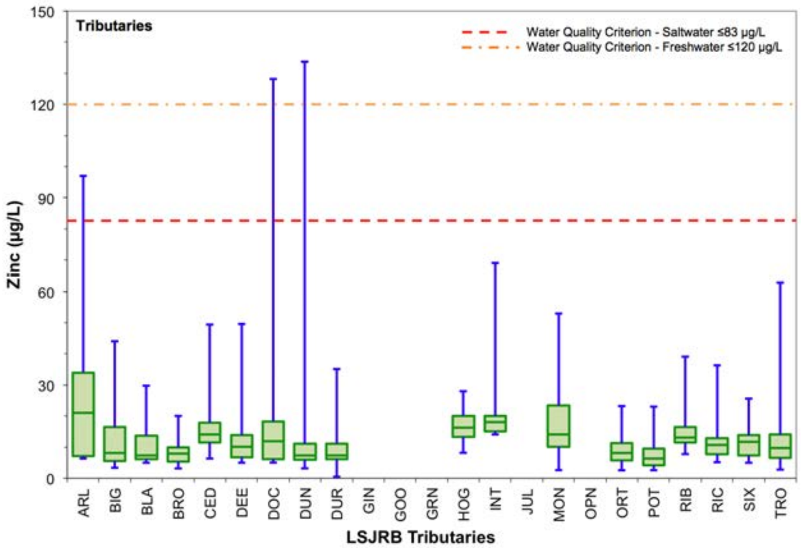


Figure 2.37 Water column zinc variation over twenty-three tributaries of the Lower St. Johns River Basin (see key above for tributary codes)

2.8.2. Arlington River

2.8.2.1. <u>About the Arlington River</u>

- East of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL Documents: Nutrients
- Verified Impaired 2009 (priority): Mercury (high)
- WBID Area: 1.6 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

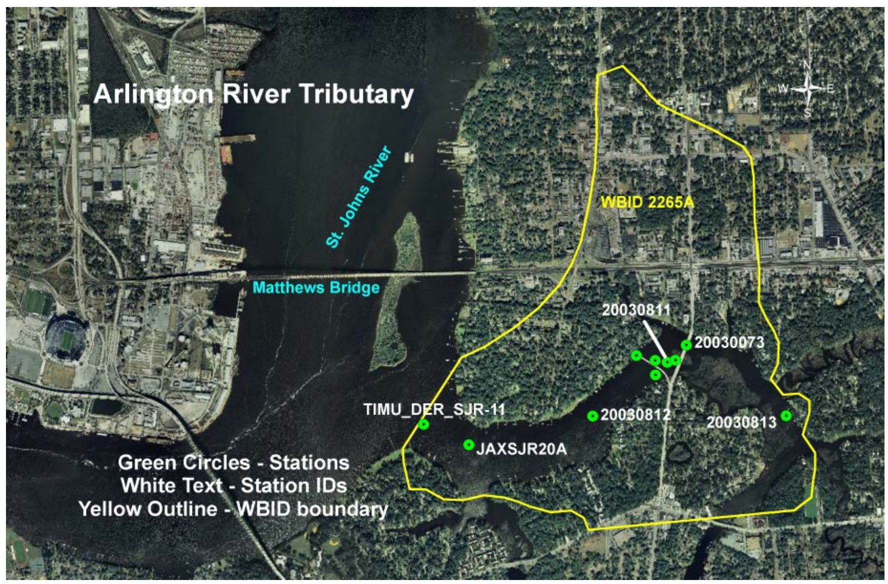


Figure 2.38 The Arlington River Tributary (WBID 2265A)

2.8.2.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Arlington River WBID 2265A (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.38) above and the graphs/tables in this section.

2.8.2.3. <u>Discussion</u>

Water quality data for the Arlington River are shown in Table 2.1. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**) and the tributary has thus been identified as impaired for nutrients. Elevated levels of phosphorus may be a result of effluent from the Monterey WWTF that is discharged into the river, fertilizer runoff from the surrounding residential area, or other unidentified sources. A TMDL document for nutrients was finalized in 2009 (**Magley 2009b**).

The Arlington River has been identified as being impaired for mercury based on fish advisories (**Donner 2008**), and this will be addressed in the recently revised draft statewide mercury TMDL document (**DEP 2012c**) scheduled for completion in 2013.

Table 2.1 Water Quality Data for the Arlington River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	3.20	7.47	10.4	20	1982 - 2008
Total Nitrogen (mg/L)	<1.54	0.60	0.97	1.40	12	2007
Total Phosphorus (mg/L)	<0.12	0.082	0.143	0.210	14	2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	5.10	11.3	16.0	10	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	0.99	1.82	2.70	13	2007 - 2008
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.022	0.022	0.022	3	2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	1.03	1.81	8.10	15	2007 - 2008
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.45	1.06	2.13	4	2007
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	6.30	28.1	97.0	11	1982 - 2008
Fecal Coliform (log #/100 mL)	<2.6	0.90	1.90	2.24	11	2007
Turbidity (NTU)	<29	1.40	24.9	1298	125	1998 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.3. Big Fishweir Creek

2.8.3.1. About Big Fishweir Creek

- West of Downtown, South of I-10
- Primary Land Use: Residential
- Current TMDL Documents: Fecal Coliform with BMAP (2009)
- Verified Impaired 2009 (priority): None
- WBID Area: 3.7 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.39 Big Fishweir Creek (WBID 2280)

2.8.3.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Big Fishweir Creek WBID 2280 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.39) above and the graphs/tables in this section.

2.8.3.3. Discussion

Water quality data for Big Fishweir Creek are shown in Table 2.2. Recently a TMDL document (**Wainwright and Hallas 2009a**) was released to address Fecal coliform (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP to address this issue was published (**DEP 2009b**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011a**) and 2012 (**DEP 2012a**); they list several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.2 Water Quality Data for Big Fishweir Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.50	5.25	11.8	136	2003 - 2010
Total Nitrogen (mg/L)	<1.54	0.16	0.83	2.70	76	1999 - 2010
Total Phosphorus (mg/L)	<0.12	0.025	0.101	0.540	97	2003 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.68	6.95	32.0	12	2005 - 2008
Arsenic (µg/L)	≤50 FW ≤50 SW	0.34	0.77	4.10	19	2007 - 2010
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.046	0.139	0.230	4	2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.56	3.06	10.1	13	2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	1.00	1.76	3.50	11	2007
Silver	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	3.33	5.39	44.0	26	2003 - 2008
Fecal Coliform (log #/100 mL)	<2.6	-0.52	1.98	5.41	153	1999 - 2011
Turbidity (NTU)	<29	0.85	6.27	52.0	175	1999 - 2011

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.4. Black Creek

2.8.4.1. About Black Creek

- West of the St Johns River at the Clay/Duval county line
- Primary Land Use: Forested
- Current TMDL Documents: Lead – 2415B
- Verified Impaired 2009 (priority): Lead – 2415B (high)
- WBID Area: 15.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

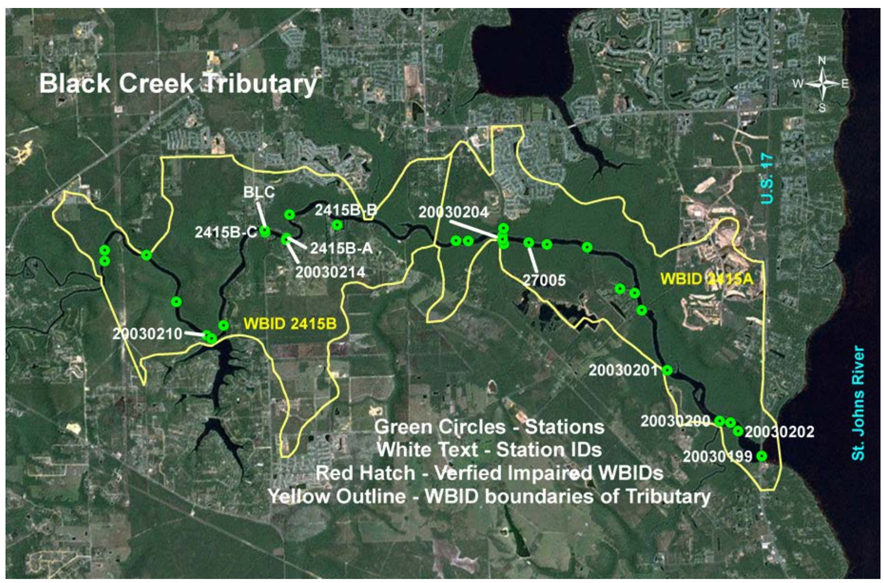


Figure 2.40 The Black Creek Tributary (WBID 2415A/B)

2.8.4.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Black Creek WBID 2415A/B (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.40) above and the graphs/tables in this section.

2.8.4.3. Discussion

Water quality data for Black Creek are shown in Table 2.3. As compared to other tributaries in the LSJR, Black Creek is less impacted for many of the assessed water quality parameters. While average dissolved oxygen levels generally remained above the site-specific WQC; in summer months dissolved oxygen decreased below this limit (Table 2.3; Figure 2.41). This variation has been determined to be the natural condition of Black Creek (**DEP 2009c**). Chlorophyll-*a* concentrations were generally below the proposed WQC, except for in August, where peak concentrations were measured. The increase in chlorophyll-*a* corresponded with the decreased dissolved oxygen in Black Creek (Table 2.3; Figure 2.42). Recently, lead has been identified as impaired in Black Creek and a TMDL document has recently been finalized (**Lewis and Mandrup-Poulsen 2009**) to address this issue.

Table 2.3 Water Quality Data for Black Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	2.84	6.07	11.3	235	1982 - 2008
Total Nitrogen (mg/L)	<1.54	0.23	0.68	2.10	348	1997 - 2010
Total Phosphorus (mg/L)	<0.12	0.025	0.081	0.247	358	1997 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.53	6.79	48.0	139	1997 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	1.10	1.35	9.74	38	1999 - 2008
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.064	0.457	1.00	7	1998 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.77	1.03	4.42	39	1998 - 2010
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.39	0.95	15.8	31	1998 - 2009
Silver	≤0.07 FW ≤0.92* SW	0.20	2.27	8.44	6	1997 - 2007
Zinc (µg/L)	≤120 FW ≤86 SW	5.00	5.78	29.7	38	1997 - 2010
Fecal Coliform (log #/100 mL)	<2.6	0.48	0.74	1.72	36	2007 - 2007
Turbidity (NTU)	<29	0.80	8.13	320	220	1997 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

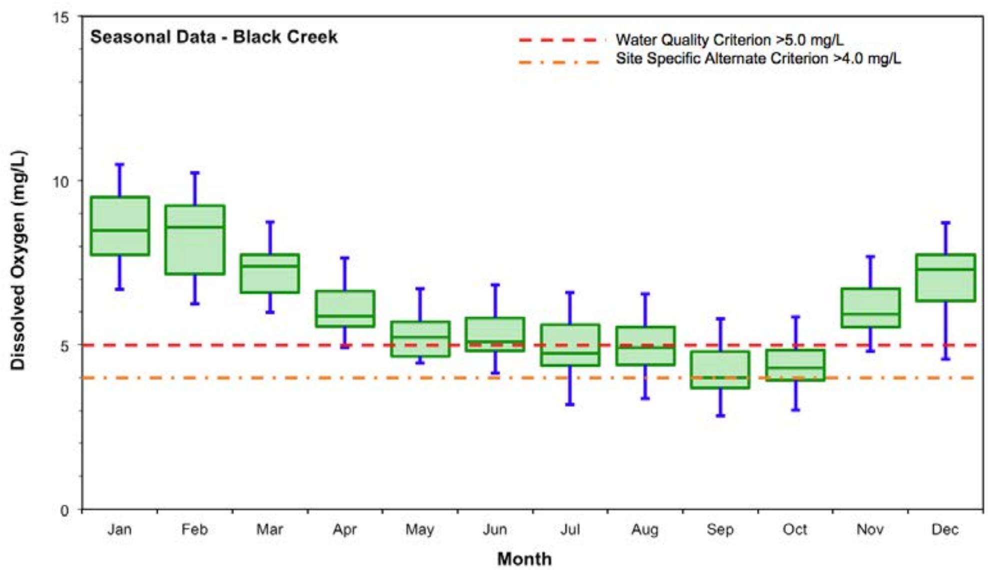


Figure 2.41 Monthly dissolved oxygen concentrations (data from 1982-2008) in Black Creek.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

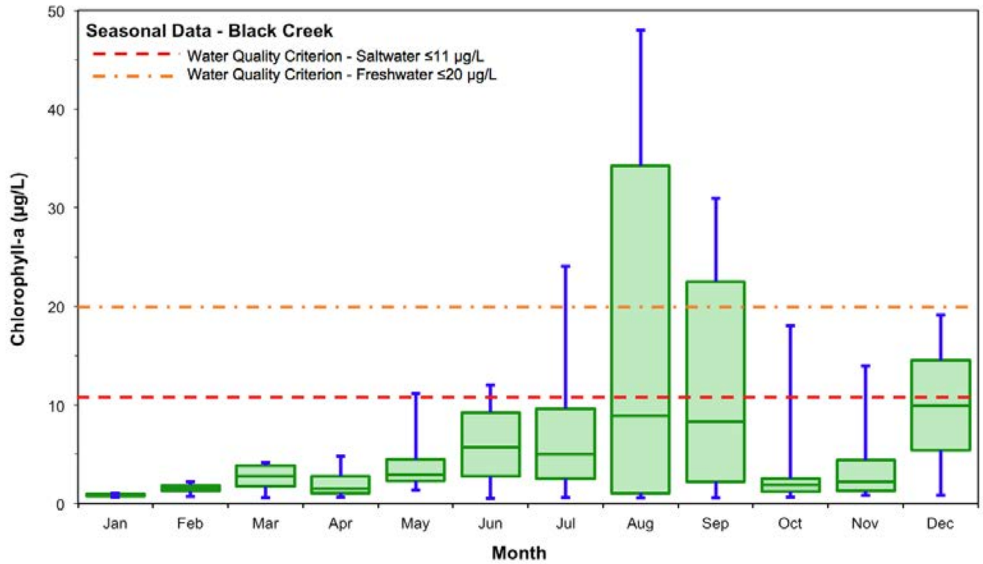


Figure 2.42 Monthly chlorophyll-a concentration (µg/L), based on data from 1997 through 2010 in Black Creek.

The maximum cadmium concentrations detected were more than threefold higher than the freshwater criterion (Table 2.3 above). In periods of higher salinity, elevated copper and nickel concentrations may be problematic, as they were detected at levels above WQC. The maximum silver concentration detected in Black Creek was more than 100 times the freshwater criterion and also substantially elevated above the SW criterion. The concentrations of silver detected have the potential for causing toxic effects to aquatic life in this area.

2.8.5. Broward River

2.8.5.1. About the Broward River

- Between downtown and JIA
- Primary Land Use: Residential/Forested
- Current TMDL Documents: None
- Verified Impaired 2009 (priority): Nutrients/Chlorophyll-*a* (medium) Mercury (high)
- WBID Area: 14.4 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

Figure 2.43 The Broward River Tributary (WBID 2191)

2.8.5.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Broward River WBID 2191 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.43) above and the graphs/tables in this section.

2.8.5.3. Discussion

Water quality data for the Broward River are shown in Table 2.4. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**). The maximum fecal coliform level at times exceeded the WQC of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL (Table 2.4). However, the averages at the

individual sampling sites, and overall, fall below the WQC. Chlorophyll-*a* levels were on average higher than the saltwater WQC and thus chlorophyll-*a* has been identified as being impaired in the Broward River.

The Broward River has been identified as being impaired for mercury based on fish advisories (**Donner 2008**), and this will be addressed in the recently revised draft statewide mercury TMDL document (**DEP 2012c**) scheduled for completion in 2013.

Table 2.4 Water Quality Data for Broward River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.90	5.12	10.0	69	2000 - 2008
Total Nitrogen (mg/L)	<1.54	0.34	0.88	1.60	23	2000 - 2007
Total Phosphorus (mg/L)	<0.12	0.041	0.146	0.250	24	2000 - 2008
Chlorophyll-a (µg/L)	<20 FW <11 SW	0.85	19.6	52.0	11	2006 - 2007
Arsenic (µg/L)	≤50 FW ≤50 SW	0.52	1.37	2.60	13	2006 - 2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.020	0.540	1.00	3	2001 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.38	0.99	2.43	16	2006 - 2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.42	0.91	2.39	14	2007
Silver	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	3.10	8.15	20.0	12	2001 - 2007
Fecal Coliform (log #/100 mL)	<2.6	0.95	1.69	3.53	54	2000 - 2008
Turbidity (NTU)	<29	1.80	8.63	27.0	32	2000 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.6. Cedar River

2.8.6.1. About the Cedar River

- At the I-10/I-295 Interchange
- Primary Land Use: Residential/Forested
- Current TMDL Documents: Fecal/Total Coliform (WBID 2262)
- Verified Impaired 2009 (priority): None
- WBID Area: 22.8 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

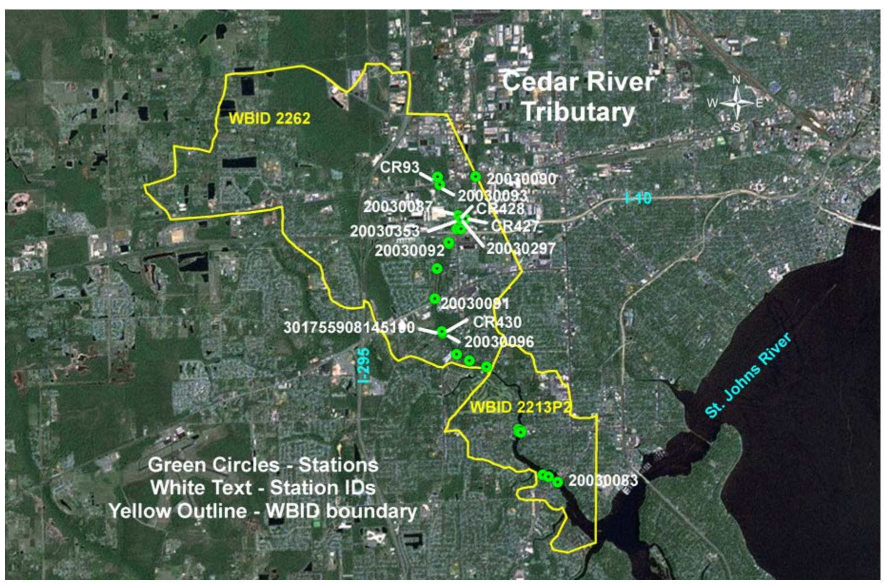


Figure 2.44 The Cedar River Tributary (WBID 2262 and 2213P)

2.8.6.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Cedar River WBID 2262 and 2213P (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.44) above and the graphs/tables in this section.

2.8.6.3. Discussion

Water quality data for the Cedar River are shown in Table 2.5. The Cedar River feeds into the Ortega River and thus is not directly a tributary of the St. Johns River. Even so, the Cedar River is tidal in nature varying in height by ~1 ft. over the

course of a day (**SJRWMD 2010d**). Salinity levels, as influenced by tidal movement, are relatively low indicating that the Ortega River buffers the Cedar River significantly from marine water intrusion. Average dissolved oxygen levels were generally above the WQC and were more stable moving upstream; however, some dissolved oxygen values were below acceptable limits (Figure 2.45). Average total phosphorus levels were higher than the recently updated WQC (**EPA 2010**), as were average levels of chlorophyll-*a*. Metal concentrations are mostly within acceptable limits, with the exception of copper and nickel, which are slightly elevated.

Table 2.5 Water Quality Data for the Cedar River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	1.30	5.83	12.4	207	1998 - 2010
Total Nitrogen (mg/L)	<1.54	0.37	0.92	1.75	98	1998 - 2010
Total Phosphorus (mg/L)	<0.12	0.032	0.148	0.454	119	1998 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.59	21.6	97.7	71	1998 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	0.65	1.25	43.7	46	1998 - 2010
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.020	0.188	10.0	15	1999 - 2008
Copper (µg/L)	≤9.3 FW ≤3.7 SW	1.10	1.52	40.0	53	1998 - 2010
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.69	1.21	40.0	29	1998 - 2008
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	6.30	8.72	49.3	75	1998 - 2010
Fecal Coliform (log #/100 mL)	<2.6	1.45	1.90	4.73	53	1999 - 2010
Turbidity (NTU)	<29	1.40	24.9	1298	125	1998 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L.

FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

In 2004, Cedar River was identified as being impaired for both fecal and total coliforms (i.e. levels significantly above 400 CFU/100 mL) and as a result, a TMDL document was finalized in 2006 (**Magley 2006b**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Currently, the Basin Management Action Plan (BMAP) to address this impairment is under development but the timeframe for its release is currently unknown.

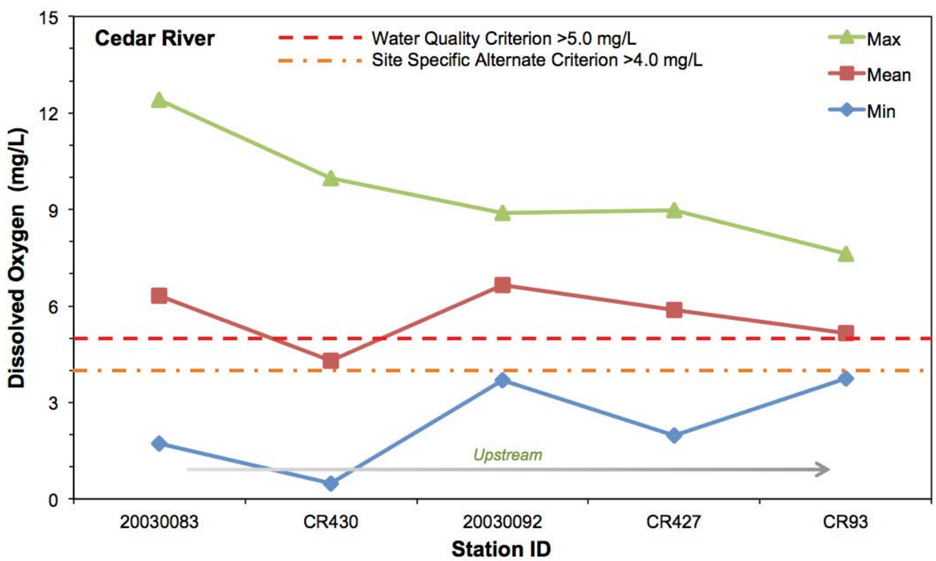


Figure 2.45 Variation of the dissolved oxygen in the Cedar River going upstream (left to right)

2.8.7. Deep Creek

2.8.7.1. About Deep Creek

- East of the St. Johns at Palatka
- Primary Land Use: Forested
- Current TMDL Documents:
  Dissolved Oxygen – 2589 (draft)
- Verified Impaired 2009 (priority):
  Dissolved Oxygen – 2549 (medium)
  Nutrients/Historical
  Chlorophyll-*a* - 2549 (medium)
- WBID Area: 60.5 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

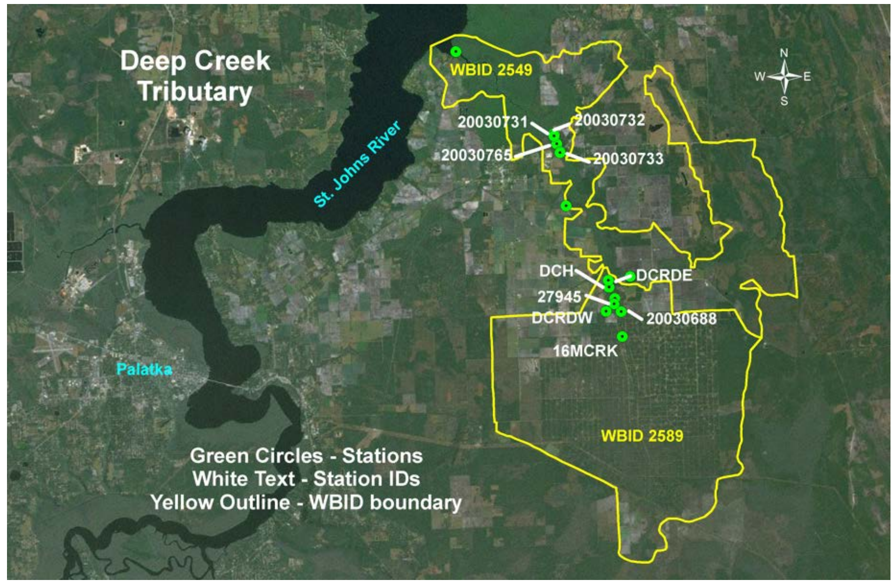


Figure 2.46 The Deep Creek Tributary (WBID 2549 and 2589)

2.8.7.2. Data sources

Data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Deep Creek WBIDs 2549 and 2589 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.46) above and the graphs/tables in this section.

2.8.7.3. Discussion

Water quality data for Deep Creek are shown in Table 2.6. Deep Creek is a tributary of the LSJR that drains the eastern banks around Hastings and Spuds, and thus receives substantial agricultural inputs, such as nutrients. Concentrations of total nitrogen were elevated (Figure 2.47) but not above the recently updated WQC (**EPA 2010**), however levels of total phosphorus were significantly above the recommended WQC (Figure 2.48), and fluctuate seasonally. Non-point source rainwater runoff is likely the major cause of the elevated nitrogen/phosphorus concentrations in this area. Likewise, chlorophyll-*a* concentrations fluctuate, with relatively elevated levels in the summer months (Figure 2.49). Dissolved oxygen concentrations in these areas reflect these conditions, with lower dissolved oxygen concentrations observed in the summer months (Figure 2.50). In addition to nutrients, organic matter, temperature and community structure (i.e. number and types of plants and animal species), among other biotic factors, may contribute to the lower dissolved oxygen concentrations in these tributaries. As a consequence of the above factors/conditions, a TMDL for dissolved oxygen is currently in draft status (**Magley 2009c**) for WBID 2589 (Sixteen Mile creek), and WBID 2549 has been determined to be impaired for dissolved oxygen and chlorophyll-*a*. Elevated concentrations of cadmium, copper, nickel, and silver have been detected in Deep Creek, as compared to the Class III WQC for metals.

Table 2.6 Water Quality Data for Deep Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.66	5.08	14.4	374	1997 - 2011
Total Nitrogen (mg/L)	<1.54	0.51	1.11	14.3	610	1997 - 2011
Total Phosphorus (mg/L)	<0.12	0.013	0.385	2.286	599	1997 - 2011
Chlorophyll-*a* (μg/L)	<20 FW <11 SW	0.53	5.41	52.8	138	1997 - 2011
Arsenic (μg/L)	≤50 FW ≤50 SW	0.77	1.90	17.04	58	1998 - 2010
Cadmium (μg/L)	≤0.3 FW ≤8.8 SW	0.500	0.815	1.28	7	1999 - 2003
Copper (μg/L)	≤9.3 FW ≤3.7 SW	1.06	1.30	14.8	96	1997 - 2010
Nickel (μg/L)	≤52 FW ≤8.3 SW	2.01	3.00	34.8	32	1997 - 2006
Silver (μg/L)	≤0.07 FW ≤0.92* SW	0.01	0.43	1.65	9	1998 - 2004
Zinc (μg/L)	≤120 FW ≤86 SW	5.00	5.39	49.7	93	1997 - 2010
Fecal Coliform (log #/100 mL)	<2.6	0.48	2.43	3.26	11	2004 - 2007
Turbidity (NTU)	<29	0.50	7.05	146	387	1997 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

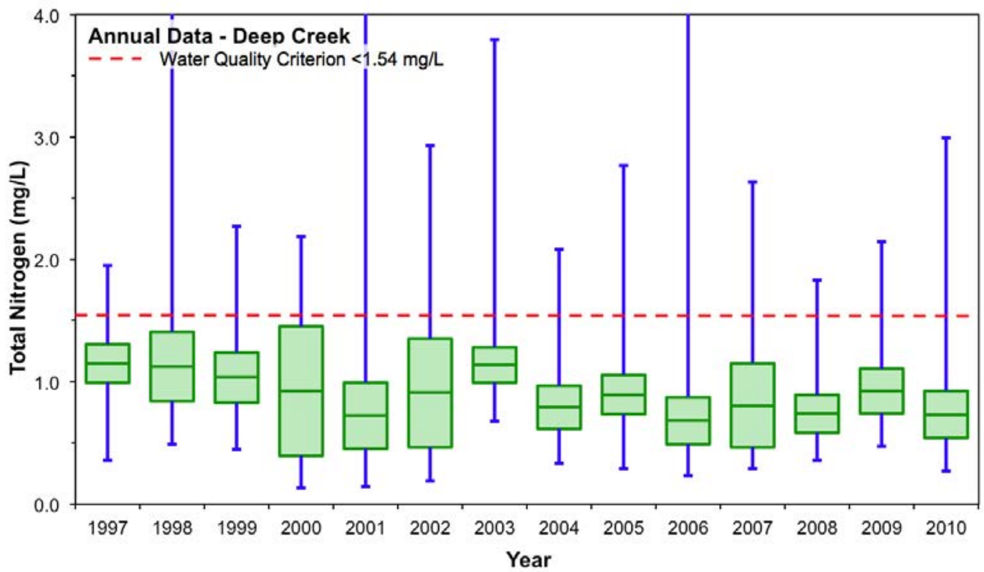


Figure 2.47 The yearly total nitrogen concentration in Deep Creek. All data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

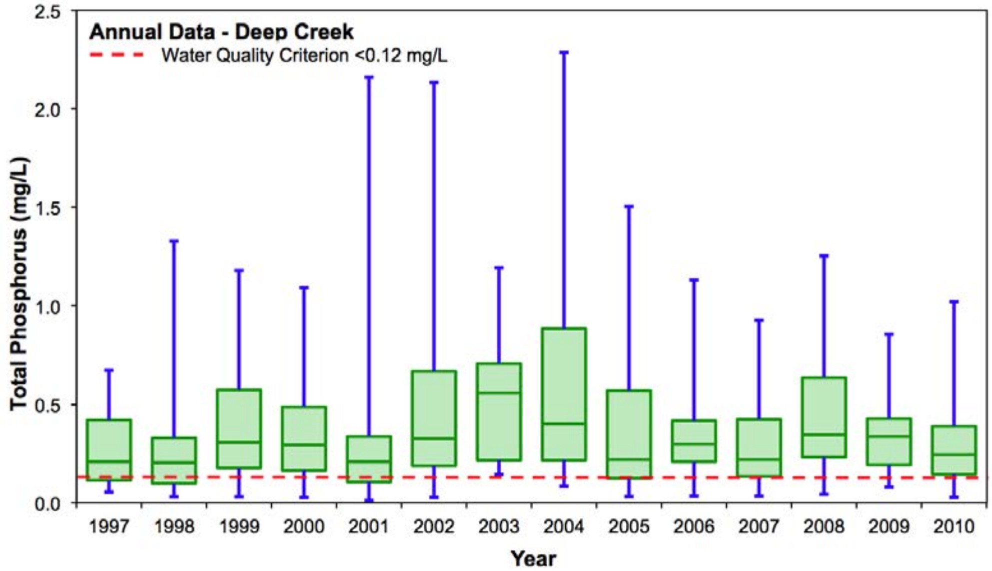


Figure 2.48 Yearly total phosphorus concentrations in Deep Creek. All data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

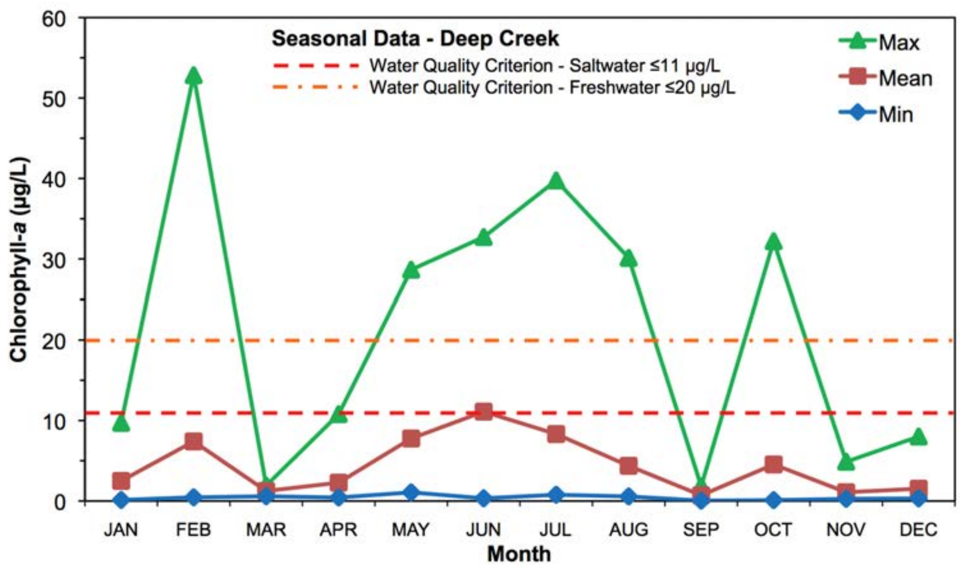


Figure 2.49 Monthly chlorophyll-a concentration (µg/L) in 1997 through 2008 in Deep Creek.

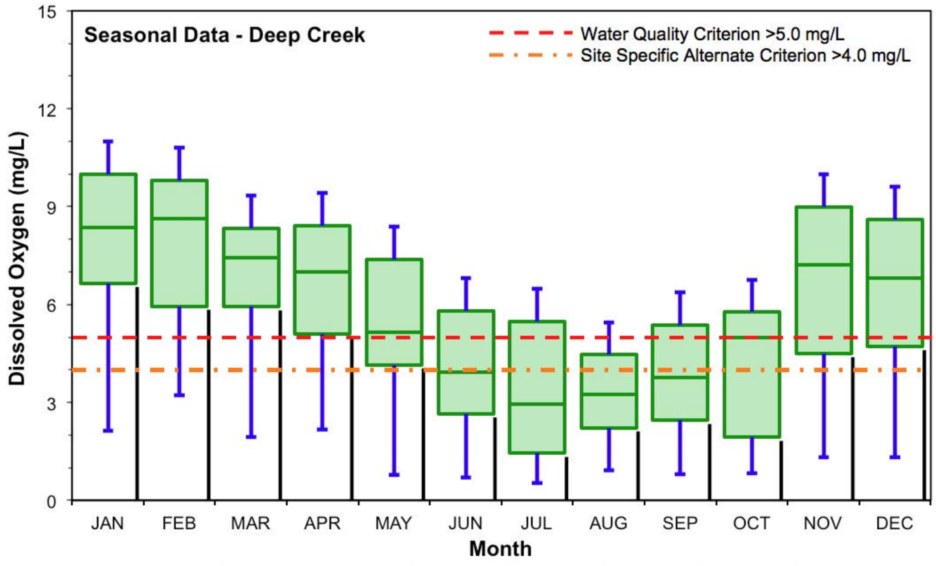


Figure 2.50 The monthly dissolved oxygen concentrations (data from 1967 to 2007) in Deep Creek. Data are presented as a box-and-whiskers plot with green boxes indicating the median ±25% (middle 50% of the data) and horizontal lines indicating median values. Blue whiskers indicate minimum and maximum values in the data set.

2.8.8. Doctors Lake

2.8.8.1. <u>About Doctors Lake</u>

- West of the St. Johns in Clay County
- Primary Land Use: Forested
- Current TMDL Documents:
  Nutrient – 2389 (draft)
  Dissolved Oxygen/
  Nutrient – 2410 (draft)
- Verified Impaired 2009 (priority):
  Dissolved Oxygen – 2410 (medium)
- WBID Area: 8.4 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

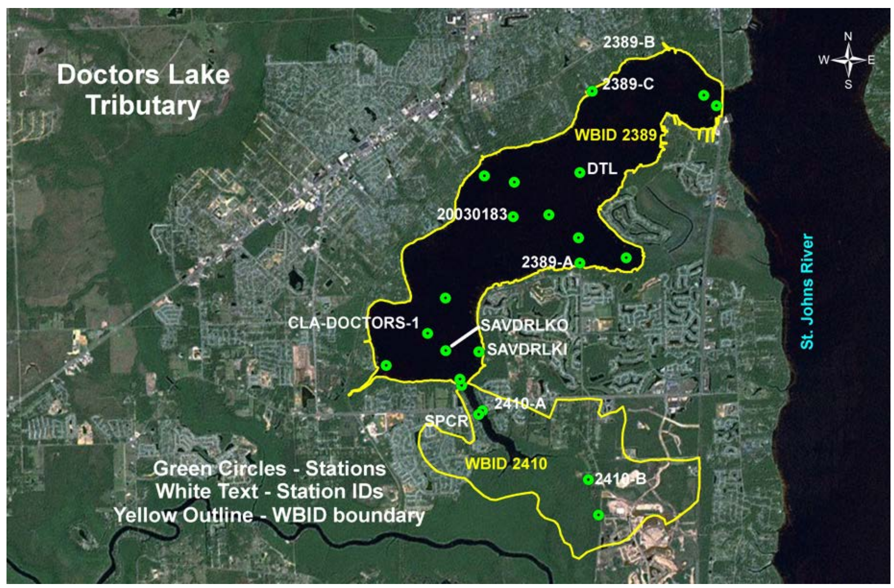


Figure 2.51 The Doctors Lake Tributary (WBID 2389 and 2410)

2.8.8.2. <u>Data sources</u>

Result data was downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Doctors Lake WBIDs 2389 and 2410 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.51) above and the graphs/tables in this section.

2.8.8.3. <u>Discussion</u>

Water quality data for Doctors Lake are shown in Table 2.7. Although average total nitrogen and total phosphorus levels were within their WQC limits, average chlorophyll-*a* concentrations far exceeded the WQC, particularly in summer months (Figure 2.52), and average dissolved oxygen levels were below the SSAC. Thus, Doctors Lake has been identified as being impaired for nutrients and a TMDL to address this is currently in draft form (**Magley 2009d**). Elevated maximum arsenic, cadmium, copper, nickel, silver, and zinc concentrations were also measured in Doctors Lake. Doctors Lake is largely used for recreational activities such as boating, fishing, and waterskiing. These activities could account for some of the copper, nickel, and zinc contamination; however, the source of the other contamination is not clear. Two small creeks

that flow from swampland merge and enter the lake from the south and the lake enters the main stem of the LSJR from the northeast through the Doctors Inlet.

Table 2.7 Water Quality Data for Doctors Lake

Parameter	Water Quality Criteria	Concentration Low	Concentration Average	Concentration High	Samples	Sampling Period
Dissolved Oxygen (mg/L)	≥5.0	0.00	8.03	14.7	1428	1997 - 2010
Total Nitrogen (mg/L)	<1.54	0.21	1.16	6.67	1991	1997 - 2010
Total Phosphorus (mg/L)	<0.12	0.010	0.081	0.477	1926	1997 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	1.25	28.5	199	978	1997 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	0.75	2.01	85.6	145	1997 - 2010
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.50	0.83	4.19	26	1999 - 2002
Copper (µg/L)	≤9.3 FW ≤3.7 SW	1.03	1.18	39.2	131	1997 - 2010
Nickel (µg/L)	≤52 FW ≤8.3 SW	2.00	2.69	30.7	43	1998 - 2003
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.20	0.29	2.20	20	1997 - 2010
Zinc (µg/L)	≤120 FW ≤86 SW	5.04	5.70	128	41	1997 - 2010
Fecal Coliform (log #/100 mL)	<2.6	No valid data available				
Turbidity (NTU)	<29	0.90	6.43	49.0	1019	1997 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

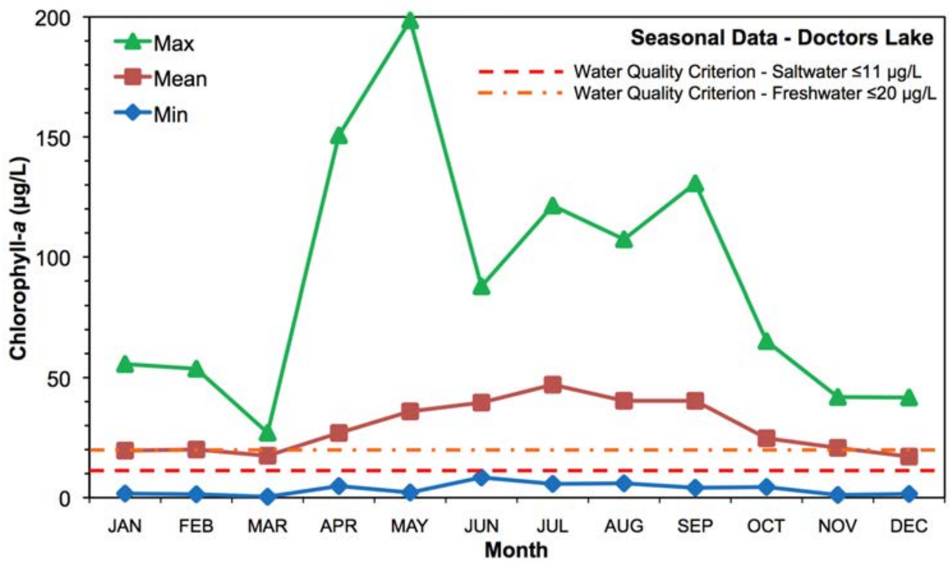


Figure 2.52 Monthly chlorophyll-a concentration (µg/L) in 1997 through 2008 in Doctors Lake. Data are presented as minimum (blue diamonds), mean (red boxes), and maximum (green triangles) values. The dotted red horizontal line indicates the proposed TMDL limit for the LSJR.

2.8.9. *Dunn Creek/Crescent Lake*

2.8.9.1. About Dunn Creek/Crescent Lake

- East of the St. Johns in Flagler Co.
- Primary Land Use: Forested/Wetlands
- Current TMDL Documents: None
- Verified Impaired 2009 (priority): Nutrients/TSI – 2606B (medium) Mercury – 2606B (high)
- WBID Area: 585 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

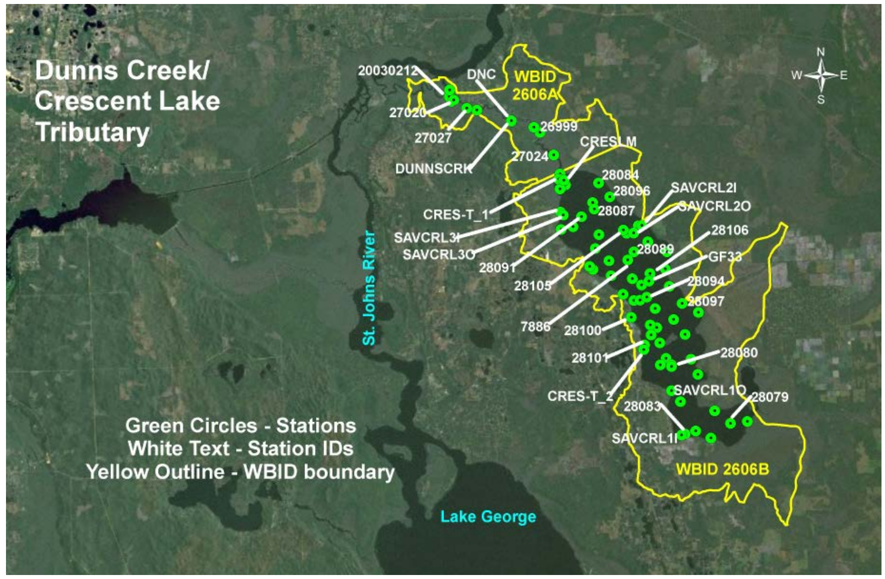


Figure 2.53 The Dunn Creek/Crescent Lake Tributary (WBID 2606A/B)

2.8.9.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Dunn Creek/Crescent Lake WBIDs 2606A/B (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.53) above and the graphs/tables in this section.

2.8.9.3. Discussion

Water quality data for Dunn Creek/Crescent Lake are shown in Table 2.8 (*Note: the majority of the data in this dataset were collected on two days*). High chlorophyll-*a* in Dunn Creek/Crescent Lake contributes to the nutrient/TSI impairment (WBID 2606B). The elevated TSI indicates that there is too much biological activity in the lake, which could lead to eutrophication and possibly excessive algal growth, if unchecked. There is a significant variation of dissolved oxygen going upstream of the creek and into the lake as evidenced by the wider spread of the maximum and minimum values (Figure 2.54). Although minimum measured dissolved oxygen values were below the WQC, average dissolved oxygen values were generally within acceptable limits, suggesting that eutrophication may not yet be a serious concern. It should also be noted that this tributary is a significant non point-source contributor to nutrient levels in the St. Johns River (**Magley and Joyner 2008**).

Table 2.8 Water Quality Data for Dunn Creek/Crescent Lake

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.53	7.50	13.8	2128	1997 - 2010
Total Nitrogen (mg/L)	<1.54	0.30	1.19	4.44	2598	1997 - 2010
Total Phosphorus (mg/L)	<0.12	0.004	0.081	0.844	2543	1997 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.54	19.5	198	1191	1997 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	0.57	0.93	5.16	87	1999 - 2010
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.021	0.38	1.02	6	1999 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.32	0.69	37.9	80	1998 - 2010
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.42	1.00	19.7	43	1998 - 2009
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.20	0.48	1.16	6	1997 - 2002
Zinc (µg/L)	≤120 FW ≤86 SW	3.20	5.23	134	83	1998 - 2010
Fecal Coliform (log #/100 mL)	<2.6	0.90	1.44	4.07	51	2002 - 2007
Turbidity (NTU)	<29	0.65	5.58	35.4	1385	1997 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

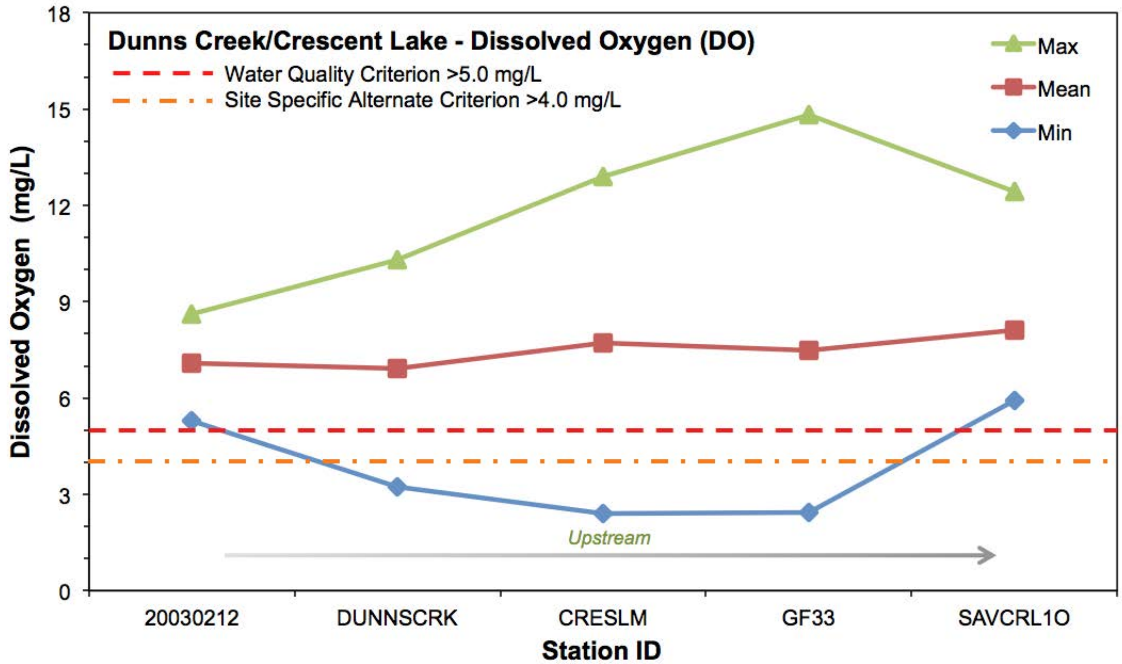


Figure 2.54 Variation of the dissolved oxygen in Dunn's Creek and Crescent Lake going upstream (left to right)
Note: The data in this graph are not consistent in sampling interval and/or timeframe.

Crescent Lake has been identified as being impaired for mercury based on fish advisories (**Donner 2008**), and this will be addressed in the recently revised draft statewide mercury TMDL document (**DEP 2012c**) scheduled for completion in 2013.

2.8.10. Durbin Creek

2.8.10.1. About Durbin Creek

- East of the St. Johns River
  South of I-295
- Primary Land Use: Forested
- Current TMDL Documents:
  Fecal coliform
- Verified Impaired 2009 (priority):
  None
- WBID Area: 26.2 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

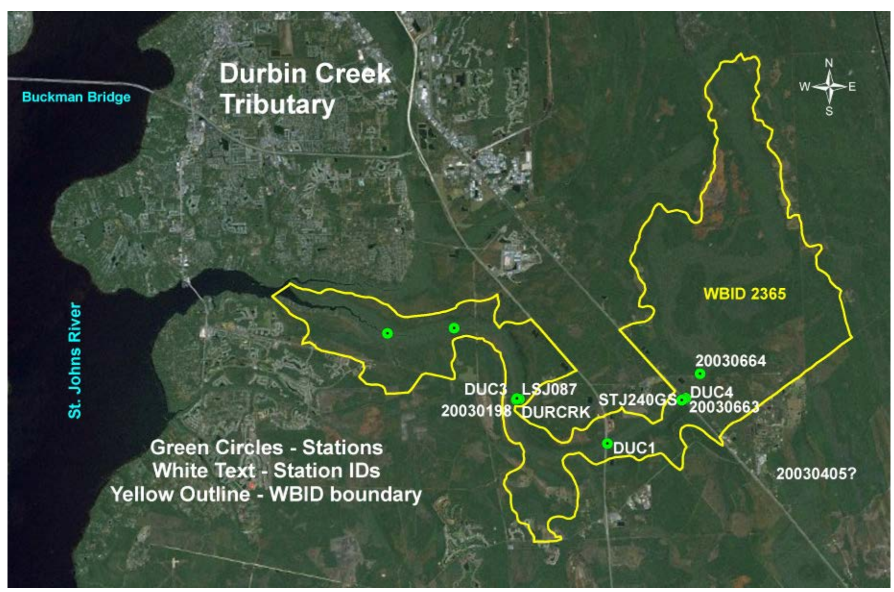


Figure 2.55 The Durbin Creek Tributary (WBID 2365)

2.8.10.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Durbin Creek WBID 2365 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.55) above and the graphs/tables in this section.

2.8.10.3. Discussion

Water quality data for Durbin Creek are shown in Table 2.9. Average dissolved oxygen levels in Durbin Creek are relatively low when compared to other tributaries of the LSJR (Figure 2.28). However, no causative pollutant (specific environmental condition) has been identified and thus no TMDL is required as it is the "natural condition" of the water body (**DEP 2009c**). Currently, a TMDL document is available for fecal coliform in Durbin Creek (**Magley 2006a**) and a BMAP is under development. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*).

Table 2.9 Water Quality Data for Durbin Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.40	4.10	9.46	155	1997 - 2010
Total Nitrogen (mg/L)	<1.54	0.27	1.16	3.50	99	1997 - 2010
Total Phosphorus (mg/L)	<0.12	0.019	0.084	0.481	116	1997 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.58	3.66	32.6	28	1997 - 2008
Arsenic (µg/L)	≤50 FW ≤50 SW	0.51	1.62	6.11	11	2000 - 2008
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.032	0.69	1.13	6	1998 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.48	1.54	3.13	12	1998 - 2008
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.39	1.56	16.2	21	1999 - 2010
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.03	0.38	0.72	2	2004 - 2008
Zinc (µg/L)	≤120 FW ≤86 SW	0.49	4.68	35.1	33	1997 - 2010
Fecal Coliform (log #/100 mL)	<2.6	0.60	1.36	3.67	44	1999 - 2008
Turbidity (NTU)	<29	0.75	4.07	26.0	150	1997 - 2009

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.11. Ginhouse Creek

2.8.11.1. About Ginhouse Creek

- South of the St. Johns River just west of Craig Airfield
- Primary Land Use: Residential
- Current TMDL Documents: None
- Verified Impaired 2009 (priority): None
- WBID Area: 2.0 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

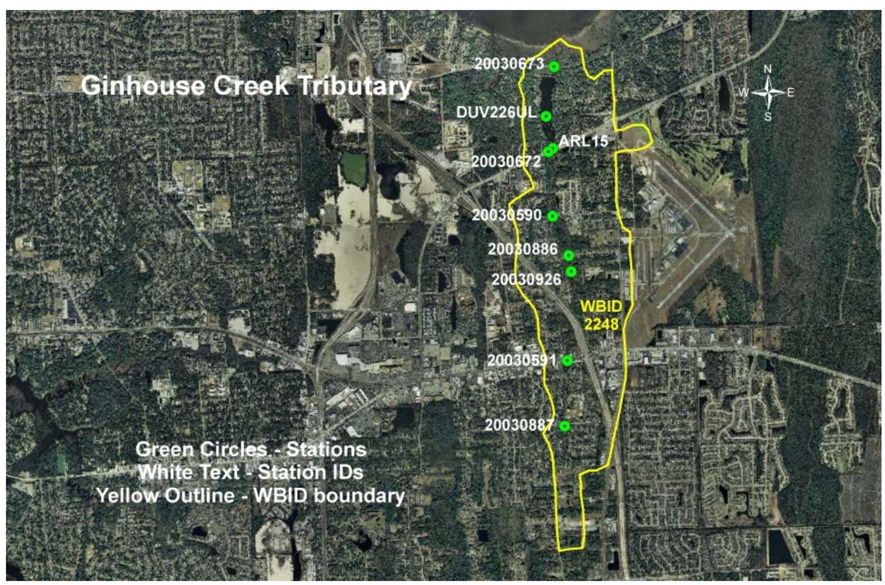


Figure 2.56 The Ginhouse Creek Tributary (WBID 2248)

2.8.11.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Ginhouse Creek WBID 2248 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.56) above and the graphs/tables in this section.

2.8.11.3. Discussion

Water quality data for Ginhouse Creek are shown in Table 2.10, note however that no metals data were available. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**); however, average total nitrogen, chlorophyll-*a* and dissolved oxygen levels were within acceptable limits. Fecal coliform levels are elevated but not above the WQC.

Table 2.10 Water Quality Data for Ginhouse Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	1.40	5.34	9.70	59	2002 - 2008
Total Nitrogen (mg/L)	<1.54	0.41	0.99	2.40	15	2006 - 2007
Total Phosphorus (mg/L)	<0.12	0.063	0.142	0.270	16	2006 - 2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.64	22.1	94.0	8	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	No valid data available				
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	No valid data available				
Copper (µg/L)	≤9.3 FW ≤3.7 SW	No valid data available				
Nickel (µg/L)	≤52 FW ≤8.3 SW	No valid data available				
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	1.52	2.13	3.78	56	2002 - 2008
Turbidity (NTU)	<29	0.60	5.16	20.0	28	2006 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.12. Goodbys Creek

2.8.12.1. About Goodbys Creek

- East of the St. Johns River opposite NAS Jacksonville
- Primary Land Use: Residential
- Current TMDL Documents: Fecal coliform with BMAP (2009)
- Verified Impaired 2009 (priority): None
- WBID Area: 5.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

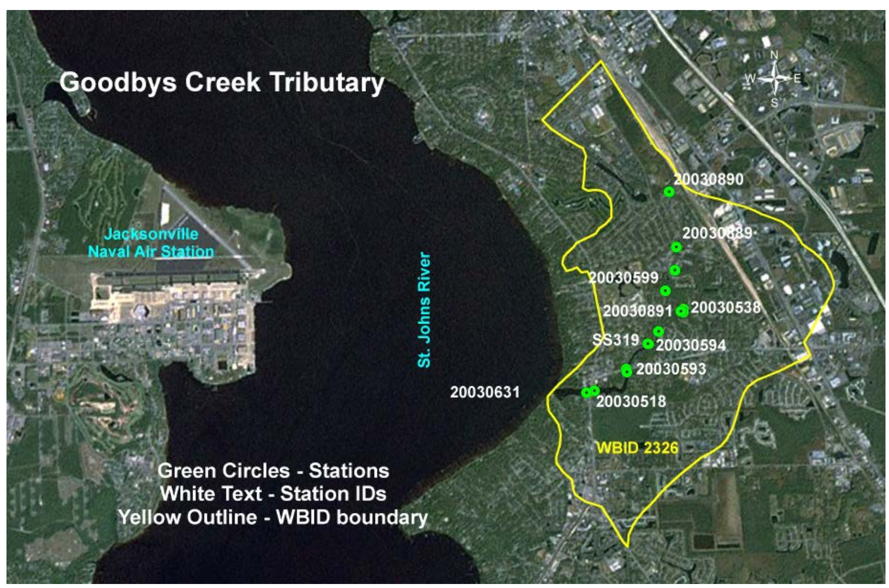


Figure 2.57 The Goodbys Creek Tributary (WBID 2326)

2.8.12.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Goodbys Creek WBID 2326 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.57) above and the graphs/tables in this section.

2.8.12.3. Discussion

Water quality data for Goodbys Creek are shown in Table 2.11. Average phosphorus levels in Goodbys Creek exceeded the recently updated WQC (**EPA 2010**); however, average total nitrogen, dissolved oxygen and chlorophyll-*a*

concentrations were within acceptable limits. The fecal coliform level, averaged over all the stations in Goodbys Creek, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. Analysis by station is shown in Figure 2.58, going from the furthest downstream, within the main stem of the St. Johns River, to the furthest upstream. The average remains at or above the state maximum until station 20030899, near Old Kings Road.

A TMDL is available for fecal coliform in Goodbys Creek (**Wainwright 2005**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for Goodbys Creek was released in December 2009 (**DEP 2009b**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011a**) and 2012 (**DEP 2012a**); they list several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.11 Water Quality Data for Goodbys Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.60	5.30	12.0	152	1999 - 2010
Total Nitrogen (mg/L)	<1.54	0.48	0.89	2.00	17	1999 - 2007
Total Phosphorus (mg/L)	<0.12	0.078	0.155	0.310	18	1999 - 2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	1.50	3.17	5.70	3	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	No valid data available				
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	No valid data available				
Copper (µg/L)	≤9.3 FW ≤3.7 SW	No valid data available				
Nickel (µg/L)	≤52 FW ≤8.3 SW	No valid data available				
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	0.85	1.65	4.06	120	1999 - 2011
Turbidity (NTU)	<29	2.00	7.71	21.0	57	1999 - 2011

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

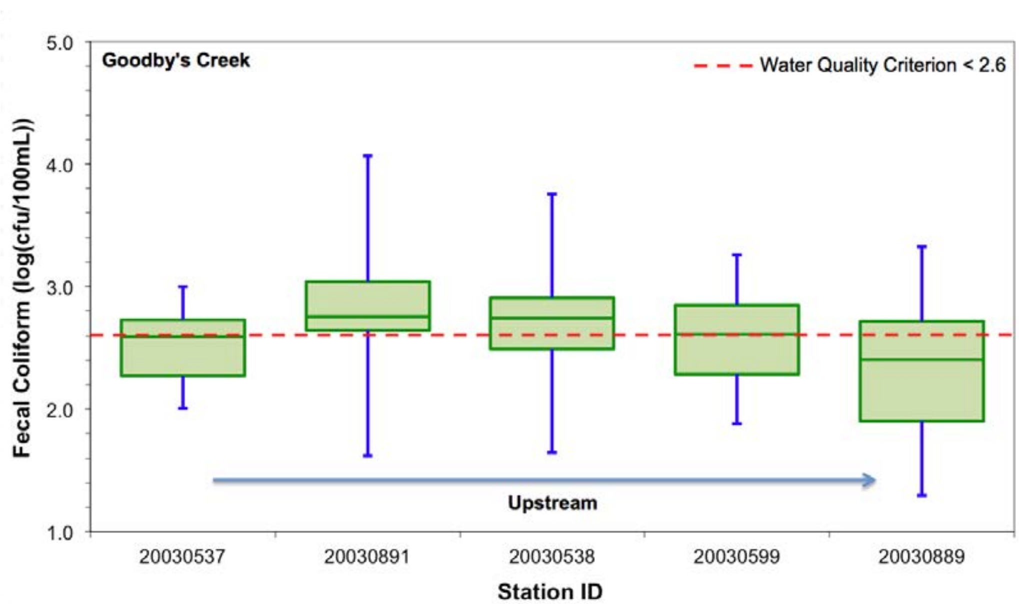


Figure 2.58 Fecal coliform in Goodbys Creek from downstream to upstream. Data are presented as the log of number of fecal coliform bacteria per 100 mL; the maximum, mean, and minimum values at each station are shown.

2.8.13. Greenfield Creek

2.8.13.1. About Greenfield Creek

- West of the Intercoastal Waterway
- Primary Land Use: Residential
- Current TMDL Documents:
  Fecal Coliform with BMAP 2010
- Verified Impaired 2009 (priority):
  Dissolved Oxygen (Medium)
- WBID Area: 2.9 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

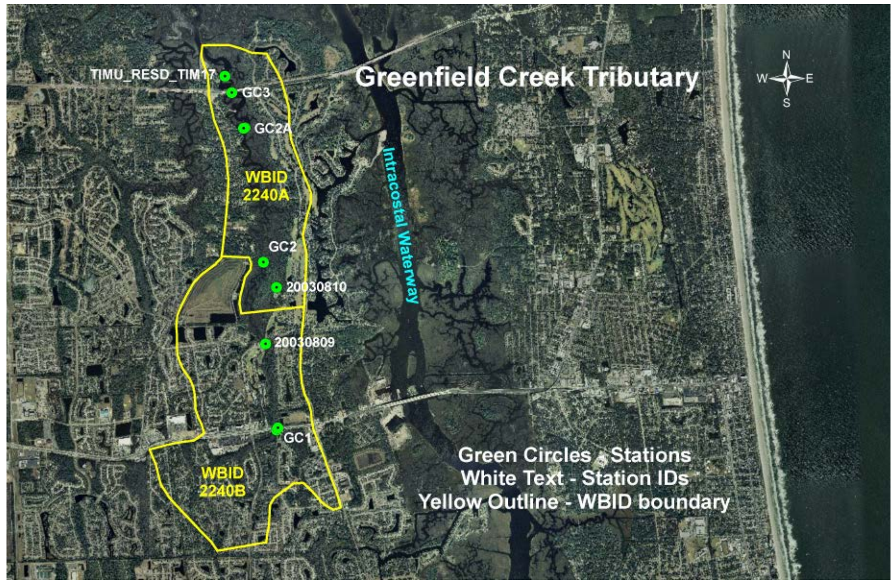


Figure 2.59 Greenfield Creek (WBID 2240A/2240B)

2.8.13.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Greenfield Creek WBID 2240A/2240B (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.59) above and the graphs/tables in this section.

2.8.13.3. Discussion

Water quality data for Greenfield Creek are shown in Table 2.12. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**) and average total nitrogen, dissolved oxygen and chlorophyll-*a* concentrations were within acceptable limits. *(Note: the datasets for these parameters are relatively small in comparison to other parts of the basin).* Dissolved oxygen has been identified as impaired (**DEP 2009d**) in Greenfield Creek. Recently a TMDL document (**Wainwright and Hallas 2009a**) was released to address Fecal coliform.

The BMAP for Greenfield Creek (**DEP 2010a**) was released in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The Greenfield Creek watershed does not contain any permitted point sources for industrial wastewater. It contains the Girvin Road Landfill, which has been inactive since 1992; this landfill received not only solid waste but sludge from the Neptune Beach Sewage Treatment Plant. The watershed also contains numerous outfalls for stormwater discharge. The sewer system serves 84% of households in the watershed. JEA reported only one sanitary sewer overflow in the watershed, which occurred in 2002 and potentially impacted surface waters. WSEA estimates that there are 177 on-site sewage treatment and disposal systems (septic systems) in use. An Annual Progress Report for this BMAP was published in 2011; it lists several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT (**DEP 2011b**).

Table 2.12 Water Quality Data for Greenfield Creek

Parameter	Water Quality Criteria (WQC)	Concentration Low	Concentration Average	Concentration High	Samples	Sampling Period
Dissolved Oxygen (mg/L)	≥5.0	3.20	5.47	8.00	27	1997 - 2007
Total Nitrogen (mg/L)	<1.54	0.75	1.35	3.90	13	2007
Total Phosphorus (mg/L)	<0.12	0.075	0.201	1.00	12	2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	2.30	14.9	41.0	10	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	No valid data available				
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	No valid data available				
Copper (µg/L)	≤9.3 FW ≤3.7 SW	No valid data available				
Nickel (µg/L)	≤52 FW ≤8.3 SW	No valid data available				
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	1.77	2.79	4.02	16	2002 - 2008
Turbidity (NTU)	<29	1.30	10.6	45.0	13	2007

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.14. Hogan Creek

2.8.14.1. About Hogan Creek

- Downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL Documents: Fecal coliform with BMAP (2009)
- Verified Impaired 2009 (priority): Dissolved Oxygen (medium)
- WBID Area: 3.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

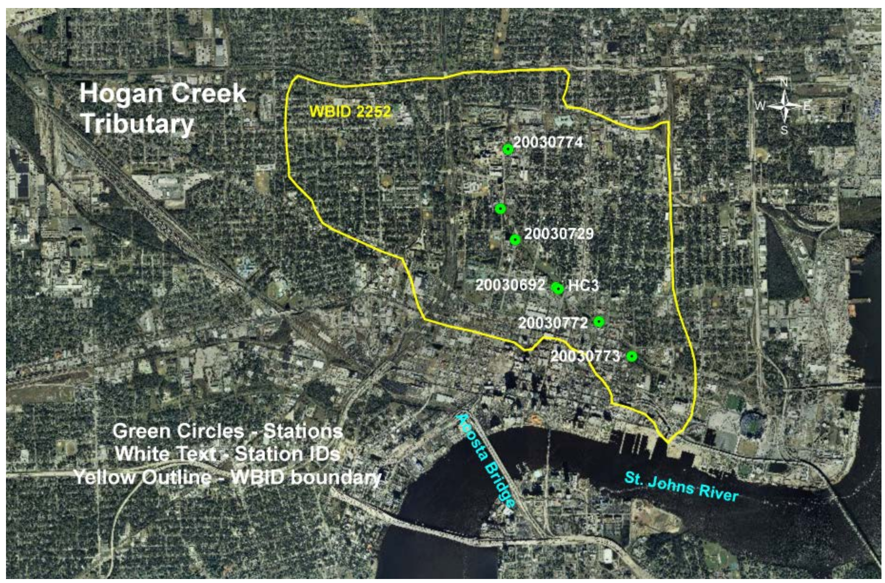


Figure 2.60 The Hogan Creek Tributary (WBID 2252)

2.8.14.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Hogan Creek WBID 2252 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.60) above and the graphs/tables in this section.

2.8.14.3. Discussion

Water quality data for Hogan Creek are shown in Table 2.13. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**). Average total nitrogen and chlorophyll-*a* concentrations were within acceptable limits. *(Note: the datasets for these parameters are relatively small in comparison to other parts of the basin).* As the average level of dissolved oxygen is below the WQC, Hogan Creek has been identified as being impaired for this parameter.

The fecal coliform level, averaged over all the stations in Hogan Creek, is just below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, a TMDL for fecal coliform in Hogan Creek was finalized in 2006 (**Wainwright 2006c**). (*Note: the data analysis in the TMDL is based on different criteria than*

that used in this report). Subsequently, a BMAP for Hogan Creek was released in December 2009 (**DEP 2009b**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011a**) and 2012 (**DEP 2012a**); they list several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.13 Water Quality Data for Hogan Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.40	4.08	10.6	55	2000 - 2008
Total Nitrogen (mg/L)	<1.54	0.59	0.78	0.99	5	2000 - 2007
Total Phosphorus (mg/L)	<0.12	0.100	0.144	0.190	5	2000 - 2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	4.40	13.7	23.0	2	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	0.56	1.19	2.10	4	2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.062	0.50	0.94	2	2001 - 2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	1.40	6.87	11.6	3	2001 - 2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.53	0.84	1.04	3	2007
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.03	0.03	0.03	1	2007
Zinc (µg/L)	≤120 FW ≤86 SW	8.20	17.2	28.0	4	2001 - 2007
Fecal Coliform (log #/100 mL)	<2.6	0.00	2.42	4.51	49	2000 - 2008
Turbidity (NTU)	<29	3.90	7.49	18.0	17	2000 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.15. Intracoastal Waterway

2.8.15.1. <u>About the Intracoastal Waterway</u>

- Near the mouth of the St. Johns River
- Primary Land Use: Marsh/Wetland
- Current TMDL Documents: None
- Verified Impaired 2009 (priority): Mercury (high)
- WBID Area: 23.9 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

Figure 2.61 The Intracoastal Waterway Tributary (WBID 2205C)

2.8.15.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Intracoastal Waterway WBID 2205C (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.61) above and the graphs/tables in this section.

2.8.15.3. <u>Discussion</u>

Water quality data for the Intracoastal Waterway are shown in Table 2.14. All parameters listed are within normal limits except for slightly elevated copper, phosphorus and copper. Based on this data the ICW is relatively healthy and does not provide a significant nutrient load to the St. Johns River.

The ICW has been identified as being impaired for mercury based on fish advisories (**Donner 2008**), and this will be addressed in the recently revised draft statewide mercury TMDL document (**DEP 2012c**) scheduled for completion in 2013.

Table 2.14 Water Quality Data for the Intracoastal Waterway

Parameter	Water Quality Criteria	Concentration Low	Concentration Average	Concentration High	Samples	Sampling Period
Dissolved Oxygen (mg/L)	≥5.0	2.87	6.02	10.11	163	2002 - 2010
Total Nitrogen (mg/L)	<1.54	0.16	0.75	4.43	117	2005 - 2010
Total Phosphorus (mg/L)	<0.12	0.018	0.106	0.284	106	2007 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	1.42	5.16	18.0	71	2005 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	1.50	2.42	12.0	15	2005 - 2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.094	0.094	0.094	1	2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.86	1.28	7.90	17	2005 - 2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.54	2.56	5.80	4	2005 - 2007
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	14.0	27.2	69.0	5	2007
Fecal Coliform (log #/100 mL)	<2.6	0.48	0.97	1.93	17	2007
Turbidity (NTU)	<29	1.80	7.28	23.5	89	2005 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.16. Julington Creek

2.8.16.1. About Julington Creek

- East of the St. Johns River at the I-95/I-295/9A intersection
- Primary Land Use: Marsh/Wetland
- Current TMDL Documents: Fecal coliform
- Verified Impaired 2009 (priority): Fecal coliform (high)
- WBID Area: 20.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

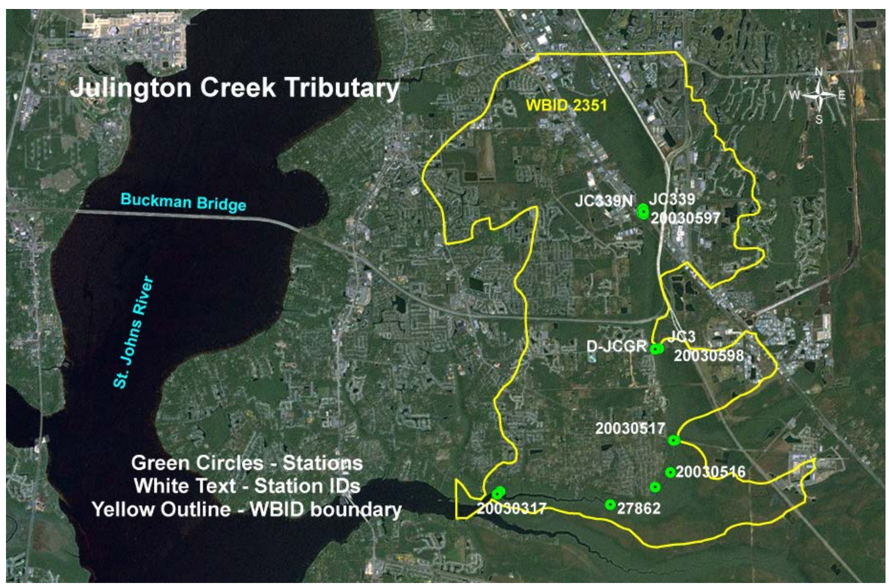


Figure 2.62 The Julington Creek Tributary (WBID 2351)

2.8.16.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Julington Creek WBID 2351 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.62) above and graphs/tables in this section.

2.8.16.3. Discussion

Water quality data for Julington Creek are shown in Table 2.15. The fecal coliform level, averaged over all the stations in Julington Creek, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, a TMDL for fecal coliform has recently been published (**Rhew 2009**). (*Note: the data analysis in*

the TMDL is based on different criteria than that used in this report). Julington Creek is also an area in which relatively high ammonia levels have been measured.

Table 2.15 Water Quality Data for Julington Creek

Parameter	Water Quality Criteria	Concentration Low	Concentration Average	Concentration High	Samples	Sampling Period
Dissolved Oxygen (mg/L)	≥5.0	0.60	5.43	9.37	95	1999 - 2010
Total Nitrogen (mg/L)	<1.54	0.43	0.66	1.31	41	1999 - 2005
Total Phosphorus (mg/L)	<0.12	0.034	0.083	0.214	48	1999 - 2005
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	1.07	2.33	5.59	8	2004 - 2005
Arsenic (µg/L)	≤50 FW ≤50 SW	No valid data available				
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	No valid data available				
Copper (µg/L)	≤9.3 FW ≤3.7 SW	3.09	4.15	5.24	5	2005
Nickel (µg/L)	≤52 FW ≤8.3 SW	No valid data available				
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	0.65	6.84	17.3	10	2004 - 2005
Fecal Coliform (log #/100 mL)	<2.6	1.00	1.83	3.78	25	1999 - 2007
Turbidity (NTU)	<29	1.40	4.93	17.0	30	1999 - 2006

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.17. Moncrief Creek

2.8.17.1. About Moncrief Creek

- North of Downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL Documents: Fecal/Total coliform with BMAP (2010)
- Verified Impaired 2009 (priority): Mercury (high)
- WBID Area: 5.9 sq. mi.
- Beneficial Use: Class III F (Recreational – Marine)

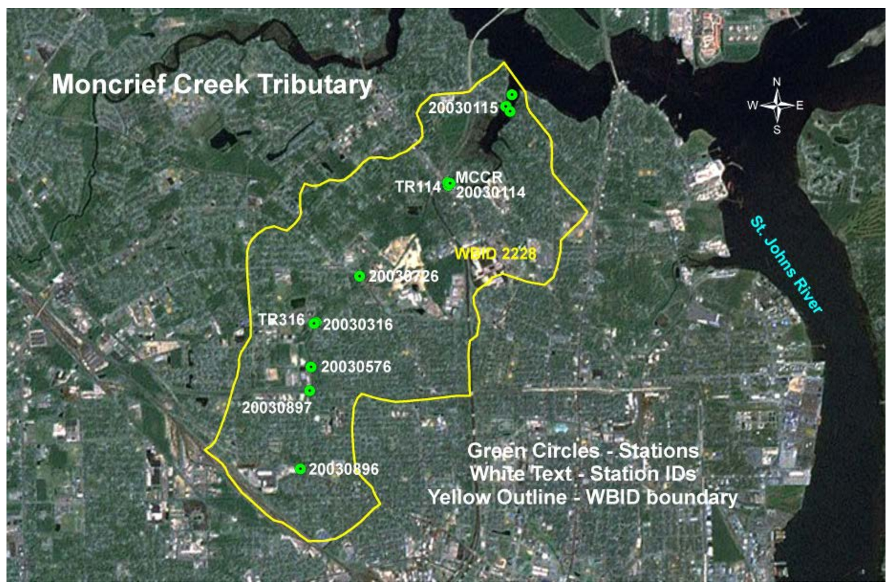


Figure 2.63 The Moncrief Creek Tributary (WBID 2228)

2.8.17.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Moncrief Creek WBID 2228 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.63) above and the graphs/tables in this section.

2.8.17.3. Discussion

Water quality data for Moncrief Creek are shown in Table 2.16. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**). Average total nitrogen and dissolved oxygen concentrations were within acceptable limits, and chlorophyll-*a* concentrations were only slightly elevated. Average copper concentrations were elevated relative to other tributaries and some concentrations were well above WQC.

The fecal coliform level, averaged over all the stations in Hogan Creek, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, there is some variation in the levels dependent on the location. Analysis by station is shown in Figure 2.64, going from downstream to upstream. The furthest downstream station at which fecal coliform data are available is station 20030114, near the intersection of I-95 and Norwood Avenue, and the furthest upstream station is station 20030897, near Kings Road. Beginning at station TR316 the average level exceeds the state maximum at every station. This is an old neighborhood that has been populated for many decades and contains both residential and light industrial development. South of the Martin Luther King Jr. Parkway, the average level is lower than the state maximum.

A TMDL for fecal coliform was finalized for Moncrief Creek in 2006 (**Wainwright 2006b**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for Moncrief Creek (**DEP 2010a**) was released in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The Moncrief Creek watershed contains four permitted point sources for industrial wastewater, as well as numerous outfalls for stormwater discharge. A sewer system serves 90% of households in the watershed. Between 2002 and 2006, JEA reported 17 sanitary sewer overflows in the watershed, five of which potentially impacted surface waters. WSEA estimates that there are 989 on-site sewage treatment and disposal systems (septic systems) in use. JEA has been conducting two large projects to replace or rehabilitate failing or leaking infrastructure in this watershed. COJ has constructed two wet detention projects and has worked with WSEA to add new sewer lines in order to eliminate 210 septic systems. An Annual Progress Report for this BMAP was published in 2011; it lists several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT (**DEP 2011b**).

Table 2.16 Water Quality Data for Moncrief Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.41	6.61	11.3	153	1998 - 2011
Total Nitrogen (mg/L)	<1.54	0.31	0.91	1.51	66	1998 - 2010
Total Phosphorus (mg/L)	<0.12	0.018	0.187	1.31	87	1998 - 2010
Chlorophyll-*a* (μg/L)	<20 FW <11 SW	0.80	13.8	140	59	1998 - 2010
Arsenic (μg/L)	≤50 FW ≤50 SW	2.23	3.68	124	26	1998 - 2010
Cadmium (μg/L)	≤0.3 FW ≤8.8 SW	1.00	4.37	10.6	6	1998 - 2002
Copper (μg/L)	≤9.3 FW ≤3.7 SW	2.02	2.37	40.0	31	1998 - 2010
Nickel (μg/L)	≤52 FW ≤8.3 SW	2.72	21.18	40.0	9	2000 - 2008
Silver (μg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (μg/L)	≤120 FW ≤86 SW	2.63	5.47	53.1	51	1998 - 2010
Fecal Coliform (log #/100 mL)	<2.6	1.00	1.80	4.95	85	1999 - 2011
Turbidity (NTU)	<29	1.70	9.65	39.9	134	1998 - 2011

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

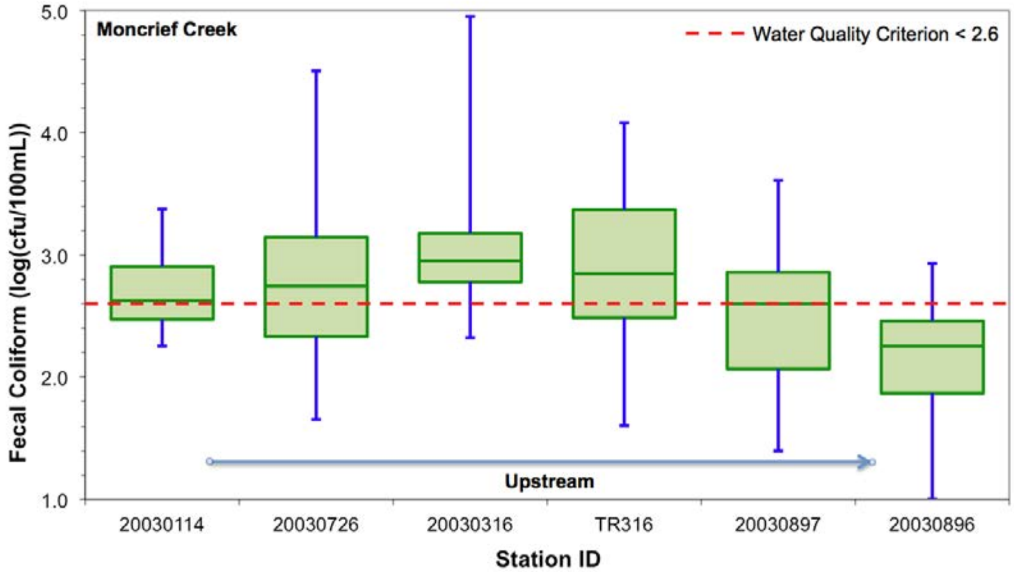


Figure 2.64 Fecal coliform in Moncrief Creek from downstream to upstream. Data are presented as the log of the number of fecal coliform bacteria per 100 mL; the maximum, mean, and minimum values at each station are shown.

2.8.18. Open Creek

2.8.18.1. About Open Creek

- West of the Intracoastal Waterway
- Primary Land Use: Residential
- Current TMDL Documents:
  Fecal Coliform with BMAP (2009)
- Verified Impaired 2009 (priority):
  None
- WBID Area: 6.5 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

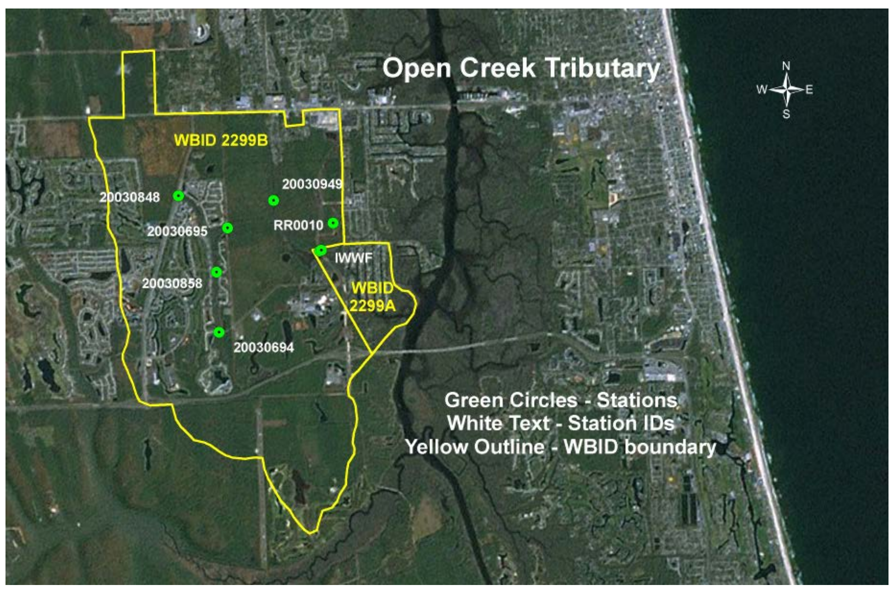


Figure 2.65 Open Creek (WBID 2299A and 2299B)

2.8.18.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in Open Creek WBID 2299A and 2299B (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.65) above and the graphs/tables in this section.

2.8.18.3. Discussion

Water quality data for Open Creek are shown in Table 2.17. Average nutrient levels (total nitrogen, total phosphorus, and dissolved oxygen) and turbidity were in the normal range. *(Note: the datasets for these parameters are relatively small in comparison to other parts of the basin).*

The fecal coliform level, averaged over all the stations in Hogan Creek, is elevated but below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, there is some variation in the levels dependent on the location. Figure 2.66 shows fecal coliform levels at various stations on Open Creek. These do not go in a downstream-to-upstream direction because these points lie on different streams that are tributaries to Open

Creek. All are above the water quality criterion except 20030848, which is near the intersection of Hodges Boulevard and Danforth Road.

A TMDL document (**Wainwright and Hallas 2009b**) was released to address fecal coliform. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP to address this issue was published (**DEP 2010a**). Annual Progress Reports for this BMAP were issued in 2011 (**DEP 2011a**) and 2012 (**DEP 2012a**); they list several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT.

Table 2.17 Water Quality Data for Open Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.80	5.53	12.0	79	2002 - 2010
Total Nitrogen (mg/L)	<1.54	0.35	0.65	1.00	13	2007
Total Phosphorus (mg/L)	<0.12	0.035	0.052	0.092	14	2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.79	3.50	8.70	11	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	No valid data available				
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	No valid data available				
Copper (µg/L)	≤9.3 FW ≤3.7 SW	No valid data available				
Nickel (µg/L)	≤52 FW ≤8.3 SW	No valid data available				
Silver	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	No valid data available				
Fecal Coliform (log #/100 mL)	<2.6	0.30	1.99	4.04	68	2002 - 2010
Turbidity (NTU)	<29	1.50	4.82	7.90	19	2007 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

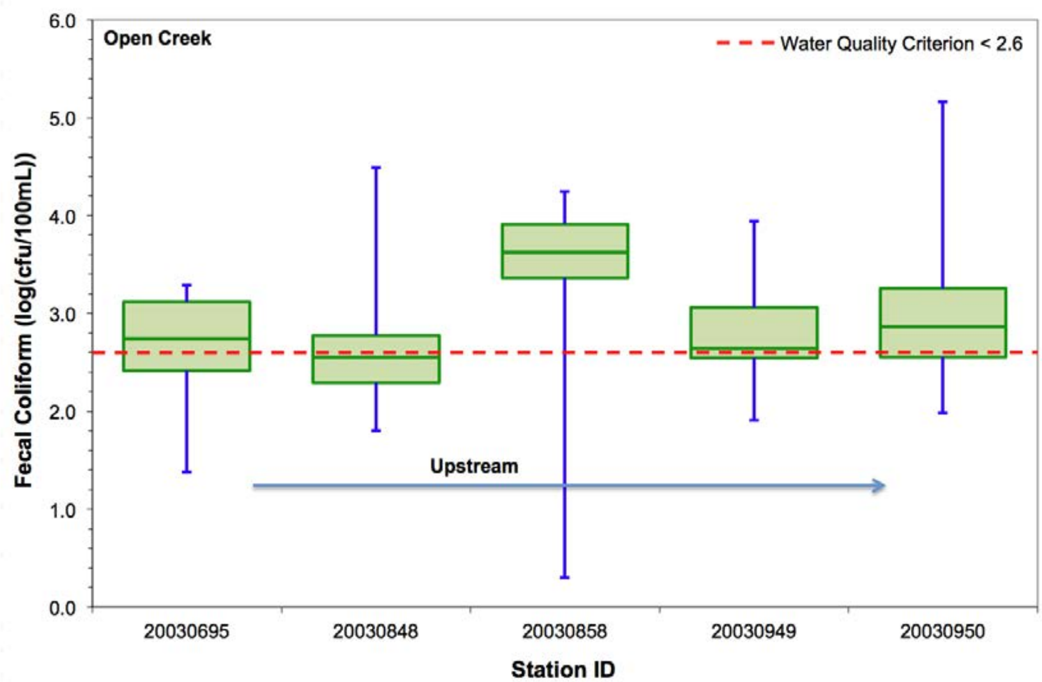


Figure 2.66 Fecal coliform in Open Creek from downstream to upstream. Data are presented as the log of the number of fecal coliform bacteria per 100 mL; the maximum, mean, and minimum values at each station are shown.

2.8.19. Ortega River

2.8.19.1. <u>About the Ortega River</u>

- West of NAS Jax and the St. Johns
- Primary Land Use: Residential
- Current TMDL Documents:
  Fecal coliform – 2213P1
  DO/Nutrient – 2213P1 (draft)
- Verified Impaired 2009 (priority):
  None
- WBID Area: 29.0 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

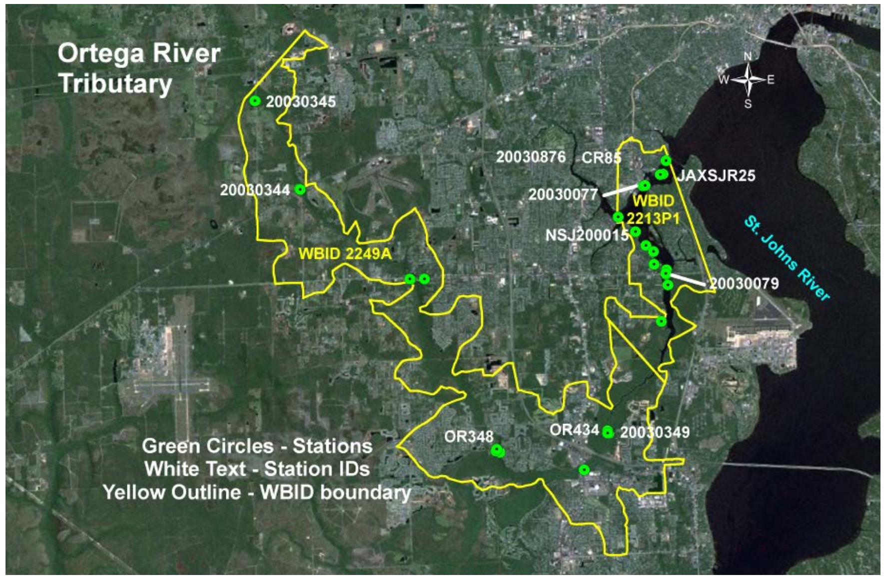


Figure 2.67 The Ortega River Tributary (WBID 2213P1 and 2249A)

2.8.19.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Ortega River WBID 2213P and 2249A (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.67) above and the graphs/tables in this section.

2.8.19.3. <u>Discussion</u>

Water quality data for the Ortega River are shown in Table 2.18. Average total nitrogen, total phosphorus, dissolved oxygen and chlorophyll-*a* concentrations were within acceptable limits. The fecal coliform level, averaged over all the sampling sites in the Ortega River, is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. The average at each individual sampling site also falls below the critical level. However, this analysis brings together data from both WBIDs and if the data is separated by WBID, WBID 2213P1 (downstream) has a significantly higher fecal coliform level than WBID 2249A.

Table 2.18 Water Quality Data for the Ortega River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.25	4.74	11.6	164	1998 - 2010
Total Nitrogen (mg/L)	<1.54	0.25	0.84	2.47	121	1998 - 2010
Total Phosphorus (mg/L)	<0.12	0.024	0.079	0.836	105	1998 - 2010
Chlorophyll-*a* (μg/L)	<20 FW <11 SW	0.51	3.77	64.0	41	1998 - 2009
Arsenic (μg/L)	≤50 FW ≤50 SW	0.54	2.20	46.8	17	1999 - 2009
Cadmium (μg/L)	≤0.3 FW ≤8.8 SW	0.021	1.12	2.50	4	2000 - 2007
Copper (μg/L)	≤9.3 FW ≤3.7 SW	0.55	2.83	10.0	11	1998 - 2010
Nickel (μg/L)	≤52 FW ≤8.3 SW	0.46	5.98	20.8	7	2000 - 2009
Silver	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (μg/L)	≤120 FW ≤86 SW	2.50	4.19	23.3	40	1998 - 2009
Fecal Coliform (log #/100 mL)	<2.6	1.00	1.33	3.68	61	1999 - 2007
Turbidity (NTU)	<29	0.58	6.67	64.0	197	1998 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.20. Pottsburg Creek

2.8.20.1. About Pottsburg Creek

- East of the St. Johns River at the JTB/I-95 intersection
- Primary Land Use: Residential
- Current TMDL Documents: Fecal coliform with BMAP (2010)
- Verified Impaired 2009 (priority): None
- WBID Area: 9.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

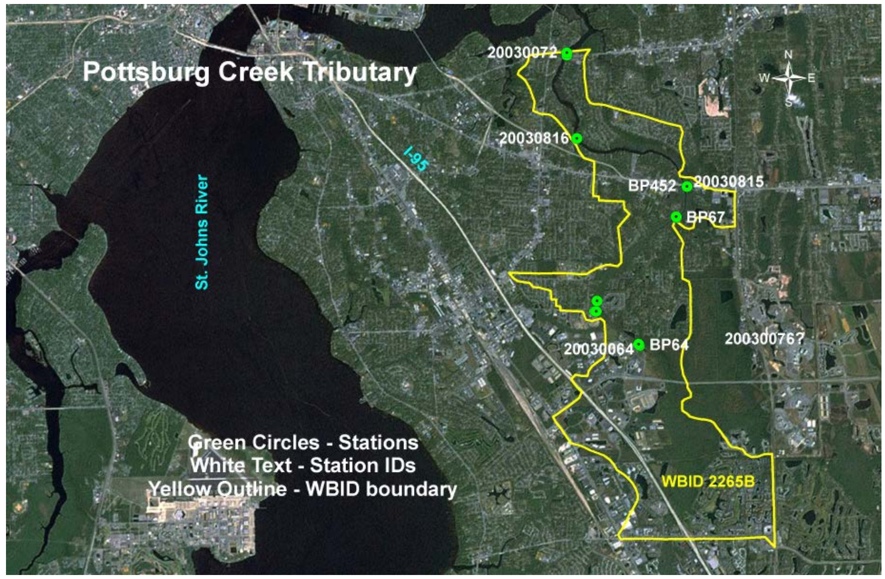


Figure 2.68 The Pottsburg Creek Tributary (WBID 2265B)

2.8.20.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Pottsburg Creek WBID 2265B (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.68) above and the graphs/tables in this section.

2.8.20.3. Discussion

Water quality data for Pottsburg Creek are shown in Table 2.19. Average phosphorus levels were higher than the recently updated WQC (**EPA 2010**), however, average dissolved oxygen and chlorophyll-*a* were within limits. Although fecal coliform data in Table 2.19 (1999-2007) indicates that the average is below the WQC, fecal coliform levels in this residential tributary were identified as impaired in 2004. Consequently, a TMDL for fecal coliform was published (**Rhew 2009**).

A BMAP for Pottsburg Creek (**DEP 2010a**) was released in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The Pottsburg Creek watershed contains one permitted point source for industrial wastewater, as well as numerous outfalls for stormwater discharge. A sewer system serves 33% of households in the watershed. Between 2001 and 2006, JEA reported 13 sanitary sewer overflows in the watershed, two of which potentially impacted surface waters. WSEA estimates that there are 1,585 on-site sewage treatment and disposal systems (septic systems) in use. COJ has constructed three wet detention projects and has worked with WSEA to add new sewer lines in order to eliminate 354 septic systems. An Annual Progress Report for this BMAP was published in 2011; it lists several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT (**DEP 2011b**).

Table 2.19 Water Quality Data for Pottsburg Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.69	5.85	10.5	48	2003 - 2010
Total Nitrogen (mg/L)	<1.54	0.36	0.89	1.40	16	1999 - 2007
Total Phosphorus (mg/L)	<0.12	0.042	0.164	0.423	29	2003 - 2007
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	2.00	15.7	39.0	11	2007
Arsenic (µg/L)	≤50 FW ≤50 SW	0.83	1.89	3.30	10	2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.027	0.027	0.027	1	2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.88	2.59	7.50	11	2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.87	2.03	5.09	11	2007
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	2.61	5.40	23.0	18	2003 - 2007
Fecal Coliform (log #/100 mL)	<2.6	1.85	2.03	3.05	27	1999 - 2007
Turbidity (NTU)	<29	0.10	6.79	22.0	58	1999 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.21. Ribault River

2.8.21.1. About the Ribault River

- Northwest of Downtown
- Primary Land Use: Residential
- Current TMDL Documents: Fecal coliform
- Verified Impaired 2009 (priority): Nutrients/Chlorophyll-*a*
- WBID Area: 9.7 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

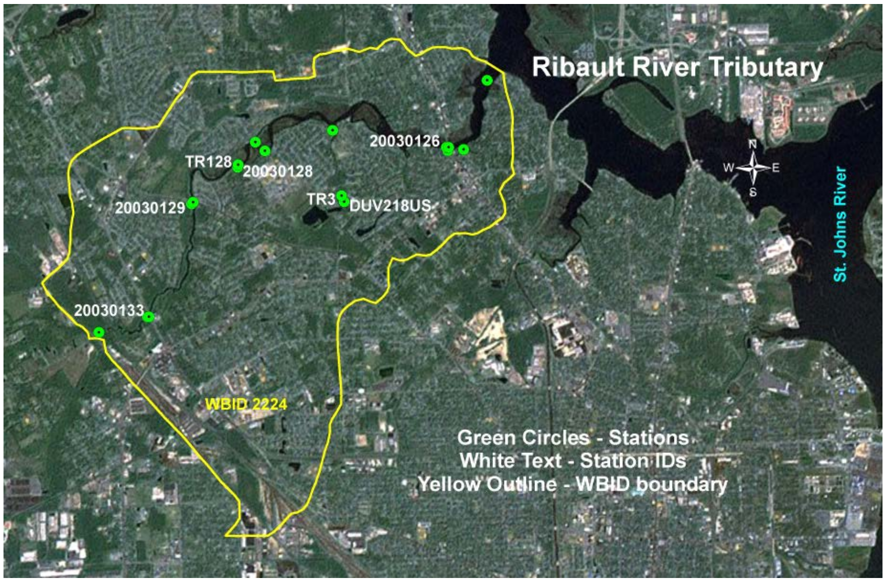


Figure 2.69 The Ribault River Tributary (WBID 2224)

2.8.21.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Ribault River WBID 2224 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.69) above and the graphs/tables in this section.

2.8.21.3. Discussion

Water quality data for the Ribault River are shown in Table 2.20. The Ribault River is located in a highly residential area and consequently is a contributor to elevated levels of phosphorus found in the tributary. High levels of chlorophyll-*a* have also been measured and the river has been designated impaired but no TMDL has been published at this time.

The fecal coliform level, averaged over all the sampling sites in the Ribault River, is elevated but below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units per 100 mL. However, a TMDL does exist for fecal coliform in the Ribault River (**Wainwright 2006a**) and a BMAP is under development. (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*).

