2018 River Report

State of the Lower St. Johns River Basin, Florida

Water Quality

Fisheries

Aquatic Life

Contaminants

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 Florida Southern College, Lakeland, FL. The report was supported by the Environmental Protection Board of the City of Jacksonville. 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 four parts---the website (http://www.sjrreport.com) the brochure, the full report, and an appendix. The 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. Reviewing this report does not imply agreement with opinions and conclusions reached by the Report's authors.

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Melissa Simmons, JU

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 individuals for their contributions toward the development of this report while they were undergraduate students:

Laura Elston, JU
Bobbi Estabrook, JU
Jessica Fernquist, JU
Jessica Goodman, JU
Julia Goodman, JU
Julie Hammon, JU
Leon Huderson, III, JU
Jingu Gene Kang, JU
Ryan Keith, JU
Rebecca Lucas, JU
Nicole Martin, JU
David Roueche, JU
Logan Wood, JU
Jenna Manis, JU
Samuel Dixie, JU
Anthony Flock, JU
Sara Debellis, JU
Alexis Crouch, JU
Keenan Carpenter, JU
Krystal Dannenhoffer, JU
Emma Fowler, JU
Andrea Pertoso, UNF
Katie Anagnostou, UNF
Sydney Peyton, JU

Sincerely,

Gerry Pinto, Principal Investigator, JU
Gretchen Bielmyer-Fraser, JU
Nisse Goldberg, JU
Anthony Ouellette, JU
An-Phong Le, Florida Southern College

Radha Pyati, Principal Investigator, UNF
Charles Closmann, UNF
Brian Zoellner, UNF
Niki Spadaro, Technical Editor

Executive Summary

The Eleventh State of the River Report is a summary and analysis of the health of the Lower St. Johns River Basin (LSJRB) available at http://www.sjrreport.com. The Report addresses four main areas of river health: water quality; fisheries; aquatic life; and contaminants. This year's Report includes a special section on applications of the Report to K-12 schools in Duval County. As noted below, some indicators have improved, others have worsened, and still others have remained unchanged.

The trends of some indicators have improved:

- Total phosphorus levels in the saltwater reach of the mainstem are improving.
- Dissolved oxygen levels in the tributaries are improving for the first time in many years.
- Metal concentrations in the mainstem have improved: all metals examined in this Report - arsenic, cadmium, copper, lead, nickel, silver, and zinc - indicated concentrations, even maxima, that were below water quality criteria.
- Conditions for three critical wildlife species have shown improvement: the bald eagle, the wood stork, and the Florida manatee.

The trends of some indicators have worsened:

- Salinity has gradually risen over the last two decades and is expected to continue its increase, with increasing potential negative impacts on submerged aquatic vegetation and the aquatic life that depends upon it.
- Nonnative species increased from 56 total species in 2008 to 87 in 2018, and the spread of lionfish and Cuban treefrogs is of particular concern due to their impacts on the native ecosystem.
- Wetlands continue to be lost to development pressures.

The trends of many indicators are unchanged:

- Chlorophyll a, an indicator of harmful algal blooms, continues to exhibit exceedances and algal bloom events, and characterizing chlorophyll a levels is complicated by limitations in data collection.
- Fecal coliform levels in the tributaries remain significantly above both previously used and newly developed water quality criteria.
- Submerged aquatic vegetation has experienced recent regrowth due to rainfall, but the long-term trend is uncertain and the low number of sampling sites increases this uncertainty.
- Most finfish and invertebrate species are not in danger of overfishing, with the exception of channel and white catfish, which both have the potential to be overfished in the near future.

This year's Report contains a Highlight section on K-12 applications of the Report. Four threads of content valuable to K-12 educators are discussed, followed by the ways in which Report concepts meet state and national standards for science education. Finally, pre-service teachers at the University of North Florida used the Report in their teacher education curriculum, accompanied by field water monitoring kits. The Ribault and Trout Rivers have been identified as good sampling sites close to Duval County Schools, and Ribault High School has used the kit and the content.