Table 2.20 Water Quality Data for the Ribault River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	2.30	5.06	11.3	54	2002 – 2008
Total Nitrogen (mg/L)	<1.54	0.68	1.16	1.70	23	2006 - 2007
Total Phosphorus (mg/L)	<0.12	0.120	0.251	0.400	19	2006 - 2007
Chlorophyll-a (µg/L)	<20 FW <11 SW	4.40	35.0	150	20	2006 - 2007
Arsenic (µg/L)	≤50 FW ≤50 SW	0.80	1.31	3.00	18	2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.024	0.070	0.303	7	2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	1.32	2.65	6.40	13	2006 - 2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.76	0.98	1.90	18	2006 - 2007
Silver (µg/L)	≤0.07 FW ≤0.92* SW	No valid data available				
Zinc (µg/L)	≤120 FW ≤86 SW	7.80	11.7	39.0	19	2006 - 2007
Fecal Coliform (log #/100 mL)	<2.6	1.58	1.94	3.34	25	2002 - 2007
Turbidity (NTU)	<29	3.70	10.8	31.0	24	2006 - 2007

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.22. Rice Creek

2.8.22.1. About the Rice Creek

- West of Palatka
- Primary Land Use: Forested/Wetland
- Current TMDL Documents: None
- Verified Impaired 2009 (priority): Dissolved Oxygen (medium) Nutrients/Chlor-a (medium), Nutrients/Hist Chlor-a (medium), Dioxin (not available)
- WBID Area: 31.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

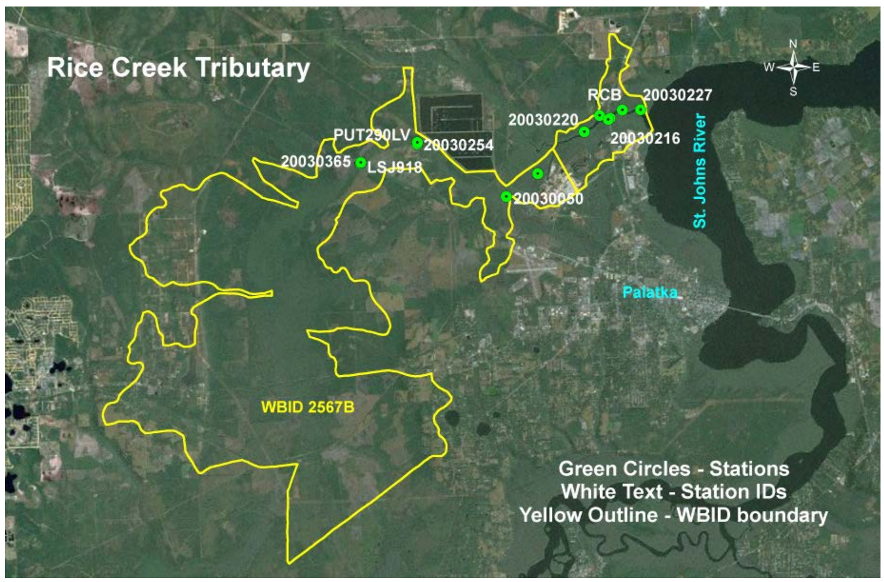


Figure 2.70 The Rice Creek Tributary (WBID 2567A/B)

2.8.22.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Rice Creek WBID 2567A/B (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.70) above and the graphs/tables in this section.

2.8.22.3. Discussion

Water quality data for Rice Creek are shown in Table 2.21. Rice Creek is predominantly surrounded by wetlands, forests including The Rice Creek Wildlife Management Area, and a pulp mill (Georgia Pacific). Dissolved oxygen and total nitrogen levels were below their WQC, however total phosphorus, chlorophyll-*a* and turbidity levels are elevated, suggesting the river has the potential for eutrophication. Currently, no TMDL documents have been developed for the impairments identified in WBID 2567A. Recently, Rice Creek has been identified as being impaired for dioxin (WBID 2567A) and the COJ is working with Georgia Pacific to address this issue.

Table 2.21 Water Quality Data for the Rice Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.36	5.64	11.1	412	1997 - 2010
Total Nitrogen (mg/L)	<1.54	0.12	1.32	6.78	368	1997 - 2010
Total Phosphorus (mg/L)	<0.12	0.010	0.112	0.556	375	1997 - 2010
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.52	13.2	70.4	144	1997 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	0.46	1.94	5.96	20	1999 - 2010
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.50	0.67	1.09	7	1998 - 2002
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.14	1.71	9.86	43	1997 - 2010
Nickel (µg/L)	≤52 FW ≤8.3 SW	1.07	1.65	21.3	133	1997 - 2010
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.20	0.86	1.76	3	1998 - 2002
Zinc (µg/L)	≤120 FW ≤86 SW	5.13	6.37	36.4	63	1997 - 2010
Fecal Coliform (log #/100 mL)	<2.6	1.30	1.94	3.36	18	2002 - 2004
Turbidity (NTU)	<29	1.20	7.21	37.9	215	1997 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.23. Sixmile Creek

2.8.23.1. About the Sixmile Creek

- East of the St. Johns River in St. Johns County
- Primary Land Use: Forested/Wetland
- Current TMDL Documents: None
- Verified Impaired 2009 (priority): None
- WBID Area: 59.5 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.71 The Sixmile Creek Tributary (WBID 2411)

2.8.23.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Sixmile Creek WBID 2411 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.71) above and the graphs/tables in this section.

2.8.23.3. Discussion

Water quality data for Sixmile Creek are shown in Table 2.22. Dissolved oxygen levels in Sixmile Creek are relatively low, compared to other tributaries (Figure 2.28); however, this is likely attributed to the wetland areas surrounding the creek and therefore it is not listed as impaired (**DEP 2009c**). Chlorophyll-*a* levels have exceeded WQC in the past but recent data have shown levels are decreasing. Silver levels are elevated, yet this has not been identified as an impairment.

Table 2.22 Water Quality Data for the Sixmile Creek

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.58	5.00	10.2	216	1997 - 2010
Total Nitrogen (mg/L)	<1.54	0.49	1.03	2.50	380	1997 - 2010
Total Phosphorus (mg/L)	<0.12	0.011	0.092	0.477	385	1997 - 2010
Chlorophyll-a (µg/L)	<20 FW <11 SW	0.57	13.1	74.7	156	1997 - 2010
Arsenic (µg/L)	≤50 FW ≤50 SW	0.91	2.32	12.3	18	1999 - 2009
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.50	0.81	1.26	5	1999 - 2002
Copper (µg/L)	≤9.3 FW ≤3.7 SW	1.09	1.96	5.30	25	1999 - 2010
Nickel (µg/L)	≤52 FW ≤8.3 SW	2.00	3.79	23.1	22	1999 - 2010
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.20	0.72	2.10	10	1997 - 2007
Zinc (µg/L)	≤120 FW ≤86 SW	5.00	12.1	25.6	9	1997 - 2009
Fecal Coliform (log #/100 mL)	<2.6	2.43	2.43	2.43	1	2004
Turbidity (NTU)	<29	0.50	2.64	33.5	197	1997 - 2010

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.8.24. Trout River

2.8.24.1. About the Trout River

- North of Downtown Jacksonville
- Primary Land Use: Residential/Wetland
- Current TMDL Documents: Fecal coliform with BMAP (2010) DO/Nutrients - 2203 (draft)
- Verified Impaired 2009 (priority): Nutrients/ Chlorophyll-*a* – 2203 (medium) Mercury – 2203A (high) Fecal coliform – 2223 (low)
- Beneficial Use: Class III M/Class III F (Marine -> Freshwater)

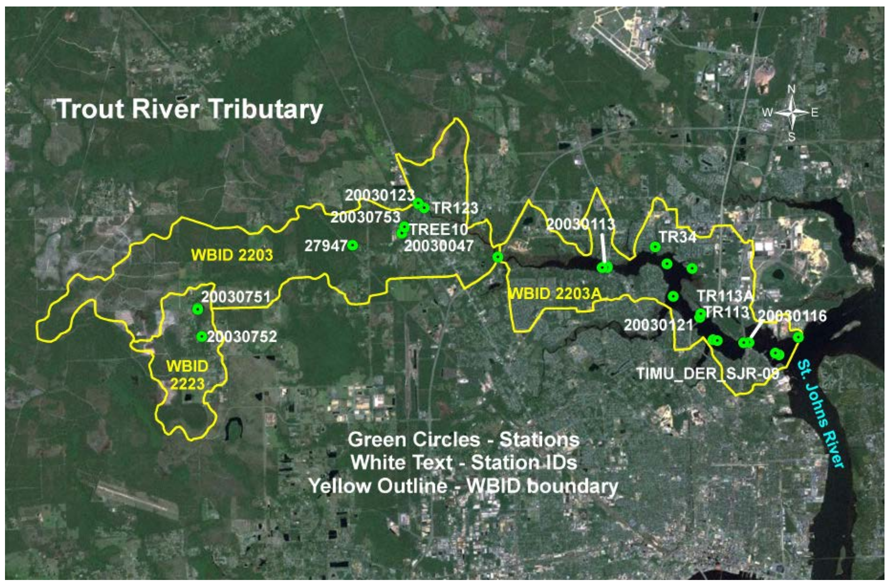


Figure 2.72 The Trout River Tributary (WBIDs 2203/2203A/2223)

2.8.24.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010g**) and filtered based on the stations (**DEP 2010h**) in the Trout River WBIDs 2203/2203A/2223 (**DEP 2011c**). The filtered dataset was used to generate the image (Figure 2.72) above and the graphs/tables in this section.

2.8.24.3. Discussion

Water quality data for the Trout River are shown in Table 2.23. Overall (all WBIDs) average phosphorus levels were higher than the recently updated WQC (**EPA 2010**) and average total nitrogen, dissolved oxygen and chlorophyll-*a* concentrations were within acceptable limits. However, nutrient levels have been found to be, on average, higher than the WQC for WBID 2203 and a TMDL to address this issue has been published (**Magley 2009a**).

The fecal coliform level, averaged over all the stations in the Trout River (Table 2.23), is below the critical level of 2.6, which is the logarithm of the state maximum of 400 colony-forming-units (cfu) per 100 mL. However, a TMDL for fecal coliform was finalized in 2009 (**Wainwright and Hallas 2009c**) for WBIDs 2203 and 2203A in the Trout River. (*Note: the*

data analysis in the TMDL is based on different criteria than that used in this report). Subsequently, a BMAP for the Trout River (**DEP 2010a**) was released in August 2010. It describes sources of fecal coliform in the watershed, and completed and ongoing activities conducted by state and local agencies that are anticipated to reduce fecal coliform loading in the tributary. The BMAP describes two WBIDS: the upper Trout River (2203), and the lower Trout River (2203A). The upper Trout River watershed contains one permitted point source for industrial wastewater, and the lower Trout River contains two of those; both have numerous outfalls for stormwater discharge. The sewer system serves 100% of households in the upper Trout River watershed, and 73% in the lower Trout River watershed. Between 2001 and 2007, JEA reported 21 sanitary sewer overflows in the lower Trout River watershed, six of which potentially impacted surface waters, and none in the upper Trout River. WSEA estimates that there are 819 on-site sewage treatment and disposal systems (septic systems) in use in the upper Trout River, and 2,964 in the lower Trout River. COJ has completed two flood control projects in the lower Trout River watershed. An Annual Progress Report for this BMAP was published in 2011; it lists several repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT (**DEP 2011b**).

The Trout River has been identified as being impaired for mercury based on fish advisories (**Donner 2008**), and this will be addressed in the recently revised draft statewide mercury TMDL document (**DEP 2012c**) scheduled for completion in 2013.

Table 2.23 Water Quality Data for the Trout River

Parameter	Water Quality Criteria	Concentration			Samples	Sampling Period
		Low	Average	High		
Dissolved Oxygen (mg/L)	≥5.0	0.50	5.31	10.8	143	1982 - 2010
Total Nitrogen (mg/L)	<1.54	0.32	1.02	3.30	52	1997 - 2008
Total Phosphorus (mg/L)	<0.12	0.031	0.230	0.860	74	1997 - 2008
Chlorophyll-*a* (µg/L)	<20 FW <11 SW	0.67	6.72	27.0	27	1997 - 2008
Arsenic (µg/L)	≤50 FW ≤50 SW	0.70	1.34	2.80	22	2007
Cadmium (µg/L)	≤0.3 FW ≤8.8 SW	0.021	0.022	0.023	3	2007
Copper (µg/L)	≤9.3 FW ≤3.7 SW	0.37	0.80	31.2	31	2006 - 2007
Nickel (µg/L)	≤52 FW ≤8.3 SW	0.41	1.26	3.70	12	2006 - 2007
Silver (µg/L)	≤0.07 FW ≤0.92* SW	0.079	0.086	0.093	2	2007
Zinc (µg/L)	≤120 FW ≤86 SW	2.80	5.07	63.0	35	1982 - 2007
Fecal Coliform (log #/100 mL)	<2.6	0.60	1.27	3.94	54	2000 - 2008
Turbidity (NTU)	<29	1.30	7.93	39.0	94	1997 - 2008

Note: Hardness-dependent freshwater criteria for cadmium, copper nickel, and zinc were generated based on a hardness concentration of 100 mg/L. FW=freshwater; SW=saltwater. The asterisk indicates a proposed criterion, which has not yet been adopted.

2.9. Groundwater

2.9.1. Groundwater Overview

An aquifer is a geologic formation that can hold and transfer water, depending on its permeability, which is largely a function of its pore space and the connectivity of that pore space. In limestone aquifer formations, erosion of the rock by weakly acidic water solutions over long periods of time creates fissures and open channels in the rock which lead to increased water movement and holding capacity, and ultimately, to changes in the landscape; such as sinkholes, caves, lakes, as well as underground streams and free flowing springs which are known as karst topography. Florida has all of these in abundance, including 27 of the nation's 78 first order of magnitude springs (**Samek 2004**).

Florida has long had the luxury of a vast resource of mostly drinking-quality groundwater in the limestone and dolomite geologic formations known as the Floridan Aquifer system. It is one of the most productive aquifers in the world (**UGA 2002**). These carbonate rocks were formed by depositing calcium carbonate on the floor of a shallow ocean region millions of years ago starting in the Paleocene (Cedar Keys Limestone) to Eocene (Avon Park, Ocala and Suwanee Limestones) to early Miocene Period (Tampa Limestone), largely by the warming of the shallow water areas and action of

corals, mollusks and other sea creatures which create calcium carbonate (limestone) shells for protection. Over very long periods of time, thick layers were deposited and turned into rock by compression and heating. Much later, ocean reflooding of these areas of calcium carbonate rock allowed some magnesium from the seawater to exchange with the calcium ions to make dolomite or a combination of the two materials called dolomitic limestone. Later lowering of the ocean levels during an ice age (actually a series of them) exposed the Florida Peninsula above the surface and beaches formed on top of the carbonate rock layers. These beach areas were developed by quartz sands from the eroding granites of the Appalachian Mountain chain, with silt and clays from the weathering of feldspars. The sand was brought to the coast by many rivers which deposited the sand, clay and silts at the ocean edge; where it was deposited in river deltas, clay beds and sandbars. Storms and coastal currents continued to move the beach sand and silty clays around until eventually they became the covering layer over the Floridan Aquifer in shallow bays or lagoons (**Scott 1988**). These relatively simple processes combined in complex ways to form most of the geology of Florida. The Floridan Aquifer is further divided into an Upper Floridan Aquifer and a Lower Floridan Aquifer which are separated by a less permeable layer referred to as the middle confining unit, mostly composed of clay or a carbonate-anhydrite mix which restricts flow between the two layers. The Upper Floridan and its properties are well known from the numerous wells drilled into it for consumptive water uses from agriculture to municipal potable water (drinking water) supplies to industrial uses. The Lower Floridan Aquifer is less well known both geologically and with regard to its water quality since it is deeper and thus there are fewer boreholes (wells) that reach that level. Part of the Lower Floridan Aquifer contains saltwater or brackish water (**UGA 2002**).

As shown below (Figure 2.73), the Floridan Aquifer is extensive and underlies portions of adjacent states as well as Florida. The Floridan Aquifer is sometimes very near or at the surface, as in Western North Florida (brown), but most is covered by newer sediments which in most areas are a relic of beach erosion and deposition which form a cap-like upper surface to the aquifer. Of note is the eastward extent of the thinning cap structure in the Middle Basin of the St Johns River, which (in part) enables the many springs in that section of the St Johns River. A thicker cap layer exists both North and South of the Middle Basin.

In the areas adjacent to the LSJR Basin, this geologic cap is usually the Hawthorn group. It is a mixed group of thinner layers consisting of mixed phosphates, clays and dolomites and occasional beds of clean quartz sands. This group allowed a high head pressure for artesian wells in the pre-development era along the LSJR.

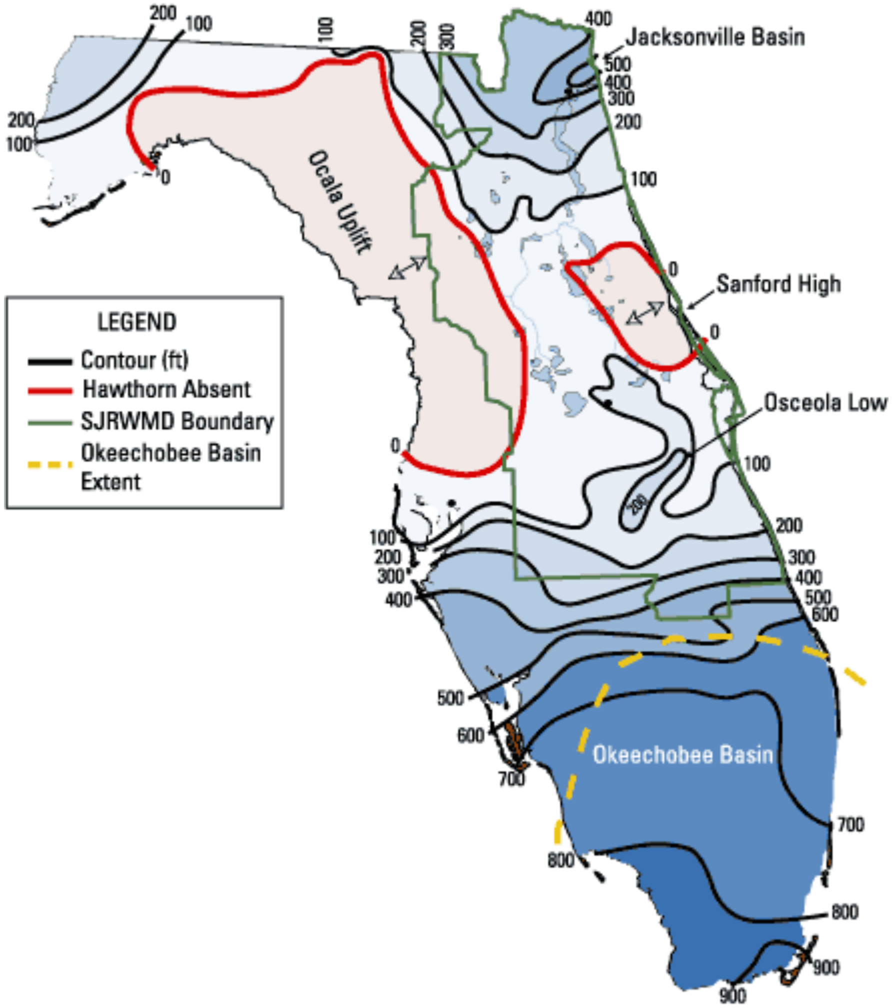


*Figure 2.73 Approximate limits of the Hawthorn Group, along with structural controls (**USGS 2012c** Figure 6)*

2.9.2. The Potentiometric Surface

Ultimately, the movement of groundwater is governed by the water pressure within an aquifer and its slope. A diagram that helps visualize the groundwater movement direction and speed is a plot of the potentiometric surface, which is the height of standing water in wells that reach the aquifer. The height of the water is equivalent to the head pressure in the aquifer, and if the head pressure in feet exceeds the elevation of the terrain where the well is located, the well will be an artesian well and water will flow without a pump. Figure 2.74 is the USGS plot of the 1960 potentiometric surface with a North-South elongated maximum along the Clay-Bradford County line just west of Keystone Heights, Fl. The spacing between the contour lines is also important as it relates to the speed of groundwater flow; the closer the lines are together the faster the flow rate, and the direction of flow is perpendicular to the lines. So the more contour lines in an area the faster the groundwater moves across those lines. Note the slower groundwater flow indicated by the 80 foot contour east and south of the maximum near Keystone Heights, which then becomes faster flow between the 80 foot and 70 foot contours. Two areas of maximum groundwater movement are west of Green Cove Springs (between 30 and 80 foot contours) and near Gainesville, west of Newnans Lake (between 75 and 50 foot contours). Very slow flow is indicated north of Starke (70 foot contour) to the Duval, Union and Baker County lines along Highway US 301 and adjacent areas.

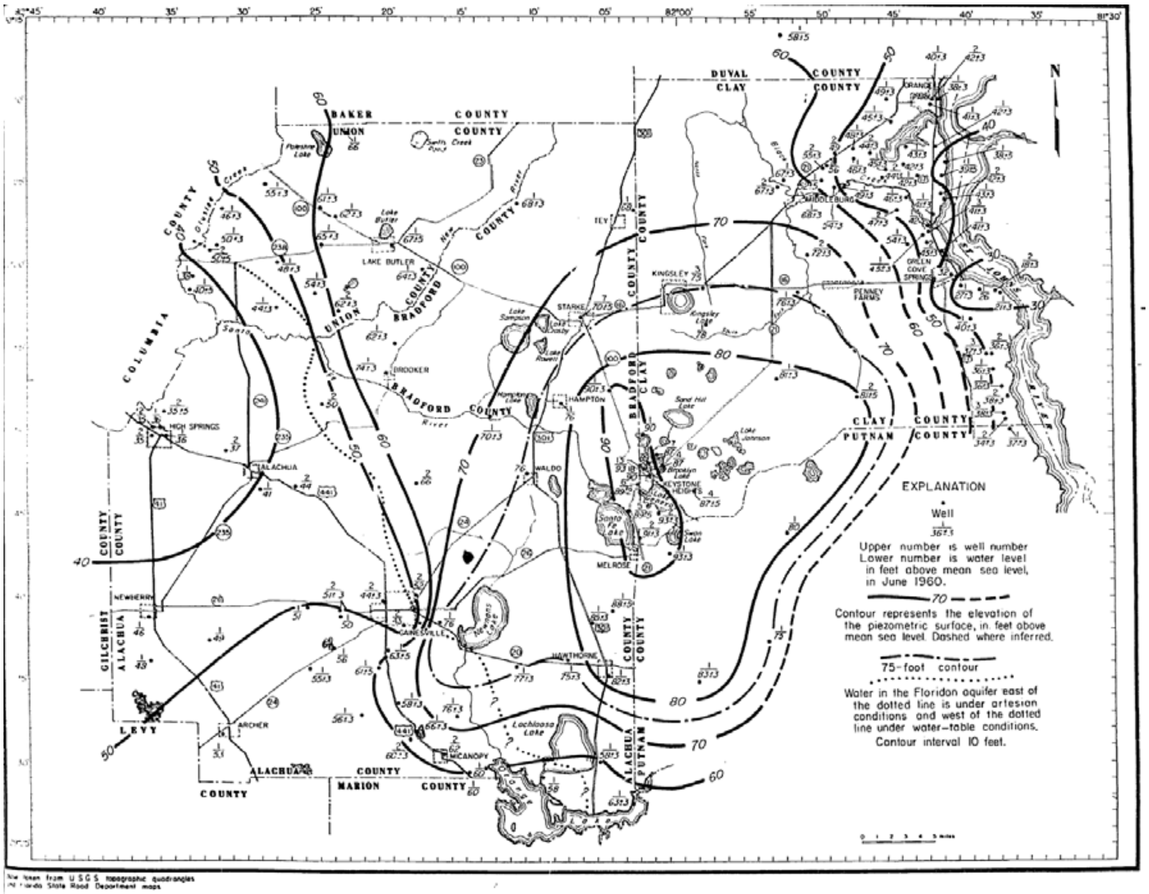


Figure 80. Alachua, Bradford, Clay, and Union counties, Florida, showing contours on the piezometric surface of the Floridan aquifer in June 1960.

*Figure 2.74 Piezometric Surface of the Floridan Aquifer (**Clark 1964** Figure 80)*

In more recent times, in some areas of North and Central Florida we have used more groundwater than is produced by rainfall recharge to the Floridan Aquifer System. This is essentially mining the groundwater. This process was very common in the Western U.S. where rainfall is scarce and development was rapid, but the limits to that level of growth became apparent.

Recently water supply studies have indicated that groundwater supplies are insufficient to meet the future public water supply needs of Central Florida, and specifically the counties of Orange, Seminole and Osceola in the greater Orlando region of the St Johns River Water Management District. Similarly, the portions of Orange, Osceola and Polk counties within the South Florida Water Management District, and the areas of Polk County in the Southwest Florida Water Management District, all have the same issue. As a result the three water management districts have designated the region of concern as the Central Florida Coordination Area (CFCA).

In addition, an extensive study of the use of the St Johns River for an Alternative Water Supply was recently completed. The St. Johns River Water Management District completed a four-year "Water Supply Impact Study" (**SJRWMD 2012f**) in February 2012 that evaluated the potential environmental effects of proposed withdrawals from the St. Johns and Ocklawaha rivers on the plants, animals and water resources of the St. Johns River. The study concluded that minimal impact would occur with the use of up to 155 million gallons per day withdrawal from the St Johns River.

The SJRWMD emphasizes that water conservation, the use of reclaimed water and surface water, and perhaps even desalinization of brackish water or seawater will be alternatives for Florida's future water supply (see **SJRWMD 2012e**).

2.9.3. Minimum Flows and Levels (MFLs)

As part of conserving and restoring our water resources and protecting the local ecology, Minimum Flows and Levels have been established by the SJRWMD for many of the lakes and streams in the District area. The goal of MFLs are to ensure "natural systems needs as defined by minimum flows and levels are satisfied first before any water supply withdrawal is allowed. MFLs address the entire flow regime of the river (high flow, moderate flow and low flow) and any

proposed water supply withdrawal must demonstrate compliance with all established MFLs before a consumptive use permit (see **SJRWMD 2012c**) is issued" (**SJRWMD 2012e**). If required to ensure compliance with MFLs, specific projects can be designed to withdraw water during times of moderate to high flow so that no water is withdrawn during periods of low flow."

Two areas of special concern are the Harris Chain of Lakes in North Central Florida and the Etoniah Creek basin in North Florida (Figure 2.75). The Upper Etoniah Creek Basin includes several lakes in the Keystone Heights area fed by Alligator Creek that originates in Camp Blanding at Blue Pond, and ultimately supplies water to the rest of the chain of Lakes (including Lakes Lowry, Magnolia, Brooklyn and Geneva), the Etoniah Creek Basin and the St Johns River. Recently Lakes Brooklyn, Cowpens, and Geneva were listed as in "Recovery", status that requires actions to improve their condition. Lake Geneva for example had not met its MFL for over 20 years. Lake Grandin is now listed in "Prevention" status, which requires additional measures to prevent further decline.

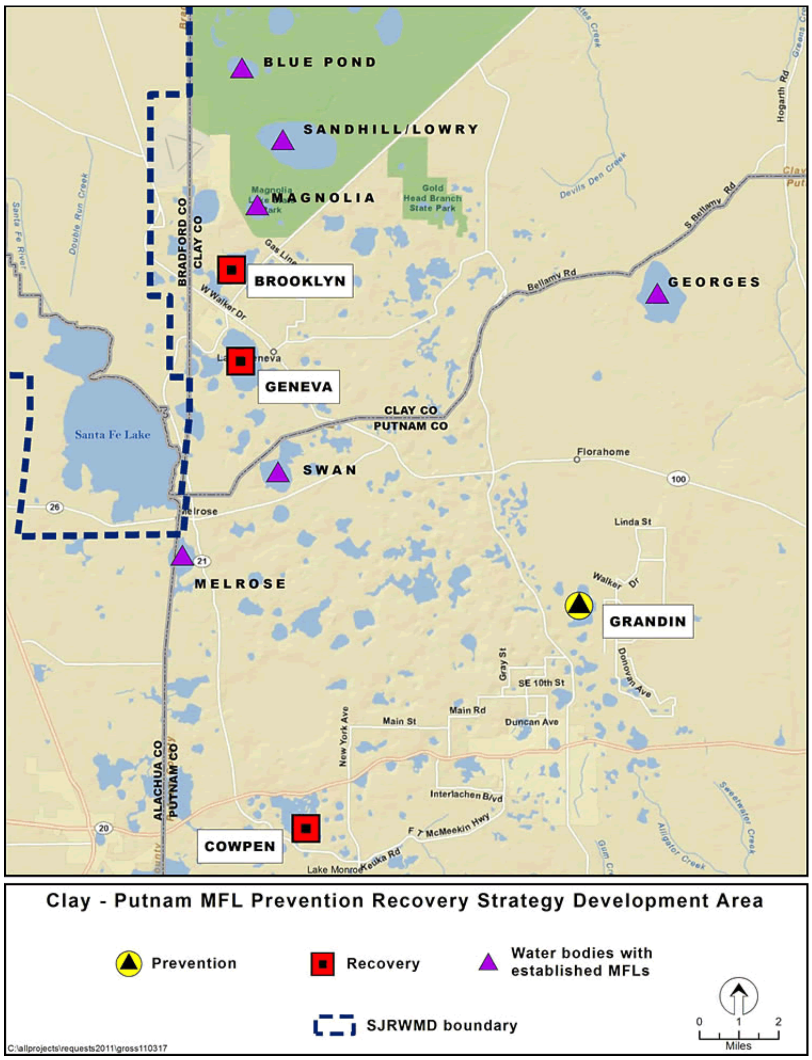


*Figure 2.75 Clay/Putnam County Minimum Flows and Levels (Figure in **SJRWMD 2012b**)*

Part of the blame for the decline of these lakes, in addition to continuing drought is the decline in the potentiometric surface height in the Keystone Heights Region that was near 90 feet and is now at least ten feet lower (see Figure 2.76). SJRWMD studies indicate that as much as five feet of diminished lake levels is related to overall aquifer water withdrawals by pumping (wells). These withdrawals are dominated by municipal water supplies and agriculture in the Upper Etoniah Basin and adjacent areas.

Meetings are being held to determine short, mid and long-term recovery methods for these lakes, and the recent JEA consumptive use permit requires efforts to help the lakes recover. How this will all work out remains to be seen, but any additional water recycled to these areas ultimately adds water to the Upper Floridan Aquifer through recharge.

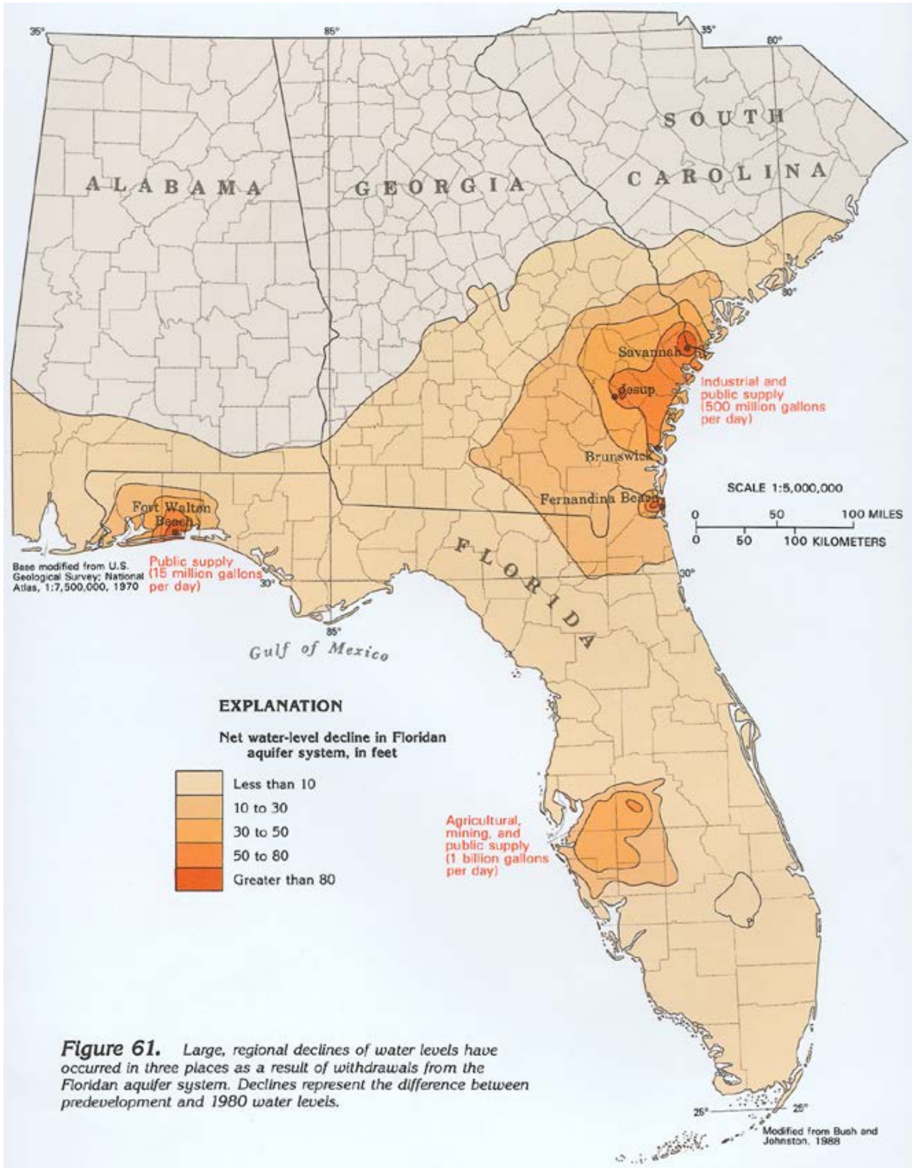


Figure 61. *Large, regional declines of water levels have occurred in three places as a result of withdrawals from the Floridan aquifer system. Declines represent the difference between predevelopment and 1980 water levels.*

*Figure 2.76 Floridan Aquifer Water Levels (**USGS 2012a** Figure 61)*

3. Fisheries

3.1. Introduction

3.1.1. General Description

The lower basin of the St. Johns River supports a diverse and abundant fish and invertebrate community of commercial and recreational value to the public. Invertebrate commercial fisheries account for the largest percentage of landings with blue crabs comprising over 85% of the total landings for 2011 (**FWRI 2011a**). In the same year, finfish fisheries accounted for 15% of the total catch with striped mullet, sheepshead, croaker and flounder being the most commonly caught species in the five counties associated with the lower basin of the St. Johns River (Figure 3.1). Recreationally, the St. Johns area supports high numbers of red drum, spotted seatrout, croaker, sheepshead, flounder, largemouth bass and bluegill that are sought by both local and visiting anglers.

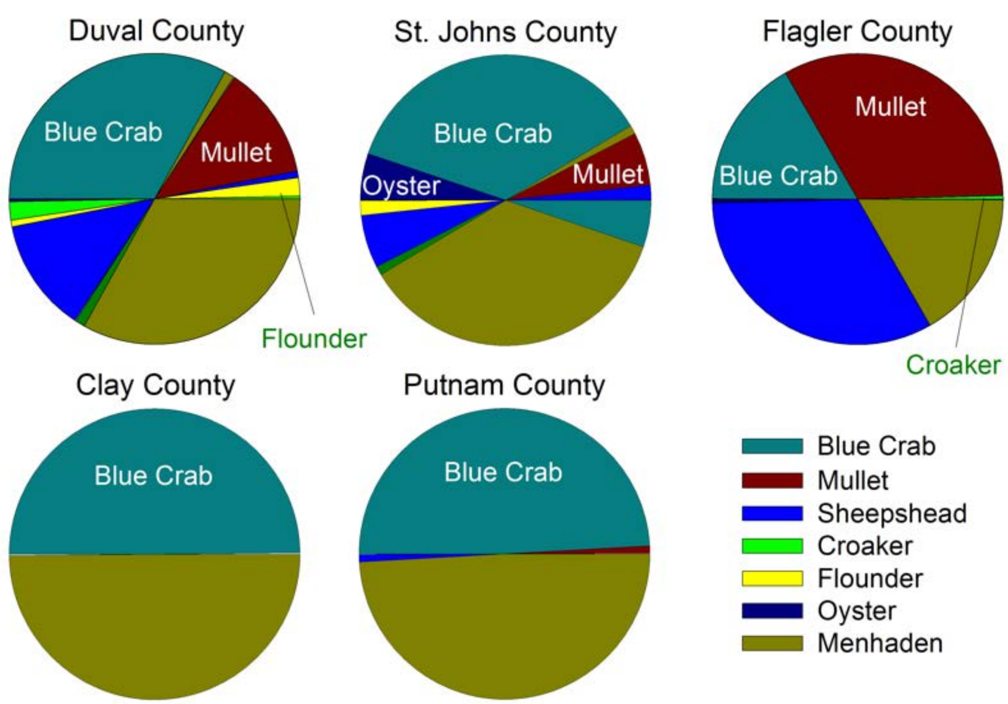


Figure 3.1. Percent comparison of commercially important fish and invertebrates caught by fisherman of five counties associated with the lower basin of the St. Johns River in 2011. These data do not differentiate between fish and invertebrates caught in the St. Johns River or the Intracoastal Waterway (ICW).

3.1.2. *Data Sources & Limitations*

Two sources of data were referenced in interpreting status and trends of fish and invertebrates. All available literature was used to examine potential long-term trends (1955-2011) in fish communities via the presence or absence of species encountered in the particular study. Such comparisons may give insight into whether the overall fish community was the same for the time periods compared. A major weakness of this comparison is that it gives no information on how the numbers of a given species may have changed with time. In most cases, the collection methods in the studies were not the same. Consequently, the conclusions that can be drawn from these kinds of comparisons are limited.

The status and trends documented for species in this section are derived from two sources of data. The focal datasets come from commercial landings reports (1994-2011), and the fisheries independent monitoring data (2001-2011) obtained from the Florida Fish and Wildlife Research Institute (FWRI). For commercial landings data, there are uncertainties associated with either the exact location of where a fish was caught and/or the method of estimating total number of landings for a given area. In particular, these data do not differentiate between fish and invertebrates caught in the St. Johns River or the Intracoastal Waterway (ICW). Additionally, changes in fishery regulations through the years limit what can be said of landings between certain time periods. In most cases, total landings are graphed. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends are investigated using a Kendal Tau correlation analysis.

The most statistically reliable data used in this report come from ongoing research conducted by the Fish and Wildlife Research Institute (See Appendix 3.1.1 for river areas sampled). Data are presented in two forms. The first form displays for each species yearly indices of abundance for three age classes (young of the year, juveniles, and subadults/adults) encountered within the lower basin of the river. The second form displays the monthly length frequency diagrams for each species for the 11-year sampling period. Both forms of display allow for more specific insight into temporal trends. Potential trends in all these data are investigated using Kendal Tau correlation analysis. Finally, scientific literature was used where appropriate to supplement these data, and form our conclusions on trends and status.

3.1.3. *Health of Fish and Invertebrates*

There is not much information on the health of fish and invertebrates from the lower basin of the St. Johns River. In the mid-1980s, there were concerns with fish health in the St. Johns River when high numbers of fish with external lesions (called ulcerative disease syndrome - UDS) were reported by local fishermen. A comprehensive 1987 study (**CSA 1988**) from Clapboard Creek to Lake George revealed only 73 lesioned fish out of 69510 (0.11%). However, this study also observed a higher percentage (5 %) of lesioned fish in the Talleyrand area with the main affected fish being southern flounder, weakfish, yellowfin menhaden, southern stingray and Atlantic croaker. FWRI research suggests that a major cause of the lesions is a water mold (*Aphanomyces invadans*) that is more likely to infect stressed fish. Fish can be stressed when exposed to unusual changes in salinity, temperature and water quality.

During the summer and fall of 2010, there was a sequence of unusual events in the LSJR involving extensive fish kills, cyanobacteria blooms, foam formation and bottlenose dolphin deaths. From late May until July 2010, there were extensive fish kills within the St. Johns River from Lake George to the downtown Jacksonville area. The mortality event lasted much longer than mortality events caused from hypoxia. While multiple species of dead fish were observed, white catfish, red drum, longnose gar, Atlantic stingrays, and menhaden were reported to be most affected by the event. Generally, most

observed dead fish did not have lesions or sores. Co-occurring with the fish kill were cyanobacteria blooms of *Aphanizomenon cf. flos-aqua* followed by blooms of other algal species. Fish histopathology suggested that cyanobacteria-degrading bacteria may have played a role in this fish morality event. During mid-October, a second, less widespread fish mortality event occurred in the river in which smaller fish, mostly menhaden, were found with lesions near the caudal fin. This later fish kill may have been because of a bloom the fungus *Aphanomyces invadans*.

FWRI has investigated external abnormalities such as lesions in fish since 2000. They surveyed fish and invertebrates for the presence of abnormal growths, colors and ulcers or gross external abnormalities (GEA). They also sampled mercury levels in muscle tissue from the shoulder area in similar sized (generally larger) spotted seatrout, red drum, southern flounder, southern kingfish (whiting), and blue crabs.

The incidence of GEAs was found to be less than one percent from 2001 to 2010 (**FWRI 2001; FWRI 2002; FWRI 2003; FWRI 2004; FWRI 2005; FWRI 2006; FWRI 2007; FWRI 2008c; FWRI 2009; FWRI 2010**). During this time period, the percent of fish affected by GEAs has varied between 0.001 to 0.4 % (Figure 3.2). While 26 species of fish with GEAs have been encountered by FWRI from 2001 to 2010, the most commonly observed fish with GEAs during this time period are striped mullet, menhaden, sheepshead, and largemouth bass.

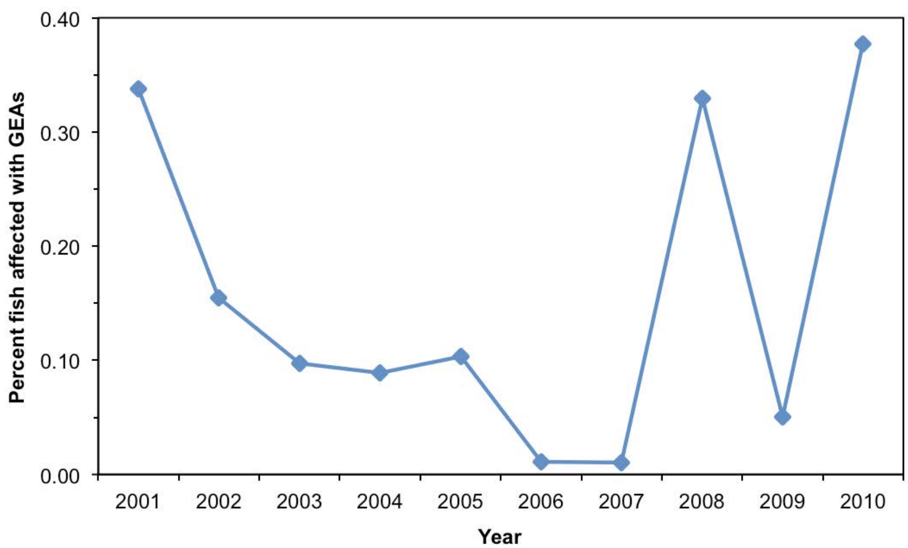


Figure 3.2. The percent of fish encountered with gross external abnormalities (GEAs) for each year of the ongoing FWRI study. A Kendall tau correlation revealed no significant trend over time (τ=-0.400; Not statistically significant) in the percent fish encountered with GEAs from 2001 to 2010.

Mercury has been detected in a number of freshwater, estuarine and marine species in the state of Florida. Statewide, FDOH issues consumption advisories for a number of marine and estuarine fish (**FDOH 2012**). Generally, these are large, long-lived predatory species which bioaccumulate high concentrations of mercury, over their lifetimes. Consumption advisories recommend the amount of the affected fish species that can safely be eaten in a given time span. It is recommended that fish that exceed a concentration of 1.5 parts per million (ppm) of mercury not be eaten by anyone. The general population can still eat fish with a 0.3 ppm mercury concentration although there are more limiting human consumption advisories for children and women of child-bearing age (sensitive populations) when concentrations in fish exceed 0.1 ppm (**Goff 2010**).

In the lower St. Johns River, the Department of Health advises limited consumption (1-8 meals per month---depends on the species) of Atlantic croaker, Atlantic thread herring, Atlantic weakfish, black drum, brown bullhead, redbreast sunfish, bluegill, black crappie, gulf and southern flounder, jack crevalle, hardhead catfish, red drum, sand seatrout, sheepshead, spotted seatrout, southern kingfish, striped and white mullet, spot, warmouth, largemouth bass, bowfin, and/or gar. Everyone is advised to eat no king mackerel larger than 31 inches, and no sharks larger than 43 inches (**FDOH 2012**). Note that more restricted consumption is recommended for children and pregnant/lactating women. For more information about consuming fish, see the Florida Department of Health's website. For more information about mercury in fish and other species, see Section 5.4.4.

3.2. Finfish Fishery

3.2.1. General description

The St. Johns River lower basin supports a fish community of great ecological, commercial and recreational value to the public. Most of the fish sought after are predaceous fish that are important in maintaining community balance in the areas where they occur. Historically, American eel and shad were huge fisheries in the St. Johns, although populations have decreased to such low levels that they are now not the focus of most commercial fisherman (**McBride 2000**). Currently, the premier commercially harvested estuarine or marine fish in the lower basin are striped mullet, flounder, sheepshead, menhaden, black drum, croaker and whiting. However, American eels, spotted seatrout, and weakfish are also commercially harvested. In freshwater sections of the river, important species commercially harvested include catfish, gar, bluegill/rehear sunfish, shad, American eels, and non-native tilapia. Of the five counties studied, Duval County had the overall highest landings (over 430,116 lbs. in 2011) and catch, the most fish species per year (only includes fish caught within the river and ICW).

The St. Johns River supports a diverse recreational fishery in the lower basin. Within the different sections of the river, significant fisheries exist for freshwater, estuarine or saltwater fish. Popular saltwater species sought after are red drum, spotted seatrout, flounder and sheepshead. Premier freshwater species include largemouth bass, blue gill and catfish. The abundance of some of these fish species in the river has resulted in a number of very high profile fishing tournaments occurring each year - red drum and bass tournaments being among the most popular.

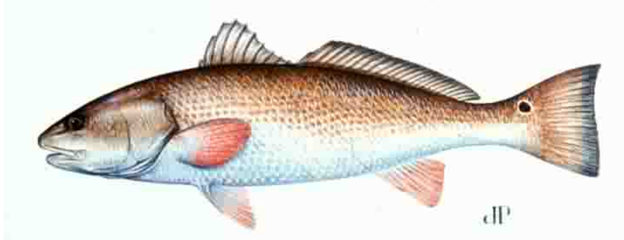
3.2.2. Long-term trends

For many years, humans have benefited from the thriving fish communities that utilize the lower basin of the St. Johns River. Indeed, a number of the species sought after today, such as spotted seatrout and sheepshead, were commented on by the naturalist William Bartram as far back as the late 1700s. However, despite the importance of river fisheries over the years, only a few studies have rigorously sampled fish populations in the St. Johns River. In response to this need for more information, the Fish and Wildlife Research Institute started a monthly fish-sampling program in 2001 that is designed to understand fish population changes with time in estuarine areas of Northeast Florida.

The available long-term research suggests that many of the same species present today (~170 species total) were present in the river back in the late 1960s (**McLane 1955**; **Tagatz 1968b**; **FWRI 2007**). However, it is unclear whether the numbers of individual species have changed during this time period because of different sampling methods used in these studies. Currently, the most numerically dominant species in the lower basin include anchovy, striped mullet, killifish, menhaden, Atlantic croaker, spot, silversides, and silver perch.

A preliminary study by L. McCloud with St. Johns River Water Management District (SJRWMD) compared current FWRI fish data with those collected by M. Tagatz in 1968. Her research suggested that at some areas of the river, observed fish communities were 50% different between 1968 and the 2001-2006 time period. She further suggests that the observed differences in fish communities in these areas may have been the result of a transition zone between marine and freshwater moving further upstream. One of the unique aspects of the St. Johns Estuary is the ability of some marine fish to ascend far upstream into freshwater. For instance, stingrays are abundant in a number of freshwater areas in the river. However, most fish are sensitive to their environment, and can move from an area in response to unsuitable changes in important environmental factors such salinity, dissolved oxygen, and temperature.

3.2.3. Red Drum (Sciaenops ocellatus)



http://myfwc.com/marine/fish/reddrum.jpg

3.2.3.1. General Life History

Red drum (also called puppy drum, channel bass, spottail bass, red bass and redfish (**FWRI 2008f**)) are predatory fish that are found in the estuarine sections of the St. Johns River. During the fall and winter, they spawn at dusk in coastal waters near passes, inlets and bays. Newly hatched young live in the water column for 20 days before settling to the sea floor bottom where they will develop into juveniles that live within estuary creeks and rivers. Young fish will become reproductively mature fish at around three years of age, and may ultimately live for approximately 40 years (**Murphy and Taylor 1990**), and reach a maximum length of five feet.

3.2.3.2. Significance

Red drum are ecologically important as both a predator and prey in the food web of the St. Johns River. They are bottom feeders that eat crabs, shrimp, worms and small fish. Their predators include larger fish, birds, and turtles.

A strong recreational fishery exists for red drum. The recreational fishery for red drum is an estuarine and near-shore fishery, targeting small, "puppy drum" and large trophy fish. Trophy-size fish are caught along the mid- and south coastal barrier islands, while smaller red drum are taken in shallow estuarine waters. Red drum has not been commercially harvested since 1988 to minimize impacts to natural populations.

3.2.3.3. Trend

The FWRI data set shows consistent trends in abundance from 2001 to 2011 (Figure 3.3). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.018; N.S.), juvenile (τ =-0.200; N.S.) nor subadults/adults (τ =-0.220; N.S.). Young of the year appear in the river in September and become juveniles in approximately one year (Appendix 3.2.3a).

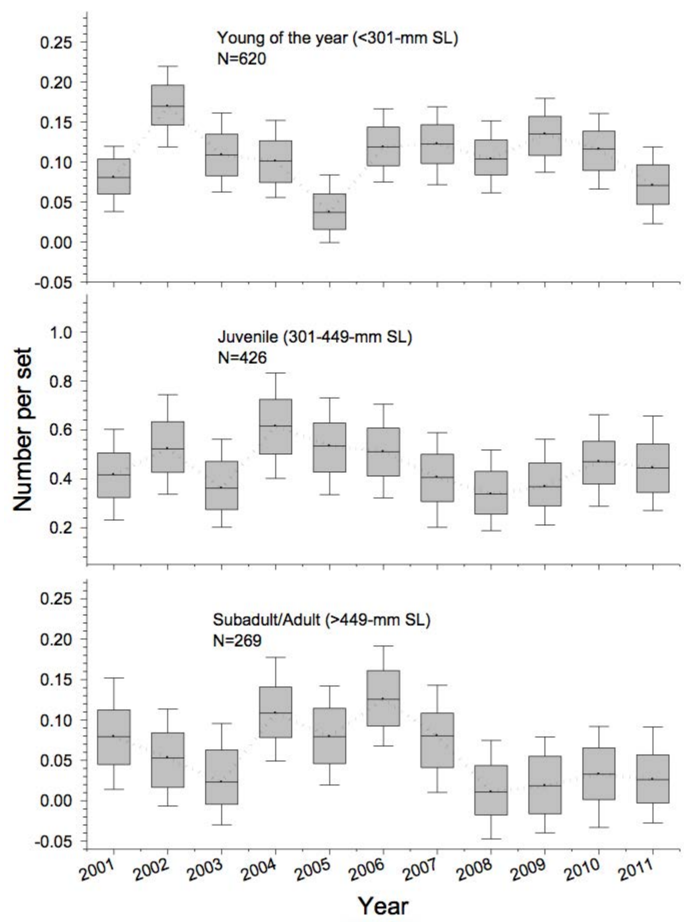


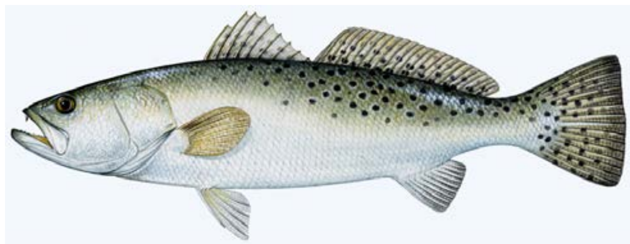
Figure 3.3. Number of young of the year, juveniles, and subadults/adults of red drum caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.3.4. Current Status and Future Outlook

Red drum are a very important recreational fishery in the lower St. Johns River. It appears they are safe from overexploitation (**Murphy and Munyandorero 2008**). There is concern that increased fishing activity may in the future cause decreases in fish numbers through direct loss of fish captured, and mortality of "returned" fish. Consequently, close monitoring of reproduction and abundance in local populations is essential for ensuring the long-term maintenance of red drum in LSJRB.

Recreationally, two red drum can be caught per person per day throughout the year. Individual fish must be between 18 and 27 inches in length (**FWC 2012**). No red drum can be sold for profit.

3.2.4. Spotted Seatrout (Cynoscion nebulosus)



http://www.floridasportfishing.com/magazine/images

3.2.4.1. General Life History

The spotted seatrout is a bottom-dwelling predator that is common in estuarine and shallow coastal habitats in Northeast Florida. It is a carnivore that preys on a number of small fish species such as anchovies, pinfish and menhaden. Reproduction tends to occur during the night within the river from spring through fall with a peak during April through July. The young often form schools of up to 30-50 individuals. Individual fish will become sexually mature in 2-3 years. Their expected lifespan is 8-10 years. They may reach a maximum length of three feet.

3.2.4.2. Significance

Spotted seatrout are very important in both the benthic and planktonic food webs in the St. Johns. As newly hatched young they are planktivores, feeding primarily on copepods within the plankton. As they grow, they shift to larger prey including shrimp, and eventually a number of smaller fish within the river. A number of predators feed on seatrout including Atlantic croaker, cormorants, brown pelicans, bottlenose dolphin, and sharks.

There are recreational and commercial spotted seatrout fisheries within the St. Johns River. Recreationally, the fish is the premier game fish in the area for visiting and local anglers. Annual commercial landings for the state of Florida were over 4 million lbs. in the 1950s and 1960s, and down to 45,000 lbs. in 2006 (**Murphy, et al. 2006**). Out of this value, the lower St. Johns River (and the neighboring ICW) accounts for approximately 5,000 lbs.. harvested annually. Reductions in landings since the 1950s and 1960 have been in large part due to more stringent fishing regulations.

3.2.4.3. Trend

Commercial landings decreased substantially in the mid-1980s and again in the mid-1990s (Figure 3.4; Appendix 3.2.4a). However, landings have generally remained variable but consistent for the whole river since 1996 (Appendix 3.2.4a). The substantial mid 1990s decrease may be due to the impact of the gill net ban (**Murphy, et al. 2006**). The FWRI data set shows consistent trends in abundance from 2001 to 2011 (Figure 3.5). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.200; N.S.), juvenile (τ =0.111; N.S.) nor subadults/adults (τ =0.111; N.S.). However, there was a small peak in the number of young of the year (<91 mm) caught in 2007. Young of the year appear in the river in May and become juveniles within one year (Appendix 3.2.4b).

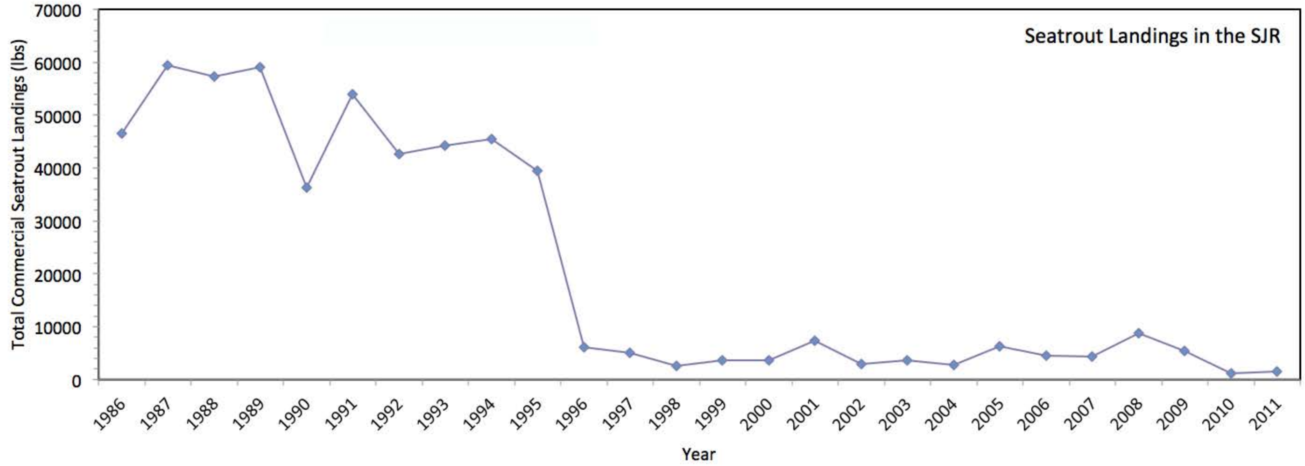


Figure 3.4. Commercial landings (in lbs.) of spotted seatrout within the lower basin of the St. Johns River from 1986 to 2011. Note that gill nets were banned in 1995.

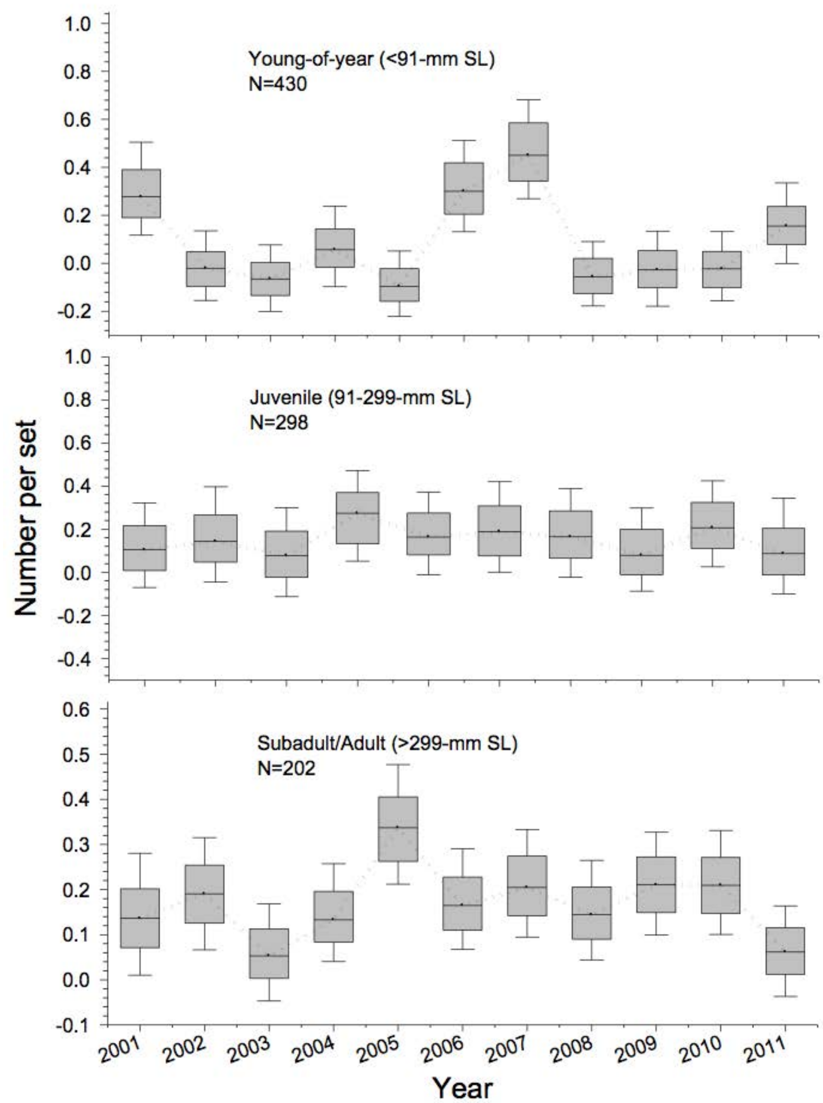


Figure 3.5. Number of young of the year, juveniles, and subadults/adults of spotted seatrout caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.4.4. Current Status & Future Outlook

The spotted seatrout recreational fishery has grown in the last fifteen years while the commercial fishery has remained somewhat stable. There has been concern that there could be a decrease in landings with time that may be related to: 1) changes in fishing regulations, 2) coastal development, and 3) fishing pressure (**Murphy, et al. 2011**). Despite this concern, a recent Florida Wildlife Research Institute (FWRI) stock assessment suggests that spotted seatrout are not being overfished within the Northeast Florida region (**Murphy, et al. 2011**).

Recreationally, spotted seatrout are considered a restricted species (**Murphy, et al. 2011**). However, they can be caught all months of the year. The legal size range is 15 to 20 inches with a daily limit of six per person (**FWC 2012**).

3.2.5. Largemouth Bass (Micropterus salmoides)

http://www.usbr.gov/.../activities_largemouth_bass.jpg

3.2.5.1. General Life History

Largemouth bass are predatory fish that occupy shallow brackish to freshwater habitats, including upper estuaries, rivers, ponds and lakes. When young, they are carnivores feeding on zooplankton, insects and crustaceans including crayfish. As they get older, they feed on a variety of organisms such as larger fish, crayfish, crabs, frogs, and salamanders. They reproduce from December through May (**FWC 2010b**). The male builds nests in hard-bottom areas along shallow shorelines. The female then lays her eggs in the nest, where they are fertilized as they enter the nest. The male will guard the nest, and later, the young fry. The fry initially swim in tight schools, and then disperse when they reach about one inch in size. Largemouth bass may live up to 16 years growing in excess of 22 inches in length.

3.2.5.2. Significance

Largemouth bass are very important in freshwater benthic food webs in the lower St. Johns River. Their willingness and aggressiveness to feed on any appropriately sized prey is significant in affecting the abundance of many organisms in the same habitat. Recreationally, bass are a popular game fish in the area for visiting and local anglers.

3.2.5.3. Trend

FWRI research in the past eleven years shows fairly similar yearly abundances from 2001 to 2011 (Figure 3.6). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.055; N.S.), juvenile (τ =0.164; N.S.) nor subadults/adults (τ =-0.200; N.S.). Young of the year appear in the river in April and become juveniles within one year (Appendix 3.2.5a).

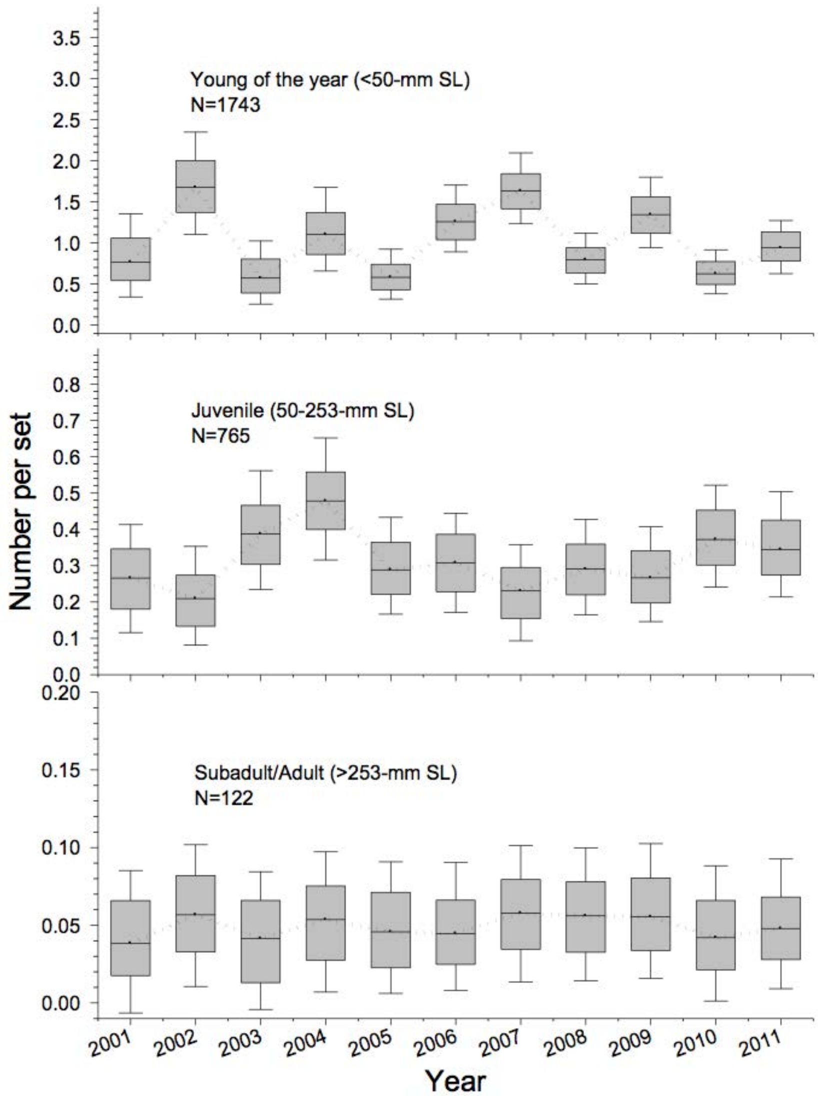


Figure 3.6. Number of young of the year, juveniles, and subadults/adults of large mouth bass caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.5.4. Current Status & Future Outlook

There is not enough information to assess the status of the recreational fishery associated with largemouth bass in the lower St. Johns River. However, they are not likely to be overfished in the near future. Bass are commonly raised in hatcheries and stocked in lakes and ponds throughout Florida.

Recreational fishermen are permitted to take largemouth bass all months of the year. A daily limit of five per person is allowed with minimum size of 14 inches and only one of the five being more than 22 inches (**FWC 2012**).

3.2.6. Channel & White Catfish (Ictalurus punctatus & Ameiurus catus)

http://myfwc.com/.../images/raverart/White-Catfish.jpg

3.2.6.1. General Life History

Channel and white catfish are omnivorous fish that can be found in primarily freshwater rivers, streams, ponds and lakes. During their lifetime, they may feed on insects, crustaceans (including crayfish), mollusks and fish. They reproduce in the river in the spring and summer months. The male builds nests where the female lays the eggs and fertilization occurs. The male will guard the nest and later the young fry. The fry will leave the nest one week after hatching. As they mature, catfish will tend to occupy bottom areas with slow moving currents. Individuals may live 11-14 years.

3.2.6.2. Significance

Both catfish species are very important in benthic food webs in the more freshwater sections of the lower St. Johns River. They are abundant, and feed on a wide variety of organisms during their lifetime (**DeMort 1990**). They are a major component of the freshwater commercial fishery in Florida. There is also a large recreational catfish fishery within the river. Channel catfish are often stocked in ponds and lakes to maintain population numbers.

3.2.6.3. Trend

Commercial landings of catfish decreased substantially in the mid-1990s (Figure 3.7). This mid 1990s decrease may be due to the impact of the Florida gill net ban. Since this time period, landings have been decreasing in the north (landings mostly likely from tributaries in this area) sections of the river (Appendix 3.2.6a). The FWRI data set shows variable but consistent trends in abundance for both the channel and white catfish from 2001 to 2011 (Figures 3.8 and 3.9). Kendall tau correlation analyses revealed no temporal trend during this time period for channel catfish in number per set for young of the year (τ =-0.309; N.S.), juvenile (τ =0.164; N.S.) nor subadults/adults (τ =0.164; N.S.). However, there did appear to be a decrease in subadult/adult abundance from 2001-2005 before numbers started to become relatively similar (Figure 3.8). While somewhat variable, young of the year of this species appear in the river in June and become juveniles in approximately one year (Appendix 3.2.6b). In terms of white catfish, there were also no trends observed in number per set for young of the year (τ =0.055; N.S.), juvenile (τ =0.091; N.S.) nor subadults/adults (τ =0.091; N.S.). However, the temporal patterns were particularly variable for young of the year with peaks encountered during 2003 and 2006. While also fairly variable, young of the year appear in the river in June and become juveniles in approximately one year (Appendix 3.2.6c).

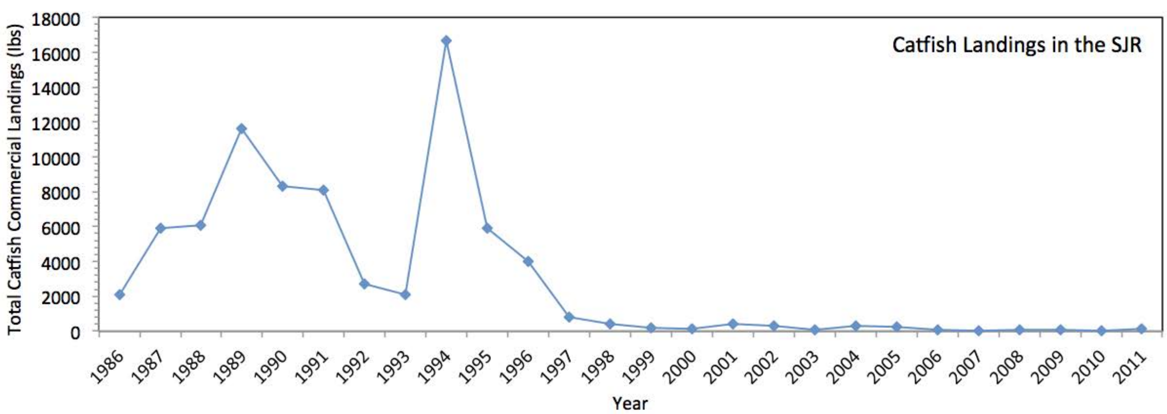


Figure 3.7. Commercial landings (in lbs.) of catfish within the lower basin of the St. Johns River from 1986 to 2011. Note that the gill net ban went into effect in 1995.

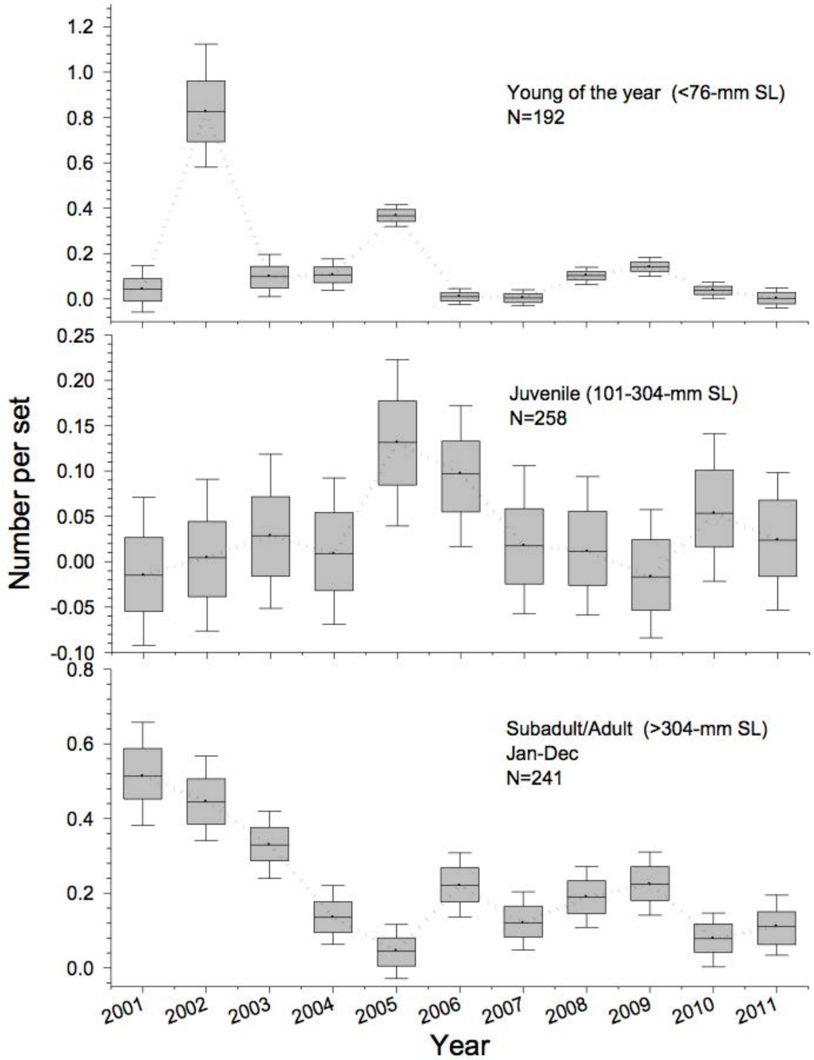


Figure 3.8. Number of young of the year, juveniles, and subadults/adults of channel catfish caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

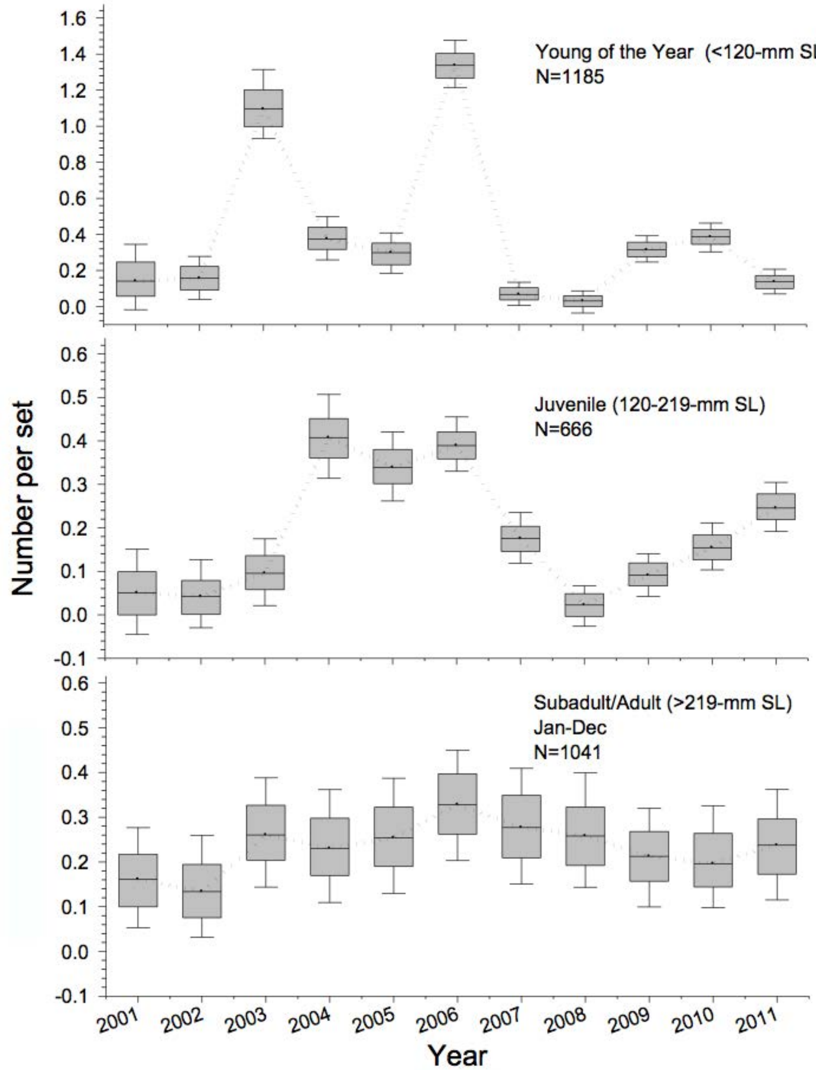


Figure 3.9. Number of young of the year, juveniles, and subadults/adults of white catfish caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.6.4. Current Status and Future Outlook

Both species of catfish are generally common in the St. Johns River. The decrease in commercial landings may be more related to changes in fishing regulations over the years, although this is not known for sure. Further, both species of catfish are commonly raised in hatcheries and stocked in lakes and ponds throughout Florida. If future research suggests that their abundance is decreasing to unacceptable levels, areas of the river can be re-stocked. FWC is in the process of implementing freshwater species into its marine trip ticket program to more effectively assess freshwater landings in various parts of Florida. Consequently, the potential exists for overfishing of these species in the future. With the exception of Fish Management Areas, there are no bag or possession limits on either species of catfish (**FWC 2011**).

3.2.7. Striped Mullet (Mugil cephalus)

http://www.floridafishandhunt.com/.../stripemul.jpg

3.2.7.1. General Life History

Striped mullet (also known as black mullet) are detritivores that have a wide salinity range. They are abundant in freshwater and inshore coastal environments often being found near mud bottoms feeding on algae, and decaying plant material. Mullet migrate offshore to spawn with their resultant larvae eventually drifting back to coastal waters and marsh estuaries. Developing individuals will become sexually mature at three years and live from 4-16 years. Older fish may ultimately reach lengths of up to three feet.

3.2.7.2. Significance

Mullet are considered extremely important in benthic food webs in all sections of the lower St. Johns River. They are abundant and significant in the transfer of energy from the detrital matter they feed on to their predators such as birds, seatrout, sharks and marine mammals. The commercial mullet fishery has been the largest among all fisheries in the St. Johns for many years with over 100,000 lbs. harvested annually. Additionally, mullet are sought after recreationally for their food and bait value.

3.2.7.3. Trend

Commercial landings have been fairly variable since the 1980s (Figure 3.10). Commercial landings and landings per trip have been consistent yet particularly low this past year (Appendix 3.2.7a). The FWRI data set shows variable yearly abundances from 2001 to 2011 (Figure 3.11). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.055; N.S.), juvenile (τ =0.164; N.S.) nor subadults/adults (τ =-0.200; N.S.). Young of the year appear in the river in January and become juveniles within one year (Appendix 3.2.7b).

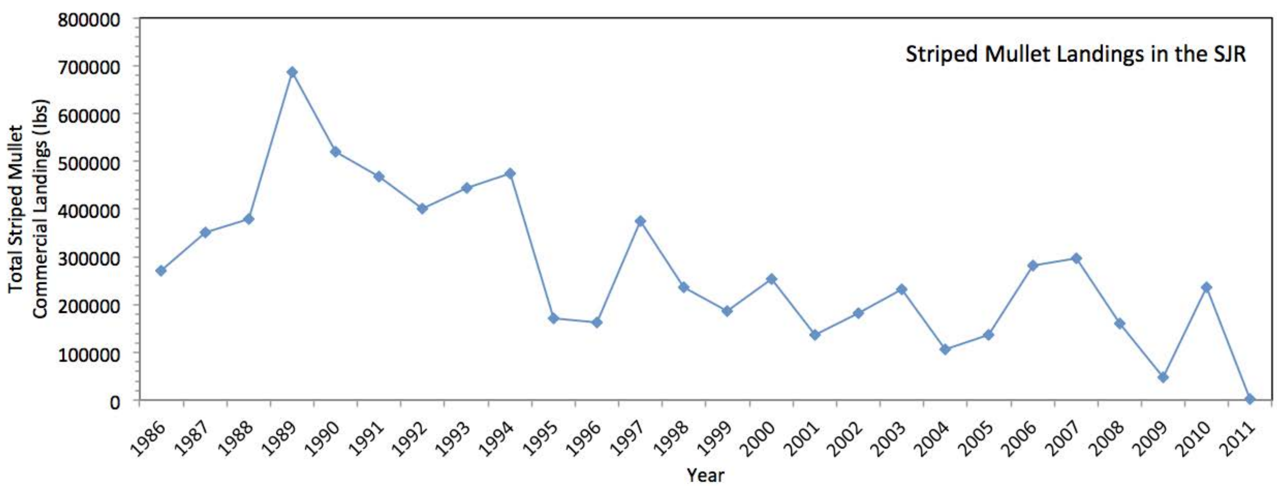


Figure 3.10. Commercial landings (in lbs.) of striped mullet within the lower basin of the St. Johns River from 1986 to 2011.

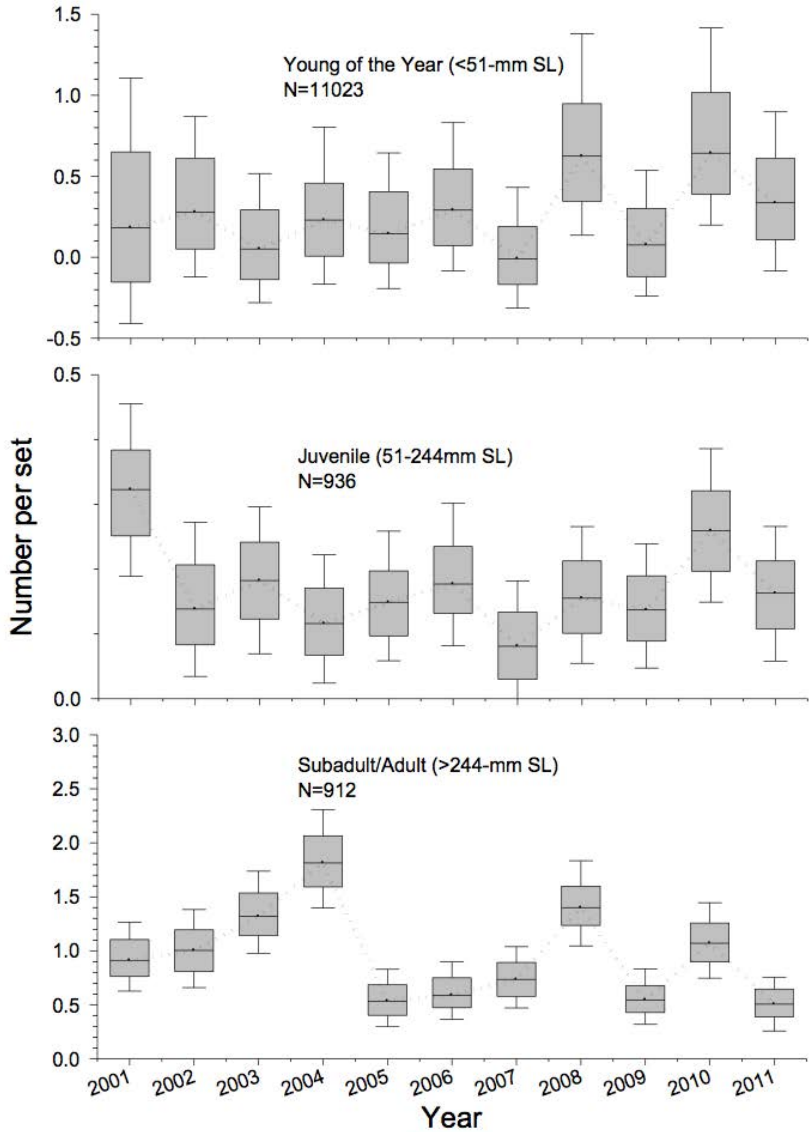


Figure 3.11. Number of young of the year, juveniles, and subadults/adults of striped mullet caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.7.4. <u>Current Status & Future Outlook</u>

Striped mullet in the St. Johns River continue to be important commercially and recreationally. Populations appear to be healthy and sustainable into the foreseeable future along the east coast of Florida (**Mahmoudi 2005**). Recreational fishing limitations are 50 fish maximum (includes Striped and Silver mullet) per harvester per day. There is no closed season (**FWC 2012**).

3.2.8. Southern Flounder (Paralichthys lethostigma)

http://www.uvm.edu/~jbartlet/nr260/animal%20life/marine/southernflounder.gif

3.2.8.1. General Life History

The southern flounder is a common flounder in inshore channels and estuaries associated with the St. Johns River. It is a bottom-dwelling predator that feeds on shrimp, crabs, snails, bivalves and small fish. During the fall and winter it moves offshore to spawn. Larvae will develop and drift in the plankton while being transported (primarily via wind driven currents) back to estuaries and lagoons where they will settle and develop into juveniles and then adults. The southern flounder may grow up to 36 inches and live to approximately three years of age.

3.2.8.2. Significance

Flounder are important ecologically, recreationally and commercially to humans in the lower St. Johns River area. They are abundant and important in maintaining ecological balance in their roles as both predator and prey. They feed on small invertebrates such as bivalves and snails, and are preyed on by sharks, marine mammals and birds. The commercial flounder fishery is one of the larger ones in Northeast Florida. Flounder are also highly sought after recreationally for their excellent food value.

3.2.8.3. Trend

Commercially, total landings of all flounders have decreased significantly after 1995 (Figure 3.12; Appendix 3.2.8a). Total flounder landings have decreased significantly for the north river section but have been consistent in the southern section of the river (Appendix 3.2.8a). However, the commercial catch per trip has slowly increased since the drastic decrease of the mid-1990s. The mid 1990s decrease in commercial landings may be due to the impact of the gill net ban. Finally, the FWRI data set shows no upward or downward trends in abundance from 2001 to 2011 (Figure 3.13). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.309; N.S.), juvenile (τ =-0.164; N.S.) nor subadults/adults (τ =-0.236; N.S.). Young of the year (<136 mm Standard length) appear in the river in January and become juveniles within approximately one year (Appendix 3.2.8b).

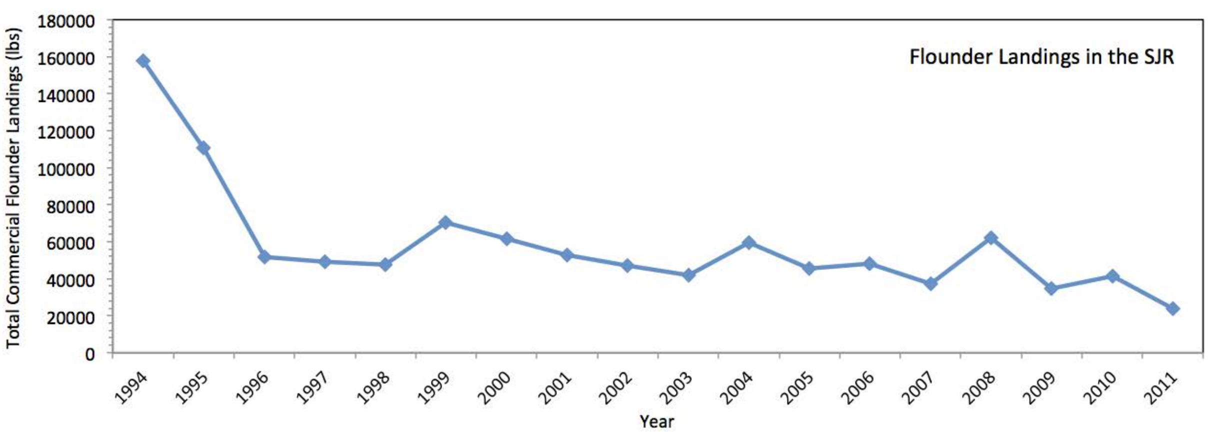


Figure 3.12. Commercial landings (in lbs.) of southern flounder within the Lower Basin of the St. Johns River from 1986-2011.

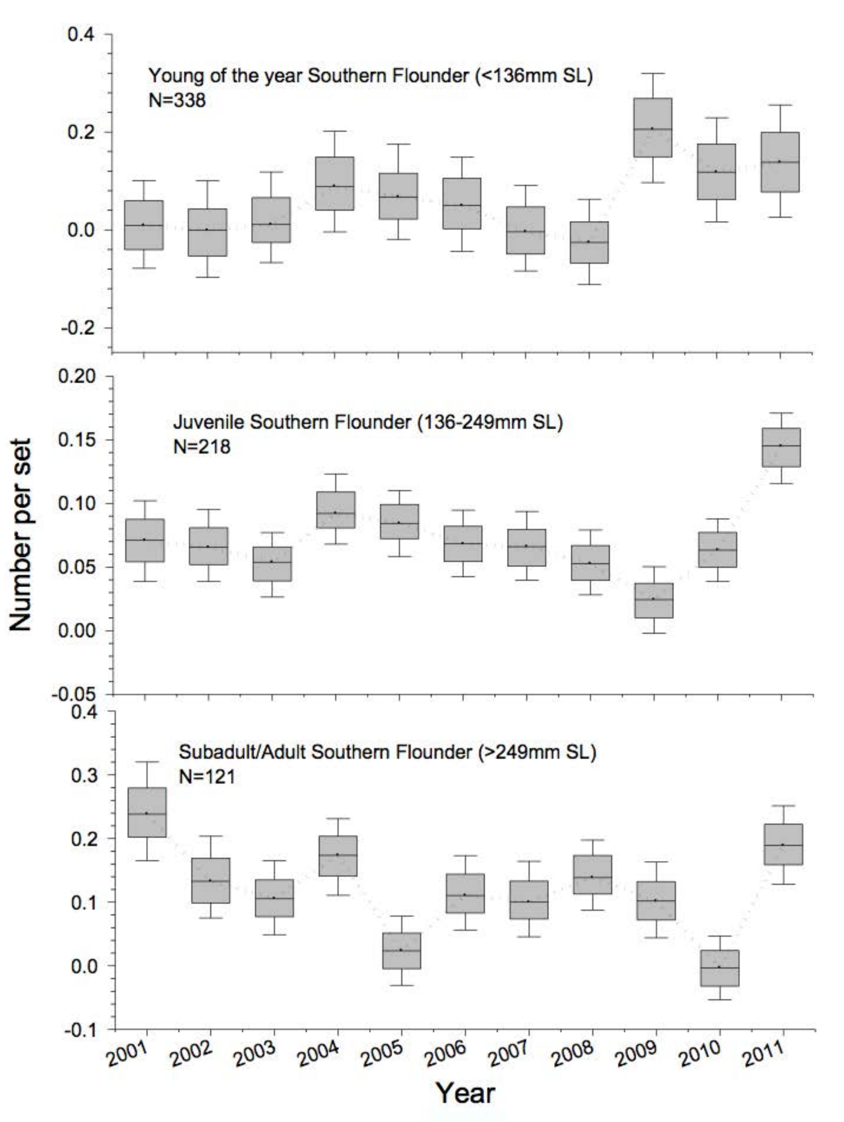


Figure 3.13. Number of young of the year, juveniles, and subadults/adults of southern flounder caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.8.4. Current Status & Future Outlook

The southern flounder continues to be important recreationally and commercially in the lower St. Johns River. They are fairly common in the St. Johns River, and appear to have no short-term risk of being overfished along the Florida east coast (**FWRI 2008d**). However, to help ensure their maintenance, it is important to have a better understanding of the reproductive and life history ecology of populations within the river. Recreationally, flounder can be caught all months of the year. Legal minimum size range is 12 inches with a daily limit of ten fish per person (**FWC 2012**).

3.2.9. Sheepshead (Archosargus probatocephalus)

http://myfwc.com/marine/fish/sheepshead.jpg

3.2.9.1. General Life History

Sheepshead are common nearshore and estuarine fish that are very often associated with pilings, docks and jetties. They have a very impressive and strong set of incisor teeth that are used to break apart prey such as bivalves, crabs and barnacles. Adults will migrate offshore during the spring to spawn. Fertilized eggs will develop into larvae offshore and be carried towards the coast by currents primarily driven by the wind. The larvae will enter the mouths of inlets and settle in shallow grassy areas. Developing individuals may reach a maximum length of three feet.

3.2.9.2. Significance

Sheepshead are ecologically, recreationally and commercially important in northeast Florida. They are important in maintaining the estuarine and coastal food web as both a predator and prey. They feed on bottom dwelling invertebrates (i.e. bivalves and barnacles) and are fed on by larger predators such as sharks and marine mammals. The commercial fishery is one of the larger ones within the river. Recreationally, sheepshead are highly valued by fisherman in the area for their high food value.

3.2.9.3. Trend

Overall, commercial landings have been stable with occasional fluctuations (Figure 3.14). Total landings have been more variable to the north, and decreasing for the whole and north sections of the river (Appendix 3.2.9a). It should be noted that data from the southern counties most likely includes a significant number of fish caught in the ICW. The FWRI data set shows no upward or downward trends in abundance from 2001 to 2011 (Figure 3.15). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.164; N.S.), juvenile (τ =-0.309; N.S.) nor subadults/adults (τ =-0.127; N.S.). There are more subadults/adults (>268mm standard length) encountered than the other two age classes (Figure 3.15). Young of the year (<131 mm Standard length) appear in the river in May and become juveniles within approximately one year (Appendix 3.2.9b).

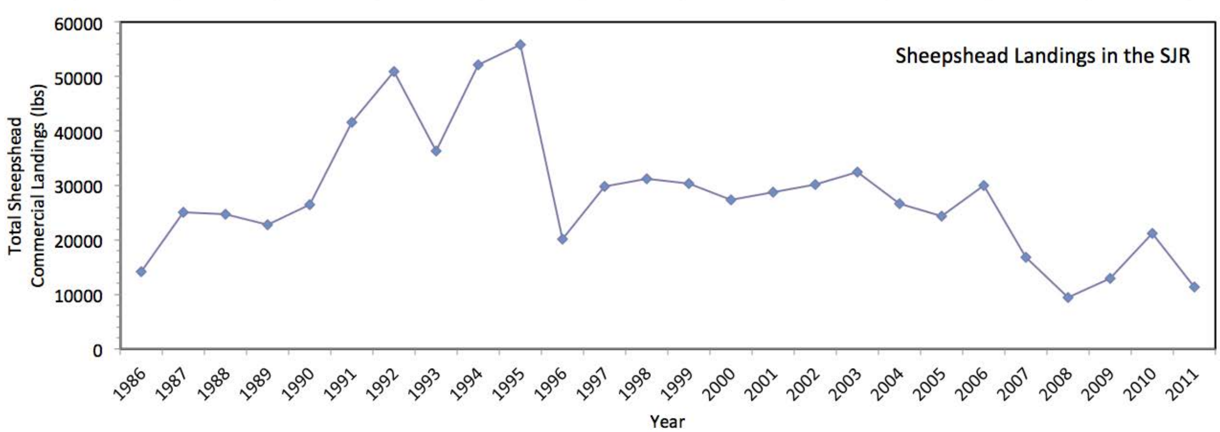


Figure 3.14. Commercial landings (in lbs.) of sheepshead within the lower basin of the St. Johns River from 1986 to 2011.

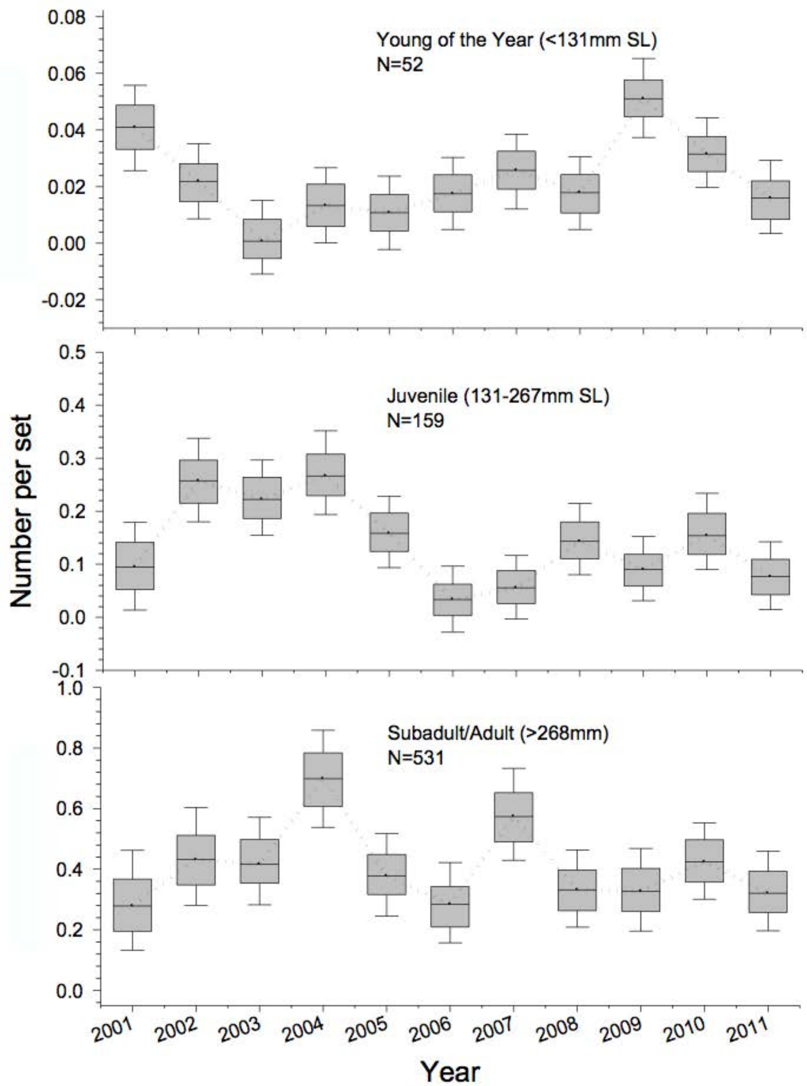


Figure 3.15. Number of young of the year, juveniles, and subadults/adults of sheepshead caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.9.4. Current Status & Future Outlook

Sheepshead continue to be important as both recreational fishermen and commercial fisheries. They are common in the St. Johns River, and appear abundant enough along the Florida east coast to maintain populations with current levels of harvest (**Munyandorero, et al. 2006**). They can be caught all months of the year. Legal minimum size is 12 inches with a daily limit of fifteen fish per person (**FWC 2012**).

3.2.10. Atlantic Croaker (Micropogonias undulatus)

http://www.floridafishandhunt.com/.../atlcroaker.jpg

3.2.10.1. General Life History

The Atlantic croaker is a bottom-dwelling predator that is commonly encountered around rocks and pilings in estuarine habitats. They are named for the croaking sound they make which is accomplished by scraping muscles against their swim bladder. They use their barbels to sense prey such as large invertebrates and fish. Adults will migrate offshore during winter and spring to spawn. Their offspring will develop in the plankton and be transported back inshore, where they will settle in vegetated shallow marsh areas. They grow rapidly and may attain a maximum length of 20 inches.

3.2.10.2. Significance

Croakers are important to the St. Johns area in a number of ways. They are very abundant and consequently extremely important in the food web as both predator and particularly as prey. They feed on small invertebrates, and are fed on by red drum, seatrout, and sharks. For many years, their commercial fishery has been one of the biggest in the St. Johns. Additionally, they are recreationally caught for their food value.

3.2.10.3. Trends

Commercially, total landings have decreased for the northern section of the river but have been temporally consistent to the south (Figure 3.17: Appendix 3.2.10a). The catch per trip has remained consistent for the north and south sections of the river. In both sets of commercial data, landings are lower in the southern sections of the river (Appendix 3.2.10a). The FWRI data set shows consistent trends in abundance from 2001 to 2011 (Figure 3.17). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.091; N.S.), juvenile (τ =0.164; N.S.) nor subadults/adults (τ =0.273; N.S.). Young of the year (<100 mm Standard length) appear in the river in October and become juveniles in approximately one year (Appendix 3.2.10b). Generally, smaller Atlantic Croaker have been observed in more freshwater areas of the river, and appear to move to more estuarine areas as they get larger (**Brodie 2009**).

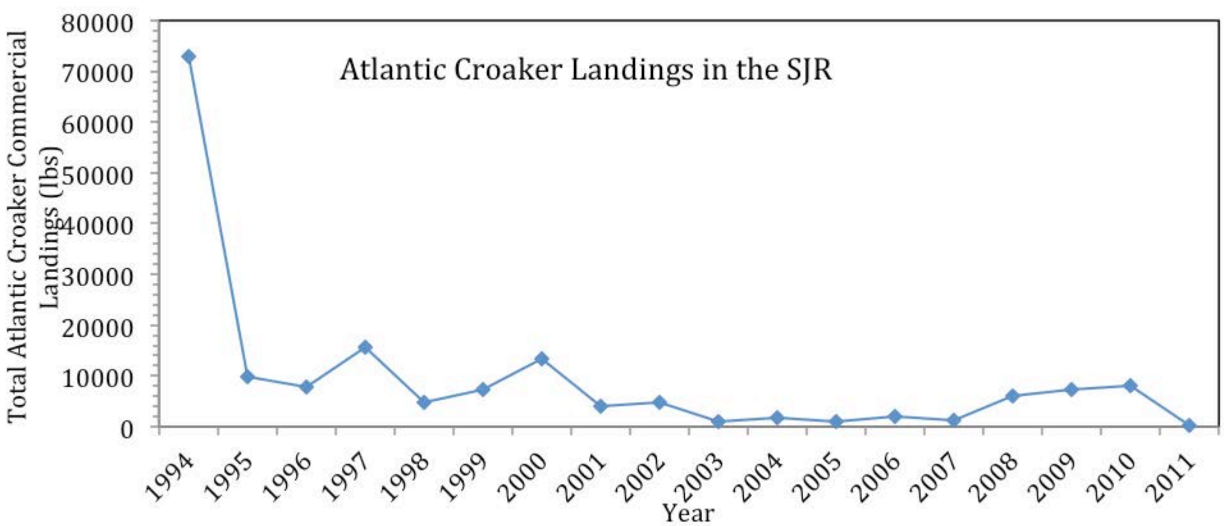


Figure 3.16. Commercial landings (in lbs.) of Atlantic croaker within the lower basin of the St. Johns River from 1986 to 2011.

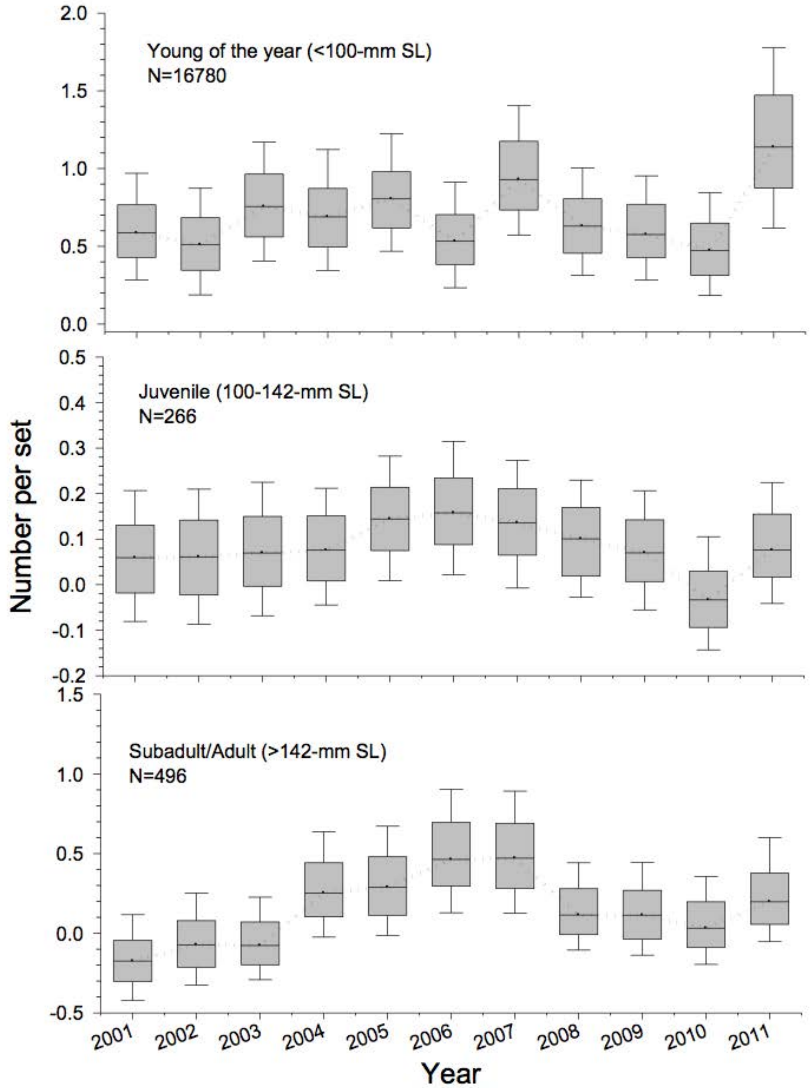


Figure 3.17. Number of young of the year, juveniles, and subadults/adults of Atlantic croaker caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.2.10.4. Current Status & Future Outlook

Atlantic croaker are common in the St. Johns River and continue to be important commercially and recreationally. While there does not appear to be a major risk of landings decreasing significantly in the next few years, there has never been a stock assessment performed on any Florida population (**FWRI 2008a**). Recreationally, they can be caught all months of the year. There is no legal size limit (**FWC 2012**).

3.2.11. Baitfish

http://floridasportfishing.com/magazine/baifish

3.2.11.1. General Life History

Baitfish encompass the multitude of small schooling fish that are the most abundant fishes in the lower St. Johns River. There are at least two-dozen species of baitfish in Florida including anchovies, menhaden, herring, killifish, sheepshead

minnows and sardines. Many of the baitfish species such as Spanish sardines and thread herring are planktivores. However, many may also eat small animals such as crabs, worms, shrimp and fish.

There is high diversity in life history patterns among baitfish species in the lower St. Johns River. However, most migrate seasonally either along the coast and/or away from shore. Many become sexually mature at about one year reproducing by spawning externally at either the mouth of estuaries (menhaden) or offshore (sardines, anchovy). In both cases, larvae hatch out, and are carried by currents to estuaries where the young will eventually join large schools of juvenile and adult fish. In most cases, individuals do not live longer than four years.

3.2.11.2. Significance

Baitfish are very important to the lower St. Johns area. Because they are very abundant, baitfish are extremely important in the food web as prey for a number of larger fish species. They are also important as omnivores that recycle plant and/or animal material that is then available for higher trophic levels. They are commercially and recreationally caught for their bait value. They are caught for recreational use as bait but also are used commercially in various products such as fertilizers, fishmeal, oil and pet food. The primary fisheries in this group are focused on anchovy, menhaden, sardines, and herring (**FWC 2000**). However, smaller fisheries catch killifish, sheepshead minnows and sardines.

3.2.11.3. Trends

Commercial landings decreased in the mid-1990s and have been highly sporadic since then (Figure 3.18; Appendix 3.2.11). The decrease during the mid-1990s may have been due to the Florida gill net ban. While landings of baitfish have remained temporally consistent, the catch per trip has decreased for the northern section of the river. Further, baitfish landings are generally lower in the southern sections of the river.

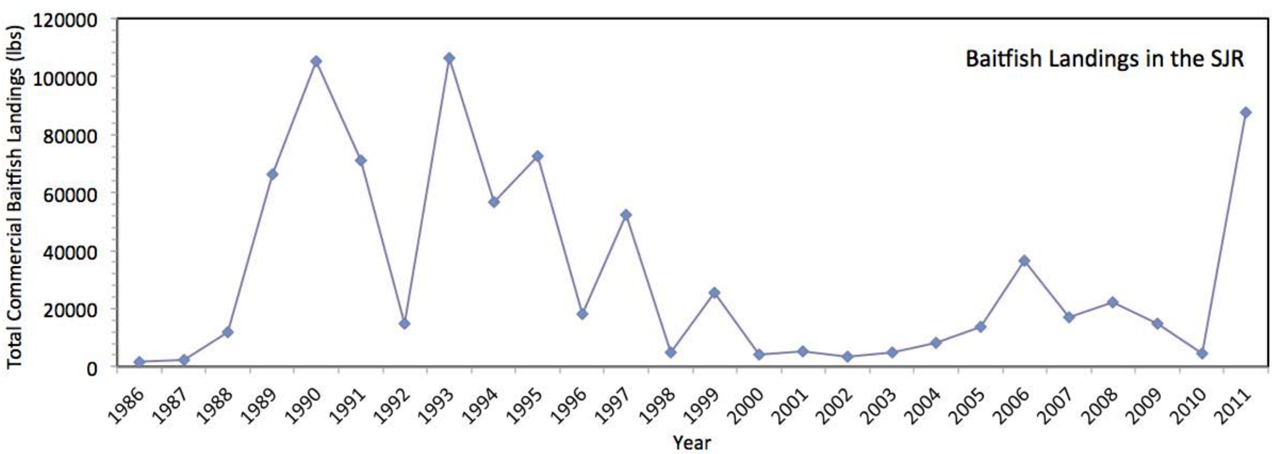


Figure 3.18. Commercial landings (in lbs.) of baitfish within the lower basin of the St. Johns River from 1986 to 2011.

3.2.11.4. Current Status & Future Outlook

Baitfish are very abundant in the St. Johns River and continue to be important commercially and recreationally. They are likely to be sustainable into the foreseeable future. However, researchers at the Fish and Wildlife Research Institute (FWRI) currently are monitoring and assessing the effects of their fisheries management efforts. Recreationally, they can be caught all months of the year. There is no legal size limit (**FWC 2012**).

3.3. Invertebrate Fishery

3.3.1. General description

The invertebrate community is very important to the overall ecology of the St. Johns River lower basin. It is also important economically for commercial and recreational fisheries. Commercially harvested invertebrates in the lower basin include blue crabs, bait shrimp and stone crabs. Of the five counties studied, Duval County generally reports the highest catch of crabs (generally over 500,000 lbs. per year). Recreational fisheries in the area are probably significant for the species mentioned although the level of significance is unclear since there are few reports on recreational landings.

3.3.2. Blue Crab (Callinectes sapidus)

http://www.jacqueauger.com/.../natural/blue_crab.jpg

3.3.2.1. General Life History

The blue crab (**FWRI 2008b**) is a very common benthic predator that inhabits estuarine and nearshore coastal habitats in Northeast Florida. They are general feeders (omnivores) that will eat fish, aquatic vegetation, molluscs, crustaceans and worms (**FWRI 2001**). In the St. Johns River, they reproduce from March to July, and then again from October to December (**Tagatz 1965**; **Tagatz 1968a**; **Tagatz 1968c**). Females carry fertilized eggs and migrate towards the more marine waters near the mouth of the river where they will release their eggs into the water. At this point, the young are called zoea, and they drift and develop along the continental shelf for 30-45 days. Wind and currents eventually transport the larger megalops larvae back to the estuarine parts of the river where they will settle in submerged aquatic vegetation (SAV) that serves as a nursery for them. Within 6-20 days of landing at this location, the young will molt and become what is recognizable as a blue crab. In 12-18 months, young crabs will then become sexually mature, ultimately reaching a width of eight inches.

3.3.2.2. Significance

Blue crabs are very important in both the benthic and planktonic food webs in the St. Johns. They are important predators that can affect the abundance of many macroinvertebrates such as bivalves, smaller crabs, and worms. They are also important prey for many species. Smaller crabs provide food for drum, spot, croaker, seatrout and catfish; while sharks and rays eat larger individuals.

A strong recreational blue crab fishery exists, although there are relatively few data on it. The blue crab fishery is the largest commercial fishery in the lower St. Johns River. It easily accounts for over 85% of commercial fisheries in the river with over one million lbs. harvested annually. Duval County typically reports the highest number of crab landings of the five counties associated with the lower basin of the river with values often over 500,000 lbs. harvested annually.

3.3.2.3. Data Sources

Blue crab data were collected from commercial reports (1994 to 2011) of landings made to the state, and research (2001-2011) from the FWRI.

3.3.2.4. Limitations

The primary limitation with the commercial landing data is that it does not account for young crabs that are too small to be harvested. Additionally, there may be uncertainties regarding location of where the crabs are collected. For instance, fisherman (crabbers) landings reports are made from their home counties, although it is uncertain what part of the river the crabs were actually caught. Changes in harvesting regulations through the years limit what can be said of landings between certain time periods. In this report, total landings are graphed. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends investigated using Kendall tau analysis. In terms of the FWRI collection methods assessed in this study, the subsequent data are likely to not have caught the complete size range of crabs that exist within the river.

3.3.2.5. Trend

Commercial landings of blue crabs have been variable with no upward or downward trend from 1994 to 2011 (Figure 3.19). Additionally, more landings occur in the southern versus northern section of the river (Appendix 3.3.2a). The FWRI

data set shows consistent trends in abundance from 2001 to 2011 (Figure 3.20). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ =0.382; N.S.), juvenile (τ =0.183; N.S.) nor subadults/adults (τ =0.164; N.S.). The appearance of juveniles (20-126 mm Standard length) is not very pronounced from available data but appears to occur in highest numbers beginning in August (Appendix 3.3.2b).

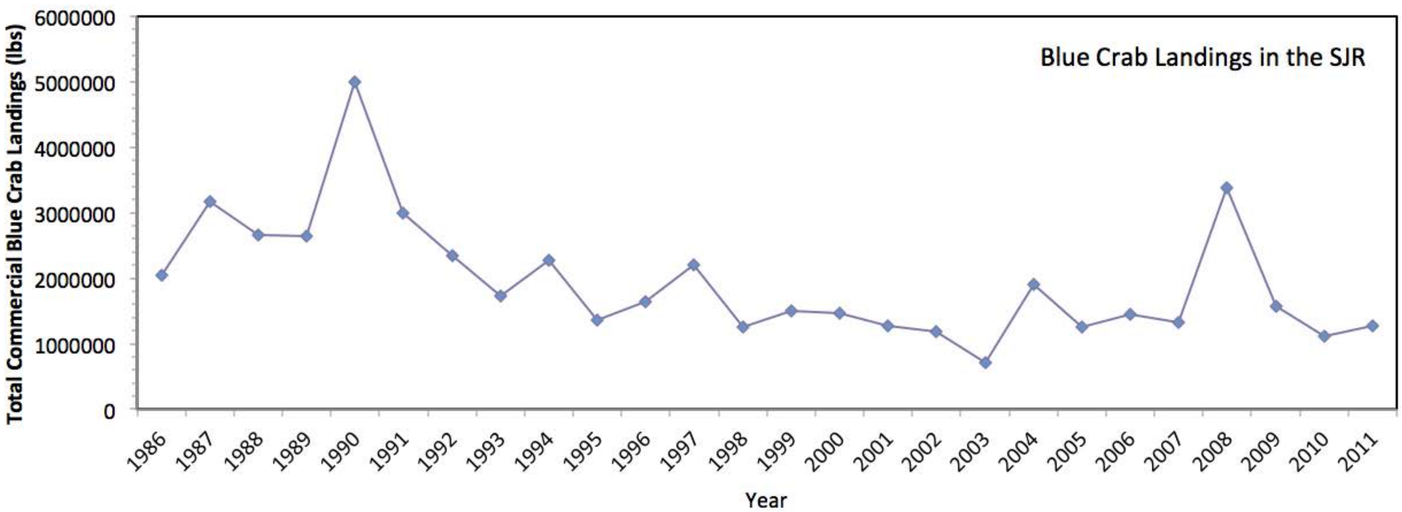


Figure 3.19. Commercial landings (in lbs.) of blue crabs within the lower basin of the St. Johns River from 1986 to 2011.

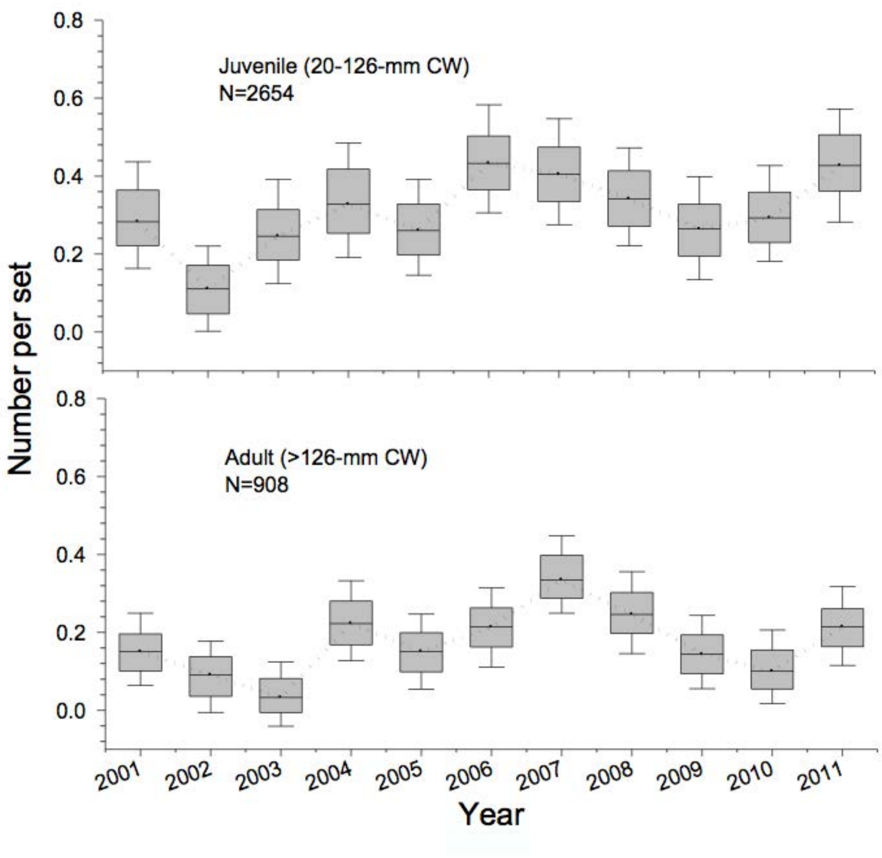


Figure 3.20. Number of juveniles and adults of blue crabs caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

3.3.2.6. Current Status & Future Outlook

The blue crab commercial fishery continues to be the premier invertebrate fishery within the lower basin of the St. Johns River. The recreational fishery is also likely to be very large, although there is no information available on it.

While common within the river, there is uncertainty regarding whether blue crabs are being overfished or not in Florida. This uncertainty is because the maximum age of blue crabs in Florida is not known. Maximum age is one component that is used in a stock assessment model. Depending on the value used, it can affect whether the model suggests crabs are overharvested or not (**Murphy, et al. 2007**). Consequently, this piece of information is needed to more accurately assess blue crab stocks in Florida. Currently, there is no required license to fish recreationally using five or fewer traps. In the St. Johns River, five or fewer traps can be used to recreationally catch blue crabs throughout the year (10 gallons whole per harvester per day) except from January 16th to 25th. Crabs can also be caught using dip nets, crab pots, and handlines (**FWC 2012**).

3.3.3. Penaeid shrimp - White, pink & brown (Litopenaeus setiferus, Farfantepenaeus duorarum & F. aztecus)

3.3.3.1. General Life History

There are three penaeid shrimp species that exist within the estuaries and nearshore waters of the northeast Florida region. They are the white, pink, and brown shrimp. The white shrimp is the most common species in local waters. All three are omnivorous feeding on worms, amphipods, molluscs, copepods, isopods and organic detritus. White shrimp reproduce during April to October, whereas pink and brown shrimp can spawn year round (**FWRI 2006**). However, peak spawning for brown shrimp is from February to March and from spring through fall for pink shrimp. All species spawn offshore in deeper waters with larvae developing in the plankton and eventually settling in salt marsh tidal creeks within estuaries. From there, young will develop for approximately 2-3 months. As they get larger, they start to migrate towards the more marine waters of the ocean where they will become sexually mature when they reach lengths between 3-5 inches. While they generally do not live long (a maximum 1.5 years), they may reach maximum lengths of up to seven inches.

3.3.3.2. Significance

Penaeid shrimp are very important in both the benthic and planktonic food webs in the St. Johns. They are important predators that can affect the abundance of many small macroinvertebrates (see list above). They are also important prey for many species. As smaller individuals such as post-larvae and juveniles, they provide food for sheepshead minnows, insect larvae, killifish and blue crabs. As adult shrimp, they are preyed on by a number of the finfish found within the river.

The lower St. Johns River supports both recreational and commercial shrimp fisheries. The recreational fishery is likely to be large although there is relatively little information on it. In contrast, the commercial shrimp fishery is one of the largest fisheries in the region. However, most shrimp obtained for human consumption are caught by trawlers offshore. Commercial trawling in the lower St. Johns River represents a much smaller fishery.

3.3.3.3. Data Sources

Penaeid shrimp data were collected from commercial reports (1986 to 2011) of total bait shrimp landings (generally collected within the river) made to the State. These data likely include white, brown and pink shrimp, although their relative proportions are unknown. Data for only white shrimp were also collected and assessed from research (2001-2011) from the Fish and Wildlife Research Institute (FWRI).

3.3.3.4. Limitations

The primary limitation with the commercial landing data is there are uncertainties regarding the location of where shrimp are collected. For instance, shrimp fisherman landings reports are made from their home counties although it is sometimes uncertain what part of the river shrimp were actually caught in. Additionally, changes in harvesting regulations through the years may limit what can be said of landings between certain time periods. In this report, total landings are graphed. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends investigated using Kendall tau analysis. In terms of the FWRI data set, the collection methods assessed in this study may not have caught the complete size range of shrimp that exist within the river.

3.3.3.5. Trend

The commercial total landings of bait shrimp data suggests that penaeid shrimp landings have been variable with no upward or downward trend (Figure 3.21). However, from 2001 to 2011 there have been drastic fluctuations among the years with peak landings occurring in 2004. Far more bait shrimp are reported in the northern versus southern sections of the lower St. Johns River (Appendix 3.3.3a). The FWRI data set shows consistent trends in abundance for white shrimp from 2001 to 2011 (Figure 3.22). Kendall tau correlation analyses revealed no temporal trend in the number of white shrimp captured per set (τ =0.455; N.S.). The highest number of small white shrimp were encountered in the river from May to July (Appendix 3.3.3b).

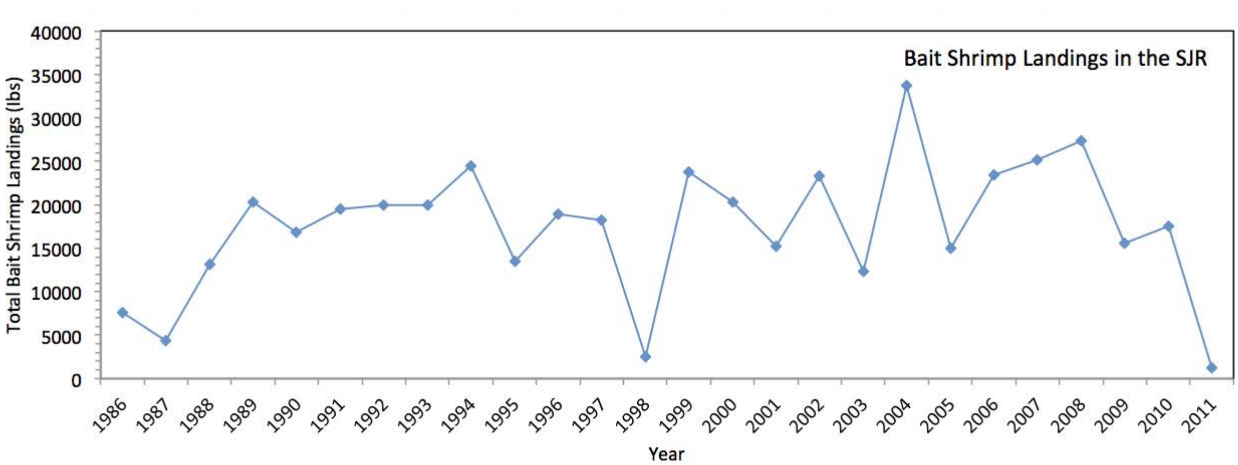


Figure 3.21. Commercial landings (in lbs.) of bait shrimp within the lower basin of the St. Johns River from 1986 to 2011.

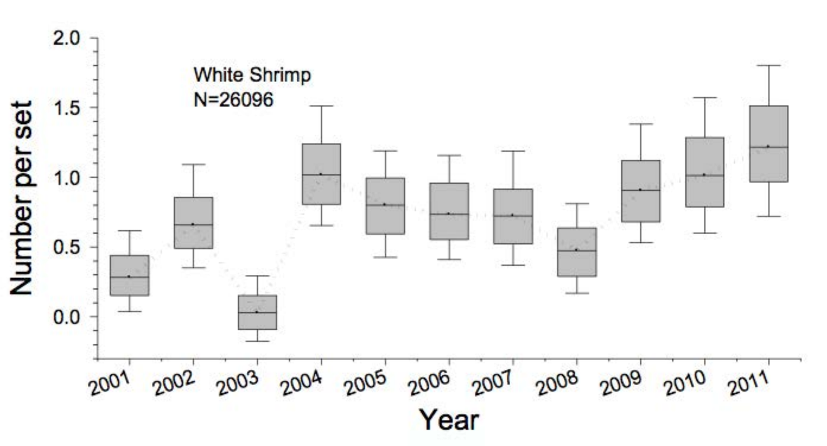


Figure 3.22. Number of juveniles and adults of white shrimp caught within the lower basin of the St. Johns River from 2001-2011. The N value indicates the total number of sets completed for the time period.

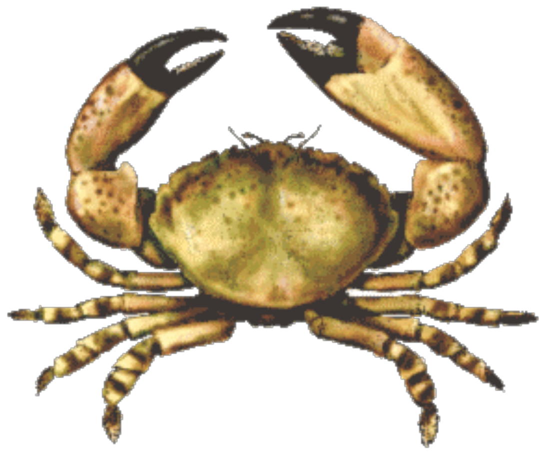
3.3.3.6. Current Status & Future Outlook

Commercial harvesting of penaeid shrimp for bait is a relatively small fishery in the St. Johns River. The recreational fishery is probably moderately sized, although there are no available data on it. Generally, penaeid shrimp are very abundant in the region. They may be at slight risk of being overfished in the south Atlantic region (see **FWRI 2008e** for a

review). However, the South Atlantic Fishery Management Council and Gulf of Mexico Fishery Management Council have established fishery management plans for shrimp to try to ensure they are not overharvested (**FWRI 2008e**).

Recreationally, shrimp can be harvested (five gallons per person per day) via dip net, cast net, push net, one frame net or beach seine. The season is closed during April and May in Nassau, Duval, St. Johns, Putnam, Flagler and Clay Counties (**FWC 2012**).

3.3.4. Stone Crabs (Menippe mercenaria)



http://www.ocean.udel.edu/.../species_stonecr.gif

3.3.4.1. General Life History

The stone crab is a fairly common benthic predator that inhabits hard bottoms (such as oyster reefs) and grass beds in the northeast Florida area. Stone crabs are opportunistic carnivores feeding on oysters, barnacles, snails, clams, etc. In Florida, stone crabs reproduce from April through September (**FWRI 2006**). It is unclear where stone crabs sexually reproduce, and females will carry eggs for approximately two weeks before the eggs hatch. The larvae will drift in the plankton and settle and metamorphose into juvenile forms of the adult in about four weeks. In approximately two years, the crabs will then become sexually mature and reach a width of 2.5 inches. They may live as long as seven years.

3.3.4.2. Significance

Stone crabs are important predators and prey in the estuarine community in the St. Johns River. As important predators, they can affect the abundance of many macroinvertebrates such as bivalves, smaller crabs, and worms. They are also important prey when both young and older. As larvae in the plankton they are preyed on by filter-feeding fish, larval fish and other zooplankton. As adults, they are preyed on by many larger predators in the river.

The stone crab fishery is unique in that the crab is not killed. The claws are removed (it is recommended to only take one claw so the animal has a better chance of survival) and the animal is returned to its habitat. While there probably is a recreational stone crab fishery in the area, there is relatively little information on it. The stone crab commercial fishery is relatively new and small in the lower St. Johns River. The highest number of claw landings within the river basin likely comes from Duval County. Claw landings from other counties of the lower St. Johns River most likely come from collections made in the Intracoastal Waterway (ICW).

3.3.4.3. Data Sources

Stone crab data were collected from commercial reports of landings made to the State between 1994 and 2010. There were no available recreational landings data.

3.3.4.4. Limitations

The primary limitation with the commercial landing data is it does not account for young crabs that are too small to be harvested. Additionally, there are uncertainties regarding location of where crab claws are collected. For instance, fisherman (crabbers) landings reports are made from their home counties although the crab claws may have been collected elsewhere. For stone crabs reported by southern counties of the lower basin, it is more likely that the claws were

collected in the Intracoastal Waterway (ICW) than the river itself. Additionally, changes in harvesting regulations through the years may limit what can be said of landings between certain time periods. Total landings are shown in this report. However, in order to best assess comparison of landings over the years, landings per trip are calculated, and trends investigated using Kendal tau analysis.

3.3.4.5. Trend

Commercial landings of stone crabs have been variable despite an increase in the number of deployed traps (**FWRI 2001**). Peak landings occurred in 1994 and 1997 with generally low landings occurring from 1998 to 2006 (Figure 3.23). Most landings were reported by the more southern counties of the lower St. Johns River basin (Appendix 3.3.4a). However, this is most likely a reflection of crab claws caught in the Intracoastal Waterway of the more southern counties than in the river itself.

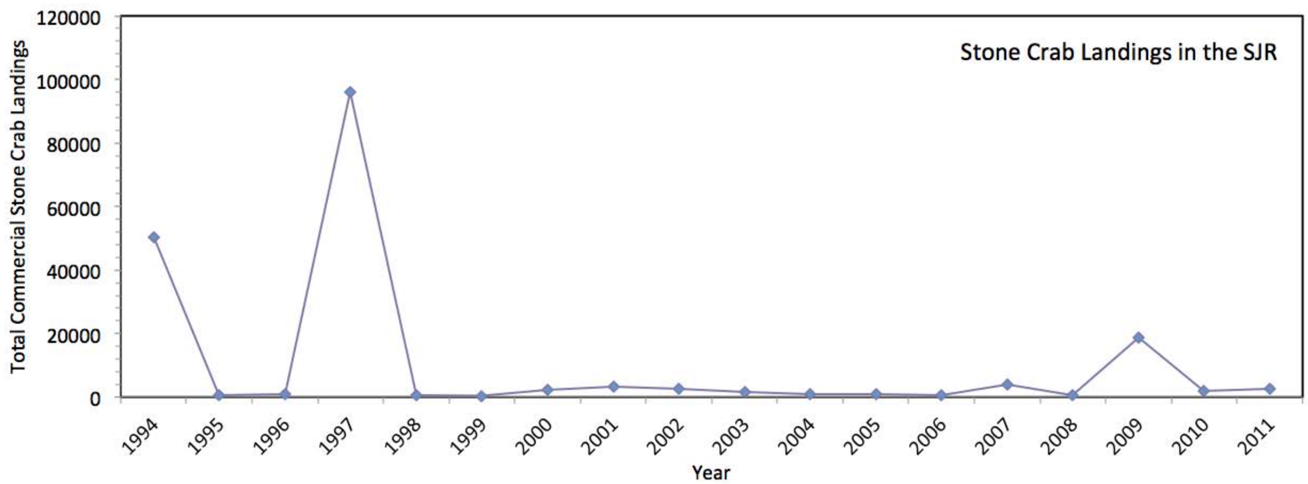


Figure 3.23. Commercial landings (in lbs.) of stone crab claws within the lower basin of the St. Johns River from 1986 to 2011

3.3.4.6. Current Status & Future Outlook

Stone crabs are not currently at risk of being overfished but are probably now at a level of landings that is all that can be harvested under current conditions along the Florida east coast (**Muller, et al. 2006**). To minimize negative impacts from commercial fisherman, the Florida state legislature implemented a crab trap reduction program in 2002. Currently, there is a daily limit of one gallon of minimum-sized 2 ¾-inch claws to only be collected during the season from October 15 to May 15 (**FWC 2012**).

4. Aquatic Life

4.1. Submerged Aquatic Vegetation (SAV)

4.1.1. Description

Dating back to 1773, records indicate that extensive SAV beds existed in the river (**Bartram 1928**). Since that time, people have altered the natural system by dredging, constructing seawalls, contributing chemical contamination, and sediment and nutrient loading (**DeMort 1990**; **Dobberfuhl 2007**). SAV found in the LSJRB (see Table 4.1) are primarily freshwater and brackish water species. Commonly found species include: tape grass *(Vallisneria americana)*, water naiad *(Najas guadalupensis)*, and widgeon grass *(Ruppia maritima)*. Tape grass forms extensive beds when conditions are favorable. Water naiad and widgeon grass form bands within the shallow section of the SAV bed. Tape grass is a freshwater species that tolerates brackish conditions, water naiad is exclusively freshwater and wigeon grass is a brackish water species that can live in very salty water (**Sagan 2010; White, et al. 2002)**. *Ruppi*a does not form extensive beds. It is restricted to the shallow, near shore section of the bed and has never formed meadows as extensive as *Vallisneria* even when salinity has eliminated *Vallisneria* and any competition, or other factors change sufficiently to support *Ruppia* (**Sagan 2010**).

Other freshwater species include: muskgrass *(Chara sp.)*, spikerush *(Eleocharis sp.)*, water thyme *(Hydrilla verticillata*; an invasive non-native weed), baby's-tears *(Micranthemum sp.)*, sago pondweed *(Potamogeton pectinatus)*, small pondweed *(Potamogeton pusillus)*, awl-leaf arrowhead *(Sagittaria subulata)* and horned pondweed *(Zannichellia palustris)* (**IFAS 2007**; **Sagan 2006**; **USDA 2007**). **DeMort 1990** surveyed four locations for submerged macrophytes in the LSJR and indicated that greater consistency in species distributions occurred south of Hallows Cove (St. Johns County) with tape grass being the dominant species. North of this location widgeon grass and sago pondweed were the dominant species, until 1982-1987 when tape grass coverage increased 30%, and is now the most dominant species encountered.

The greatest distribution of SAV in Duval County is in waters south of the Fuller Warren Bridge (**Kinnaird 1983b**; **Dobberfuhl 2002**; **Dobberfuhl and Trahan 2003**; **Sagan 2004**; **Sagan 2006**; **Sagan 2007**). Submerged aquatic vegetation in the tannin-rich, black water LSJR is found exclusively in four feet or less of water depth. Poor sunlight penetration prevents the growth of SAV in deeper waters. **Dobberfuhl 2007** confirmed that the deeper outer edge of the grass beds occurs at about three feet in the LSJRB. Rapid regeneration of grass beds occurs annually in late winter and spring when water temperatures become more favorable for plant growth and the growing season continues through September (**Dobberfuhl 2007**; **Thayer, et al. 1984**). SAV beds, especially *Vallisneria*, are present year-round and are considered "evergreen" in Florida (**Sagan 2010**).

Sunlight is vital for good growth of submerged grasses. Sunlight penetration may be reduced because of increased color, turbidity, pollution from upland development, and/or disturbance of soils. Deteriorating water quality has been shown to cause a reduction in grass beds. This leads to erosion and further deterioration of water quality.

In addition to the amount of light, the frequency and duration of elevated salinity events in the river can adversely affect the health of SAV (**Jacoby 2011**). In lab studies, **Twilley and Barko 1990** showed that tape grass grows well from 0-12 parts per thousand of salinity and can tolerate water with salinities up to 15-20 parts per thousand for short periods of time. Also, SAV requires more light in a higher salinity environment because of increased metabolic demands (**Dobberfuhl 2007**). Finally, evidence suggests that greater light availability can lessen the impact of high salinity effects on SAV growth (**French and Moore 2003**; **Kraemer, et al. 1999**).

Dobberfuhl 2007 noted that, during drought conditions, there is an increase in light availability that likely causes specific competition between the grasses and organisms growing on the surface of the grasses (Table 4.1). Many of these epiphytic organisms block light and can be detrimental to normal growth of the tape grass. As a result, this fouling causes an increase in light requirements for the SAV (**Dunn, et al. 2008**).

Table 4.1 Submerged Aquatic Vegetation in the Lower St. Johns River

(Photo: SJRWMD)

Tape grass *(Vallisneria americana)*

- Teeth on edge of leaves
- Leaves flat, tape-like; 0.5–4 cm wide
- Leaves taper at tip
- No obvious stem
- Height: 4–90 cm
  (a small one can be confused with *Sagittaria subulata*)

(Photo: SJRWMD)

Water naiad *(Najas guadalupensis)*

- Leaf whorls not tightly packed
- Leaf pairs/whorls separated by large spaces on stem
- Leaves opposite, usually in pairs, sometimes in whorls of three
- Leave with teeth (must look closely); 2 mm wide

(Photo: SJRWMD)

Widgeon grass *(Ruppia maritima)*

- Leaves alternate, tapering at end
- Leaves thread-like; 0.5 mm wide
- Height: 4–20 cm

(Photo: Kerry Dressler)

Muskgrass *(Chara sp.)*

- Leaf whorls separated by conspicuous spaces
- Leaf not forked
- Leaves stiff and scratchy to touch
- Height: 2–8 cm

(Photo: SJRWMD)

Spikerush *(Eleocharis sp.)*

- No teeth on leaves
- Leaves round, pencil-like; 1–3 mm wide
- Leaves as broad at tip as at base
- Height: 1–5 cm

(Photo: Kerry Dressler)

Water thyme *(Hydrilla verticillata)*

- Leaf whorls tightly packed
- Leaves opposite, in whorls of four to eight leaves
- Leaves with conspicuous teeth, making plant scratchy to the touch
- Leaf tip pointed; leaves 2–4 mm wide

- Height: 5–15 cm


(Photo: SJRWMD)

Baby's-tears *(Micranthemum sp.)*

- Leaf whorls not tightly packed
- Leaf opposite, in whorls of three to four leaves
- No teeth on leaves
- Leaf tip rounded; 2–4 mm wide
- Height: 2–15 cm


(Photo: SJRWMD)

Sago pondweed *(Potamogeton pectinatus)*

- Leaves alternate; 0.5–4.5 cm wide
- No teeth on leaves
- Leaves long and narrowing with pointed tips
- Stems thread-like
- Height: 5–20 cm


(Photo: SJRWMD)

Small pondweed *(Potamogeton pusillus)*

- Leaves alternate; 0.5–3 mm wide
- No teeth on leaves
- Leaves long and narrow with blunted or rounded tips
- Stems thread-like
- Height: 5–20 cm


(Photo: SJRWMD)

Awl-leaf arrowhead *(Sagittaria subulata)*

- No teeth on leaves
- Leaves triangular, spongy; 3–8 mm wide
- Leaves taper at tip
- Height: 1–5 cm


(Photo: SJRWMD)

Horned pondweed (Zannichellia palustris)

- Leaves opposite
- No teeth on leaves
- Long narrow leaves with blunted tips
- Stems thread-like
- Often seen with kidney-shaped fruit
- Height: 1–8 cm

4.1.2. Significance

SAV provides nurseries for a variety of aquatic life, helps to prevent erosion, and reduces turbidity by trapping sediment. Scientists use SAV distribution and abundance as major indicators of ecosystem health (**Dennison, et al. 1993**). SAV is important ecologically and economically to the LSJRB. SAV persists year round in the LSJRB and forms extensive beds which carry out the ecological role of "nursery area" for many important invertebrates, and fish. Also, aquatic plants and SAV provide food for the endangered West Indian manatee *Trichechus manatus* (**White, et al. 2002**). Manatees consume

from 4-11% of their body weight daily, with *Vallisneria americana* being a preferred food type (**Bengtson 1981**; **Best 1981**; **Burns Jr, et al. 1997**; **Lomolino 1977**). Fish and insects forage and avoid predation within the cover of the grass beds (**Batzer and Wissinger 1996**; **Jordan, et al. 1996**). Commercial and recreational fisheries, including largemouth bass, catfish, blue crabs and shrimp, are sustained by healthy SAV habitat (**Watkins 1995**). **Jordan 2000** mentioned that SAV beds in LSJRB have three times greater fish abundance and 15 times greater invertebrate abundance than do adjacent sand flats. **Sagan 2006** noted that SAV adds oxygen to the water column in the littoral zones (shallow banks), takes up nutrients that might otherwise be used by bloom-forming algae (See Section 2.5, Algae Blooms) or epiphytic alga, reduces sediment suspension, and reduces shoreline erosion.

Over the years, dredging to deepen the channel for commercial and naval shipping in Jacksonville, has led to salt water intrusion upstream. The magnitude of this intrusion over time has not been well quantified (See Section 1.2.3 Ecological Zones). Further deepening is likely to impact salinity regimes that could be detrimental to the grass beds. This is especially important if harbor deepening were to occur in conjunction with freshwater withdrawals for the river (**SJRWMD 2012g**). On April 13th 2009, the Governing Board of the St. Johns River Water Management District (SJRWMD) voted on a permit to allow Seminole County to withdraw an average of 5.5 million gallons of water a day (mgd) from the St. Johns River. Seminole County's Yankee Lake facility would eventually be able to withdraw up to 55 mgd. This initial permit from Seminole County represents the beginning of an Alternative Water Supply (AWS) program that could eventually result in the withdrawal of over 260 mgd from the St. Johns and Ocklawaha Rivers (**St. Johns Riverkeeper 2009**). The impact of water withdrawal on salinity is currently under investigation by a team of researchers from the SJRWMD who will be participating in data collection, analyses, interpretation, and report writing. The National Research Council peer review committee provided peer review, and a final report was made available in early 2012. (**NRC 2011**) On May 10th 2011, JEA was granted a consolidated consumptive use permit to withdraw a base amount of 142 mgd of groundwater (based on JEA's demonstrated water demand in 2021). This amount can increase to 155 mgd by 2031 upon meeting several key conditions, and if JEA achieves reuse greater than the permit's conditions by providing more reclaimed water to other permitted groundwater users, the allocation could increase up to 162.5 mgd as these other groundwater uses are reduced or eliminated (**SJRWMD 2012g**).

4.1.3. Data Sources & Limitations

The SJRWMD has conducted year-round sampling of SAV since 1998 at numerous stations along line transects of St. Johns River (1.25 miles apart) (**Hart 2012**). The routine field sampling performed provides information about inter-annual relative changes in SAV by site and region. Data evaluated in this report was for the years 1989, and 2000 through 2010. For maps of the individual transect locations see Appendix: 4.1.7.1.A-D.

The parameters used as indicators of grass bed condition were (1) mean bed length (includes bare patches) and grass bed length (excludes bare patches), (2) total percent cover by SAV (all species), and (3) *Vallisneria* percent cover. The data were broken down into six sections of the St. Johns River as follows: (1) Fuller Warren to Buckman, (2) Buckman to Hallows Cove, (3) Hallows Cove to Federal Point, (4) Federal Point to Palatka, (5) Palatka to Mud Creek Cove, and (6) Crescent Lake (Appendix: 4.1.7.1.A-D). The data set includes one of the most intense El Nino years (1998) followed by one of the most intense drought periods (1999-2001) in Florida history. Both of these weather phenomena exaggerate the normal seasonal cycle of water input/output into the river. Also, a series of shorter droughts occurred during 2005-2006 and 2009-2010. Normally, grass bed length on western shorelines tends to be longer than on eastern shorelines; and this is likely because of less wave action caused by the prevailing winds and broader shallower littoral edges compared to the east bank. Therefore, the shore-to-shore differences are most pronounced in Clay County-western shore sites and St. Johns County-eastern shore sites (**Dobberfuhl 2009**). For a list of grass species encountered within each section and a comparison of the variation among grass bed parameters, including canopy height and water depth, see Appendix: 4.1.7.1 A-D.

Because of the importance of color and salinity, rainfall and salinity levels were examined. Rainfall data were provided by SJRWMD (**Rao, et al. 1989**; **SJRWMD 2012d**) (Figure 4.1), the National Hurricane Center (**NOAA 2012a**), and the Climate Prediction Center (**NOAA 2012b**) (see Appendix: 4.1.7.1.E. for rainfall, hurricanes, and El Nino). Salinity data from 1991 to 2011 were provided by the Environmental Quality Division of the City of Jacksonville. Water quality parameters are measured monthly at ten stations in the main stem of the St. Johns River at the bottom (5 m), middle (3 m), and surface (0.5 m) depths. Additional data on salinity from 1994 to 2011 came from the SJRWMD, and correspond with five specific

SAV monitoring sites (Appendix: 4.1.7.1.F. Salinity). These data are discussed further in Section 4.4 (Threatened & Endangered Species). Note that "spot sampling" cannot be used to adequately match water quality parameters and grass bed parameters; because plants like *Vallisneria* integrate conditions that drive their responses. To evaluate such responses "high-frequency" data is required (**Jacoby 2011**). Moreover, information is limited about duration and frequency of elevated salinity events in the river and how that relates to the frequency and duration of rainfall. Also, there is limited information about the ability of SAV growing in different regions of the river to tolerate varying degrees of salinity. In 2009, the SJRWMD began to conduct research to evaluate this question by transplanting tape grass from one area to other areas in the river, thus exposing it to varying degrees of salinity for varying periods of time (**Jacoby 2011**). These same concerns are echoed by the Water Science and Technology Board's review of the St. Johns River Water Supply Impact Study (**NRC 2011** p5) – see a list of select findings under 4.1.5. Future Outlook.

4.1.4. Current Status & Trend

For the period 1989, and 2000 through 2007: The section of the St. Johns River north of Palatka had varying trends in all the parameters that usually increase and decrease according to the prevailing environmental conditions. For the period 2008-2011, the data showed a declining trend in grass bed parameters – this is in spite of some recovery in grass beds condition in 2011. Also, salinity was negatively correlated with percent total cover, and the proportional percent of tape grass (Appendix: 4.1.7.1.A-C). Aerial survey observations of manatees and their habitat in Duval County continue to indicate decline in grass bed coverage north of the Buckman Bridge (Bolles School to Buckman-east bank, and some parts from NAS JAX to Buckman-west bank, but not including Mulberry Cove).

There was a declining trend in all the parameters (2001-2007) south of Palatka and in Crescent Lake. From 2007-2009 the data suggested an increasing trend in all parameters. In 2010, data showed a declining trend, but in 2011 the trend was increasing again. Over the longer-term (2001-2011) there was a declining trend in grass bed length (Appendix: 4.1.7.2.C-D).

The availability of tape grass decreased significantly in the LSJRB during 2000-2001. This may be because the severe drought during this time caused higher than usual salinity values which contributed to high mortality of grasses. Factors that can adversely affect the grasses include excess turbidity, nutrients, and phytoplankton (see section 2.5 Algae Blooms). In 2003, environmental conditions returned to a more normal rainfall pattern. As a result, lower salinity values favored tape grass growth. In 2004, salinities were initially higher than in 2003 but decreased significantly after August with the arrival of heavy rainfall associated with four hurricanes that skirted Florida (Hurricanes Charley, Francis, Ivan and Jeanne). Grass beds north of the Buckman Bridge regenerated from 2002-2006 and then declined again in 2007 due to the onset of renewed drought conditions (**White and Pinto 2006b**). Drought conditions ensued from 2009-2010, leading to a further decline in the grass beds. Under normal conditions, SAV in the river south of Palatka and Crescent Lake is dynamic (highly variable), and significantly influenced by rainfall, runoff and water color (**Dobberfuhl 2009**).

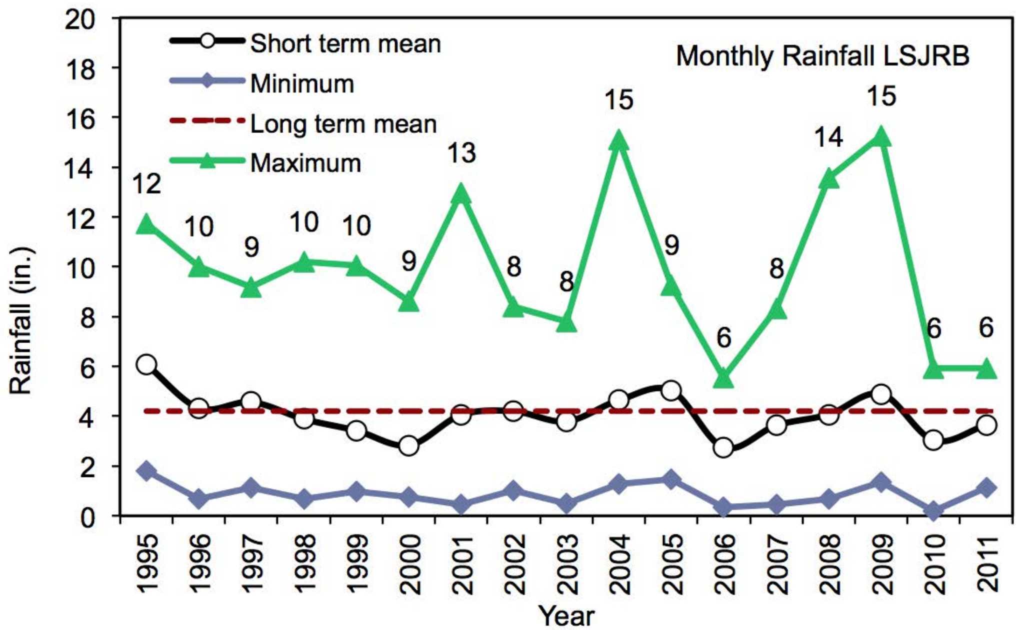


Figure 4.1. Monthly rainfall maximum, minimum, long term and short term annual means for LSJRB. Data are for the period June 1995 to December 2011 (solid lines). Average of monthly rainfall for periods 1951-1960 and 1995-2010 were not significantly different (dotted line). Data source: ***Hart 2012****.*

4.1.5. Future Outlook

Continuation of long-term monitoring of SAV is essential to detect changes over time. Grass bed indices, along with water quality parameters, should be used to determine the current state of health. They can then be used to identify restoration goals of the SAV habitat, which will preserve and protect the wildlife and people who rely on the habitat for either food, shelter and their livelihood. Further indices of the health and status of grass beds should be developed that express the economic value of the resource as it pertains to fisheries and other quality-of-life indices such as aesthetics, recreation, and public health.

Learning more about SAV response to drought and/or periods of reduced flow can provide crucial understanding as to how water withdrawals, dredging, and the issue of future sea level rise will affect the health of the ecosystem by adversely altering salinity profiles.

Select Water Supply Impact Study Findings (**NRC 2011**):

- "During Phase I, the District predicted that projected future water withdrawals could have dramatic consequences on SAV in some areas, especially where V. *americana* populations now fluctuate in the lower St. Johns River."
- "Although V. *americana* presumably could migrate further upstream, there is less shallow water area there, so a net loss of habitat is still expected."
- "..more spatially explicit predictions of the salinity increases in the littoral zone" were recommended and, "To enhance their monitoring program, the District should consider adding at least one continuous salinity monitoring station in the littoral zone during Phase II to detect short-term salinity excursions where V. *americana* is at risk."
- "The workgroup should also undertake more study of salinity tolerance of local populations from the St. Johns River, perhaps via mesocosm studies, in order to validate the values derived from the literature."
- "Finally, the workgroup might assess whether any other existing SAV species, for example Ruppia maritima, might be able to take the place of V. *americana* as a dominant macrophyte in the littoral zone."

Figure 4.2 A variety of wetlands can be found along the Lower St. Johns River Basin including salt marshes in the brackish, tidal coastal areas (left) and cypress-lined, freshwater, river swamps to the south of Jacksonville, Florida (right). (Photos: Heather P. McCarthy)

4.2. Wetlands

4.2.1. Description

Some of the most biologically diverse and productive systems on earth, wetlands are lands that are partially or periodically inundated with water during all or part of the year (**Myers and Ewel 1990**). The term *wetland* is broadly used to describe an area that is transitional between aquatic and terrestrial ecosystems. Within the LSJRB, these ecosystems include both coastal and freshwater wetlands (Figure 4.2). Interconnected to one another and the ocean, ***coastal wetlands*** include all wetlands that are influenced by the tides within the St. Johns River watershed as it drains into the Atlantic Ocean (**Stedman and Dahl 2008**). ***Freshwater wetlands*** are typically inland, landlocked or further upstream in the Middle and Upper Basins of the St. Johns River. Wetland ecosystems described in this section are typically broken down into vegetation types based on physiognomy, or growth form of the most dominant plants: 1) forested wetlands and 2) non-forested wetlands. ***Forested wetlands*** are usually fresh water and include swampy areas that are dominated by either hardwood trees like tupelo, bay, mangrove or gum, or by coniferous trees like cypress, pond pine or cedar. Forested wetlands can be mixed and include a variety of trees. ***Non-forested wetlands*** can be marine, estuarine or freshwater, and include marshy areas that are dominated by soft-stemmed grasses, rushes and sedges. Non-forested wetlands include wet prairies and mixed scrub-shrub wetlands dominated by willow and wax myrtle. The term *wetland* also includes non-vegetated areas like tidal sand or mud flats, intertidal zones along shorelines, intermittent ponds and oyster bars.

4.2.2. Significance

Wetlands perform a number of crucial ecosystem functions including assimilation of nutrients and other non-point source pollutants from upland sources. Additionally, wetlands serve as natural flood mitigation devices, minimize local flooding, and, thereby, reduce property loss and the external cost of floods to communities (**Brody, et al. 2007**). Wetlands also provide nursery grounds for many commercially and recreationally important fish; areas for refuge, nesting, and forage for migratory birds; shoreline stabilization; and critical habitat for a wide variety of aquatic and terrestrial wildlife (**Groom, et al. 2006**; **Mitsch and Gosselink 2000**).

4.2.3. The Science and Policy of Wetlands in the U.S.: The Past, the Present, and the Future

Since the 1970s when wetlands were recognized as *valuable* resources, accurately describing wetland resources and successfully mitigating for the destruction of wetlands have been ongoing pursuits in this country. In short, during the last few decades wetland science and policy have been driven by a) calculating wetland loss, and b) determining how to compensate for the loss. Developments in this effort to compensate for lost wetlands have arisen slowly over time as science pushes policy and vice versa. The result has been adaptive management and evolving regulations.

Wetland mitigation, as we know it today, was not initially a part of the Section 404 permitting program as outlined in the original 1972 Clean Water Act, but "was adapted from 1978 regulations issued by the Council on Environmental Quality

as a way of replacing the functions of filled wetlands where permit denials were unlikely" (**Hough and Robertson 2009**). However, it was not until 1990 that the USACE and EPA actually defined mitigation. It was defined as a three-part, sequential process: 1) permit-seekers should first try to ***avoid*** wetlands; 2) if wetlands cannot be avoided, then permit-seekers should try to ***minimize*** impacts; and 3) if wetland impacts cannot be avoided or minimized, then permit-seekers must ***compensate*** for the losses.

4.2.3.1. The Past: A Focus on Wetland Acreage

During the 1980s-1990s, assessments of wetland losses (and the mitigation required as compensation) typically focused on ***acres*** of wetlands. In 1988, President G.H. Bush pledged "no net-loss" of wetlands. This pledge was perpetuated by President Clinton in 1992, and President G.W. Bush in 2002 (**Salzman and Ruhl 2005**). In order to ascertain whether this goal was being achieved or not, the USFWS was mandated to produce status and trends reports using the National Wetlands Inventory data. In 1983, the first report, *Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950s to 1970s,* calculated a net annual loss of wetlands during this time period equivalent to 458,000 acres per year (**Frayer, et al. 1983**). In 1991, the second report, *Status and Trends of Wetlands in the Conterminous United States, mid-1970s to mid-1980s,* reported a decline in the rate of loss to 290,000 acres per year (**Dahl and Johnson 1991**). In 2000, the USFWS released the third report, *Status and Trends of Wetlands in the Conterminous United States 1986 to 1997*, which concluded the net annual loss of wetlands had further declined to 58,500 acres per year (**Dahl 2000**).

4.2.3.2. The Present: A Focus on Wetland Functions

Although the USFWS reports marked the first comprehensive, scientific, and statistical attempts to *quantify* wetlands in the United States, their value was recognizably limited because their results did not, and could not, evaluate the *quality* or *condition* of the acres of wetlands reported. In 2001, the National Research Council (NRC) concluded that "the committee is not convinced that the goal of no net loss for permitted wetlands is being met for wetland functions" (**NRC 2001**). This shifted the focus from wetland acres to wetland functions. The NRC pushed a new research agenda, which led to the refinement of scientific methods for assessing the ecological functions of wetlands. States called for expanded data collection and more comprehensive and standardized assessment techniques. By 2004, DEP had adopted uniform methods in Florida "to determine the amount of mitigation needed to offset adverse impacts to wetlands and other surface waters and to determine mitigation bank credits awarded and debited" (**DEP 2007a**). For the first time, the methods systematically and consistently considered wetland functions, and not just acreage.

In 2006, the fourth report by the USFWS, *Status and Trends of Wetlands in the Conterminous United States 1998 to 2004*, calculated for the first time a *net gain* of wetlands in the U.S. equivalent to 32,000 acres per year (**Dahl 2006**). This result was publicized, celebrated, scrutinized, and criticized. The central shortfall of the USFWS analyses was that wetland functions were not considered. This shortfall was briefly addressed in a footnote in the middle of the 112-page report: "One of the most important objectives of this study was to monitor gains and losses of all wetland areas. The concept that certain kinds of wetlands with certain functions (e.g., human-constructed ponds on a golf course) should have been excluded was rejected. To discriminate on the basis of qualitative considerations would have required a much larger and more intensive qualitative assessment. The data presented do not address functional replacement with loss or gain of wetland area" (**Dahl 2006**). The results of the 2006 report solidified the acceptance among scientists and policymakers that the simplistic addition and subtraction of wetland acres does not produce a wholly accurate portrayal of the status of wetlands. In short, any comprehensive evaluation of the status of wetlands needs to include a thorough consideration of what types of wetlands are being lost or gained and the ecosystem functions those wetlands provide.

Toward this end, publications began to emphasize that the USFWS's reported net gain of wetlands in the U.S. must be viewed alongside some important caveats and exceptions (**CEQ 2008**). For instance, some important types of wetlands were declining, although the overall net gain was positive. In 2008, USFWS and NOAA released an influential report entitled *Status and Trends of Wetlands in the Coastal Watersheds of the Eastern United States 1998-2004* (**Stedman and Dahl 2008**). This report calculated an annual loss of coastal wetlands at a rate of 59,000 acres per year (prior to Hurricanes Katrina and Rita in 2005). The report states: "The fact that coastal watersheds were losing wetlands despite the national trend of net gains points to the need for more research on the natural and human forces behind these trends and to an expanded effort on conservation of wetlands in these coastal areas" (**CEQ 2008**). The report emphasizes the important functions of coastal wetlands and the need for more detailed tracking of wetland gains and losses.

4.2.3.3. The Present: A Focus on Wetland Mitigation Banking

The last decade has also been marked by the growing popularity of ***wetland mitigation banking***. To offset the impacts of lost wetlands caused by a permitted activity, the SJRWMD or USACE (with the consent of DEP) may allow a permit-holder to purchase compensatory mitigation credits from an approved mitigation bank. Wetland mitigation banks are designed to compensate for unavoidable impacts to wetlands that occur as a result of federal or state permitting processes (**NRC 2001**). Since the 2000s, federal and state agencies have favored this market-based approach over the previously more common, but "poorly designed, inadequately implemented, and infrequently monitored" on-site individual project mitigation (**Ruhl, et al. 2008**). By 2008, it was reported that mitigation banking accounted for more than 30 percent of all regulatory mitigation arising from the Section 404 permitting process (**Ruhl, et al. 2008**). Although more successful than previous approaches, mitigation banking has its own set of inherent problems and inadequacies. As **Salzman and Ruhl 2005** explain, "different types of wetlands maybe exchanged for one another; wetlands in different watersheds might be exchanged; and wetlands might be lost and restored in different time frames."

According to **Salzman and Ruhl 2005**, "Despite all its potential shortcomings, WMB [wetland mitigation banks] certainly remain popular. Credits in Florida are now trading anywhere from $30,000-$80,000 per acre. There clearly is demand and banks are still being created to supply it." Of course, the price that a permit-holder pays per mitigation credit varies by bank and time. For example, in October 2007, SJRWMD approved the Florida Department of Transportation (FDOT) to purchase 55 mitigation bank credits from the East Central Florida Mitigation Bank at a purchase price of $32,000 per credit with up to ten additional credits for $38,000 each for unexpected impacts (**SJRWMD 2007b**).

To facilitate mitigation banking within Northeast Florida, the SJRWMD has delineated mitigation basins. In most cases, mitigation credits can only be purchased within the same mitigation basin as the permitted project where wetland loss is expected. The SJRWMD mitigation basins closely resemble, but do not exactly align with, the USGS drainage basins. Within the LSJRB, all or part of the following SJRWMD mitigation basins can be found: Northern St. Johns River & Northern Coastal, Tolomato River & Intracoastal Nested, Sixmile & Julington Creeks Nested, Western Etonia Lakes, St. Johns River (Welaka to Bayard), and Crescent Lake (**SJRWMD 2010c**).

According to the most recent data available, there are six mitigation banks approved by both the DEP and the SJRWMD that have service areas that fall within the LSJRB boundaries (Table 4.2, **DEP 2010i**; **SJRWMD 2010c**). The definition and use of mitigation bank service areas are explained below according to the SJRWMD (**SJRWMD 2010c**):

A mitigation bank's service area is the geographic area in which mitigation credits from the bank may be used to offset adverse impacts to wetlands and other surface waters. The service area is established in the bank's permit. The mitigation service areas of different banks may overlap. With three exceptions, mitigation credits may only be withdrawn to offset adverse impacts of projects located in the bank's mitigation service area. The following projects or activities are eligible to use a mitigation bank even if they are not completely located in the bank's mitigation service area:

a) Projects with adverse impacts partially located within the mitigation service area;
b) Linear projects, such as roadways, transmission lines, pipelines; or
c) Projects with total adverse impacts of less than one acre in size.

Before mitigation credits for these types of projects may be used, SJRWMD must still determine that the mitigation bank will offset the adverse impacts of the project and either that:

a) On-site mitigation opportunities are not expected to have comparable long-term viability due to such factors as unsuitable hydrologic conditions or ecologically incompatible existing adjacent land uses; or
b) Use of the mitigation bank would provide greater improvement in ecological value than on-site mitigation.

Table 4.2. Wetland Mitigation Banks Serving the Lower St. Johns River Basin, Florida (Source: SJRWMD 2010c).

MITIGATION BANK NAME	ACREAGE	CREDIT TYPE	AVAILABLE CREDIT BALANCE	COUNTIES IN SERVICE AREA
Barberville Conservation Area Mitigation Bank	358 acres (in Volusia County)	General Wetlands	0.28	St. Johns, Flagler, Putnam, Volusia, Seminole, Marion, Lake
Northeast Florida Wetland Mitigation Bank	774 acres (in Duval County)	General Wetlands	16.29	Duval, Nassau, Clay
Longleaf Mitigation Bank	3,020 acres (in Nassau County)	Freshwater	437.62	Nassau, Baker, Duval
Loblolly Mitigation Bank	6,247 acres (in Duval County)	Forested Freshwater	7.03	Nassau, Duval, Baker, Clay, St. Johns, Putnam
Tupelo Mitigation Bank	1,524 acres (in St. Johns County)	General Wetlands	30.69	St. Johns, Duval, Clay, Baker
Sundew Mitigation Bank	2,107 acres (in Clay County)	Forested Freshwater	23.6	Duval, Clay, St. Johns, Putnam, Flagler
Farmton Mitigation Bank	23,922 acres (in Volusia County)	General Wetlands	135.45	Flagler, Volusia, Lake, Seminole, Orange, Brevard, Osceola
Brick Road Mitigation Bank	2,945 acres (in Flagler County)	Forested Freshwater	27.39	St. Johns, Putnam, Flagler, Volusia

4.2.3.4. The Future: A Focus on Wetland Services

The future of wetland policies is rising out of the emerging science of ecosystem services (**Ruhl, et al. 2008**). As applied to wetlands, the *science of ecosystem functions* investigates how wetlands function in ecosystems (e.g., as nursery grounds, shelter, or food for wildlife). The emerging *science of ecosystem services* examines how wetlands serve human populations. As explained by **Ruhl, et al. 2008**, recent research documents that "wetlands can provide important services to local populations, such as air filtering, micro-climate regulation, noise reduction, rainwater drainage, pollutant treatment, and recreational and cultural values."

Ecosystem services research is just beginning to develop cost-effective methods to quantify what has long been intuitively recognized, but not quantified in the wetland permitting process – some people benefit and some lose as a result of wetland alteration in this country. For example, wetland mitigation banking has led to a migration of wetlands from urban to rural areas (**Ruhl and Salzman 2006**). Real estate prices typically drive developers to eliminate wetlands on high-priced urban land, while driving bankers to establish wetland banks on lower-priced rural land. Consequently, wetland resources are moved from one place to another, and the ecosystem services that they provide move with them. In this case, the services provided by wetlands are taken from the city dwellers and given to rural residents. These services, like sediment capture, groundwater recharge, water filtration, and flood mitigation, have real economic value associated with them. Calculating the dollar value of such services to people is a challenging, but not impossible, endeavor. The economic value of wetlands to retain stormwater surges or buffer shorelines was clear after Hurricanes Katrina and Rita hit the Gulf Coast of the U.S., where coastal wetlands have been substantially diminished (**Stedman and Dahl 2008**). One study examining wetland permits granted by the USACE in Florida between 1997 and 2001 determined that "one wetland permit increased the average cost of each flood in Florida by $989.62" (**Brody, et al. 2007**). Likewise, studies have estimated that the economic value of wetland-dependent recreation in Northeast Florida is in the range of $700 million per year (**Kiker and Hodges 2002**). The wetland-dependent activities with the greatest economic value to Northeast Florida are recreational saltwater fishing ($301.6 million per year), followed by wildlife viewing ($226.5 million per year). If these kinds of services are transferred from one human population or one community to another, the economic and social repercussions can be substantial.

Partially in response to the growing body of knowledge regarding wetland services, the USACE and EPA published a landmark overhaul of U.S. wetland regulations in April 2008 (**USACE and EPA 2008**). Not only did the rule consolidate the regulatory framework and require consideration of wetland functions, according to **Ruhl, et al. 2008**, "the new rule also for the first time introduces ecosystem services into the mitigation decision-making standards, requiring that 'compensatory mitigation…should be located where it is most likely to successfully replace lost…services.'" However, this requirement may be slightly ahead of the science – the necessary databases and scientific methods needed to fully consider the costs and benefits of ecosystem services do not yet exist. Although the new rule acknowledges that compensatory mitigation affects how wetland services are distributed and delivered to distinct human populations, there are few methods available for assessing these services quickly and reliably at any given site.

As the EPA and USACE promulgate this new rule, the necessary databases and methodologies are simultaneously being developed. At the regional level, the SJRWMD has posted a comprehensive online database of all mitigation bank ledgers (**SJRWMD 2010c**). At the national level, the USACE and EPA are developing a single online database to track mitigation banking activities called the *Regional Internet Bank Information Tracking System (RIBITS)* (**ERDC 2012**). RIBITS provides only limited access to the public, and is currently only deployed in Mobile, Norfolk, and Sacramento Districts and being beta-tested in Portland District. Concurrently, the EPA and USACE are developing a GIS-enabled database to *spatially* track and map permits and mitigation bank transactions, which will interface and complement the RIBITS database (**Ruhl, et al. 2008**). When the RIBITS and GIS-enabled programs are linked and deployed in the USACE Jacksonville District, it will greatly add to the understanding of the Federal wetland permitting and mitigation process in Florida and the LSJRB specifically.

4.2.4. Data Sources on Wetlands in the LSJRB

4.2.4.1. Data Sources for Wetland Spatial Analyses

A total of eight GIS (Geographic Information System) maps that contain data on wetlands vegetation were available and analyzed. The GIS maps were created by either the Department of Interior USFWS or the SJRWMD from high-altitude aerial photographs (color infrared or black-and–white photos) with varying degrees of consideration of soil type, topographical and hydrologic features, and ground-truthing. In this analysis, each parcel of land or water was outlined and assigned a category, creating distinct polygons for which area (i.e., number of acres) can be calculated. These areas were used to calculate total wetlands and total acres within the LSJRB for each year available (Table 4.3).

Table 4.3. Comparison of Wetland Maps - Lower St. Johns River Basin, Florida.

GIS MAP ANALYZED	TOTAL WETLAND AREA IN LSJRB (ACRES)	TOTAL LAND/WATER AREA IN LSJRB (ACRES)
SJRWMD-corrected National Wetlands Inventory map (produced from 1971-1992 lumped data, processed by SJRWMD in 2001, 2003)	727,631	849,512 ACRES INCLUDING DEEPWATER. Non-wetland upland acres not specified in this map.
SJRWMD Wetland & Deep Water Habitats map (based on National Wetlands Reconnaissance Survey maps from 1972-1980, processed 1996 by SJRWMD, dated 2001)	870,576	3,110,209
SJRWMD Wetlands & Vegetation Inventory map (based on District's Wetlands Mapping Project 1984-2002, finished 2002, accuracy of wetland boundaries estimated at 80-95%)	441,072	2,208,172
SJRWMD Land Use/Land Cover map (based on 1973 data)	440,048	2,100,552
SJRWMD Land Use/Land Cover map (based on 1990 data)	435,662	2,605,247
SJRWMD Land Use/Land Cover map (based on 1995 data)	450,595	1,910,422
SJRWMD Land Use/Land Cover map (based on 2000 data)	444,467	1,851,447
SJRWMD Land Use/Land Cover map (based on 2004 data)	451,702	1,868,003
* Lumped dates for maps result from the consolidation of aerial photographs taken during different years.		* 1.8 million acres is considered the accurate area of the LSJRB (according to the SJRWMD). Demonstrates that maps are not statistically comparable for total wetland area.

4.2.4.2. Data Sources for Wetland Permit Analyses

Within the LSJRB, there are two governmental entities that grant permits for the destruction, alteration, and mitigation of wetlands: 1) SJRWMD, and 2) U.S. Army Corps of Engineers (USACE). The differing regulatory definitions of wetlands used by Federal and State agencies are outlined in Appendix 4.2.A.

The wetland permit analysis conducted for this report reveals how the acreage of wetlands has changed over time according to the historical wetland permits granted through the SJRWMD Environmental Resource Permitting Program. Records of permits granted by the USACE were not analyzed for this report.

4.2.5. Limitations

4.2.5.1. Limitations of Wetland Spatial Analyses

The identification of vegetation type from an aerial photograph is an imperfect process, and any errors generated during the initial phases of GIS map production are perpetuated in this report. The metadata associated with the SJRWMD Wetlands & Vegetation Inventory map estimates the margin of error in wetlands delineation from aerial photographs to vary according to the type of vegetation being identified and range from five to 20% (**SJRWMD 2010b**). The metadata states: "The main source of positional error, in general, is due to the difficulty of delineating wetland boundaries in transitional areas. Thematic accuracy: correct differentiation of wetlands from uplands: 95%; correct differentiation of saline wetlands from freshwater or transitional wetlands: 95%; correct differentiation of forested, shrub, herbaceous, or other group forms: 90%; correct differentiation of specific types within classes: 80%. Accuracy varies for different locations, dates, and interpreters."

In addition to interpretational errors, wetland maps do not accurately reflect wetlands habitats that vary seasonally or annually (e.g., the spatial extent of floating vegetation or cleared areas can be dramatically different depending on the day the aerial photo was taken). Aerial photographs pieced together to create wetlands maps may be of different types (high altitude vs. low altitude, color infrared, black-and-white, varying resolutions and varying dates). Sometimes satellite imagery is used to create wetlands maps, which is considered less accurate for wetland identification (**USGS 1992**).

Analyses are further limited by inconsistencies and shortcomings in the wetland classification codes used (e.g., wetland codes used in the SJRWMD Land Use/Land Cover map of 1973 were markedly different than codes used since 1990). Additionally, wetland classification codes do not always address whether a wetland area has been diked/impounded, partially drained/ditched, excavated, or if the vegetation is dead (although the National Wetlands Inventory adds code modifiers to address the impacts of man). Further, wetland mapping classification categories often do not differentiate between natural and manmade wetlands. For example, naturally occurring freshwater ponds may be coded identically with ponds created for stormwater retention, golf courses, fishing, aesthetics, water management, or aquaculture. Some maps classify drained or farmed wetlands as uplands, while others classify them as wetlands. An unknown number of additional discrepancies may exist between maps.

Lastly, most of the spatial information in wetlands maps has not been ground-truthed or verified in the field, but is based on analyses of aerial photographs and other maps.

4.2.5.2. Limitations of Wetland Permit Analyses

A shortcoming of the records of wetlands impacted through regulatory permitting processes is that they do not address total wetland acres in the region. Permit records only attempt to report the relative gain/loss of wetlands each year.

Additionally, acreage recorded as mitigated wetlands do not always represent an actual gain of new wetland acres (e.g., mitigation acres may represent preexisting wetlands in a mitigation bank or formerly existing wetland acres that are restored or enhanced). Thus, a true net change in wetlands (annually or cumulatively) cannot be calculated from permit numbers with certainty.

Further, changing environmental conditions require that field verification of mitigated wetlands occur on a regular basis over long time periods. The actual spatial extent, functional success, health of vegetation, saturation of soil, water flow, etc. of mitigated wetlands can change over time. On-ground site visits can verify that the spatial extent of anticipated wetlands impacted (as recorded on permits) equals actual wetlands impacted and confirm the ecological functionality of mitigated wetlands.

The wetland permit analyses presented in this report are limited, because: 1) the analyses include all wetland permits granted within the entire SJRWMD region (not just those permits that fall within the LSJRB boundaries), and 2) the analyses do not address the wetland impacts and mitigation as permitted by the USACE.

Coupling analyses of permit records and GIS maps provides a better, though still limited, assessment of the status and trends of wetlands in the LSJRB than either alone.

4.2.6. Current Status

The current status of wetlands in Florida is considered UNSATISFACTORY, because a historical decrease in wetlands has been documented statewide. The current status of wetlands in the LSJRB is considered UNCERTAIN, because the reported statewide losses cannot be calculated with certainty for just the LSJRB.

4.2.6.1. Current Status of Wetlands in the LSJRB

The conclusions on the current status of wetlands in the LSJRB that can be gleaned from GIS maps are limited. Total wetland acres in the LSJRB cannot be determined with certainty from available data. The high margin of error associated with the delineation of wetlands from aerial photographs renders the wetlands maps unsuitable for total acreage calculations (see differences in total wetlands areas and total land/water areas calculated from maps listed in Table 4.2).

Based on one wetlands map (thought to be most accurate and complete for this kind of information), 83% of all wetlands in the LSJRB are freshwater, and three percent are estuarine and marine wetlands (Figure 4.3, based on SJRWMD-corrected National Wetlands Inventory Map). Freshwater wetlands are dominated mostly by freshwater forests, followed by freshwater unconsolidated bottoms and shores (ponds).

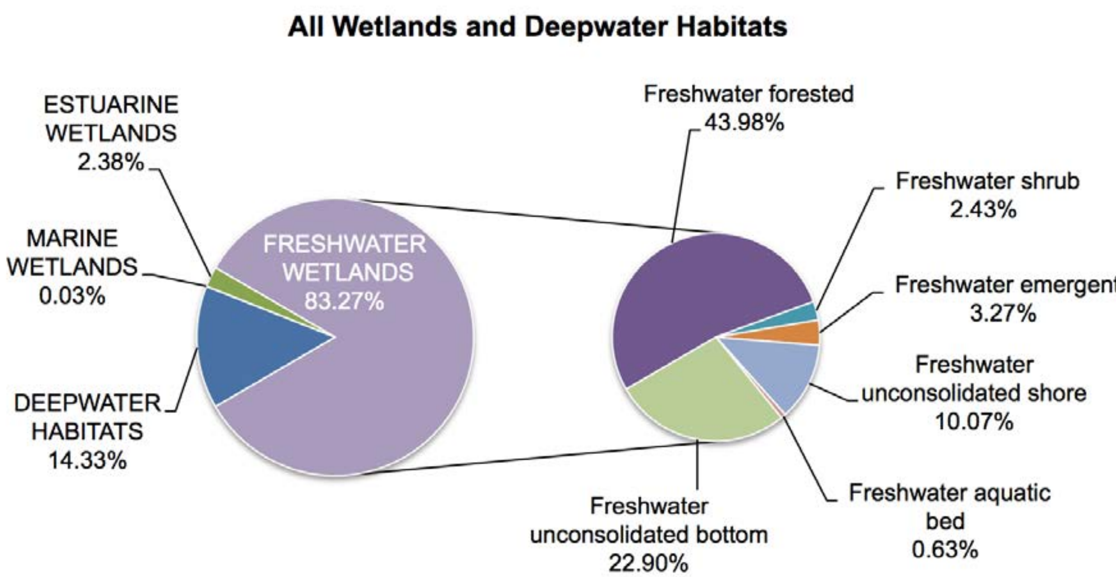


*Figure 4.3 The percentages of each wetland type in the Lower St. Johns River Basin, Florida (Source: **SJRWMD 2010b**).*

The following trends in wetlands within Florida and certain sections of the LSJRB are also notable:

- In Florida, the conversion of wetlands for agriculture, followed by urbanization, has contributed to the greatest wetland losses (**Dahl 2005**).
- The Upper Basin (the marshy headwaters of the St. Johns River) has experienced substantial historical wetland loss, and by 1983, it was estimated that only 65% of the original floodplain remained (**SJRWMD 2000**).
- **Dahl 2005** states, "modest estuarine salt marsh gains were observed in the counties of ... Duval and St. Johns counties" between 1985 and 1996.
- **Hefner 1986** state that "over a 50-year period in Northeast Florida, 62 percent of the 289,200 acres of wetlands in the St. Johns River floodplain were ditched, drained, and diked for pasture and crop production (**Fernald and Patton 1984**)."

- According to **DEP 2002**, "the 1999 District Water Management Plan notes seven to 14 percent losses of wetlands in Duval County from 1984 to 1995, according to National Wetlands Inventory maps."

4.2.6.2. Current Status of Wetlands in Florida

A discussion of wetland status in the LSJRB is incomplete without an evaluation of wetlands within a broader, historical context. Although wetlands maps do not reveal with any statistical certainty how many acres of wetlands in the LSJRB have been gained or lost over time, there are reliable historical records in the literature that estimate how many wetland acres have been lost *throughout the state of Florida* over time. A literature search was conducted to compile comparable and quantifiable estimates of historical wetland change in Florida over time. Because data occurring within just the LSJRB could not be extracted from statewide data, information for the whole state of Florida was evaluated and compiled in Appendix 4.2.B.

Prior to 1907, there were over 20 million acres of wetlands in Florida, which comprised 54.2% of the state's total surface area (Figure 4.4). By the mid-1950s, the total area of wetlands had declined to almost 15 million acres. The fastest rate of wetland destruction occurred between the 1950s and 1970s, as the total area of wetlands dropped down to 10.3 million acres. Since the mid-1970s, total wetland area in Florida appears to have risen at a slight rate (Figure 4.4). Net increases in total statewide wetlands are attributed to increases in freshwater ponds, such as manmade ponds created for fishing, artificial water detention or retention, aesthetics, water management, and aquaculture (**Dahl 2006**). The average of all compiled wetlands data in Florida revealed that the state retained a total of 11,371,900 acres by the mid-1990s (occupying 30.3% percent of state's surface area). This translates into a cumulative net loss of an estimated 8,940,607 acres of wetlands in Florida since the early 1900s (a loss of 44% of its original wetlands).

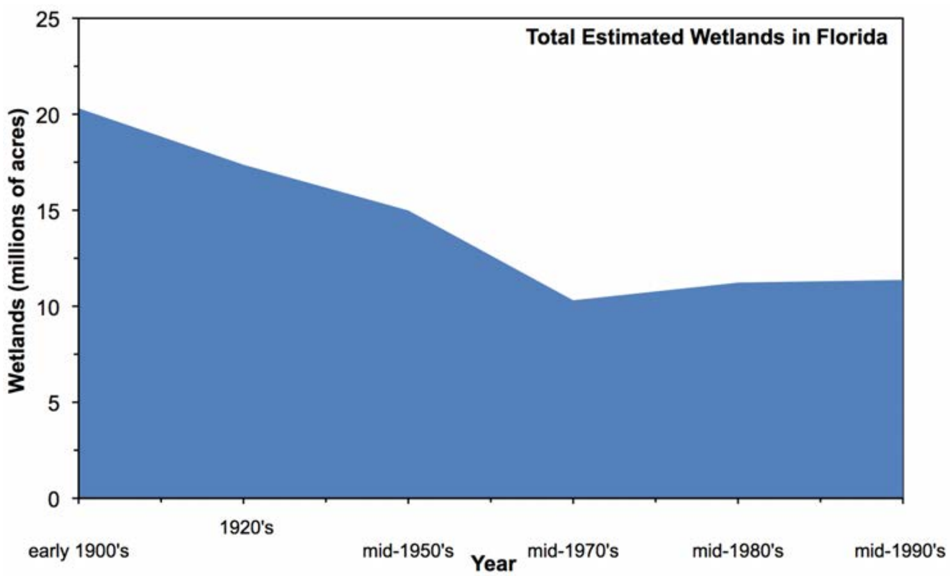


Figure 4.4 Total estimated wetlands per generalized time period in Florida. Based on averages calculated from a literature search (complete data table with references in Appendix 4.2.B.)

4.2.7. Current Trends in Wetlands in the LSJRB

Trends in wetlands can only be ascertained from sequential, time-series data. The only dataset of this type regarding wetlands within the LSJRB is contained within Land Use/Land Cover maps from the SJRWMD. These Land Use/Land Cover maps include spatial data on wetland types and were produced in 1973, 1990, 1995, 2000, and 2004.

4.2.7.1. Trends in Total Wetlands Acreage

Acres per year of wetlands derived from the SJRWMD Land Use/Land Cover maps are not comparable or statistically robust in order to establish trends in total wetland acreage over time. The lack of comparability between years stems from differences in the techniques, scale, and wetlands interpretation. The lack of statistical strength stems from a number of problems associated with the data, most importantly is the small sample size (*n*=5). Therefore, the current trend in total wetland acreage within the LSJRB is considered UNCERTAIN.

4.2.7.2. Trends in Wetland Vegetation

Although the total wetland acreage cannot be statistically compared from year to year, the relative contribution of different wetland types can be statistically compared with an acceptable degree of reliability. These comparisons attempt to assess how the quality of wetlands in the LSJRB might have changed over time.

Most categories of wetlands used in the SJRWMD Land Use/Land Cover maps were not consistent over the years. Notably, the categories used in 1973 were markedly different from the categories used in the 1990-2004 maps. In order to statistically compare between wetland types, categories were consolidated into several levels of groupings (see Appendix 4.2.C.).

When wetland codes are grouped into two broad categories (forested wetlands and non-forested wetlands), significant trends are noted. There appears to have been a shift in the composition of wetland communities over time from forested to non-forested wetlands (Figure 4.5). Forested wetlands comprised 91% of the total wetlands in 1973, and constituted only 75% of total wetlands in 2004.

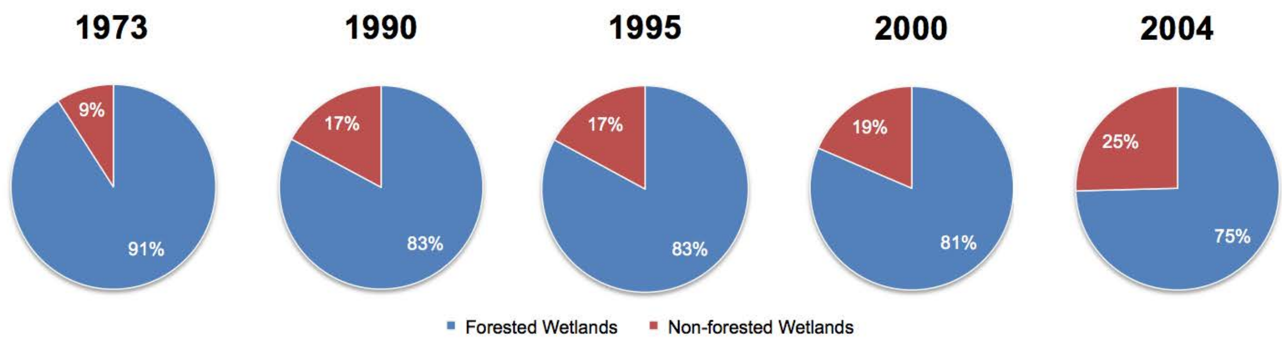


Figure 4.5 Percent of Forested Wetlands and Non-forested Wetlands in the Lower St. Johns River Basin based on Land Use/Land Cover Maps (SJRWMD).

The shift from forested to non-forested wetlands is a significant 30-year trend (according to the SJRWMD Land Use/Land Cover maps analyzed). Non-parametric statistics were used to examine whether the proportion of forested versus non-forested wetlands was significantly different between sequential years (Chi-Square Goodness-of-Fit Test results provided in Appendix 4.2.D.). The differences between the years were *statistically significant at the 0.05 level* for all years, except between 1990 and 1995, when there was no change in relative proportions of each type of wetland. Furthermore, regression analyses also revealed that the observed increase in non-forested wetlands was statistically significant at the 0.05 level (r2 = 0.88, p-value = 0.019). The decrease in forested wetlands was also statistically significant at the 0.05 level (r2 = 0.81, p-value = 0.028; regression plots in Appendix 4.2.E.). Supplemental graphs are provided in Appendices 4.2.F. and 4.2.G. These graphs examine how additional finer categorical groupings of wetlands appear to have changed over time (no significant trends detected).

4.2.8. Wetland Permit Trends in the LSJRB

4.2.8.1. Trends in Wetland Acreage Impacted and Mitigated by Permits Granted by SJRWMD

According to the Environmental Resource Permits granted by SJRWMD during the fiscal years examined, annual losses (acres of wetlands negatively impacted) have been consistently lower than annual gains (acres of wetland mitigation required) (Figure 4.6; Appendix 4.2.H.; **SJRWMD 2012a**). That is, wetlands are being mitigated (i.e., created, restored, enhanced, or preserved in upland/wetland areas) at a rate greater than they are being destroyed. However, an increasing trend over time in the number of acres of wetlands negatively impacted was evident during the years examined. This increasing trend in ***wetlands impacted*** was *statistically significant at the 0.05 level* (r^2 = 0.38, p-value = 0.012). The increasing trend for total ***wetlands mitigated*** was *not statistically significant* (r^2 = 0.095, p-value = 0.253). The data did not fit either an increasing or decreasing trend. Regression plots for both are provided in Appendix 4.2.I.

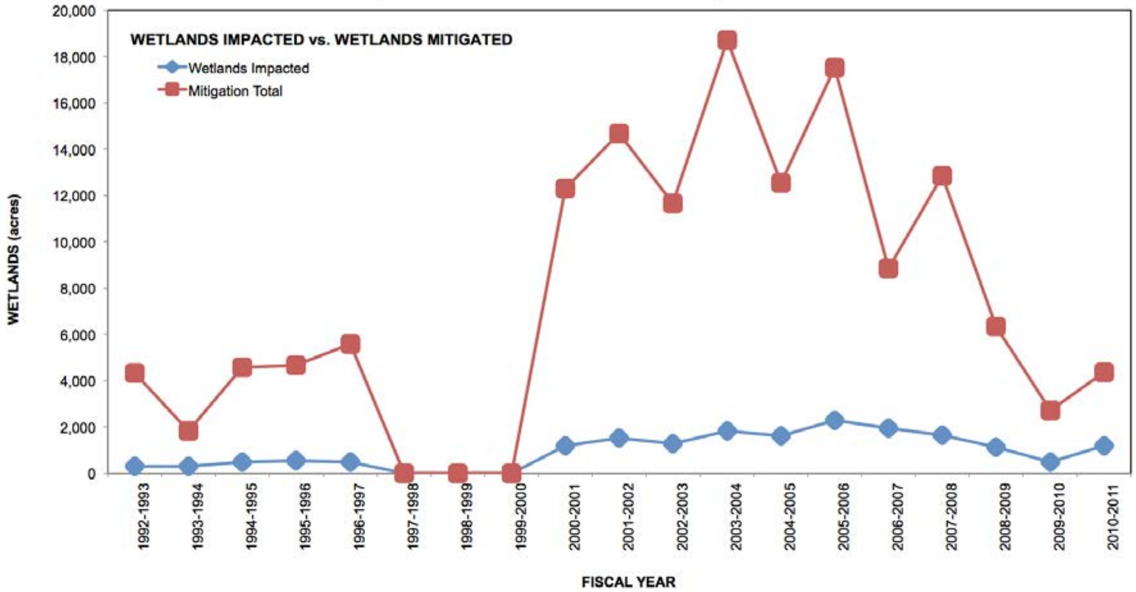


Figure 4.6 Acres of wetlands impacted and mitigation required by the SJRWMD Environmental Resource Permitting Program throughout the entire SJRWMD.

The effects of the permitting process on wetlands are generally permanent changes. In fact, permits usually require that mitigation be sustained in perpetuity. Because changes build upon one another, it may be more appropriate to view annual data cumulatively, rather than year-to-year (Figure 4.7 displays the cumulative impacts since Fiscal Year 2000-2001).

The increasing trends of cumulative wetlands impacted and mitigated were both *statistically significant at the 0.001 level* ($r^2 = 0.996$, p-value = 0.0000000017; $r^2 = 0.991$, p-value = 0.000000022, respectively).

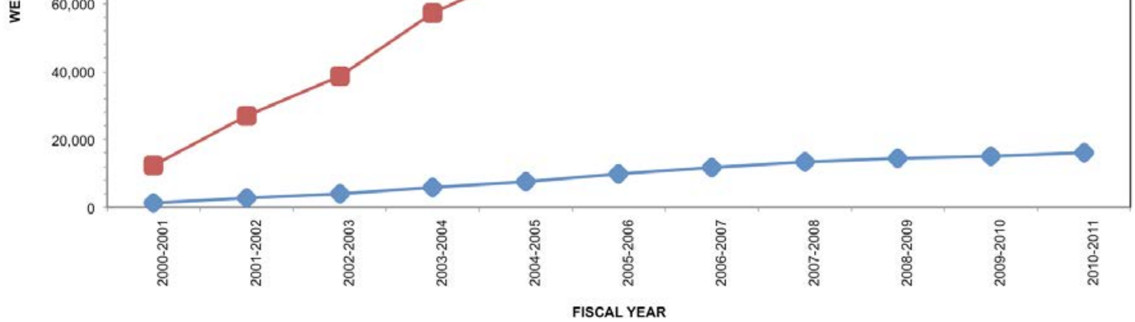


Figure 4.7 The cumulative wetlands impacted and mitigated by the SJRWMD Environmental Resource Permitting Program throughout the entire SJRWMD.

According to SJRWMD permit records, the methods used to mitigate wetlands have changed over time (Figure 4.8). During the early 1990s, wetland areas were most commonly mitigated by the creation of new wetlands or through wetland restoration. During the 2000s, very few wetlands were created or restored—most mitigation occurred through the preservation of uplands/wetlands. This trend can be partially explained by the increasing use of wetland mitigation banks.

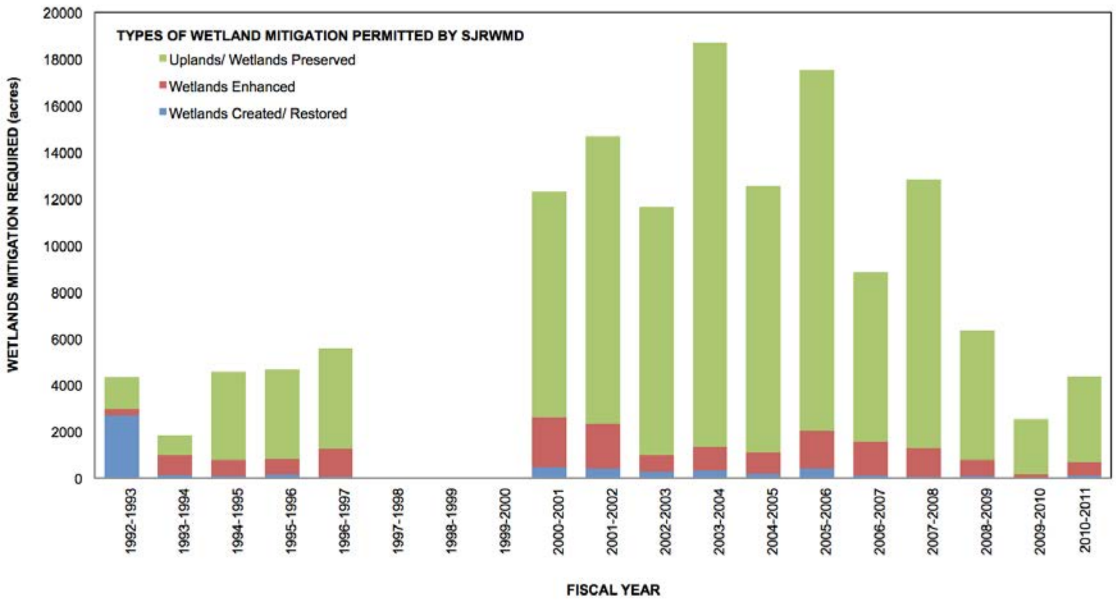


Figure 4.8 The types of mitigation permitted through the SJRWMD Environmental Resource Permitting Program throughout the entire SJRWMD since Fiscal Year 1992-1993 (some data missing due to SJRWMD database problems).

4.2.8.2. Trends in Wetland Acreage Impacted/Mitigated by Permits Granted by USACE

For a complete analysis of wetlands impacted and mitigation in the LSJRB, data needed from the USACE would include the location, total acres, type of vegetation, maturation/stage of wetland, wetland functions replaced, and wetland services replaced. A similar data deficit was found by the NRC, which concluded that "data available from the Corps were not adequate for determining the status of the required compensation wetlands" (**NRC 2001**).

4.2.9. Future Outlook

WETLANDS IMPACTS DATABASE NEEDED. During the development of this report, it became clear that wetlands data for Northeast Florida are disconnected, incomplete, and have not been recorded with the precision needed to accurately assess trends over time. It is not even possible to determine with statistical certainty whether the total acres of wetlands in the LSJRB has gone up or down during recent decades. One consolidated database pulling together records of wetlands permits granted by both State and Federal agencies is needed. Such a database could be available online and be queried by the public, so they can see when, where, and how wetlands are being impacted and mitigated. Additionally, project-specific and/or summary reports could be provided to local, State, and Federal agencies, which play an advisory or decision-making role in wetlands permitting and management.

HIGH VULNERABILITY. Many remaining wetlands are susceptible to alteration and fragmentation due to growing population pressures in Northeast Florida. The total spatial extent of wetlands negatively impacted through the SJRWMD permit process is increasing each fiscal year. These impacts are magnified by the losses of wetlands permitted by the USACE (the evaluation of these Section 404 permits is limited in this study). Although not quantifiable from available databases, the two permitting processes might be leading to a cumulative, gradual loss of wetland ecosystem functions and services. If national trends hold true in Northeast Florida, coastal wetlands might be particularly vulnerable (**Stedman and Dahl 2008**). Additionally, the environmental consequences of the gradual shift from forested wetlands to non-forested wetlands require attention and further study.

Additionally, wetlands in the LSJRB will be affected in the future due to surface water withdrawals from the river as permitted by the SJRWMD. In order to fully understand and predict the potential effects, the SJRWMD released the *St. Johns River Water Supply Impact Study* in February 2012 after a peer review by the National Academy of Sciences — National Resource Council (SJRWMD 2012b). In this study, the St. Johns River was divided into segments for analysis – the first three of which fall into the LSJRB:

- SEGMENT 1 ("Mill Cove") – extends 39.6 km from Mayport to the Fuller Warren Bridge.