The full Report provides an in-depth look at many aspects of the LSJRB. Section 1 provides an overview of the Report and the basin and describes the basin's landscape, human occupancy, and environmental management spanning the 1800s to early 2018. Section 2 describes water quality in terms of dissolved oxygen, nutrients, algal blooms, turbidity, fecal coliform, tributaries, and salinity. Section 3 addresses the state of the river's finfish and invertebrate fisheries. Section 4 examines the condition of aquatic life, encompassing plants, animals, and wetlands. Section 5 discusses conditions and importance of contaminants in the LSJRB. These contaminants include air and water emissions of chemicals in the LSJRB, as reported to EPA Toxics Release Inventory; mercury, the subject of a statewide reduction effort; metals, in both sediments and the water column; polycyclic aromatic hydrocarbons; polychlorinated biphenyls; and pesticides.

LIST OF ABBREVIATIONS AND ACRONYMS

AEF	American Eagle Foundation
AKA	Also Known As
ATSDR	Agency for Toxic Substances & Disease Registry
AWS	Alternate Water Supply
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
DOM	Dissolved Organic Matter
DRI	Development of Regional Impact
EPA	U.S. Environmental Protection Agency
EPB	Jacksonville Environmental Protection Board
ESA	Endangered Species Act
FDHSMV	Florida Department of Highway Safety & Motor Vehicles
FDOH	Florida Department of Health
FDOT	Florida Department of Transportation
FLZ	Freshwater Lacustrine Zone
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
GSI	Gonadosomatic Index
HAB	Harmful Algal Bloom
HSDC	Highest Single Day Count (of Manatees)
HMW	High Molecular Weight
ICW	Intracoastal Waterway
JAXPORT	Port of Jacksonville, Florida
JIA	Jacksonville International Airport
JU	Jacksonville University
LDI	Landscape Development Intensity
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
MRZ	Mesohaline Riverine Zone
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 System
NRC	National Research Council
NPS	National Park Service
NTU	Nephelometric Turbidity Units
PAHs	Polyaromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCU	Platinum Cobalt Unit
PEL	Probable Effects Level
PLRG	Pollutant Load Reduction Goal
ppt	Parts per Thousand
OCPs	Organochlorine Pesticides
OLZ	Oligohaline Lacustrine Zone
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	Trophic State Index
UDS	Ulcerative Disease Syndrome
UNF	University of North Florida
USA	United States of America
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
VSU	Valdosta State University
WBID	Waterbody Identifier
WHO	World Health Organization
WQC	Water Quality Criterion
WSEA	Jacksonville Water & Sewer Expansion Authority
WWII	World War II
WWTF	Waste Water Treatment Facility

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Highlight: K-12 Applications of the Report

H1. Introduction

The State of the Lower St. Johns River Basin Report was analyzed to identify elements useful to pre-collegiate educators. From this analysis, four major threads were identified as valuable to these personnel. The first relates to science-specific content. The Report offers a resource for background information (for teachers and their students) about content such as biological and chemical measures of water body health and the use of these data as evidence to support assessments. Examples of these indicators include dissolved oxygen, nutrients, turbidity, and biological assays.

The second thread connects to the data presented in the Report. Teachers can use this information to help their students understand how phenomena are described and generated through empirical observation and evidence collection, and used as indicators of watershed health. As an example, data in the Report are presented and, based on defined water quality criteria or benchmarks, an assessment made for the tributaries within the SJR watershed. Students can see how data are represented to make a case of the health indicators of these tributaries. They can also use these data to make their own calculations, representations, and conclusions.

Third, the Report offers a potential resource related to the "Nature of Science" components of the state and national standards. These components are central for students to understand how science is practiced. As a specific example of how the Report can provide a resource in this area, discussion of limitations of water quality assessments are found throughout the Report. These descriptions provide students an authentic example of scientific uncertainty and the limits of available data. The authors provide students a clear rationale for their uncertainty (e.g., due to differences in sampling methods, changes in definitions due to public policy, and ongoing questions of causation). These examples could provide useful points for teachers when discussing their students' own empirical work or current topics like global climate change or natural selection.

Finally, the Report offers a resource for cross-disciplinary curriculum development. Topics such as geographical history and human impact on the watershed are logical areas to make connections between the social studies and science subject areas. Through the use of the background information and data in the Report, students can better understand issues facing policy makers and the public when they try to understand and suggest management strategies for the LSJR watershed.