- SEGMENT 2 ("Doctor's Lake") – extends 25.4 km from the Fuller Warren Bridge south to a line in the vicinity of Fleming Island.
- SEGMENT 3 ("Deep Creek") – extends 98.1 km from Fleming Island to Little Lake George.

The expected impacts to wetlands in the above segments of the LSJR were analyzed under four different modeling scenarios. One scenario was constructed to create a baseline that was used directly to assess salinity changes. Three scenarios were based on modeled data, a full water withdrawal, and various treatments of land use data, Upper SJRB projects, and sea level rise (**SJRWMD 2012g**). According to the SJRWMD (2012b), the overall results were that "some specific wetland types were reduced in area under each scenario. However, loss in total wetland area was not shown under any scenario with any of the analytical approaches used" (p 10-80, SJRWMD 2012b). More specific results of the study are summarized below.

Based on the modeling results, each segment within the LSJRB is expected to experience a change in annual mean salinity, which would, in turn, affect wetland communities. River Segment 1 is predicted to experience a change in mean annual salinity of 0.32 psu, followed by a 0.12 psu change in Segment 2, and 0.011 psu change in Segment 3. The likelihood of salinity effects in Segments 1 and 3 were deemed to be "low," because Segment 1 is already dominated by saltmarsh species which would tolerate the increase in salinity without negative impacts. The increase in salinity in Segment 3 was very small and was not expected to cause noticeable shifts in vegetation. However, river Segment 2 is considered the area of greatest concern, because this area between the Fuller Warren Bridge and the Shands Bridge, is dominated by hardwood swamps and extensive areas of freshwater and transitional vegetation. In this segment, salinity effects were deemed to be "high."

The *St. Johns River Water Supply Impact Study* also evaluated changes in patterns of water inundation and water depth (SJRWMD 2012b). However, the segments contained within the LSJRB were not analyzed for change in stage, because water levels in the LSJR are so heavily influenced by sea level. According to this study, the modeled water level change in the Segments 1-4 due to water withdrawals was less than 1 cm. Throughout the entire SJR, the average depth change ranged between 4 cm to less than 2 cm depending on the scenario used. The category of wetlands most negatively impacted throughout the state was "freshwater marshes."

Using the Ortega River as a model system, the *St. Johns River Water Supply Impact Study* examined whether surface water withdrawals could potentially cause movement in the freshwater/saltwater interfaces along the river. SJRWMD researchers identified sampling stations along the Ortega River and conducted vegetation studies. They determined five main wetland plant communities along a gradient from freshwater to brackish water: Hardwood Swamp, Tidal Hardwood Swamp, Lower Tidal Hardwood Swamp, Intermediate Marsh, and Sand Cordgrass Marsh. The soil salinity breakpoints and river salinity breakpoints, where one plant community type shifts to another type, were determined (Table 4.4.).

Table 4.4. Soil and River Salinity Breakpoints Causing Wetland Vegetation Shifts in the St. Johns River Basin, Florida (as determined in SJRWMD 2012b).

Soil Salinity Breakpoint	River Salinity Breakpoint	Predicted Distance Moved in St. Johns River
0.47 psu	3.218 psu	2.83 km
1.53 psu	4.13 psu	3.10 km
2.44 psu	4.93 psu	3.30 km
3.41 psu	5.77 psu	3.34 km

The study predicted upstream movement of vegetation boundaries of up to 1.13 km along the Ortega River. When the Ortega River model was applied to the entire St. Johns River, the directional shift of wetland vegetation community types ranged from 3.34 km to less than 0.21 km (SJRWMD 2012b).

Thus, certain types of wetland communities will be negatively impacted by future surface water withdrawals in the St. Johns River. These impacts must be considered cumulatively with other expected impacts from future changes in land use, surface water runoff, rainfall, navigational works, groundwater, and sea level rise.

QUESTIONABLE QUALITY. Further investigation is needed to determine the quality and longevity of mitigated wetlands and their ability to actually perform the ecosystem functions of the wetlands they "replace." An increasing proportion of these mitigation wetlands represent uplands/wetlands preserved elsewhere, including many acres in wetland mitigation banks. If preserved wetlands represent already functional wetlands, then they do not replace the ecosystem services lost. The USACE and the EPA have released new rules regarding compensatory mitigation of wetlands impacted by USACE permits (took effect on June 9, 2008). According to the Federal Register, the new rule emphasizes "a watershed approach" and requires "measurable, enforceable ecological performance standards and regular monitoring for all types of compensation" (**USACE 2007**). How these new changes may or may not affect wetland mitigation in the LSJRB warrants future investigation.

In summary, the future outlook for the health of the LSJRB depends upon detailed, accurate, consolidated record-keeping of wetland impacts, the cumulative impact of parcel-by-parcel loss of wetland ecosystem functions and services, and the success of wetlands enhanced, created, or restored.

4.3. Macroinvertebrates

1) http://eurekalert.org/multimedia/, 2) http://marine.usf.edu/images/amphipod.jpg, 3) http://fl.biology.usgs.gov/pics/nonindig_misc_mollusks/bivalves/bivalves_6.html
4) http://naturalresources.nsw.gov.au/, 5) http://moldychum.com, 6) http://jaxshells.org/coco.jpg,
7) http://umaine.edu/marine/people/sites/slindsay/LindsayLab/Assets/images/q5.jpg, 8) http://jeh-temp.co.uk/Shell_Images/G-L/Ilyanassa_obsoleta.jpg

4.3.1. *Description*

Benthic macroinvertebrates include invertebrates (animals without a backbone) that live on or in the sediment. This includes a variety of relatively small organisms such as crabs (decapods), snails (gastropods), shrimp, clams (bivalves), insects (mostly flies), segmented worms (polychaetes), nonsegmented worms (nemerteans and platyhelminthes), barnacles (cirripedians), and some others. In many cases, these organisms are extremely abundant. For instance, a one square meter area of mud can have as many as 40,000 organisms living within it!

There is high diversity in how long these organisms live and how they reproduce. In many areas of the St. Johns River, there is relatively high turnover of individuals with life spans of a few years at most. Most of these organisms produce young that spend some time drifting as microscopic organisms (larvae) in the plankton, before settling to the bottom where they will eventually become sexually mature adults. Other species either brood their young or lay egg cases.

4.3.2. *Significance*

There are multiple reasons why benthic macroinvertebrates are important in the lower St. Johns River Basin. First, because many of these organisms are so plentiful, they are an important component of the river's food web. Indeed, many of the adults of these species serve as food for commercially and recreationally important fish and invertebrate species. Their microscopic young can also be very abundant, providing food resources for smaller organisms such as important larval and juvenile fish species.

*Macroinvertebrates are also important because they can exert a strong influence on their environment by affecting the aeration and sediment size of the river bottom. In high abundances, they can literally change the sediment to accommodate other animals tha**t live on or near the sediment.***

*Finally, the assemblage of macroinvertebrates can provide insight into the degree of stress or pollution that is occurring in a given area of the river **(Gray 1979; Pearson and Rosenberg 1978)**. Consequently, they can serve as a good biological indicator of the health of a river or estuary. For more information on pollution in benthic invertebrates see the CONTAMINANTS section of this report.*

4.3.3. Data Sources

Macroinvertebrate community data used to assess long-term trends were obtained from the Florida Department of Environmental Protection (DEP), Florida's Inshore Marine and Assessment Program (IMAP), and the St. Johns River Water Management District (SJRWMD). The primary data set (1974-1995) was provided courtesy of the Jacksonville DEP office. Supplemental data from DEP's "Fifth-Year" Assessments were obtained online (**DEP 2009e**). The more recent IMAP macroinvertebrate data (2000-2004) was provided courtesy of the Florida Wildlife Research Institute (FWRI), and the Environmental Protection Agency (EPA). Macroinvertebrate data for 2005 were provided by the St. Johns River Water Management District (SJRWMD). All four data sets were combined to increase the temporal strength of the analyses. In an attempt to limit bias in community information, only data collected via Ponar and Young modified Van Veen grabs were used. Macroinvertebrates were assessed for the north (Duval County) and south (St. Johns, Flagler, Clay & Putnam Counties) sections of the lower St. Johns River. Within each of these sections of the river, the macroinvertebrate community was assessed by using collected data in a Shannon-Wiener diversity index. Diversity Indices have the value of mathematically accounting for both the number and abundance of each species encountered in a sample. **Evans and Higman 2001** classify moderate diversity at index values of 2 to 3, and low diversity at values less than 2. To assess community diversity change (for each river section) over the years, the diversity index versus time was investigated using a Kendal Tau correlation analysis. As another assessment of potential community differences among year and river section, a sample similarity matrix was constructed using a Bray Curtis Similarity Index. This Index was then analyzed using non-metric multi-dimensional scaling (MDS). Finally, scientific literature supplemented these data sets to strengthen insight on long-term patterns for macroinvertebrate communities within the river.

4.3.4. Limitations

While the dataset covers a long time period (~30 years), a few important limitations exist. First, similar regions were not sampled throughout the entire time period. In particular, the southern areas of the lower basin were less often visited than northern sections of the river. Additionally, while data collected via Ponar and Young modified Van Veen grabs is more similar than other collection techniques (i.e. dredges, sediment cores, quadrats), the methods used in this study could affect community comparison between earlier samples (mostly petite Ponar grabs) with those of more recent collections (mostly Young modified Van Veen grabs). Further, because of the natural variability when sampling, there probably were not enough replicates (total number varied between 1 to 10 from year to year) to accurately assess potential differences. Often microhabitat variability can be as high as site variability. Finally, the dataset assesses macroinvertebrates in deeper sections of the river, because sampling did not occur in shallow areas where boat access was limited.

4.3.5. Trend (UNCERTAIN)

Macroinvertebrate diversity was highly variable during the time period (1974-2004) of the study (Figure 4.9). The species diversity varied from a value of 1.3 to 2.9 (1-400 species) - low to moderate diversity as per **Evans and Higman 2001**. There was a similar lack of trend in diversity for both the northern (Kendal Tau statistic=-0.057; Not significant) and southern (Kendal Tau Statistic=0.029; Not significant) sections of the river (Figure 4.9). As expected, the community of macroinvertebrates was generally different between the north and south sections of the river regardless of most time periods sampled (Figure 4.10). Generally throughout the study, the north river section differed from the south by having greater percentages of cirripedians, polychaetes and nemerteans, and less dipterans, oligochaetes and molluscans. However, there were drastic changes in what types of macroinvertebrates dominated an area in both river sections during the course of the study (Figure 4.10 and 4.11). In the 1970s, the northern river section was dominated by barnacles,

polychaetes, and amphipods. In contrast, the southern river area was dominated by molluscs, amphipods, polychaetes, oligochaetes, and fly larvae. In the 1980s, the north section was dominated by polychaetes and barnacles, and the south river was mostly oligochaetes and fly larvae. During the 1990s, another shift had occurred with the north being mostly amphipods, molluscs, polychaetes, and barnacles. The southern parts of the river also shifted with dominant species being molluscs (mostly bivalves and snails), and fly larvae. By the 2000s, the northern community was fairly similar to that during the 1990s although there were higher numbers of decapods and oligochaetes. In contrast, the southern river section shifted more dramatically with higher percentages of nemerteans and polychaetes, and less fly larvae, being observed than during the 1990s.

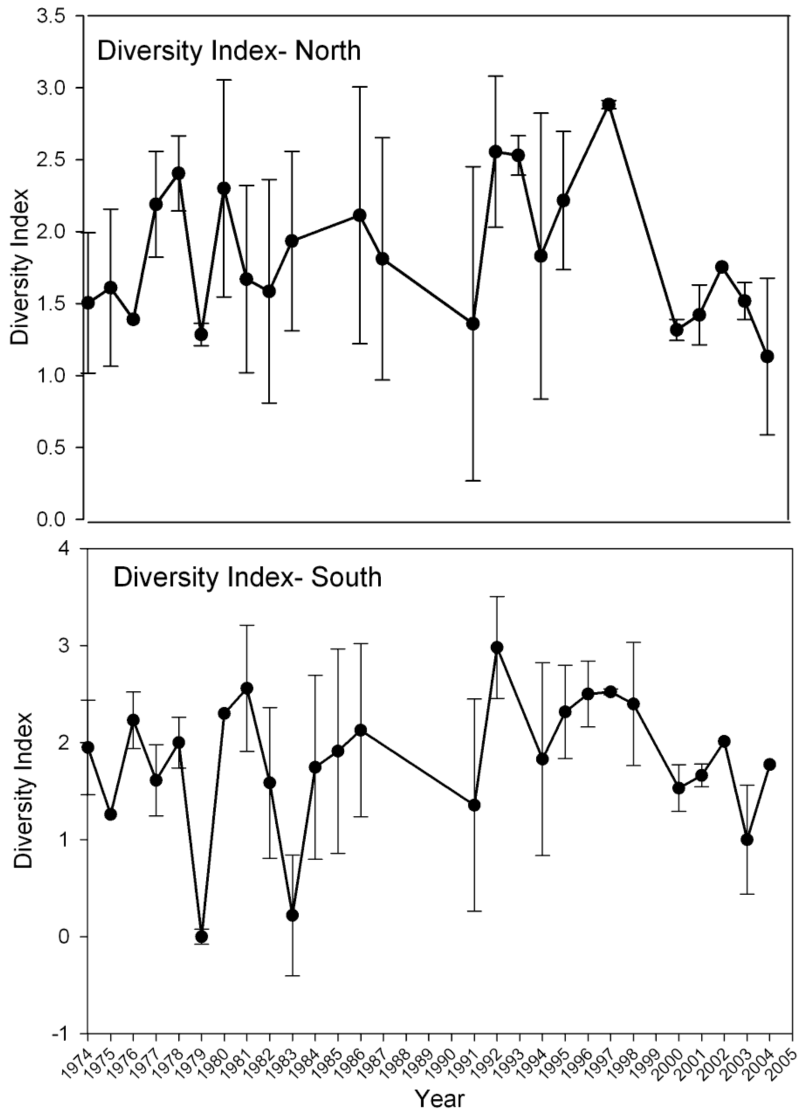


Figure 4.9 A comparison of the diversity of macroinvertebrates between the northern and southern sections of the Lower Basin of the St. Johns River. Evans and Higman (2001) classify moderate diversity at index values of 2-3, and low diversity at values less than 2. The number of replicates varied between 1 to 10 for each year of the study. The vertical bars of each point indicate the degree of variability (standard deviation) for each date.

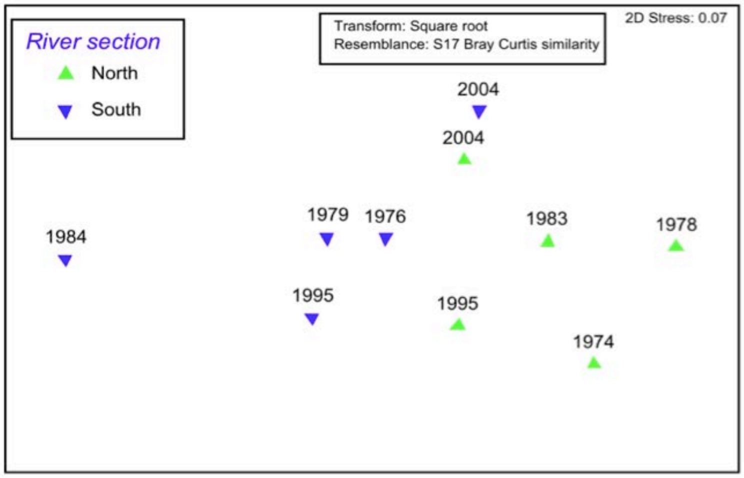


Figure 4.10 A multidimensional scaling plot (MDS) of macroinvertebrate community data (north and south sections of the river) for select years from 1974 to 2004. Generally, the proximity of noted symbols (representing year and river location) with each other represent how closely related they are in terms of the species and abundance of macroinvertebrate. Analyses were computed from means of replicates taken for each year.

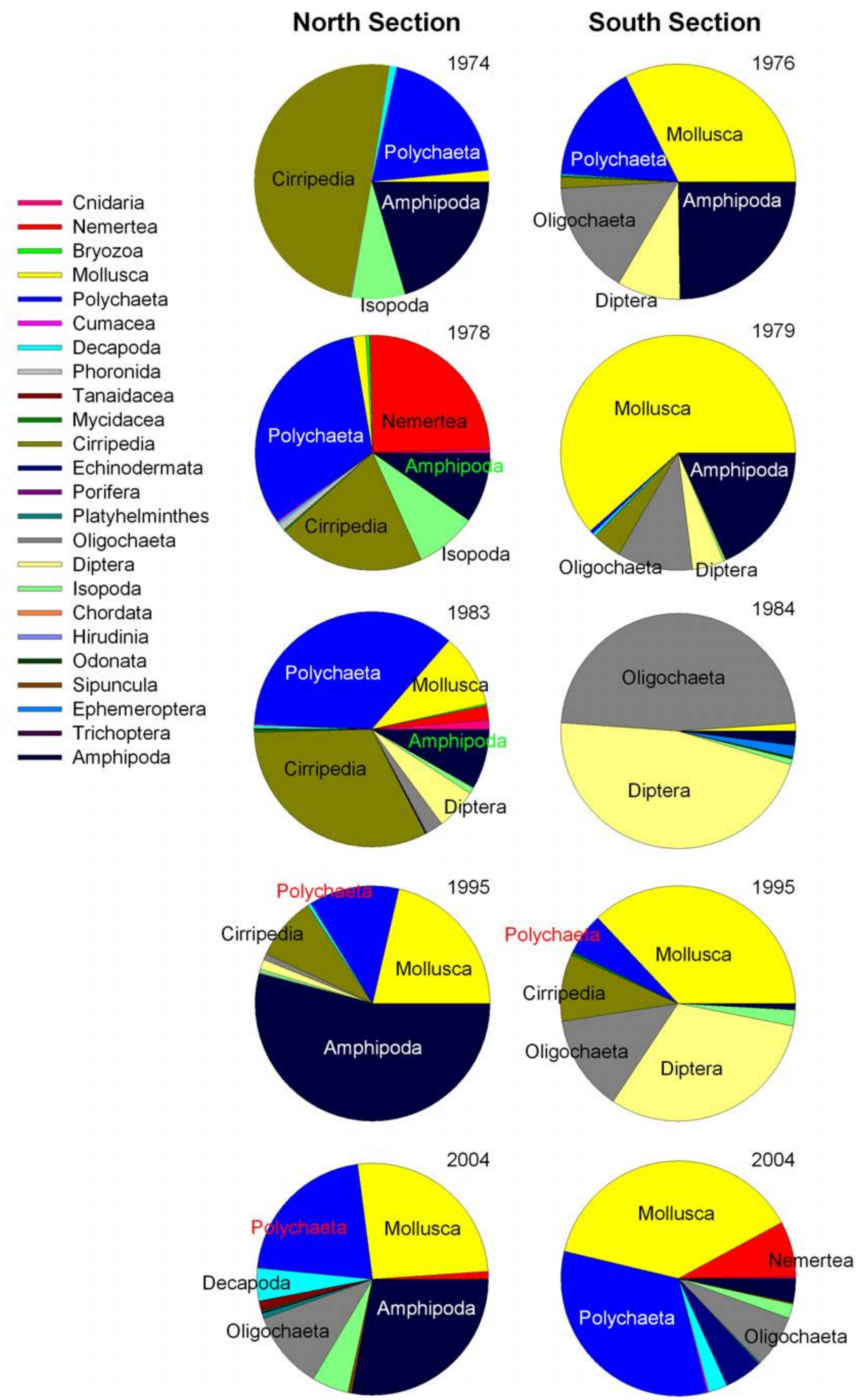


Figure 4.11 A comparison of the percentage of macroinvertebrate groups encountered between northern and southern sections of the Lower Basin of the St. Johns River from the 1970s-2000s. The number of replicates varied between 1 and 10 for each year of the study.

4.3.6. Current Status (UNSATISFACTORY)

Macroinvertebrates encountered in the St. Johns River are highly variable in diversity and abundance. The number of species in a single sample can vary from one to over twenty while the number of individuals of a given species could vary from none to as high as forty thousand per meter squared! As might be expected, the species encountered in our study change as one transitions from the saltwater dominated northern sections of the river to the freshwater areas in the south (For a complete list of species see Appendix 4.3.6). Certainly, community shifts are expected in response to the natural changes in environmental factors.

In the 2000s, the dominant animal groups were primarily pollution-tolerant species in both the north and south sections of the St. Johns River. To the north, the dominant species were primarily pollution-tolerant bivalves (dominated by the clam *Rangia cuneata*), polychaete worms (dominated by *Strebliospio spp*.), and amphipods (several species). Similar trends in macroinvertebrates encountered in the St. Johns River were documented by **Mason Jr 1998**), **Cooksey and Hyland 2007**, **Evans and Higman 2001**, **Evans, et al. 2004**, and **Vittor 2001; Vittor 2003**. **Evans and Higman 2001** encountered high numbers of abnormalities in insect larvae in the Cedar-Ortega River basin and Julington Creek. Towards the south of the lower basin, dominant taxa were more freshwater-tolerant (as expected) but still pollution-tolerant. In these southern areas, dominant taxa included snails (primarily *Littoridinops sp*.), oligochaetes (earthworm group), insects (primarily fly larvae), and amphipods (primarily *Corophium lacustre*). **Evans, et al. 2004** observed that the most pollution-tolerant species occurred at fresh-dominated mainstem (FM) sites than more salt-dominated mainstem sites (SM). However, the number of pollution tolerant species at FM sites was not different than those encountered at their fresh- or salt-dominated tributary sites. Additionally, they observed that there was a tendency among sites dominated by freshwater organisms, where deformities were most prevalent, for the number of deformities to be highest at sites dominated by pollution-tolerant species.

It is expected that high abundances of macroinvertebrates will persist within the St. Johns River. However, the types of organisms that make up these communities can shift significantly - often in response to changes in water quality, salinity or temperature. Indeed, some of these shifts in the community are likely a result of the naturally dynamic and often stressful, nature of the St. Johns River. For instance, **Cichra 1998**) suggests that freshwater areas of the river may often be naturally affected by increased salinity. It is important to recognize that the mechanism by which many of these organisms may be affected is by either direct impact to adults or to the offspring that spend part of their time in the water column as plankton. During the planktonic stage of these organisms lives, environmental gradients (i.e. salinity, temperature, dissolved oxygen) within the river can affect where young are and how they are transported to adult habitat. The section of the LSJR that transitions from salt to freshwater may be significant in affecting larval transport to adult habitats. Recent replicate winter plankton tows comparing surface zooplankton communities from Dames Point (22.5 ppt; SD ±0.10), Jacksonville University (12.6 ppt; SD ±0.80), and the San Marco (6.55 ppt; SD ±0.23) sections of the river revealed significantly different communities (Figure 4.12). While a number of these organisms can likely traverse this salinity gradient (water temperature and dissolved oxygen were similar among the three sites), others may use their sensory and larval swimming abilities to stay in preferred areas with respects to salinity and temperature gradients within the river (see larval behavior review by **Young 1995**). Consequently, changes in salinity in the river may affect larval transport and ultimately where adult populations exist within the river.

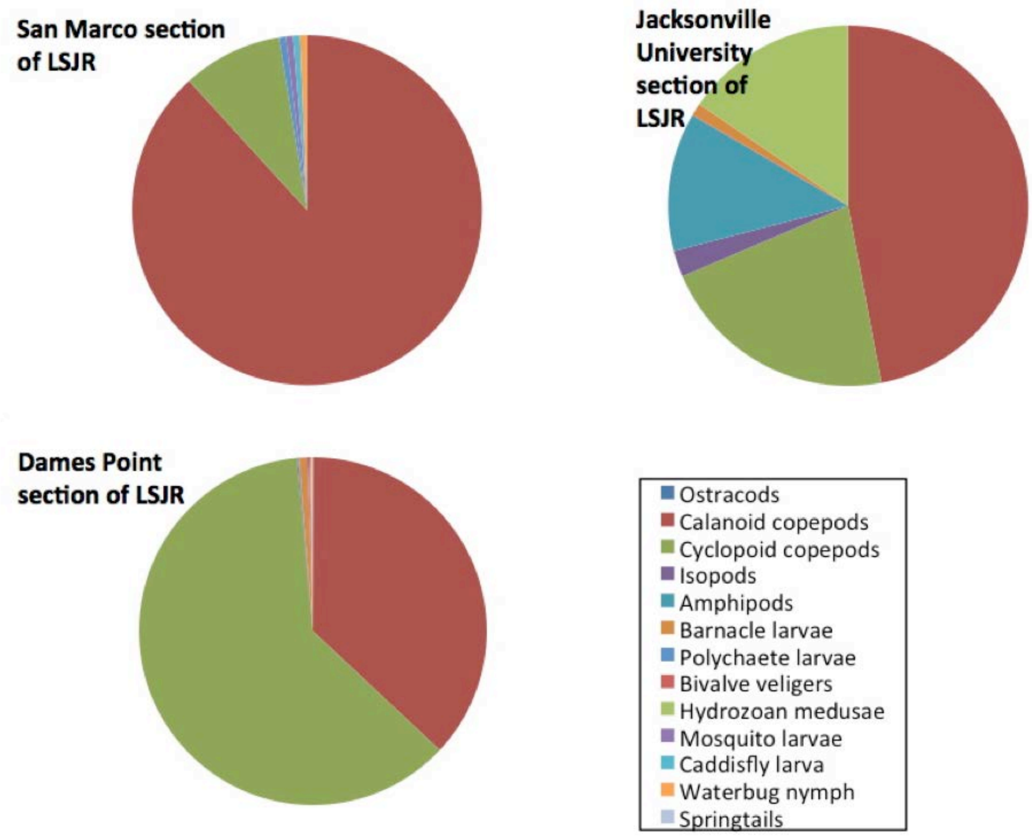


Figure 4.12 A comparison of mean relative percentage of zooplankton groups encountered on replicate (n=4) surface plankton tows during winter 2009. Plankton nets used in this comparison had a mouth diameter of 0.5 m with a mesh size of 225 µm. All plankton tows were run from behind a boat for 20 minutes within two days of each other and on similar tides.

A potential concern is if macroinvertebrate communities change in a large area within the river, then species that feed on these organisms may be positively or negatively affected. Such changes could therefore have profound effects up the food chain and affect abundances of ecologically, commercially or recreationally important species (for example red drum, spotted sea trout, or flounder).

4.4. Threatened & Endangered Species

The species examined in this section are Federally-listed threatened and endangered species that occur in Duval, Clay, St. Johns, Putnam, Flagler and Volusia Counties in the LSJRB (**USFWS 2010**). These animals are protected under the Endangered Species Act of 1973 (**Congress 1973**). The West Indian Manatee, Bald Eagle and Wood Stork are considered primary indicators of ecosystem health because of their direct use of the St. Johns River ecosystem. The data available for these species were relatively more robust than data on the also listed Shortnose Sturgeon, Piping Plover, Florida Scrub-jay, and Eastern Indigo Snake. In addition, other endangered species of interest to the area include the North Atlantic Right Whale and Loggerhead Sea Turtle. However, because these animals are associated with the coastal and offshore boundaries of the LSJRB, they are not discussed in this report. All these examples convey in part the diverse nature of endangered wildlife affected by people's activities in the LSJRB. These species, and many more, add to the overall diversity and quality of life we enjoy and strive to protect and conserve for the future. It is important to be aware that human actions within the LSJRB affect the health of the entire ecosystem, and that the St. Johns River is a critical component of this system. Research, education and public awareness are key steps to understanding the implications of our actions towards the environment. The list of species examined here does not include all species protected under Florida State (131 species within the state) and Federal Laws (15 species within LSJRB) (see Appendix 4.4.1). It is likely that in the future this list will need to be periodically updated as changes occur over time or indicator species and data are identified. For additional supporting information the reader is asked to refer to the appendices section of the report.

4.4.1. The Florida Manatee (Endangered)

Source: G Pinto

4.4.1.1. Description

In 1967, under a law that preceded the Endangered Species Act of 1973 the manatee was listed as an endangered species (**Udall 1967**). Manatees are also protected at the Federal level under the Marine Mammal Protection Act of 1972 (**Congress 1972**), and by the State under the Florida Manatee Sanctuary Act of 1978 (**FWC 1978**).

The Florida manatee (*Trichechus manatus latirostris*) is a large aquatic mammal that inhabits the waters of the St. Johns River year round and may reach a length of 12 feet and a weight of 3,000 lbs. (**Udall 1967**; **USFWS 2001**). They are generally gray to dark-brown in color; have a seal-like body tapering to a flat, paddle-shaped tail. Two small forelimbs on the upper body have three to four nails on each end. The head is wrinkled and the face has large prehensile lips with stiff whiskers surrounding the nasal cavity flaps. They are not often observed during winter (December-February) being generally most abundant in the St. Johns River from late April through August. Because of their herbivorous nature all are found in relatively shallow waters where sunlight can penetrate and stimulate plant growth. Manatees do not form permanent pair bonds. During breeding, a single female, or cow, will be followed by a group of a dozen or more males, or bulls, forming a mating group. Manatees appear to breed at random during this time. Although breeding and birth may occur at any time during the year, there appears to be a slight spring calving peak. Manatees usually bear one calf, although twins have been recorded. Intervals between births range from three to five years (**JU 2012**). In 1989, Florida's Governor and Cabinet identified 13 "Key" counties experiencing excessive watercraft-related mortality of manatees and mandated that these counties develop County Manatee Protection Plans (MPPs). The following counties have state-approved manatee protection plans: Brevard, Broward, Citrus, Collier, Dade, Duval, Indian River, Lee, Martin, Palm Beach, Sarasota, St. Lucie, and Volusia (**FWC 2010a**). In 2006, although not one of the original 13 "Key" counties, Clay County also voluntarily developed a State-approved MPP. St. Johns County also voluntarily developed a manatee plan, but it is has not been approved by State or Federal agencies. Putnam County does not have a MPP, whereas Flagler County is in the process of developing one. The Duval MPP was last revised in 2006, and will again be revised in 2010.

Jacksonville University has conducted some 690 aerial surveys with over 15,544 manatee sightings (1994–2011). These year–round surveys covered the shorelines of the St. Johns River, its tributaries (Jacksonville to Black Creek), and the Atlantic Intracoastal Waterway (Nassau Sound to Palm Valley). During the winter, industrial warm water sources were also monitored for manatee presence (aerial and ground surveys). It was observed that when water temperatures decrease (December through March); the majority of manatees in the LSJRB migrate to warmer South Florida waters (**White and Pinto 2010**).

Within the St. Johns River, survey data indicate that manatees feed, rest and mate in greater numbers south of the Fuller Warren Bridge where their food supply is greatest relative to other areas in Duval County. Sightings in remaining waters have consisted mostly of manatees traveling or resting. Manatees appear to use the Intracoastal Waterway as a travel corridor during their seasonal (north/south) migrations along the east coast of Florida. Data indicate that manatees stay close to the shore, utilizing small tributaries for feeding when in these waters (**White, et al. 2002**). Aerial surveys of

manatees, by various organizations and individuals, in northeast Florida have occurred prior to 1994 and are listed in **Ackerman 1995**.

There are two sub-populations of manatees that use the LSJRB. The first sub-population consists of 400 manatees from the Blue Springs area (**Hartley 2012**), of which numbers visiting the LSJRB are not known (**Ross 2012**). Most of the animals in the LSJRB (about 260 manatees) (**White and Pinto 2006b**; **White and Pinto 2006a**) are members of the greater Atlantic region sub-population, with 2,432 animals in 2011 along the entire east coast of Florida (**FWRI 2012b**). No synoptic survey occurred in 2012 because weather conditions were not preferable. The warm winter meant that manatees did not aggregate well at warm water sources for counting. In 2011, 21 observers from 10 organizations counted 2,432 manatees on Florida's east coast and 2,402 on the west coast for a sum of total of 4,834 (**FWRI 2011b**). No animals were observed in the northeast synoptic survey area in 2011. The weather conditions in 2010 were the coldest for the longest duration in Florida metrological history. Consequently, manatees were more concentrated at warm water sources throughout the state resulting in the highest count ever recorded with 2,780 animals on the east coast, and 2,296 animals on the west coast for a sum total of 5,076. From all these, two animals were observed in the northeast synoptic survey area in 2010. The previous high count in 2009 was 2,148 animals on the east coast, and 1,654 animals on the west coast for a total of 3,802 (**FWRI 2012c**). It should be noted that because of differences in the ability to conduct accurate aerial surveys the synoptic results cannot be used to assess population trends. For more information see Appendix 4.4.1.A_Synoptic Counts. This information is based on the results of long-term radio tracking and photo-identification studies (**Beck and Reid 1998**; **Reid, et al. 1995**). **Deutsch, et al. 2003** reported that the Lower St. Johns River south of Jacksonville was an important area visited by 18 tagged manatees that were part of a 12-year study of 78 radio-tagged and tracked manatees from 1986 to 1998. Satellite telemetry data support the fact that most animals come into the LSJRB as a result of south Florida east coast animals migrating north/south each year (**Deutsch, et al. 2000**). Scar pattern identification suggests that significant numbers of manatees are part of the Atlantic sub-population. Only three manatee carcasses (1988, 1989, and 1991) have been recovered in the Jacksonville area, and another three between the Buckman Bridge and Palatka (1989, 1997, and 2003) that have been identified as animals that came from the Blue Springs sub-population (**Beck 2012**).

*"Synoptic" can be defined as a general Statewide view of the number of manatees in Florida. The Florida Fish and Wildlife Conservation Commission (FWC) uses these surveys to obtain a general count of manatees statewide. The FWC coordinates an interagency team that conducts the synoptic surveys from one to three times each year (weather permitting). The synoptic surveys are conducted in winter and cover all of the known wintering habitats of manatees in Florida. The survey is conducted to meet Florida state statute 370.12 (4), which requires an annual, impartial, scientific benchmark census of the manatee population. From 1991 through 2011, the counts have been conducted 27 times (**FWRI 2012c**).*

4.4.1.2. Significance

The St. Johns River provides habitat for the manatee along with supporting tremendous recreational and industrial vessel usage that threatens them. From 2000 to 2011, pleasure boats have increased the most and represent about 97% of all vessels. In general all counties in LSJRB, except Duval County, had an increasing trend in vessel numbers. Duval County was the only County that had a decreasing trend. For information about each county see Appendix 4.4.1.A Vessel Statistics. Watercraft deaths of manatees continue to be the most significant threat to survival. Boat traffic in the river is diverse and includes port facilities for large industrial and commercial shippers, commercial fishing, sport fishing and recreational activity. Florida Department of Highway Safety and Motor Vehicles (**FDHSMV 2012**) records show that there were 34,483 registered boaters in Duval County in 2002. This number increased to 34,494 by 2007, and decreased to 29,412 by 2011. Port statistics indicated that about 4,060 vessels use the Port each year (**JAXPORT 2012**). This represents on average a 13% increase since 2007. In addition to this, in 2004, there were 100 cruise ship passages to and from the Port, and by 2007, this number rose to 156. In 2008 there was a decrease to 92 cruise ship passages, and then from 2009-2011 the number of passages has remained stable from 148 to 154. Large commercial vessel calls and departures are projected to increase significantly when TraPac, owned by the Japanese steamship company Mitsui O.S.K. Lines (MOL), expects to double JAXPORT's yearly container ship traffic (**JAXPORT 2007**). Also, in order to accommodate larger ships, the JAXPORT dredged turning basins in 2008 and plans to deepen the channel in 2012/2013. Dredging can cause a change in vessel traffic patterns and increase noise in the aquatic environment that can potentially harm manatees because they cannot hear oncoming vessels (**Gerstein, et al. 2006**). Dredging a deeper channel can also affect the salinity conditions in

the estuary by causing the salt water wedge to move further upstream (**Sucsy 2008**), which may negatively impact biological communities like tape grass beds on which manatees rely for food (**Twilley and Barko 1990**).

4.4.1.3. Data Sources & Limitations

Aerial survey data collected by Jacksonville University (Duval County 1994-2011, and Clay County 2002-2003) were used in addition to historic surveys by Florida Fish and Wildlife Conservation Commission (FWC) (Putnam 1994-1995). Ground survey data came from Blue Springs State Park (1970-2011). The Florida Wildlife Research Institute (FWRI) provided manatee mortality data. Other data sources include the USGS Sirenia Project's radio and satellite tracking program, manatee photo id catalogue, tracking work by Wildlife Trust and various books, periodicals, reports and web sites.

Aerial survey counts of manatees are considered to be conservative measures of abundance. They are conducted by slow-speed flying in a Cessna high-wing aircraft at altitudes of 700-1000 ft. (**JU 2012**) and visually counting observable manatees. The survey path was the same for each survey and followed the shorelines of the St. Johns River and tributaries, about every two weeks. Throughout the year, survey time varied according to how many manatees were observed. This is because more circling is often required to adequately count them. The quality of a survey is hampered by a number of factors including weather conditions, dark nature of the water, the sun's glare off the water surface, the water's surface condition, and observer bias. The units of aerial surveys presented here are the average number of manatees observed and the Single Highest Day Count of manatees per survey each year. The number of surveys each year averaged 19 ± 3.3 SD (range 15-26/yr.).

The actual location that a watercraft-related mortality occurred can be difficult to determine because animals are transported by currents or injured animals continue to drift or swim for some time before being reported. In addition, the size of the vessel involved in a watercraft fatality is often difficult to determine with frequency and consistency.

Because the frequency and duration of elevated salinity events in the river can adversely affect the health of Submerged Aquatic Vegetation (SAV) on which manatee rely for food, rainfall and salinity were examined in conjunction with the number of manatees. Salinity data were provided by Dana Morton (Environmental Quality Division, City of Jacksonville). Water quality parameters are measured monthly at ten stations in the main stem of the St. Johns River at the bottom (5 m), middle (3 m), and surface (0.5 m) depths. Data on rainfall came from the SJRWMD and NOAA (Appendix: 4.1.7.1.E. Rainfall, Hurricanes, and El Nino), and salinity data for specific SAV monitoring sites came from SJRWMD (Appendix: 4.1.7.1.F. Salinity).

4.4.1.4. Current Status

Aerial surveys: The average numbers of manatees observed on aerial surveys in Duval County and adjacent waters decreased prior to the drought (2000-2001) and then increased again after the drought (2000-2005). In 2005, drought conditions developed again and numbers began to decline (Figure 4.13). Since 2009, manatee numbers have begun to increase again. The longer-term trend (1994-2011) appears to be relatively stable, when excluding the variation caused by the droughts.

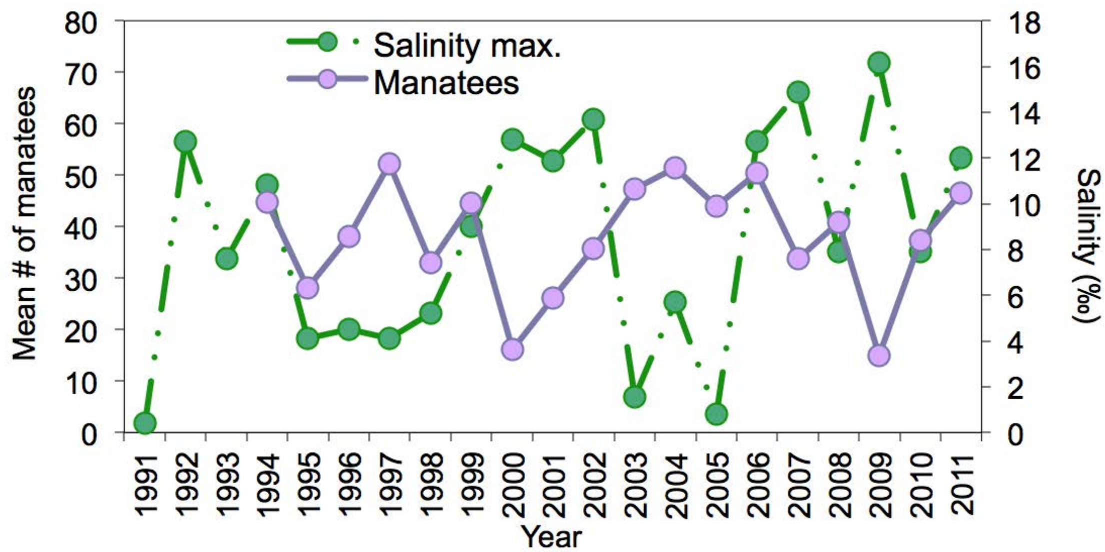


Figure 4.13. Mean numbers of manatees per survey in Duval Co., FL and adjacent waters 1994-2011. Data source: Jacksonville University and City of Jacksonville (Appendix 4.4.1.A).

Single highest day counts of manatees appear to have increased to a level slightly higher than prior to the drought but the increase is not statistically significant (2000-2005). The large dip in numbers in 1999-2000 can be attributed to the effects of the drought that caused manatees to move further south out of the Duval County survey area in search of food (Figure 4.14). A second dip in numbers (2005-2009) occurred as a result of another series of droughts. In 2010, manatee numbers began to increase again; however, the rate of increase was considerably less in 2011.

"Single Highest Day Count" of manatees is defined as the record highest total number of manatees observed on a single aerial survey day during the year. This provides a conservative indication of the maximum number of manatees in the study area.

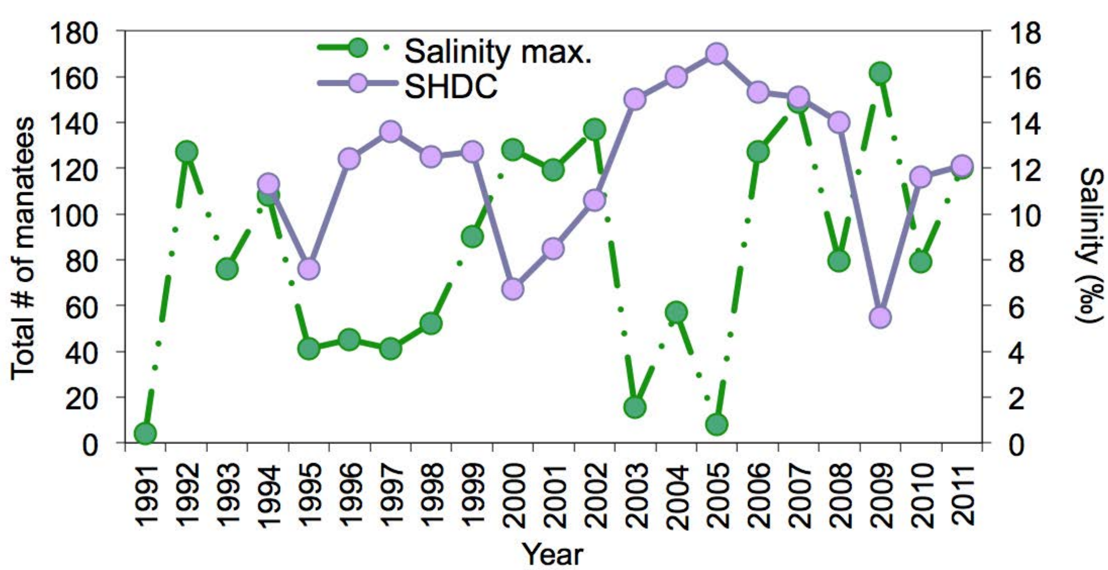


Figure 4.14. Single Highest Day Count per year of manatees in Duval Co., FL 1994-2011. Data source: Jacksonville University and City of Jacksonville (Appendix 4.4.1.A).

Ground surveys: Blue Springs is located about 40 miles south of the LSJRB within the St. Johns River system and, since this sub-population has increased over the years, we could potentially see more animals using the LSJRB in the future. The population of Blue Springs only numbered about 35 animals in 1982-83 (**Kinnaird 1983a**) and 88 animals in 1993-94 (**Ackerman 1995**). From 1990-1999, this population had an annual growth rate of about 6% (**Runge, et al. 2004**). It is the fastest growing sub-population and accounts for about 5% of the total Florida manatee count (**FWC 2007**). Ground

surveys indicate that the total number of manatees seen has increased annually from 6% (1994-2003) to 19% (2004-2011), (Figure 4.15).

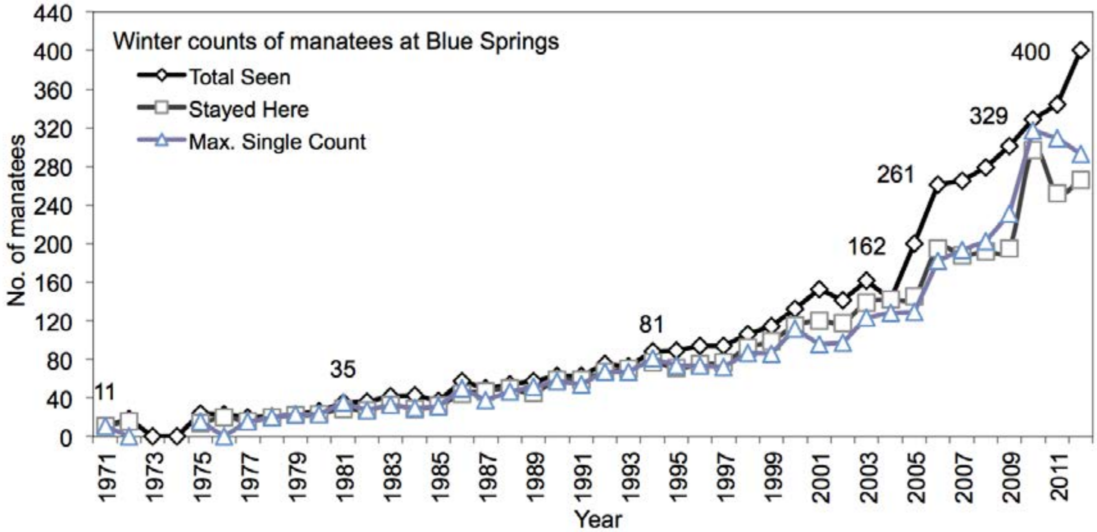


*Figure 4.15. Winter counts of Florida manatees identified at the winter aggregation site in Blue Springs State Park, Volusia Co., FL 1970-2012. Maximum Single Day Counts and animals that stayed at the site are also indicated. Data source: **Hartley 2012**.*

Mortality: There were a total of 511 manatee deaths in the LSJRB between 1981-2011, of which 164 were caused by watercraft, 9 other human, 68 perinatal, 83 cold stress, 35 other natural and 152 undetermined. The total number of manatee mortalities (all causes) increases towards the mouth of the St. Johns River with Duval County being associated with 66%, followed by Clay (13%), Putnam (12%), St. Johns (8%), and Flagler (less than 1%)(**FWRI 2012c**).

Manatee mortality categories defined by FWRI

Watercraft (Propeller, Impact, Both)	*Cold Stress*
Flood Gate/Canal Lock	*Natural, Other (Includes Red Tide)*
Human, Other	*Verified; Not Recovered*
Perinatal (Natural or Undetermined)	*Undetermined; Too decomposed*

There were no deaths in Flagler during 2011. Watercraft-related mortalities in 2011, as a percentage of the total mortality by-county, was highest in Duval (60%) followed by Putnam (24%), St. Johns (12%), and Clay (4%). Over the past few years, an unusually high number of watercraft related manatee deaths in Duval County resulted from encounters with large, probably commercial, vessels. Since most deaths in the basin occurred in Duval County, watercraft deaths in Duval County were compared in six-year increments beginning 1981 thru 2010. From 1981 to 2004, watercraft deaths of manatees averaged 33% (range 29-36%). From 2004 to 2010, watercraft mortality increased to 49% (Appendix 4.4.1.A). In 2010, watercraft-caused mortality decreased to 32% of total manatee mortalities in LSJRB. However, this is higher than the rate for the state of Florida, which was 23% of total mortalities in 2010. These time periods were picked because they represent uniform time periods either side of 1994 when the Interim Duval County Manatee Protection Plan regulations were implemented. In 2009, watercraft mortality for the LSJRB was 34% of total mortality, and the State watercraft mortality rate was 23%. In 2008, watercraft-caused mortality for the LSJRB was 33% of total mortality, and the State watercraft mortality rate was 27%. In 2007, watercraft-caused mortality for the LSJRB was 32% of total mortality, and the State watercraft mortality rate was 23% (**FWC 2010c**). Mortalities from watercraft in LSJRB show an upward trend since the mid-1990s, with most reported in Duval County.

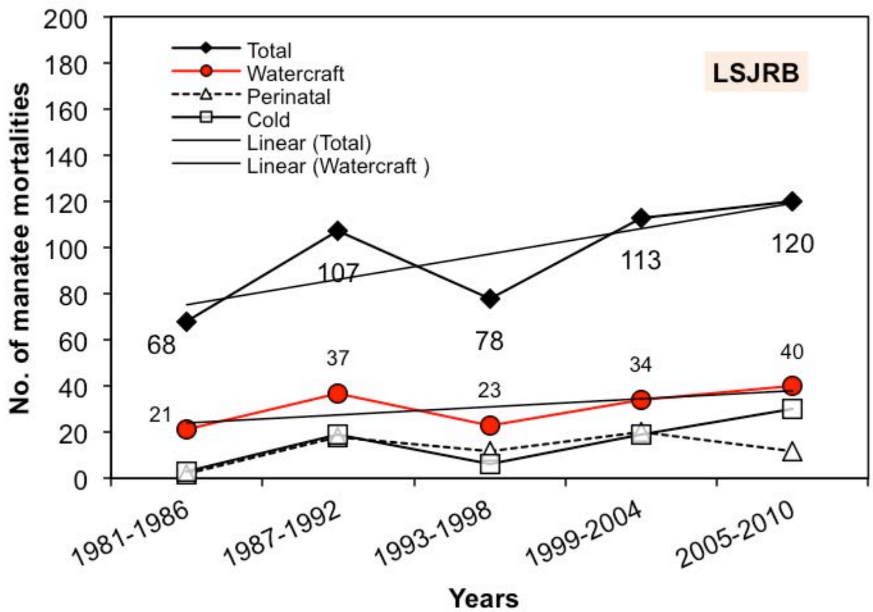


Figure 4.16. Summary of total, watercraft, perinatal, and cold stress manatee mortalities by county in LSJRB (six-year intervals from 1981-2010).

Cold stress: When manatees experience prolonged exposure to water temperatures below 68°F (20°C), they can develop a condition called cold-stress syndrome, which can be fatal. Effects of cold stress may be acute, when manatees succumb rapidly to hypothermia, or longer-lasting as chronic debilitation. Chronic cold-stress syndrome is a complex disease process that involves metabolic, nutritional, and immunologic factors. Symptoms may include emaciation, skin lesions or abscesses, fat depletion, dehydration, constipation and other gastrointestinal disorders, internal abscesses, and secondary infections.

Cold stress mortalities were particularly elevated throughout Florida during the period January to March 2010. This time frame included the coldest 12-day period ever recorded in the state of Florida with temperatures below 45°F (7.2°C) recorded in Naples and West Palm Beach. Central Florida experienced even colder temperatures. From January-April, 58 manatees were rescued and 503 manatee carcasses were verified in Florida (429 in all of 2009). Mortality was highest in the central-east and southwest regions. In LSJRB there was a total of 12 cold stress deaths between January 14th and February 15th 2010 – Clay (2), Duval (1), Flagler (0), Putnam (7), and St. Johns (2), compared to a total of 6 cold stress deaths in 2011 – Clay (0), Duval (3), Flagler (0), Putnam (2), and St Johns (1). (**FWRI 2012a**).

The State Manatee Management Plan (**FWC 2007**) requires the FWC to evaluate the effectiveness of speed zone regulations. The Plan was developed as a requirement in the process, which seeks to down list manatees from endangered to threatened status. Currently, manatees are considered endangered at both the State and Federal level.

4.4.1.5. Future Outlook

Manatees in the LSJRB are likely to continue to increase as more manatees move north because of decreases in manatee habitat and its quality in south Florida. Recovery from the most recent drought cycle (2009-2011) should allow food resources to rebound and increase the carrying capacity of the environment to support more manatees. Current information regarding the status of the Florida manatee suggests that the population is growing in most areas of the southeastern U.S. (**USFWS 2007c**). In early 2012 the area experienced drought conditions again, the effects of which have yet to play out. However, the trend in watercraft-caused deaths continues to increase over time (**FWRI 2012b**). Significant increases in vessel traffic in the LSJRB are projected to occur over the next decade as human population increases and commercial traffic doubles. More boats and more manatees could lead to more manatee deaths from watercraft because of an increased opportunity for encounters between the two. Dredging in order to accommodate larger ships significantly affects boat traffic patterns and noise in the aquatic environment (**Gerstein, et al. 2006**) and has ecological effects on the environment that ultimately impact manatees and their habitat. Freshwater withdrawals, in addition to harbor deepening, will alter salinity regimes in the LSJRB; however, it is not known yet by how much. If a sufficient change in salinity regimes occurs, it is likely to cause a die-off of the grass bed food resources for the manatee. This result would decrease carrying capacity of the environment's ability to support manatees. Some Blue Springs animals use LSJRB too, although

the interchange rate is not established yet. Animals that transition through the basin are likely to be affected by the above issues. Sea level rise is another factor likely to affect the St. Johns and about which more information regarding potential impacts is needed. In addition to this, any repositioning of point sources can alter pollution loading to the St. Johns River and should be monitored for any potential impacts to manatees (i.e. thermal/freshwater sources), and also the grass beds on which they depend for food. Moreover, the cumulative effects of freshwater withdrawals on these and other flora and fauna should be monitored to assess the impacts of water supply policy (**NRC 2011**).

"Carrying Capacity" may be defined as the maximum weight of organisms and plants an environment can support at a given time and locality. The carrying capacity of an environment is not fixed and can alter when seasons, food supply, or other factors change.

4.4.2. Bald Eagle (delisted 2007)

Photo: Dave Menke, USFWS.

4.4.2.1. Description

The bald eagle *(Haliaeetus leucocephalus)* is a large raptor with a wingspan of about seven feet and represents a major recovery success story. Bald eagles were listed as Endangered in most of the U.S. from 1967-1995 as a result of DDT pesticide contamination, which was determined to be responsible for causing their eggshells to be fragile and break prematurely. The use of DDT throughout the U.S. was subsequently banned, though it is still present in the environment (See Section 5.6 Pesticides). In 1995, bald eagle status was upgraded to Threatened and numbers of nesting pairs increased from just under 500 (1960's) to over 10,000 (2007).

As a result of this tremendous recovery, bald eagles were delisted June 28, 2007 (**AEF 2012**; **USFWS 2007a**; **USFWS 2008a**; **USFWS 2008d**). The eagles are found near large bodies of open water such as the St. Johns River, tributaries, and lakes, which provide food resources like fish. Nesting and roosting occurs at the tops of the highest trees (**Jacksonville Zoo 2012a**; **Scott 2003d**). Bald eagles are found in all of the United States, except Hawaii. Eagles from the northern United States and Canada migrate south to over winter while some southern bald eagles migrate slightly north for a few months to avoid excessive summer heat (**AEF 2012**). Wild eagles feed on fish predominantly, but also eat birds, snakes, carrion, ducks, coots, muskrats, turtles, and rabbits. Bald eagles have a life span of up to 30 years in the wild and can reach 50 years in captivity (**AEF 2012**; **Jacksonville Zoo 2012a**; **Scott 2003d**). Young birds are brown with white spots. After five years of age the adults have a brown-black body, white head, and tail feathers. Bald eagles can weigh from 10-14 lbs. and females tend to be larger than males. They reach sexual maturity at five years, and then find a mate that they will stay with as long as they live (**AEF 2012**).

4.4.2.2. Significance

From 2006-2010, there was an average of 59 active nests out of a total of 107 bald eagle nests surveyed. The nests were located mainly along the edges of the St. Johns River, from which the birds derive most of their food (Appendix 4.4.2.A.). Most of the nests seem to be in use about 57% of the time. Active nests represented 53% (range 47-62%) of the total nests surveyed from 2006-2008. In 2010, the number of active nests increased to 70%. Data for 2009 indicated much fewer nests, because of a change in survey protocol starting November 2008 (**Gipson 2011**).

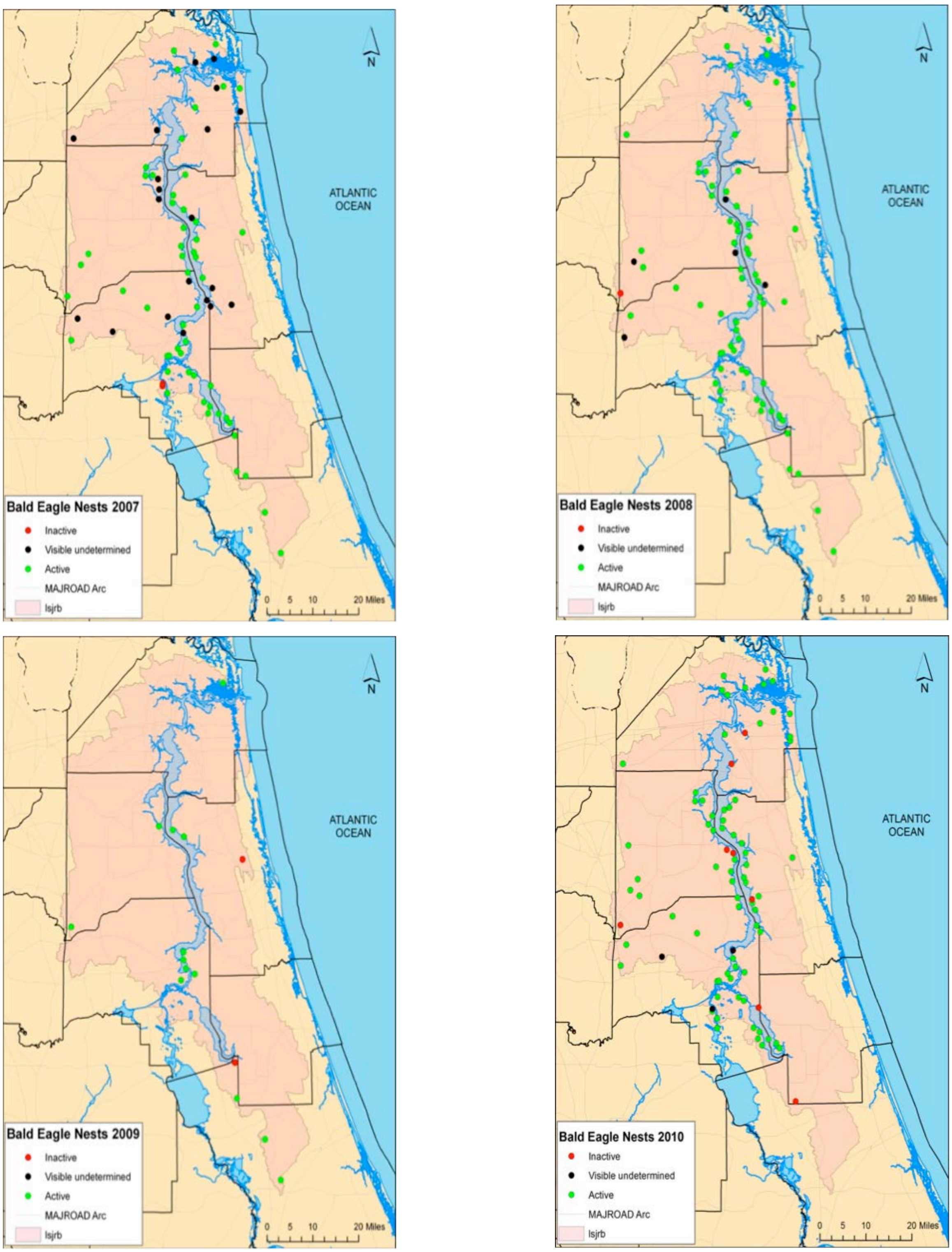


*Figure 4.17 Bald eagle nesting sites in LSJRB 2007-2010. (Source data: **Gipson 2011**).*

4.4.2.3. Data Sources & Limitations

Data came from a variety of sources: Audubon Society winter bird counts, Florida Fish and Wildlife Conservation Commission, Jacksonville Zoo and Gardens, United States Fish and Wildlife Service and various books and web sites. No new data for the LSJRB area was available from FWCC for 2011. Various groups conduct periodic surveys and the state has a 5-Year management plan (**FWC 2008a**) to monitor the eagle's continued welfare (**FWC 2008a**; **USFWS 2008a**). Known bald eagle nesting territories within the state of Florida were surveyed by FWC during the 2009 nesting season with fixed-wing or rotary-wing aircraft beginning in late November 2008 and extending through mid-April 2009. Nest locations were determined with the use of aircraft-based GPS units. Accuracy of locations is estimated to be within 0.1 miles of the true location. In 2008, the statewide bald eagle nesting territory survey protocol changed. The protocol change reduces annual statewide survey effort and increases the amount of information gained from the nests that are visited during the survey season. Nest productivity is now determined for a sub-sample of the nests that are surveyed annually. Nest activity and productivity information are critical to determining if the goals and objectives of the Bald Eagle Management Plan are being met (**FWC 2008a**).

4.4.2.4. Current Status

In Alaska, there are over 35,000 bald eagles. However, in the lower 48 states of the U.S., there are now over 5,000 nesting pairs and 20,000 total birds. About 300-400 mated pairs nest every year in Florida and constitute approximately 86% of the entire southern population (**Jacksonville Zoo 2012a**). Statewide eagle nesting surveys have been conducted since 1973 to monitor Florida's bald eagle population and identify their population trends. Now that this species is no longer listed as Threatened, the primary law protecting it has shifted from the Endangered Species Act to the Bald and Golden Eagle Act (**AEF 2012**; **USFWS 2008b**; **USFWS 2008c**). According to Jacksonville winter bird counts by the Duval Audubon Society, numbers sighted have increased overall since the pesticide DDT was banned in the 1960s (Figure 4.18).

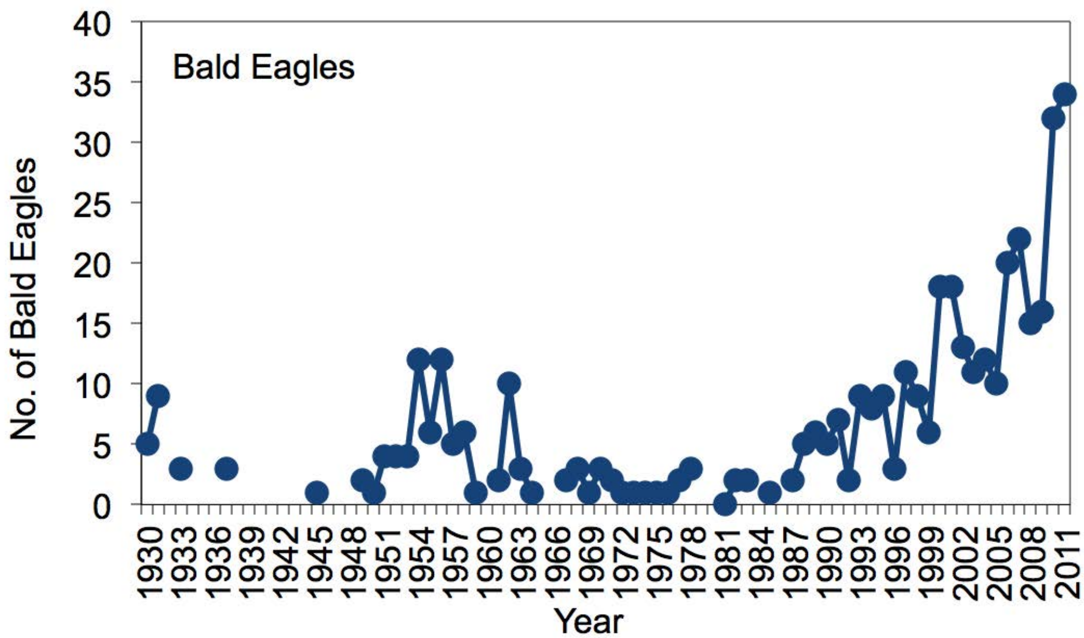


Figure. 4.18. Long term trend in the number of bald eagles counted during winter bird surveys (1929-2011) in Jacksonville, FL Source data. ***Audubon 2010a*** *(Appendix 4.4.2.A).*

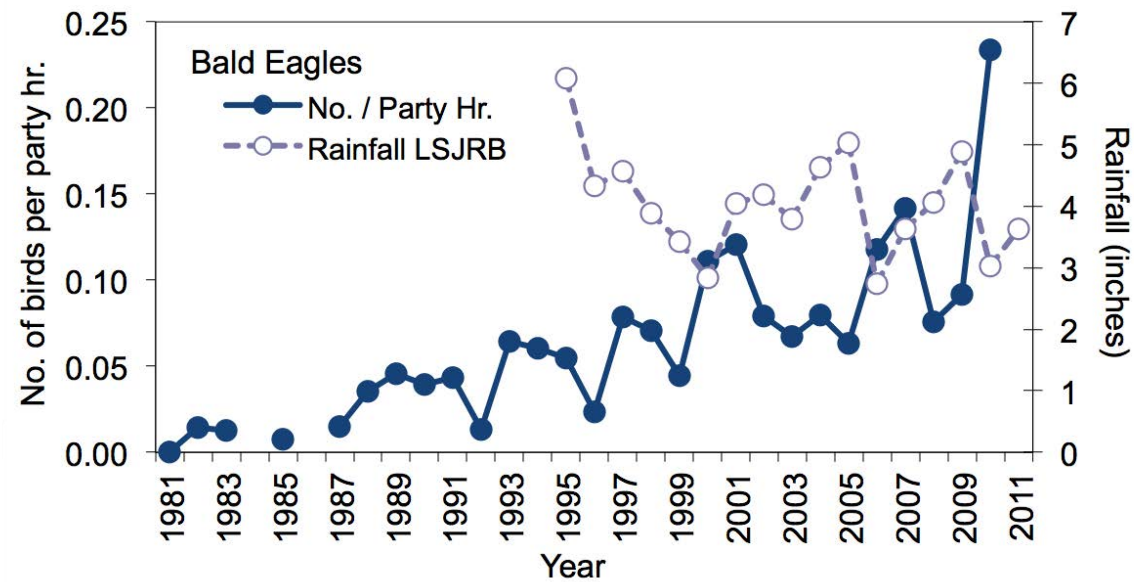


Figure 4.19. Long term trend in the number of bald eagles counted per party hour and rainfall (1995-2010) in Jacksonville, FL
Source data: ***Audubon 2010a*** *and* ***SJRWMD 2012d****. (Appendix 4.4.2.A).*

In a recent Kendall tau correlation analysis of rainfall for the LSJRB, count data for Audubon count circle (FLJA) was negatively correlated to rainfall with respect to numbers of eagles (τ = -0.364; p=0.021; n=17), but was not found to be significant with respect to numbers of eagles and party hours of effort (τ = -0.267; p=0.075; n=16). Note that no data on party hours was available in 2011 (Figure 4.19/4.20).

Eagle counts are expressed as numbers of birds per party hour, which accounts for variations due to the effort in sampling the birds. Each group of observers in the count circle for a day is considered one "party" and counts are conveyed together with the number of hours the observers recorded data (note this is not the number of hours of observation multiplied by the number of observers). Number of birds per party hour is defined as the average of the individual number per party hour values for each count circle in the region. In the case of no observations of a given species by a circle within the query region, a value of zero per party hour is averaged in.

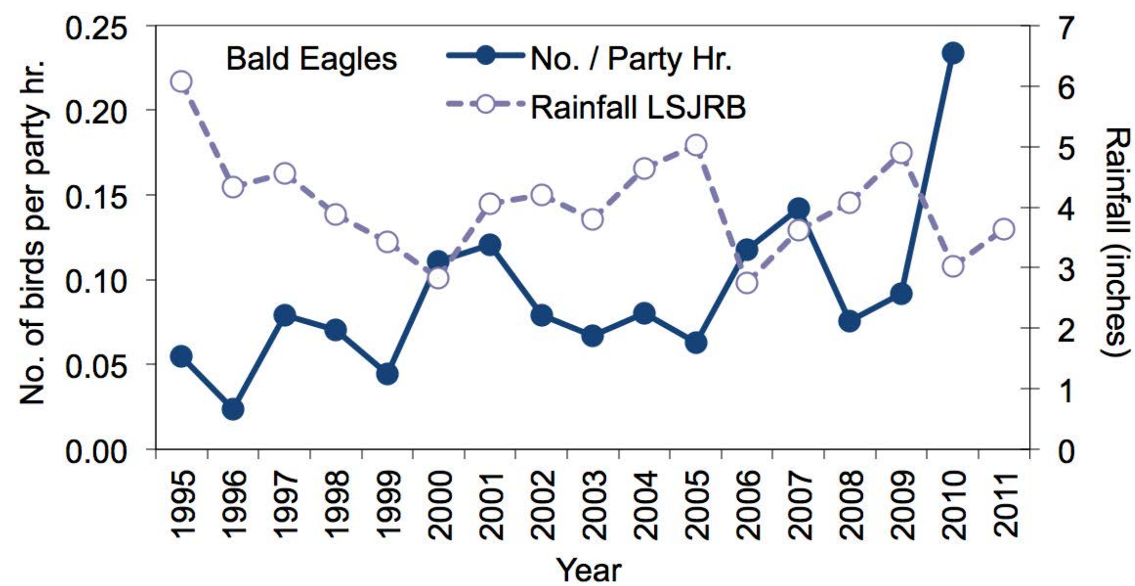


Figure 4.20. Recent trends in the number of bald eagles counted per party hour and rainfall (1995-2011) in Jacksonville, FL
Source data: ***Audubon 2010a*** *and* ***SJRWMD 2012d*****. (Appendix 4.4.2.A).*

There was a decreasing trend in rainfall 1995-2000, which represents a prolonged period of severe drought (coincides with 1997 El Niño year). Bald eagle numbers surged as the drought deepened probably because of a concentration of their prey as water levels fell. Then, rainfall increased again from 2000-2005 with averages approaching and finally exceeding the norm by 2005. During this period, the number of eagles declined somewhat, presumably because prey resources were more spread out. Also, there was an increase in severe storms (including hurricanes, which usually have a higher potential to affect the U.S during La Niña years) during this time period. Following 2005, another drought ensued (2005-2006), and rainfall declined at a faster rate than previously. Again, eagle numbers surged. From 2006-2009 rainfall increased toward pre drought levels again and eagle numbers declined. Following 2009 another drought cycle began and the eagle numbers increased abruptly, this time at a greater rate than ever before (See Appendix: 4.1.7.1.E. rainfall, hurricanes, and El Niño).

4.4.2.5. <u>Future Outlook</u>

Although they have a good future outlook, bald eagles are still faced with threats to their survival. Environmental protection laws, private, State, and Federal conservation efforts are in effect to keep monitoring and managing these birds. Even though bald eagles have been delisted, it is imperative that we do our part to protect and monitor them, because they are key indicators of ecosystem health. The use of DDT pesticide is now outlawed in the U.S. Threats include harassment by people that injure and kill eagles with firearms, traps, power lines, windmills, poisons, contaminants, and habitat destruction with the latter cause the most significant (**AEF 2012**; **FWC 2008a**; **USFWS 2008a**).

4.4.3. Wood Stork (Endangered)

Photo by Wayne Lasch (PBS&J)

4.4.3.1. <u>Description</u>

The wood stork *(Mycteria americana)* was listed as Endangered in 1984 and is America's only native stork. The reason for the ESA listing was declining numbers of nesting pairs from about 20,000 (1930s) to 3,000-5,000 pairs in the 1970s (**Jacksonville Zoo 2012b**). Wood storks have recently been recommended for down-listing to Threatened status (**USFWS 2007d**). It is a large white bird with long legs and contrasting black feathers that occur in groups. Its head and neck are naked and black in color. Adult birds weight 4-7 lbs. and stand 40-47 inches tall, with a wingspan in excess of 61 inches. Males and females appear identical. Their bill is long, dark and curved downwards (yellowish in juveniles). The legs are black with orange feet, which turn a bright pink in breeding adults.

Wood storks nest throughout the southeastern coastal plain from South Carolina to Florida and along the Gulf coast to central and South America. Nesting occurs in marsh areas, wet prairies, ditches, and depressions, which are also used for foraging. They feed on mosquito fish, sailfin mollies, flagfish, and various sunfish. They also eat frogs, aquatic salamanders, snakes, crayfish, insects, and baby alligators. They find food by tactolocation (a process of locating food organisms by touch or vibrations). Nesting occurs from February to May, and the timing and success is determined primarily by water levels. Pairs require up to 450 lbs. of fish during nesting season. Males collect nesting material, which the female then uses to construct the nest. Females lay from 2-5 eggs (incubation approx. 30 days). To keep eggs cool, parents shade eggs with out-stretched wings and dribble water over them. Wood storks can live up to ten years but mortality is high in the first year (**USFWS 2002**; **Scott 2003e**).

4.4.3.2. Significance

Wood stork presence and numbers can be an indication of the health of an ecosystem. The wood stork is also Florida's most endangered species of wading bird that requires temporary wetlands (isolated shallow pools that dry up and concentrate fish for them to feed on). Scarcity of this specific habitat type due to human alteration of the land causes nesting failures, as has been reported in the Everglades (**Scott 2003e**).

4.4.3.3. Data Sources & Limitations

Data came from Audubon Society winter bird counts from 1962-2010, U.S. Fish and Wildlife Service surveys and *Southeast US Wood Stork Nesting Effort Database*, FWC/FWRI collaborative work in the SJRWMD area, and Donna Bear-Hull of the Jacksonville Zoo and Gardens from 2000-2011. The Audubon winter bird count area consists of a circle with a radius of ten miles surrounding Blount Island. The USFWS has conducted aerial surveys, which are conservative estimates of abundance and are limited in their use for developing population estimates. However, they still remain the most cost-effective method of surveying large areas. Ground surveys on individual colonies, like at the zoo, tend to be more accurate but cost more on a regional basis (**USFWS 2002**).

4.4.3.4. Current Status

An increasing trend since the 1960s was indicated by the Audubon Society winter bird count data for Jacksonville (Figure 4.21. and Appendix 4.4.3.A).

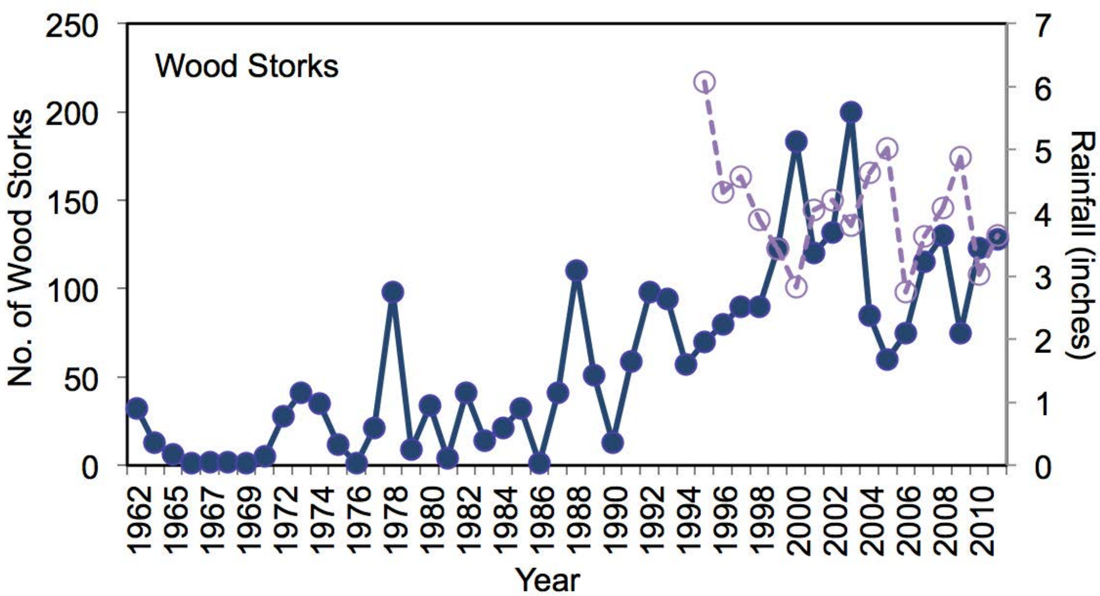


Figure 4.21. Long term trend of the number of Wood Storks counted during winter bird surveys (1961-2011) Jacksonville, Florida Source data: ***Audubon 2010a*** *and* ***SJRWMD 2012d*** *(Appendix 4.4.3.A).*

Rainfall appears to affect wood stork status in several different ways. In the short term (1995-2011), rainfall for the LSJRB was negatively correlated with numbers of wood storks (τ =-0.409; p=0.011; n=17) (Figure 4.21). There was a decreasing trend in rainfall 1995-2000, which represents a prolonged period of severe drought (coincident with 1997 El Niño year). Wood storks surged in numbers as the drought deepened probably because of a concentration of prey as water levels fell. Then from 2000-2002, water levels became too low to support nesting or prey, causing a decline in numbers of wood storks (**Rodgers Jr, et al. 2008a**). Rainfall increased again from 2000-2005 with averages approaching, and finally exceeding, the norm by 2005. During this period the numbers of Wood storks continued to decline because of a natural lag in population and food supply. Then, numbers increased again by 2003. Although rainfall continued to increase, numbers of wood storks fell dramatically from 2003-2005. This was probably due to increased storm activity that damaged wood stork colonies, particularly in 2004 when four hurricanes skirted Florida. Also, higher water levels may have caused depressed productivity to breeding adults by dispersing available prey (**Rodgers Jr, et al. 2008b**). Another drought ensued from 2005-2006 and rainfall declined at a faster rate than previously. As before, stork numbers began to

increase initially. Then, from 2006-2009, rainfall continued to increase, and wood stork numbers declined. In 2010, another cycle of drought began, and wood storks began to increase (See Appendix: 4.1.7.1.E. rainfall, hurricanes, and El Niño).

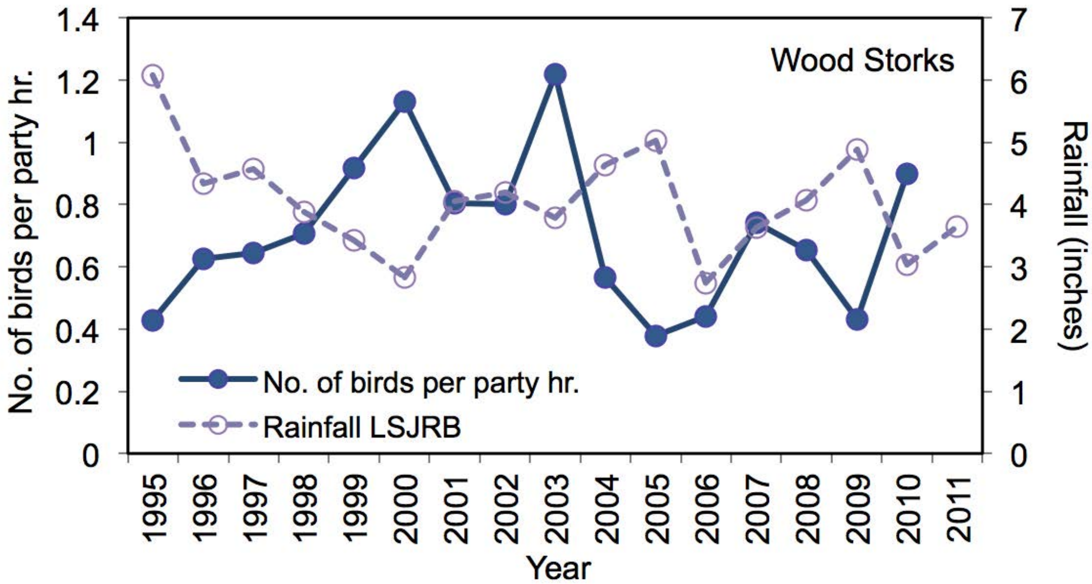


Figure 4.22. Recent trends in the number of wood storks counted per party hour and rainfall (1995-2010) in Jacksonville, FL Source data: ***Audubon 2010a*** *and* ***SJRWMD 2012d****. (Appendix 4.4.2.A).*

Rainfall data for LSJRB (1995-2010) was negatively correlated with Wood storks when party hours of effort were considered (τ = -0.6; p=0.0006; n=16). Note that data on the number of birds per party hour (Audubon count circle FLJA) was unavailable for 2011 (Figure 4.22).

Brooks and Dean 2008 describe increasing wood stork colonies in northeast Florida as somewhat stable in terms of numbers of nesting pairs (Appendix 4.4.3.A). A press release by the USFWS (**Hankla 2007**) stated that the data indicate that the wood stork population as a whole is expanding its range and adapting to habitat changes and for the first time since the 1960s, that there had been more than 10,000 nesting pairs. For a map of the distribution of wood stork colonies and current breeding range in the southeastern U.S. see Figure 4.23.

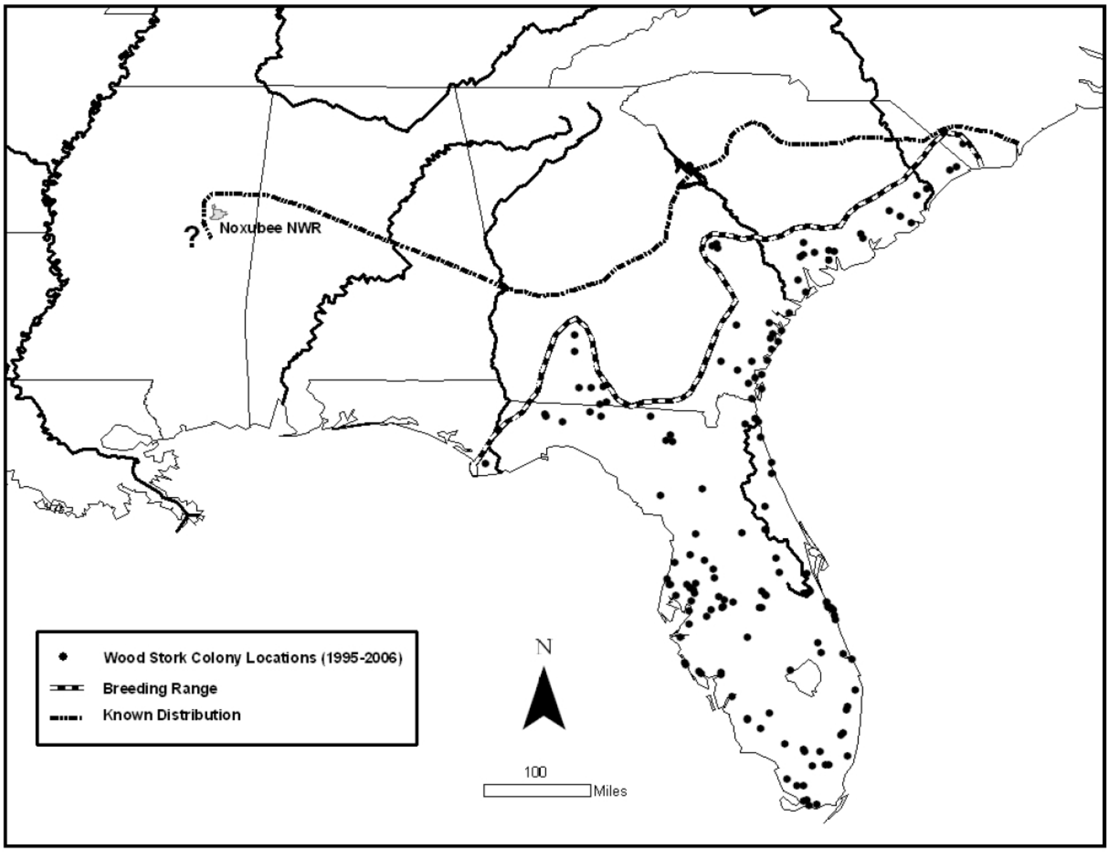


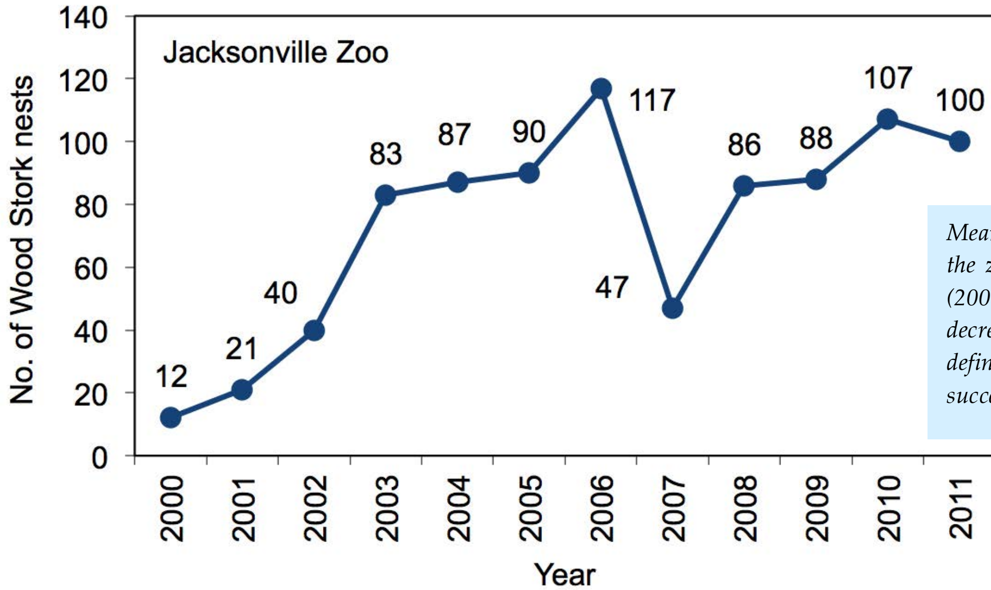
*Figure 4.23. Distribution of wood stork colonies and current breeding range in the southeastern U.S. (**USFWS 2007d**).*

Rodgers Jr, et al. 2008b made a comparison of wood stork productivity across colonies from different regions of Florida. Northern colonies in Florida exhibited greater productivity than those at more southerly latitudes. However, fledgling success was highly variable by year and colony. Local weather conditions and food resources were particularly important in determining nesting and fledgling success. Rainfall during the previous 12-24 months had a significant effect on fledging rates, as did both wetland and non-wetland habitats on fledging rate and colony size (**Rodgers Jr, et al. 2010**).

In the LSJRB, there are several colonies of interest, three of these for which data are available include:

(1) Jacksonville Zoo and Gardens: This colony was formed in 1999 and has continued to show consistent growth. This group continues to have the highest number and productivity of birds in central and north Florida (**Rodgers Jr, et al. 2008a**) (Figure 4.24, 4.25 and Appendix 4.4.3.B). It is considered the most important recently-established rookery in Duval County (**Brooks 2012**). Donna Bear-Hull from the Jacksonville Zoo reported that the 4th year colony doubled in size from 40 breeding pairs (111 fledged chicks) in 2002 to 84 pairs (191 fledged chicks) in 2003. Since 2003, the colony's growth rate has slowed due to space limitations. Local adverse weather conditions (drought) that had an impact on the population and its food supply prevailed in 2005. As food supply was probably concentrated as water levels fell, the colony continued to grow, reaching a high of 117 pairs (267 fledged chicks) in 2006. Then in 2007 a crash occurred and numbers of pairs declined to 47 (58 fledged chicks). In 2008, there was a rebound with the population almost doubling from the previous year to 85 pairs (181 fledged chicks) (**Bear-Hull 2012**; **USFWS 2004**). In 2009, the nesting and fledgling rates were not significantly different from the previous year (**USFWS 2012**). In 2010, the number of wood storks increased to 107 pairs and 276 fledged chicks. In 2011, wood storks decreased to 100 pairs and 213 fledged chicks.

In 2003, the zoo formed a conservation partnership with USFWS to monitor the birds/nests more closely (twice weekly). Since that time, the zoo has banded 11 chicks (of 1,060 fledglings) and nine adults. In addition, four adults have been fitted with satellite monitoring tags. The nine banded adults have returned every year to the zoo site (**Jacksonville Zoo 2012b**).



Mean success rate of nests at the zoo increased from 90% (2009) to 98% (2010), then decreased to 93% (2011) defined as at least one successful hatch.

Figure 4.24. Number of wood stork nests at Jacksonville Zoo (2003-2011)
Source data: ***Bear-Hull 2012****;* ***USFWS 2005****;* ***USFWS 2007d****.*

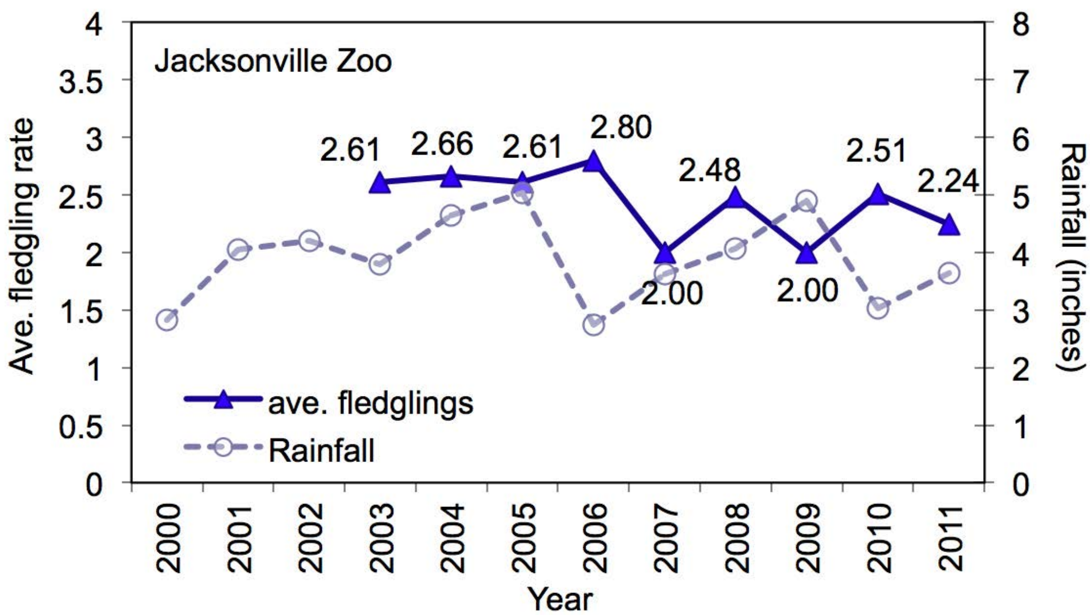


Figure 4.25. Wood stork productivity chicks/nest/yr. at Jacksonville Zoo (2003-2011).
Source data: ***Bear-Hull 2012****;* ***SJRWMD 2012d****;* ***USFWS 2005****;* ***USFWS 2007d****.* ***Rodgers Jr. 2011****).*

(2) Dee Dot Colony: In 2005, the USFWS reported that there were over a hundred nests in this cypress swamp impounded lake in Duval County. However, the fledgling rate was low (1.51 chicks/nest in 2003, and 1.42 chicks/nest in 2004). Fledgling rates greater than two chicks/nest/year are considered acceptable productivity (**USFWS 2005**). Furthermore, the number of nests decreased from 118 in 2003 to 11 in 2007. This decline was probably due to nesting failure in 2003 caused by winds greater than about 20 mph and rain in excess of 1.5 inches/hr.) (**Rodgers Jr, et al. 2008b**; **Rodgers Jr, et al. 2008a**). Fledgling rate improved from an average of 1.75 chicks/nest/year (2003-2005) to 2.11 chicks/nest/year in 2006 (**USFWS 2007d**). The rate then declined to 1.45 (2007), and rose back to 2.07 (2008) (**Rodgers Jr, et al. 2008b**; **Rodgers Jr, et al. 2008a**). Rainfall continued an upward trend; however, data on wood storks were unavailable for 2009-2011.

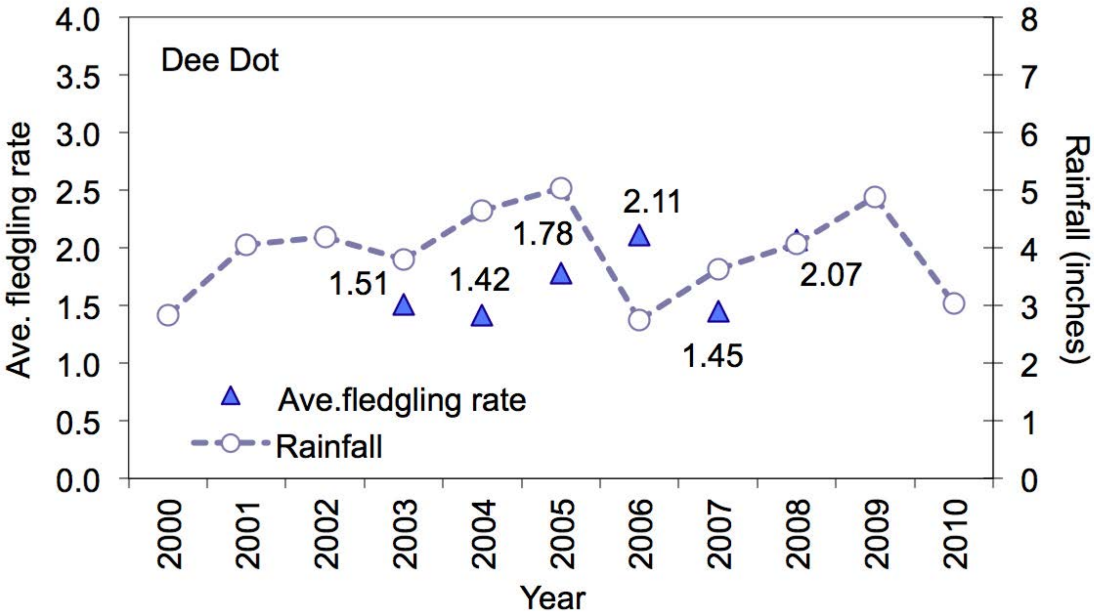


Figure 4.26. Wood stork productivity (chicks/nest/year) at Dee Dot (2003-2011).
*Source data: **SJRWMD 2012d**; **Rodgers Jr, et al. 2008b**; **USFWS 2005**; **USFWS 2007d**.*

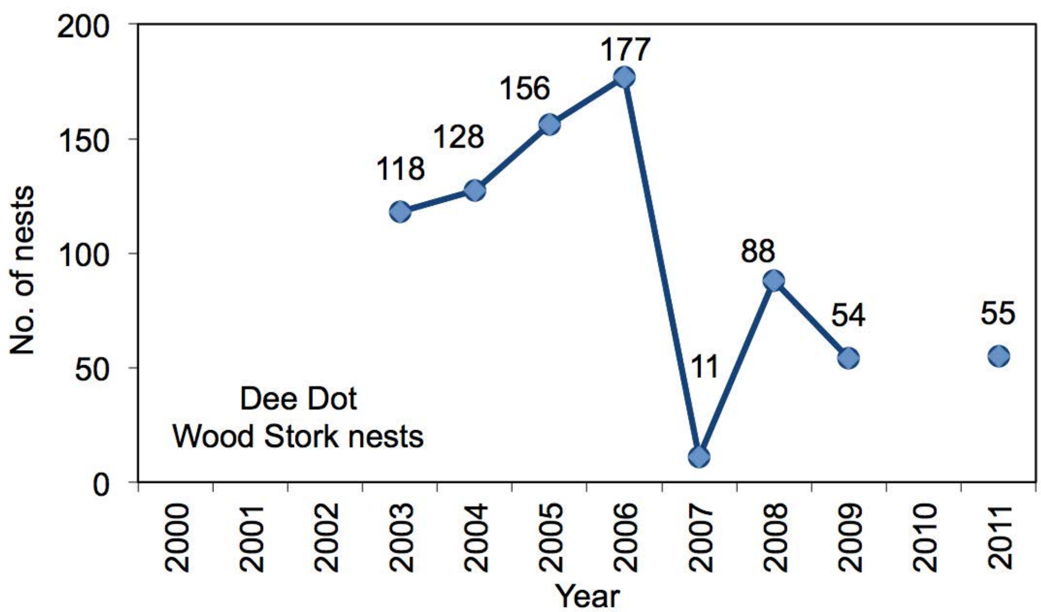


Figure 4.27. Number of wood stork nests at Dee Dot (2003-2011) Note: there were no data for 2010.
*Source data: **USFWS 2012**; **Rodgers Jr, et al. 2008b**; **Rodgers Jr, et al. 2008a**.*

(3) Pumpkin Hill Creek Preserve State Park: This colony in Duval County had 42 nests in 2005 and 2008 (down from 68 in 2003) and fledgling rate averaged 1.44 chicks/nest/year in those years (**USFWS 2005**). Lack of rainfall during the breeding season (March to August) resulted in no water below the trees in 2004 that contributed to nest failures. Flooding following post-August 2004 hurricane season resulted in a return of breeding storks in 2005 (**Rodgers Jr, et al. 2008a**). In 2009, the colony was described as being active, but no data were available (**Brooks 2012; USFWS 2012**). This site was inactive during 2010 and 2011.

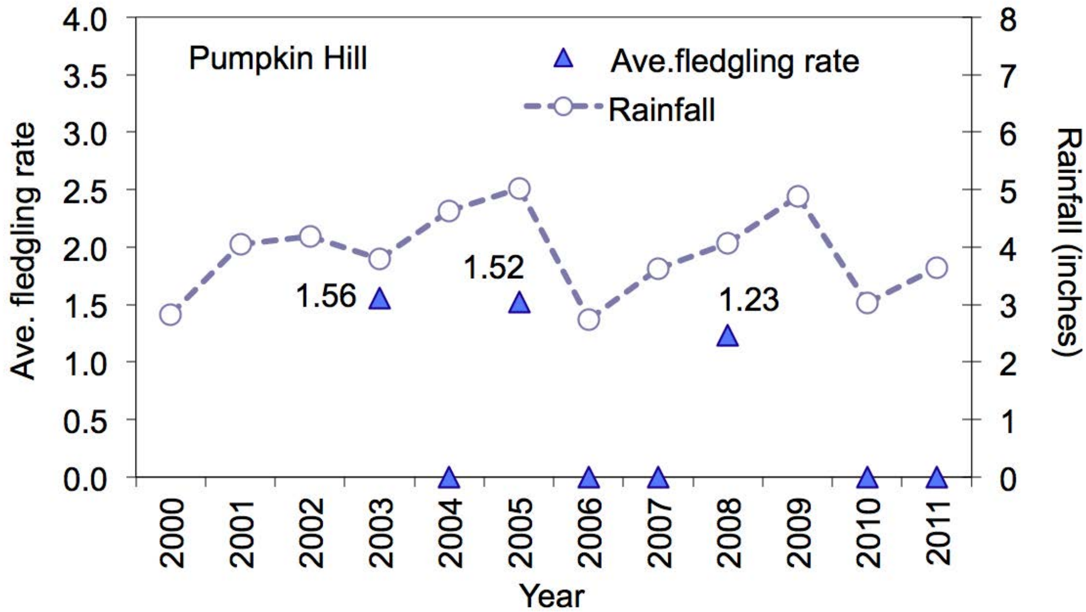


Figure 4.28. Wood stork productivity (chicks/nest/year) at Pumpkin Hill (2003-2011). There are two colonies at this site, which is characterized by cypress-dominated domes. In 2004, 2006, 2007, 2010, and 2011 there was no activity. Source data: ***USFWS 2012****;* ***Rodgers Jr, et al. 2008b****;* ***Rodgers Jr, et al. 2008a****.*

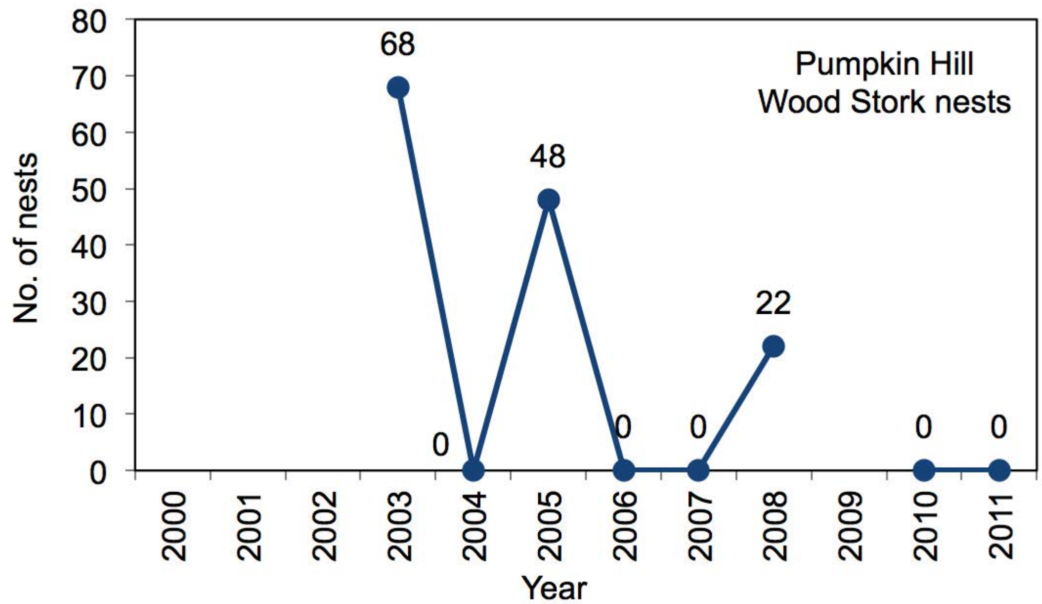


Figure 4.29. Number of wood stork nests at Pumpkin Hill (2003-2011). In 2004, 2006, 2007, 2010, and 2011 there was no activity. In 2009, the colony was active. Source data: ***USFWS 2012****;* ***Rodgers Jr, et al. 2008b****;* ***Rodgers Jr, et al. 2008a****.*

4.4.3.5. Future Outlook

Historically the wood stork breeding populations were located in the Everglades but now their range has almost doubled in extent and moved further north. The birds continue to be protected under The Migratory Bird Treaty Act and state laws. Although they are not as dependent on the Everglades wetlands, wetlands in general continue to need protection. Threats continue to exist such as contamination by pesticides, harmful algae blooms, electrocution from power lines and human disturbance such as road kills. Adverse weather events like severe droughts, thunderstorms or hurricanes also threaten the wood storks. The USFWS Wood Stork Habitat Management Guidelines help to address these issues. Continued monitoring is essential for this expanding and changing population (**USFWS 2007d**).

4.4.4. Piping Plover (Threatened)

Source: **USFWS 2007e**

4.4.4.1. Description

The Piping Plover *(Charadrius melodus)* has been a protected species under the Endangered Species Act since January 10, 1986 and is threatened along the Atlantic Coast. There are three populations of the Piping Plover, The Great Plains, Great Lakes and Atlantic Coast. The piping plover breeds on coastal beaches from Newfoundland and southeastern Quebec to North Carolina. These birds winter primarily on the Atlantic Coast from North Carolina to Florida, although some migrate to the Bahamas and West Indies. Piping plovers were common along the Atlantic Coast during much of the 19th century, but nearly disappeared due to excessive hunting for the millinery trade. Following passage of the Migratory Bird Treaty Act in 1918, numbers recovered to a 20th Century peak, which occurred during the 1940s. The current population decline is attributed to increased development and recreational use of beaches since the end of World War II. The most recent surveys place the Atlantic population at less than 1,800 pairs (**USFWS 1996**). Its name *Charadrius melodus* comes from its call notes, plaintive bell-like whistles that are often heard before the bird is seen.

Piping plovers are small, stocky, sandy-colored shore birds that resemble sandpipers. Adults have yellow-orange legs, a black band across the forehead from eye to eye, and a black ring around the base of the neck. Piping plovers run in short starts and stops, blending into the pale background of open, sandy habitat on outer beaches where they feed and nest. In late March or early April, they return to their breeding grounds, where a pair then forms a depression in the sand somewhere on the high beach close to the dunes (**USFWS 2007e**). Normally, new pairs are formed each breeding season. The males will perform aerial displays to attract the attention of unpaired females during courtship (**Audubon 2010a**). Sometimes their nests are found lined with small stones or fragments of shell (**USFWS 2007e**). Usually nests are found close to, but not in, areas of patchy vegetation and often close to a log rock or other prominent object (**Audubon 2010a**). The adults, both male and female, incubate the eggs for about four weeks, after which four eggs are hatched. The eggs, like the piping plovers, are camouflaged by the surrounding sand or cobblestones and are rarely seen unless stepped on. The surviving young are flying in about 30 days. When on the forage, they look for marine worms, crustaceans, and insects that they pluck from the sand. When the young are out foraging and a predator or intruder comes close, the young will squat motionless on the sand while the parents attempt to attract the attention of the intruder, often by faking a broken wing. However, if the adults spend too much time doing this, the eggs and chicks become vulnerable to predators and to overheating in the hot sun (**Scott 2003b**; **USFWS 2007e**).

4.4.4.2. Significance

The piping plover is one of many species that have suffered from drastic ecosystem changes, like river channelization, impoundment, and shoreline development (**Stukel 1996**). Critical wintering habitat designated by USFWS in 2001 for the bird exists from Nassau Sound to the St. Johns River.

4.4.4.3. Data Sources & Limitations

Data came from Audubon winter counts for Jacksonville in addition to a variety of books, reports and web sites. The winter bird count area consists of a circle with a radius of ten miles surrounding Blount Island.

4.4.4.4. Current Status

Current wintering populations in Florida showed decline attributed mainly to increased development and recreational use of beaches in the last sixty years. In 2005, Bird Life International estimated the entire piping plover population at 6,410, comprising of three groups- Atlantic Coast (52%), Great Plains (46%), and Great Lakes (2%). Totals in the Atlantic Coast population increased from 1,892 birds in 1991 to 3,350 birds in 2003. Totals for the Great Plains area increased from 2,744 birds in 1991 to 3,284 birds in 1996, then decreased to 2,953 birds in 2001. In the Great Lakes region, the population increased from 32 birds in 1991 to 110 birds in 2004. Overall there has been a total population increase of 9.5% (using the 1996 data) to 32.6% (using the 1991 data). However, the 1996-2001 data indicate a slight decline of the Great Plains population. The increases are the result of sustained management initiatives (**Audubon 2010a**; **BirdLife 2008**). Although numbers of birds per party hour appear to have increased slightly since the mid-1980s, the Jacksonville data (Figure 4.30) did not indicate that a significant trend was present over the long term (1929-2009). When considering the intermediate term (1985-2011) there was an increasing trend ($\tau = 0.422$; $p=0.00127$; $n=26$) (Figure 4.31). In the short term (1995-2011) there was no trend indicated (Appendix 4.4.5).

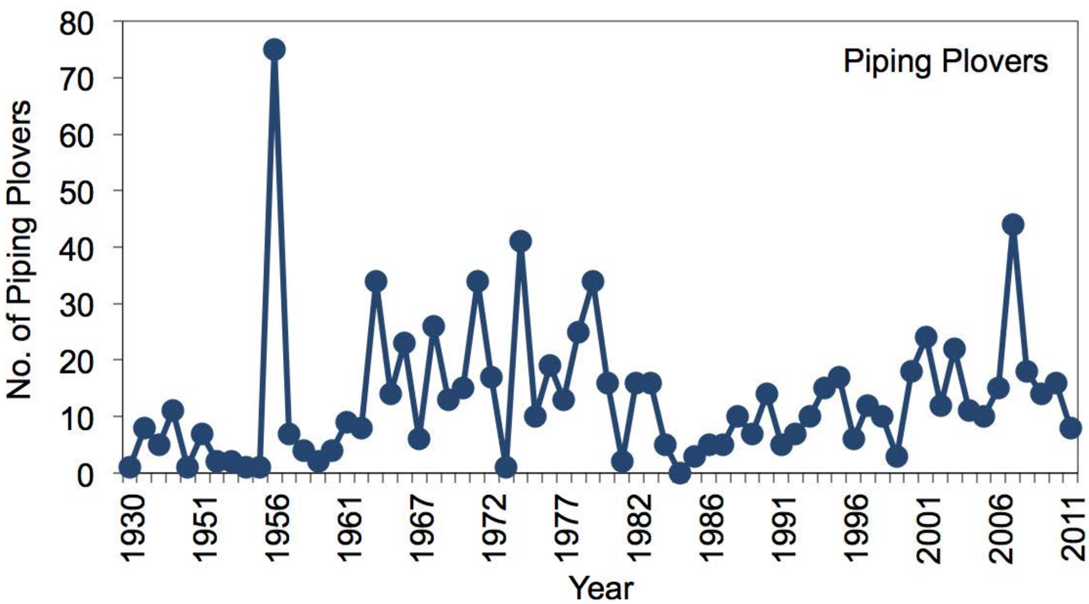


*Figure 4.30. Numbers of piping plovers counted during winter bird surveys (1929-2011) in Jacksonville, Florida. Source data: **Audubon 2010a**.*

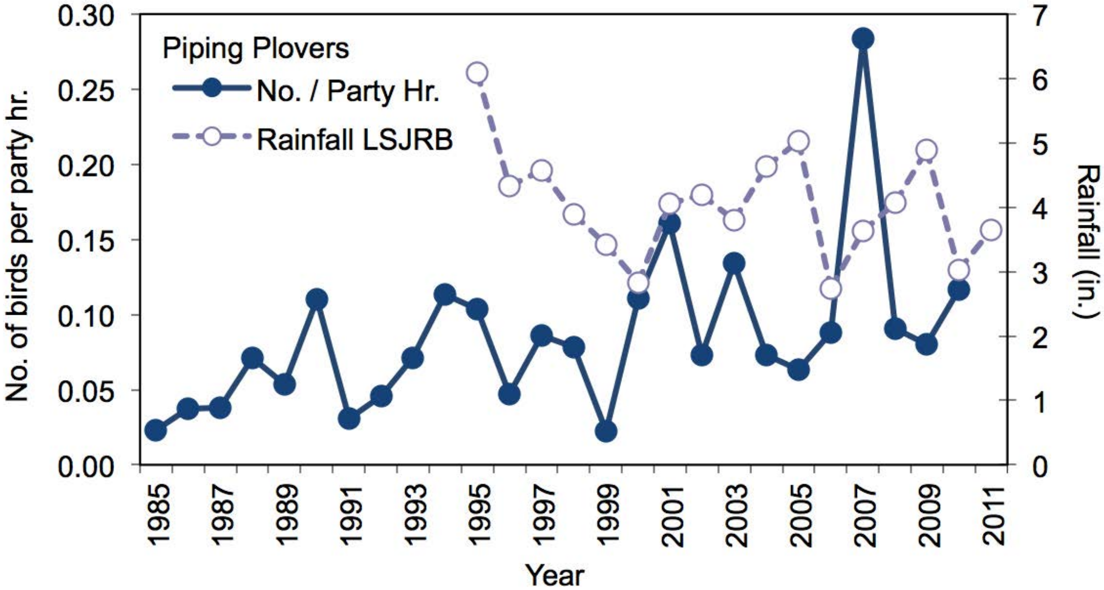


*Figure 4.31. Recent trends in the number of piping plovers counted per party hour and rainfall (1985-2011) in Jacksonville, Florida. Source data: **Audubon 2010a** and **SJRWMD 2012d***

4.4.4.5. Future Outlook

The piping plover can be protected by respecting all areas which are fenced or posted for protection of wildlife, and by not approaching piping plovers or their nests. Pets should be kept on a leash where shorebirds are present. Trash or food scraps should not be left behind or buried at beaches because they attract predators, which may prey on piping plovers' eggs or chicks. Structures called exclosures are sometimes erected around a nest to protect the eggs from predators. The Endangered Species Act provides penalties for taking, harassing, or harming the piping plover and affords some protection to its habitat. By protecting the piping plover, other species such as the Federally endangered roseate tern (Florida population is listed as threatened), the threatened northeastern beach tiger beetle (not found in Florida), the threatened seabeach amaranth (not reported from Florida), the endangered least tern, the common tern, the black skimmer, and the Wilson's plover, may also benefit from the piping plover protection efforts (**Scott 2003b**; **USFWS 2007e**).

4.4.5. Shortnose Sturgeon (Endangered)

Source: USFWS

4.4.5.1. Description

The Shortnose sturgeon *(Acipenser brevirostru)* was listed as Endangered in 1967. It is a semi-anadromous fish that swims upstream to spawn in freshwater before returning to the lower estuary, but not the sea. Shortnose are found in rivers along the east coast from Canada to Florida. The species is particularly imperiled because of habitat destruction and alterations that prevent access to historical spawning grounds. The St. Johns River is dammed in the headwaters, heavily industrialized and channelized near the sea, and affected by urbanization, suburban development, agriculture, and silviculture throughout the entire basin. Initial research conducted by the National Marine Fisheries Service in the 1980's and 1990's culminated in The Shortnose Sturgeon Recovery and Management Plan of 1998 (**FWRI 2011c**; **NMFS 1998**).

"Anadromous" fish live in the ocean, but return to freshwater to spawn.

4.4.5.2. Significance

There are no legal fisheries or by-catch allowances for Shortnose Sturgeon in U.S. waters. Principal threats to the survival of this species include blockage of migration pathways at dams, habitat loss, channel dredging, and pollution. Southern populations are particularly at risk due to water withdrawal from rivers and ground waters and from eutrophication (excessive nutrients) that directly degrades river water quality causing loss of habitat. Direct mortality is known to occur from getting stuck on cooling water intake screens, dredging, and incidental capture in other fisheries (**NMFS 1998**).

4.4.5.3. Data Sources & Limitations

Data were limited to a few specimen captures recorded in the literature, which consisted of books, reports and web sites. Shortnose sturgeons have been encountered in the St. Johns River since 1949 - Big Lake George and Crescent Lake (**Scott 2003c**). Five shortnose sturgeons were collected in the St. Johns River during the late 1970s (**Dadswell, et al. 1984**) and, in 1981, three sturgeons were collected and released by the Florida Game and Freshwater Fish Commission. All these captures occurred far south of LSJRB in an area that is heavily influenced by artesian springs with high mineral content. None of the collections was recorded from the estuarine portion of the system (**NMFS 1998**). From 1949-1999, only 11 specimens had been positively identified from this system. Eight of these captures occurred between 1977 and 1981. In August 2000, a cast net captured a shortnose sturgeon near Racy Point just north of Palatka. The fish carried a tag that had been attached in March 1996 by Georgia Department of Natural Resources near St. Simons Island, Georgia. During 2002/2003 an intensive sampling effort by researchers from the Fish and Wildlife Research Institute captured one 1.5 kg (3.3 lbs.) specimen south of Federal Point, again near Palatka. As a result, FWRI considers it unlikely that any sizable population of shortnose sturgeon currently exists in the St. Johns River. In addition, the rock or gravel substrate required for successful reproduction is scarce in the St. Johns River and its tributaries. Absence of adults and marginal habitat indicate that shortnose sturgeons have not actively spawned in the system and that infrequent captures are transients from other river systems (**FWRI 2011c**).

4.4.5.4. Current Status

The species is likely to be declining or almost absent in the LSJRB (**FWRI 2011c**). Population estimates are not available for the following river systems: Penobscot, Chesapeake Bay, Cape Fear, Winyah Bay, Santee, Cooper, ACE Basin, Savannah, Satilla, St. Marys and St. Johns River (Florida). Shortnose sturgeon stocks appear to be stable and even increasing in a few large rivers in the north but remain seriously depressed in others, particularly southern populations (**Friedland and Kynard 2004**).

4.4.5.5. Future Outlook

The Shortnose Sturgeon Recovery and Management Plan (**NMFS 1998**) identifies recovery actions to help reestablish adequate population levels for de-listing. Captive mature adults and young are being held at Federal fish hatcheries operated by the U.S. Fish and Wildlife Service for breeding and conservation stocking.

4.4.6. Florida Scrub-Jay (Threatened)

Source: FWC

4.4.6.1. Description

The Florida scrub-jay *(Aphelocoma coerulescens)* was listed as threatened in 1987. It is 12 inches long and weighs 2.5-3 ounces. Adults have blue feathers around the neck that separate the whiter throat from the gray under parts. They have a white line above the eye that often blends into their whitish forehead. The backs are gray and the tails are long and loose in appearance. Scrub-jays up to five months old have a dusky brown head and neck and shorter tail. In the late summer and early fall, it is almost impossible to differentiate the juveniles from the adults. During this time juveniles undergo a partial molt of body feathers. Adult males and females have identical plumage, but are set apart by a distinct "hiccup" call vocalized only by the females (**BCNRM 2008**). **FWC 2008b** describes the bird as partly resembling the blue-jay *(Cyanocitta cristata)*. The Florida scrub-jay differs from a blue-jay in that it is duller in color, has no crest, has longer legs and tail, and lacks the bold black and white marking of the blue-jay (**BCNRM 2008**). As one of the few cooperative breeding birds in the United States, the fledgling scrub-jays typically remain with the breeding pair in their natal territory as "helpers" (**BCNRM 2008**). These family groups range from two to eight birds. Pre-breeding groups usually just have one pair of birds with no helpers or families of three or four individuals. The helpers within the groups participate by looking out for predators, predator-mobbing, helping with territorial defense against neighboring scrub-jay groups, and the feeding of both nestlings and fledglings. On average, Florida scrub-jays typically do not begin mating until they are at least 2-3 years of age. Nestlings can be observed from March 1 through June 31 and are usually found in shrubby oaks 1-2 meters (3-7 ft.) in height. Each year a new nest is built, usually about 1-3 meters (3-10 ft.) above ground and structured as a shallow basket of twigs lined with palmetto fibers (**FWC 2008b**). Most nests contain three or four eggs, which are incubated for 17-18 days. Fledging occurs 16-19 days after hatching. The fledglings are reliant on the adults for food for up to two months after leaving the nest. Once they become independent, Florida scrub-jays live out their entire lives within a short distance of where they were hatched (**BCNRM 2008**).

Florida scrub-jay populations are found in small isolated patches of sand pine scrub, xeric oak scrub, and scrubby flat woods in peninsular Florida. Scrub-jays occupy territories averaging 22 acres in size, but they hunt for food mostly on or near the ground. Their diet is made up of mostly terrestrial insects, but may also include tree frogs, lizards, snakes, bird eggs and nestlings, and juvenile mice. Acorns form one of the most important foods from September to March (**BCNRM 2008**).

4.4.6.2. Significance

Populations occur on the southwest boundary of the LSJRB (**USFWS 2007b**) and add to the overall species diversity in the basin.

4.4.6.3. Data Sources & Limitations

Information was gathered from books, reports and web sites, but limited data were available for the LSJRB.

4.4.6.4. Current Status

The population of the scrub-jays has declined by 90% over the last century and by 25% since 1983. In 1983 the estimated population was 8,000 birds according to the Audubon Society (**Audubon 2007b**). A single bird was reported in Jacksonville in 1950/51 (**Audubon 2007a**) and 3 birds were observed in winter of 2000 (**Audubon 2010b**). The species is now being legally protected by the USFWS and the FWC. The Florida scrub-jay is being studied in their natural habitats and in areas undergoing rapid development. In addition, land acquisition activities have been ongoing in Florida to purchase the remaining privately-owned oak scrub habitat in order to conserve critical habitat for the scrub-jay (**FWC 2008b**). Since the late 1980s, scrub-jays have been reported to have been extirpated (locally extinct since people settled in the area) from Broward, Dade, Duval, Gilchrist, Pinellas, St. Johns, and Taylor counties (**USFWS 1990**). A 1992-1993 survey indicated that scrub-jays were also extirpated from Alachua and Clay counties. Scrub-jays are still found in Flagler, Hardee, Hendry, Hernando, Levy, Orange, and Putnam counties, but ten or less pairs remained in these counties and were considered functionally extirpated (**Fitzpatrick, et al. 1994**). Subsequent information indicated that at least one breeding pair remained in Clay County as late as 2004 and an individual bird was observed in St. Johns County in 2003 (**USFWS 2007b**). **Fitzpatrick, et al. 1994** indicated that scrub-jays have been noticeably reduced along their former range all along the Atlantic coast (Figure 4.32).

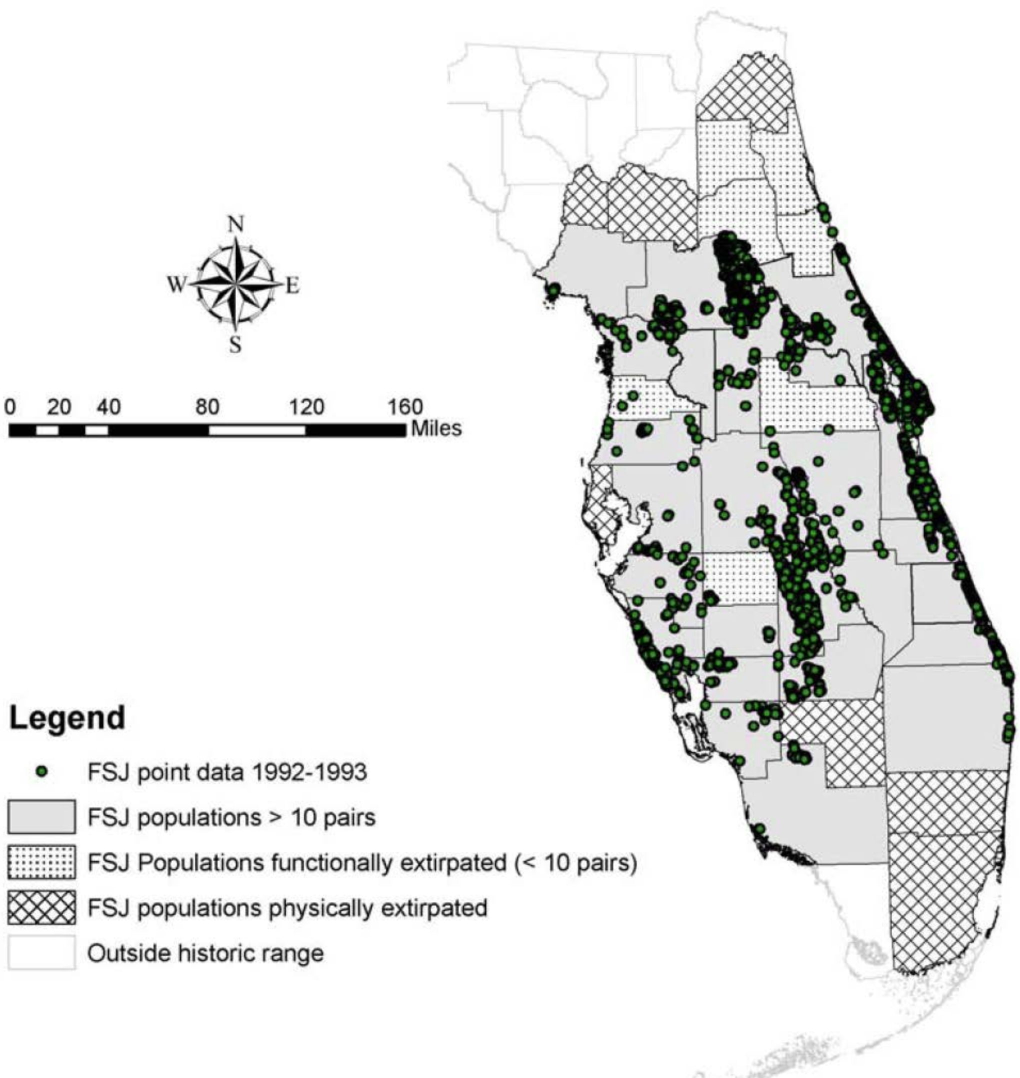


Figure 4.32. Historical vs. current scrub-jay distribution. Stripping and/or shading reflect known new sightings of scrub-jays since the 1992-1993 statewide survey. Source: ***USFWS 2007b****.*

4.4.6.5. Future Outlook

Florida Audubon developed a Recovery Resolution Plan (**USFWS 1990**) for the Florida scrub-jay, and has also played a big role in their protection. FWC suggests the following measures to help protect Florida scrub-jays:

1) *The best protection is to protect scrub-jay populations on managed tracts of optimal habitat.*
2) *Provide habitat by planting, protecting, and growing patches of shrubby scrub live oak, Chapman's oak, myrtle oak, and scrub oak on your property. Also, maintain landscaping at a maximum height of 3 meters (10 ft.) if you live on or near scrub-jay habitat.*
3) *Encourage passage and strict enforcement of leash laws for cats and dogs in your community and protect areas being used by nesting scrub-jays from domestic animals, especially cats.*
4) *Limit pesticide use because pesticides may limit or contaminate food used by the jays.*
5) *Report any harassment of Scrub jays or their nests to 1-888-404-FWCC (3922).*

4.4.7. Eastern Indigo Snake (Threatened)

Source: USFWS.

4.4.7.1. Description

The Eastern Indigo snake *(Drymarchon corais couperi)* is the largest snake found in the US and is protected by federal (1978) and state laws (1971). Typically an adult is 1.5-2 m (5-6 ft.) long, and 5-7 cm (2-3 inches) in girth. The range is currently restricted to Florida and southeastern Georgia with isolated populations in other parts of Georgia and in Alabama. They are most common on the Upper and Lower Florida Keys. Breeding occurs between November and April (**Dodd Jr and Barichivich 2007**; **Scott 2003a**).

4.4.7.2. Significance

Indigos are habitat generalists that require large areas of unsettled land from 25-450 acres in which to roam, depending on the season (**Hyslop 2007**; **Hyslop, et al. 2006**; **Moler 1985**; **Zappalorti 2008**). Habitats used vary widely. Sandhill communities are preferred, but Indigo snakes can also be found in pine flatwoods, scrub, coastal strand ecosystems and orange groves (**Scott 2003a**). The snake is diurnal and will subdue and swallow prey whole, feeding on water snakes and a large variety of small prey along the edges of waterways and marshes. Indigo snakes are well known for using Gopher tortoise burrows for refuge (**Dodd Jr and Barichivich 2007**; **Scott 2003a**). However, Gopher tortoise populations have been severely reduced in some areas which may affect Indigos (**Scott 2003a**).

4.4.7.3. Data Sources & Limitations

Information was gathered from books, reports and web sites but there were limited data available for LSJRB. **Dodd Jr and Barichivich 2007**) mention that most information regarding habitat, use and requirements for the Indigo snake is found in unpublished, non peer-reviewed, and largely inaccessible agency reports.

4.4.7.4. Current Status

The literature indicates declining populations throughout its range because of habitat destruction and fragmentation from development, vehicle collisions, gassing burrows (illegal activity 3925.002 FAC), illegal collection and mortality caused by domestic dogs and humans (**Lawler 1977**; **Moler 1992**; **Scott 2003a**; **Stevenson, et al. 2003**).

4.4.7.5. Future Outlook

The focus of habitat protection should be on large non-fragmented tracts of land of about 2,500 acres in size (**Dodd Jr and Barichivich 2007**; **Moler 1992**). **Moler 1992** proposes that mitigation funds from developments that unavoidably eliminate habitat should be pooled to allow for such large land acquisitions. In north Florida's xeric habitats the future status of Indigos is closely linked to that of Gopher tortoises (**Dodd Jr and Barichivich 2007**; **Moler 1992**; **Scott 2003a**). Rebuilding the tortoise populations will benefit the Indigo snake. Furthermore, **Moler 1992** asserts that laws against violations such as "gassing" of tortoise burrows should be strongly enforced. Recent work in southeast Georgia has focused on trapping methods, survival rates, and seasonal shifts in shelter and microhabitat use (**Hyslop, et al. 2009a; Hyslop, et al. 2009b; Hyslop, et al. 2009c**).

4.5. Non-native Aquatic Species

4.5.1. Description

The invasion and spread of non-native, or "exotic," species is currently one of the most potent, urgent, and far-reaching threats to the integrity of aquatic ecosystems around the world (**NRC 1995**; **NRC 1996**; **NRC 2002**; **Ruckelshaus and Hays 1997**). Non-native species can simply be defined as "any species or other biological material that enters an ecosystem beyond its historic, native range" (**Keppner 1995**).

4.5.2. Significance

The transport and establishment of non-native aquatic species in the St. Johns River watershed is significant due to a number of ecosystem, human health, social, and economic concerns.

4.5.2.1. Ecosystem Concerns

"Generalizations in ecology are always somewhat risky, but one must be offered at this point. The introduction of exotic (foreign) plants and animals is usually a bad thing if the exotic survives; the damage ranges from the loss of a few native competing species to the total collapse of entire communities" (**Ehrenfeld 1970**). The alarming increase in the number of documented introductions of non-native organisms is of pressing ecological concern (**Carlton and Geller 1993**). This concern is supported by the evidence that non-native species, within just years of introduction, are capable of breaking down the tight relationships between resident biota (**Valiela 1995**). Once introduced, exotic species may encounter few (if any) natural pathogens, predators, or competitors in their new environment.

The non-native plant *Hydrilla verticillata* is the #1 aquatic weed in Florida. Native to Asia, hydrilla was likely introduced to Florida in the 1950s (**Simberloff, et al. 1997**) and has spread through the Lower St. Johns River Basin since at least 1967 (**USGS 2012b**). Even the smallest fragment of hydrilla can rapidly grow and reproduce into dense canopies, which are poor habitat for fish and other wildlife. Hydrilla is a superb competitor with native species by monopolizing resources and shading out other native plants. Huge masses of hydrilla slow water flow, obstruct waterways, reduce native biodiversity, and create stagnant areas ideal for the breeding of mosquitoes (**McCann, et al. 1996**). The negative impacts of hydrilla have been so pervasive and intense in Florida, that U.S. scientists have experimentally released four biological control insects from Pakistan that feed on hydrilla in its native habitat and have also stocked infested Florida lakes with non-reproducing Chinese grass carp *(Ctenopharyngodon idella)*, which preferentially eat hydrilla (**Richard and Moss 2011**). Introducing exotics to control exotics, of course, can produce a secondary layer of ecological problems and unforeseen implications.

A number of non-native herbivorous fish are altering native ecosystems in the Lower St. Johns River. Many of these fish are common in the aquarium trade and include the Eurasian goldfish (*Carassius auratus*; which commonly becomes brown in the wild), Mozambique tilapia *(Oreochromis mossambicus)*, African blue tilapia *(Oreochromis aureus)*, South American

brown hoplo *(Hoplosternum littorale),* and a number of unidentified African cichlids *(Cichlidae spp.)* (**Brodie 2008**; **USGS 2012b**). Additionally, several species of South American algae-eating catfish commonly known in the aquarium trade as "plecos," including the suckermouth catfish *(Hypostomus sp.)* and vermiculated sailfin catfish *(Pterygoplichthys disjunctivus)* appear to be established in the Lower St. Johns River (**USGS 2012b**). As most aquarium enthusiasts know, "plecos" are extremely efficient algae eaters, and, when released into the wild, can have profound impacts on the native community of aquatic plants and animals.

4.5.2.2. Human Health Concerns

Non-native aquatic species can negatively affect human health. Some non-native microorganisms, such as blue-green algae and dinoflagellates, produce toxins that cause varying degrees of irritation and illness in people (**Hallegraeff and Bolch 1991**; **Hallegraeff, et al. 1990**; **Stewart, et al. 2006**). During the summer of 2005, large rafts of toxic algal scum from Lake George to the mouth of the St. Johns River in Mayport, Florida, brought headline attention to toxic bloom-forming algae. The organisms responsible for this bloom were two toxin-producing cyanobacteria (blue-green algae) species: the cosmopolitan *Microcystis aeruginosa* and the non-native *Cylindrospermopsis raciborskii* (**Burns Jr 2008**). *C. raciborskii* has been recorded throughout tropical waters globally, but appears to be expanding into temperate zones as well throughout the U.S. and the world (**Jones and Sauter 2005**; **Kling 2004**). *Cylindrospermopsis* may have been present in Florida since the 1970s, however its presence in the St. Johns River Basin was not noted prior to 1994 (**Chapman and Schelske 1997**; **Phlips, et al. 2002**; **SJRWMD 2005**). Genetic studies reveal strong genetic similarities between populations in Florida and Brazil, suggesting the two populations continually mix or came from the same source relatively recently (**Dyble, et al. 2002**).

Cylindrospermopsis now appears to bloom annually each summer in the St. Johns River with occasionally very high concentrations in excess of 30,000 cells/ml (**Phlips, et al. 2002**). During the intense bloom of 2005, the Florida Department of Health released a human health alert recommending that people avoid contact with waters of the St. Johns River, because the toxins can cause "irritation of the skin, eyes, nose and throat and inflammation in the respiratory tract" (**FDOH 2005**). This public health concern will likely continue to menace the Lower St. Johns River Basin in the foreseeable future, particularly when the water becomes warm, still, and nutrient-rich: conditions favorable to the formation of algal blooms.

4.5.2.3. Social Concerns

The invasion of a non-native organism can disrupt traditional patterns of commercial, recreational, and subsistence fishing or can alter navigational or industrial use patterns (**GESAMP 1997**; **Shiganova 1998**). A number of non-native aquatic species, such as the charrua mussel *(Mytella charruana)* and Asian green mussel *(Perna viridis)*, are prolific reproducers that will foul most any hard surface. On a large scale, this fouling, of course, can lead to tremendous economic losses to industries. Just as importantly, yet often overlooked, non-native species can be serious nuisances on a small scale. They foul people's recreational boats and personal docks. They foul sunken ships and sites of historical and cultural value. Clean-up and control of aquatic pests, such as the floating plant water hyacinth *(Eichhornia crassipes)*, can have high economic costs to citizens, not only in taxpayer dollars, but in out-of-pocket money as well. In general, many non-native species reproduce so successfully in their environment, that they create unsightly masses that negatively impact recreation and tourism. Such unsightly masses, as those created by water hyacinth *(Eichhornia crassipes)* or hydrilla *(Hydrilla verticillata)*, also shift the way we view and appreciate the aesthetic, intrinsic qualities of our aquatic ecosystems.

4.5.2.4. Economic Concerns

History has shown that the establishment of non-native species can have far-reaching economic impacts on fisheries, seafood industries, aquaculture, and landside industries (**GESAMP 1997**). Shoreside industries are affected by a number of non-native aquatic species that are prolific reproducers and will foul most any hard surface. In the Great Lakes, the Eurasian zebra mussel (*Dreissena polymorpha*) is literally clogging the vitality of water-dependent, landside industries by the excessive fouling of underwater structures and engineering works (**Hedgpeth 1993**; **Johnson and Carlton 1996**). The U.S. has spent billions of dollars on efforts to control such organisms (**Johnson and Carlton 1996**; **Labi 1996**).

Even locally, excessive fouling by successful non-native species can lead to economic losses to industries. In 1986, the South American charrua mussel (*Mytella charruana)* caused extensive fouling at Jacksonville Electric Authority's Northside Generating Station on Blount Island, Jacksonville, Florida (**Lee 2012a**). The charrua mussel probably hitchhiked to the St. Johns River in the ballast water of a ship from South America and continues to persist in the area as evidenced by

collections in Mayport, Marineland, and the Arlington area of Jacksonville as recently as 2008 (**Lee 2008a**). Other non-native fouling organisms identified in the St. Johns River include the Asian clam *(Corbicula fluminea),* Indo-Pacific green mussel *(Perna viridis),* and Indo-Pacific striped barnacle *(Balanus amphitrite).* Cleaning these fouling organisms from docks, bridges, hulls of boats and ships, and industrial water intake/discharge pipes is time-consuming and extremely costly.

4.5.3. Data Sources

Numerous online databases containing non-native species reports were queried. The most comprehensive listing of species is maintained in the Nonindigenous Aquatic Species (NAS) database of the United States Geological Service (**USGS 2012b**). Additional records and information were obtained from agency reports, books, published port surveys, and personal communication data (complete list of data sources in Appendix 4.5.A.).

4.5.4. Limitations

We expect that many more non-native species are found within the LSJRB, but specimens have not been collected or formally recorded with any local or state governmental agency. These sightings are typically lost and are not included in this study. Additionally, it is expected that numerous non-native species are unrecognized or unrecorded, either because they are *naturalized*, *cryptogenic,* or because the taxonomic expertise to identify foreign species, subspecies, or hybrids is not available.

*A naturalized species is any non-native species that has adapted and grows or multiplies as if native (**Horak 1995**).*

*A cryptogenic species is an organism whose status as introduced or native is not known (**Carlton 1987**).*

4.5.5. Current Status

A total of 64 non-native aquatic species are documented and believed to be established in the LSJRB (see Table 4.4; Appendix 4.5.B.).

The non-native species recorded in the Lower Basin include a variety of lifeforms of organisms, including floating or submerged aquatic plants (25%), molluscs (22%), fish (20%), crustaceans (19%), amphibians (3%), jellyfish (1%), mammals (2%), reptiles (3%), tunicates (2%), ectoproct – bryozoans (2%), and algae/seaweeds (1%).

A majority (56%) of the non-native species that have been introduced into the LSJRB are freshwater (Figure 4.32). The habitats that are most commonly utilized by these non-native species are watercourses (32%), lakes (31%), and marine habitats (18%). Other habitats utilized include agricultural areas, disturbed areas, estuaries, riparian zones, urban areas, and wetlands.

The majority (25%) of the non-native aquatic species that have been introduced into the LSJRB have native ranges in South America (Figure 4.34).

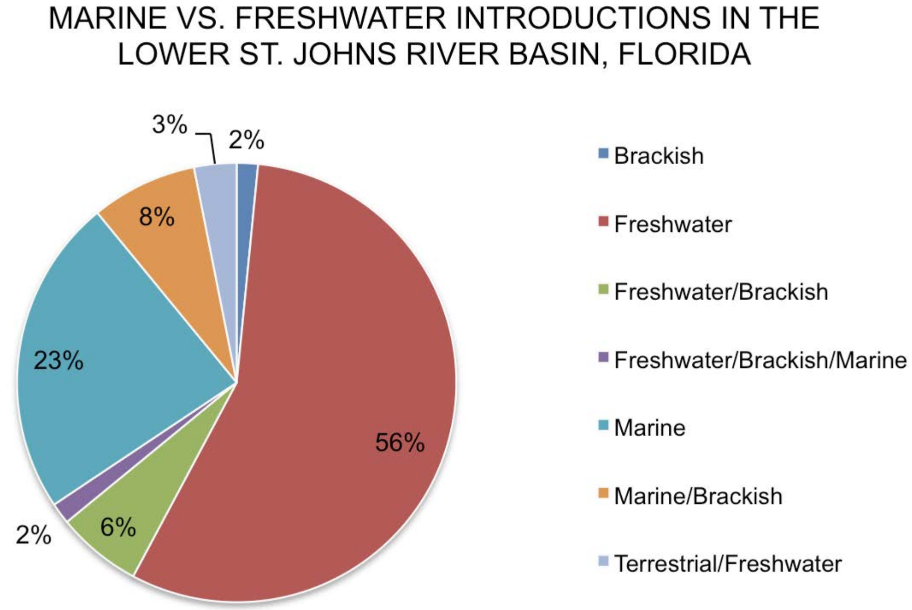


Figure 4.33 Aquatic Systems Utilized by Non-native Aquatic Species Introduced into the Lower St. Johns River Basin, Florida.

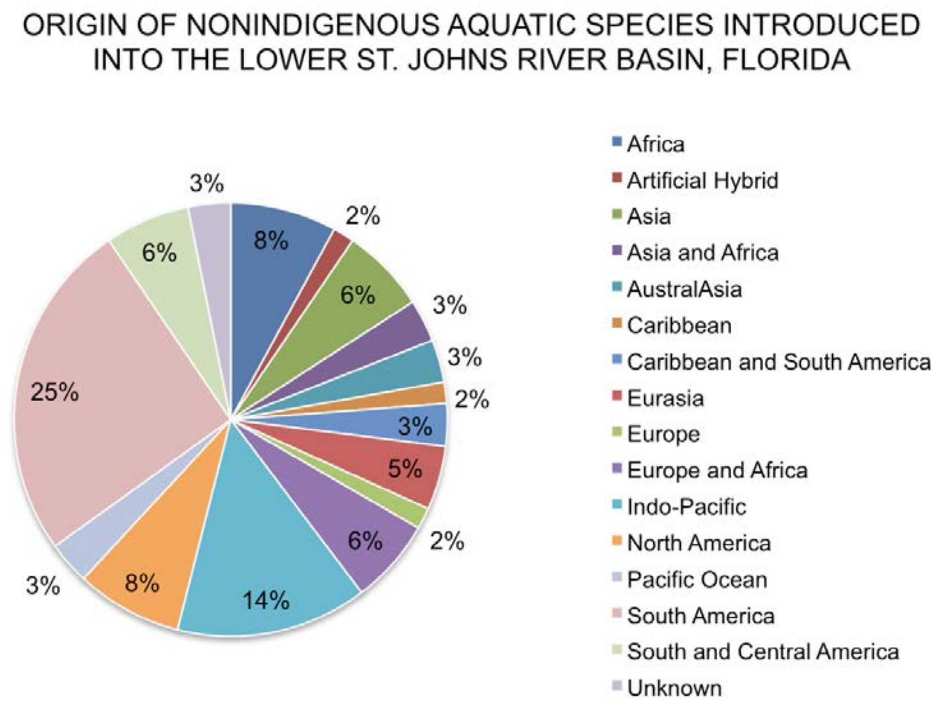
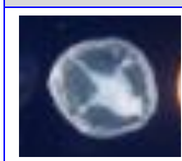
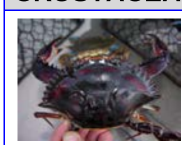
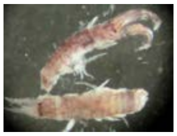
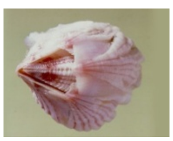
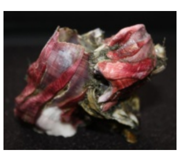
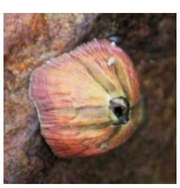
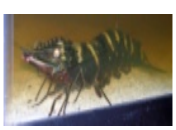
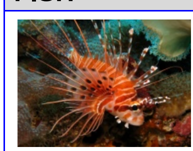


Figure 4.34 Native Habitat of Non-native Aquatic Species Introduced into the Lower St. Johns River Basin, Florida.

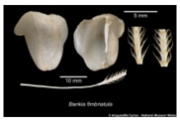
Table 4.3 Non-native aquatic species recorded in the Lower St. Johns River Basin

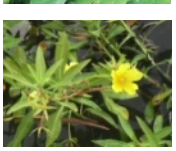
LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
AMPHIBIANS								
	Cane toad *Photo: USGS NAS*	*Bufo marinus*	Freshwater, Brackish	Intentionally introduced to several locations in South Florida between 1936 and 1958.	South and Central America	Humans, Range expansion from South Florida populations	No	**USGS 2012b**
	Cuban treefrog *Photo: USGS NAS*	*Osteopilus septentrionalis*	Terrestrial, Freshwater	First detected in Key West before 1928. Spread northward through Keys. Now recorded in southern half of Florida.	Caribbean	Dispersing northward from S. Florida populations, floating vegetation/debris, humans, vehicles, bulk freight/cargo, plant or parts of plants	No	**USGS 2012b**
TUNICATES								
	Pleated (or rough) sea squirt *Photo: SERTC/SC DNR*	*Styela plicata*	Marine	Unknown; Documented on ships in NY and Philadelphia in the 1800s; Reported offshore Jacksonville as early as 1940.	Indo-Pacific? This species is now found in tropical and warm-temperate oceans around the world.	Ship/boat hull fouling; Ship ballast water/sediment; Importation of mollusk cultures	No	**De Barros, et al. 2009; GBIF 2012d**
ECTOPROCTS - BRYOZOANS								
	Brown bryozoan	*Bugula neritina*	Marine, Brackish	Beaufort, NC (1878 record); Dry Tortugas (1900 record); widespread in SE Atlantic by mid-1900's.	Native range is unknown - probably Mediterranean Sea (1758 record).	Ship/boat hull fouling	No	**Eldredge and Smith 2001; GBIF 2012c; NEMESIS 2012**
JELLYFISH								
	Freshwater jellyfish *Photo: USGS NAS*	*Craspedacusta sowerbyi*	Freshwater	First described in Philadelphia in 1928. Recorded throughout the US. Most common in temperate states in eastern US	Asia	Aquaculture stock, other live animal, plant or parts of plants	No	**USGS 2012b**
CRUSTACEANS								
	Bocourt swimming crab *Photo: Big Bend Brian*	*Callinectes bocourti*	Marine, Brackish	First US report was Biscayne Bay, FL, 1950.	Caribbean and South America	From the Caribbean via major eddies in Gulf Stream or southern storm events	Federal Injurious Wildlife List "No such live fish, mollusks, crustacean, or any progeny or eggs thereof may be released into the wild" (without a permit from FWC) (U.S. Lacey Act; 50 CFR Ch. I Sec. 16.13)	**USGS 2012b**
	Indo-Pacific swimming crab *Photo: SC DNR*	*Charybdis hellerii*	Marine	First US report was South Carolina (1986), Indian River Lagoon, FL (1995)	Indo-Pacific	Ship ballast water/sediment, or drift of juveniles from Cuba	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
	Green porcelain crab *Photo: D. Knott*	*Petrolisthes armatus*	Marine, Brackish	Indian River Lagoon, FL (1977), Georgia (1994), and SC (1995)	Caribbean and South America	Natural range expansion, Ship ballast water/sediment, importation of mollusk cultures	Federal Injurious Wildlife List (U.S. Lacey Act)	**Power, et al. 2006**
	Slender mud tube-builder amphipod *Photo: VIMS*	*Corophium lacustre*	Freshwater, Brackish	First record in the St. Johns River in 1998.	Europe and Africa	Ship ballast water/sediment from Europe	Federal Injurious Wildlife List (U.S. Lacey Act)	**GBIF 2012b; Power, et al. 2006**
	Skeleton shrimp *Photo: D. Knott*	*Caprella scaura*	Marine	Caribbean Sea (1968), St. Johns River (2001)	Indian Ocean	Ship/boat hull fouling; Ship ballast water/sediment	Federal Injurious Wildlife List (U.S. Lacey Act)	**Foster, et al. 2004; GBIF 2012a**
	Wharf roach *Photo: Ruppert and Fox (1998)*	*Ligia exotica*	Marine	Unknown	Northeast Atlantic and Mediterranean Basin	Bulk freight/cargo, Ship ballast water/sediment, Shipping material from Europe	Federal Injurious Wildlife List (U.S. Lacey Act)	**Power, et al. 2006**
	Striped barnacle *Photo: A. Cohen*	*Balanus amphitrite*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling	Federal Injurious Wildlife List (U.S. Lacey Act)	**Power, et al. 2006**
	Triangular barnacle *Photo: D. Elford*	*Balanus trigonus*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling	Federal Injurious Wildlife List (U.S. Lacey Act)	**GSMFC 2010**
	Barnacle *Photo: C. Baike*	*Balanus reticulatus*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling	Federal Injurious Wildlife List (U.S. Lacey Act)	**GSMFC 2010**
	Titan acorn barnacle *Photo: H. McCarthy*	*Megabalanus coccopoma*	Marine	First recorded in Duval Co, FL - 2004; Common by 2006.	Pacific Ocean	Ship/boat hull fouling	Federal Injurious Wildlife List (U.S. Lacey Act)	**Frank 2008a**
	Mediterranean acorn barnacle *Photo: H. McCarthy*	*Megabalanus antillensis* *(also known as M. tintinnabulum)*	Marine	Unknown	Europe (Mediterranean Sea)	Ship/boat hull fouling	Federal Injurious Wildlife List (U.S. Lacey Act)	**Masterson 2007; McCarthy 2011**
	Asian tiger shrimp *Photo: M. Watkins, FWRI-Jacksonville*	*Penaeus monodon*	Marine, Brackish	First recorded in Duval Co, FL – 2008.	Australasia	Aquaculture stock	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
FISH								
	Lionfish *Photo: A. Baeza*	*Primarily Pterois volitans (red lionfish) with a small number of Pterois miles (devil firefish)*	Marine	First U.S. reports were Dania, FL (1985) and Biscayne Bay (1992). Offshore Jacksonville (2001).	Indo-Pacific	Humans: aquarium releases or escapes	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
	Goldfish *Photo: USGS NAS*	*Carassius auratus*	Freshwater	Intentional releases in the US, late 1600's.	Eurasia	Intentional release, Ornamental purposes, Stocking, Aquarium trade, Escape from confinement, Landscape/fauna "improvement"	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
	Unidentified cichlids *Photo: USGS NAS*	*Cichlidae spp.*	Freshwater	Recorded in LSJRB between 2001 and 2006.	Africa	Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**Brodie 2008; GSMFC 2010; USGS 2012b**
	Blue tilapia *Photo: USGS NAS*	*Oreochromis aureus*	Freshwater	In 1961, 3,000 fish stocked in Hillsborough Co, FL. Recorded in LSJRB between 2001 and 2006.	Europe and Africa	Humans: Intentional fish stocking	Federal Injurious Wildlife List (U.S. Lacey Act)	**Brodie 2008; GSMFC 2010; USGS 2012b**
	Mozambique tilapia *Photo: USGS NAS*	*Oreochromis mossambicus*	Freshwater, Brackish	1960's - Introduced/established in Dade Co, FL. Recorded in LSJRB between 2001 and 2006.	Africa	Humans: Stocked, intentionally released, escapes from fish farms, aquarium releases	Federal Injurious Wildlife List (U.S. Lacey Act)	**Brodie 2008; GSMFC 2010; USGS 2012b**
	Unidentified tilapia *Photo: USGS NAS*	*Tilapia spp.*	Freshwater	Recorded in LSJRB between 2001 and 2006.	Africa	Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**Brodie 2008; GSMFC 2010**
	Unidentified Pacu *Photo: USGS NAS*	*Colossoma or Piaractus sp.*	Freshwater	1984-1989	South America	Aquaculture stock (Fish farm escapes or releases), Humans (aquarium releases)	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
	Brown Hoplo *Photo: USGS NAS*	*Hoplosternum littorale*	Freshwater	First recorded in Indian River Lagoon, 1995.	South America	Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
	Wiper (Hybrid Striped Bass) (Whiterock = *female striped bass x male white bass,* Sunshine Bass = *male striped bass x female white bass*) *Photo: T. Pettengill*	*Morone chrysops x saxatilis (Artificial hybrid between the white bass and the striped bass)*	Freshwater, Brackish, Marine	Intentionally stocked in the 1970's. Identified in 1992.	Artificial Hybrid	Humans: Intentional fish stocking	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
	Unidentified armored catfish *Photo: USGS NAS*	*Loricariidae spp.*	Freshwater	Recorded in LSJRB between 2001 and 2006.	South and Central America	Aquaculture stock (Fish farm escapes or releases), Humans (aquarium releases)	Federal Injurious Wildlife List (U.S. Lacey Act)	**Brodie 2008; FWRI 2005**
	Suckermouth catfish *Photo: L. Smith*	*Hypostomus sp.*	Freshwater	1974, 2003	South and Central America	Aquaculture stock (Fish farm escapes or releases), Humans (aquarium releases)	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
	Southern sailfin catfish *Photo: K.S. Cummings*	*Pterygoplichthys anisitsi*	Freshwater	2007	South America	Humans: Likely aquarium release	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**
	Vermiculated sailfin catfish *Photo: USGS NAS*	*Pterygoplichthys disjunctivus*	Freshwater	2003	South America	Aquaculture stock (Fish farm escapes or releases), Humans (aquarium releases)	Federal Injurious Wildlife List (U.S. Lacey Act)	**USGS 2012b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
MAMMALS								
	Nutria *Photo: USGS NAS*	*Myocaster coypus*	Freshwater, Terrestrial	1956, 1957, 1963 Introduced into Florida for fur farming.	South America	Humans: escaped or released from captivity	Possession of nutria prohibited without a license from FWC (F.S. 372.98)	**USGS 2012b**
MOLLUSCS								
	Asian clam *Photo: USGS NAS*	*Corbicula fluminea*	Freshwater	Florida in 1964; 1990- Volusia County; 1975- Lake Oklawaha; 1974-76 Black Creek	Asia and Africa	Humans, Live seafood, Bait, Aquaculture stock, Water	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008b; Lee 2008a**
	Charrua mussel *Photo: H. McCarthy*	*Mytella charruana*	Marine	1986- Jacksonville; 2004- Mosquito Lagoon; 2006- Mayport (Duval Co), 2006- Marineland (Flagler Co)	South America	Ship ballast water/sediment	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008a**
	Green mussel *Photo: H. McCarthy*	*Perna viridis*	Marine, Brackish	1999- Tampa Bay; 2003- St. Augustine and Jacksonville	Indo-Pacific	Ship ballast water/sediment, Ship/boat hull fouling, Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**Frank 2008a**
	Paper pondshell *Photo: B. Frank*	*Utterbackia imbecillis*	Freshwater	Lake Oneida, UNF (Duval Co, FL) 2005, Recorded in 1990 in Sawgrass area	North America: Native in Mississippi River and Great Lakes	Other live animal, plant or parts of plants, ship/boat	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008b; Lee 2008a**
	Red-rim melania *Photo: B. Frank*	*Melanoides tuberculata*	Freshwater	1976- Willowbranch Creek, Riverside, Jacksonville, FL	Asia and Africa	Other live animal, plant or parts of plants, ship/boat	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008b; Lee 2008a**
	Fawn melania *Photo: B. Frank*	*Melanoides cf. turricula*	Freshwater	Fruit Cove (St. Johns Co, FL) 2006; Arlington area of Jacksonville (Duval Co, FL) 2006	North America: Native in western US and Canada	Other live animal, plant or parts of plants, ship/boat	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008a**
	Spiketop applesnail *Photo: B. Frank*	*Pomacea diffusa*	Freshwater	2006	South America	Humans: probable aquarium releases	Federal Injurious Wildlife List (U.S. Lacey Act)	**Frank 2008b**
	Channeled applesnail *Photo: Georgia DNR*	*Pomacea canaliculata*	Freshwater	Unknown	South America	Humans: probable aquarium releases	Federal Injurious Wildlife List (U.S. Lacey Act)	**Frank 2008b**
	Island applesnail *Photo: B. Frank*	*Pomacea insularum*	Freshwater	Unknown	South America	Humans: probable aquarium releases	Federal Injurious Wildlife List (U.S. Lacey Act)	**Frank 2008b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
	Mouse-ear marshsnail *Photo: B. Frank*	*Myosotella myosotis*	Marine	Unknown	Europe	Bulk freight/cargo, Ship ballast water/sediment,	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008a**
	Striped falselimpet *Photo: B. Frank*	*Siphonaria pectinata*	Marine	Unknown	Europe and Africa (Mediterranean Sea)	Bulk freight/cargo, Ship ballast water/sediment, Ship/boat hull fouling, Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008a; McCarthy 2008**
	Fimbriate shipworm *Photo: A. Cymru (Nat'l Museum of Wales)*	*Bankia fimbriatula*	Marine	Unknown	Pacific?	Ship/boat hull fouling, Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008a**
	Striate Piddock shipworm *Photo: J. Wooster*	*Martesia striata*	Marine	Unknown	Indo-Pacific?	Ship/boat hull fouling, Humans	Federal Injurious Wildlife List (U.S. Lacey Act)	**Lee 2008a**
	Gulf Wedge Clam *Photo: B. Frank*	*Rangia cuneata*	Brackish	Present in Atlantic east coast Pleistocene deposits; First live Atlantic record in 1946.	Prior to 1946, native range was considered Gulf Coast of northern FL to TX.	Possible vectors: transplanted seed oysters, oyster shipments, ballast water	Federal Injurious Wildlife List (U.S. Lacey Act)	**Carlton 1992; Carlton 2012; Foltz, et al. 1995; GBIF 2012c; Lee 2012b; NEMESIS 2012; Verween, et al. 2006**
REPTILES								
	Red-eared slider *Photo: USGS NAS*	*Trachemys scripta elegans*	Freshwater, Brackish	Unknown	North America: US midwestern states to northeastern Mexico	Humans - pet releases and escapes	Illegal in Florida: Red-eared sliders less than 4" carapace length may not be bought, sold, or bred after July 1, 2008 without a permit from FWC. (F.A.C. 68-5.001 and 68-5.002; F.S. 372.26).	**USGS 2012b**
	Razorback Musk Turtle *Photo: R.C. Thomson*	*Sternotherus carinatus*	Freshwater	1958 specimen collected Putnam Co.; 2008 first verified voucher specimen recorded in Florida	Native to 6 states: statewide in LA, southern MS, southern AR, southeastern OK, eastern TX, small portion of southwestern AL	Humans - pet releases and escapes	No	**Krysko, et al. 2011; USGS 2012b**
AQUATIC PLANTS								
	Alligator-weed *Photo: USGS NAS*	*Alternanthera philoxeroides*	Freshwater	1887-1894 in Florida, 1982-1992 specimens collected	South America	Ship ballast water/sediment	Class I Prohibited Aquatic Plant (F.A.C. 62C-52) -- "Under no circumstances will these species be permitted for possession, collection, transportation, cultivation, and importation.")	**McCann, et al. 1996; USGS 2012b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
	Para grass *Photo: F. & K. Starr*	*Urochloa (Brachiaria) mutica*	Freshwater	1982-1992	Africa	Humans: intentional release for agriculture	No	**McCann, et al. 1996; USGS 2012b**
	Water spangles *Photo: IFAS Univ. of Florida*	*Salvinia minima*	Freshwater	1928 - First report for North America in and along St. Johns River; 2003 - expanding range	South and Central America	Ship ballast water/sediment, Humans, Aquarium trade	Class I Prohibited Aquatic Plant (F.A.C. 62C-52)	**McCann, et al. 1996; USGS 2012b**
	Hydrilla *Photo: USGS NAS*	*Hydrilla verticillata*	Freshwater	1967-1994 (USGS), early 1950s (Simberloff et al.)	Asia	Debris associated with human activities, Ship/boat, Aquarium trade, Garden waste disposal	Federal Noxious Weed List (Public Law 108-412; 7 C.F.R. Ch. III Part 360); Regulated Plant Pest List (U.S.D.A. Animal & Plant Health Inspection Service); Class I Prohibited Aquatic Plant	**McCann, et al. 1996; USGS 2012b**
	Water-hyacinth *Photo: USGS NAS*	*Eichhornia crassipes*	Freshwater	First released 1880's, 1990-1994	South America	Humans, Aquarium trade, Garden escape	Class I Prohibited Aquatic Plant (F.A.C. 62C-52)	**McCann, et al. 1996; USGS 2012b**
	Water-lettuce *Photo: USGS NAS*	*Pistia stratiotes*	Freshwater	Described in Florida in 1765 (Bartram 1942)	South America	Ship ballast water/sediment	Class II Prohibited Aquatic Plant (F.A.C. 62C-52) -- May be cultured in nurseries for export out of the State; "Shall not be imported or collected from the wild"	**McCann, et al. 1996; USGS 2012b**
	Brazilian waterweed *Photo: USGS NAS*	*Egeria densa*	Freshwater	1969-1995, First record at St. Johns River at Cross Florida Barge Canal (1969)	South America	Humans: accidental aquarium releases, intentional release for control of mosquito larvae	No	**McCann, et al. 1996; USGS 2012b**
	Water sprite *Photo: A. Murray*	*Ceratopteris thalictroides*	Freshwater	1984-1992 specimens collected	Australasia	Humans	No	**McCann, et al. 1996; USGS 2012b**
	Wild taro *Photo: K. Dressler*	*Colossian esculenta*	Freshwater	Introduced to FL by Department of Agriculture in 1910; 1971-1992 specimens collected	Africa	Humans	No	**USGS 2012b**
	Uruguay water-primrose *Photo: Washington State Noxious Weed Control Board*	*Ludwigia uruguayensis*	Freshwater	1998 specimen collected	South America	Humans	No	**USGS 2012b**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	PROHIBITED STATUS?	REFERENCE
	Marsh dewflower *Photo: L. Lee*	*Murdannia keisak*	Freshwater	1960 specimen collected	Asia	Humans	No	**USGS 2012b**
	Parrot-feather *Photo: USGS NAS*	*Myriophyllum aquaticum*	Freshwater	1940-1995 specimens collected	South America	Humans	No	**McCann, et al. 1996; USGS 2012b**
	Brittle naiad *Photo: USGS NAS*	*Najas minor*	Freshwater	1983-1984 specimens collected, in US since 1930's	Eurasia	Humans	No	**McCann, et al. 1996; USGS 2012b**
	Crested floating-heart *Photo: C. Jacono*	*Nymphoides cristata*	Freshwater	2003 specimen collected	Asia	Humans	No	**USGS 2012b**
	Water-cress *Photo: WI DNR*	*Nasturtium officinale*	Freshwater	1995 specimens collected	Eurasia	Humans	No	**McCann, et al. 1996; USGS 2012b**
	Torpedo grass *Photo: V. Ramey*	*Panicum repens*	Freshwater	1982-1992 specimens collected, Lower Kississimee Valley 1920s	Europe	Humans	No	**McCann, et al. 1996; USGS 2012b**
ALGAE / SEAWEEDS / PHYTOPLANKTON								
	Blue-green alga *Photo: Umwelt Bundes Amt*	*Cylindrospermopsis raciborskii*	Freshwater	1950's first ID in the US; 1995 first ID in Florida	South America (High degree of genetic similarity with specimens from Brazil)	Humans, Other live animal (digestion/ excretion), aquarium trade, Ship ballast water/sediment, Ship/boat, Water (interconnected waterways)	No	**Dyble, et al. 2002**

4.5.6. Trend

The cumulative number of non-native aquatic species introduced into the LSJRB has been increasing since records were kept prior to 1900 (Figure 4.35). This trend is the reason that the category is assigned a CONDITIONS WORSENING status – indicating that non-native species are contributing to a declining status in the health of the St. Johns River Lower Basin.

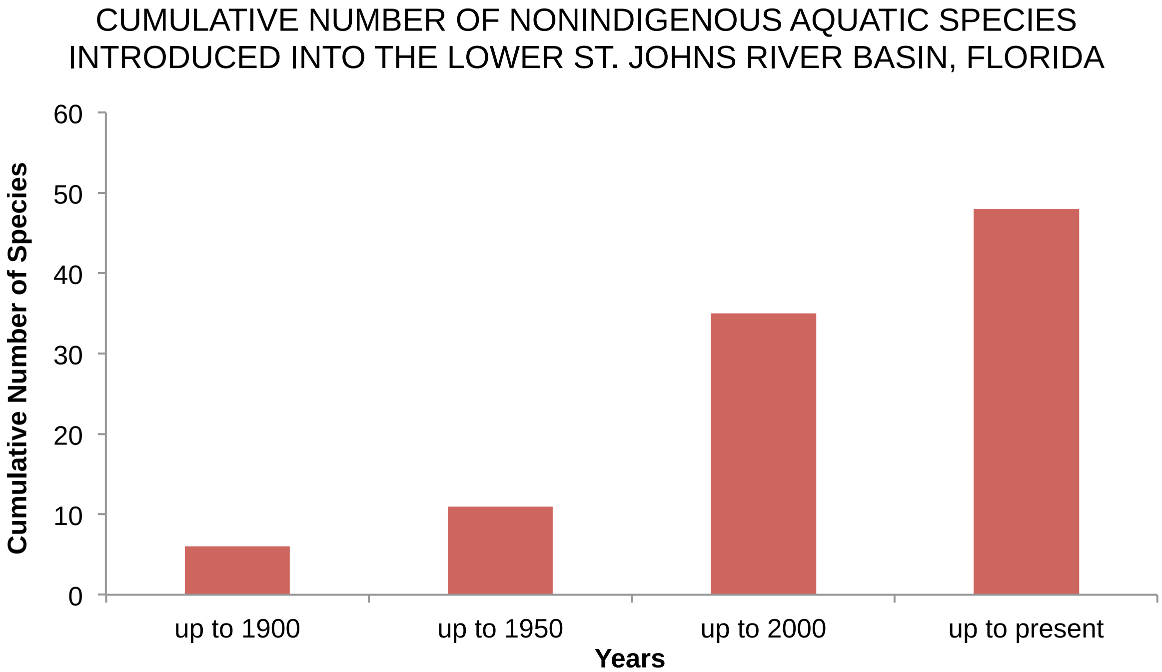


Figure 4.35 Increasing Number of Non-native Aquatic Species Introduced into the Lower St. Johns River Basin, Florida since the turn of the 20th century.

Non-native plants and animals arrive in the St. Johns River watershed by various means. The most common vector of transport has been humans (36%), followed by ship ballast consisting of water and/or sediment (17%), ship/boat hull fouling (13%), and aquaculture stock (11%) (Figure 4.36). One of the most widespread ways that non-native species arrive in Florida is when people accidentally or intentionally release exotic aquarium plants or pets into the wild. Such releases not only violate State and Federal laws but can have devastating impacts on native ecosystems and native biodiversity.

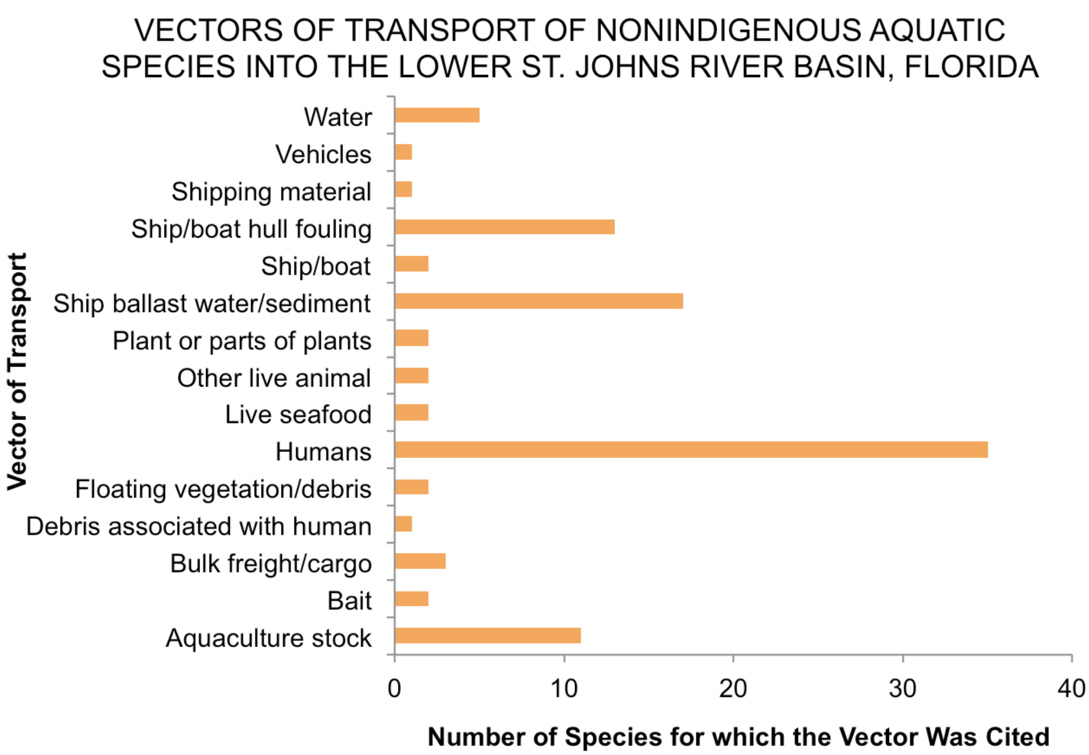


Figure 4.36 Vectors of Transport Cited for Bringing Non-native Aquatic Species into the Lower St. Johns River Basin, Florida.

Non-native aquatic species have been introduced into the Lower Basin by the aquarium trade (23%), as hitchhikers on ships, boats, or vehicles (23%), intentional releases by people (13%), or through the intentional stocking of the St. Johns River, its tributaries, or interconnected lakes (7%) (Figure 4.37).

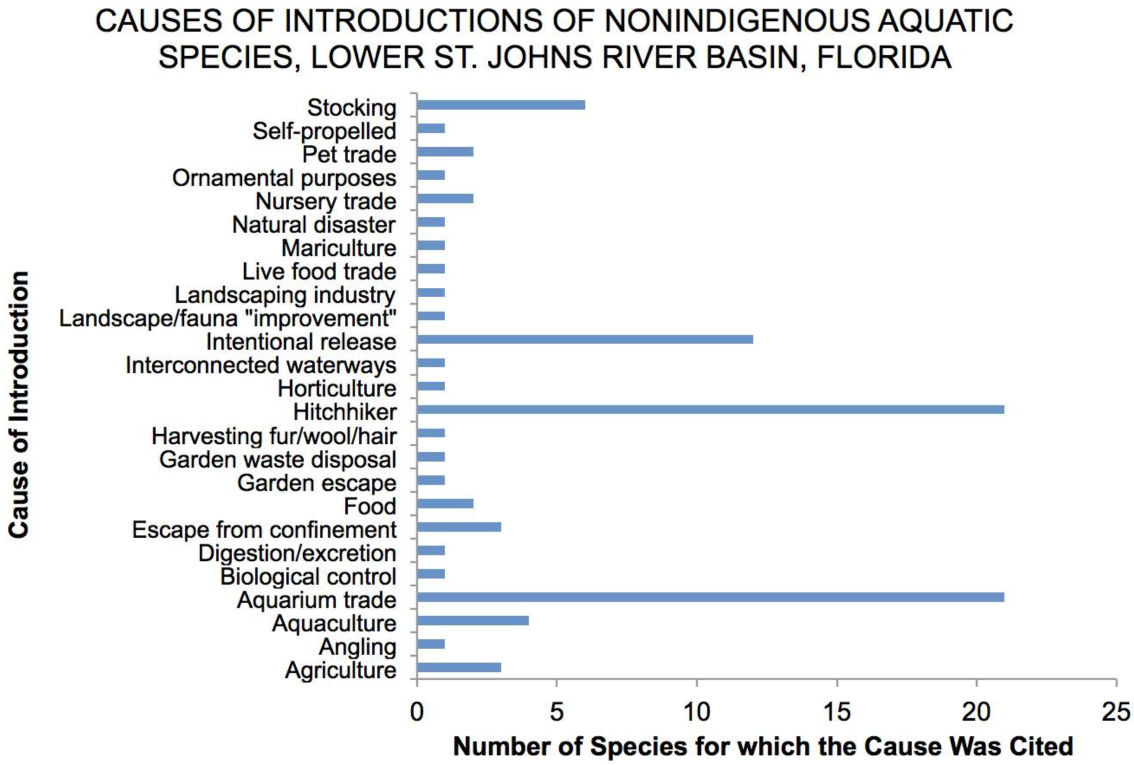


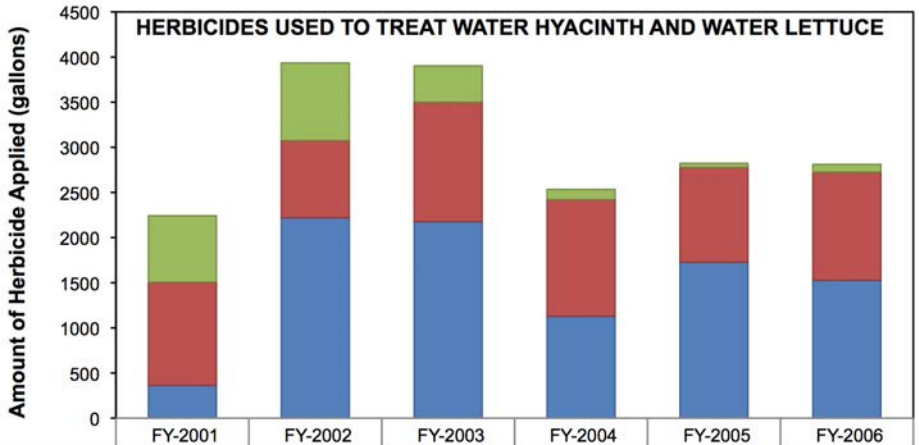
Figure 4.37 Sources for the Introduction of Non-native Aquatic Species into the Lower St. Johns River Basin, Florida.

4.5.7. Future Outlook

IRREVERSIBLE IMPACTS. Once an non-native species becomes naturalized in a new ecosystem, the environmental and economic costs of eradication are usually prohibitive (**Elton 1958**). Thus, once an invasive species gets here, it is here to stay, and the associated management costs will be passed on to future generations. Since the early 1900s, taxpayer dollars have been paying for ongoing efforts to control the spread of invasive non-native aquatic species in the St. Johns River.

Case Study: Water Hyacinth. One of the most, *if not the most*, notorious and devastating introductions of a non-native species into the St. Johns River is the lovely South American aquatic plant known as the water hyacinth. Water hyacinth was introduced into the river in 1884 near Palatka. By 1896, it had spread throughout most of the Lower St. Johns River Basin and was already hindering steamboat navigation. Water hyacinth causes changes in water quality and biotic communities by severely curtailing oxygen and light diffusion and reducing water movement by 40 to 95% (**McCann, et al. 1996**). If growth remains unchecked, these non-native aquatic plants form dense mats that obstruct waterways, disrupt transportation, and modify natural hydrology patterns and native communities and biodiversity.

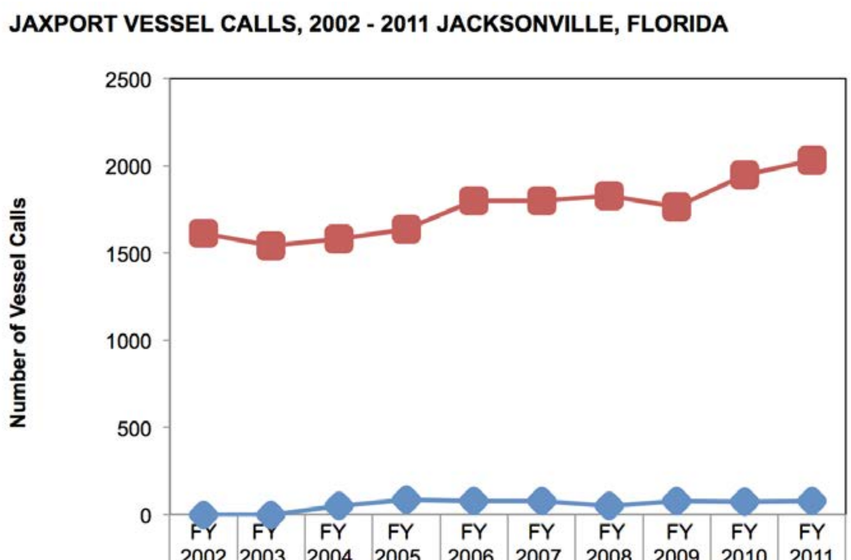
The U.S. Army Corps of Engineers (USACE) periodically sprays herbicides on the St. Johns River to control the growth of this weedy invader. From 2001 to 2006, the USACE sprayed an average of 3,042 gallons of herbicide annually on about 5,102 acres of the St. Johns River and its tributaries (Figure 4.38). This represents an average of 608 acres in the Lower Basin that were treated with herbicides during this time period (**USACE 2012**). It is likely that the use of herbicides to control invasive aquatic plants will continue into the future with negative impacts on the health of the St. Johns River watershed. The financial and ecological impacts will be multiplied, if additional invasive species become a public nuisance requiring periodic control.



	FY-2001	FY-2002	FY-2003	FY-2004	FY-2005	FY-2006
Glyphosate	736	859	404	113	45	86
Diquat	1145	857	1323	1293	1052	1199
2,4-D (Amine)	362	2219	2177	1129	1727	1527

*Figure 4.38 Gallons of Herbicide Applied on the St. Johns River, Florida to Control the Growth of Water Hyacinth (Eichhornia crassipes) and Water Lettuce (Pistia stratiotes) from Fiscal Year 2001 to 2006 (**USACE 2012**).*

HIGH RISK. There is a high probability that future invasions of non-native aquatic species will occur in the Lower St. Johns River Basin. This study found that the two most significant vectors for transporting non-native organisms were humans and ship ballast (Figure 4.24), and that both of these vectors are expected to increase in coming years, thereby increasing the likelihood for additional and potentially more frequent introductions. Human population growth in Northeast Florida is projected to more than double by 2060 (**Zwick and Carr 2006**). Additionally, the number of ships visiting the Port of Jacksonville has increased since 2002 (Figure 4.39) and is expected to increase further due to the addition of a new cargo terminal and an increasing number of cruise ship visits (**JAXPORT 2012**).



	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011
Cruise Vessel Calls	0	0	50	86	78	78	50	78	74	77
Cargo Vessel Calls	1,611	1,539	1,582	1,635	1,799	1,800	1,827	1,765	1947	2030

Figure 4.39 Number of Cruise Ships and Cargo Ships Calling on Port of Jacksonville, Florida (JaxPort) Terminals between Fiscal Year 2002 and 2011.

Additional invasions into the Lower St. Johns River Basin are expected from adjacent or interconnected water bodies. For example, 19 non-native aquatic species not found in the LSJRB have been recorded in the Upper St. Johns River Drainage Basin (**USGS 2012b**). It is likely that these species will disperse into the LSJRB in the future. Moreover, rising global temperatures may also contribute to a northward expansion in the range of non-native species from Central and South Florida.

5. Contaminants

5.1. Background

5.1.1. Chemicals in the Environment

Contaminants are chemicals that are found at unnatural concentrations in any given environment. Some are produced solely by human activity, but many are also produced naturally in small quantities. These naturally occurring compounds become contaminants when they are introduced into organisms or ecosystems in much higher quantities than normal, often as a result of human activity (examples are polyaromatic hydrocarbons, or PAHs, and metals). Furthermore, the natural concentrations of these compounds often vary with local geology and environment. Thus, it is much more difficult to detect human input and harmful concentrations for naturally occurring compounds than for those that are produced solely by human activity.

A chemical becomes environmentally significant when it is prevalent, persistent, and toxic. The prevalence of a chemical in any system depends on how much of it goes in and how quickly it goes out, either by flowing out or by degrading. A compound that is persistent breaks down slowly and is removed slowly. The probability of long-term toxic effects increases with persistence. Some types of chemicals are taken up and stored in fat tissues of plants and animals with little or no degradation, i.e., they ***bioaccumulate***. Bioaccumulated chemicals are stored in tissues of prey organisms so when prey are eaten, the chemicals can be transferred to predators and travel up the food chain in increasingly higher levels, i.e., they ***biomagnify***. Thus, organisms containing the bioaccumulated chemicals act as a reservoir, which is only slowly depleted. Chemicals in four environmentally significant categories are evaluated here. The categories include 1) polyaromatic hydrocarbons (PAHs), 2) metals, 3) polychlorinated biphenyls (PCBs), and 4) pesticides. These chemicals vary in their chemical structure, their sources, and their specific fates and effects, but they all have a high potential for prevalence, persistence, toxicity and bioaccumulation.

Information about chemical contamination is often held in the sediments of rivers. Many of the environmentally important compounds are attracted to the organic matter in sediments and end up there, regardless of how they enter the water body. Plants and animals that live in sediments, benthic organisms, are directly exposed to contaminated sediments, so assessments of their toxic responses to contaminants are particularly important in determining overall river health.

Figure 5.1 Sediment at Talleyrand, LSJR

5.1.2. Impact Assessment

There are at least three questions about contamination that scientists must answer to understand its environmental importance. First, how widespread or frequent is the contamination, i.e., what percentage of sediments that are collected are contaminated? Second, how bad is the contamination, i.e., how do concentrations found in the sediment compare to background or toxicity guidelines? Finally, is the situation getting better or worse, i.e., are concentrations going up or

down over time? These are the questions that we attempt to address for contaminants in the LSJR sediments. In this study, we evaluated the frequency, toxicity, and trends for individual contaminants, ultimately determining the relative importance of the four different chemical classes in stressing the LSJR sediments and benthic biota.

The rate at which chemicals are released into the environment clearly affects their potential environmental impact. In a addition to analyzing sediments to assess the history of contamination in the LSJR, we examined the status and trends of reported chemical releases into the atmosphere and waterways of the LSJR using the Toxics Release Inventory database provided by EPA (**EPA 2012c**).

5.1.2.1. Sediment Quality Guidelines

Environmental toxicology is the study of the effects of contaminants on ecosystem inhabitants, from individual species to whole communities. While toxicity is often viewed in terms of human health risk, human risk is one of the most difficult toxicity "endpoints," or measures, to accurately quantify. It is environmental toxicity, or effects on ecosystems and aquatic organisms, that is the focus of our assessment of contaminants in the LSJR.

The environmental impact of a toxic compound can be evaluated several ways. One way is by comparing the concentrations in the LSJR to various toxicity measures. When the concentration of a contaminant in sediment is greater than the toxicity measure, it is an ***exceedance***. Most sediment quality guidelines for contaminants are based on the impact of contaminants on sediment-dwelling benthic macroinvertebrates, assessing both the individual species' health and the community structure. Since these organisms are at the beginning of the fisheries food chain, their health is a good indicator of general river health. One toxicity measure that is quite protective of the health of aquatic organisms is a ***Threshold Effects Level*** (**TEL**). This is the concentration at which a contaminant begins to affect some sensitive species. When the number of sites that have concentrations greater than the TEL is high, there is a higher possibility that some sensitive organisms are affected. A second, less protective guideline is the ***Probable Effects Level*** (**PEL**). This is the concentration above which many aquatic species are likely to be affected. The TEL and PEL sediment quality guidelines for marine systems are used in this assessment, with emphasis on the latter. These were the guidelines that were most widely available for the compounds of interest, plus much of the heavily impacted areas are in the marine section of the LSJR. Some alternative guidelines are used and identified for some compounds for which there were no marine TEL or PEL guidelines (**MacDonald 1994**; **NOAA 2008**). Specific values are listed in Appendix 5.1.A.

In an approach similar to **Long, et al. 1995** and **Hyland, et al. 1999**, we evaluated overall toxicity of nearly 40 chemicals on the river ecosystem by calculating a PEL quotient, or **toxicity pressure**, for each sample. The quotient is the concentration of a contaminant in the sediment divided by the PEL value. If the quotient, or toxicity pressure, is greater than one, adverse impacts on benthic organisms are probable. As the quotient increases, we can assume that the probability of toxic effects increases. The quotients are used to compare the effects of different chemicals and to understand their relative importance in the impairment of the river health.

While sediment quality guidelines are useful tools, it is important to appreciate the limitations of simple comparisons in the extremely complex LSJR. A major difficulty in assessing toxic impacts is that the accessibility, or bioavailability, of a contaminant to organisms may vary with sediment type. Two sediments with similar contaminant concentrations but different physical and chemical features can produce very different environmental impacts, and we know that LSJR sediments are highly variable. Furthermore, each sediment quality guideline can be specific to certain organisms and endpoints (e.g., death of fish, reproductive effects of sea urchin, sea worm community structure, etc.) and cannot easily be extrapolated to other organisms or endpoints. As a consequence, guidelines from different organizations are sometimes different. Finally, separate guidelines are often established for marine and freshwater environments, though few estuarine guidelines exist that apply to the LSJR. These challenges limit our assessment of the impacts of various contaminants on the LSJR to one that is general and relative in scope.

5.2. Sediment Data Sources and Analysis

The data used in this report came from several major studies carried out on the Lower St. Johns River from 1983 to 2007. They were conducted by the SJRWMD (**Delfino, et al. 1992**: **Delfino, et al. 1991a**; **Durell, et al. 2004**; **Higman, et al. 2008**) and the Florida Department of Environmental Protection (**Delfino, et al. 1991a**; **Pierce, et al. 1988**), Data were used from the National Oceanographic and Atmospheric Administration’s National Status and Trends Mussel Watch program

(**NOAA 2007b**) and Benthic Surveillance Watch (**NOAA 2007a**) program. Data from STORET databases managed by EPA (modern) and DEP were included in this year's river report. The STORET data were from studies by the National Park Service Water Resources Division, Florida Department of Environmental Protection, and the Marine Research Institute of the Florida Fish & Wildlife Conservation Commission. Savannah Laboratories (**SLES 1988**), **Cooksey and Hyland 2007**, and **Dames and Moore 1983** also generated data that were analyzed in this report. The best and most recent data came from an extensive set of studies conducted by the SJRWMD. This ongoing study began in 1996 and provides a long-term sediment quality assessment of the LSJR (**Durell, et al. 2004**; **Durell, et al. 1997**; **Higman, et al. 2008**).

A summary of the sources of data is given in Appendix 5.2.A. The database that was generated represents a substantial portion of existing data for LSJR contaminants. It is not exhaustive however, and should be considered a starting point from which omitted past and future studies can be added. In particular, modern pesticides, other important priority pollutants and emerging pollutants, such as endocrine disruptors, should also be included. Future additions of data on concentrations of contaminants in water and organisms will also add to the quality of the assessment.

The contaminants we selected for evaluation had the highest abundance of data available for several years and adequate site information. Sometimes we omitted potentially important contaminants because of analytical differences between studies. The data were first compiled from each source for approximately 200 analytes at nearly 500 sites, over a span of 20 years, and then were culled for location and analytical comparability. We omitted data from some years when the numbers of samples were too few, or when extreme values distorted the analysis. For example, Deer Creek samples in 1991 that consisted of nearly pure creosote (**Delfino, et al. 1991b**) were omitted.

Sediment contamination was assessed by calculating average concentrations, percent exceedances of sediment quality guidelines, and average toxicity quotients, or toxicity pressure. These parameters were compared between years and regions of the river. Data below the detection limit were evaluated as zeroes in these calculations. The numbers of samples for each contaminant, year, and area are given in Appendix 5.2.B.

Trends were assessed by plotting median annual concentrations against time and determining the significance of an upward or downward slope of any line (Spearman Rank correlation coefficients $p<0.05$). Because of the limitations of the data, all trends were confirmed by graphical analysis and Pearson Product coefficient > 0.5. Trend statistics are given in Appendix 5.2.C.

Advances in analytical technology during the last 20 years have dramatically reduced the concentration at which some chemicals can be detected. This can skew interpretations of temporal trends, which we attempted to avoid by transforming the zero values in the data to minimum detectable levels. Where possible, the reported minimum detection limits were substituted for zero values. In some cases, we estimated a minimum level of detection by finding the lowest nonzero value in a given year and halving it. Using minimum detection limits reduces the possibility of erroneously concluding there is an increasing trend because of differences in analytical detection limits.

There are numerous sources of variability in reported sediment concentrations reported, including analytical differences, sampling variations, physical and chemical characteristics of the sediment, and even differences in definitions of reporting parameters such as minimum detectable limits. Furthermore, there are large differences in the numbers of samples in different regions, all taken at irregular intervals. These data gaps limit the applicability of many different standard statistical tests. Thus, major harmful contaminants and their spatial and temporal trends can be difficult to positively identify and requires judicious use of statistics and careful review of all data. Box and whisker plots of the data are given in Appendix 5.2.D, which illustrate the distribution of the values for each contaminant in each region for each year.

5.2.1. Regions of the LSJR

Within the LSJR basin, there is a large variation in the types of ecosystems, land uses, and hydrology. As a consequence, the distribution and potential impacts of contaminants will vary widely within the basin at any given time. To analyze contaminants in the LSJR, we divided it into four regions (Figure 5.2) with roughly similar hydrologic and land use characteristics. Where possible, trends were tracked within each region, and comparisons were made between the regions.

One region, Area 1, is a composite of the basins of three tributaries on the western side of the LSJR. The western tributaries area is composed of the Trout River (including Moncrief Creek and Ribault River tributaries), Long Branch Creek, the Cedar-Ortega system, Big Fishweir Creek, and Rice Creek. Despite their distance from one another, they were combined because they share the unfortunate characteristic of having such high levels of contamination for some chemicals that they mathematically obscure trends in the rest of the lower basin. The northernmost region, Area 2, the north arm, stretches from the coast at Mayport to Talleyrand, and has an extensive maritime industry. It is strongly tidal with a range of salinity from marine to estuarine. Moving south, the next region is Area 3, or the north main stem, which includes urban Jacksonville and extends down to Julington Creek. The southernmost region in the LSJR, Area 4 or the south main stem, stretches from the Duval County boundary, past Palatka to the Ocklawaha and fresher water. Additional information about the different regions is given in Appendix 5.2.E.

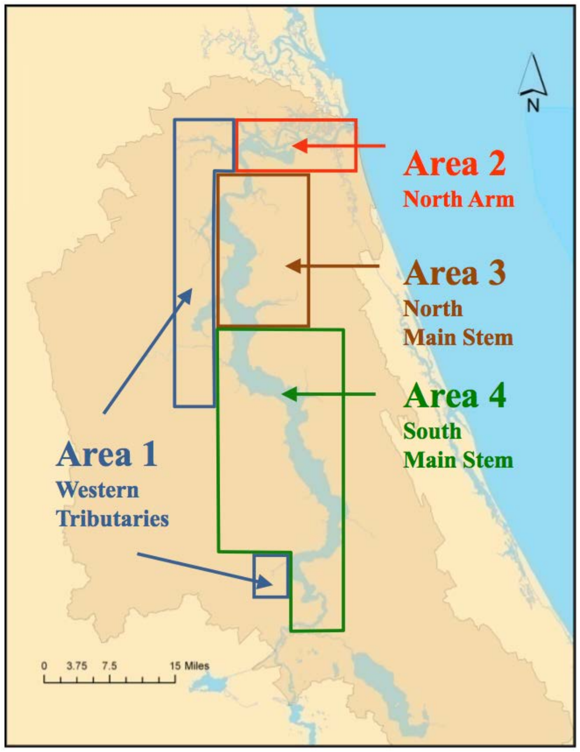


Figure 5.2 Areas of the LSJR studied for sediment contamination: Area 1 – western tributaries (including Trout River, Moncrief Creek, Ribault River, Long Branch Creek, Cedar-Ortega Basin, and Rice Creek); Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See Appendix 5.2.E for additional details.

5.3. Toxics Release Inventory: Point sources of contaminants in the LSJR region

The EPA's Toxics Release Inventory (TRI) program was established as a provision of the Emergency Planning and Community-Right-to-Know Act designed to protect communities from chemical hazards. The legislation was enacted in 1986 after serious industrial accidents in Bhopal India and in West Virginia resulted in numerous fatalities. The program was expanded under the 1990 Pollution Prevention Act so that today the TRI program requires facilities to report the quantities of more than 650 toxic chemicals that they release into the environment. Annually, they must report how much of each of these compounds is released on-site into the air, to surface water, to groundwater, to landfills, and to surface impoundments. They must also quantify how much they treat on-site and how much is transported off-site for treatment or disposal (e.g., to publicly-owned municipal treatment plants or to landfills). Facilities are not required to report their releases if they have fewer than 10 employees or if they discharge less than various threshold limits for different chemicals (**EPA 2012c**). The reported quantities may be derived from direct measurement, modeling estimates, or by "emission factors." The emission factors are usually averages of available data on emission rates of facilities in a particular source category (e.g., electric utilities, on-road vehicles) (**EPA 2012b**).

The TRI provides information that can be used to estimate point source loading of hundreds of chemicals released into the environment by dozens of industries. Local, statewide or national trends can be examined. We determined the annual loading of toxic compounds into the LSJR basin from 2001 to 2010 using data from EPA's TRI-NET database (**EPA 2012e**).

Emissions into the atmosphere and discharges into LSJR surface waters were analyzed since chemicals released to these media are most likely to affect the LSJR, though significant discharges to land are also reported for many industries (Table 5.0). The environmental impact of atmospheric emissions is more difficult to determine than direct surface water discharges because of uncertainties in the fate of chemicals in the atmosphere and the potential impact from both long-range and local sources. However, higher local emissions will certainly increase the likelihood of local impact. In the following discussion, atmospheric emissions are addressed separately from surface water discharges.

Analyses of air emissions included all reporting facilities in the nine counties in the LSJR watershed: Clay, Duval, Flagler, Putnam, St. Johns, Volusia, Alachua, Baker, and Bradford. Even if facilities are not located directly on the river, nearby emissions in the county are potential sources of pollutants in the river, though exactly how much finds its way into the river is largely unknown. For discharges into the LSJR surface waters, we included facilities that discharged directly into the SJR or its tributaries, as determined by the Form R report submitted by the facilities to the EPA. It is important to note that the magnitude of discharges or emissions does not always directly relate to human health effects or environmental harm. For example, very large quantities of manganese discharged into waterways are much less problematic than much smaller quantities of mercury or dioxins.

Table 5.1 Reported Releases of Chemicals by Industries in the LSJR Basin (EPA 2012e).

		Tons Chemicals Released	No. Toxic Chemicals	No. Industries	No. Facilities
2001-2010	On-site[1]	94,778	79	24	131
	Air[2]	65,390	73	24	128
	Water[3]	2,095	41	12	21
2010	On-site[1]	5,469	52	22	77
	Air[2]	3,965	48	21	73
	Water[3]	162	28	9	13

1 On-site releases include emissions to air, discharges to surface waters and disposal on land (e.g., landfills, surface impoundments)

2 Air emissions from facilities in nine LSJR counties. 3 Water discharges into the LSJR and its tributaries.

Typically, industrial facilities emit more chemicals into the atmosphere than into surface water (Table 5.1). The reporting facilities in the nine LSJR counties released 72% of their waste into the atmosphere and only 3% into surface waters in 2010. The rest of the on-site releases were to landfills and surface impoundments.

Between 2001 and 2010, the reported annual release of chemicals to the atmosphere declined by half to 8 million pounds (Figures 5.3 and 5.4). Reductions in emissions by St. Johns River Power Park and Northside Generating Station, Seminole Electric and Gainesville Regional Utilities at Deerhaven were responsible for most of the decline. Sulfuric acid declined the most, 5 million pounds or 73%, over a decade. Reported emissions of methanol and styrene also declined significantly between 2001 and 2010.

Despite the substantial reductions in sulfuric acid emissions, 80 percent of the chemicals reported to be released to the LSJR region atmosphere in 2010 were acid gases, mostly released by electric utilities. Of the total atmospheric releases in 2010, 14% were composed of methanol, ammonia and styrene that were emitted by a variety of industries (i.e., paper and wood products, chemical, metal, electric, plastics and rubber, transportation equipment, cement and food). The remaining 42 chemicals released into the atmosphere were organic and inorganic compounds such as polyaromatic hydrocarbons (0.1 % of the total or 7,000 lbs.) and metals (0.4% or 30,000 lbs.), discussed in more detail in Sections 5.4 and 5.5.