H2. Connections to Standards

The Report can support teaching approaches advocated by the authors of major policy documents including the National Science Education Standards (**NRC 1996a**), Science for All Americans (**Rutheford and Ahgren 1990**), the Florida Sunshine State Standards (**FDOE 2010**), Common Core Standards (**CCSSI 2012**), and the Next Generation Science Standards (**NRC 2013**).

These approaches include teaching through inquiry, where students are active learners through posing questions, examining data and finding patterns, and creating, examining and revising models, explanations, or solutions to issues. The Report supports teachers in these efforts by providing authentic data and presenting important issues related to management of the watershed. These resources can allow students to investigate questions that are relevant to their community and bring their understanding to bear when devising solutions to local LSJR watershed problems (e.g., saltwater intrusion, water conservation). One example could include striking a balance between the positive economic impact of expanding shipping in Jacksonville with the needs of suitable habitat for wildlife.

The Report provides a resource to support real-world curricular connections and critical thinking — areas that are central components of the Next Generation Science Standards (**NRC 2013**) and connected to the Common Core Standards (**CCSSI 2012**). To build relevance and real-world connections within the curriculum, cross-curricular materials should focus on tributaries and social components (i.e., Aldo Leopold's "sense of place") of the students' surroundings. This development could allow teachers to develop broader connections with the content of the Report. This broadening of the curriculum scope to connect to neighborhoods near schools is intended to build awareness of the watershed and that inter-connectedness of the components in the ecosystem. Through these materials, students will hopefully find science and nature in their everyday environments.

In addition to connecting to the tributaries in neighborhoods to meet the interests of students, the Report can be modified to meet the needs of students with varying reading levels. Educators can modify the text of the Report for grade level appropriate reading and science content. As the district advances in its use of technology (i.e., e-readers), teachers can modify text to meet the needs and interests of students.

H3. Current Impact

To broaden the impact of the Report, we evaluated its current use and gathered information to determine the best route forward. Up to this point, the Report has been used as a background information (e.g., definitions of terms, descriptions of the watershed) source. Broadening the focus to use the Report as a data source is a logical next step. Based on feedback from school personnel, the best route to data collection and sharing are ready-made materials like the World Water Monitoring Challenge kits.

Using input from faculty of the University of North Florida Departments of Biology and Chemistry, we determined the World Water Monitoring Challenge kits were a good option to use to proceed. Balancing cost, simplicity, and durability of the tests were factors in this decision. These tests correspond to some indicators within the Report, providing a connection between the Report and testing completed by secondary students.

Additionally, school administrators indicated an interest in students being able to share data with other students (either across schools or districts). The World Water Monitoring Challenge kit coordinators allow students to upload their data into a worldwide database.

From earlier discussions with school science education personnel, Jacksonville's schools were discussed as possible targets for this use. With the proximity of these schools, and their locations within the watershed, students could get a better understanding of the community surrounding their school, while making a more concrete, real-world connection to environmental science concepts. While there are important science topic areas to address, there is also an important, more general focus that has been an issue. Students struggle with engagement at the secondary level, which impacts motivation and achievement. By providing more relevant topics and real-world connections students are more apt to connect to science curriculum and instruction. The water sampling from the watershed and examining the Report provides students with a real-world case that helps them connect not only to the curriculum, but their community.

To this date, the Ribault and Trout Rivers have been identified as sample sites, as they tributaries that are in close proximity to the urban core schools. These tributaries also have boat landings that are accessible for sampling. Additional sites in the Jacksonville area may also be suitable for student sampling.

In the summer of 2015 and spring of 2016, 11 pre-service teachers were trained on the use and relevance of these kits in meeting required curriculum standards. The sessions were designed to build relevance and real world connections within the curriculum. Materials focused on tributaries and social components (e.g., Aldo Leopold's "sense of place," Emdin's "reality pedagogy") of the students' surroundings. This curriculum scope, through connections to community near schools, was intended to build awareness of the watershed and that inter-connectedness of the components in the ecosystem. The training with these materials was designed to help pre-service teachers show their students that science and nature are in their everyday environments.