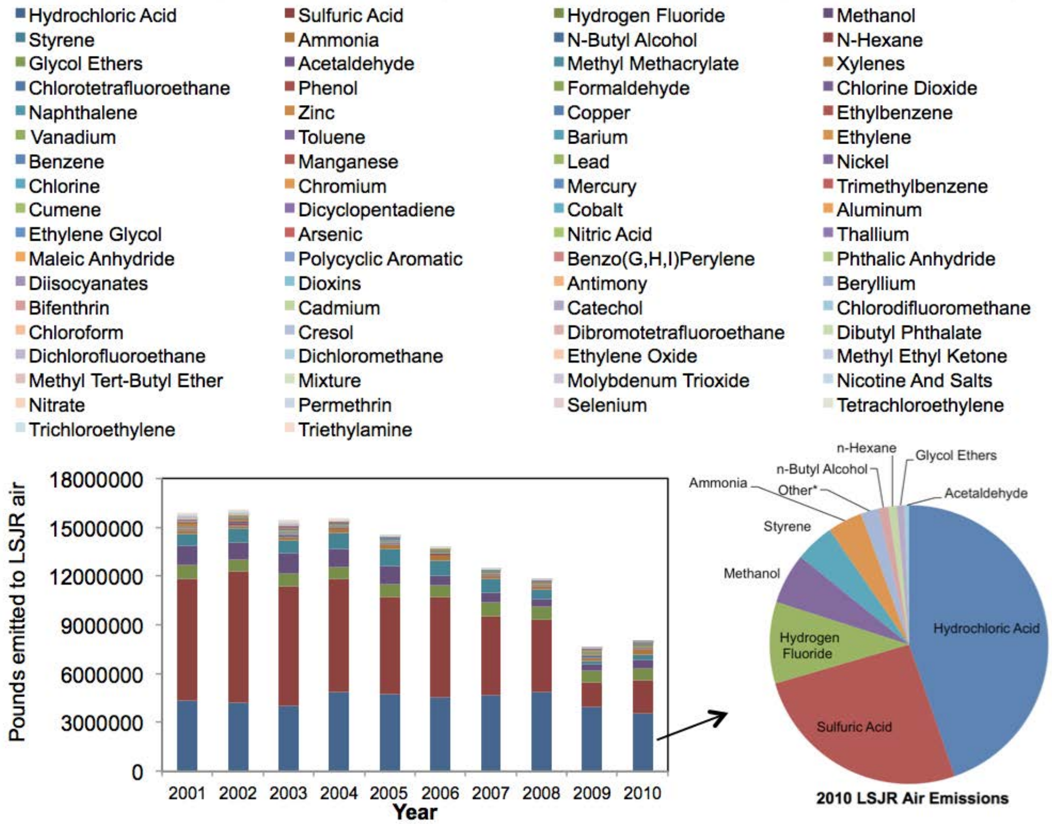


*Figure 5.3 Trends and status of 79 chemicals released to the atmosphere by industries in the nine-county LSJR basin as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the distribution of 8 million pounds of chemicals emitted in 2010. The Other category in the inset is composed of 36 chemicals ranging from 25,000 pounds of methyl methacrylate to 20 grams of dioxins.*

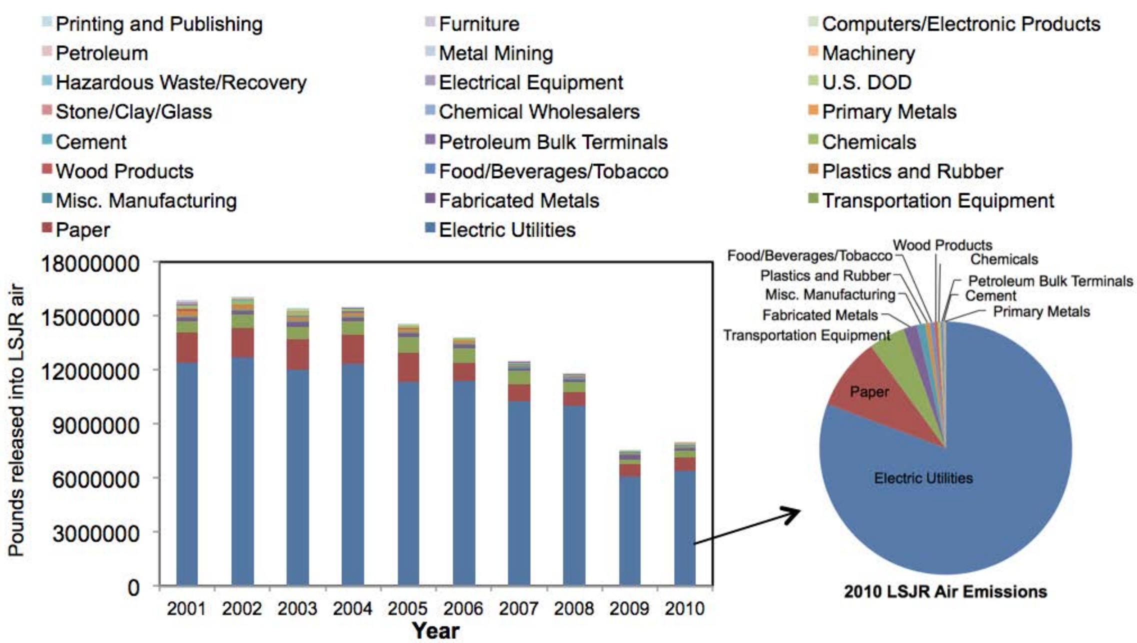


*Figure 5.4 Trends and status of 23 industries releasing chemicals to the atmosphere in the nine-county LSJR basin as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the major industries emitting 8 million pounds of chemicals in 2010. Industries reporting air emissions less than 5,000 pounds are not indicated and include computers/electronic products, petroleum, metal mining, machinery, hazardous waste/recovery, electrical equipment, U.S. DOD, stone/clay/glass, chemical wholesalers, and the primary metals industries.*

Unlike atmospheric emissions, discharges into the LSJR were similar in 2001 and 2010 with fluctuations in discharges of nitrate and manganese by the paper industry and U.S. DOD affecting overall SJR loading during the decade (Figures 5.5 and 5.6). There was a widespread reduction of discharges by industries that are relatively small dischargers, but an

exception was the electric utility industry which reported a 70% increase (nearly 5,000 pounds) in total annual chemicals discharged between 2001 and 2010, mostly in the form of barium, cobalt, and manganese.

In 2010 most of the chemicals reported to be discharged directly into the SJR and its tributaries were nitrates released by the U.S. Department of Defense (68%, 222,000 lbs.) and the pulp and paper industry (12%, 40,000 lbs.). These discharges, along with manganese discharged by the paper industry, comprise 95% of the total reported chemicals released into the LSJR in 2010 (Figures 5.5 and 5.6).

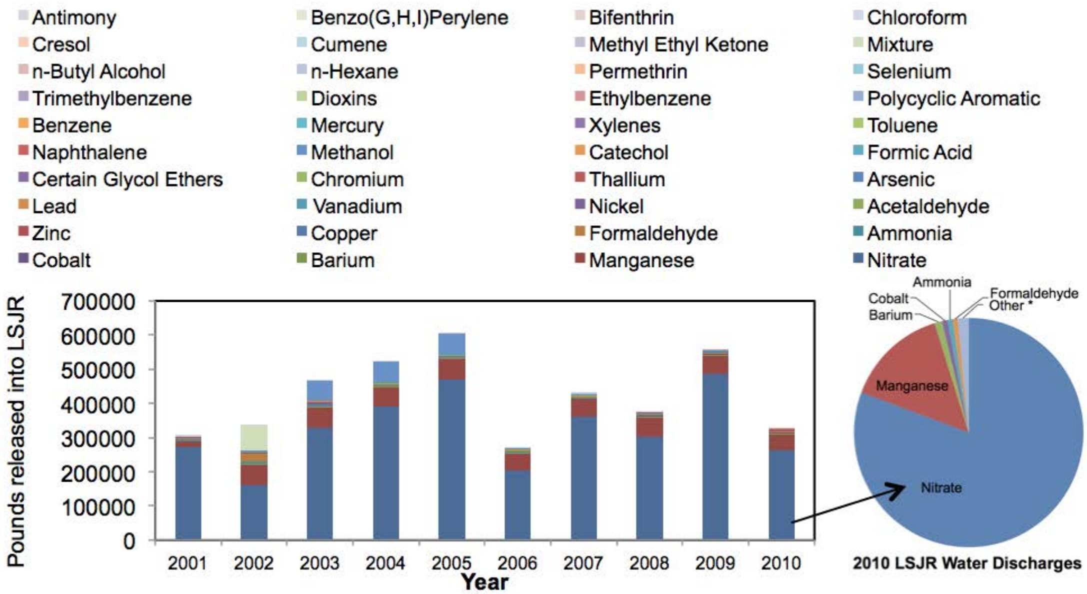


Figure 5.5 Trends and status of 40 chemicals released to the LSJR and its tributaries as reported in the Toxics Release Inventory (EPA 2012c). Inset shows the distribution of 324,000 pounds of chemicals discharged in 2010. The Other category in the inset is composed of 21 chemicals ranging from 800 pounds of copper to a few grams of dioxins.

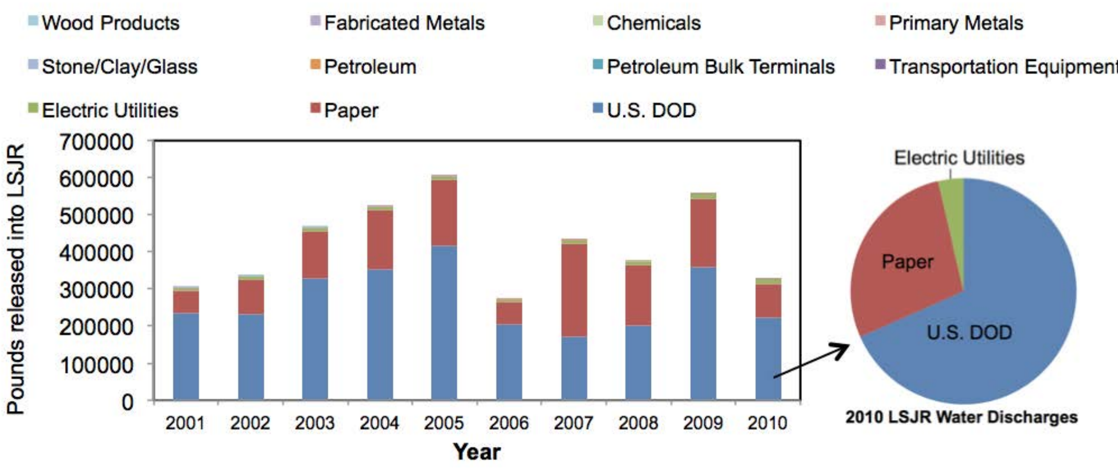


*Figure 5.6 Trends and status of 11 industries releasing chemicals into the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the major industries emitting 324,000 pounds of chemicals in 2010. Industries reporting air emissions less than 5,000 pounds are not indicated and include computers/electronic products, petroleum, metal mining, machinery, hazardous waste/recovery, electrical equipment, U.S. DOD, stone/clay/glass, chemical wholesalers, and the primary metals industries.*

In summary, industries in the LSJR region reported the release of nearly 35 million pounds of chemicals into the air and into the river and its tributaries in 2010, with 95% released into the air. Local emissions to the atmosphere, mostly from electric utilities, are primarily composed of acid gases followed by methanol, styrene, ammonia and metals. Air emissions have halved between 2001 and 2010, similar to the rest of the state and the U.S. (**EPA 2012d**). Dozens of additional chemicals are released at slower rates. The LSJR surface waters received 324,000 pounds of chemicals in 2010, mostly nitrates and manganese released by the U.S. Department of Defense and the paper industry. The rate of discharge of chemicals into the LSJR surface waters in 2010 is 7% greater than in 2001 while the rest of the state and US discharged about 10% less since 2001.

Overall, TRI data suggest that the mass of contaminants released to the atmosphere from point sources in the LSJR region has significantly declined over a decade though little change in overall surface water discharges has occurred. These reductions in atmospheric emissions may be related to the recently enacted rules for reducing air emissions of mercury and other toxic compounds from coal-fired utilities (**EPA 2012a**). Emissions are frequently estimated from production-dependent emission factors, thus the decline in reported emissions may reflect the general decline in U.S. industrial productivity during the last several years.

5.4. Polyaromatic Hydrocarbons (PAHs)

5.4.1. Background: PAHs

Polyaromatic hydrocarbons are a class of over a 100 different chemicals, some of which are carcinogenic. They are often found in the environment in complex mixtures. Sometimes the patterns of distribution of the different types of PAHs can give clues to their sources and fates. They are often subdivided into classes of small, Low Molecular Weight (LMW) compounds, and larger High Molecular Weight (HMW) compounds. The two subclasses of PAHs tend to have different sources, environmental fates, and toxic effects, although there is considerable overlap in their characteristics.

PAHs arise from two major pathways. Pyrogenic ("fire"-generated) PAHs are formed during the combustion of organic matter, including fossil fuels. The PAHs formed by combustion tend to be the HMW type. Petrogenic ("petroleum"-generated) PAHs are also formed naturally and are precursors and components of complex organic matter including oil, coal, and tar. Petrogenic PAH mixtures tend to have more of the LMW type of PAH.

Although PAHs are naturally occurring, large quantities are introduced into the environment by human activities, particularly through fossil fuel handling and combustion. About 80% of PAH emissions are from stationary sources such as power plants, and 20% come from mobile sources such as automobiles and trucks, but the distribution can change with locale. Urban environments have more vehicular-related PAHs than rural or agricultural areas (**ATSDR 1995**). They may also be introduced into the aquatic environment from creosote in preserved wood, which may be a significant historic source of PAHs in the north main stem, Area 3, of the LSJR.

PAHs are mainly introduced into water bodies by the settling of PAH-laden atmospheric particles into the water, and by the discharge of wastewaters containing PAHs. Spills of petroleum products and the leaching of hazardous waste sites into water bodies are other ways that PAHs enter the aquatic environment. Once they are in the water, the PAHs tend to settle into the sediments, especially the HMW PAHs. The LMW PAHs also associate with particles, but to a lesser extent. As a result, the LMW PAHs can be transported farther by the river's tides and currents.

PAHs can be degraded by microbes and broken down by sunlight. Biodegradation accounts for the majority of removal in slow-moving, turbid waters typical of some of the LSJR. Many aquatic organisms can metabolize and excrete PAHs, particularly the LMW types, so the chemicals are not extensively passed up the food chain. However, HMW PAHs can accumulate in fish, amphipods, shrimp, and clams since they are only slowly degraded and reside in fats in organisms (**ATSDR 1995**: **Baird 1995**).

EPA has focused on 17 different PAHs primarily because they are the most harmful, have the highest risk for human exposure, are found in highest concentrations in nationally listed hazardous waste sites, and because there is information available about them (**ATSDR 1995**). In our analysis of the LSJR sediment data, 13 of the 17 EPA compounds were examined in detail as well as two that are not on the EPA list. These PAHs were selected for study because of the extensiveness of the data, the uniformity of the study methods, and their presence in the LSJR.

5.4.2. Current Status: PAHs

Polyaromatic hydrocarbons were found mostly at concentrations between the TEL and PEL guidelines. Most (~70%) of the samples in the western tributaries, Area 1, and the north arm, Area 2, had PAH concentrations exceeding the TEL, suggesting a low-level stress on sensitive benthic organisms by these compounds (Figure 5.7). The north arm had the most exceedances of the PELs, indicating that adverse impacts on benthic organisms from PAHs in that region are probable.

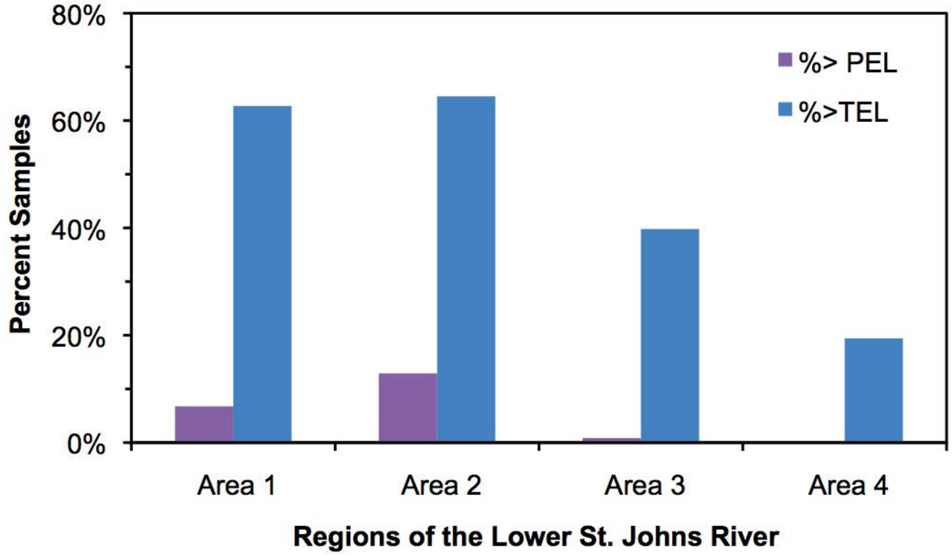


Figure 5.7 Percentage of samples from 2000-2007 with PAH concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for one or more PAHs. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

The toxicity pressure from PAHs was evaluated for each region using all data available since the 2000s. In Figure 5.8, the relative toxicity pressure from each PAH and the cumulative toxic pressure in each region can be compared. The PAHs exert similar overall toxic effects in Areas 1 and 2, but the PAHs responsible for the majority of the effects were different between the two regions, suggesting different sources of PAHs. The north arm, Area 2, is impacted most by acenaphthene (toxicity quotient >1) but fluoranthene, naphthalene, and 2-methyl naphthalene also contribute significantly to the toxicity pressure (toxicity quotient > 0.5).

In Area 1, the western tributaries, anthracene was the largest single contributor to PAH toxicity, while other PAHs exerted similar, low-level effects (Figures 5.8 and 5.9). Within Area 1, the highest levels for anthracene were found in Rice Creek in 2000-2003, with an average concentration nearly ten times the anthracene PEL (89 ppm), as shown in Figure 5.9. Levels near the PEL were also found in the Cedar-Ortega and Trout Rivers. Sediments in the north and south main stem regions (Areas 3 and 4) had average concentrations between the two guidelines, and were similar in their patterns of PAH contamination. The north arm, Area 2, where the shipping industry is prevalent, sediments had higher proportions of acenaphthene, naphthalene, and 2-methyl naphthalene, LMW PAHs, than the rest of the main stem.

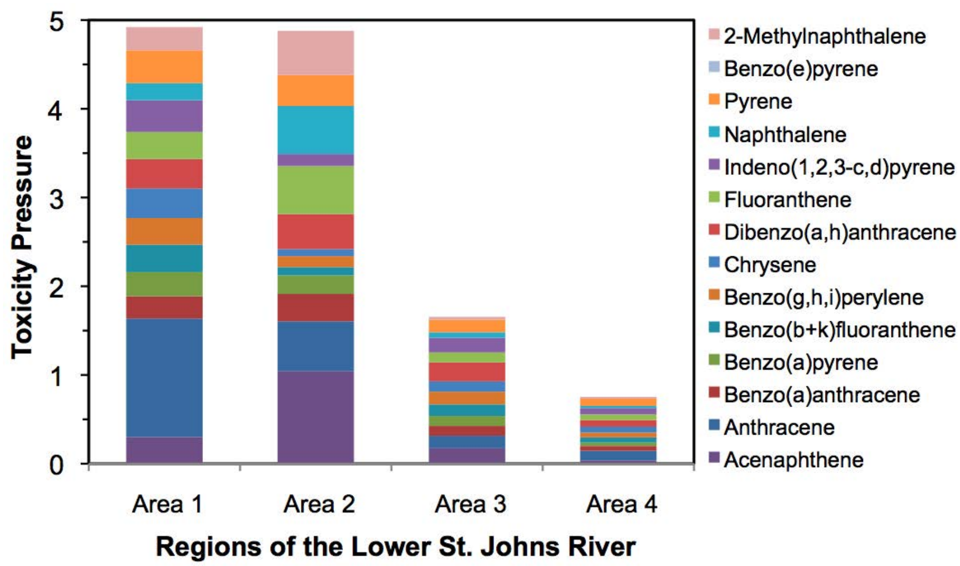


Figure 5.8 Average toxicity pressure of PAHs in sediments from 2000-2007 in the four areas of the LSJR. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

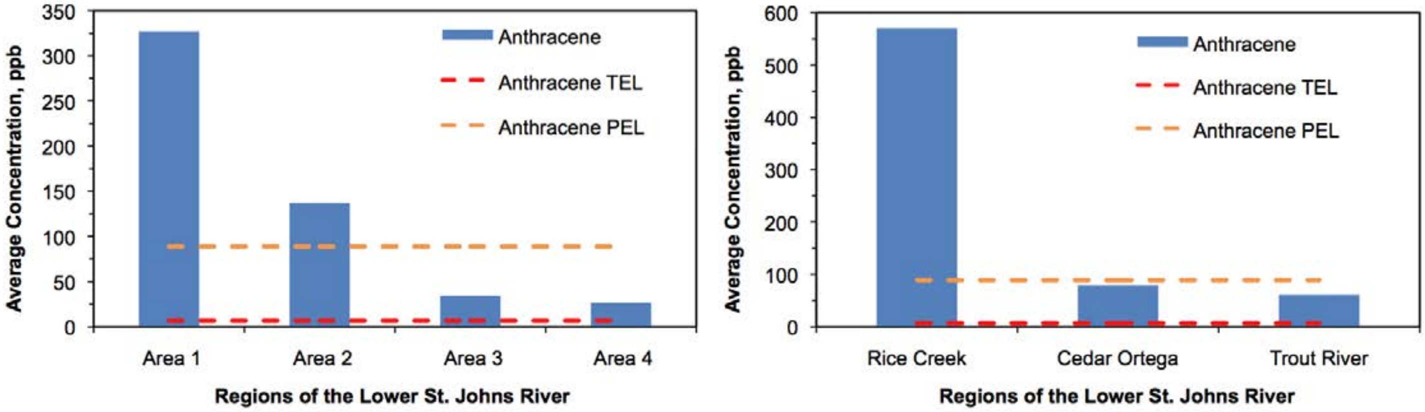


Figure 5.9 Average concentrations of anthracene in sediments from 2000-2007 in the four areas of the LSJR and in three streams in Area 1. Sediment quality guidelines for anthracene are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

5.4.3. *Trends: PAHs*

There was extreme contamination of Deer Creek from the Pepper Industries' creosote tanks near Talleyrand that was documented in 1991 (**Delfino, et al. 1991a**). Creosote is a product of coal tar that is used for wood preservation. While Deer Creek was the worst contaminated site, there were several other hot spots reported over the years for various PAHs. In the late 1980s, there were several sites all along the LSJR that had extremely elevated levels of PAHs, including acenaphthene in the north main stem, Area 3, at NAS Jacksonville (278 ppb), fluoranthene in Dunn Creek in the north arm, Area 2, (10,900 ppb), and pyrene in Goodby's Creek (8470 ppb). Most recently, the highest concentrations of naphthalene and anthracene (LMW PAHs) occurred in Rice Creek in 2002.

There are encouraging signs that some PAH levels have gone down since the late 1980s. Data were not collected continuously over the years, but for many PAHs, high concentrations found in the late 1980s declined dramatically to lower levels in 1996 where they have remained at lower concentrations. This pattern was particularly evident in Areas 3 and 4, the north and south main stem regions (Figure 5.10) and may reflect recovery from the creosote contamination during that time. Some of the PAH load in the western tributaries has also declined since the 1980s.

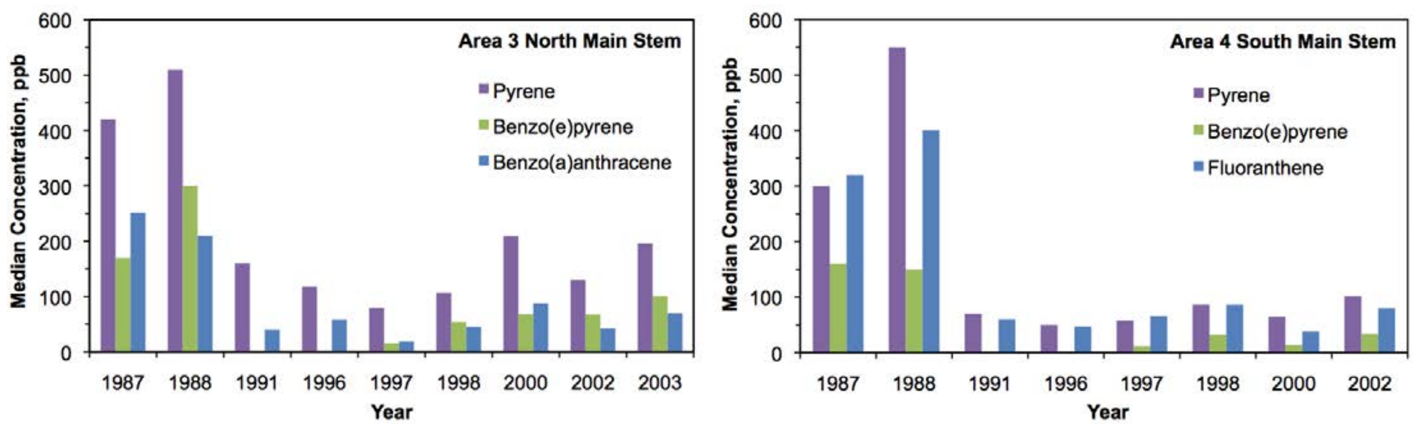


Figure 5.10 Median concentrations of PAHs in sediments from 2000-2007 in Area 3 (north main stem) and Area 4 (south main stem). Note that years are not continuous. See text in Section 5.2 for data sources.

However, since the 1990s, several PAH levels may be slowly rising in the main stem. While there are too few data points for a rigorous trend analysis, there may be a modest increase in most PAHs in Areas 3 and 4, similar to those shown for pyrene in Figure 5.11. Despite the uncertainty due to a lack of data, it is important to continue monitoring locales such as Clay and St. Johns Counties, which are rapidly becoming more urbanized, and can be expected to generate the PAHs typical of those land uses.

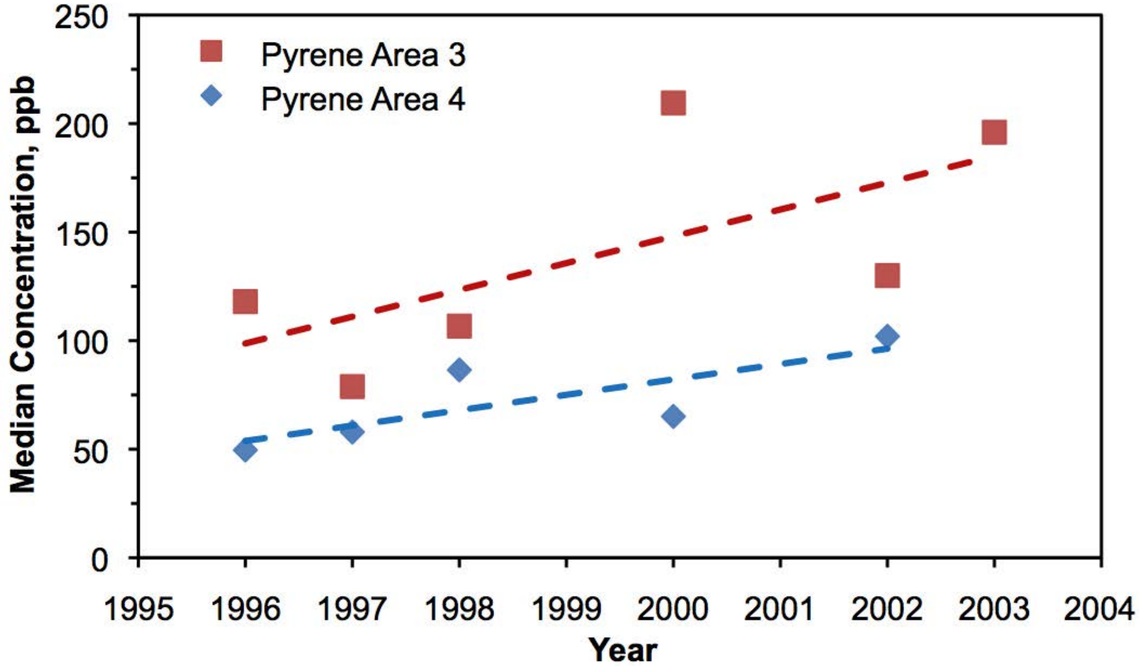


Figure 5.11 Apparent rise of median concentrations of pyrene in LSJR sediments since 1996 in Area 3 (north main stem) and Area 4 (south main stem). Dashed lines represent trend lines. See text in Section 5.2 for data sources.

5.4.4. PAHs in Oysters

In the Mussel Watch Project of NOAA's National Status and Trends Program (**NOAA 2007b**), oysters in Chicopit Bay in the north arm, Area 2, of the LSJR were analyzed for PAHs from 1989-2003 (Figure 5.12). These data show that there is a broad spectrum of PAH contaminants in Chicopit Bay oysters, but the PAHs with the most consistently high levels are pyrene and fluoranthene. There is no apparent decrease in the total PAH values in the oysters, despite decreasing trends of other contaminants such as PCBs, some pesticides, and some metals (**O'Connor and Lauenstein 2006**). In the 2000s, the sediment PAHs in the Area 2 north arm has a distribution similar to oysters with a predominance of fluoranthene, naphthalene and 2-methylnaphthalene. However, the high levels of acenaphthene found in the sediment in the 2000s were not reflected in oyster tissue.

The PAHs in the oysters have many possible sources, but several are often associated with petroleum contamination, a possible result of Chicopit's proximity to a shipping channel with high boat traffic. This appears especially true in 2003 when the concentrations in oysters approached the levels of the 1980s. The 2003 oysters also had more of the methylated LMW PAHs that suggest petrogenic origins of the compounds. Standards for consumption are sparse for PAHs (**EPA 2007**), but for the compounds for which there are standards (anthracene, acenaphthene, fluoranthene, fluorene, and pyrene), the levels found in these oysters would not be harmful. However, as noted, there are few direct data about the hazard of consumption of PAHs, including the notoriously carcinogenic benzo(a)pyrene or other PAH carcinogens.

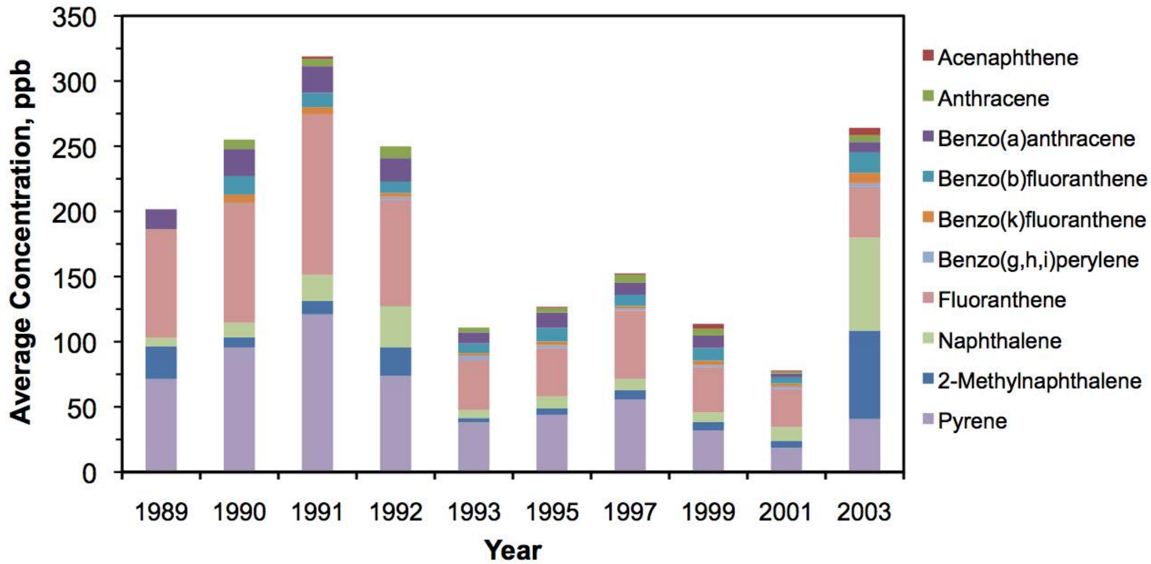


Figure 5.12 Concentration of select PAHs in oysters in Chicopit Bay, LSJR (Area 2 – north arm). Note that years are not continuous. See text in Section 5.2 for data sources.

5.4.5. *Point Sources of PAHs and related compounds in the LSJR Region*

Reported PAH emissions to the LSJR region atmosphere have dropped by 70% over the last decade, mainly due to reductions in emissions by electric utilities and the paper industry (**EPA 2012e**). In 2010 these industries emitted 200 pounds into the atmosphere in the LSJR region. Direct surface water discharges of PAHs have declined from nearly 20 pounds in 2001 to a pound in 2010, all of which is now released by electric utilities.

Polyaromatic hydrocarbons are chemically similar to other aromatic hydrocarbons, including some of those reported in the TRI program. Emissions of PAHs in the LSJR region correlated with those of toluene (Pearson $r^2 = 0.8$) , xylenes ($r^2 = 0.85$), trimethylbenzene ($r^2=0.79$), and naphthalene ($r^2=0.54$). All experienced significant drops in emission rates over the decade. Despite the similarity of their overall trends, overall reductions were due to changes in emissions of various industries. For example, naphthalene emissions reported by electric utilities and petroleum bulk terminals increased substantially, but the declines in the chemical industry emissions outweighed the effect of the other two industries. Emissions of xylenes have dropped since 2001 primarily due to reductions by the transportation equipment industry between 2003 and 2004, while the chemical industry emissions of trimethylbenzene steadily declined since 2001.

Overall, there was a significant drop in point source releases of PAHs and related compounds into the air and water in the LSJR region between 2001 and 2010. Several industries have shared in reducing the overall aromatic hydrocarbon loading to the region

5.4.6. *Summary: PAHs*

Portions of the LSJR appear to still be recovering from severe creosote contamination from the 1980s, but there are likely to be additional petroleum and combustion sources. The PAHs occur at levels that may be problematic in some areas, and there continues to be widespread contamination. Near the port in Area 2, the combined impacts from power plants, shipping, and the maritime industry are likely to cause this region to continue to be the most heavily impacted by PAHs into the future. There is direct evidence that these compounds reside in consumable organisms in the river in that area. There is a possible rise of PAHs in the southern main stem portion of the river, which may be beginning to suffer the same stress from urban impact that the north main stem experiences. In summary, PAHs in the LSJR are likely to be a significant source of stress to sediment-dwelling organisms, despite their overall decline since the 1980s. A drop in the release of PAHs into the region by industries since 2001 may effect a gradual improvement in the next few years if the emission rates remain stable or decrease.

5.5. Metals

5.5.1. Background: Metals

Metals are naturally occurring components of the mineral part of a sediment particle. Major metals in sediments are aluminum, iron, and manganese and these are often used to differentiate types of sediment (more like terrestrial soil or limestone bedrock). Sediment composition varies naturally with local geography and environment, and so the concentrations of metals in sediments also vary naturally. Sediments in the main stem LSJR have widely different geologic sources. By contrast, the Cedar-Ortega system sediment characteristics suggest common geologic sources (**Durell, et al. 2004**; **Scarlatos 1993**). As a result of this natural variability, it is difficult to always determine if metal levels are elevated because of human activities or simply because of the nature of the sediments. Concentrations of metals of high concern, like lead or chromium, are often compared to aluminum concentrations to try to determine what amount is the result of human input (**Alexander, et al. 1993**; **Schropp and Windom 1988**).

One of the major human sources of most metals in the environment is from coal and oil combustion. Metals are present in these fuels in small quantities, but since massive amounts of fuel are combusted, large quantities of these elements are released into the atmosphere, often fated for future deposition into water bodies. Ore smelting and refining, mining, and various manufacturing processes also introduce metals into the environment, usually as point sources. Some metals have been, or are currently used in pesticides. An example is copper, which is used to control algae. Metallic contamination also occurs with various metal-working enterprises where metal fabrications are produced and processed. Another avenue for metals to enter into aquatic environments is from leaching from hazardous waste sites (**Baird 1995**). The metals that we have evaluated in this study include mercury, lead, cadmium, copper, silver, zinc, and chromium.

5.5.2. Current Status: Metals

Metals in general have been elevated over natural background levels in sediments all throughout the LSJR for at least two decades and continue to do so today. Nearly all (75-91%) of the sediments that were analyzed since 2000 have had concentrations of chromium, zinc, lead, cadmium, or mercury (discussed in more detail below) that are greater than natural background levels (**NOAA 2008**), sometimes by very large amounts. Sediments in Rice Creek that were analyzed in 2002 had mercury levels that were about 100 times greater than natural background levels. High metal concentrations were found in sediments elsewhere throughout the river, including the Cedar-Ortega system, Moncrief Creek off the Trout River, Broward Creek, and Doctors Lake.

Table 5.2 Average Metal Concentrations and Percentage of Samples Exceeding Background and Sediment Quality Guidelines in the LSJR Sediments from 2000-2007[1] (see text in Section 5.2 for data sources)

	Average, ppm	Background, ppm[1]	% > Background	TEL[2], ppm	% > TEL	PEL[2], ppm	% > PEL
Copper	29	25	42%	19	50%	108	4%
Chromium	50	13	78%	52	45%	160	1%
Zinc	139	38	72%	124	47%	271	7%
Lead	45	17	65%	30	50%	112	7%
Silver	0.6	0.5	38%	0.7	20%	2	5%
Cadmium	0.6	0.3	66%	0.7	36%	4	0%
Mercury	0.1	0.1	61%	0.1	39%	0.7	1%

1 BG = Natural background concentrations (**NOAA 2008**) 2 TEL=Threshold Effects Level (sensitive species may be affected); PEL = Probable Effects Level (some species affected)

Despite some hot spots, metals in sediments are generally present at concentrations near or below their TELs. About 40% of the 2000-2007 samples exceeded TELs for one or more metals, and up to 5% exceeded the PEL. Two important contributors to overall metal toxicity, zinc in the Cedar River in Area 1, and silver in Area 2, had average concentrations between their respective TELs and PELs (Figure 5.13). These findings suggest that the metals found throughout the LSJR individually exert a low-level stress. However, taken together these metals can be an important class of stressor to the river, as indicated by a cumulative toxicity pressure greater than one (Figure 5.14).

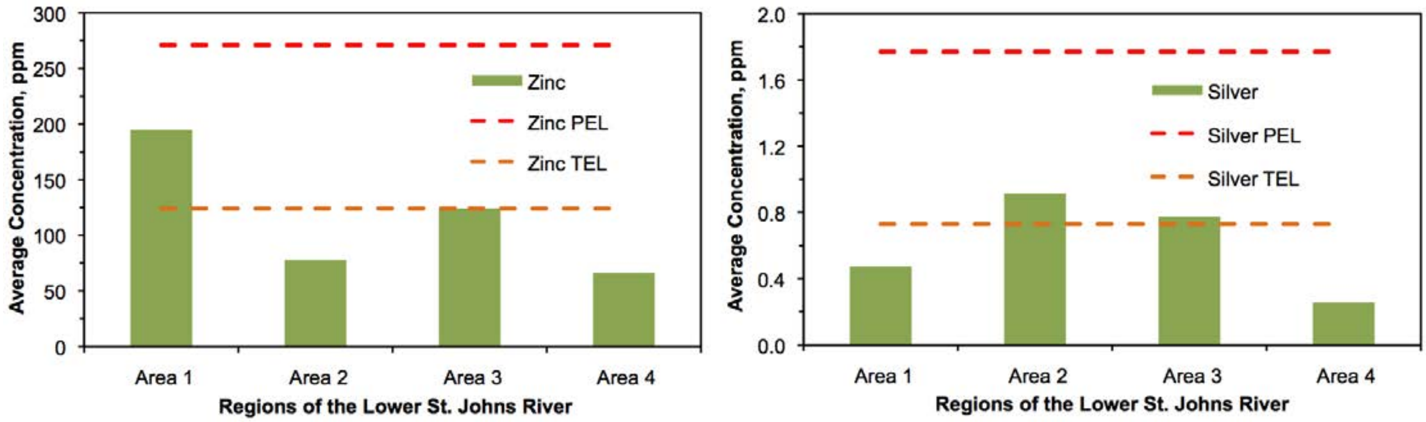


Figure 5.13 Average concentrations of zinc and silver in sediments from 2000-2007 in the four areas of the LSJR. Sediment quality guidelines for zinc and silver are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

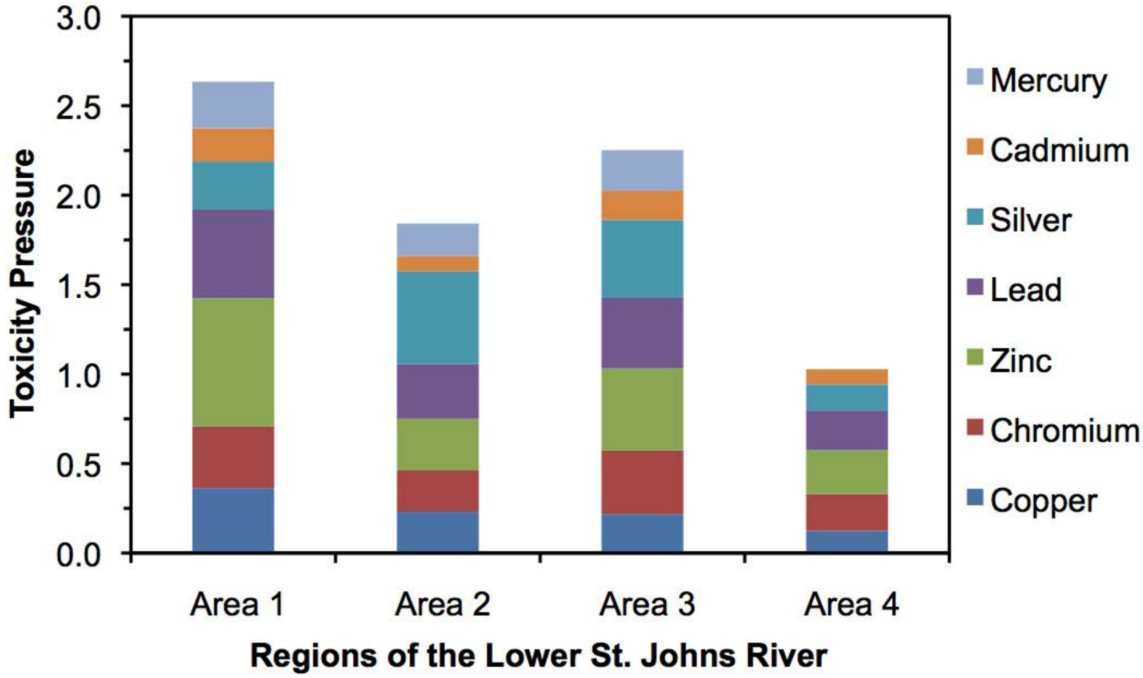


Figure 5.14 Toxicity pressure of metals in sediments from 2000-2007 in the four areas of the LSJR. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. Note no mercury data were available from 2000-2007 in Area 4. See text in Section 5.2 for data sources.

5.5.3. Trends: Metals

There is little evidence of a widespread decrease in metals since the 1980s, in contrast to the PAHs. Different metals exhibit slightly different trends with time, but none appear to be significantly declining in any area. Metals in Area 3, the north main stem, have increased since 1983, but the rate of increase has slowed since the mid-1990s (Figure 5.15). Since that time, the overall toxicity pressure from these six metals has generally remained between one and three (Figure 5.16). Although we did not see a decrease in lead concentrations from the ban of lead products from gasoline, sediment cores analyzed by other researchers give a more accurate picture of the historical record of contamination. The core studies do show recovery from lead contamination since the 1970s (**Durell, et al. 2005**).

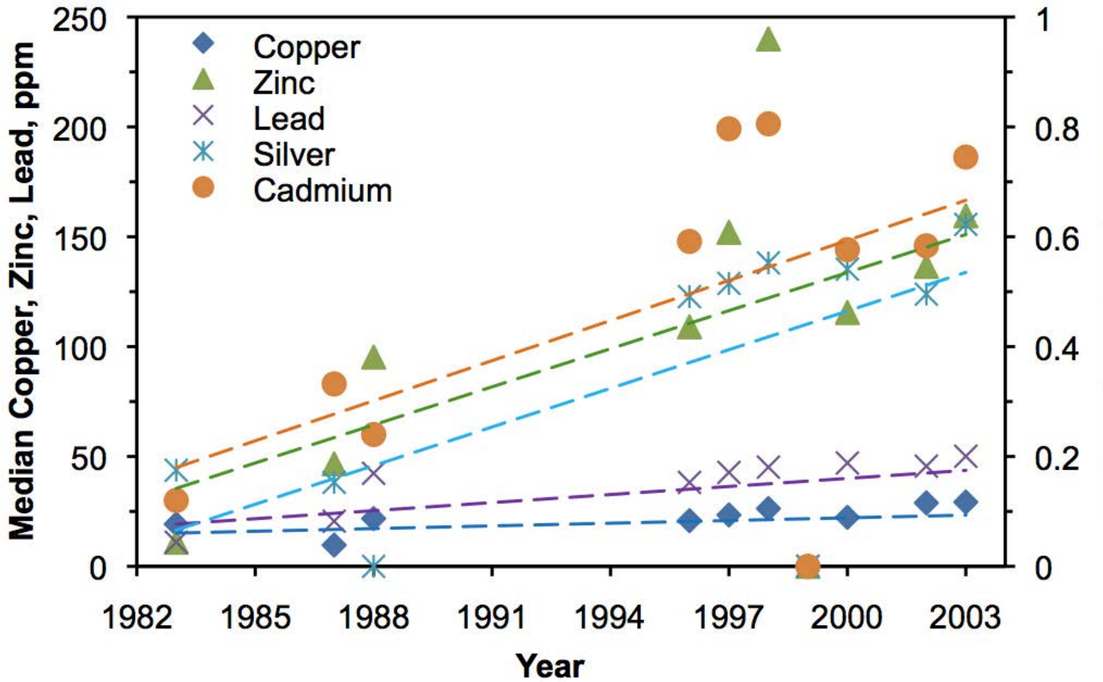


Figure 5.15 Median concentrations of copper, zinc, lead, silver, and cadmium in sediments in Area 3, the north main stem. Trend lines are shown as dashed lines. See text in Section 5.2 for data sources.

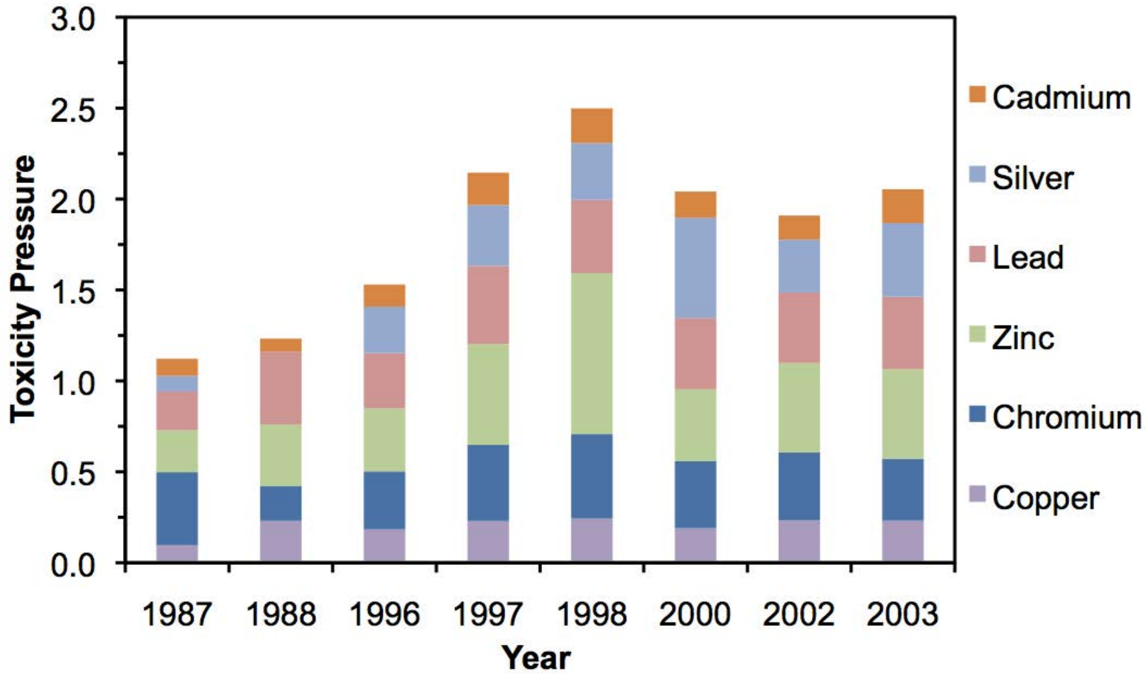


Figure 5.16 Toxicity pressure from metals in the LSJR in Area 3, north main stem. Note that years are not continuous. See text in Section 5.2 for data sources.

5.5.4. *Point Sources of Metals in the LSJR Region*

Most metals emitted to the atmosphere declined significantly between 2001 and 2010, with a 95% reduction in vanadium released by electric utilities accounting for most of the decline (Figure 5.17). In addition, nickel, chromium and cobalt declined significantly over a decade while copper and aluminum increased slightly (Figure 5.18). In 2010, many different metals were released to the atmosphere in the LSJR basin, but zinc, vanadium, copper and barium were the most abundant and together comprised about 73% of all metal releases.

In contrast to atmospheric emissions, surface water discharges of metals did not decrease between 2001 and 2010. Most releases of metals into the surface waters of the LSJR in 2010 were reported by the paper industry. The chemicals

consisted primarily of manganese (45,000 lbs.) followed by lead (365 lbs.). The electric utility industry was the second largest reported discharger into surface waters of the LSJR with releases of 11,000 pounds of metals in 2010. It has more diverse effluent constituents than the paper industry with high levels of barium, cobalt, and manganese. Increases in emissions of the latter chemicals are also responsible for the 100% increase in metals discharges into the LSJR by electric utilities between 2001 and 2010 (Figures 5.19 and 5.20), despite that industry's significant reduction in air emissions.

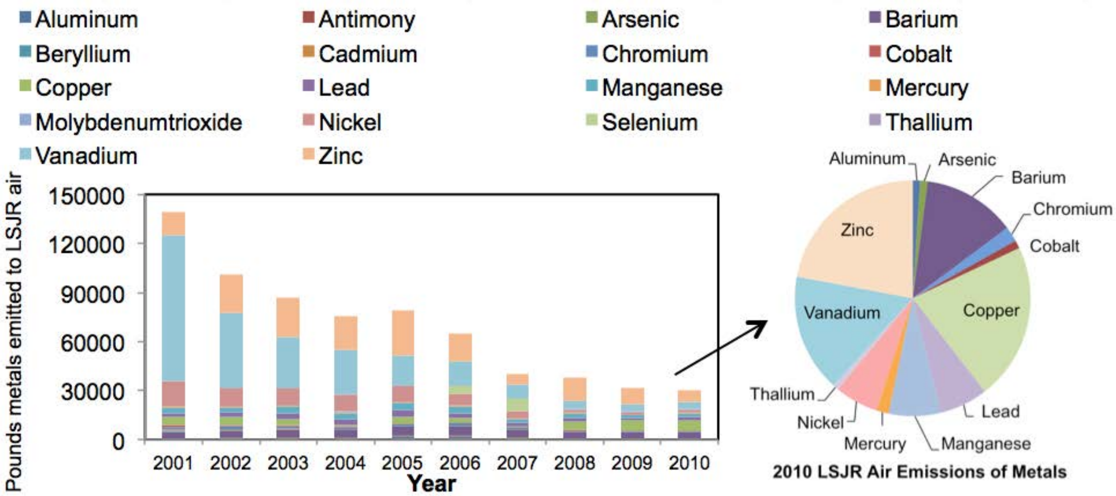


*Figure 5.17 Trends and status of 18 metals released into the atmosphere of the nine-county LSJR region as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the distribution of 30,000 pounds of metals emitted in 2010.*

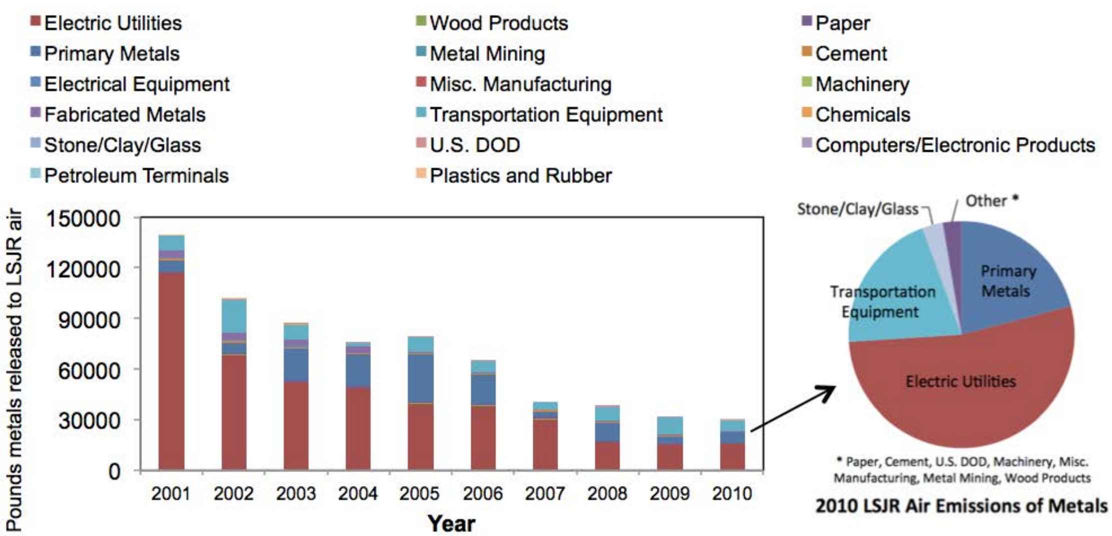


*Figure 5.18 Trends and status of 17 industries releasing metals into the atmosphere of the nine-county LSJR region as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the major industries emitting 30,000,000 pounds of metals in 2010.*

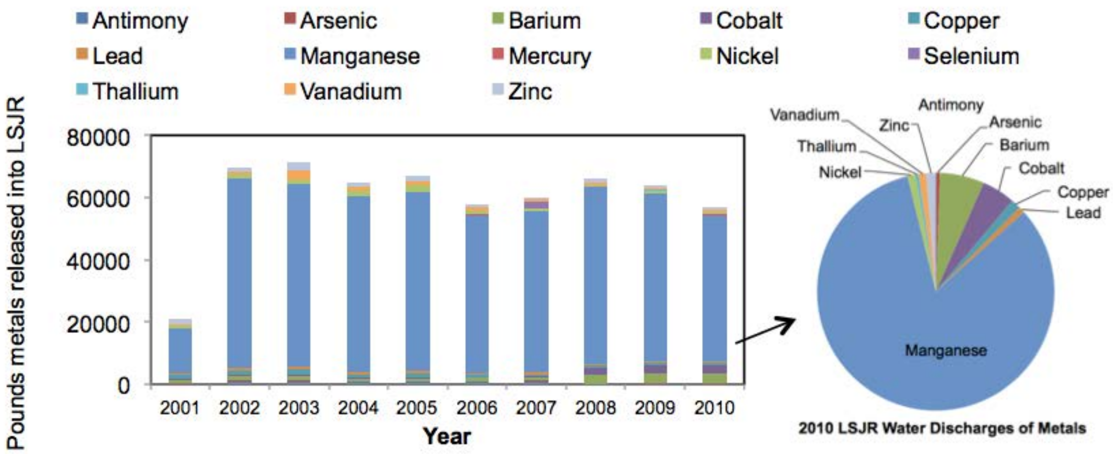


*Figure 5.19 Trends and status of 13 metals released to the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the distribution of 57,000 pounds of metals discharged in 2010.*

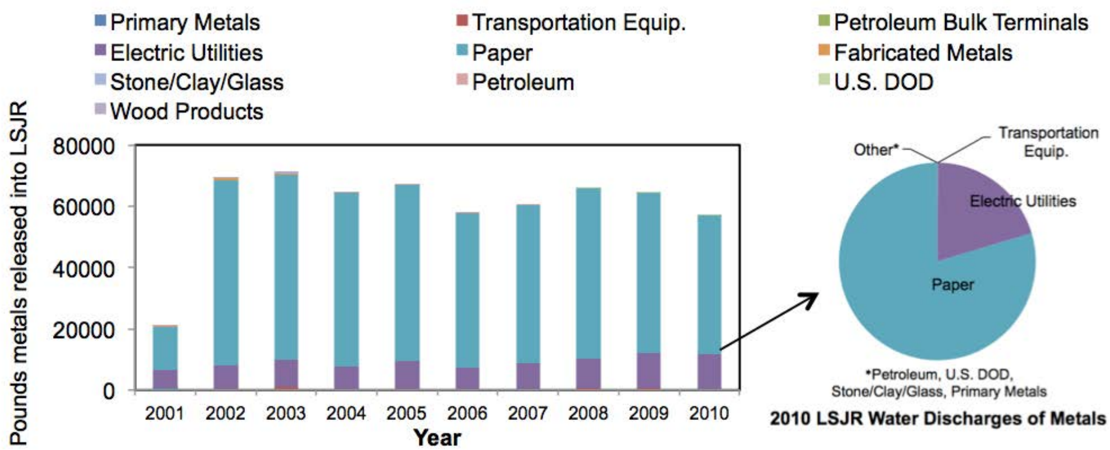


*Figure 5.20 Trends and status of 10 industries releasing metals into the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2012e**). Inset shows the major industries discharging 57,000 pounds of metals in 2010.*

5.5.5. Mercury in the LSJR

5.5.5.1. Background: Mercury

Like most metals, mercury has natural and anthropogenic sources. As a constituent of the earth's crust, it is released to the atmosphere by natural geologic processes. However, anthropogenic activities can substantially increase the mobilization of mercury into the atmosphere. In an assessment of national sources of mercury, EPA determined that approximately 60% of the mercury deposited in the US had anthropogenic sources (**EPA 1997b**). Though there is evidence there is more mercury in the atmosphere since the Industrial Revolution, there is little certainty about trends since that time (**EPA 1997a**).

People introduce mercury into the atmosphere by fuel combustion, ore mining, cement manufacture, solid waste incineration, or other industrial activities. Fertilizers, fungicides, and municipal solid waste also contribute to mercury loading but combustion is the primary anthropogenic source (Figure 5.21).

The LSJR emissions reflect national trends in that most waste mercury is emitted from coal power plants (**EPA 1997a**).

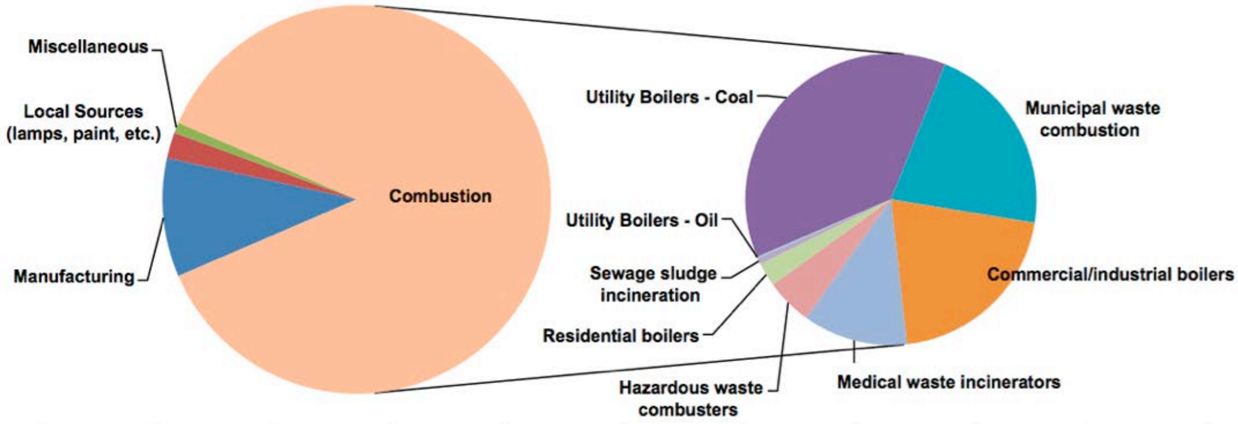


*Figure 5.21 National emissions of mercury in the US totaled 158 tons in 1994-1995. Combustion is responsible for the large majority (left graph) with coal combustion the most important type (right graph) (**EPA 1997a**).*

When mercury is released to the atmosphere, the most common type of release (**EPA 1997a**), its fate is highly dependent on the form of the mercury, meteorological conditions, and the location of the source. Elemental gaseous mercury Hg^0, is the most abundant in the atmosphere and stays there for long periods of time. Oxidized species, Hg II forms, are more water-soluble and are washed out of the atmosphere and are readily transported to rivers and streams. Local and regional modeling of the fate of mercury indicates that a substantial portion of emitted mercury travels farther than 50 km from the original source (**EPA 1997a**). Consequently it is extremely difficult to isolate specific sources of mercury to a particular watershed. Considerable effort at the federal and state level has been devoted to understanding how mercury travels and cycles throughout the globe.

Once deposited into an aquatic environment, mercury can be transformed by microorganisms to an organic form, methyl mercury. Methyl mercury production is promoted by low nutrients, low oxygen, and high dissolved organic carbon levels which are typical of many Floridian lakes, blackwater streams, and wetlands. Methyl mercury binds to proteins in tissue and therefore readily bioaccumulates. All of the mercury present in prey fish is transferred to predators and the mercury biomagnifies in organisms as it travels up the food chain. High level predators with long life-spans, such as largemouth bass in freshwater and king mackerel in marine systems, accumulate the most mercury in their tissue and therefore they generally have the highest concentrations (**Adams and McMichael Jr 2001; Adams, et al. 2003**). Humans, as top predators, consume mercury in fish also and this is the route by which most people are exposed to mercury (**EPA 2001**). It is important to realize that when anthropogenic mercury is mobilized to the atmosphere, it will continue to cycle, in some form, through the atmosphere, water bodies, land, or organisms (Figure 5.22).

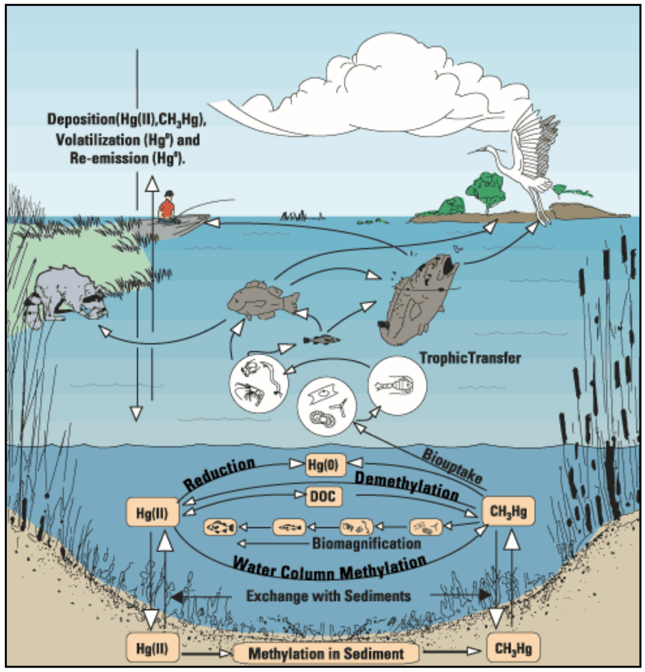


Figure 5.22. The mercury cycle. Mathematical models must accurately describe each step to predict the effect of mercury sources on fish tissue. Source: ***USGS 2004****.*

The human health effect of mercury depends on the form, the mode of exposure, and the concentration. Methyl mercury is particularly worrisome because it is the form that is most toxic, it is most easily absorbed through the human gastrointestinal tract and it is released to the bloodstream after consumption. It passes readily into most tissues, including the brain and kidneys, where it can cause permanent damage. Exposure to pregnant women is particularly hazardous since it is passed from mothers to their children through the placenta before birth, and through nursing after birth. Methyl mercury is a neurotoxin and its effect on developing fetus' and children is of high concern. It also appears to affect cardiovascular and immunological health of all human populations. High levels of the metallic form of mercury (Hg0) also cause problems but inorganic salts of mercury (Hg II) do not pass as easily into the brain so neural damage is not as certain (**ATSDR 2000**, **EPA 2001**).

Both EPA and FDEP have begun to evaluate the significance of mercury contamination in water bodies based on human health risks from fish consumption, rather than based on simple water column concentrations (**EPA 2001**, **DEP 2009a**, **FDOH 2012**). As discussed in Section 3 of this report and below, when mercury is found in fish or shellfish, health agencies may limit consumption, particularly for women of child-bearing age and children. There are 16 fresh water bodies in the LSJR basin for which the FDOH has placed consumption limits for some fish species because of mercury (**FDOH 2012**), as indicated in Appendix 3.1.3. In addition, there were 34 water bodies or segments of water bodies listed as impaired in the 2009 303(d) list for TMDL development based on health effects from consumption of fish contaminated with mercury (**DEP 2009a**) (see Section 1 and Appendix 1 D).

A methyl mercury fish tissue criterion has been developed that is designed to protect the health of general and sensitive populations while allowing people to consume as much fish as possible (**EPA 2001**, **ATSDR 1999**). Sensitive populations consist of children and women of child-bearing age. To determine if mercury found in fish is harmful to human health, toxicologists use a reference dose (a dose that causes no ill effect) of 0.0001 mg mercury/kg human body weight per day for sensitive populations, and 0.0003 mg mercury/kg human body weight per day for the general population. These are the amounts of mercury that can be safely consumed. When fish tissue exceeds safe levels, FDOH, in concert with FWC and FDEP, issues advisories that recommend limiting consumption to a certain number of meals per week or month, or restricting it entirely. Meals should be limited for the general population when mercury in fish tissue exceeds 0.3 ppm and when it exceeds 0.1 ppm for sensitive populations. When fish tissue exceeds 1.5 ppm, the general population should not eat any of the fish. Sensitive populations should not eat any fish with mercury concentrations greater than 0.85 ppm. (**EPA 2001**, **Goff 2010**). As long as monitored fish contain low enough concentrations of mercury so that people will not consume more than the reference dose at standard rates of consumption, then no restrictions will apply.

Plans are underway for mercury to be regulated under a statewide or regional TMDL by 2012 (see Section 1 in this report for additional information about TMDLs). The ultimate goal of the TMDL effort is to reduce the levels of mercury in fish in waterways where fish consumption advisories have been issued. To develop the mercury TMDLs, a number of complex, statewide analyses must be conducted. Scientists must quantify the amount of mercury that is present in Florida waterways (in fish, water and sediment), and then they must identify all of its sources. To establish how much mercury emissions must be reduced to protect human health, they must determine how much mercury is in the atmosphere and how much of it finds its way into fish under many different conditions and environments.

To gather the necessary information to develop the mercury TMDL, intensive monitoring of atmospheric mercury, along with other metals and air quality parameters, is underway at four statewide “Supersites.” These sites are in rural Jacksonville, the panhandle, in the south, and on the southwest coast of Florida. In each of these four regions, wet deposition of mercury is intensively investigated at several additional sites (“Intensives”). More limited precipitation information is being collected at two more sites. In addition to atmospheric monitoring, extensive analysis of mercury in fish, primarily largemouth bass, and water quality is underway in over 100 freshwater lakes and 100 streams. The selected sites vary in acidity, trophic status and color, all parameters that affect the fate of mercury in water bodies and its uptake by fish and other organisms. These data are being used to predict levels in unmonitored sites. Mathematical models of the emissions, transport, and rates of deposition of mercury into waterways are being developed as well as models to predict the concentrations in fish with different mercury loading rates and in different aquatic environments. (**DEP 2007b; DEP 2011d**). A draft report on the status of the Florida mercury TMDL was issued by FDEP May 24, 2012 (**DEP 2012c**).

In the following, mercury contamination in the LSJR is reviewed with respect to its potential impact on aquatic ecosystems and with respect to its potential impact on human health. In addition, release of mercury to the LSJR region is assessed.

5.5.5.2. Current and Future: Mercury in LSJR Sediments

The influx of information about mercury sources and levels that will arise from the TMDL process will provide much needed information about the extent of the contamination throughout the state. In the LSJR, there is some mercury information but the amount of data is limited. For example, there is no information for the south main stem, Area 4, for recent years and other areas in the LSJRB have limited numbers of samples. In addition, changes in standard methods of analysis make it difficult to track trends. The mercury database will be improved with the mercury TMDL process and future river status reports will summarize the results of that regulatory action.

Sites where mercury has been analyzed in sediments over the years are shown in Figure 5.23, and the results of those analyses are given in Table 5.3. The distribution of mercury, the TEL, PEL, and hot spots in various years is shown in Figure 5.24. Mercury levels that exceed natural background levels and the most protective environmental guidelines are found throughout the main stem. There are isolated locations in the LSJR, particularly in Rice Creek and the Cedar-Ortega system, where mercury occurs at concentrations high enough to impair the health of organisms. It is possible that mercury will bioaccumulate in those fish, crabs, and shellfish that spend most of their lives at these highly contaminated sites.

It should be noted that the toxicity pressure reflects the overall toxicological stress on the ecosystems of the river. It does not address human toxicity, which arises when we consume toxic metals that have found their way into the environment, via contaminated biota. Human health effects are discussed in the following section.

Table 5.3 Average Mercury Concentrations and Percentage of Samples Exceeding Background and Sediment Quality Guidelines in the LSJR Sediments (see text in Section 5.2 for data sources)

Mercury	1983	1988	1996	1997	1998	1999	2000	2002	2003	2007
Average Conc., ppm	0.5	0.1	0.3	0.2	0.6	0.2	0.2	0.1	0.1	0.1
No. of Samples	13	28	143	52	214	40	45	28	25	16
% > BG[1]	15%	64%	80%	77%	95%	80%	67%	71%	76%	38%
% > TEL[2]	15%	32%	63%	75%	75%	53%	36%	39%	48%	38%
% > PEL[2]	15%	0%	6%	0%	30%	8%	2%	0%	0%	0%

BG = Natural background concentrations (**NOAA 2008**) TEL=Threshold Effects Level (sensitive species may be affected); PEL = Probable Effects Level (some species affected)

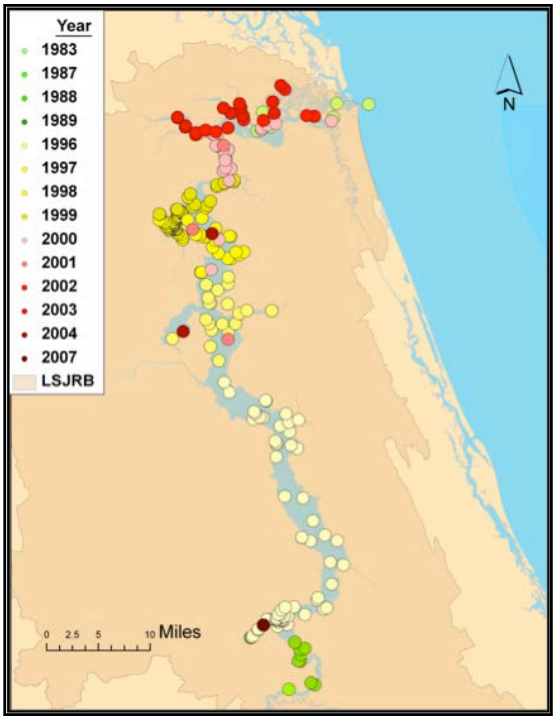


Figure 5.23 Mercury sediment sample sites.

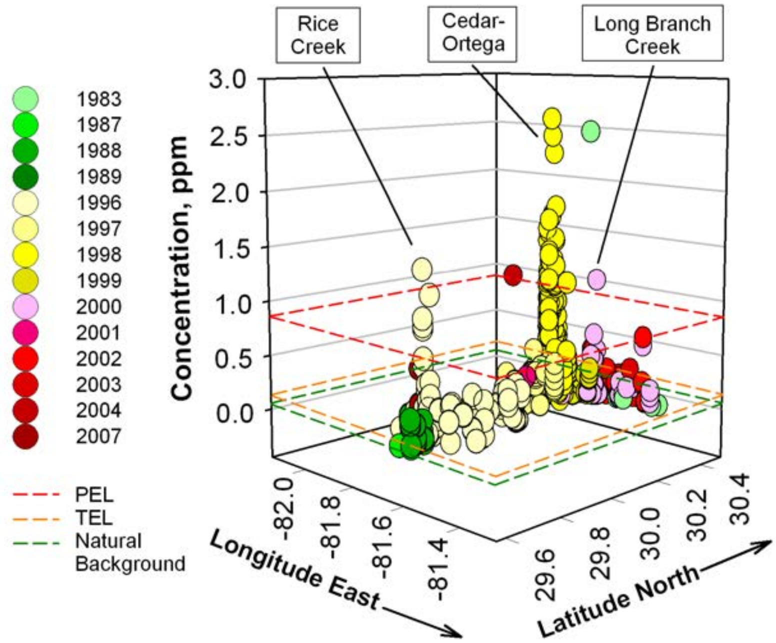


Figure 5.24 Mercury Sediment Quality Guidelines and LSJR sediment hot spots (scale of mercury concentrations does not show Rice Creek 2007 maxima). See text in Section 5.2 for data sources.

5.5.5.3. Mercury in LSJR Fish and Shellfish

The diverse types of fish that live in the LSJR were reviewed in Section 3 in this report. As noted, there is considerable overlap of freshwater, estuarine, and marine species in the dynamic LSJR system. In the following data sets, the marine and estuarine species associated with the LSJR were caught north of Doctors Lake. Of the marine and estuarine species discussed, King mackerel, Spanish mackerel, gag grouper, and bull shark are generally found offshore, while the others reside largely in coastal and estuarine waters. The freshwater species were caught south of Doctors Lake. The species that are reported are considered important because of their economic significance. Some species are also closely monitored because they are at high risk for elevated concentrations due to their large size and trophic status (**Adams, et al. 2003**).

As shown in Figure 5.25, most species in the northern marine section of the LSJR, had low levels of mercury in their tissue, including blue crabs and oysters. The only data that exceeded FDOH's most restrictive advisory levels for the general population were those reported in the Section 303(d) Impaired Waters listing for mercury, as indicated in Figure 5.25. Those data, collected throughout Florida's coastal and offshore waters, resulted in impaired designations for the marine and estuarine main stem and seven tributaries north of Doctors Lake. The King mackerel and bull shark, top predator species that are large and long-lived, have significantly elevated levels compared to the other species. Levels in marine/estuarine species in the LSJR are comparable to or less than the averages for the individual species for the entire state of Florida (**Adams, et al. 2003**). However, as discussed in Section 3, advisories have been issued for all Florida coastal waters for numerous species including Atlantic croaker, dolphin, gag grouper, King mackerel, sharks, red drum, southern flounder, spotted seatrout, and southern kingfish (**FDOH 2012**). Additional information about consumption advisories is available in Section 3 of this report.

In the fresh portions of the river south of Doctors Lake, the main stem, tributaries, and large connected lakes, fish have been extensively sampled in the last 10 years (Figure 5.26). Levels exceeding the 0.3 mg/kg fish tissue criterion have been found primarily for largemouth bass, which caused the southern part of the LSJR main stem, Lake Broward, and Crescent Lake to be designated as impaired. Not included in this discussion are several smaller, isolated southern lakes that have been listed as impaired due to elevated concentrations of mercury, again primarily in largemouth bass. As with the LSJR marine and estuarine fish, LSJR freshwater fish mercury levels are generally comparable to the rest of the state.

Furthermore, the 1998-2005 national average for largemouth bass was 0.46 ppm, which is similar to LSJR values (**Scudder, et al. 2009**).

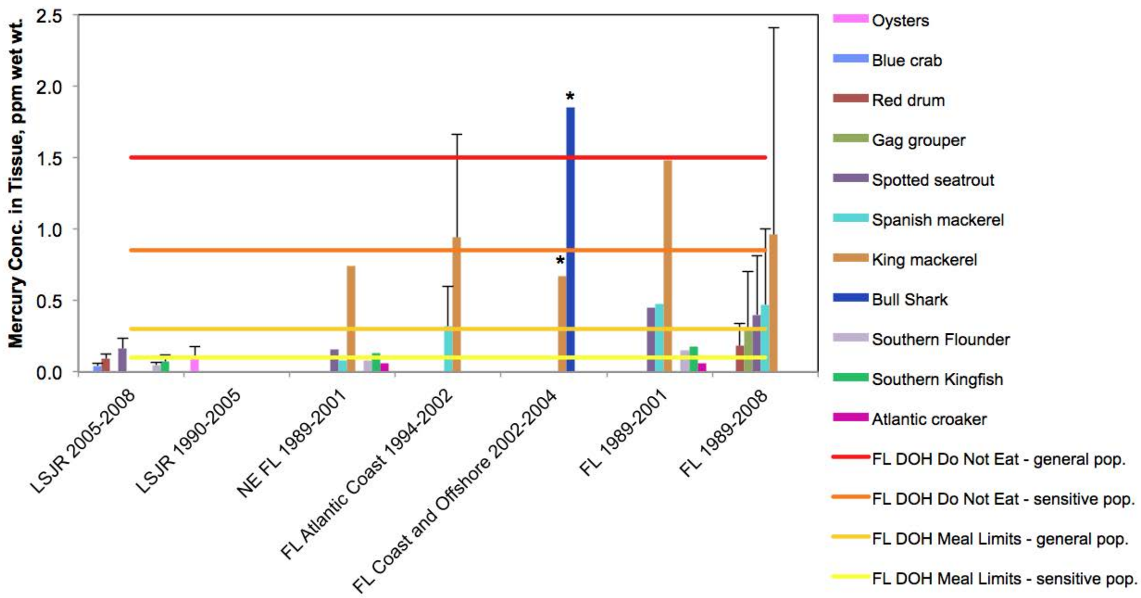


*Figure 5.25 Average mercury concentrations in estuarine and marine invertebrates and fish caught in coastal waters, offshore, and in the LSJR north of Doctors Lake. An asterisk means the data set was used for 2009 303(d) impaired water listing for the marine/estuarine main stem and 7 tributaries north of Doctors Lake. Standard deviation bars are shown. Data sources include **Adams, et al. 2003; Adams and McMichael 2007; Axelrad 2010; Brodie 2008; Goff 2010; NOAA 2007b**. Numbers of fish and available variance information are given in Appendix 5.12.*

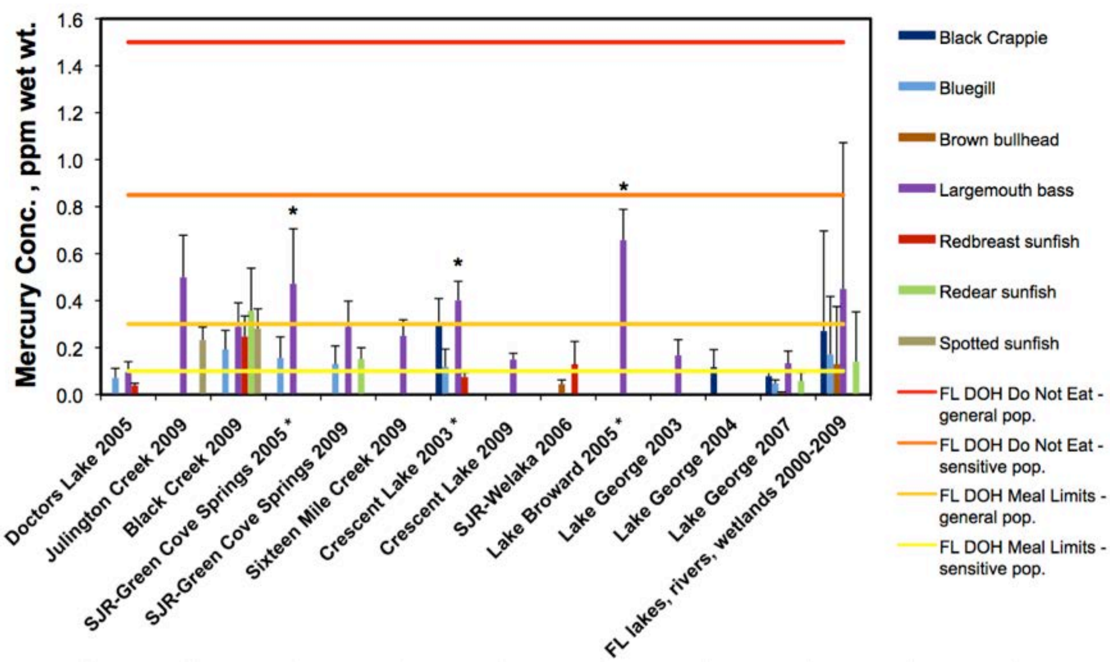


*Figure 5.26 Average mercury concentrations in freshwater fish caught in the LSJR main stem and tributaries south of Doctors Lake, as well as other Florida waterways. An asterisk means the data set was used for 2009 303(d) impaired water listing for the indicated water bodies in the LSJRB. Data sources include **Axelrad 2010; Goff 2010; Lange 2010**. Numbers of fish and available variance information are given in Appendix 5.12.*

There are a number of consumption advisories due to mercury contamination in fish in the LSJR region, and most fish contain at least small amounts of mercury. However, high levels of mercury in fish are found mostly in the top predators and in only a few of the fresh water bodies sampled. By consuming mostly lower-level predators and smaller, short-lived fish species (e.g., Atlantic croaker, flounder, sunfish) people can benefit from this healthy food source with minimal risk.

5.5.5.4. Point Sources of Metals in the LSJR Region

More than half of the atmospheric mercury emissions were from electric utilities in 2010, though the industry has reduced its emissions by two-thirds since 2001 (Figure 5.27). In particular, St. Johns River Power Plant and Northside Generating Station reduced mercury emissions to a quarter of 2001 levels by 2010 (Figure 5.28).

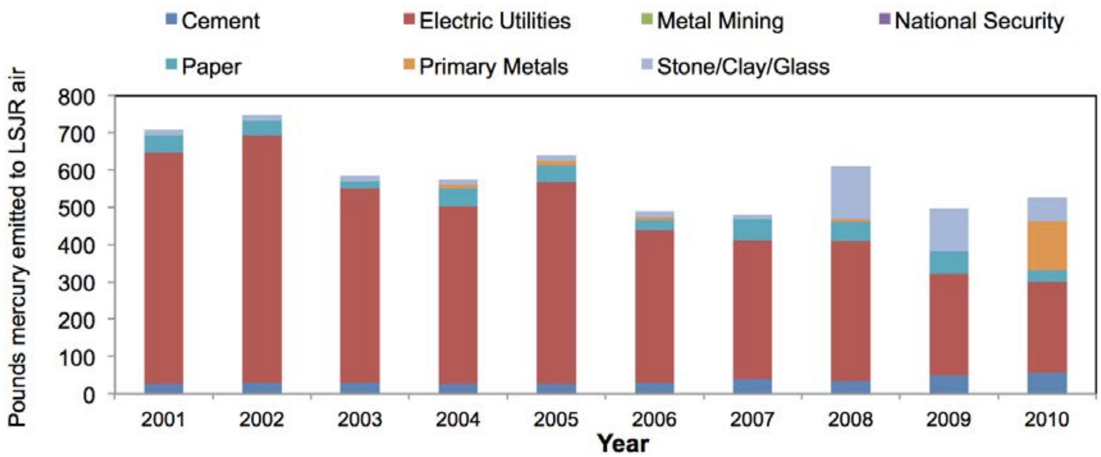


*Figure 5.27 Emissions of mercury in to the atmosphere of the nine-county LSJR basin by industry (**EPA 2012e**)*

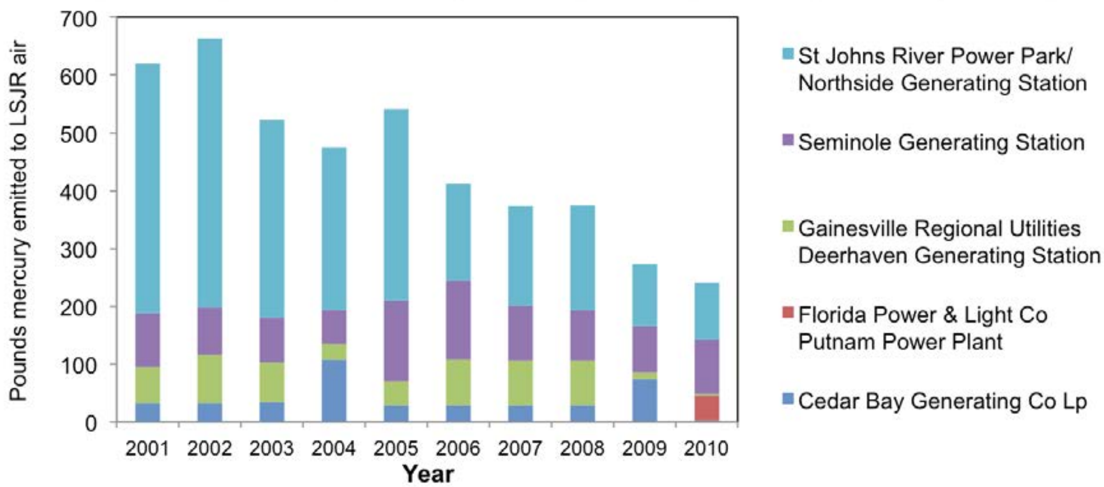


*Figure 5.28 Emissions of mercury into the atmosphere of the nine-county LSJR basin by electric utilities (**EPA 2012e**)*

Mercury releases into the LSJR and tributaries significantly dropped in 2004 with Seminole Generating station dramatically reducing its output of mercury. St. Johns River Power Park and Northside Generating Station are the main sources of mercury discharges into the river in the LSJR basin as of 2010 (Figure 5.29).

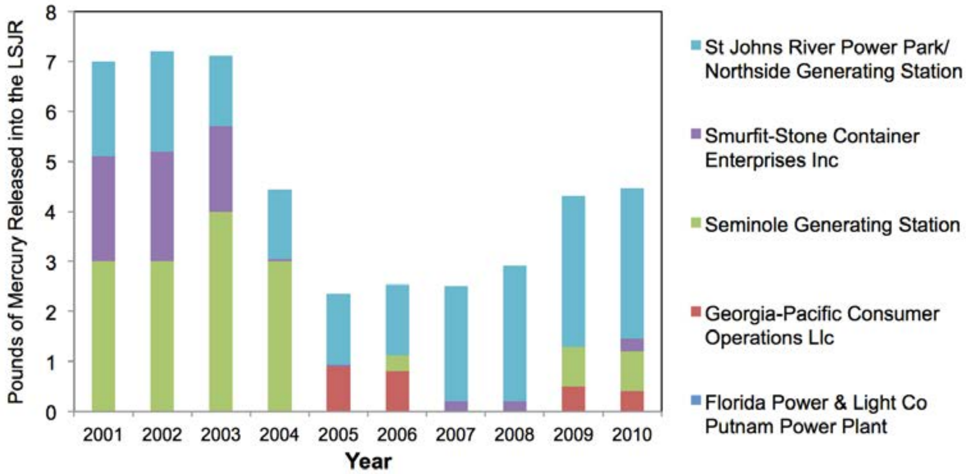


*Figure 5.29 Discharges of mercury into the nine-county LSJR basin and its tributaries by electric utilities (**EPA 2012e**).*

5.6. Polychlorinated Biphenyls (PCBs)

5.6.1. Background: PCBs

Polychlorinated biphenyls, PCBs, are synthetic chemical mixtures that were used for their nonflammable and insulating properties until they were restricted in the U.S. in the 1970s. They provided temperature control in transformers and capacitors, and were also used for lubrication and other heat transfer applications. They were sold primarily under the name of Arochlors in the U.S. They are still found in old fluorescent lighting fixtures, appliances containing pre-1977 PCB capacitors, and old hydraulic oil. The characteristics of the fluids were changed by modifying the mixture components, so each of the major Arochlor formulations is composed of different concentrations and combinations of the 209 PCB chemicals. Until the mid 1970s, PCBs were also used in manufacturing processes for a wide range of different substances, from plastics to paint additives. By 1979, the manufacture of PCBs in the U.S. was prohibited and their import, use, and disposal, were regulated by EPA (**EPA 1979**). One of the most visible PCB legacies in the U.S. is the Hudson River, where capacitor plants discharged wastewaters into the river resulting in contaminated sediments in rivers and estuaries for decades to come.

PCBs are inert, which makes them industrially valuable but environmentally harmful. They do not react readily by microbes, sunlight, or by other typical degradation pathways. They are not very soluble in water, so the lighter ones tend to evaporate and the heavier ones tend to associate with particles, whether in the air, soil or sediments. Another important consequence of PCBs' chemical properties is that they are compatible with fatty tissue, allowing extensive uptake and bioaccumulation in the fats of plants and animals. They are readily biomagnified because they are not easily metabolized and excreted.

PCBs are introduced directly into the environment today primarily from hazardous waste sites and improper disposal of old appliances and oils. However, they also may be transported long distances in the atmosphere, either in gas form or attached to particles. Particulate-bound PCBs often find their way into water bodies. Like PAHs, sometimes sources of PCB contamination can be elucidated by examining different patterns of contamination of the different PCB constituents, but several processes obscure those patterns. Weathering, currents and tides, multiple sources in a large drainage basin, and repeated cycles of evaporation, sorption and deposition all tend to mix everything up so individual sources are not usually identifiable unless there is a very specific, current source.

Because of methodological developments over the years and variable definitions of "total PCBs", it is not feasible to compare total PCB or mixture concentrations (like Arochlors). Consequently, several individual PCBs were evaluated here and total PCBs were estimated from those values. The specific eight PCBs we decided to evaluate were selected on the basis of their presence in the LSJR and on the availability of comparable data. We estimate that the PCBs we examined in this study represent 20% of the total PCBs that were actually present. More information about the calculations we used to estimate total PCBs is given in Appendix 5.3.A.

5.6.2. Current Status: PCBs

Polychlorinated biphenyls are produced only by human activity so their simple presence denotes human impact. The majority of the sediments contained some PCBs. Specifically, 84-100% of sediment samples collected from 1996 to 2003 in the four river regions contained PCBs. Most had levels that could affect sensitive species, as indicated by concentrations greater than TEL guidelines (Figure 5.30). However, in most of the river, the estimated total PCB concentrations were far below the probable effects level of 189 ppm, producing a low toxicity pressure throughout the basin. The PCBs were often found at levels typical for urban, industrialized environments (**Daskalakis and O'Connor 1995**). Most of the river's sediments had concentrations of PCBs well below the 80 ppb that characterizes a "high" level compared to the rest of the coastal areas in the country (**Durell, et al. 2004**).

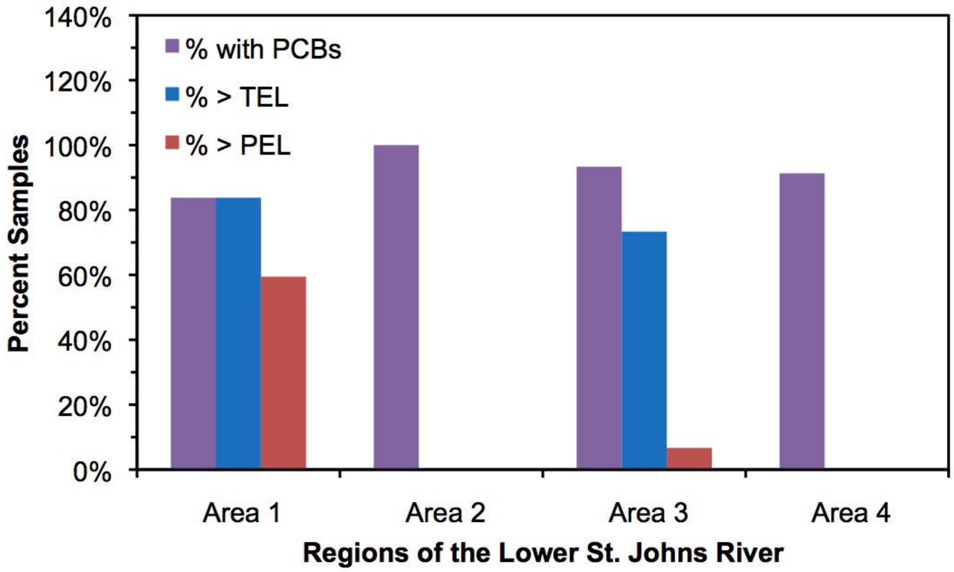
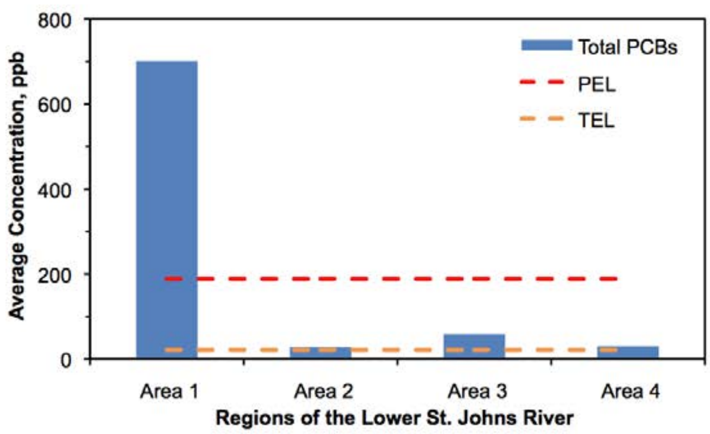


Figure 5.30 Percentage of sediment samples from 2000-2007 that contain PCBs and have PCBs concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for PCBs. See text in Section 5.2 for data sources.

The picture changes somewhat when we partition the river. It becomes apparent that the western tributaries, Area 1, have far more toxicity pressure from PCBs than the main stem portions of the river. In Cedar River and Rice Creek, the average PCB concentration exceeded, by a factor of ten, the concentrations that are considered high for the nation's coastal areas (**Daskalakis and O'Connor 1995**). Particularly high levels were found in the Cedar-Ortega in the late 1990s. In 2000-2003, Rice Creek was a hot spot for PCBs 105, 118, 128, 180 and 206, the first two of which are among the most toxic (**ATSDR 2000**) (Figure 5.31).



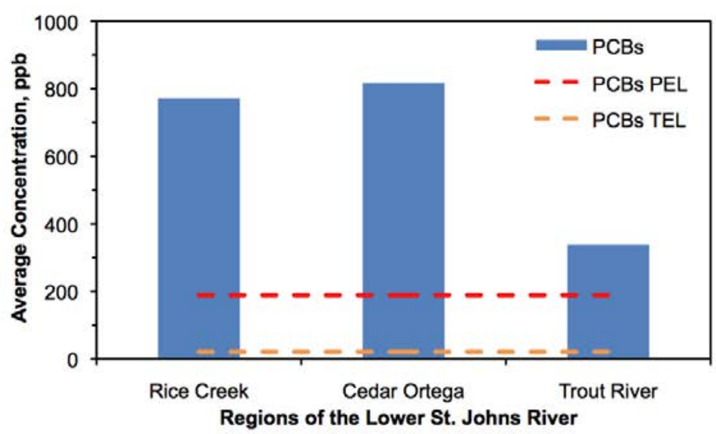


Figure 5.31 Average concentrations of PCBs in sediments from 2000-2007 in the four areas of the LSJR and in three streams in Area 1. Sediment quality guidelines for PCBs are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

5.6.3. Trends: PCBs

There are data only for 1996-2003 for PCBs, so trends are difficult to identify. However, the distributions of the PCBs we examined appear to be reasonably constant along the river and across the years, an outcome of the persistence of the long-banned substances.

5.6.4. Summary: PCBs

PCBs persist in the LSJR long after regulatory and environmental controls were put into place. They are weathering but continue to exert their influence, with little discernable changes in concentration over time. Outside of the highly contaminated western tributaries, Area 1, these compounds by themselves are not likely to be major stressors of benthic organisms, but may exert a low-level toxicity pressure throughout the basin.

5.7. Pesticides

5.7.1. Background: Pesticides

Pesticides enter water bodies from a number of different pathways. They are applied directly to control aquatic nuisances such as water hyacinth. They can be components of runoff from residential, agricultural, and other commercial applications. They also come from the atmosphere, usually attached to particles. As a consequence, pesticides are widespread in residential, urban, and agricultural areas. Pesticides are very diverse in their chemistry and environmental fate, in large part because pests are also diverse. Target species include mold, bacteria, rats, spiders, barnacles, mosquitoes and more, and each species has a metabolism that is vulnerable to different chemicals.

Pesticide manufacture and use has evolved significantly towards protecting the environment since the times when lead and arsenic compounds were dusted in homes to control insects (**Baird 1995**). Efforts have been made to create pesticides that can specifically target the pest and that can degrade after their function has been performed. However, pesticides that were used historically continue to be environmentally important because of their persistence. Organochlorine compounds (molecules containing carbon and chlorine) were introduced in the 1930s and bear some similarity to PCBs in their characteristics and environmental fate. They were effective for long periods of time against insects in homes, institutions, crops, and livestock, largely because they were nearly non-degradable. Because of their longevity, these compounds remain in the environment today despite being regulated and removed from manufacture up to forty years ago. Because of their broad-based toxicity, they have widespread effects on non-target organisms. Because of the toxicity of their primary degradation products, their environmental impacts are very long term. Their affinity for fats and organic matter makes them reside in sediments and fats of organisms and allows them to move up the food chain. Several organochlorine compounds and their degradation products are the focus of this review because of their environmental significance and the availability of historic data.

It is important in the future to also evaluate pesticides currently used, which tend to be less persistent but more toxic. The varied land uses in the LSJR basin, along with its extensive recreational and commercial maritime activities, cause a broad spectrum of pesticides to be loaded into the river. The U.S. Army Corps of Engineers directly applies herbicides 2,4-D, diquat, and glyphosate in the southern parts of the river for the control of water hyacinths and water lettuce (**USACE 2008**). The city of Jacksonville sprays malathion, organophosphates, and pyrethroids for mosquito control (**COJ 2010**). Agriculture in southern LSJR contributes to the pesticide load as well. While estimates of current total pesticide loading rates into the LSJR are elusive, it is reasonable to suppose that some of the most commonly detected pesticides in agricultural, residential, and urban U.S. streams (**Gilliom, et al. 2006**) will be present in the LSJRB. These include the herbicides atrazine, metolachlor, simazine, and prometon, as well as the insecticides diazinon, chlorpyrifos, carbaryl, and malathion. Finally, the tributyl tins used by the maritime industry should be reviewed. These common pesticides represent 11 different classes of chemical structures that will have very different fates and impacts on the environment.

In this study, four organochlorine pesticides and their primary degradation products were assessed. These compounds were primarily used as insecticides and removed from market in the 1970s. Aldrin was used against termites and other insects in urban areas. Dieldrin is a degradation product of aldrin, and was also used directly against termites. Endrin targeted insects and rodents, usually in agriculture, and endrin aldehyde is its degradation product. Heptachlor and its degradation product, heptachlor epoxide, are used here as markers for chlordane contamination since the complex

chlordane mixtures are difficult to compare across years and analytical methods. Chlordanes were used in agriculture and in households, especially for termite control. Finally, the notorious insecticide DDT and its degradation products, DDE and DDD are also reviewed.

5.7.2. *Status and Trends: Pesticides*

Organochlorine pesticides have been found all throughout the LSJR sediments for years (Figure 5.32), an expected outcome given their history of use and persistence. Like PCBs, pesticides were most prevalent in Area 1, the western tributaries, which contained the most sediments with concentrations that exceeded the pesticide PELs. However, the overall detection rate, exceedance rate, and pesticide toxicity pressure is much less than that of the PCBs. Even in the western tributaries, the toxicity quotient was less than one, and in the rest of the river, cumulative toxicity pressure from organochlorine pesticides is fairly minimal with a toxicity quotient close to 0.2. The organochlorine pesticide most responsible for toxicity pressure in the river is DDD, a degradation product of DDT, but in some years and regions, heptachlor and dieldrin were also important (Figure 5.33).

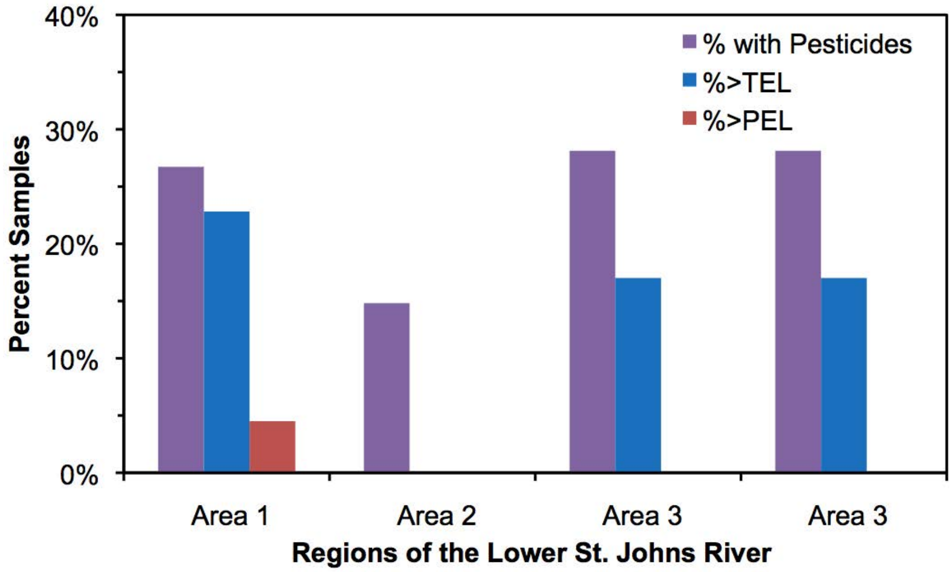


Figure 5.32 Percentage of sediment samples from 2000-2007 that contain organochlorine pesticides and have concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for one or more pesticides. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

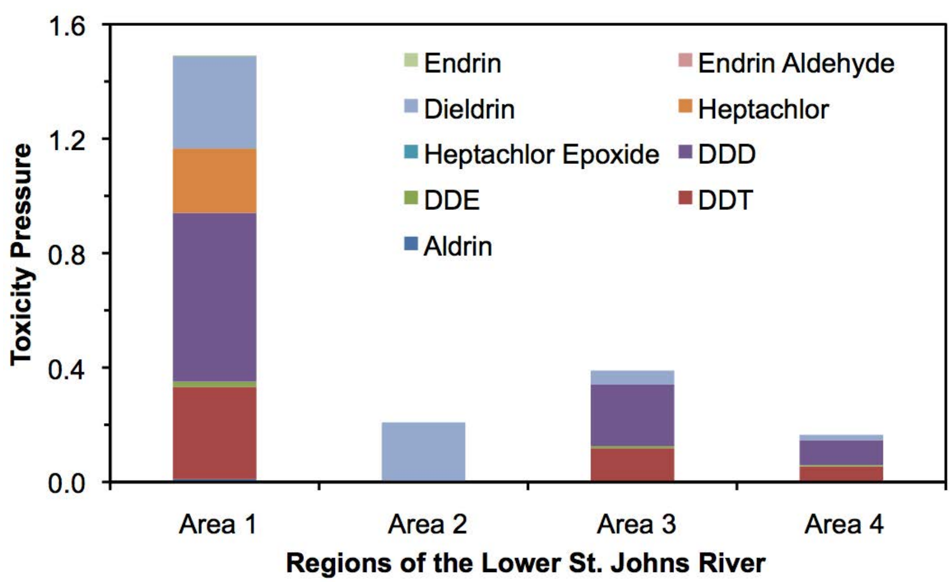


Figure 5.33 Toxicity pressure from different organochlorine pesticides and their degradation products. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

5.7.3. Summary: Pesticides

Organochlorine pesticides are present in the LSJR sediments, mostly at levels that might not cause significant adverse impacts on the benthic ecosystems, but that may add to the overall toxic burden of sensitive organisms. As with many other contaminants, the Cedar-Ortega system is the most contaminated area (**Ouyang, et al. 2003**). The DDT compounds were found most frequently and at the highest levels, compared to the other organochlorine pesticides. They exerted the most toxic pressure, though dieldrin and heptachlor were also significant in recent years.

5.8. Conclusions

The history of compromised sediment quality in the LSJR from industrial and urban activities continues today in many of the downstream regions of the river (Figure 5.34). Some contaminants, such as organochlorine pesticides and PCBs, are legacies of past misjudgments, but they continue to plague the river by their persistence in the sediments. Other contaminants, such as PAHs, are common byproducts of modern urban life and the shipping industry, though the LSJR may still suffer from PAHs from past mishandling of creosote. Metals are pervasive throughout the basin at levels substantially above what is considered natural background levels and there is no sign that concentrations are diminishing. Overall, the downstream LSJR basin contaminant levels are similar to other large, industrialized, urban rivers. However, upstream in Area 4, the extent of contamination appears less, with no samples that exceeded toxicity standards, but there is also less data about that region so the status is uncertain. Reductions in emissions and discharges of PAHs and metals reported by many industries since 2001 may lead to lower levels of contaminants in the LSJR system in the future.

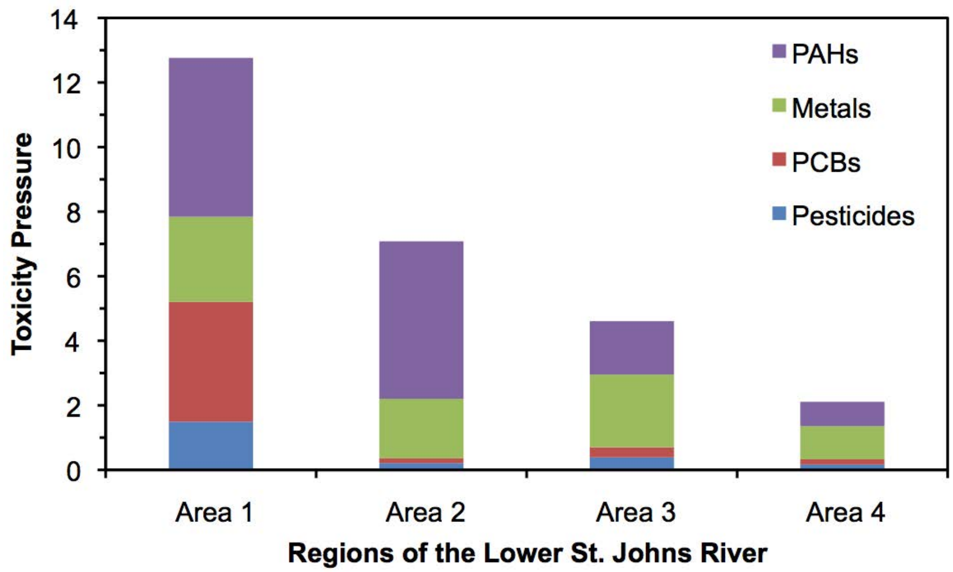


Figure 5.34 Average cumulative toxicity pressures of contaminants in sediments in different areas of the LSJR from 2000 – 2007. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north main stem; Area 4 – south main stem. See text in Section 5.2 for data sources.

There are some lower basin sediments with very high levels of contaminants compared to other coastal sediments. In particular, several of the tributaries have shown severe contamination over the years. Of particular concern is the large Cedar-Ortega basin, which has repeatedly exhibited among the highest levels and frequencies of contamination over the years. It has been recognized at least since 1983 that the large, complex network of tributaries is burdened by years of discharges of wastewaters and runoff from small, poorly managed industries, and from identified and unidentified hazardous waste sites. This is particularly true of Cedar River. The Cedar-Ortega basin also suffers from its location in the middle of the LSJR, where the transition between riverine and oceanic inputs promotes sedimentation and reduces flushing. These factors produce a highly stressed system. However, recent construction of a stormwater treatment facility on the Cedar River should improve the situation in that area. Rice Creek is another western tributary of the LSJR that has exhibited long-term pressure from a variety of contaminants and it has often had the highest contaminant concentrations in the region. The north arm section of the river to Talleyrand is heavily impacted by PAHs, and suffers from proximity to power plants, shipping, petroleum handling, and legacy contamination.

Outside of the areas of highest concern, contaminants act as underlying stressors all throughout the basin. Their individual effects may be minor, but their cumulative effects become important. There are small variations in the specific compounds that are most important from site to site and year to year, but many areas continue to be contaminated by more than one chemical at levels that are likely to be harmful to the river's benthic inhabitants. Even the relatively pristine south main stem portion of the LSJR has contamination that may affect sensitive organisms.

However, there may be future improvements. Overall, the mass of contaminants released to the atmosphere from point sources in the LSJR region has significantly declined over a decade, though little change in surface water discharges has occurred.

6. Aquatic Toxicology

The data reported in this section came from an extensive literature review using the ScienceDirect database (**Elsevier 2012**). Some studies used data collected from the SJR and others were laboratory or field toxicological studies with the contaminants and/or organisms found in the LSJR.

6.1. Polycyclic Aromatic Hydrocarbons (PAHs)

6.1.1. Sources

Information concerning sources of PAHs and concentrations in the sediment of the LSJR is provided in section 5.3.

6.1.2. Fate

PAHs have a low affinity for the water phase and will tend to bind to phase boundaries, such as surface microlayers and the surface of particles, particularly organic phases (i.e. organisms and the organic fraction of sediments) (**Karickhoff 1981**).

6.1.3. Toxicity

Although PAH accumulation does occur in organisms from all trophic levels (**Cailleaud, et al. 2009; Carls, et al. 2006**), the PAH concentrations do not biomagnify up the food chain (**Broman, et al. 1990**). High molecular weight (HMW) PAHs are metabolized by most aquatic organisms to some extent; however, vertebrates have a greater metabolizing capacity than invertebrates (**Baussant, et al. 2001a; Cailleaud, et al. 2009**). Invertebrates, such as bivalves and polychaetes, are particularly slow to eliminate PAHs (**Baussant, et al. 2001a; Baussant, et al. 2001b**). PAH concentrations in several parts of the LSJR continue to be elevated (Section 5.3) as is reflected in the PAH concentrations observed in oysters collected in the LSJR (Section 5.3.4).

Because threshold PAH concentrations in the fish that result in toxicity (critical body residues) of PAHs are relatively constant, acute toxicity in fish is generally thought to be a function of the bioconcentration factor, resulting in narcosis. PAH toxicity occurs in lipids, particularly in the nervous system of fish, resulting in dysfunction (**Barron, et al. 2004; Barron, et al. 2002**). Although narcosis is reversible, depending on the PAH concentration, it may result in reduced predator avoidance and prey capture ability. PAH acute toxicity values (concentrations causing mortality to 50% of the organism; LC50s) range from 5 to 2,140 mg/L, with the HMW PAHs (e.g. benzo(a)pyrene) being most toxic (**Neff and Burns 1996**).

The chronic toxicity of PAHs is poorly studied. **Donkin, et al. 1989** reported a reduced feeding rate and reduced growth in bivalves exposed to PAHs. Flounder fed a phenanthrene-contaminated diet exhibited decreased levels of 17B-estradiol (**Monteiro, et al. 2000**). While several studies have suggested deformities and long-term growth and survival effects in fish embryos exposed to low levels of PAHs, the mechanism of toxicity is still unclear (**Barron, et al. 2004; Incardona, et al. 2004**). **Sepúlveda, et al. 2002** reported the accumulation of both LMW and HMW PAHs in the livers of Florida largemouth bass collected from different locations in the LSJR. The liver PAH concentrations were highest in the largemouth bass collected from Palatka, followed by Green Cove and Julington Creek, with the lowest concentrations detected in those collected from Welaka. Largemouth bass with elevated PAH and pesticide residues in their livers had decreased sex hormones. Furthermore, females had both lower vitellogenin (egg yolk precursor molecule) concentrations and a lower ratio of fish gonad weight to body weight (gonadosomatic index; GSI), which could affect reproduction in the fish (**Sepúlveda, et al. 2002**).

6.2. Metals

6.2.1. *Sources:*

Sources of metals entering aquatic systems are discussed in Sections 2.7.1 and 5.4.1.

6.2.2. *Fate:*

Metals may be suspended in the water column for various time periods, depending on a variety of abiotic and biotic factors. In the water column, metals can reversibly bind to organic and particulate matter, form inorganic complexes, and be passed through the food chain (**Di Toro, et al. 2001**). Various chemical reactions favor the transfer of metals through the different phases. Ultimately, metals partition in the sediment, as has occurred in the LSJR; however, metals may be remobilized into the interstitial water by both physical and chemical disturbances. Benthic biota then may be affected by metals in the sediment, both by ingestion of metal-contaminated substrate and by exposure through the interstitial water. The presence of metals in the interstitial water is primarily controlled by the presence of iron sulfide in the sediments (**Boothman, et al. 2001**). All major pollutants will displace iron and tightly bind to sulfide, thus making them less available to cause toxicity to organisms.

6.2.3. *Toxicity*

Once in aquatic systems, most waterborne metals exert toxicity by binding to and inhibiting enzymes on the gill or gill-like structure of aquatic organisms (**Bielmyer, et al. 2006b; Bury, et al. 2003**). This leads to a disruption in ion and water balance in the organism and ultimately death, depending on the metal concentration and exposure time. In saltwater, fish drink water to maintain water balance and therefore, the intestine is another site for metal accumulation and ion disruption (**Bielmyer, et al. 2005b; Shyn, et al. 2012**). Ingestion of metal contaminated diets can also cause intestinal metal accumulation and potentially toxicity to the consumer (**Bielmyer, et al. 2005b; Bielmyer and Grosell 2011**). Decreased respiration, decreased reproductive capacity, kidney failure, neurological effects, bone fragility, mutagenesis (genetic mutation), and other effects have been observed in aquatic biota after metal exposure. Several water quality parameters can modify the toxicity of metals including: salinity, DO, dissolved organic carbon concentration (humic and fulvic substances), sulfide concentration, pH, water hardness and alkalinity, as well as other variables (**Campbell 1995**). The toxicity of metals may therefore vary in different parts of the LSJR, reflecting the changes in water chemistry (**Ouyang, et al. 2006**) as well as the organisms that reside there. Metal toxicological studies using organisms or water from the LSJR are scarce. **Grosell, et al. 2007** and **Bielmyer, et al. 2012b** collected *Fundulus heteroclitus* (killifish) from the LSJR and used them in acute (96 h) toxicological studies in the laboratory to determine the influence of salinity on copper, zinc, nickel, and cadmium toxicity to the larvae. As salinity increased, toxicity generally decreased for the metals tested. In freshwater, significant mortality to larval killifish occurred after exposure to copper (**Grosell, et al. 2007**), zinc (**Bielmyer, et al. 2012a**) and cadmium (Bielmyer et al. unpublished) at concentrations reported in the LSJR over the past five years (see section 2.7); however significant larval mortality was only observed after exposure to higher nickel concentrations than those found in the LSJR (**Bielmyer, et al. 2012b**). The presence of killifish is important in the LSJR because they are a common food source for many larger fish. Exposure to these metals for long time periods may cause deleterious effects, such as decreased growth and/or reproduction, in various species at even lower concentrations. Exposure to 50 μg/L for 21 days caused decreased growth in hybrid striped bass in freshwater; whereas, those exposed to the same concentration in saltwater did not suffer growth reduction (**Bielmyer, et al. 2006b**). Generally, larval fish are more sensitive to metals than adults, and invertebrates can be even more sensitive than larval fish (**Bielmyer, et al. 2007**). In water collected from Green Cove Springs, exposure to silver concentrations as low as 0.34 μg/L for the invertebrate crustacean, *Ceriodaphnia dubia* (common food sources for larval fish), and 6 μg/L for fathead minnows, respectively, caused 50% mortality to the organisms (**Bielmyer, et al. 2007**). These silver concentrations have been reported to occur in parts of the LSJR. Many zooplankton exposed to metals, particularly through their diets, have been shown to be very sensitive to metals (**Bielmyer, et al. 2006a**) and to accumulate metals (**Bielmyer, et al. 2012c**). Metal exposure to the lower trophic levels may impact higher-level consumers by decreasing food availability and/or by introducing metal exposure via the diet. **Sepúlveda, et al. 2002** reported the accumulation of both metal and organic contaminants in the livers of Florida largemouth bass collected from four different locations in the LSJR: Welaka, Palatka, Green Cove, and Julington Creek. The highest mean liver metal concentrations were found in bass from Julington Creek (silver, arsenic, chromium, copper,

zinc) and Welaka (cadmium, mercury, lead, selenium, tin). The zinc concentrations accumulated in the liver of the fish from Julington Creek were similar to those observed in adult killifish after exposure to 75 μg/L Zn in the laboratory (**Shyn, et al. 2012**).

6.3. Polychlorinated biphenyls (PCBs)

6.3.1. Sources

The principal route of PCB transport to aquatic environments is from waste stream waters, downstream movement by means of solution and re-adsorption onto particles, and the transport of sediment itself, until eventually reaching estuaries and coastal waters. More information concerning sources and uses of PCBs is provided in Section 5.5.

6.3.2. Fate

PCBs have a high affinity for suspended solids (organic matter) and are very insoluble in water. Due to their properties, PCBs are found in much higher concentrations in sediment and biota than in water. Sediment can become a significant source as well, because of desorption, diffusion, and possible re-suspension of PCBs in the water column. Removing contaminated sediments is the predominant mechanism of PCB removal.

6.3.3. Toxicity

The effects of PCBs on wildlife as a result of waterway contamination have been extensively documented over the years. During the 1960s, mink farmers in the Great Lakes region fed their mink fish from Lake Michigan tributaries that had been contaminated with PCBs. These ranch mink suffered severe outcomes including high mortality rates and reproductive failure. PCB contamination in the Hudson River from 1947-1977 by the General Electric Company led to fishing bans which were not changed until 1995 when fishing became permissible on a catch-and-release basis only. The state of New York recommends that children under age 15 and pregnant women not eat any fish from the 200-mile stretch of the river that has been designated as an EPA Superfund site.

PCBs can bioaccumulate in the fat tissue of organisms since they are highly lipophilic (**Cailleaud, et al. 2009; Fisk, et al. 2001**) and can also be directly toxic to aquatic organisms. **Cailleaud, et al. 2009** reported a preferential accumulation of HMW PCBs and preferential elimination of LMW PCBs in an estuarine copepod. Unlike PAHs, PCBs can biomagnify up the food chain and top-level carnivores are particularly susceptible to toxicity (**Guillette Jr., et al. 1999**). Since PCBs are chemically inert, they are highly resistant to chemical breakdown and are therefore very persistent in the environment. **Sepúlveda, et al. 2002** reported the accumulation of PCBs in the livers of Florida largemouth bass collected from different locations in the LSJR. The liver PCB concentrations were highest in the largemouth bass collected from Green Cove and Julington Creek, as compared with those collected from Welaka. PCBs exert toxicity in aquatic organisms primarily via endocrine disruption and neurotoxicity (**Fossi and Marsili 2003**). Reported effects of PCB exposure include male feminization due to increased estradiol, reduced male and female fertility, modified immune system, and altered reproductive behavior. Acute toxicity values (96 h LC50s) range from 12 μg/L to 10 mg/L for aquatic invertebrates and range from 8 μg/L to 100 mg/L for fish. **Bergeron, et al. 1994** demonstrated an increased percentage of female hatchling turtles after exposure of the eggs to PCBs in the laboratory. Likewise, **Guillette Jr., et al. 1999** reported reproductive abnormalities in the hatchling and juvenile alligators of Lake Apopka, FL, thought to have been caused by embryonic exposure to PCBs and other environmental contaminants.

Due to their endocrine-disrupting properties, PCBs may threaten aquatic ecosystems at both the individual and the population level.

6.4. Pesticides

Pesticides are quite diverse, primarily including insecticides, herbicides, fungicides and rodenticides. Due to their prevalence in the LSJR and toxicity, this review will focus on insecticides.

6.4.1. Sources

Information regarding sources of pesticides can be found in Section 5.6.

6.4.2. Fate

Organochlorine insecticides (OCs) such as dichlorodiphenyltrichloroethane (DDT), aldrin, dieldrin, endrin, chlordane, and benzene hexachloride exhibit low volatility, chemical stability, lipid solubility, and a slow rate of biotransformation and degradation. In many cases, the biotransformation products inside the organism could exhibit similar toxicity as the original parent chemical; such is the case for DDT and its biotransformed metabolites, dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD). This class of insecticides proved to be highly effective and persistent, which was ideal for remediating target pests. However, they are also broad spectrum, meaning they can affect a variety of species, including non-target species. Additionally, like PCBs they can biomagnify in the environment and resist chemical breakdown (**Woodwell, et al. 1967**). Because of their chemical structure, OCs primarily partition into biota and sediment. A biomagnification assessment in the Carmans River Estuary demonstrated significant biomagnification of DDT up the food chain (**Woodwell, et al. 1967**). During its peak use, DDT led to a decline in populations of several bird species, such as the bald eagle and the peregrine falcon.

After the ban of OCs, anticholinesterase insecticides such as organophosphates (OPs) and carbamate esters (CEs) were primarily used. This class of insecticides undergoes extensive biotransformation and is therefore considered nonpersistent, relative to the earlier insecticides. These insecticides are water soluble and can remain in the water column and/or be taken up by organic matter such as plants and animals. **Karen, et al. 1998** reported the removal of the OP insecticide, chlorpyrifos, from the water column and accumulation in the plant, *Elodea densa*, after a two-week period.

Pyrethroids are the newest (1980s) major class of insecticide accounting for one third of the world's pesticide application, and are derived from the extract of dried pyrethrum or chrysanthemum flowers. Pyrethroid use has increased with the declining use of OPs (**Baskaran, et al. 1999**). Although, pyrethroids are more hydrophobic than OPs, they only minimally accumulate in the environment and do not biomagnify (**Phillips, et al. 2010**). Pyrethroids do, however, quickly adsorb to sediment when they enter the aquatic environment (**Miyamoto and Matsuo 1990**). Benthic organisms that inhabit the sediment and porewater may be more at risk for exposure to pyrethroids than pelagic organisms.

6.4.3. Toxicity:

Insecticides generally act as neurotoxicants (poison nervous system) to aquatic organisms, although the toxic mechanisms differ between classes (**Karami-Mohajeri and Abdollahi 2011**). OCs, such as DDT, mainly affect sodium channels in the axons of nerve cells, causing them to remain open for longer than normal (**Karami-Mohajeri and Abdollahi 2011**). This results in continual excitability of the nervous tissue. In addition to damage to the nervous system, OCs have also caused reproductive effects in exposed organisms. Since Lake Apopka, FL became polluted with difocol and DDT from various sources, including a pesticide spill in 1980 and agricultural and urban runoff, the wildlife inhabiting the area has suffered severe effects. Due to the biomagnification capabilities of these contaminants, animals at the top of the food chain were most affected. Alligator populations declined due to adverse reproductive outcomes, such as reduced phallus size in males, abnormal ovarian morphology in females, modified sex steroid concentrations in both sexes, and reduced hatching success in alligator eggs (**Guillette Jr., et al. 1999; Guillette Jr., et al. 1994**). Similar effects have been observed in juvenile alligators from another Florida lake, Lake Okeechobee as well (**Crain, et al. 1998**). Further, **Rauschenberger, et al. 2004** suggested that yolk OC burdens were predictive of maternal tissue burdens and that some OCs are maternally transferred in the American alligator. After exposure to the OC insecticides, methoxychlor and DDE, accumulation of the contaminants in the ovaries of female bass and an inhibition of sex steroids were reported (**Borgert, et al. 2004**). DDT and other chlorinated pesticides were found in the livers of largemouth bass collected from the LSJR (**Sepúlveda, et al. 2002**). **Gelsleichter, et al. 2006** reported an elevated liver OC concentration in the livers of stingrays collected from Lake Jesup, in the SJR. Further, they concluded that stingray reproduction was still occurring; however, elevated serum steroid concentrations and white blood cell counts were noted, suggesting that endocrine and immune function may be altered.

The anticholinesterase insecticides have a reduced mammalian toxicity, as compared to OCs. They act by inhibiting acetylcholinesterase, which is the enzyme that destroys acetylcholine, resulting in continual stimulation of electrical activity in the nervous system. OPs are generally more effective than CEs, but they also have been shown to affect more non-target organisms. **Karen, et al. 2001** reported a significant decrease in brain acetylcholine activity and vertebral yield strength in the estuarine fish, *Fundulus heteroclitus* (commonly found in the LSJR) after exposure to environmentally relevant concentrations (in many areas) of the OP insecticide, chlorpyrifos.

Pyrethroids have an extremely low toxicity to birds and mammals and are less susceptible to biotransformation when ingested; however, they are very toxic to invertebrates and fish. As compared to the other insecticides, they are more specific in the species they target, including a range of household, veterinary, and post-harvest storage insects; and only few chronic effects have been reported as a result of exposure. The primary site of pyrethroid toxicity is the sodium channels in the nerve membrane (**Gordon 1997**), resulting in repetitive neuronal discharge (similar to DDT). The sodium channels are modified by either preventing inactivation or enhancing activation of the sodium channel when it is at rest (**Zlotkin 1999**). This action of pyrethroids results in paralysis, collapse, and inhibition of the righting reflex (**Moskowitz, et al. 1994**). Secondary toxicity to aquatic organisms, such as blue-gill and fathead minnow, has been reported, including disruption of ion regulation at the gill and decreased respiration (**Bradbury and Coats 1989**). The amphipod, *Hyalella azteca* has been shown to be extremely sensitive to pyrethroids (**Ding, et al. 2010**), possibly due to their high lipid content, and thus greater ability to store pyrethroids, relative to other organisms (**Katagi 2010**).

More toxicological data is needed to discern the effects of the contaminants in the LSJR on the organisms that reside there. The water chemistry in the river could modify the toxicity of many of the contaminants present. However, in many instances more than one type of contaminant has been shown to simultaneously occur. The degree to which exposure to elevated concentrations of multiple contaminants may affect aquatic life in the LSJR is unknown. It is clear that contaminant accumulation has occurred in several species inhabiting the LSJR, therefore the possibility of deleterious effects remains.

7. Glossary

Abiotic- non-living elements of the environment; chemical reactions that are not biologically mediated

Aeration- the incorporation of air or oxygen

Aerial survey- an organism count usually conducted in an airplane or from any vantage point above the study area

Algae- diverse single or multi-cellular photosynthetic organisms that live in aquatic or moist environments

Alkalinity- measure of a solution's ability to neutralize an acid

Ammonium- NH_4^+; the form of nitrogen that is most abundant in the LSJR

Amphipod- crustacean with seven different pairs of legs

Anadromous- describing fish that travel from saltwater to freshwater to spawn

Anthropogenic- caused or produced by humans

Aquaculture- cultivation of aquatic animals or plants

Aquifer- underground layer of porous rock which supplies water to wells and springs

Artesian spring- the site of water that is released by pressure from between layers of impermeable rock, naturally or via a well system

Assimilation- the process of taking up and incorporating a foreign component into the existing environment without causing a change in the water quality or functioning of the ecosystem

Atlantic Intracoastal Waterway- approximately 1200 mile, non-coastal boating channel that intersects the lower St. Johns River and extends from Key West, FL to Norfolk, VA

Barbel- slender 'feeler' used by certain fish for touch or taste

Barnacle- shellfish that live attached to surfaces like rocks, ships, and pilings

Barrier island- accumulations of sand that are separated from the mainland by open water

Basin Management Action Plan (BMAP)- a comprehensive set of strategies--permit limits on wastewater facilities, urban and agricultural best management practices, conservation programs, financial assistance and revenue generating activities, etc.--designed to implement the pollutant reductions established by the TMDL, as described by the FDEP

Benthic- bottom-dwelling

Bioaccumulation- the process by which a compound builds up in an organism as it grows older and larger

Bioavailability- the degree to which a compound is readily taken up by organisms in an environment

Biodegradation- breakdown of a substance by microorganisms

Biomagnify- the process by which chemicals stored in the tissues of prey organisms are transferred up the food chain at increasingly higher levels

Biomass- organic material (which can be used as a renewable fuel source) made from plants and microorganisms

Biota- the living elements of the environment

Bivalve- crustaceans with two hinged shells, such as a clam

Brackish- describing water that is salty, but not as salty as seawater

Brood- to sit upon or incubate eggs

Carcinogenic- cancer-causing

Cardiovascular- of or pertaining to the system in the human body which includes the heart and the transport of blood for the exchange of oxygen and carbon dioxide

Carnivore- an organism whose diet primarily or exclusively consists of meat

Carrion- the remains of a dead animal

Carrying capacity- maximum number of individuals an environment can support at a given time and location

Chlorophyll-*a*- light-harvesting pigment molecule that can be used as an indicator for algae concentration

Cirripedians- group of organisms that includes barnacles and their relatives

Clean Water Act (CWA)- was enacted in 1948 as the Federal Water Pollution Control Act, reorganized and expanded in 1972, and amended in 1977; the goal of the act is to implement research, programs, and restrictions in order to maintain the health of the nation's waters (33 U.S.C. 1251 et seq.)

Conductivity- ability of water to conduct electricity and thus an indirect measurement of salinity

Confluence- the place where two water bodies flow together

Coniferous- cone-bearing

Consumption advisory- issued by the Department of Health, a recommendation of the amount of a contaminated fish species that can safely be eaten in a given time

Copepods- tiny freshwater crustaceans with a rudder-like appendage for movement

Creosote- product of coal tar used for wood preservation

Cryptogenic- organism whose status as introduced or native is not known

Cyanobacteria- photosynthetic, aquatic microbes, some of which are linked to human and animal disease and harmful algal blooms

DDT- (Dichlorodiphenyltrichloroethane) a widely used pesticide that was eventually found to cause damage to wildlife and thus banned in 1972

Decapods- crustaceans with five pairs of legs like crabs, lobsters, and shrimp

Degradation product- chemicals resulting from partial decomposition or chemical breakdown of substances

Denitrification- conversion of nitrate (NO_3^-) to nitrogen gas

Deposition- the transfer of airborne pollutants to the surface of the earth and its water bodies via rain, gases, or gravity

Detritivore- organism whose diet is mostly or exclusively comprised of decayed, organic debris

Detritus- disintegrated debris from the decay of organic material

Dinoflagellates- diverse group of protists, some of which can produce toxins at high levels due to periods of rapid reproduction

Dioxin- highly toxic by-product of industrial processes involving chlorine

Dip net- a bag net attached to a pole used to scoop objects out of the water

Dipterans- insects with one pair of wings such as gnats, mosquitoes, and flies

Dissolved oxygen- concentration of oxygen that is soluble in water at a given altitude and temperature

Diurnal- describing a cycle that has distinguishable patterns during a period of twenty-four hours

Drainage basin- the area of land that drains into a specific river or tributary

Dredge- to deepen or widen a body of water by the removal of mud, silt, etc.

Ecosystem- the complex order of interactions between living and non-living components in a certain environment

Effluent- an outflow of treated or non-treated sewage from a wastewater facility or point source

El Niño/La Niña- weather pattern characterized by unusually warm/cool ocean temperatures in the Equatorial Pacific- that affects wind and levels of rainfall

Endangered Species Act of 1973- designed to establish cooperation between Federal and State legislation to support groups whose purpose is to conserve endangered species and their respective ecosystems (16 U.S.C. 1531)

Endocrine- the system of the body specializing in the delivery of secretions such as hormones

Epilimnion- upper layer of water in a lake

Epiphytic- describing a plant that grows non-parasitically on another plant and derives moisture and nutrients from the air

Erosion- the wearing away of materials, often due to natural processes like wind or water

Estuary- the wide part of a river where it meets the ocean; contains saltwater and freshwater

Eutrophic- nutrient-rich condition resulting in a high concentration of phytoplankton

Eutrophication- increase in organic matter to a system, possibly resulting in a harmful algal bloom-

Exceedance- an instance in which the concentration of a contaminant in sediment is greater than the toxicity measure

Extirpated- locally extinct due to human interference

Extrapolated- extended via estimation

Fauna- all of the animals within a given environment

Fecal coliform bacteria- natural component of digestive systems of birds and mammals, some of which are harmful to humans

Filamentous- describing the long chains of cells into which some algae are divided

Fisheries- designated places for fishing or the fishing industry in general

Fledgling- young bird that has grown enough feathers for flight

Flood plain- area of land surrounding a river that is subject to flooding in periods of high water

Flora- all of the plants in a given environment

Florida Manatee Sanctuary Act of 1978- protects manatees and their habitats from harm due to motorboat operation and human activity by regulating speed limits in specified areas of frequent manatee sightings (379.2431(2), Florida Statutes)

Fossil fuels- coal, oil, and natural gas, which are major sources of energy

Freshwater- total dissolved solids concentrations less than 1,000 milligrams per liter, as defined by the USGS

Fry- very young fish or small adult fish

Fulvic acid- complex organic molecule derived from decaying organic matter; soluble in any pH

Fungicide- anything that kills fungus or its spores, especially a chemical

Gastrointestinal tract- the organs of the human body involved in digestion, such as the esophagus, stomach, and intestines

Geologic- pertaining to the structure and formation of the earth, as recorded in rocks

Gill net- a net through which a fish is allowed to move forward, but not backward, due to the gills becoming caught in the net

Geographic Information Systems (GIS)- a system that integrates computer hardware and software for the analysis of spatial and non-spatial data

Global Positioning Satellite (GPS)- satellite-based navigation system originally constructed for military use by the U.S. Department of Defense

Ground-truthing- collecting spatial data in the field to support or dispute data collected by satellite or other remote means

Haline- salty or relating to the degree of saltiness

Handline- heavy duty fishing line manipulated by the hands, as opposed to a rod and reel

Hatchery- place for hatching fish that are used to restock streams

Harmful algal bloom- phenomenon that occurs when microscopic algae reproduce rapidly and form visible colonies that can deplete oxygen in the water, inhibit sunlight penetration, or produce toxins thus reducing the water quality of the affected area

Headwaters- source waters of a river

Herbicide- a substance that kills plants, especially weeds

Herbivore- an organism whose diet mostly or exclusively consists of plant matter

High Molecular Weight (HMW)- describing heavier PAH's that settle to the sediment in solid particles and take weeks or months to break down via microorganisms; carcinogenic to lab animals and possibly humans

Horticulture- division of agriculture that studies the cultivation of gardens

Humic acid- complex organic molecule derived from decaying organic matter; soluble only at pH > 2

Hydrologic- pertaining to water and its properties

Immunological- of or pertaining to the science of disease

Impoundment- collection of water in a reservoir for irrigation

Indicator species- organism whose chemical or physical properties can be used as a partial determinant of environmental health

Inert- pertaining to a compound that does not readily take part in chemical reactions

Infrastructure- basic framework of facilities serving a certain area, such as roads or sewer systems

Inorganic- pertaining to a chemical compound that does not contain carbon

Invertebrate- animal without a backbone

Isopod- crustacean with protective body-plates, two pairs of antennae, seven pairs of short legs, and the ability to curl into a ball; lives in moist environments

Jetty- structure in a body of water used to divert a current and protect a harbor

Kendall tau correlation analysis- statistical test which measures the strength of the relationship between two

ordinal variables when the data is ranked from lowest to highest

Lacustrine- of or pertaining to a lake

Lagoon- a shallow body of fresh or salt water connected to a larger water body

Landing- fish and shellfish that are caught and sold, or the physical structure where boats are launched or docked

Lift station- machinery used to move wastewater uphill

Ligand- ion or molecule that bonds to the central metal atom in a compound

Limestone bedrock- calcium carbonate-rich layer beneath the looser materials of the earth's surface

Littoral- of or pertaining to the shallow, shore region of a body of water

Low Molecular Weight (LMW)- describing lighter PAH's that can evaporate into the air, breaking down in days or weeks by reacting with sunlight and other chemicals; less toxic to humans and are not carcinogenic

Macroinvertebrate- animal lacking a backbone (like worms, snails, and insects) that can be seen without a microscope; often used to determine the health of an aquatic ecosystem

Macrophytes- plants that are either rooted or free-floating and large enough to be seen without a microscope

Main stem- the principal channel within a given drainage basin into which all the tributaries flow

Malathion- organophosphate insecticide used in public health pest control programs

Mariculture- farming of aquatic plants and animals in saltwater

Marine- of or pertaining to the sea, usually denoting saltwater

Marine Mammal Protection Act of 1972- legislation that recognizes the importance of marine mammals, their endangering factors and, subsequently, encourages research and conservation (16 U.S.C. 1361)

Maritime- of or pertaining to the sea

Marsh- low land characterized by fluctuating fresh or saltwater levels, lack of trees, abundance of grasses, and nutrient rich soil

Mesohaline- water with a salinity range of 5-18 ppt

Metabolism- physical and chemical processes of an organism that use energy to build materials or produce energy by breaking down materials

Metadata- information about certain items of data, such as (provide a couple of examples)

Meteorological- of or pertaining to weather-related science

Methyl mercury- neurotoxin formed by the transformation of elemental mercury by bacteria in sediment

Microbes- microscopic organisms abundant in the environment; some are capable of causing diseases, but many are essential to life

Microhabitat- a small, specialized habitat usually within a larger habitat

Midden- mound formed by generations of natural waste, such as oyster shells, being deposited in the same spot by local inhabitants

Millinery- industry of women's hats and bonnets

Mineral- inorganic, naturally occurring substance that has specific chemical and physical properties

Mitigation bank- wetland, stream, or other aquatic resource area that has been restored, established, enhanced, or preserved for the purpose of providing compensation for unavoidable impacts to aquatic resources; banks are approved, reviewed, and overseen by an Interagency Review Team (IRT)

Molluscans- invertebrates that are protected by a shell, such as snails, mussels, and oysters

Molt- in birds, the shedding of feathers in preparation for the growth of new feathers

Municipal Solid Waste (MSW)- nonhazardous, household and commercial refuse that is regularly disposed of and usually processed by a city facility

Native- species that originated from its current habitat

Naturalized- an adapted, non-native species that grows or multiplies as if native

Nemerteans- flatworms

Nestling- bird too young to leave the nest

Neurotoxin- substance that damages the central nervous system, i.e. the brain or spinal cord

Nitrification- process that results in nitrogen being more readily available in the environment

Nitrogen fixation- converting non-reactive nitrogen to reactive nitrogen

Non-native- any species or other biological material that enters an ecosystem beyond its historic, native range

Non-parametric statistics- statistical methods that do not rely on the estimation of the mean or standard deviation that describe the distribution of the variable of interest in the population

Non-point source- indirect origin of pollution, such as runoff or dust and rain deposition

Oligochaetes- segmented worms, such as the earthworm

Oligohaline- water with a salinity of 0.5-5 ppt

Omnivorous- organism whose diet is comprised of both meat and plants

Organic- pertaining to a chemical compound containing carbon

Organochlorine compounds- molecules containing carbon and chlorine

Organophosphate- an organic compound containing phosphorous derived from phosphoric acid (H_3PO_4)

Orthophosphate- PO_4^{-3}; in water, exists as $H_2PO_4^-$ in acidic conditions or as HPO_4^{2-} in alkaline conditions

Overexploitation- the overuse of natural resources for human applications, usually resulting in environmental damage

Oxidant- a chemical compound that readily gains electrons or transfers oxygen atoms to other chemical species

Oxidize- to chemically combine with oxygen

Particulate- extremely tiny particles (diameter of 10 micrometers or less) of solid or liquid whose harm lies in the potential to pass through air to the lungs

Perinatal- relating to a certain period of time before and after birth

Periphyton- community of tiny plants and animals that attach to the surface of rocks or larger aquatic plants; often used to determine water quality due to their sensitivity to the environment

Peroxide- highly reactive compound containing two single-bonded oxygen atoms in the -1 oxidation state

Petrogenic- generated by the accidental or purposeful release of oil

Petroleum- oil formed, after millions of years, from pressurized decomposed organic matter; source of many fuels, such as gasoline

pH- a measure of the acidity of a compound on a scale of one to fourteen (1-14), one (1) being the most acidic

Photosynthesis- the cellular process by which energy is produced via light absorption

Physiognomy- the outward appearance of a thing

Phytoplankton- microscopic aquatic plants

Planktivores- organisms whose diet mostly or exclusively consists of phytoplankton or zooplankton

Planktonic- describing that which is numerous, aquatic, microscopic and free floating

Plumage- all of the feathers on a bird

Point source- direct source of pollution with a continuous flow

Pollutant- physical or chemical substance that impairs the health of water, soil, or atmosphere

Pollutant Load Reduction Goal (PLRG)- amount that pollution needs to be decreased in order to meet the TMDL of a certain area

Polyaromatic Hydrocarbons (PAHs)- chemical compounds consisting of fused aromatic rings produced by the incomplete combustion of wood, petroleum, and coal or by the release of oil

Polychaetes- marine worms

Polychlorinated biphenyls (PCBs)- two bonded benzene rings with at least two chlorines at any of certain numbered positions

Population- the collective of a certain species living in a designated area and time

Ppt, ppm, ppb- parts per thousand, million, and billion, respectively; ppm is milligrams per liter (mg/L) and ppb is micrograms per liter (μg/L) in aqueous solution

Predatory/Predaceous- describing an organism that lives by hunting and eating other organisms

Prehensile- adapted for grasping or holding

Prey- animal hunted and eaten by another animal

Probable Effects Level (PEL)- concentration of contaminant above which many aquatic species are likely to be affected

Productivity- the fixation of solar energy by plants and the subsequent use of that energy by other trophic levels; measure of efficient output of a system

Pyrethroids- synthetic insecticide whose chemical composition is modeled after natural insecticides found in plants

Pyrogenic- generated as the byproduct of the incomplete combustion of wood, petroleum, or coal

Quadrat- a tool divided into squares used to assess concentration of a species over a certain surface area

"Red tide"- discoloration of water due to prolific reproduction of toxin-producing dinoflagellates

Reference dose- amount of a compound that generally causes no ill effect to humans

Refinery- facility where a crude product is purified

Regression analysis- statistical method that attempts to measure the link between two or more phenomena

Respiration- the process by which an organism takes in oxygen and gives off carbon dioxide

Rookery- breeding place of birds

Runoff- water moving downhill under the influence of gravity to replenish rivers or lakes; can move via streams, sewers, or drains and is affected by rainfall and weather

Salinity- a measure of saltiness

Sand pine scrub- uplands dominated by pine trees and interspersed with bare areas of sand or other plants suited for a dry, sandy environment; fires are important for the maintenance of this ecosystem

Scrubby flat woods- a habitat dominated by oaks (live, Chapman's, myrtle, scrub), but pines (slash, sand, longleaf) may be present along with wiregrass, fetterbush, wax myrtle, and gallberry

Seawall- barricade that protects the shore from the force of ocean waves

Sediment- organic and inorganic material that settles to the bottom of a body of water

Seine- long net with weights at the bottom and floats on the top edge, which is hauled by its ends to close around a group of fish

Septic system- sewage system consisting of an underground tank where human waste is collected and purified by specialized bacteria

Shannon-Wiener diversity index- a statistical measurement that compares the species abundance and richness (number of species) of two distinct habitats

Single Highest Day Count- record highest total number of manatees observed on a single aerial survey during the year, providing a conservative indication of the maximum number of manatees in the study area

Sinkholes- a natural cavity in the earth created by the erosion of rock, especially limestone

Slough- stagnant swamp in which water collects

Smelting- the process of obtaining metal from an ore by melting it at high temperatures

Solubility- the degree to which a compound dissociates in a certain solution

Sorption- process by which molecules of one compound take up and hold the molecules of another substance

Spawn- to deposit eggs

Stock assessment model- a business decision-making tool for fishery managers that utilizes recent and historical data to predict future fishery trends

Submerged Aquatic Vegetation (SAV)- rooted plants that do not grow above the surface of the water

Tactolocation- process of locating food by touch or vibrations

Tannic acid- phenolic compounds (those containing C_6H_5OH) found in plant parts; water-soluble at most pH's; bind to toxic metal ions, reducing their availability

Taxa- groups of organisms with common characteristics and designated by a shared name (singular: *taxon*)

Taxonomic- of or pertaining to the systematic arrangement of organisms according to shared characteristics

Telemetry- technology for the remote transmission of data

Temporary wetlands- isolated shallow pools that dry up and expose fish for birds to eat

Threshold Effects Level (TEL)- concentration at which a contaminant begins to affect species that have low tolerances for that contaminant

Topographical- pertaining to the representation of physical features on a map

Total Maximum Daily Load (TMDL)- calculation of the maximum amount of a pollutant that a waterbody can

receive and still safely meet water quality standards, as defined by the EPA

Toxicity pressure- concentration of a contaminant in the sediment divided by the PEL value

Toxicology - the study of the effects of contaminants on ecosystem inhabitants, from individual species to whole communities

Toxin- poison naturally produced by a living organism

Trace metals- metallic elements that are found in small amounts in the natural environment and some organisms, but can be very harmful at high levels, such as copper, zinc, or nickel

Transect - conceptual lines, perpendicular to the shore, along which data is collected at regular intervals

Tributary- a stream or creek that flows into the main stem river

Trophic State Index- indicator of the productivity and balance of the food chain in an ecosystem

Trophic status- the position of an organism on the food chain

Turbidity- measure of the light scattered by suspended particles in water, high levels of which can diminish the health of estuarine ecosystems

Ulcerative disease syndrome (UDS)- in reference to fish, the appearance of external lesions usually caused by some contaminant or extreme change in water quality

Ultraviolet light- high frequency light waves invisible to the human eye that can sometimes enable chemical reactions

Urbanization- process by which the proportion of people living in cities increases

Van Veen grab- sampler with weighted jaws, chain suspension, powering cable, doors, and screens designed to take large samples of sediment in soft bottoms

Vector- any agent that acts as a carrier or transporter

Vermiculated- worm-like markings

Water column- a conceptual term used to describe the vertical area of water from the surface to the sediment; water quality varies throughout the depths of the column

Watershed- the whole region from which a river receives its supply of water

Watershed Approach Framework- environmental management strategy that utilizes public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, considering ground and surface water flow

Water table- sub-surface layer of the earth that contains water but is not as saturated as the groundwater layer beneath it; depth varies according to topography and recent weather

Wetland- broadly used to describe a transitional area between aquatic and terrestrial ecosystems

Wet prairies- freshwater wetland dominated by grasses with characteristically high species diversity and rich soil

Whorl- a set of leaves in a circular pattern

Xeric oak scrub- patches of low growing oaks interspersed with bare areas of white sand

Zooplankton- microscopic aquatic animals

8. References

Ackerman BB. 1995 In: O'Shea TJ, Ackerman BB, Percival HF, editors. Population Biology of the Florida Manatee. Washington (DC): National Biological Service (NBS). Aerial Surveys of Manatees: A Summary and Progress Report. p 13-33. <http://research.myfwc.com/publications/publication_info.asp?id=42463> Accessed August 1, 2012.

Adams DH, McMichael Jr RH. 2001. Mercury Levels in Marine and Estuarine Fishes of Florida. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). Technical Report TR-6. 41 pp <http://research.myfwc.com/publications/publication_info.asp?id=40831> Accessed August 1, 2012.

Adams DH, McMichael Jr RH, Henderson GE. 2003. Mercury Levels in Marine and Estuarine Fishes of Florida 1989–2001. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). Technical Report TR-9. 64 pp <http://research.myfwc.com/publications/publication_info.asp?id=43959> Accessed August 1, 2012.

Adams DH, McMichael RH. 2007. Mercury in King Mackerel, *Scomberomorus cavalla*, and Spanish Mackerel, *S. maculatus*, From Waters of the South-eastern USA: Regional and Historical Trends. Mar. Freshw. Res.; 58(2):187-193 <http://dx.doi.org/10.1071/MF06096> Accessed August 1, 2012.

Adamus C, Clapp D, Brown S. 1997. Surface Water Drainage Basin Boundaries of the St. Johns River Water Management District: A Reference Guide. Palatka (FL): St. Johns River Water Management District (SJRWMD). Technical Publication SJ97-1. 117 pp <http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ97-1.pdf> Accessed August 1, 2012.

AEF. 2012. More About Bald Eagles. [Internet] Pigeon Forge (TN): The American Eagle Foundation (AEF). <http://www.eagles.org/programs/eagle-facts/more-about-bald-eagles.php> Accessed August 1, 2012.

Alexander CR, Smith RG, Calder FD, Schropp SJ, Windom HL. 1993. The Historical Record of Metal Enrichment in Two Florida Estuaries. Estuar. Coasts; 16(3B):627-637 <http://dx.doi.org/10.2307/1352800> Accessed August 1, 2012.

Alsop DH, Wood CM. 2000. Kinetic Analysis of Zinc Accumulation in the Gills of Juvenile Rainbow Trout: Effects of Zinc Acclimation and Implications for Biotic Ligand Modeling. Environ. Toxicol. Chem.; 19:1911-1918 <http://dx.doi.org/10.1897/1551-5028(2000)019%3C1911:KAOZAI%3E2.3.CO;2> Accessed August 1, 2012.

Anderson W, Goolsby DA. 1973. Flow and Chemical Characteristics of the St. Johns River at Jacksonville, Florida. Tallahassee (FL): U.S. Geological Survey (USGS). Information Circular 82. 66 pp <http://aquacomm.fcla.edu/1212/1/anderson_flow.pdf> Accessed August 1, 2012.

Armingeon N. 2008 *Personal communication* to Welsh P.

Ashley KH. 2010. Mocama Archaeology. [Internet] Jacksonville (FL): University of North Florida Archaeology Laboratory. <http://www.unf.edu/~kashley/Mocama.html> Accessed August 1, 2012.

ATSDR. 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. Atlanta (GA): Center for Disease Control (CDC), Agency for Toxic Substances and Disease Registry. TP69. 487 pp <http://www.atsdr.cdc.gov/ToxProfiles/tp69.pdf> Accessed August 1, 2012.

ATSDR. 1999. Toxicological Profile for Mercury. Atlanta (GA): Center for Disease Control (CDC), Agency for Toxic Substances and Disease Registry. TP46. 676 pp <http://www.atsdr.cdc.gov/toxprofiles/tp46.pdf> Accessed August 1, 2012.

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (PCBs). Atlanta (GA): Center for Disease Control (CDC), Agency for Toxic Substances and Disease Registry. TP17. 984 pp <http://www.atsdr.cdc.gov/ToxProfiles/tp17.pdf> Accessed August 1, 2012.

Audubon. 2007a. Christmas Bird Count Data. [Internet] Washington (DC): National Audubon Society. <http://audubon2.org/cbchist/count_table.html> Accessed August 1, 2012.

Audubon. 2007b. Florida Scrub-Jay (*Aphelocoma coerulescens*). [Internet] New York (NY): National Audubon Society. <http://birds.audubon.org/species/floscr> Accessed August 1, 2012.

Audubon. 2010a. The 109th Christmas Bird Count. [Internet] New York (NY): National Audubon Society. <http://birds.audubon.org/american-birds-2008-2009-summary-109th-christmas-bird-count> Accessed August 1, 2012.

Audubon. 2010b. Florida Scrub-Jay (*Aphelocoma coerulescens*): Florida. [Internet] Washington (DC): National Audubon Society. <http://gbbc.birdsource.org/gbbcApps/report?cmd=showReport&reportName=SpeciesCity&species=flsjay&state=US-FL&year=2009> Accessed August 1, 2012.

Aurand D, Daiber FC. 1973. Nitrate and Nitrite in the Surface Waters of Two Delaware Salt Marshes. Chesapeake Sci.; 14(2):105-111 <http://dx.doi.org/10.2307/1350875> Accessed August 1, 2012.

Axelrad D. 2010 *Personal communication* to Sonnenberg L.

Baird C. 1995. Environmental Chemistry. 2nd edition. New York (NY): W.H. Freeman and Company. 528 p ISBN: 978-0716731535 <http://www.amazon.com/dp/0716731533> Accessed August 1, 2012.

Barron MG, Carls MG, Heintz R, Rice SD. 2004. Evaluation of Fish Early Life-stage Toxicity Models of Chronic Embryonic Exposures to Complex Polycyclic Aromatic Hydrocarbon Mixtures. Toxicol. Sci.; 78(1):60-67 <http://dx.doi.org/10.1093/toxsci/kfh051> Accessed August 1, 2012.

Barron MG, Hansen JA, Lipton J. 2002 In: Ware GW, editor. Reviews of Environmental Contamination and Toxicology. Volume 173. Springer-Verlag. ISBN: 978-0387953397 Association Between Contaminant Tissue Residues and Effects in Aquatic Organisms. p 1-37. <http://www.springer.com/life+sciences/ecology/book/978-0-387-95339-7> Accessed August 1, 2012.

Bartram W. 1928. Travels of William Bartram. Van Doren M, editor. New York (NY): Dover Publications. 414 p ISBN: 978-0486200132 <http://store.doverpublications.com/0486200132.html> Accessed August 1, 2012.

Bartram W. 1998. The Travels of William Bartram - Naturalist Edition, Edited with Commentary and an Annotated Index by Francis Harper. Athens (GA): University of Georgia Press. 824 p ISBN: 978-0820320274 <http://www.ugapress.org/index.php/books/travels_of_william_bartram/> Accessed August 1, 2012.

Baskaran S, Kookana RS, Naidu R. 1999. Degradation of Bifenthrin, Chlorpyrifos and Imidacloprid in Soil and Bedding Materials at Termiticidal Application Rates. Pest. Sci.; 55(12):1222-1228 <http://dx.doi.org/10.1002/(SICI)1096-9063(199912)55:12%3C1222::AID-PS83%3E3.0.CO;2-7> Accessed August 1, 2012.

Batzer DP, Wissinger SA. 1996. Ecology of Insect Communities in Nontidal Wetlands. Ann. Rev. Entomol.; 41(1):75-100 <http://dx.doi.org/10.1146/annurev.en.41.010196.000451> Accessed August 1, 2012.

Baussant T, Sanni S, Jonsson G, Skadsheim A, Børseth JF. 2001a. Bioaccumulation of Polycyclic Aromatic Compounds: 1. Bioconcentration in Two Marine Species and in Semipermeable Membrane Devices During Chronic Exposure to Dispersed Crude Oil. Environ. Toxicol. Chem.; 20(6):1175-1184 <http://dx.doi.org/10.1002/etc.5620200606> Accessed August 1, 2012.

Baussant T, Sanni S, Skadsheim A, Jonsson G, Børseth JF, Gaudebert B. 2001b. Bioaccumulation of Polycyclic Aromatic Compounds: 2. Modeling Bioaccumulation in Marine Organisms Chronically Exposed to Dispersed Oil. Environ. Toxicol. Chem.; 20(6):1185-1195 <http://dx.doi.org/10.1002/etc.5620200607> Accessed August 1, 2012.

BCNRM. 2008. An Ecological Overview of Scrub Habitat and Florida Scrub-jays in Brevard County. [Internet] Viera (FL): Brevard County Natural Resources Management (BCNRM). <http://www.brevardcounty.us/environmental_management/wildlife_scrub_jay.cfm> Accessed August 1, 2012.

Bear-Hull D. 2012 *Personal communication* to Pinto G.

Beck CA. 2012 *Personal communication* to Pinto G.

Beck CA, Reid JP. 1998 In: O'Shea TJ, Ackerman BB, Percival HF, editors. Population Biology of the Florida Manatee. Washington (DC): National Biological Service (NBS). An Automated Photo-Identification Catalog for Studies of the Life History of the Florida Manatee. p 120-134. <http://gcmd.nasa.gov/records/GCMD_usgsbrdfcscsirenia.html> Accessed August 1, 2012.

Bengtson JL. 1981 Ecology of Manatees (*Trichechus manatus*) in the St. Johns River, Florida. (Ph.D.) St. Paul (MN): University of Minnesota. 126 p. Accessed August 1, 2012.

Benke AC, Cushing CE. 2005. Rivers of North America. Burlington (MA): Elsevier/Academic Press. 1168 p ISBN: 978-0120882533 <http://www.elsevierdirect.com/product.jsp?isbn=9780123750884> Accessed August 1, 2012.

Bergeron JM, Crews D, McLachlan JA. 1994. PCBs as Environmental Estrogens: Turtle Sex Determination as a Biomarker of Environmental Contamination. Environ. Health Perspect.; 102(9):780-781 <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1567153/> Accessed August 1, 2012.

Best RC. 1981. Food and Feeding Habits of Wild and Captive Sirenia. Mammal Rev.; 11(1):3-29 <http://dx.doi.org/10.1111/j.1365-2907.1981.tb00243.x> Accessed August 1, 2012.

Bielmyer GK, Brix KV, Capo TR, Grosell M. 2005a. The Effects of Metals on Embryo-larval and Adult Life Stages of the Sea Urchin, *Diadema antillarum*. Aquat. Toxicol.; 74(3):254-263 <http://dx.doi.org/10.1016/j.aquatox.2005.05.016> Accessed August 1, 2012.

Bielmyer GK, Bullington JB, DeCarlo CA, Chalk SJ, Smith K. 2012a. The Effects of Salinity on Acute Toxicity of Zinc to Two Euryhaline Species of Fish, *Fundulus heteroclitus* and *Kryptolebias marmoratus*. Integrative and Comparative Biology; Advance Access <http://dx.doi.org/10.1093/icb/ics045> Accessed August 1, 2012.

Bielmyer GK, DeCarlo C, Morris C, Carrigan T. 2012b. The Effects of Salinity and Water Chemistry on Acute Nickel Toxicity to Fundulus heteroclitus and Kryptolebias marmoratus. Comp. Biochem. Physiol. C; Submitted.

Bielmyer GK, Gatlin D, Isely JJ, Tomasso JR, Klaine SJ. 2005b. Responses of Hybrid Striped Bass to Waterborne and Dietary Copper in Freshwater and Saltwater. Comp. Biochem. Physiol. C; 140(1):131-137 <http://dx.doi.org/10.1016/j.cca.2005.01.014> Accessed August 1, 2012.

Bielmyer GK, Grosell M. 2011 In: Bury N, Handy R, editors. Surface Chemistry, Bioavailability and Metal Homeostasis in Aquatic Organisms: An Integrated Approach. London (England): Kings College. ISBN: 978-1907491023 Emerging Issues in Marine Metal Toxicity. p 129-158. <http://www.sebiology.org/publications/Book_Series.html> Accessed August 1, 2012.

Bielmyer GK, Grosell M, Brix K. 2006a. Toxicity of Silver, Zinc, Copper, and Nickel to the Copepod *acartia tonsa* Exposed via a Phytoplankton Diet. Environ. Sci. Technol.; 40(6):2063-2068 <http://dx.doi.org/10.1021/es051589a> Accessed August 1, 2012.

Bielmyer GK, Grosell M, Paquin PR, Mathews R, Wu KB, Santore RC, Brix KV. 2007. Validation Study of the Acute Biotic Ligand Model for Silver. Environ. Toxicol. Chem.; 26(10):2241-2246 <http://dx.doi.org/10.1897/06-634R.1> Accessed August 1, 2012.

Bielmyer GK, Jarvis TA, Harper BT, Butler B, Rice L, Ryan S, McLoughlin P. 2012c. Metal Accumulation From Dietary Exposure in the Sea Urchin, *Strongylocentrotus droebachiensis*. Arch. Environ. Contam. Toxicol.; 63(1):86-94 <http://dx.doi.org/10.1007/s00244-012-9755-6> Accessed August 1, 2012.

Bielmyer GK, Tomasso JR, Klaine SJ. 2006b. Physiological Responses of Hybrid Striped Bass to Aqueous Copper in Freshwater and Saltwater. Arch. Environ. Contam. Toxicol.; 50(4):531-538 <http://dx.doi.org/10.1007/s00244-005-0131-7> Accessed August 1, 2012.

BirdLife. 2008. Species Factsheet: Piping Plover (*Charadrius melodus*). [Internet] Cambridge (England): BirdLife International. <http://www.birdlife.org/datazone/speciesfactsheet.php?id=3127> Accessed August 1, 2012.

Blake NM. 1980. Land Into Water – Water Into Land: A History of Water Management in Florida. Tallahassee (FL): University Press of Florida. 344 p ISBN: 978-0813006420 <http://florida.theorangegrove.org/og/items/626e4cf0-0156-898a-745c-76b32eeab65e/1/> Accessed August 1, 2012.

Boothman WS, Hansen DJ, Berry WJ, Robson DL, Helmstetter A, Corbin JM, Pratt SD. 2001. Biological Response to Variation of Acid-Volatile Sulfides and Metals in Field-exposed Spiked Sediments. Environ. Toxicol. Chem.; 20(2):264-272 <http://dx.doi.org/10.1002/etc.5620200206> Accessed August 1, 2012.

Borgert CJ, Gross TS, Guiney PD, Osimitz TG, Price B, Wells C. 2004. Interactive Effects of p,p'-Dichlorodiphenyldichloroethylene and Methoxychlor on Hormone Synthesis in Largemouth Bass Ovarian Cultures. Environ. Toxicol. Chem.; 23(8):1947-1956 <http://dx.doi.org/10.1897/03-424> Accessed August 1, 2012.

Boström B, Anderson JM, Fleischer S, Jansson M. 1988. Exchange of Phosphorus Across the Sediment-water Interface. Hydrobiologia; 170(1):229-244 <http://dx.doi.org/10.1007/BF00024907> Accessed August 1, 2012.

Boström B, Jansson M, Forsberg C. 1982 In: Bernhardt H, editor. Nutrient Remobilization from Sediments and its Limnological Effects. Volume 18. Stuttgart (Germany): E. Schweizerbart'sche Verlagsbuchhandlung. ISBN: 978-3510470167 Phosphorus Release from Lake Sediments. p 5-59. <http://www.schweizerbart.de/publications/detail/isbn/3510470168> Accessed August 1, 2012.

Bowman RD. 2009 *Personal communication* to McCarthy H.

Bradbury SP, Coats JR. 1989. Toxicokinetics and Toxicodynamics of Pyrethroids Insecticides in Fish. Environ. Toxicol. Chem.; 8(5):373-380 <http://dx.doi.org/10.1002/etc.5620080503> Accessed August 1, 2012.

Brenner M, Schelske CL, Keenan LW. 2001. Historical Rates of Sediment and Nutrient Accumulation in Marshes of the Upper St. Johns River Basin, Florida, USA. J. Paleolimnol.; 26(3):241-257 <http://dx.doi.org/10.1023/A:1017578330641> Accessed August 1, 2012.

Brodie R. 2008 *Personal communication* to McCarthy H.

Brodie R. 2009 *Personal communication* to McCarthy D.

Brody RW. 1994. Volume 6 of the Lower St. Johns River Basin Reconnaissance: Biological Resources. Palatka (FL): St. Johns River Water Management District (SJRWMD). Technical Publication SJ94-2. 113 pp <http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ94-2.pdf> Accessed August 1, 2012.

Brody SD, Zahran S, Maghelal P, Grover H, Highfield WE. 2007. The Rising Costs of Floods: Examining the Impact of Planning and Development Decisions on Property Damage in Florida. J. Amer. Plan. Assoc.; 73(3):330-345 <http://dx.doi.org/10.1080/01944360708977981> Accessed August 1, 2012.

Broman D, Näuf C, Lundbergh I, Zebühr Y. 1990. An In Situ Study on the Distribution, Biotransformation and Flux of Polycyclic Aromatic Hydrocarbons (PAHs) in an Aquatic Food Chain (Seston-*Mytilus edulis* L.-*Somateria mollissima* L.) from the Baltic: An Ecotoxicological Perspective. Environ. Toxicol. Chem.; 9(4):429-442 <http://dx.doi.org/10.1002/etc.5620090404> Accessed August 1, 2012.

Brooks B. 2012 *Personal communication* to Pinto G.

Brooks WB, Dean TF. 2008. Measuring the Breeding Status of the Southeast U.S. Population of Wood Storks. Waterbirds; 31(SP1):50-59 <http://dx.doi.org/10.1675/1524-4695(2008)31%5B50:MTBSOT%5D2.0.CO;2> Accessed August 1, 2012.

Bruland KW. 1980. Oceanographic Distributions of Cadmium, Zinc, Nickel and Copper in the North Pacific. Earth Planet. Sci. Lett.; 47(2):176-198 <http://dx.doi.org/10.1016/0012-821X(80)90035-7> Accessed August 1, 2012.

Bruland KW. 1983 In: Riley JP, Chester R, editors. Chemical Oceanography. Volume 8. New York (NY): Academic Press. ISBN: 978-0125886086 Trace Elements in Seawater. p 157-220. <http://www.amazon.com/dp/012588608X> Accessed August 1, 2012.

Bryan GW. 1976 In: Lockwood APM, editor. Effects of Pollutants on Aquatic Organisms. Cambridge (England): University Press. ISBN: 0521211034 Some Aspects of Heavy Metal Tolerance in Aquatic Organisms. p 7-34. <http://www.amazon.com/dp/0521211034> Accessed August 1, 2012.

Bryan GW, Hummerstone LG. 1971. Adaptations of the Polychaete *Nereis diversicolor* to Estuarine Sediments Containing High Concentrations of Heavy Metals. I. General Observations and Adaptations to Copper. J. Mar. Biol. Assoc. UK; 51(4):845-863 <http://dx.doi.org/10.1017/S0025315400018014> Accessed August 1, 2012.

Buker GE. 1992. Jacksonville: Riverport - Seaport. Columbia (SC): University of South Carolina Press. 192 p ISBN: 978-0872497900 <http://ufdc.ufl.edu/NF00000148/00001/> Accessed August 1, 2012.

Burkholder JM, Glasgow Jr HB. 1997a. *Pfiesteria piscicida* and Other *Pfiesteria*-like Dinoflagellates in the Mid-Atlantic and Southeastern United States. National Institute of Environmental Health Sciences Workshop on Hazardous Marine/Freshwater Microbes and Toxins. Research Triangle Park (NC). p 5.

Burkholder JM, Glasgow Jr HB. 1997b. *Pfiesteria piscicida* and Other *Pfiesteria*-like Dinoflagellates: Behavior, Impacts, and Environmental Controls. Limnol. Oceanogr.; 42(5 part 2):1052-1075 <http://www.aslo.org/lo/toc/vol_42/issue_5_part_2/1052.pdf> Accessed August 1, 2012.

Burns Jr JW. 2008 In: Hudnell HK, editor. Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs. New York (NY): Springer-Verlag. ISBN: 978-0387758640 Chapter 5. Toxic Cyanobacteria in Florida Waters. p 127-137. <http://www.epa.gov/cyano_habs_symposium/monograph/Ch05.pdf> Accessed August 1, 2012.

Burns Jr JW, Chapman AD, Messer E, Konwinski J. 1997. Submerged Aquatic Vegetation of the Lower St. Johns River. Palatka (FL): St. Johns River Water Management District (SJRWMD). 225 pp.

Bury NR, Walker PA, Glover CN. 2003. Nutritive Metal Uptake in Teleost Fish. J. Exp. Biol.; 206(1):11-23 <http://dx.doi.org/10.1242/jeb.00068> Accessed August 1, 2012.

Cailleaud K, Budzinski H, Le Menach K, Souissi S, Forget-Leray J. 2009. Uptake and Elimination of Hydrophobic Organic Contaminants in Estuarine Copepods: An Experimental Study. Environ. Toxicol. Chem.; 28(2):239-246 <http://dx.doi.org/10.1897/07-664.1> Accessed August 1, 2012.

Campbell D. 2009 *Personal communication* to McCarthy H.

Campbell PGC. 1995 In: Tessier A, Turner DR, editors. Metal Speciation and Bioavailability in Aquatic Systems. New York (NY): Wiley Interscience. ISBN: 978-0471958307 Interactions Between Trace Metals and Aquatic Organisms: A Critique of the Free-ion Activity Model. p 45-102. <http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471958301.html> Accessed August 1, 2012.

Campbell PGC, Paquin PR, Adams WJ, Brix KV, Juberg DR, Playle RC, Ruffing CJ, Wentsel RS. 2000 In: Andren AW, Bober TW, editors. Silver in the Environment: Transport, Fate, and Effects. Pensacola (FL): Society of

Environmental Toxicology and Chemistry (SETAC). ISBN: 978-1880611449 Risk Assessment. p 97-134. <https://http://www.setac.net/setacssa/ecssashop.show_product_detail?p_mode=detail&p_product_serno=42> Accessed August 1, 2012.

Carls MG, Short JW, Payne J. 2006. Accumulation of Polycyclic Aromatic Hydrocarbons by Neocalanus copepods in Port Valdez, Alaska. Mar. Pollut. Bull.; 52(11):1480-1489 <http://dx.doi.org/10.1016/j.marpolbul.2006.05.008> Accessed August 1, 2012.

Carlton JT. 1987. Patterns of Transoceanic Marine Biological Invasions in the Pacific Ocean. Bull. Mar. Sci.; 41(2):452-465 <http://openurl.ingenta.com/content?genre=article&issn=0007-4977&volume=41&issue=2&spage=452&epage=465> Accessed August 1, 2012.

Carlton JT. 1992. Introduced Marine and Estuarine Mollusks of North America: An End-of-the-20th-Century Perspective. J. Shellfish Res.; 11(2):489-505 <http://www.biodiversitylibrary.org/page/15141774> Accessed August 1, 2012.

Carlton JT. 2012 *Personal communication* to Lee H, McCarthy H.

Carlton JT, Geller JB. 1993. Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms. Science; 261(5117):78-82 <http://dx.doi.org/10.1126/science.261.5117.78> Accessed August 1, 2012.

CEQ. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal. Washington (DC): The White House Council on Environmental Quality. <http://georgewbush-whitehouse.archives.gov/ceq/wetlands/2008/index.html> Accessed August 1, 2012.

Chapman AD, Schelske CL. 1997. Recent Appearance of *Cylindrospermopsis* (Cyanobacteria) in Five Hypereutrophic Florida Lakes. J. Phycol.; 33(2):191-195 <http://dx.doi.org/10.1111/j.0022-3646.1997.00191.x> Accessed August 1, 2012.

Cichra CE. 1998. Benthic Macroinvertebrate Monitoring in the Lower St. Johns River, Florida, 1993-1995. Palatka (FL): St. Johns River Water Management District (SJRWMD). 231 pp.

Clark W. 1964. Report of Investigations 35. Tallahassee (FL): Florida Geological Survey. Water Resources of Alachua, Bradford, Clay, and Union Counties. p 170. <http://ufdc.ufl.edu/UF00001222/00001/149j> Accessed August 1, 2012.

Clesceri LS. 1989. Standard Methods for the Examination of Water and Wastewater. 17 edition. Baltimore (MD): American Public Health Association (APHA). 1624 p ISBN: 978-0875531618 <http://www.standardmethods.org/> Accessed August 1, 2012.

COJ. 2009. Wastewater Facility Inventory [Internet] Jacksonville (FL): City of Jacksonville (COJ), Environmental and Compliance Department. <http://www.coj.net/Departments/Environmental-and-Compliance/Environmental-Quality/WWF-04-Chart.aspx> Accessed August 1, 2012.

COJ. 2010. Environmental Compliance Department Mosquito Control FAQ. [Internet] Jacksonville (FL): City of Jacksonville (COJ), Environmental and Compliance Department. <http://www.coj.net/Departments/Environmental-and-Compliance/Mosquito-Control/Frequently-Asked-Questions.aspx> Accessed August 1, 2012.

Congress. 1972. Marine Mammal Protection Act of 1972, (16 U.S.C. § 1531 et seq.) 92nd Congress. <http://www.nmfs.noaa.gov/pr/pdfs/laws/mmpa.pdf> Accessed August 1, 2012.

Congress. 1973. Endangered Species Act of 1973, (16 U.S.C. § 1361 et seq.) 93rd Congress. <http://www.nmfs.noaa.gov/pr/pdfs/laws/esa.pdf> Accessed August 1, 2012.

Cooksey C, Hyland JL. 2007. Sediment Quality of the Lower St. Johns River, FL: An Integrative Assessment of Benthic Fauna, Sediment-Associated Stressors, and General Habitat Characteristics. Mar. Pollut. Bull.; 54(1):9-21 <http://dx.doi.org/10.1016/j.marpolbul.2006.09.007> Accessed August 1, 2012.

Crain DA, Guillette Jr. LJ, Pickford DB, Percival HF, Woodward AR. 1998. Sex-Steroid and Thyroid Hormone Concentrations in Juvenile Alligators (Alligator mississippiensis) from Contaminated and Reference Lakes in Florida. Environ. Toxicol. Chem.; 17(3):446-452 <http://dx.doi.org/10.1002/etc.5620170315> Accessed August 1, 2012.

Crooks JB. 2004. Jacksonville: The Consolidation Story, from Civil Rights to Jaguars. Gainesville (FL): University Press of Florida. 274 p ISBN: 978-0813027081 <http://www.upf.com/book.asp?id=CROOKS04> Accessed August 1, 2012.

CSA. 1988. A Final Report for St. Johns River Ichthyofaunal Survey. Jupiter (FL): Continental Shelf Associates (CSA).

Dadswell MJ, Taubert BD, Squiers TS, Marchette D, Buckley J. 1984. Synopsis of Biological Data on Shortnose Sturgeon, *Acipenser brevirostrum* LeSueur 1818. Washington (DC): National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS). Technical Report NMFS-14, FAO Fisheries synopsis No. 140.

45 pp <http://www.nmfs.noaa.gov/pr/pdfs/species/shortnosesturgeon_biological_data.pdf> Accessed August 1, 2012.

Dahl TE. 2000. Status and Trends of Wetlands in the Conterminous United States 1986 to 1997. Washington (DC): U.S. Fish and Wildlife Service (USFWS). 82 pp <http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-in-the-Conterminous-United-States-1986-to-1997.pdf> Accessed August 1, 2012.

Dahl TE. 2005. Florida's Wetlands: An Update on Status and Trends 1985 to 1996. Washington (DC): U.S. Fish and Wildlife Service (USFWS). 80 pp <http://www.fws.gov/wetlands/Documents/Floridas-Wetlands-An-Update-on-Status-and-Trends-1985-to-1996.pdf> Accessed August 1, 2012.

Dahl TE. 2006. Status and Trends of Wetlands in the Conterminous United States 1998 to 2004. Washington (DC): U.S. Fish and Wildlife Service (USFWS). 112 pp <http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-in-the-Conterminous-United-States-1998-to-2004.pdf> Accessed August 1, 2012.

Dahl TE, Johnson CE. 1991. Wetlands Status and Trends in the Conterminous United States, Mid-1970's to Mid-1980's. Washington (DC): U.S. Fish and Wildlife Service (USFWS). 28 pp <http://www.fws.gov/wetlands/Documents/Wetlands-Status-and-Trends-in-the-Conterminous-United-States-Mid-1970s-to-Mid-1980s.pdf> Accessed August 1, 2012.

Dame R, Alber M, Allen D, Mallin MA, Montague C, Lewitus A, Chalmers A, Gardner R, Gilman C, Kjerfve B and others. 2000. Estuaries of the South Atlantic Coast of North America: Their Geographical Signatures. Estuar. Coasts; 23(6):793-819 <http://dx.doi.org/10.2307/1352999> Accessed August 1, 2012.

Dames and Moore. 1983. Deepwater Ports Maintenance Dredging Study; Results, Interpretations and Recommendations - Ports of Jacksonville, Tampa, Manatee and Pensacola. Tallahassee (FL): National Oceanic and Atmospheric Administration (NOAA). Final Report Vol. 1. 348 pp <http://www.gpo.gov/fdsys/pkg/CZIC-tc224-f6-d36-1983-v-ii/pdf/CZIC-tc224-f6-d36-1983-v-ii.pdf> Accessed August 1, 2012.

Daskalakis KD, O'Connor TP. 1995. Distribution of Chemical Concentrations in US Coastal and Estuarine Sediment. Marine Environ. Res.; 40(4):381-398 <http://dx.doi.org/10.1016/0141-1136(94)00150-N> Accessed August 1, 2012.

Davis JE, Arsenault R, editors. 2005. Paradise Lost? This Environmental History of Florida. Gainesville (FL): University Press of Florida; 420 p ISBN: 978-0813028262 <http://www.upf.com/book.asp?id=DAVISF05> Accessed August 1, 2012.

Davis TF. 1925. History of Jacksonville, Florida and Vicinity 1513-1924. St. Augustine (FL): The Florida Historical Society and The Record Company. 513 p ISBN: 978-0935259063 <http://ufdc.ufl.edu/NF00000013/00001> Accessed August 1, 2012.

De Barros RC, Da Rocha RM, Pie MR. 2009. Human-Mediated Global Dispersion of *Styela plicata* (Tunicata, Ascidiacea). Aquat. Invasions; 4(1):45-57 <http://dx.doi.org/10.3391/ai.2009.4.1.4> Accessed August 1, 2012.

Delfino JJ, Coates JA, Davis WM, Garcia KL, Jacobs MW, Marincic KJ, Signorella LL. 1991a. Toxic Pollutants in Discharges, Ambient Waters, and Bottom Sediments: Final Report. Tallahassee (FL): Florida Department of Environmental Protection (DEP). Contract No. MW266. 1105 pp.

Delfino JJ, Coates JA, Davis WM, Garcia KL, Signorella LL. 1991b. Toxic Organic Pollutant Content of Sediments Within the SJRWMD Non-Swim Areas. Palatka (FL): St. Johns River Water Management District (SJRWMD). Contract No. 90D214. 109 pp.

Delfino JJ, Coates JA, Garcia KL, Signorella LL. 1992. Toxic Organic Pollutant Content of Sediments Within the SJRWMD Non-Swim Areas. Palatka (FL): St. Johns River Water Management District (SJRWMD). Contract No. 90D214. 59 pp.

DeMort CL. 1990 In: Livingston RJ, editor. The Rivers of Florida. Volume 83. New York (NY): Springer-Verlag. ISBN: 978-0387973630 Chapter 7. The St. Johns River System. p 97-120. <http://www.springer.com/life+sciences/ecology/book/978-0-387-97363-0> Accessed August 1, 2012.

Dennison WC, Orth RJ, Moore KA, Stevenson JC, Carter V, Kollar S, Bergstrom PW, Batiuk RA. 1993. Assessing Water Quality with Submersed Aquatic Vegetation: Habitat Requirements as Barometers of Chesapeake Bay Health. BioScience; 43(2):86-94 <http://dx.doi.org/10.2307/1311969> Accessed August 1, 2012.

DEP. 2002. Basin Status Report: Lower St. Johns. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Division of Water Resource Management. 404 pp <http://waterwebprod.dep.state.fl.us/basin411/sj_lower/status/Lower_St_Johns2.pdf> Accessed August 1, 2012.

DEP. 2004. Adopted Verified Lists of Impaired Waters for the Group 2 Basins: Lower St. Johns River. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP), Division of Water Resource Management. <http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/adopted/cycle1/LSJRverified5-13-04.xls> Accessed August 1, 2012.

DEP. 2007a. Mitigation and Mitigation Banking, Uniform Mitigation Assessment Method (UMAM). [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/wetlands/mitigation/umam.htm> Accessed August 1, 2012.

DEP. 2007b. Plan for Development of a Statewide Total Maximum Daily Load for Mercury (Mercury TMDL). Tallahassee (FL): Florida Department of Environmental Protection (DEP), Bureau of Laboratories/Division of Water Resource Management/Division of Air Resource Management. 9 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/mercury/merc-tmdl-plan-draft.pdf> Accessed August 1, 2012.

DEP. 2008a. Basin Management Action Plan: For the Implementation of Total Daily Maximum Loads for Nutrients Adopted by the Florida Department of Environmental Protection for the Lower St. Johns River Basin Main Stem. Tallahassee (FL): Lower St. Johns River TMDL Executive Committee and Florida Department of Environmental Protection, Division of Water Resource Management, Bureau of Watershed Management. 194 pp <http://www.dep.state.fl.us/water/watersheds/docs/bmap/adopted-lsjr-bmap.pdf> Accessed August 1, 2012.

DEP. 2008b. Integrated Water Quality Assessment for Florida: 2008 305(b) Report and 303(d) List Update. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Division of Environmental Assessment and Restoration, Bureau of Watershed Management. 156 pp <http://www.dep.state.fl.us/water/docs/2008_Integrated_Report.pdf> Accessed August 1, 2012.

DEP. 2008c. Surface Water Improvement and Management Program (SWIM). [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/watersheds/swim.htm> Accessed August 1, 2012.

DEP. 2009a. Adopted Verified Lists of Impaired Waters for the Group 2 Basins: Lower St. Johns River. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 13 pp <http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/adopted/cycle2/lsjr-verified-c2.xls> Accessed August 1, 2012.

DEP. 2009b. Basin Management Action Plan for Implementation of the Total Maximum Daily Loads for Fecal Coliform Adopted by the Florida Department of Environmental Protection in the Lower St. Johns River Tributaries Basin. Tallahassee (FL): Lower St. Johns River Tributaries Basin Working Group and Florida Department of Environmental Protection. 260 pp <http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-tribs-fecal-bmap.pdf> Accessed August 1, 2012.

DEP. 2009c. Delist List of Impaired Waters for the Group 2 Basins: Lower St. Johns River. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 24 pp <http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/adopted/cycle2/lsjr-delist-c2.xls> Accessed August 1, 2012.

DEP. 2009d. Final Verified Lists of Impaired Waters and Delist Lists for Cycle 2 Group 2 Basins. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP), Division of Water Resource Management. <http://www.dep.state.fl.us/water/watersheds/assessment/adopted_gp2-c2.htm> Accessed August 1, 2012.

DEP. 2009e. Florida Department of Environmental Protection - Northeast District. [Internet] Jacksonville (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/northeast/> Accessed August 1, 2012.

DEP. 2009f. Florida's NPDES Stormwater Program. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/stormwater/npdes/index.htm> Accessed August 1, 2012.

DEP. 2009g. Northwest District Water Quality Outlook. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/northwest/Ecosys/waterquality/outlook.htm> Accessed August 1, 2012.

DEP. 2009h. St. Johns River at a Glance. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/northeast/RAAG/default.htm> Accessed August 1, 2012.

DEP. 2010a. Basin Management Action Plan for Implementation of the Total Maximum Daily Loads for Fecal Coliform Adopted by the Florida Department of Environmental Protection in the Lower St. Johns River Tributaries Basin. Tallahassee (FL): Lower St. Johns River Tributaries Basin Working Group and Florida Department of Environmental Protection. 333 pp <http://www.dep.state.fl.us/water/watersheds/docs/bmap/bmap-lsjt2.pdf> Accessed August 1, 2012.

DEP. 2010b. Basin Management Action Plans. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. <http://www.dep.state.fl.us/water/watersheds/bmap.htm> Accessed August 1, 2012.

DEP. 2010c. Classification of Surface Waters, Usage, Reclassification, Classified Waters, 62-302.400 Florida Department of State (FDOS). <https://http://www.flrules.org/gateway/ruleNo.asp?id=62-302.400> Accessed August 1, 2012.

DEP. 2010d. Final TMDL Documents. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/tmdl/final_tmdl.htm> Accessed August 1, 2012.

DEP. 2010e. Florida Department of Environmental Protection. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us> Accessed August 1, 2012.

DEP. 2010f. Florida Drought Conditions. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/Drought/faq.htm> Accessed August 1, 2012.

DEP. 2010g. Florida STORET: Search Water Data. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://survey.dep.state.fl.us/DearSpa/default.do?page=waterdata> Accessed August 1, 2012.

DEP. 2010h. Florida STORET: Station Search. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://survey.dep.state.fl.us/DearSpa/default.do?page=stations> Accessed August 1, 2012.

DEP. 2010i. Mitigation Banks Permitted Under 373.4135, F.S. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/wetlands/mitigation/mitbanks.htm> Accessed August 1, 2012.

DEP. 2010j. Northeastern District BMAP Status. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. <http://www.dep.state.fl.us/water/watersheds/docs/bmap/bmap_status_ned.pdf> Accessed August 1, 2012.

DEP. 2010k. River at a Glance: Welaka Public Boat Ramp. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/northeast/RAAG/Welaka.htm> Accessed August 1, 2012.

DEP. 2010l. Table: Surface Water Quality Criteria, 62-302.530 Florida Department of State (FDOS). <https://http://www.flrules.org/gateway/ruleNo.asp?id=62-302.530> Accessed August 1, 2012.

DEP. 2010m. Total Maximum Daily Loads Program. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/tmdl/index.htm> Accessed August 1, 2012.

DEP. 2010n. Watershed Management. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. <http://www.dep.state.fl.us/water/watersheds/> Accessed August 1, 2012.

DEP. 2011a. 2010 Progress Report For the Lower St. Johns River Basin Tributaries Basin Management Action Plan I. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 112 pp <http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-tribs1_prog_rpt2010.pdf> Accessed August 1, 2012.

DEP. 2011b. 2011 Progress Report For the Lower St. Johns River Basin Tributaries Basin Management Action Plan II. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 161 pp <http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-tribs2-bmap-apr-2011.pdf> Accessed August 1, 2012.

DEP. 2011c. Basin Downloads: Waterbody ID Run 43. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://waterwebprod.dep.state.fl.us/basin411/downloads/WBID_Run43.zip> Accessed August 1, 2012.

DEP. 2011d. DRAFT Plan for Development of a Statewide Total Maximum Daily Load for Mercury. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/tmdl/merctmdl.htm> Accessed August 1, 2012.

DEP. 2012a. 2011 Progress Report For the Lower St. Johns River Basin Tributaries Basin Management Action Plan I. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 95 pp <http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-tribs1_prog_rpt2011.pdf> Accessed August 1, 2012.

DEP. 2012b. Identification of Impaired Surface Waters, 62-303 Florida Department of State (FDOS). <http://www.flrules.org/gateway/ruleno.asp?id=62-303.100> Accessed August 1, 2012.

DEP. 2012c. Mercury TMDL for the State of Florida (Revised Draft 7/6/12). Tallahassee (FL): Florida Department of Environmental Protection (DEP), Bureau of Laboratories/Division of Water Resource Management/Division of Air Resource Management. 110 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/mercury/florida-merc-tmdl-draft-070612.pdf> Accessed August 1, 2012.

DEP. 2012d. TMDL Project Implementation Activities: June 2012. [Internet] Tallahassee (FL): Florida Department of Environmental Protection (DEP). <http://www.dep.state.fl.us/water/watersheds/docs/bmap/bmap_activities.pdf> Accessed August 1, 2012.

DETR. 1998. Digest of Environmental Statistics No. 20. London (England): The Stationary Office, Department of the Environment, Transport and the Regions (DETR). <http://www.defra.gov.uk/statistics/files/pas-summary-1997.pdf> Accessed August 1, 2012.

Deutsch CJ, Reid JP, Bonde RK, Easton DE, Kochman HI, O'Shea TJ. 2000. Seasonal Movements, Migratory Behavior, and Site Fidelity of West Indian Manatees Along the Atlantic Coast of the United States as Determined by Radio-telemetry. Tallahassee (FL): University of Florida, Florida Cooperative Fish and Wildlife Research Unit. Final Report. Research Work Order No. 163. 254 pp <http://www.aquaticcommons.org/1067/> Accessed August 1, 2012.

Deutsch CJ, Reid JP, Bonde RK, Easton DE, Kochman HI, O'Shea TJ. 2003. Seasonal Movements, Migratory Behavior, and Site Fidelity of West Indian Manatees Along the Atlantic Coast of the United States. Wildlife Monogr.; 151:1-77 <http://www.jstor.org/stable/3830830> Accessed August 1, 2012.

Di Toro DM, Allen HE, Bergman HL, Meyer JS, Paquin PR, Santore RC. 2001. Biotic Ligand Model of the Acute Toxicity of Metals. 1. Technical Basis. Environ. Toxicol. Chem.; 20(10):2383-2396 <http://dx.doi.org/10.1002/etc.5620201034> Accessed August 1, 2012.

Ding Y, Weston DP, You J, Rothert AK, Lydy MJ. 2010. Toxicity of Sediment-Associated Pesticides to Chironomus dilutus and Hyalella azteca. Arch. Environ. Contam. Toxicol.; 61(1):83-92 <http://dx.doi.org/10.1007/s00244-010-9614-2> Accessed August 1, 2012.

Dobberfuhl DR. 2002. Distribution of Submerged Aquatic Vegetation in the Lower St. Johns River, 1998 Atlas. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ2002-PP1. 46 pp <http://www.sjrwmd.com/technicalreports/pdfs/PP/SJ2002-PP1.pdf> Accessed August 1, 2012.

Dobberfuhl DR. 2007. Light Limiting Thresholds for Submerged Aquatic Vegetation in a Blackwater River. J. Aquat. Bot.; 86(4):346-352 <http://dx.doi.org/10.1016/j.aquabot.2007.01.003> Accessed August 1, 2012.

Dobberfuhl DR. 2009 *Personal communication* to Pinto G.

Dobberfuhl DR, Trahan N. 2003. Distribution of Submerged Aquatic Vegetation in the Lower St. Johns River, 2001 Atlas. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ2003-PP1. 52 pp <http://www.sjrwmd.com/technicalreports/pdfs/PP/SJ2003-PP1.pdf> Accessed August 1, 2012.

Dodd Jr CK, Barichivich WJ. 2007. Movements of Large Snakes (*Drymarchon, Masticophis*) in North-central Florida. Florida Sci.; 70(1):83-94 <http://www.cnah.org/pdf_files/691.pdf> Accessed August 1, 2012.

Donkin P, Widdows J, Evans SV, Worrall CM, Carr M. 1989. Quantitative Structure-activity Relationships for the Effect of Hydrophobic Organic Chemicals on Rate of Feeding by Mussels *(Mytilus edulis)*. Aquat. Toxicol.; 14(3):277-294 <http://dx.doi.org/10.1016/0166-445X(89)90021-0> Accessed August 1, 2012.

Donner B. 2008. 2008 Fish Advisories by WBID. Tallahassee (FL): Florida Department of Environmental Protection (DEP).

Dufour AP. 1984. Health Effects Criteria for Fresh Recreational Waters. Washington (DC): U.S. Environmental Protection Agency (EPA). EPA 600/1-84-004. 33 pp <http://www.epa.gov/nerlcwww/frc.pdf> Accessed August 1, 2012.

Dunn AE, Dobberfuhl DR, Casamatta DA. 2008. A Survey of Algal Epiphytes from *Vallisneria americana* Michx. (Hydrocharitaceae) from the Lower St. Johns River, Florida. Southeast. Nat.; 7(2):229-244 <http://dx.doi.org/10.1656/1528-7092(2008)7%5B229:ASOAEF%5D2.0.CO;2> Accessed August 1, 2012.

Durako MJ, Murphy MD, Haddad KD. 1988. Assessment of Fisheries Habitat: Northeast Florida. St. Petersburg (FL): Florida Department of Environmental Protection (DEP), Department of Natural Resources, Bureau of Marine Research. Volume 45. 51 pp <http://research.myfwc.com/publications/publication_info.asp?id=23627> Accessed August 1, 2012.

Durell GS, Fredriksson JS, Higman JC. 2004. Sediment Quality of the Lower St. Johns River and Cedar-Ortega River Basin: Chemical Contaminant Characteristics. Palatka (FL): St. Johns River Water Management District (SJRWMD).

SJ2004-SP43. 190 pp <http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2004-SP43.pdf> Accessed August 1, 2012.

Durell GS, Higman JC, Fredriksson JS, Neff J. 2005. Chemical Contamination of Sediments in the Cedar-Ortega River Basin. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ2005-SP5. 188 pp <http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2005-SP5.pdf> Accessed August 1, 2012.

Durell GS, Seavey JA, Hunt CD. 1997. Status of Sediment Quality in the St. Johns River Water Management District: Physical and Chemical Characteristics. Revised. Palatka (FL): St. Johns River Water Management District (SJRWMD). Contract No. 95J169. 250 pp <http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ98-SP5.pdf> Accessed August 1, 2012.

Dyble J, Paerl HW, Neilan BA. 2002. Genetic Characterization of *Cylindrospermopsis raciborskii* (Cyanobacteria) Isolates from Diverse Geographic Origins Based on *nifH* and *cpcBA*-IGS Nucleotide Sequence Analysis. Appl. Environ. Micobiol.; 68(5):2567-2571 <http://dx.doi.org/10.1128/AEM.68.5.2567-2571.2002> Accessed August 1, 2012.

Earthjustice. 2008. Complaint for Declaractory and Injuctive Relief. Oakland (CA): Sierra Club. 25 pp <http://www.earthjustice.org/library/legal_docs/complaint-and-exhibits-fwf-v-usepa-07-17-08.pdf> Accessed August 1, 2012.

EDR. 2012. Demographic Estimating Conference Database. [Internet]: The Florida Legislature, Office of Economic and Demographic Research (EDR). <http://edr.state.fl.us/Content/conferences/population/index.cfm> Accessed August 1, 2012.

Ehrenfeld DW. 1970. Biological Conservation. New York (NY): Holt, Rinehart and Winston. 226 p ISBN: 978-0030800498 <http://www.amazon.com/dp/0030800498> Accessed August 1, 2012.

Eisler R. 1993. Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel (MD): U.S. Fish and Wildlife Service (USFWS). 26. 79 pp <http://www.pwrc.usgs.gov/infobase/eisler/CHR_26_Zinc.pdf> Accessed August 1, 2012.

Eisler R. 1996. Silver Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel (MD): U.S. Fish and Wildlife Service (USFWS). 32. 63 pp <http://www.pwrc.usgs.gov/infobase/eisler/CHR_32_Silver.pdf> Accessed August 1, 2012.

Eldredge LG, Smith CM. 2001. A Guidebook of Introduced Marine Species in Hawaii. Manoa, HI: B.P. Bishop Museum and the University of Hawaii. Bishop Museum Technical Report 21. 70 pp <http://www2.bishopmuseum.org/HBS/invertguide/species_pdf/guide.pdf > Accessed August 1, 2012.

Elsevier. 2012. ScienceDirect.com. [Internet] New York (NY): Elsevier. <http://www.sciencedirect.com/> Accessed August 1, 2012.

Elton CS. 1958. The Ecology of Invasions by Animals and Plants. Chicago (IL): The University of Chicago Press. 196 p ISBN: 978-0226206387 <http://press.uchicago.edu/ucp/books/book/chicago/E/bo3614808.html> Accessed August 1, 2012.

EPA. 1979. PCBs; Manufacturing, Processing, Distribution in Commerce and Use Bans. Fed. Reg.; 44:31514 <http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=400019ZU.txt> Accessed August 1, 2012.

EPA. 1986. Ambient Water Quality Criteria for Bacteria - 1986. Washington (DC): Environmental Protection Agency (EPA), Office of Water. EPA440/5-84-002. 24 pp <http://water.epa.gov/scitech/swguidance/standards/upload/2009_04_13_beaches_1986crit.pdf> Accessed August 1, 2012.

EPA. 1997a. Mercury Study Report to Congress; Volume I: Executive Summary. Washington (DC): Environmental Protection Agency (EPA), Office of Air Quality Planning & Standards and Office of Research and Development. EPA-452/R-97-004. 95 pp <http://www.epa.gov/ttn/oarpg/t3/reports/volume1.pdf> Accessed August 1, 2012.

EPA. 1997b. Mercury Study Report to Congress; Volume II: An Inventory of Anthropogenic Mercury Emissions in the United States. Washington (DC): Office of Air Quality Planning & Standards and Office of Research and Development. EPA-452/R-97-004. 181 pp <http://www.epa.gov/ttn/oarpg/t3/reports/volume2.pdf> Accessed August 1, 2012.

EPA. 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury. Washington (DC): Environmental Protection Agency (EPA). EPA-823-R-01-001. 303 pp <http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/pollutants/methylmercury/upload/2009_01_15_criteria_methylmercury_mercury-criterion.pdf> Accessed August 1, 2012.

EPA. 2002a. Methods for Estimating the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. Washington (DC): Environmental Protection Agency (EPA), Office of Water. EPA-821-R-02-012. 275 pp <http://water.epa.gov/scitech/methods/cwa/wet/upload/2007_07_10_methods_wet_disk2_atx.pdf> Accessed August 1, 2012.

EPA. 2002b. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Washington (DC): Environmental Protection Agency (EPA), Office of Water. EPA-821-R-02-013. 350 pp <http://water.epa.gov/scitech/methods/cwa/wet/upload/2007_07_10_methods_wet_disk3_ctf.pdf> Accessed August 1, 2012.