Feedback from the summer session was used to modify materials. This modification included adapting the directions to be able to change font sizes and vocabulary to meet the needs of students in the targeted high schools.

In the summer of 2016, 12 graduate pre-service teachers were trained on the use of the World Water Monitoring Challenge kits. Modified procedure and data collection sheets were used during the session and made available to the pre-service teachers for use in their own classrooms.

Pre-service teacher feedback from the work with the kit has reflected a greater connection between the curriculum, community and the watershed. Reflective assessments indicated that they considered the watershed to be part of their community to a greater extent.

In the summer of 2017, these kits continued to be used with the addition of lab equipment from the University of North Florida Department of Biology at a sampling site at Harbor View Boat Landing on the Ribault River in the urban core of Jacksonville. This was the first time pre-service teachers completed on-site sampling and testing.

The intent of this session was to show multiple, low-cost testing methods for use in secondary classrooms. Additionally, it is intended that having the pre-service teachers at a sampling site will demonstrate the feasibility of using St. Johns River tributaries for field trips or teacher-collected samples (for lesson plans see Appendix A).

Two additional professional development sessions were added to help the pre-service teachers build relevance in their curriculum to connect to the backgrounds of their students. The concept was to build upon the pre-service teachers' understandings of the neighborhood surrounding their schools to not only include the social and economic assets, but to also include the natural. As part of these new sessions, students read Dumping in Dixie: Race, Class, and Environmental Quality (**Bullard 1990**) and wrote reflections.

A pre- and post-session short-answer survey was administered to 11 of the 12 graduate pre-service teachers. Prior to the sessions, 9 out of the 11 had not connected ecological communities, like the St. Johns River Watershed, into their conception of the community surrounding their schools. Multiple participants saw the Jacksonville urban core as "city" and devoid of natural resources. After completion of the sessions, 11 of 11 reported seeing a connection between the ecosystem and the community. This is an important finding, as one of the goals of the training was to help the graduate pre-service teachers see relevance between ecological concepts and their students' environment. In the survey the graduate pre-service teachers reported learning about methods of building real-world, ecological connections for students within the curriculum, bringing water samples to the classroom, developing independent science fair projects using the watershed, and developing student statistical capabilities within the context of water sampling.

As reported in 2016, a Ribault teacher (part of an earlier cohort of graduate pre-service teachers who completed training with the World Water Monitoring Challenge kits) has been using the kit supplemented with materials provided by the St. Johns Riverkeeper. She continues to report higher engagement and higher student performance on aquatic ecosystem benchmark assessments when compared to other environmental science classes at Ribault High School. For her students, the ecosystem section of these exams showed the highest scores.

H4. Conclusion

The Report provides an important resource for teachers to make important connections between science and the students' environment. This helps make science more concrete and engages them in real-world problem solving. Additionally, materials can be modified to support science learning at multiple curricular levels. The Report team hopes to help teachers in these endeavors. Please contact us if you are interested in seeking guidance and support.

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), the University of North Florida (UNF), and Florida Southern College (FSC). Over the years, 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 (COJ), 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 the *River Accord* partners, including COJ, the St. Johns River Water Management District (SJRWMD), JEA, Jacksonville Water and Sewer Expansion Authority (WSEA; formally dissolved in June 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 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
  - Salinity
- FISHERIES
  - Finfish Fishery
  - Invertebrate Fishery
- AQUATIC LIFE
  - Submerged Aquatic Vegetation
  - Wetlands
  - Macroinvertebrates
  - Threatened and Endangered Species
  - Non-native Aquatic Species
- CONTAMINANTS
  - Toxics Release Inventory: Point Sources of Contaminants in the LSJR Region
  - Polyaromatic Hydrocarbons (PAHs)
  - Metals
  - Polychlorinated Biphenyls (PCBs)
  - Pesticides

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, and in other cases, the designation is based on alternative criteria as described in the sections.

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.