EPA. 2007. Integrated Risk Information System (IRIS) Substance List. [Internet] Washington (DC): U.S. Environmental Protection Agency (EPA), Office of Research and Development. <http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction=iris.showSubstanceList> Accessed August 1, 2012.

EPA. 2008. Clean Water Act History. [Internet] Washington (DC): Environmental Protection Agency (EPA). <http://www.epa.gov/lawsregs/laws/cwahistory.html> Accessed August 1, 2012.

EPA. 2010. Water Quality Standards for Florida's Lakes and Flowing Waters. EPA-HQ-OW-2009-0596. Fed. Reg.; 75(233):75762-75806 <https://federalregister.gov/a/2010-29943> Accessed August 1, 2012.

EPA. 2012a. Mercury and Air Toxics Standards (MATS). [Internet] Washington (DC): Environmental Protection Agency (EPA). March 27, 2012 <http://www.epa.gov/mats/> Accessed August 1, 2012.

EPA. 2012b. Technology Transfer Network: Clearinghouse for Inventories & Emissions Factors. [Internet] Washington (DC): Environmental Protection Agency (EPA). December 28, 2011 <http://www.epa.gov/ttn/chief/ap42/index.html> Accessed August 1, 2012.

EPA. 2012c. Toxics Release Inventory (TRI) Program. [Internet]: Environmental Protection Agency (EPA). <http://www.epa.gov/tri/index.htm> Accessed August 1, 2012.

EPA. 2012d. TRI Explorer Releases: Trends Report, Toxics Release Inventory. [Internet] Washington (DC): Environmental Protection Agency (EPA). March 2012 <http://iaspub.epa.gov/triexplorer/release_trends?p_view=USYR&trilib=TRIQ1&sort=_VIEW_&sort_fmt=1&state=All+states&county=All+counties&chemical=CORE01&industry=ALL&year=All+years&core_year=&tab_rpt=1&fld=AIRLBY&fld=E1&fld=E2&fld=E3&fld=E4&fld=E41&fld=E42&fld=E5&fld=E52&fld=E53&fld=E53A&fld=E53B&fld=E54&fld=E51&fld=E51A&fld=E51B&fld=TSFDSP&fld=TSFDSP&fld=m10&fld=m41&fld=m62&fld=potwmetl&fld=m71&fld=m81&fld=m82&fld=m72&fld=m63&fld=m64&fld=m65&fld=m66&fld=m67&fld=m73&fld=m79&fld=m90&fld=m94&fld=m99&fld=RELLBY> Accessed August 1, 2012.

EPA. 2012e. TRI.NET. [Internet] Washington (DC): Environmental Protection Agency (EPA). July 9, 2012 <http://www.epa.gov/tri/tridotnet/index.html> Accessed August 1, 2012.

ERDC. 2012. Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS). Washington (DC): U.S. Army Corps of Engineers (USACE), Environmental Research and Development Center. <https://rsgis.crrel.usace.army.mil/ribits/f?p=107> Accessed August 1, 2012.

Evans DL, Higman JC. 2001. Benthic Macroinvertebrate Data from 20 Surface Water Sites within the Lower St. Johns River Basin. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ2001-SP9. 62 pp <http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2001-SP9.pdf> Accessed August 1, 2012.

Evans DL, Strom DG, Higman JC, Hughes E, Hoover EA, Line LM. 2004. An Evaluation of Benthic Macroinvertebrate Data from 20 Surface Water Sites Within the Lower St. Johns River Basin, 2002-2003. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ2004-SP41. 110 pp <http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ2004-SP41.pdf> Accessed August 1, 2012.

FDHSMV. 2012. Florida Vessel Owners: Statistics. Tallahassee (FL): Florida Department of Highway Safety and Motor Vehicles (FDHSMV). <http://www.flhsmv.gov/dmv/vslfacts.html> Accessed August 1, 2012.

FDOH. 2005. News Release: Health Alert for Duval, St. Johns, and Clay Counties. Tallahassee (FL): Florida Department of Health (FDOH), Duval County Health Department. <http://www.doh.state.fl.us/environment/community/aquatic/pdfs/Dvual_Press_R_81205_BG_2_.pdf> Accessed August 1, 2012.

FDOH. 2012. Your Guide to Eating Fish Caught in Florida (2012). Tallahassee (FL): Florida Department of Health (FDOH). 36 pp <http://doh.state.fl.us/floridafishadvice/2012Brochure.pdf> Accessed August 1, 2012.

Fernald EA, Patton DJ. 1984. Water Resources Atlas of Florida. Tallahassee (FL): Florida State University. 291 p ISBN: 978-0960670819 <http://www.amazon.com/dp/0960670815> Accessed August 1, 2012.

Fisk AT, Stern GA, Hobson KA, Strachan WJ, Loewen MD, Norstrom RJ. 2001. Persistent Organic pollutants (POPs) in a Small, Herbivorous, Arctic Marine Zooplankton (Calanus hyperboreus): Trends from April to July and the Influence of Lipids and Trophic Transfer. Mar. Pollut. Bull.; 43(1-6):93-101 <http://dx.doi.org/10.1016/S0025-326X(01)00038-8> Accessed August 1, 2012.

Fitzpatrick JW, Pranty B, Stith B. 1994. Florida Scrub Jay Statewide Habitat Map, 1992-1993. Lake Placid (FL): U.S. Fish and Wildlife Service (USFWS), Archbold Biological Station. Cooperative Agreement No. 14-16-0004-91-950. <http://share2.myfwc.com/scrubjay/Shared Documents/maps/> Accessed August 1, 2012.

Foltz DW, Sarver SK, Hrincevich AW. 1995. Genetic Structure of Brackish Water Clams (*Rangia spp.*). Biochemical Systematics and Ecology; 23(3):223-233 <http://dx.doi.org/10.1016/0305-1978(95)00012-J> Accessed August 1, 2012.

Forstall RL. 1995. Florida Population of Counties by Decennial Census: 1900 to 1990. Washington (DC): U.S. Census Bureau (USCB), Population Division. <http://www.census.gov/population/cencounts/fl190090.txt> Accessed August 1, 2012.

Fossi MC, Marsili L. 2003. Effects of Endocrine Disruptors in Aquatic Mammals. Pure Appl. Chem.; 75(11-12):2235-2247 <http://dx.doi.org/10.1351/pac200375112235> Accessed August 1, 2012.

Foster JM, Heard RW, Knott DM. 2004. Northern Range Extensions for *Caprella Scaura* Templeton, 1836 (Crustacea: Amphipoda: Caprellidae) on the Florida Gulf Coast and South Carolina. Gulf Caribb. Res.; 16(1):65-69 <https://http://www.dnr.state.sc.us/marine/sertc/Foster et al 2004 on Caprella scaura.pdf> Accessed August 1, 2012.

Frank B. 2008a. Jacksonville Shells. [Internet] Jacksonville (FL): Jacksonville Shell Club. <http://www.jaxshells.org> Accessed August 1, 2012.

Frank B. 2008b *Personal communication* to McCarthy H.

Frayer WE, Monahan T, Bowden DC, Graybill FA. 1983. Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950's to 1970's. St. Petersburg (FL): U.S. Fish and Wildlife Service (USFWS), National Wetlands Inventory. 31 pp <http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-and-Deepwater-Habitats-in-the-Conterminous-United-States-1950s-to-1970s.pdf> Accessed August 1, 2012.

French GT, Moore KA. 2003. Interactive Effects of Light and Salinity Stress on the Growth, Reproduction, and Photosynthetic Capabilities of *Vallisneria americana* (Wild Celery). Estuar. Coasts; 26(5):1255-1268 <http://dx.doi.org/10.1007/BF02803628> Accessed August 1, 2012.

Friedland KD, Kynard B. 2004. IUCN Red List of Threatened Species (2007) *Acipenser brevirostrum*. [Internet] Cambridge (England): International Union for Conservation of Nature and Natural Resources (IUCN). <http://www.iucnredlist.org/apps/redlist/details/222/0> Accessed August 1, 2012.

FWC. 1978. The Florida Manatee Sanctuary Act, 68C-22 Florida Department of State (FDOS). <https://http://www.flrules.org/gateway/ChapterHome.asp?Chapter=68C-22> Accessed August 1, 2012.

FWC. 2000. Sea Stats: Baitfish. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). 4 pp <http://research.myfwc.com/products/product_info.asp?id=1442> Accessed August 1, 2012.

FWC. 2007. Florida Manatee Management Plan: *Trichechus manatus latirostris*. Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC). 281 pp <http://myfwc.com/media/415297/Manatee_MgmtPlan.pdf> Accessed August 1, 2012.

FWC. 2008a. Bald Eagle Management Plan: *Haliaeetus leucocephalus*. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). 85 pp <http://myfwc.com/media/427567/Eagle_Plan_April_2008.pdf> Accessed August 1, 2012.

FWC. 2008b. Species Profile - Florida Scrub Jay: Aphelocoma coerulescens. [Internet] Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC). <http://myfwc.com/wildlifehabitats/profiles/birds/songbirds/florida-scrub-jay/> Accessed August 1, 2012.

FWC. 2010a. Manatee Protection Plans. [Internet] Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC). <http://www.myfwc.com/wildlifehabitats/managed/manatee/protection-plans/> Accessed August 1, 2012.

FWC. 2010b. Species Profile - Largemouth Bass. [Internet] St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). <http://myfwc.com/wildlifehabitats/profiles/fish/freshwater-fish/largemouth-bass/> Accessed August 1, 2012.

FWC. 2010c. St. Johns River Fish Kills. [Internet] Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). <http://myfwc.com/research/saltwater/health/reported-fish-kills-abnormalities/st-johns-river/> Accessed August 1, 2012.

FWC. 2011. Florida Freshwater Fishing Regulations 2011, Florida Fish and Wildlife Conservation Commission (FWC). <http://www.eregulations.com/wp-content/uploads/2011/06/11FLFW-Ad_Free.pdf> Accessed August 1, 2012.

FWC. 2012. Florida Saltwater Recreational Fishing Regulations 2012, Florida Fish and Wildlife Conservation Commission (FWC). <http://www.myfwc.com/media/2075479/saltwater_regulations_adfree.pdf> Accessed August 1, 2012.

FWRI. 2001. Fisheries-Independent Monitoring Program 2001 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 333 pp <http://www.lsjr.org/pdf/FIM_2001_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2002. Fisheries-Independent Monitoring Program 2002 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2003-013. 335 pp <http://www.lsjr.org/pdf/FIM_2002_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2003. Fisheries-Independent Monitoring Program 2003 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2004-003. 348 pp <http://www.lsjr.org/pdf/FIM_2003_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2004. Fisheries-Independent Monitoring Program 2004 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2005-02. 364 pp <http://www.lsjr.org/pdf/FIM_2004_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2005. Fisheries-Independent Monitoring Program 2005 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2006-10. 343 pp <http://www.lsjr.org/pdf/FIM_2005_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2006. Fisheries-Independent Monitoring Program 2006 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2007-004. 356 pp <http://www.lsjr.org/pdf/FIM_2006_Annual_Report_Web.pdf> Accessed August 1, 2012.

FWRI. 2007. Fisheries-Independent Monitoring Program 2007 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2008-006. 345 pp <http://www.lsjr.org/pdf/FIM_2007_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2008a. Atlantic Croaker, *Micropogonias undulates* (Linnaeus, 1766). St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 6 pp <http://myfwc.com/media/194607/atlantic_croaker.pdf> Accessed August 1, 2012.

FWRI. 2008b. Blue Crab, *Callinectes sapidus* Rathbun, 1896. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 6 pp <http://myfwc.com/media/195795/blue_crab.pdf> Accessed August 1, 2012.

FWRI. 2008c. Fisheries-Independent Monitoring Program 2008 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2009-002. 342 pp <http://www.lsjr.org/pdf/FIM_2008_Annual_Report_web.pdf> Accessed August 1, 2012.

FWRI. 2008d. Flounders, *Paralichthys* spp. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 6 pp <http://myfwc.com/media/194673/flounders.pdf> Accessed August 1, 2012.

FWRI. 2008e. Penaeid Shrimp. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 5 pp <http://myfwc.com/media/195867/penaeid_shrimps.pdf> Accessed August 1, 2012.

FWRI. 2008f. Red Drum, *Scianops ocellatus* (Linnaeus, 1766). St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 6 pp <http://myfwc.com/media/194654/red_drum.pdf> Accessed August 1, 2012.

FWRI. 2009. Fisheries-Independent Monitoring Program 2009 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2010-001. 340 pp <http://www.lsjr.org/pdf/FIM_2009_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2010. Fisheries-Independent Monitoring Program 2010 Annual Data Summary Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2009-002. 342 pp <http://www.lsjr.org/pdf/FIM_2010_Annual_Report.pdf> Accessed August 1, 2012.

FWRI. 2011a. Commercial Fisheries Landings in Florida. [Internet] St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). <http://myfwc.com/research/saltwater/fishstats/commercial-fisheries/landings-in-florida/> Accessed August 1, 2012.

FWRI. 2011b. Favorable Weather Leads to High Manatee Count. [Internet] Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). <http://myfwc.com/news/news-releases/2011/january/28/manateesynopticsurvey/> Accessed August 1, 2012.

FWRI. 2011c. Shortnose Sturgeon Population Evaluation in the St. Johns River, Florida. [Internet] St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). <http://myfwc.com/research/saltwater/sturgeon/research/population-evaluation/> Accessed August 1, 2012.

FWRI. 2012a. Cold-Related Mortality Event Winter 2009-2010. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). <http://myfwc.com/research/manatee/rescue-mortality-response/mortality-statistics/cold-related-2009-2010/> Accessed August 1, 2012.

FWRI. 2012b. Manatee Mortality Search. [Internet] St. Petersburg (FL): Florida Department of Agriculture. <http://research.myfwc.com/manatees> Accessed August 1, 2012.

FWRI. 2012c. Manatee Synoptic Surveys. [Internet] St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). January 2011 <http://myfwc.com/research/manatee/projects/population-monitoring/synoptic-surveys/> Accessed August 1, 2012.

Gallegos CL. 2005. Optical Water Quality of a Blackwater River Estuary: The Lower St. Johns River, Florida, USA. Estuar. Coast. Shelf Sci.; 63(1-2):57-72 <http://dx.doi.org/10.1016/j.ecss.2004.10.010> Accessed August 1, 2012.

GBIF. 2012a. Occurrence Records for *Caprella scaura* (Templeton, 1836). Copenhagen, Denmark: Global Biodiversity Information Facility. <http://data.gbif.org/species/5178082/> Accessed August 1, 2012.

GBIF. 2012b. Occurrence Records for *Corophium lacustre* (Vanhöffen, 1911). Copenhagen, Denmark: Global Biodiversity Information Facility. <http://data.gbif.org/species/2217325/> Accessed August 1, 2012.

GBIF. 2012c. Occurrence Records for *Rangia cuneata* (G. B. Sowerby I, 1831). Copenhagen, Denmark: Global Biodiversity Information Facility. <http://data.gbif.org/species/5188971/> Accessed August 1, 2012.

GBIF. 2012d. Occurrence Records for *Styela plicata* (Lesueur, 1823). Copenhagen, Denmark: Global Biodiversity Information Facility. <http://data.gbif.org/species/2331954/> Accessed August 1, 2012.

Gelsleichter J, Walsh CJ, Szabo NJ, Rasmussen LEL. 2006. Organochlorine Concentrations, Reproductive Physiology, and Immune Function in Unique Populations of Freshwater Atlantic Stingrays (Dasyatis sabina) from Florida's St. Johns River. Chemosphere; 63(9):1506-1522 <http://dx.doi.org/10.1016/j.chemosphere.2005.09.011> Accessed August 1, 2012.

Gerstein ER, Blue JE, Pinto GF, Barr S. 2006. Underwater Noise Radiation from Dredging and the Zones of Masking that Impact Manatee Hearing in the Lower St. Johns River, Jacksonville, FL. Jacksonville (FL): City of Jacksonville (COJ), Jacksonville Waterways Commission (JWC). Final draft - contract No. 8548. 55 pp.

GESAMP. 1997. Opportunistic Settlers and the Problem of the Ctenophore *Mnemiopsis leidyi* Invasion in the Black Sea. London (England): Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). Number 58. 96 pp <http://www.gesamp.org/data/gesamp/files/media/Publications/Reports_and_studies_58/gallery_1357/object_1387_large.pdf> Accessed August 1, 2012.

Gilliom RJ, Barbash JE, Crawford CG, Hamilton PA, Martin JD, Nakagaki N, Nowell LH, Scott JC, Stackelberg PE, Thelin GP and others. 2006. Pesticides in the Nation's Streams and Ground Water, 1992-2001 (Revised February 2007). Washington (DC): U.S. Geological Survey (USGS). Circular 1291. 184 pp <http://pubs.usgs.gov/circ/2005/1291/pdf/circ1291.pdf> Accessed August 1, 2012.

Gipson J. 2011 *Personal communication* to Pinto G.

GLD&D. 2001. Future Opportunities: $31.6-million Deepening Funded for Jacksonville. Oak Brook (IL): Great Lakes Dredge & Dock Company. Circular 26. 3 pp.

Goff K. 2010 *Personal communication* to Sonnenberg L.

Gordon D. 1997. Toxins and Signal Transduction. Amsterdam: Harwood. ISBN: 978-9057020780 Sodium Channels as Targets for Neurotoxins: Mode of Action and Interaction of Neurotoxins with Receptor Sites on Sodium Channels. p 119-149. <http://www.crcpress.com/product/isbn/9789057020780> Accessed August 1, 2012.

Granberry J. 1956. Timucua I: Prosodics and Phonemics of the Mocama Dialect. Int. J. Amer. Ling.; 22(2):97-105 <http://www.jstor.org/stable/1263585> Accessed August 1, 2012.

Granberry J. 1993. A Grammar and Dictionary of the Timucua Language. 3rd edition. Tuscaloosa (AL): The University of Alabama Press. 320 p ISBN: 978-0817307042 <http://www.uapress.ua.edu/product/Grammar-and-Dictionary-of-the-Timucua-Language,633.aspx> Accessed August 1, 2012.

Green EJ, Carritt DE. 1967. New Tables for Oxygen Saturation of Seawater. J. Mar. Res.; 25(2):140-147.

Groom MJ, Meffe GK, Carroll CR. 2006. Principles of Conservation Biology. 3rd edition. Sunderland (MA): Sinauer Associates, Inc. 699 p ISBN: 978-0-878-93518-5 <http://www.sinauer.com/detail.php?id=5970> Accessed August 1, 2012.

Grosell M, Blanchard J, Brix KV, Gerdes R. 2007. Physiology is Pivotal for Interactions Between Salinity and Acute Copper Toxicity to Fish and Invertebrates. Aquat. Toxicol.; 84(2):162-172 <http://dx.doi.org/10.1016/j.aquatox.2007.03.026> Accessed August 1, 2012.

GSMFC. 2010. Non-Native Aquatic Species in the Gulf of Mexico and South Atlantic Regions. [Internet] Ocean Springs (MS): Gulf States Marine Fisheries Commission (GSMFC). <http://www.gsarp.org> Accessed August 1, 2012.

Guillette Jr. LJ, Brock JW, Rooney AA, Woodward AR. 1999. Serum Concentrations of Various Environmental Contaminants and Their Relationship to Sex Steroid Concentrations and Phallus Size in Juvenile American Alligators. Arch. Environ. Contam. Toxicol.; 36(4):447-455 <http://dx.doi.org/10.1007/PL00006617> Accessed August 1, 2012.

Guillette Jr. LJ, Gross TS, Masson GR, Matter JM, Percival HF, Woodward AR. 1994. Developmental Abnormalities of the Gonads and Abnormal Hormone Concentrations in Juvenile Alligators from Contamined and Control Lakes in Florida. Environ. Health Perspect.; 102(8):680-688 <http://dx.doi.org/10.1289/ehp.94102680> Accessed August 1, 2012.

Guzman HM, Jimenez CE. 1992. Contamination of Coral Reefs by Heavy Metals Along the Caribbean Coast of Central America (Costa Rica and Panama). Mar. Pollut. Bull.; 24(11):554-561 <http://dx.doi.org/10.1016/0025-326X(92)90708-E> Accessed August 1, 2012.

Hallegraeff GM, Bolch CJ. 1991. Transport of Toxic Dinoflagellate Cysts via Ships' Ballast Water. Mar. Pollut. Bull.; 22(1):27-30 <http://dx.doi.org/10.1016/0025-326X(91)90441-T> Accessed August 1, 2012.

Hallegraeff GM, Bolch CJ, Bryan J, Koerbin B. 1990. Microalgal Spores in Ship's Ballast Water: A Danger to Aquaculture. In: Graneli E, Sundstrom B, Edler L, Anderson DM, editors. Fourth International Conference on Toxic Marine Phytoplankton. Lund (Sweden): Elsevier. p 475-480. <http://www.amazon.com/dp/044401523X> Accessed August 1, 2012.

Hankla D. 2007. U.S. Fish and Wildlife Service Announces Availability of the Wood Stork Five-Year Review. [Internet] Jacksonville (FL): U.S. Fish and Wildlife Service (USFWS), North Florida Field Office. <http://www.fws.gov/northflorida/Releases-07/005-07-Availability-of-Wood-stork-Five-Year-Reviews-092807.htm> Accessed August 1, 2012.

Hart C. 2012 *Personal communication* to Pinto G.

Hartley W. 2012 *Personal communication* to Pinto G.

Hedgpeth JW. 1993. Foreign Invaders. Science; 261(5117):34-35 <http://dx.doi.org/10.1126/science.261.5117.34> Accessed August 1, 2012.

Hefner JM. 1986. Wetlands in Florida: 1950's to 1970's. In: Estevez ED, Miller J, Morris J, Hamman R, editors. Managing Cumulative Effects in Florida Wetlands. Madison (WI): Omnipress.

Hendrickson J. 2006. The St. Johns River: Water Resource and Pollution Issues. A Seminar for Journalists. Palatka (FL): St. Johns River Water Management District (SJRWMD). 35 pp.

Hendrickson J. 2008 *Personal communication* to Welsh P.

Hendrickson J, Konwinski J. 1998. Seasonal Nutrient Import-Export Budgets for the Lower St. Johns River, Florida. Palatka (FL): St. Johns River Water Management District (SJRWMD). Contract WM598. 109 pp

<http://waterinstitute.ufl.edu/WorkingGroups/TCAA/downloads/Hendrickson_and_Konwinski_1998.pdf> Accessed August 1, 2012.

Hendrickson J, Trahan N, Gordon E, Ouyang Y. 2007. Estimating Relevance of Organic Carbon, Nitrogen and Phosphorus Loads to a Blackwater Estuary. J. Amer. Water Resources Assoc.; 43(1):264-279 <http://dx.doi.org/10.1111/j.1752-1688.2007.00021.x> Accessed August 1, 2012.

Higman JC, Hart C, Tallerico J, Baird S, Campbell D. 2008. The Lower St. Johns River Basin Sediment Quality Atlas: Riverbed Sediment Characteristics and Contaminant Concentrations. Palatka (FL): St. Johns River Water Management District (SJRWMD).

Hoang TC, Tomasso JR, Klaine SJ. 2004. Influence of Water Quality and Age on Nickel Toxicity to Fathead Minnows (*Pimephales promelas*). Environ. Toxicol. Chem.; 23(1):86-92 <http://dx.doi.org/10.1897/03-11> Accessed August 1, 2012.

Horak D. 1995. Native and Nonnative Fish Species Used in State Fisheries Management Programs in the United States. In: Schramm HL, Piper RG, editors. American Fisheries Society Symposium on Uses and Effects of Cultured Fishes in Aquatic Ecosystems. Albuquerque (NM): American Fisheries Society. p 61-67. <http://www.amazon.com/dp/0913235911> Accessed August 1, 2012.

Hough P, Robertson M. 2009. Mitigation Under Section 404 of the Clean Water Act: Where it Comes From, What it Means. Wetlands Ecol. Manage.; 17(1):15-33 <http://dx.doi.org/10.1007/s11273-008-9093-7> Accessed August 1, 2012.

Hutchinson GE. 1944. Nitrogen in the Biogeochemistry of the Atmosphere. Am. Scientist; 32(3):178-195 <http://www.jstor.org/stable/29773619> Accessed August 1, 2012.

Hyland JL, Van Dolah RF, Snoots TR. 1999. Predicting Stress in Benthic Communities of Southeastern U.S. Estuaries in Relation to Chemical Contamination of Sediments. Environ. Toxicol. Chem.; 18(11):2557-2564 <http://dx.doi.org/10.1897/1551-5028(1999)018%3C2557:PSIBCO%3E2.3.CO;2> Accessed August 1, 2012.

Hyslop NL. 2007 Movements, Habitat Use, and Survival of the Threatened Eastern Indigo Snake (Drymarchon couperi) in Georgia. (Ph.D.) Athens (GA): University of Georgia. 132 p. Accessed August 1, 2012.

Hyslop NL, Cooper RJ, Meyers JM. 2009a. Seasonal Shifts in Shelter and Microhabitat Use of Drymarchon couperi (Eastern Indigo Snake) in Georgia. Copeia; (3):458-464 <http://dx.doi.org/10.1643/CH-07-171> Accessed August 1, 2012.

Hyslop NL, Meyers JM, Cooper RJ. 2006. Movements, Survival, and Habitat Use of the Threatened Eastern Indigo Snake (*Drymarchon couperi*) in Southeastern Georgia. Athens (GA): U.S. Geological Survey (USGS), Patuxent Wildlife Research Center. Final Report to the Georgia Department of Natural Resources.

Hyslop NL, Meyers JM, Cooper RJ, Morton TM. 2009b. Survival of Radio-Implanted *Drymarchon Couperi* (Eastern Indigo Snake) in Relation to Body Size and Sex Herpetologica; 65(2):199-206 <http://dx.doi.org/10.1655/08-004R1.1> Accessed August 1, 2012.

Hyslop NL, Meyers JM, Cooper RJ, Stevenson DJ. 2009c. Indigo Snake Capture Methods: Effectiveness of Two Survey Techniques for *Drymarchon couperi* in Georgia. Florida Sci.; 72(2):93-100 <http://plaza.ufl.edu/nhyslop/Publications/Hyslop et al 2009- Drymarchon capture- FL Sci.pdf> Accessed August 1, 2012.

IFAS. 2007. UF/IFAS Center for Aquatic and Invasive Plants. [Internet] Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS). <http://plants.ifas.ufl.edu/> Accessed August 1, 2012.

IFAS. 2009. Trophic States of Florida Lakes. [Internet] Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS). <http://aquat1.ifas.ufl.edu/guide/trophstate.html> Accessed August 1, 2012.

Incardona JP, Collier TK, Scholz NL. 2004. Defects in Cardiac Function Precede Morphological Abnormalities in Fish Embryos Exposed to Polycyclic Aromatic Hydrocarbons. Toxicol. Appl. Pharmacol.; 196(2):191-205 <http://dx.doi.org/10.1016/j.taap.2003.11.026> Accessed August 1, 2012.

Jacksonville Zoo. 2012a. Biofacts: Bald Eagle. [Internet] Jacksonville (FL): Jacksonville Zoo and Gardens. <http://www.jacksonvillezoo.org/animals/birds/bald_eagle/> Accessed August 1, 2012.

Jacksonville Zoo. 2012b. Wood Stork Conservation. [Internet] Jacksonville (FL): Jacksonville Zoo and Gardens. <http://www.jacksonvillezoo.org/animals/wood_stork_conservation/> Accessed August 1, 2012.

Jacoby CA. 2011 *Personal communication* to Pinto G.

JAXPORT. 2007. JAXPORT Begins Construction of New TraPac Terminal. [Internet] Jacksonville (FL): Jacksonville Port Authority (JAXPORT). <http://www.seaportspr.com/viewportnews.cgi?newsletter_id=83&article_id=2896> Accessed August 1, 2012.

JAXPORT. 2008. Harbor Deepening. [Internet] Jacksonville (FL): Jacksonville Port Authority (JAXPORT). <http://www.jaxport.com/cargo/maritime-resources/harbor-deepening> Accessed August 1, 2012.

JAXPORT. 2012. Maritime Resources - Statistics. [Internet] Jacksonville (FL): Jacksonville Port Authority (JAXPORT). <http://www.jaxport.com/cargo/maritime-resources/marine-statistics> Accessed August 1, 2012.

Johnson LE, Carlton JT. 1996. Post-Establishment Spread in Large-scale Invasions: Dispersal Mechanisms of the Zebra Mussel *Dreissena Polymorpha*. Ecology; 77(6):1686-1690 <http://dx.doi.org/10.2307/2265774> Accessed August 1, 2012.

Jolley R, Cumming R, Lee N, Lewis L. 1982. Micropollutants Produced by Disinfection of Wastewater Effluents. Water Sci. Technol.; 14(12):45-59 <http://www.iwaponline.com/wst/01412/wst014120045.htm> Accessed August 1, 2012.

Jones RJ. 1997. Zooxanthellae Loss as a Bioassay for Assessing Stress in Corals. Mar. Ecol. Prog. Ser.; 149(1):163-171 <http://dx.doi.org/10.3354/meps149163> Accessed August 1, 2012.

Jones WW, Sauter S. 2005. Distribution and Abundance of *Cylindrospermopsis raciborskii* in Indiana Lakes and Reservoirs. Bloomington (IN): Indiana University, School of Public and Environmental Affairs. 54 pp <http://www.indiana.edu/~clp/documents/FinalCylindro Web.pdf> Accessed August 1, 2012.

Jordan F. 2000. An Evaluation of Relationships Between Submerged Aquatic Vegetation and Fish Community Structure in the St. Johns River. Final Report. New Orleans (LA): Loyola University of New Orleans, Department of Biological Sciences. 213 pp.

Jordan F, Bartolini M, Nelson C, Patterson PE, Soulen HL. 1996. Risk of Predation Affects Habitat Selection by the Pinfish *Logodon rhomboids* (Linaeus). J. Exp. Mar. Biol. Ecol.; 208(1-2):45-56 <http://dx.doi.org/10.1016/S0022-0981(96)02656-1> Accessed August 1, 2012.

JU. 2012. Jacksonville University Manatee Research Center Online (MARCO). [Internet] Jacksonville (FL): Jacksonville University (JU). <http://www.ju.edu/marco> Accessed August 1, 2012.

Karami-Mohajeri S, Abdollahi M. 2011. Toxic Influence of Organophosphate, Carbamate, and Organochlorine Pesticides on Cellular Metabolism of Lipids, Proteins, and Carbohydrates: A Systematic Review. Human Exp. Toxicol.; 30(9):1119-1140 <http://dx.doi.org/10.1177/0960327110388959> Accessed August 1, 2012.

Karen DJ, Joab BM, Wallin JM, Johnson KA. 1998. Partitioning of Chlorpyrifos Between Water and an Aquatic Macrophyte *(Elodea densa)*. Chemosphere; 37(8):1579-1586 <http://dx.doi.org/10.1016/S0045-6535(98)00141-6> Accessed August 1, 2012.

Karen DJ, Klaine SJ, Ross PE. 2001. Further Considerations of the Skeletal System as a Biomarker of Episodic Chlorpyrifos Exposure. Aquat. Toxicol.; 52(3-4):285-296 <http://dx.doi.org/10.1016/S0166-445X(00)00164-8> Accessed August 1, 2012.

Karickhoff SW. 1981. Semi-Empirical Estimation of Sorption of Hydrophobic Pollutants on Natural Sediments and Soils. Chemosphere; 10(8):833-846 <http://dx.doi.org/10.1016/0045-6535(81)90083-7> Accessed August 1, 2012.

Katagi T. 2010 In: Whitacre DM, editor. Reviews of Environmental Contamination and Toxicology. Volume 204. New York (NY): Springer-Verlag. ISBN: 978-1441914408 Bioconcentration, Bioaccumulation, and Metabolism of Pesticides in Aquatic Organisms. p 1-132. <http://dx.doi.org/10.1007/978-1-4419-1440-8_1> Accessed August 1, 2012.

Kenney WF, Waters MN, Schelske CL, Brenner M. 2002. Sediment Records of Phosphorus-Driven Shifts to Phytoplankton Dominance in Shallow Florida Lakes. J. Paleolimnol.; 27(3):367-377 <http://dx.doi.org/10.1023/A:1016075012581> Accessed August 1, 2012.

Keppner SM. 1995. U.S. Fish and Wildlife Service: National and Regional Responses to Non-Indigenous Aquatic Species. In: Balcom NC, editor. Proceedings of the Northeast Conference on Non-Indigenous Aquatic Nuisance Species. Cromwell (CT): Connecticut Sea Grant College Program. p 65-71.

Keup LE. 1968. Phosphorus in Flowing Waters. Water Res.; 2(5):373-386 <http://dx.doi.org/10.1016/0043-1354(68)90049-3> Accessed August 1, 2012.

Kiker CF, Hodges AW. 2002. Economic Benefits of Natural Land Conservation: Case Study in Northeast Florida. Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS), Department Food and

Resource Economics. 75 pp <http://www.fred.ifas.ufl.edu/economic-impact-analysis/pdf/NE-Fla-Project-Final-Report.pdf> Accessed August 1, 2012.

Kilham P. 1990. Mechanisms Controlling the Chemical Composition of Lakes and Rivers: Data from Africa. Limnol. Oceanogr.; 35(1):80-83 <http://www.aslo.org/lo/toc/vol_35/issue_1/0080.pdf> Accessed August 1, 2012.

Kilham P, Hecky RE. 1988. Comparative Ecology of Marine and Freshwater Phytoplankton. Limnol. Oceanogr.; 33(4 part 2):776-795 <http://www.aslo.org/lo/toc/vol_33/issue_4_part_2/0776.pdf> Accessed August 1, 2012.

Kinnaird MF. 1983a. Aerial Census of Manatee and Boats Over the Lower St. Johns River and the Intracoastal Waterway in Northeastern Florida. Site-Specific Reduction of Manatee Boat/Barge Mortality. Gainesville (FL): University of Florida, Florida Cooperative Fish and Wildlife Research Unit. Report 2, Agreement No. 14-16-0004-81-923. 56 pp <http://aquacomm.fcla.edu/1085/> Accessed August 1, 2012.

Kinnaird MF. 1983b. Site-Specific Analysis of Factors Potentially Influencing Manatee Boat/Barge Mortality. Site-Specific Reduction of Manatee Boat/Barge Mortality. Gainesville (FL): University of Florida, Florida Cooperative Fish and Wildlife Research Unit. Report No. 4, Agreement No. 14-16-0004-81-923. 41 pp.

Kling HJ. 2004. *Cylindrospermopsis Raciborskii* (Nostocales, Cyanobacteria): A Brief Historic Overview and Recent Discovery in the Assiniboine River (Canada). Fottea; 9(1):45-47 <http://www.fottea.cz/_contents/F09-1-2009-02.pdf> Accessed August 1, 2012.

Kozelka PB, Bruland KW. 1998. Chemical Speciation of Dissolved Cu, Zn, Cd, Pb in Narragansett Bay, Rhode Island. Mar. Chem.; 60(3-4):267-282 <http://dx.doi.org/10.1016/S0304-4203(97)00107-2> Accessed August 1, 2012.

Kraemer GP, Chamberlain RH, Doering PH, Steinman AD, Hanisak MD. 1999. Physiological Responses of Transplants of the Freshwater Angiosperm *Vallisneria Americana* Along a Salinity Gradient in the Caloosahatchee Estuary (Southwestern Florida). Estuar. Coasts; 22(1):138-148 <http://dx.doi.org/10.2307/1352934> Accessed August 1, 2012.

Kramer JR, Benoit G, Bowles KC, DiToro DM, Herrin RT, Luther III GW, Manolopoulos H, Robillard KA, Shafer MM, Shaw JR. 2000 In: Andren AW, Bober TW, editors. Silver in the Environment: Transport, Fate, and Effects. Pensacola (FL): Society of Environmental Toxicology and Chemistry (SETAC). ISBN: 978-1880611449 Environmental Chemistry of Silver. p 1-25. <https://http://www.setac.net/setacssa/ecssashop.show_product_detail?p_mode=detail&p_product_serno=42> Accessed August 1, 2012.

Krysko KL, Burgess JP, Rochford MR, Gillette CR, Cueva D, Enge KM, Somma LA, Stabile JL, Smith DC, Wasilewski JA and others. 2011. Verified Non-Indigenous Amphibians and Reptiles in Florida from 1863 through 2010: Outlining the Invasion Process and Identifying Invasion Pathways and Stages. Zootaxa; 3028:1-64 <http://www.flmnh.ufl.edu/herpetology/kk/pdf/2011_Krysko_et_al_Verified_herps_in_Florida.pdf> Accessed August 1, 2012.

Laane RWPM, Gieskes WWC, Kraay GW, Eversdijk A. 1985. Oxygen Consumption from Natural Waters by Photo-Oxidizing Processes. Netherlands J. Sea Res.; 19(2):125-128 <http://dx.doi.org/10.1016/0077-7579(85)90016-X> Accessed August 1, 2012.

Labi N. Shiploads of Aliens: Exotic Stowaways Travel Far From Home, Launching Aquatic Invasions That Wreak Havoc on Marine Life. Time Magazine 1996 October 28, 1996:64.

Lal R. 1998. Soil Erosion Impact on Agronomic Productivity and Environmental Quality. Crit. Rev. Plant Sci.; 17(4):319-464 <http://www.tandfonline.com/doi/abs/10.1080/07352689891304249> Accessed August 1, 2012.

Lamers LPM, Tomassen HBM, Roelofs JGM. 1998. Sulfate-Induced Eutrophication and Phytotoxicity in Freshwater Wetlands. Environ. Sci. Technol.; 32(2):199-205 <http://dx.doi.org/10.1021/es970362f> Accessed August 1, 2012.

Lange T. 2010 *Personal communication* to Sonnenberg L.

Lawler HE. 1977. The Status of *Drymarchon Corais Couperi* (Holbrook), The Eastern Indigo Snake, in the Southeastern United States. Herpetol. Rev.; 8(3):76-79.

Leal DR, Meiners RE, editors. 2002. Government vs. Environment. Lanham (MD): Rowman & Littlefield Publishers; 240 p ISBN: 978-0742521803 <http://www.rowmanlittlefield.com/ISBN/074252180X> Accessed August 1, 2012.

Lee H. 2008a. Jacksonville Shells. [Internet] Jacksonville (FL): Jacksonville Shell Club. <http://www.jaxshells.org> Accessed August 1, 2012.

Lee H. 2008b *Personal communication* to McCarthy H.

Lee H. 2012a. Mytella Charruana (d'Orbigny, 1846) Charrua Mussels in Duval Co., Florida. [Internet] Jacksonville (FL): Jacksonville Shell Club. <http://www.jacksonvilleshells.org/012509.htm> Accessed August 1, 2012.

Lee H. 2012b *Personal communication* to McCarthy H.

Levine SN, Schindler DW. 1992. Modification of the N:P Ratio in Lakes by in Situ Processes. Limnol. Oceanogr.; 37(5):917-935 <http://www.aslo.org/lo/toc/vol_37/issue_5/0917.pdf> Accessed August 1, 2012.

Lewis N, Mandrup-Poulsen J. 2009. Final TMDL Report: Lead TMDLs for Black Creek (WBIDs 2415B and 2415C) and Peters Creek (WBID 2444). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 52 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/black-peters-lead-tmdl.pdf> Accessed August 1, 2012.

Lomolino MV. 1977 The Ecological Role of the Florida Manatee (*Trichechus manatus latirostris*) in Water Hyacinth-Dominated Ecosystems. (M.S.) Gainesville (FL): University of Florida. 169 p. Accessed August 1, 2012.

Long ER, MacDonald DD, Smith SL, Calder FD. 1995. Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environ. Manage.; 19(1):81-97 <http://dx.doi.org/10.1007/BF02472006> Accessed August 1, 2012.

MacDonald DD. 1994. Approach to the assessment of sediment quality in Florida coastal waters. Volume 1. Tallahassee (FL): Florida Department of Environmental Protection (DEP). Chapter 6. Numerical Sediment Quality Assessment Guidelines for Florida Coastal Waters. Approach to the Assessment of Sediment Quality. p 48-75. <http://www.dep.state.fl.us/water/monitoring/docs/seds/vol1/chapter6.pdf> Accessed August 1, 2012.

Magley W. 2006a. TMDL Report: Fecal and Total Coliform TMDLs for Durbin Creek (WBID 2365). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 80 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2365.pdf> Accessed August 1, 2012.

Magley W. 2006b. TMDL Report: Fecal and Total Coliform TMDLs for the Cedar River (WBID 2262). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 80 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2262A.pdf> Accessed August 1, 2012.

Magley W. 2009a. Draft TMDL Report: Dissolved Oxygen and Nutrient TMDLs for Trout River, WBID 2203. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 104 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/draft/gp2/middletroutrivedotmd.pdf> Accessed August 1, 2012.

Magley W. 2009b. Final TMDL Report: Nutrient TMDL for Arlington River, WBID 2265A. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 89 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/arlington-river-nutr-tmdl.pdf> Accessed August 1, 2012.

Magley W. 2009c. TMDL Report: Dissolved Oxygen TMDL for Sixteen Mile Creek, WBID 2589. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 95 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/draft/gp2/sixteenmilecreekdotmdl.pdf> Accessed August 1, 2012.

Magley W. 2009d. TMDL Report: DO and Nutrient TMDLs for Swimming Pen Creek (WBID 2410) and Nutrient TMDL for Doctors Lake (WBID 2389). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 166 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/draft/gp2/swimmingdoctordonut.pdf> Accessed August 1, 2012.

Magley W, Joyner D. 2008. TMDL Report: Total Maximum Daily Load for Nutrients for the Lower St. Johns River. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. 146 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/lower-stjohns-nutrients.pdf> Accessed August 1, 2012.

Mahmoudi B. 2005. A 2005 Update of the Stock Assessment for the Striped Mullet, *Mugil cephalus*, in Florida. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 43 pp <http://myfwc.com/media/203452/stripedmullet_2005asse_1327.pdf> Accessed August 1, 2012.

Malecki LM, White JR, Reddy KR. 2004. Nitrogen and Phosphorus Flux Rates from Sediment in the Lower St. Johns River Estuary. J. Environ. Qual.; 33(4):1545-1555 <http://dx.doi.org/10.2134/jeq2004.1545> Accessed August 1, 2012.

Mallin MA, Cahoon LB, Parsons DC, Ensign SH. 2001. Effect of Nitrogen and Phosphorus Loading on Plankton in Coastal Plain Blackwater Streams. J. Freshw. Ecol.; 16(3):455-466 <http://dx.doi.org/10.1080/02705060.2001.9665832> Accessed August 1, 2012.

Mason Jr WT. 1998. Macrobenthic Monitoring in the Lower St. Johns River, Florida. Environ. Monit. Assess.; 50(2):101-130 <http://dx.doi.org/10.1023/A:1005802229832> Accessed August 1, 2012.

Masterson J. 2007. Indian River Lagoon Inventory: *Megabalanus coccopoma*, Titan Acorn Barnacle. [Internet] Fort Pierce (FL): Smithsonian Marine Station. December 1, 2007 <http://www.sms.si.edu/irlspec/Megabalanus_coccopoma.htm> Accessed August 1, 2012.

McBride RS. 2000. Florida's Shad and River Herrings (*Alosa* species): A Review of Population and Fishery Characteristics. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). Technical Report TR-5. 26 pp <http://research.myfwc.com/publications/publication_info.asp?id=40287> Accessed August 1, 2012.

McCann JA, Arkin LN, Williams JD. 1996. Nonindigenous Aquatic and Selected Terrestrial Species of Florida: Status, Pathway and Time of Introduction, Present Distribution, and Significant Ecological and Economic Effects. Gainesville (FL): National Biological Service (NBS), Southeastern Biological Science Center. 301 pp.

McCarthy D. 2008 *Personal communication* to McCarthy H.

McCarthy H. 2011 *Unpublished Work*

McCully JG. 2006. Beyond the Moon: A Conversational, Common Sense Guide to Understanding the Tides. Hackensack (NJ): World Scientific Publishing. 285 p ISBN: 978-9812566447 <http://dx.doi.org/10.1142/9789812774330> Accessed August 1, 2012.

McLane WM. 1955 The Fishes of the St. Johns River System. (Ph.D.) Gainesville (FL): University of Florida. 360 p. Accessed August 1, 2012.

Meindl CF. 2005 In: Davis JE, Arsenault R, editors. Paradise Lost? An Environmental History of Florida. Gainesville (FL): University Press of Florida. ISBN: 978-0813028262 Chapter 5: Water, Water Everywhere. p 113-140. <http://www.upf.com/book.asp?id=DAVISF05> Accessed August 1, 2012.

Meybeck M. 1982. Carbon, Nitrogen, and Phosphorus Transport by World Rivers. Am. J. Sci.; 282(4):401-450 <http://dx.doi.org/10.2475/ajs.282.4.401> Accessed August 1, 2012.

Meybeck M. 1993 In: Wollast R, Mackenzie FT, Chou L, editors. Interactions of C, N, P and S Biogeochemical Cycles and Global Change. Berlin (Germany): Springer-Verlag. ISBN: 978-3642760662 Natural Sources of C, N, P, and S. p 163-193. <http://www.springer.com/earth+sciences+and+geography/geography/book/978-3-642-76066-2> Accessed August 1, 2012.

Milanich JT. 1995. Florida Indians and the Invasion from Europe. Gainesville (FL): University Press of Florida. 304 p ISBN: 978-0813016368 <http://www.upf.com/book.asp?id=MILANF95> Accessed August 1, 2012.

Milanich JT. 1996. The Timucua. Hoboken (NJ): Wiley-Blackwell. 256 p ISBN: 978-0631218647 <http://www.wiley.com/WileyCDA/WileyTitle/productCd-0631218645.html> Accessed August 1, 2012.

Milanich JT. 1997. Missions, Timucuans, and the Aucilla. Aucilla River Times; X(1) <http://www.flmnh.ufl.edu/natsci/vertpaleo/aucilla10_1/missions.htm> Accessed August 1, 2012.

Milanich JT. 1998. Florida's Indians from Ancient Times to the Present. Gainesville (FL): University Press of Florida. 224 p ISBN: 978-0813015989 <http://www.upf.com/book.asp?id=MILANF98> Accessed August 1, 2012.

Miller JJ. 1998. An Environmental History of Northeast Florida. Gainesville (FL): University Press of Florida. 240 p ISBN: 978-0813016009 <http://www.upf.com/book.asp?id=MILLES98> Accessed August 1, 2012.

Mitchelmore CL, Verde EA, Ringwood AH, Weis VM. 2003. Differential Accumulation of Heavy Metals in the Sea Anemone *Anthopleura elegantissima* as a Function of Symbiotic State. Aquat. Toxicol.; 64(3):317-329 <http://dx.doi.org/10.1016/S0166-445X(03)00055-9> Accessed August 1, 2012.

Mitsch WJ, Gosselink JG. 2000. The Value of Wetlands: Importance of Scale and Landscape Setting. Ecol. Econom.; 35(200):25-33 <http://dx.doi.org/10.1016/S0921-8009(00)00165-8> Accessed August 1, 2012.

Miyamoto J, Matsuo M. 1990. Permethrin. Environmental Health Criteria; 94. Geneva (Switzerland): United Nations Environment Program, World Health Organization. <http://www.inchem.org/documents/ehc/ehc/ehc94.htm> Accessed August 1, 2012.

Moler PE. 1985. Home Range and Seasonal Activity of the Eastern Indigo Snake, *Drymarchon corais couperi*, in Northern Florida. Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC), Wildlife Research Laboratory. Final Performance Report, Study No. E-1-06, III-A-5. 17 pp.

Moler PE. 1992 In: Moler PE, editor. Rare and Endangered Biota of Florida: Volume III. Amphibians and Reptiles. Gainesville (FL): University Press of Florida. ISBN: 978-0813011424 Eastern Indigo Snake (*Drymarchon corais couperi*). p 181-186. <http://www.upf.com/book.asp?id=MOLERF92> Accessed August 1, 2012.

Monteiro PRR, Reis-Henriques MA, Coimbra J. 2000. Plasma Steroid Levels in Female Flounder (*Platichthys flesus*) after Chronic Dietary Exposure to Single Polycyclic Aromatic Hydrocarbons. Marine Environ. Res.; 49(5):453-467 <http://dx.doi.org/10.1016/S0141-1136(99)00085-9> Accessed August 1, 2012.

Morris IV FW. 1995. Volume 3 of the Lower St. Johns River Basin Reconnaissance: Hydrodynamics and Salinity of Surface Water. Palatka (FL): St. Johns River Water Management District (SJRWMD). Technical Publication SJ95-9. 390 pp <http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ95-9.pdf> Accessed August 1, 2012.

Mortimer CH. 1981. The Oxygen Content of Air-Saturated Freshwater Over Ranges of Temperature and Atmospheric Pressure of Limnological Interest. Stuttgart (Germany): Schweizerbart Science Publishers. 23 p ISBN: 978-3510520220 <http://www.schweizerbart.de/publications/detail/isbn/351052022X> Accessed August 1, 2012.

Moskowitz H, Herrmann R, Zlotkin E, Gordon D. 1994. Variability Among Insect Sodium Channels Revealed by Binding of Selective Neurotoxins. Insect Biochemical and Molecular Biology; 24(1):13-19 <http://dx.doi.org/10.1016/0965-1748(94)90118-X> Accessed August 1, 2012.

Muller RG, Bert TM, Gerhart SD. 2006. The 2006 Stock Assessment Update for the Stone Crab, *Menippe* spp., Fishery in Florida. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2006-011. 47 pp <http://myfwc.com/media/203200/sa_stone_crab_2006_0856.pdf> Accessed August 1, 2012.

Munyandorero J, Murphy MD, MacDonald TC. 2006. An Assessment of the Status of Sheepshead in Florida Waters Through 2004. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2006-009. 113 pp <http://research.myfwc.com/engine/download_redirection_process.asp?file=sheepsheadedited2006_1224.pdf&objid=26840&dltype=article> Accessed August 1, 2012.

Murphy MD, Chagaris D, Addis D. 2011. An Assessment of the Status of Spotted Seatrout in Florida Waters Through 2009. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2011-002. 53 pp <http://myfwc.com/media/1355905/Spotted_seatrout.pdf> Accessed August 1, 2012.

Murphy MD, Guenther CB, Mahmoudi B. 2006. An Assessment of the Status of Spotted Seatrout (*Cynoscion nebulosus*) in Florida Waters Through 2005. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2006-XXX. 195 pp <http://myfwc.com/media/1355905/Spotted_seatrout.pdf> Accessed August 1, 2012.

Murphy MD, McMillen-Jackson AL, Mahmoudi B. 2007. A Stock Assessment for the Blue Crab, *Callinectes sapidus*, in Florida Waters. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2007-006. 90 pp <http://myfwc.com/media/200959/bc_2007.pdf> Accessed August 1, 2012.

Murphy MD, Munyandorero J. 2008. A Stock Assessment of Red Drum, *Sciaenops ocellatus*, in Florida: Status of Stocks Through 2007. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). IHR 2008-008. 106 pp <http://myfwc.com/media/1353540/red-drum.pdf> Accessed August 1, 2012.

Murphy MD, Taylor RG. 1990. Tag/Recapture and Age Validation of Red Drum in Florida. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). NA86-WC-H-06136. 27 pp.

Myers RL, Ewel JJ, editors. 1990. Ecosystems of Florida. Orlando (FL): University Press of Florida; 765 p ISBN: 978-0813010229 <http://www.upf.com/book.asp?id=MYERSF90> Accessed August 1, 2012.

Naumann E. 1929. The Scope and Chief Problems of Regional Limnology. Int. Rev. Hydrobiol.; 22(1):423-444 <http://dx.doi.org/10.1002/iroh.19290220128> Accessed August 1, 2012.

Neff JM, Burns WA. 1996. Estimation of Polycyclic Aromatic Hydrocarbon Concentrations in the Water Column Based on Tissue Residues in Mussels and Salmon: An Equilibrium Partitioning Approach. Environ. Toxicol. Chem.; 15(12):2240-2253 <http://dx.doi.org/10.1002/etc.5620151218> Accessed August 1, 2012.

NEMESIS. 2012. National Exotic Marine and Estuarine Species Information System. [Internet]: Smithsonian Environmental Research Center (SERC). <http://invasions.si.edu/nemesis/index.html> Accessed August 1, 2012.

Newbold JD. 1992 In: Calow P, Petts GE, editors. The Rivers Handbook. I. Hydrological and Ecological Principles. Oxford (England): Blackwell Science Publishers. ISBN: 978-0632028327 Cycles and Spirals of Nutrients. p 379-408. <http://www.limnology.uni-muenster.de/etc/experieco/lit/respiration/newbold_1992.pdf> Accessed August 1, 2012.

Nixon SW. 1995. Coastal Marine Eutrophication: A Definition, Social Causes, and Future Concerns. Ophelia; 41(1):199-219 <http://dx.doi.org/10.1080/00785236.1995.10422044> Accessed August 1, 2012.

NMFS. 1998. Recovery Plan for the Shortnose Sturgeon (*Acipenser brevirostrum*). Washington (DC): National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS). 104 pp <http://www.nmfs.noaa.gov/pr/pdfs/recovery/sturgeon_shortnose.pdf> Accessed August 1, 2012.

NOAA. 2007a. National Center for Coastal Monitoring and Assessment: Monitoring Data - Benthic Surveillance. [Internet]: National Oceanic and Atmospheric Administration (NOAA). <http://ccma.nos.noaa.gov/about/coast/nsandt/benthic_surveillance.aspx> Accessed August 1, 2012.

NOAA. 2007b. National Center for Coastal Monitoring and Assessment: Monitoring Data - Mussel Watch. [Internet]: National Oceanic and Atmospheric Administration (NOAA). <http://ccma.nos.noaa.gov/about/coast/nsandt/musselwatch.aspx> Accessed August 1, 2012.

NOAA. 2008. Screening Quick Reference Tables. Seattle (WA): National Oceanic and Atmospheric Administration (NOAA), Office of Response and Restoration. OR&R Report 08-1. 34 pp <http://response.restoration.noaa.gov/sites/default/files/SQuiRTs.pdf> Accessed August 1, 2012.

NOAA. 2012a. 2009 Atlantic Hurricane Season. [Internet] Miami (FL): National Oceanic and Atmospheric Administration (NOAA), National Hurricane Center. <http://www.nhc.noaa.gov/2009atlan.shtml> Accessed August 1, 2012.

NOAA. 2012b. FAQ: How do El Niño and La Nina Influence the Atlantic and Pacific Hurricane Seasons? [Internet] Camp Springs (MD): National Oceanic and Atmospheric Administration (NOAA), Climate Prediction Center. <http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensofaq.shtml - HURRICANES> Accessed August 1, 2012.

NRC. 1995. Understanding Marine Biodiversity. Washington (DC): National Academies Press (NAP), National Research Council (NRC). 128 p ISBN: 978-0309083973 <http://www.nap.edu/catalog.php?record_id=4923> Accessed August 1, 2012.

NRC. 1996. Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water. Washington (DC): National Academies Press, National Research Council (NRC). 160 p ISBN: 978-0309055376 <http://www.nap.edu/catalog.php?record_id=5294> Accessed August 1, 2012.

NRC. 2000. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. Washington (DC): National Academies Press, National Research Council (NRC). 405 p ISBN: 978-0309069489 <http://www.nap.edu/catalog.php?record_id=9812> Accessed August 1, 2012.

NRC. 2001. Compensating for Wetland Losses Under the Clean Water Act. Washington (DC): National Academies Press (NAP), National Research Council (NRC). 348 p ISBN: 978-0309074322 <http://www.nap.edu/catalog.php?record_id=10134> Accessed August 1, 2012.

NRC. 2002. Predicting Invasions of Nonindigenous Plants and Plant Pests. Washington (DC): National Academies Press (NAP), National Research Council (NRC). 198 p ISBN: 978-0309082648 <http://www.nap.edu/catalog.php?record_id=10259> Accessed August 1, 2012.

NRC. 2011. Review of the St. Johns River Water Supply Impact Study: Final Report. Washington (DC): National Academies Press, National Research Council (NRC). 106 p ISBN: 978-0309225670 <http://www.nap.edu/catalog.php?record_id=13314> Accessed August 1, 2012.

O'Connor TP, Lauenstein GG. 2006. Trends in Chemical Concentrations in Mussels and Oysters Collected Along the U.S. Coast: Update to 2003. Marine Environ. Res.; 62(4):261-285 <http://dx.doi.org/10.1016/j.marenvres.2006.04.067> Accessed August 1, 2012.

Ouyang Y, Nkedi-Kizza P, Mansell RS, Ren JY. 2003. Spatial Distribution of DDT in Sediments from Estuarine Rivers of Central Florida. J. Environ. Qual.; 32(5):1710-1716 <http://dx.doi.org/10.2134/jeq2003.1710> Accessed August 1, 2012.

Ouyang Y, Nkedi-Kizza P, Wu QT, Shinde D, Huang CH. 2006. Assessment of Seasonal Variations in Surface Water Quality. Water Res.; 40(20):3800-3810 <http://dx.doi.org/10.1016/j.watres.2006.08.030> Accessed August 1, 2012.

Phillips BM, Anderson BS, Voorhees JP, Hunt JW, Holmes RW, Mekebri A, Connor V, Tjeerdema RS. 2010. The Contribution of Pyrethroid Pesticides to Sediment Toxicity in Four Urban Creeks in California, USA. J. Pest. Sci.; 35(3):302-309 <http://dx.doi.org/10.1584/jpestics.G10-34> Accessed August 1, 2012.

Phlips EJ, Bledsoe E, Cichra M, Badylak S, Frost J. 2002. The Distribution of Potentially Toxic Cyanobacteria in Florida. In: Johnson D, Harbison RD, editors. Proceedings of Health Effects of Exposure to Cyanobacteria Toxins: State of the Science. Sarasota (FL): Mote Marine Laboratory. p 22-36. <http://www.doh.state.fl.us/Environment/community/aquatic/pdfs/Cyanobacteria_200208.pdf> Accessed August 1, 2012.

Phlips EJ, Cichra M. 1998. Phytoplankton and Zooplankton Composition of the St Johns River at the City of Jacksonville, Florida and North. Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS), Department of Fisheries and Aquatic Sciences. 238 pp.

Phlips EJ, Cichra M, Aldridge FJ, Jembeck J, Hendrickson J, Brody RW. 2000. Light Availability and Variations in Phytoplankton Standing Crops in a Nutrient-rich Blackwater River. Limnol. Oceanogr.; 45(4):916-929 <http://www.aslo.org/lo/pdf/vol_45/issue_4/0916.pdf> Accessed August 1, 2012.

Phlips EJ, Hendrickson J, Quinlan EL, Cichra M. 2007. Meteorological Influences on Algal Bloom Potential in a Nutrient-rich Blackwater River. Freshw. Biol.; 52(11):2141-2155 <http://dx.doi.org/10.1111/j.1365-2427.2007.01844.x> Accessed August 1, 2012.

Pierce RH, Dixon LK, Brown RC, Rodrick G. 1988. Characterization of Baseline Conditions of the Physical, Chemical and Microbiological Environments in the St. Johns River Estuary. Sarasota (FL): Mote Marine Laboratory. Technical Report 128, DEP Contract SP132. 110 pp <https://dspace.mote.org:8443/dspace/bitstream/2075/23/1/128.pdf> Accessed August 1, 2012.

Power A, Mitchell MA, Walker R, Posey M, Alphin T, Belcher C. 2006. Baseline Port Surveys for Introduced Marine Molluskan, Crustacean and Polychaete Species in the South Atlantic Bight. Savannah (GA): University of Georgia (UGA), Georgia Sea Grant. R/HAB-15. 301 pp <http://georgiaseagrant.uga.edu/images/uploads/media/Port_Survey.pdf> Accessed August 1, 2012.

Purdum ED. 2002. Florida Waters: A Water Resources Manual from Florida's Water Management Districts. Palatka (FL): St. Johns River Water Management District (SJRWMD). 120 pp <http://www.swfwmd.state.fl.us/publications/files/floridawaters.pdf> Accessed August 1, 2012.

Rahman FA, Allan DL, Rosen CJ, Sadowsky MJ. 2004. Arsenic Availability From Chromated Copper Arsenate (CCA)-Treated Wood. J. Environ. Qual.; 33(1):173-180 <http://dx.doi.org/10.2134/jeq2004.1730> Accessed August 1, 2012.

Rao DV, Jenab SA, Clapp DA. 1989. Rainfall Analysis of Northeast Florida. Part III: Seasonal Rainfall Data. Palatka (FL): St. Johns River Water Management District (SJRWMD). Technical Publication SJ 89-1. 120 pp <http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ89-1.pdf> Accessed August 1, 2012.

Rauschenberger RH, Sepúlveda MS, Wiebe JJ, Szabo NJ, Gross TS. 2004. Predicting Maternal Body Burdens of Organochlorine Pesticides from Eggs and Evidence of Maternal Transfer in *Alligator mississippiensis*. Environ. Toxicol. Chem.; 23(12):2906-2915 <http://dx.doi.org/10.1897/03-584.1> Accessed August 1, 2012.

Reid JP, Bonde RK, O'Shea TJ. 1995 In: O'Shea TJ, Ackerman BB, Percival HF, editors. Population Biology of the Florida Manatee (*Trichechus manatus latirostris*). Washington (DC): National Biological Service (NBS). Reproduction and Mortality of Radio-Tagged and Recognizable Manatees on the Atlantic Coast of Florida. p 171-191. <http://www.fort.usgs.gov/Products/Publications/2364/2364.pdf> Accessed August 1, 2012.

Rhew K. 2009. Final TMDL Report: Fecal Coliform TMDL for Pottsburg Creek (WBID 2265B) and Julington Creek (WBID 2351). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 45 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/fecaltmdl_2265b_2351.pdf> Accessed August 1, 2012.

Richard A, Moss A. 2011. Chinese Grass Carp: Plant Management in Florida Waters. [Internet] Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS).

<http://plants.ifas.ufl.edu/manage/control-methods/biological-control/chinese-grass-carp> Accessed August 1, 2012.

Rodgers Jr JA, Barrett M, Butryn RS. 2010. Productivity and Habitat Modeling of Wood Storks *Mycteria Americana* Nesting in North and Central Florida. Final Performance Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 21 pp.

Rodgers Jr JA, Schwikert ST, Griffin GA, Bear-Hull D. 2008a. Productivity of Wood Storks *Mycteria Americana* within the St. Johns River Water Management District of North and Central Florida. Annual Report. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 9292 267 2161. 11 pp.

Rodgers Jr JA, Schwikert ST, Griffin GA, Brooks WB, Bear-Hull D, Elliott PM, Ebersol KJ, Morris J. 2008b. Productivity of Wood Storks (*Mycteria americana*) in North and Central Florida. Waterbirds; 31(SP1):25-34 <http://dx.doi.org/10.1675/1524-4695(2008)31%5B25:POWSMA%5D2.0.CO;2> Accessed August 1, 2012.

Rodgers Jr. JA. 2011 *Personal communication* to Pinto G.

Ross M. 2012 *Personal communication* to Pinto G.

Ruckelshaus MH, Hays CG. 1997 In: L. FP, Kareiva PM, editors. Conservation Biology: For the Coming Decade. 2nd edition. New York (NY): Springer-Verlag. ISBN: 978-0412096617 Chaper 6. Conservation and Management of Species in the Sea. p 112-156. <http://www.springer.com/environment/nature+conservation+-+biodiversity/book/978-0-412-09661-7> Accessed August 1, 2012.

Ruhl JB, Salzman J. 2006. The Effects of Wetland Mitigation on People. Nat. Wetlands Newsl.; 28(2):7-13 <http://papers.ssrn.com/sol3/papers.cfm?abstract_id=878331> Accessed August 1, 2012.

Ruhl JB, Salzman J, Goodman I. 2008. Implementing the New Ecosystem Services Mandate of the Section 404 Compensatory Mitigation Program: A Catalyst for Advancing Science and Policy. Stetson Law Rev.; 38(2):251-272 <http://ssrn.com/abstract=1281048> Accessed August 1, 2012.

Runge MC, Langtimm CA, Kendall WL. 2004. A Stage-Based Model of Manatee Population Dynamics. Marine Mammal Sci.; 20(3):361-385 <http://dx.doi.org/10.1111/j.1748-7692.2004.tb01167.x> Accessed August 1, 2012.

Sagan JJ. 2004. SAV Bed Architecture: Water Depth Distribution and Cover of *Najas guadalupensis*, *Ruppia maritime*, and *Vallisneria americana*. Palatka (FL): St. Johns River Water Management District (SJRWMD). Final Report SG425RA. 34 pp.

Sagan JJ. 2006. A Reanalysis of Data Related to Submerged Aquatic Vegetation Within the Lower St. Johns River: 1996-2005. Palatka (FL): St. Johns River Water Management District (SJRWMD). Contract No. SG425RA. 36 pp.

Sagan JJ. 2007. SAV Monitoring Project: Interim Reports I-IV and Draft Annual Status Reports. Interim Reports Associated with Quarterly Sampling and Groundtruth Surveys for the St. Johns River Water Management District (SJRWMD). Palatka (FL): St. Johns River Water Management District (SJRWMD). 22 pp.

Sagan JJ. 2010 *Personal communication* to Pinto G.

Salzman J, Ruhl JB. 2005. 'No Net-Loss' - Instrument Choice in Wetlands Protection. Durham (NC): Duke Law School Science, Technology and Innovation Research Paper Series. Technology & Innovation Paper No. 1. <http://ssrn.com/abstract=796771> Accessed August 1, 2012.

Samek K. 2004. Unknown Quantity: The Bottled Water Industry and Florida's Springs. J. Land Use; 19(2):569-595 <http://www.law.fsu.edu/journals/landuse/vol19_2/samek.pdf> Accessed August 1, 2012.

Scarlatos PD. 1993. A Review of Sediment Analysis, Management Techniques and Sediment Quality Data for the Lower St. Johns River Basin: Vol. 5. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ94-SP16. 371 pp <http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ94-SP16.pdf> Accessed August 1, 2012.

Schafer DL. 2007. New World in a State of Nature; British Plantations and Farms on the St. Johns River, East Florida, 1763-1784. [Internet] Jacksonville (FL): University of North Florida (UNF), Florida Online History. <http://www.unf.edu/floridahistoryonline/Plantations> Accessed August 1, 2012.

Schropp SJ, Windom HL. 1988. A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 74 pp <http://www.dep.state.fl.us/water/monitoring/docs/seds/estuarine.pdf> Accessed August 1, 2012.

Scott C. 2003a. Endangered and Threatened Animals of Florida and Their Habitats. Austin (TX): University of Texas Press. ISBN: 978-0292705296 Eastern Indigo Snake (*Drymarchon corais couperi*). p 242-244. <http://www.utexas.edu/utpress/books/scoend.html> Accessed August 1, 2012.

Scott C. 2003b. Endangered and Threatened Animals of Florida and Their Habitats. Austin (TX): University of Texas Press. ISBN: 978-0292705296 Piping Plover (*Charadrius melodus*). p 166-168. <http://www.utexas.edu/utpress/books/scoend.html> Accessed August 1, 2012.

Scott C. 2003c. Endangered and Threatened Animals of Florida and Their Habitats. Austin (TX): University of Texas Press. ISBN: 978-0292705296 Shortnose Sturgeon (*Acipenser brevirostrum*). p 253-259. <http://www.utexas.edu/utpress/books/scoend.html> Accessed August 1, 2012.

Scott C. 2003d. Endangered and Threatened Animals of Florida and Their Habitats. Austin (TX): University of Texas Press. ISBN: 978-0292705296 Southern Bald Eagle (*Haliaeetus leucocephalus leucocephalus*). p 177-180. <http://www.utexas.edu/utpress/books/scoend.html> Accessed August 1, 2012.

Scott C. 2003e. Endangered and Threatened Animals of Florida and Their Habitats. Austin (TX): University of Texas Press. ISBN: 978-0292705296 Wood Stork (*Mycteria americana*). p 168-171. <http://www.utexas.edu/utpress/books/scoend.html> Accessed August 1, 2012.

Scott TM. 1988. Bulletin - Florida Geological Survey. Volume 59. Tallahassee (FL): Florida Geological Survey. ISSN: 0271-7832 The Lithostratigraphy of the Hawthorn Group (Miocene) of Florida. p 148. <http://ufdc.ufl.edu/UF00000226/00001> Accessed August 1, 2012.

Scudder BC, Chasar LC, Wentz DA, Bauch NJ, Brigham ME, Moran PW, Krabbenhoft DP. 2009. Mercury in Fish, Bed Sediment, and Water from Streams Across the United States, 1998-2005. Reston (VA): U.S. Geological Survey (USGS). Scientific Investigations Report 2009-5109. 74 pp <http://pubs.usgs.gov/sir/2009/5109/pdf/sir20095109.pdf> Accessed August 1, 2012.

Sepúlveda MS, Johnson WE, Higman JC, Denslow ND, Schoeb TR, Gross TS. 2002. An Evaluation of Biomarkers of Reproductive Function and Potential Contaminant Effects in Florida Largemouth Bass *(Micropterussalmoidesfloridanus)* Sampled from the St. Johns River. Science of The Total Environment; 289(1-3):133-144 <http://dx.doi.org/10.1016/S0048-9697(01)01029-4> Accessed August 1, 2012.

Shabecoff P. 1988. Most Sewage Plants Meeting Latest Goal of Clean Water Act. [Internet] New York (NY): New York Times. July 28, 1988 <http://www.nytimes.com/1988/07/28/us/most-sewage-plants-meeting-latest-goal-of-clean-water-act.html> Accessed August 1, 2012.

Shiganova TA. 1998. Invasion of the Black Sea by the Ctenophore *Mnemiopsis leidyi* and Recent Changes in Pelagic Community Structure. Fish. Oceanogr.; 7(3-4):305-310 <http://dx.doi.org/10.1046/j.1365-2419.1998.00080.x> Accessed August 1, 2012.

Shuval HI, Adin A, Fattal B, Rawitz E, Yekutiel P. 1990. Integrated Resource Recovery. Wastewater Irrigation in Developing Countries - Health Effects and Technical D|Solutions. Washington (DC): The World Bank. WTP51. 362 pp <http://go.worldbank.org/SCMV1ICKM0> Accessed August 1, 2012.

Shyn A, Chalk SJ, Smith K, Charnock NL, Bielmyer GK. 2012. The Effects of Salinity on Zinc Accumulation in the Euryhaline Fish, *Fundulus heteroclitus*. Comp. Biochem. Physiol. C; Submitted.

Simberloff D, Schmitz DC, Brown TC, editors. 1997. Strangers in Paradise: Impact and Management of Nonindigenous Species in Florida. Washington (DC): Island Press; 479 p ISBN: 978-1559634298 <http://islandpress.org/ip/books/book/islandpress/S/bo3560487.html> Accessed August 1, 2012.

SJRWMD. 2000. Upper St. Johns River Basin, Three Forks Marsh and Blue Cypress Conservation Areas, Brevard and Indian River Counties, Land Management Plan. Palatka (FL): St. Johns River Water Management District (SJRWMD).

SJRWMD. 2005. Blue-Green Algae in Florida Waters: Effects on Water Quality. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.floridaswater.com/algae/bluegreen.html> Accessed August 1, 2012.

SJRWMD. 2006. 2004 Status and Trends in Water Quality at Selected Sites in the St. Johns River Water Management District. Palatka (FL): St. Johns River Water Management District (SJRWMD). Technical Publication SJ2006-6. 106 pp <http://www.sjrwmd.com/technicalreports/pdfs/TP/SJ2006-6.pdf> Accessed August 1, 2012.

SJRWMD. 2007a. Geographic Information Systems (GIS) Database. [Internet]: St. Johns River Water Management District (SJRWMD). <http://www.sjrwmd.com/gisdevelopment/docs/themes.html> Accessed August 1, 2012.

SJRWMD. 2007b. MEMORANDUM: Approval of the Mitigation Bank Agreement for Purchase of Mitigation Bank Credits for Partial Implementation of the Florida Department of Transportation Mitigation Plan. Palatka (FL): St. Johns River Water Management District (SJRWMD).

SJRWMD. 2008. Surface Water Improvement and Management (SWIM) Plan: Lower St. Johns River Basin. Palatka (FL): St. Johns River Water Management District (SJRWMD). 210 pp <http://www.sjrwmd.com/SWIMplans/2008_LSJRB_SWIM_Plan_Update.pdf> Accessed August 1, 2012.

SJRWMD. 2010a. Florida Water Management History. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.sjrwmd.com/history/index.html> Accessed August 1, 2012.

SJRWMD. 2010b. GIS Download Library. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.sjrwmd.com/gisdevelopment/docs/themes.html> Accessed August 1, 2012.

SJRWMD. 2010c. SJRWMD Mitigation Banking. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://webapub.sjrwmd.com/agws10/mt/> Accessed August 1, 2012.

SJRWMD. 2010d. Watershed Facts: Cedar River. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.floridaswater.com/watershedfacts/factPages/20030083.html> Accessed August 1, 2012.

SJRWMD. 2012a. 2012 Consolidated Annual Report, February 14, 2012. Palatka (FL): St. Johns River Water Management District (SJRWMD). 162 pp <http://www.floridaswater.com/publications/Consolidated_Annual_Report.pdf> Accessed August 1, 2012.

SJRWMD. 2012b. Clay-Putnam Strategy Development Area. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://floridaswater.com/minimumflowsandlevels/Clay-Putnam.html> Accessed August 1, 2012.

SJRWMD. 2012c. Permitting: An Overview of Water Management District Permitting. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.sjrwmd.com/permitting/> Accessed August 1, 2012.

SJRWMD. 2012d. Radar Rainfall Data. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://webapub.sjrwmd.com/agws10/hdsnew/map.html> Accessed August 1, 2012.

SJRWMD. 2012e. The St. Johns River as a Water Supply Source. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.sjrwmd.com/surfacewaterwithdrawals> Accessed August 1, 2012.

SJRWMD. 2012f. The St. Johns River Water Supply Impact Study. [Internet] Palatka (FL): St. Johns River Water Management District (SJRWMD). <http://www.sjrwmd.com/surfacewaterwithdrawals/impacts.html> Accessed August 1, 2012.

SJRWMD. 2012g. St. Johns River Water Supply Impact Study. Palatka (FL): St. Johns River Water Management District (SJRWMD). SJ2012-1. 814 pp <http://www.sjrwmd.com/technicalreports/tpubs1.html> Accessed August 1, 2012.

SLES. 1988. Chemical and Physical Characteristics of Water, Sediments and Sediment Elutriates for the Port of Jacksonville, Florida. Savannah (GA): Savannah Laboratories and Environmental Services (SLES), Inc. 54 pp.

Smith VH. 1983. Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue-Green Algae in Lake Phytoplankton. Science; 221(4611):669-671 <http://dx.doi.org/10.1126/science.221.4611.669> Accessed August 1, 2012.

Smolders AJP, Lamers LPM, Lucassen ECHET, Van der Velde G, Roelofs JGM. 2006. Internal Eutrophication: How It Works and What To Do About It – A Review. Chemistry and Ecology; 22(2):93-111 <http://dx.doi.org/10.1080/02757540600579730> Accessed August 1, 2012.

St. Johns Riverkeeper. 2008. Duval County's 50 Dirtiest Waters: The List of Shame. [Internet] Jacksonville (FL): St. Johns Riverkeeper. <http://jacksonville.com/tu-online/stories/101605/met_20040912.shtml> Accessed August 1, 2012.

St. Johns Riverkeeper. 2009. Central Florida's Thirst Threatens River. [Internet] Jacksonville (FL): St. Johns Riverkeeper. <http://www.stjohnsriverkeeper.org/thirstthreatens.asp> Accessed August 1, 2012.

Stedman S-M, Dahl TE. 2008. Status and Trends of Wetlands in the Coastal Watersheds of the Eastern United States 1998 to 2004. Washington (DC): U.S. Fish and Wildlife Service (USFWS). 32 pp <http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-in-the-Coastal-Watersheds-of-the-Eastern-United-States-1998-to-2004.pdf> Accessed August 1, 2012.

Steidinger KA, Burklew MA, Ingle RM. 1973 In: Martin DF, Padilla GM, editors. Marine Pharmacognosy: Action of Marine Toxins at the Cellular Level. New York (NY): Academic Press. The Effects of *Gymnodinium breve* Toxin on Estuarine Animals. p 179-202. <http://research.myfwc.com/publications/publication_info.asp?id=37448> Accessed August 1, 2012.

Steidinger KA, Landsberg JH, Tomas CR, Burns Jr JW. 1999. Harmful Algal Blooms in Florida. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). 63 pp <http://myfwc.com/research/redtide/task-force/reports-presentations/white-paper/> Accessed August 1, 2012.

Steinbrecher P. 2008 *Personal communication* to McCarthy H.

Stevenson DJ, Dyer KJ, Willis-Stevenson BA. 2003. Survey and Monitoring of the Eastern Indigo Snake in Georgia. Southeast. Nat.; 2(3):393-408 <http://dx.doi.org/10.1656/1528-7092(2003)002%5B0393:SAMOTE%5D2.0.CO;2> Accessed August 1, 2012.

Stewart I, Seawright AA, Schulter PJ, Shaw GR. 2006. Primary Irritant and Delayed-Contact Hypersensitivity Reactions to the Freshwater Cyanobacterium *Cylindrospermopsis raciborskii* and its Associated Toxin Cylindrospermopsin. BMC Dermatol.; 6:1-12 <http://dx.doi.org/10.1186/1471-5945-6-5> Accessed August 1, 2012.

Stork W. 1769. A Description of East-Florida, with a Journal kept by John Bartram of Philadelphia, Botanist to his Majesty for the Floridas; Upon a Journey from St. Augustine up the river St. John's as far as the Lakes. With Explanatory Botanical Notes. London (England): Nicoll and Jefferies. 40 p <http://www.amphilsoc.org/exhibits/nature/stork.htm> Accessed August 1, 2012.

Stukel ED. 1996. Piping Plover (*Charadrius melodus*). [Internet] Pierre (SD): South Dakota Department of Game, Fish and Parks. <http://www3.northern.edu/natsource/ENDANG1/Piping1.htm> Accessed August 1, 2012.

Stumm W, Morgan JJ. 1996. Aquatic Chemistry: Chemical Equilibria and Rates in Natural Waters. New York (NY): John Wiley & Sons. 1040 p ISBN: 978-0471511854 <http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471511854.html> Accessed August 1, 2012.

Sucsy PV. 2008 *Personal communication* to Pinto G.

Tagatz ME. 1965. The Fishery for Blue Crabs in the St. Johns River, Florida, with Special Reference to Fluctuations in Yield Between 1961 and 1962. Washington (DC): U.S. Fish and Wildlife Service (FWS). 11 pp <http://archive.org/download/specialscientifi501usfi/specialscientifi501usfi_bw.pdf> Accessed August 1, 2012.

Tagatz ME. 1968a. Biology of the Blue Crab, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. Fishery Bull.; 67(1):17-33 <http://fishbull.noaa.gov/67-1/tagatz.pdf> Accessed August 1, 2012.

Tagatz ME. 1968b. Fishes of the St. Johns River, Florida. Quart. Jour. Florida Acad. Sci.; 30(1):25-50 <http://ufdc.ufl.edu/UF00000193/00001> Accessed August 1, 2012.

Tagatz ME. 1968c. Growth of Juvenile Blue Crabs, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. Fishery Bull.; 67(2):281-288 <http://fishbull.noaa.gov/67-2/tagatz.pdf> Accessed August 1, 2012.

Thayer GW, Kenworthy WJ, Fonseca MS. 1984. The Ecology of Eelgrass Meadows of the Atlantic Coast: a Community Profile. Beaufort (NC): U.S. Fish and Wildlife Service (USFWS), Division of Biological Services. FWS/OBS-84/02. 165 pp <http://www.nwrc.usgs.gov/techrpt/84-02.pdf> Accessed August 1, 2012.

Thunen RL. 2010. Archaeological Excavations at the Cedar Point West site in Jacksonville, Florida. [Internet] Jacksonville (FL): University of North Florida Archaeology Laboratory. <http://www.unf.edu/~rthunen/fieldwork09/Field_Photos.html> Accessed August 1, 2012.

Tilman D. 1982. Resource Competition and Community Structure. Levin SA, Horn HS, editors. Princeton (NJ): Princeton University Press. 296 p ISBN: 978-0691083025 <http://press.princeton.edu/titles/2058.html> Accessed August 1, 2012.

Turner DR, Whitfield M, Dickson AG. 1981. The Equilibrium Speciation of Dissolved Components in Freshwater and Seawater at 25°C and 1 Atm Pressure. Geochim. Cosmochim. Acta; 45(6):855-881 <http://dx.doi.org/10.1016/0016-7037(81)90115-0> Accessed August 1, 2012.

Twilley RR, Barko JW. 1990. The Growth of Submersed Macrophytes Under Experimental Salinity and Light Conditions. Estuar. Coasts; 13(3):311-321 <http://dx.doi.org/10.2307/1351922> Accessed August 1, 2012.

Udall SL. 1967. Native Fish and Wildlife: Endangered Species. Fed. Reg.; 32(48):4001 <http://ecos.fws.gov/docs/federal_register/fr18.pdf> Accessed August 1, 2012.

UGA. 2002. Floridan Aquifer. [Internet] Athens (GA): University of Georgia. <http://coastgis.marsci.uga.edu/summit/aquifers_fla.htm> Accessed August 1, 2012.

USACE. 2007. Notice of Intent to Prepare a Draft Supplemental Environmental Impact Statement for the Jacksonville Harbor Navigation Study, General Re-Evaluation Report, Located in Duval County, FL. Fed. Reg.; 72(71):18641 <http://edocket.access.gpo.gov/2007/pdf/07-1835.pdf> Accessed August 1, 2012.

USACE. 2008. Control Activities on the St. Johns River. [Internet] Jacksonville (FL): U.S. Army Corps of Engineers (USACE), Jacksonville District. <http://www.saj.usace.army.mil/Divisions/Operations/Branches/InvSpecies/SpraySchedules.shtml> Accessed August 1, 2012.

USACE. 2012. Invasive Species Control on the St. Johns River. [Internet] Jacksonville (FL): U.S. Army Corps of Engineers (USACE), Jacksonville District. <http://www.saj.usace.army.mil/Divisions/Operations/Branches/InvSpecies/SpraySchedules.shtml> Accessed August 1, 2012.

USACE, EPA. 2008. Compensatory Mitigation for Losses of Aquatic Resources. Fed. Reg.; 73(70):19594-19705 <http://edocket.access.gpo.gov/2008/pdf/E8-6918.pdf> Accessed August 1, 2012.

USCB. 2000. Population Statistics for Clay, Duval, Flagler, Putnam, and St. Johns County, Florida. [Internet] Washington (DC): U.S. Census Bureau (USCB). <http://quickfacts.census.gov/qfd/states/12000lk.html> Accessed August 1, 2012.

USDA. 2007. Plants Database. [Internet]: U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). <http://plants.usda.gov/> Accessed August 1, 2012.

USFWS. 1990. Recovery Plan for the Florida Scrub Jay. Athens (GA): U.S. Fish and Wildlife Service (USFWS), Southeast Region. 29 pp <http://ecos.fws.gov/docs/recovery_plan/900509.pdf> Accessed August 1, 2012.

USFWS. 1996. Piping Plover (*Charadrius melodus*) Atlantic Coast Population. Revised Recovery Plan. Washington (DC): U.S. Fish and Wildlife Service (USFWS), Environmental Conservation Online System (ECOS). 236 pp <http://ecos.fws.gov/docs/recovery_plan/960502.pdf> Accessed August 1, 2012.

USFWS. 2001. Florida Manatee Recovery Plan (*Trichechus manatus latirostris*), Third revision. Atlanta (GA): U.S. Fish and Wildlife Service (USFWS), Southeast Region. 144 pp <http://www.fws.gov/northflorida/Manatee/Documents/Recovery Plan/Manatee Recovery Plan.pdf> Accessed August 1, 2012.

USFWS. 2002. Wood Stork Report. Washington (DC): U.S. Fish and Wildlife Service (USFWS). Volume 1(1). 4 pp.

USFWS. 2004. Wood Stork Report. Washington (DC): U.S. Fish and Wildlife Service (USFWS). Volume 3(1). 22 pp.

USFWS. 2005. Wood Stork Report. Washington (DC): U.S. Fish and Wildlife Service (USFWS). Volume 4(1). 16 pp.

USFWS. 2007a. Bald Eagle Soars off Endangered Species List. [Internet] Washington (DC): U.S. Fish and Wildlife Service (USFWS). <http://www.fws.gov/news/newsreleases/showNews.cfm?newsId=72A15E1E-F69D-06E2-5C7B052DB01FD002> Accessed August 1, 2012.

USFWS. 2007b. Florida Scrub-Jay (*Aphelocoma coerulescens*) 5-Year Review: Summary and Evaluation. Jacksonville (FL): U.S. Fish and Wildlife Service (USFWS), North Florida Field Office. 55 pp <http://www.fws.gov/northflorida/Scrub-Jays/2007-Review/2007-Florida-scrub-jay_5-Year_review.pdf> Accessed August 1, 2012.

USFWS. 2007c. West Indian Manatee (*Trichechus Manatus*). 5-Year Review: Summary and Evaluation. Washington (DC): U.S. Fish and Wildlife Service (USFWS), North Florida Field Office. 79 pp <http://www.fws.gov/northflorida/Manatee/2007 5-yr Review/2007-Manatee-5-Year-Review-Final-color-signed.pdf> Accessed August 1, 2012.

USFWS. 2007d. Wood Stork (*Mycteria americana*) 5-Year Review: Summary and Evaluation. Jacksonville (FL): U.S. Fish and Wildlife Service (USFWS), North Florida Field Office. 34 pp <http://www.fws.gov/northflorida/WoodStorks/2007-Review/2007-Wood-stork-5-yr-Review.pdf> Accessed August 1, 2012.

USFWS. 2007e. You Can Help Protect the Piping Plover. [Internet] Hadley (MA): U.S. Fish and Wildlife Service (USFWS), Northeast Region. <http://www.fws.gov/northeast/pipingplover/overview.html> Accessed August 1, 2012.

USFWS. 2008a. Bald Eagle. [Internet] Washington (DC): U.S. Fish and Wildlife Service (USFWS), Division of Migratory Bird Management. <http://www.fws.gov/migratorybirds/baldeagle.htm> Accessed August 1, 2012.

USFWS. 2008b. Bald Eagle Breeding Pairs 1990 - 2006. [Internet] Washington (DC): U.S. Fish and Wildlife Service (USFWS), Midwest Region. <http://www.fws.gov/midwest/eagle/population/nos_state_tbl.html> Accessed August 1, 2012.

USFWS. 2008c. Bald Eagle Management Guidelines and Conservation Measures. [Internet] Washington (DC): U.S. Fish and Wildlife Service (USFWS), Midwest Region. <http://www.fws.gov/midwest/eagle/guidelines/recreation.html> Accessed August 1, 2012.

USFWS. 2008d. Species Profile: Bald Eagle (*Haliaeetus leucocephalus*). [Internet] Washington (DC): U.S. Fish and Wildlife Service (USFWS), Environmental Conservation Online System (ECOS). <http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=B008> Accessed August 1, 2012.

USFWS. 2010. North Florida Field Office Home Page. [Internet] Washington (DC): U.S. Fish and Wildlife Service (USFWS), North Florida Field Office. <http://www.fws.gov/northflorida/> Accessed August 1, 2012.

USFWS. 2012. Southeast US Wood Stork Nesting Effort Database. [Internet]: Accessed.

USGS. 1992. Application of Satellite Data for Mapping and Monitoring Wetlands. Reston (VA): U.S. Geological Survey (USGS), Federal Geographic Data Committee (FGDC). Wetlands Subcommittee Technical Report I. <http://www.gpo.gov/fdsys/pkg/CZIC-ta595-5-u55-a66-1992/pdf/CZIC-ta595-5-u55-a66-1992.pdf> Accessed August 1, 2012.

USGS. 2004. Aquatic Cycling of Mercury in the Everglades. [Internet] Washington (DC): U.S. Geological Survey (USGS). <http://sofia.usgs.gov/projects/index.php?project_url=evergl_merc> Accessed August 1, 2012.

USGS. 2012a. Ground Water Atlas of the United States. [Internet] Reston (VA): U.S. Geological Survey (USGS). <http://pubs.usgs.gov/ha/ha730/ch_g/G-text6.html> Accessed August 1, 2012.

USGS. 2012b. Non-Indigenous Aquatic Species (NAS) Database. [Internet]: U.S. Geological Survey (USGS). <http://nas.er.usgs.gov> Accessed August 1, 2012.

USGS. 2012c. Subsurface Characterization of Selected Water Bodies in the St Johns River Water Management District, Northeast Florida. [Internet] Reston (VA): U.S. Geological Survey (USGS). <http://coastal.er.usgs.gov/publications/ofr/00-180/intro/fig6.html> Accessed August 1, 2012.

Valiela I. 1995. Marine Ecological Processes. 2nd edition. New York (NY): Springer-Verlag. 325 p ISBN: 978-0387943213 <http://www.springer.com/life+sci/ecology/book/978-0-387-94321-3> Accessed August 1, 2012.

Verween A, Kerckhof F, Vincx M, Degraer S. 2006. First European Record of the Invasive Brackish Water Clam *Rangia cuneata* (G.B. Sowerby I, 1831) (Mollusca: Bivalvia). Aquat. Invasions; 1(4):198-203 <http://www.aquaticinvasions.net/2006/AI_2006_1_4_Verween_etal.pdf> Accessed August 1, 2012.

Vittor BA. 2001. St. Johns River Benthic Community Assessment 2002. Mobile (AL): U.S. Department of Commerce.

Vittor BA. 2003. St. Johns River Benthic Community Assessment 2001-2002. Mobile (AL): U.S. Department of Commerce.

Vollenweider RA. 1968. Scientific fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Paris (France): Organisation for Economic Cooperation and Development. DAS/SCI/68.27. 192 pp.

Wainwright D. 2005. TMDL Report: Fecal Coliform TMDL for Goodbys Creek (WBID 2326). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 54 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2326.pdf> Accessed August 1, 2012.

Wainwright D. 2006a. TMDL Report: Fecal and Total Coliform TMDLs for the Ribault River (WBID 2224). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 80 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2224.pdf> Accessed August 1, 2012.

Wainwright D. 2006b. TMDL Report: Fecal Coliform and Total Coliform TMDL for Moncrief Creek (WBID 2228). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 78 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2228.pdf> Accessed August 1, 2012.

Wainwright D. 2006c. TMDL Report: Fecal Coliform TMDL for Hogan Creek (WBID 2252). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 54 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2252.pdf> Accessed August 1, 2012.

Wainwright D, Hallas JF. 2009a. Final TMDL Report: Fecal Coliform TMDL for Big Fishweir Creek, WBID 2280. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 66 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/bigfishwircreekfecalfinal.pdf> Accessed August 1, 2012.

Wainwright D, Hallas JF. 2009b. Final TMDL Report: Fecal Coliform TMDL for Open Creek, WBID 2299. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 54 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/opencreekfecalfinal.pdf> Accessed August 1, 2012.

Wainwright D, Hallas JF. 2009c. Final TMDL Report: Fecal Coliform TMDLs for Trout River, WBIDs 2203A and 2203. Tallahassee (FL): Florida Department of Environmental Protection (DEP). 75 pp <http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/troutriverfinfecal.pdf> Accessed August 1, 2012.

Wang W-X, Guo L. 2000. Bioavailability of Colloid-Bound Cd, Cr, and Zn to Marine Plankton. Mar. Ecol. Prog. Ser.; 202(1):41-49 <http://dx.doi.org/10.3354/meps202041> Accessed August 1, 2012.

Warren C. 2005 In: Davis JE, Arsenault R, editors. Paradise lost? An Environmental History of Florida. Gainesville (FL): University Press of Florida. ISBN: 978-0-813-02826-2 Chapter 7. 'Nature's Navels': An Overview of the Many Environmental Histories of Florida Citrus. p 177-200. <http://www.upf.com/book.asp?id=DAVISF05> Accessed August 1, 2012.

Watkins B. 1995. Florida Governor's Nomination of the Lower St. Johns River Estuary to the National Estuary Program. Washington (DC): U.S. Environmental Protection Agency (EPA). 169 pp.

Weiss RF. 1970. The Solubility of Nitrogen, Oxygen, and Argon in Water and Seawater. Deep Sea Res.; 17(4):721-735 <http://dx.doi.org/10.1016/0011-7471(70)90037-9> Accessed August 1, 2012.

Welsh P. 2008 *Personal communication* to McCarthy H.

Wetzel RG. 1999. Biodiversity and Shifting Energetic Stability Within Freshwater Ecosystems. Arch. Hydrobiol. Spec. Issues Advanc. Limnol.; 54(1):19-32.

Wetzel RG. 2001. Limnology: Lake and River Ecosystems. 3rd edition. San Diego (CA): Elsevier/Academic Press. ISBN: 978-0127447605 Chapter 9 - Oxygen. p 205-286. <http://www.elsevierdirect.com/product.jsp?isbn=9780127447605> Accessed August 1, 2012.

Wetzel RG, Likens GE. 2000. Limnological Analyses. 3rd edition. New York (NY): Springer-Verlag. 429 p ISBN: 978-0387989280 <http://www.springer.com/life+sci/ecology/book/978-0-387-98928-0> Accessed August 1, 2012.

White AQ, Pinto GF. 2006a. The Clay County Manatee Protection Plan. Green Cove Springs (FL): Clay County Board of Commissioners, Clay County Planning Department. 157 pp <http://www.claycountygov.com/departments/Manatee.pdf/at_download/file> Accessed August 1, 2012.

White AQ, Pinto GF. 2006b. The Duval County Manatee Protection Plan. Jacksonville (FL): City of Jacksonville (COJ), Jacksonville Waterways Commission (JWC). 240 pp <http://www.coj.net/city-council/jacksonville-waterways-commission/jwc-mpp.aspx> Accessed August 1, 2012.

White AQ, Pinto GF. 2010. Annual Update on the Duval County Manatee Protection Plan. Jacksonville (FL): City of Jacksonville (COJ), Jacksonville Waterway Commission (JWC). 62 pp <http://www.coj.net/City-Council/Docs/Jacksonville-Waterways-Commission/JWC-MPP-2011-Update.aspx> Accessed August 1, 2012.

White AQ, Pinto GF, Robison AP. 2002. Seasonal Distribution of Manatees, *Trichechus manatus latirostris*, in Duval County and Adjacent Waters, Northeast Florida. Florida Sci.; 65(3):208-221.

WHO. 1991. Environmental Health Criteria No 118: Inorganic Mercury. [Internet] Geneva (Switzerland): World Health Organization (WHO). <http://www.inchem.org/documents/ehc/ehc/ehc118.htm> Accessed August 1, 2012.

WHO. 1998. Guidelines for Drinking–Water Quality. Second Edition, Addendum to Volume 2, Health Criteria and Other Supporting Information. Geneva (Switzerland): World Health Organization. 595 pp <http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html> Accessed August 1, 2012.

Williams CD, Burns JW, Chapman AD, Flewelling L, Pawlowicz M, Carmichael W. 2001. Assessment of Cyanotoxins in Florida's Lakes, Reservoirs, and Rivers. Final Report. Palatka (FL): St. Johns River Water Management District (SJRWMD). 97 pp <http://publicfiles.dep.state.fl.us/FGS/FGS_Publications/FGS Library Documents/CyanotoxinsRiversWilliams2001.pdf> Accessed August 1, 2012.

Woodwell GM, Wurster Jr. CF, Isaacson PA. 1967. DDT Residues in an East Coast Estuary: A Case of Biological Concentration of a Persistent Insecticide. Science; 156(3776):821-824 <http://dx.doi.org/10.1126/science.156.3776.821> Accessed August 1, 2012.

Worth JE, Thomas DH. 1995. Anthropological Papers of the American Museum of Natural History: The Struggle for the Georgia Coast: an 18th-Century Spanish Retrospective on Guale and Mocama. New York (NY): American Museum of Natural History. 222 p ISBN: 978-0820317458 <http://hdl.handle.net/2246/270> Accessed August 1, 2012.

Wright RT, Nebel BJ. 2008 In: Wright RT, editor. Environmental Science. 10th edition. Upper Saddle River (NJ): Prentice Hall. ISBN: 978-0-132-30265-4 Section 3.3 - The Cycling of Matter in Ecosystems. p 67-70. <http://www.pearsonhighered.com/academic/product?ISBN=0132302659> Accessed August 1, 2012.

Young CM. 1995 In: McEdward L, editor. Ecology of Marine Invertebrate Larvae. Boca Raton (FL): CRC Press. ISBN: 978-0849380464 Behavior and Locomotion During the Dispersal Phase of Larval Life. p 249-277. <http://www.amazon.com/dp/0849380464> Accessed August 1, 2012.

Zappalorti RT. 2008. Where Have All the Indigo Snakes Gone? Florida Wildlife Mag.; 61(Jan/Feb):56-59.

Zlotkin E. 1999. The Insect Voltage-Gated Sodium Channel as Target of Insecticides. Ann. Rev. Entomol.; 44:429-455 <http://dx.doi.org/10.1146/annurev.ento.44.1.429> Accessed August 1, 2012.

Zwick PD, Carr MH. 2006. Florida 2060: A Population Distribution Scenario for the State of Florida. Gainesville (FL): University of Florida, GeoPlan Center. 29 pp <http://www.1000friendsofflorida.org/PUBS/2060/Florida-2060-Report-Final.pdf> Accessed August 1, 2012.