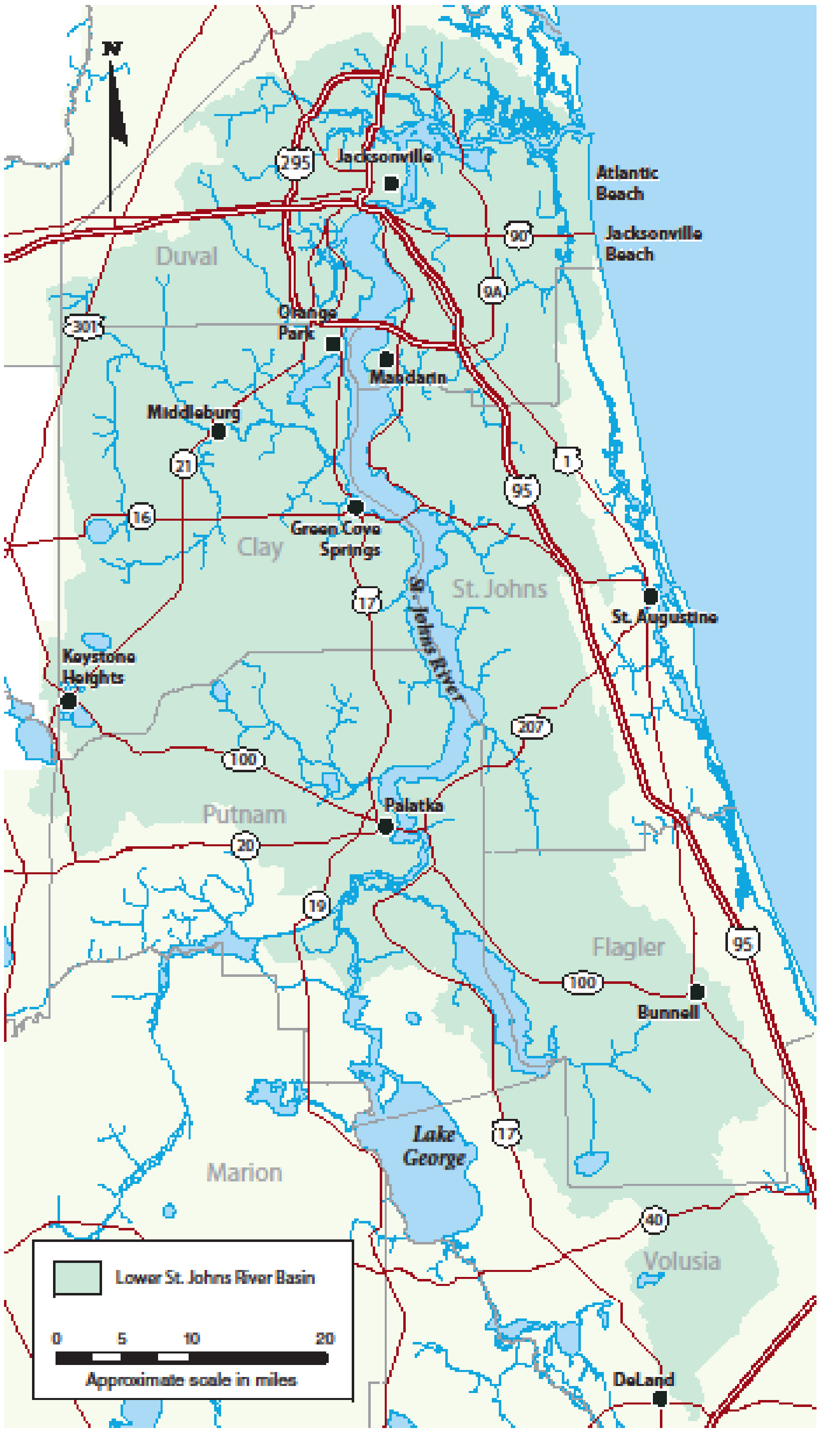


Figure 1.1 Geopolitical Map of the Lower St. Johns River Basin, Florida (basin shaded in green, ***SJRWMD 2018a****).*

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: "that portion of the St. Johns River that extends from the confluence of the St. Johns and Ocklawaha rivers near Welaka north to the mouth of the St. Johns River at Mayport in Jacksonville" (**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**; Figure 1.1). 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 Cover

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 1.2.2.A. for acres and definitions of categories).

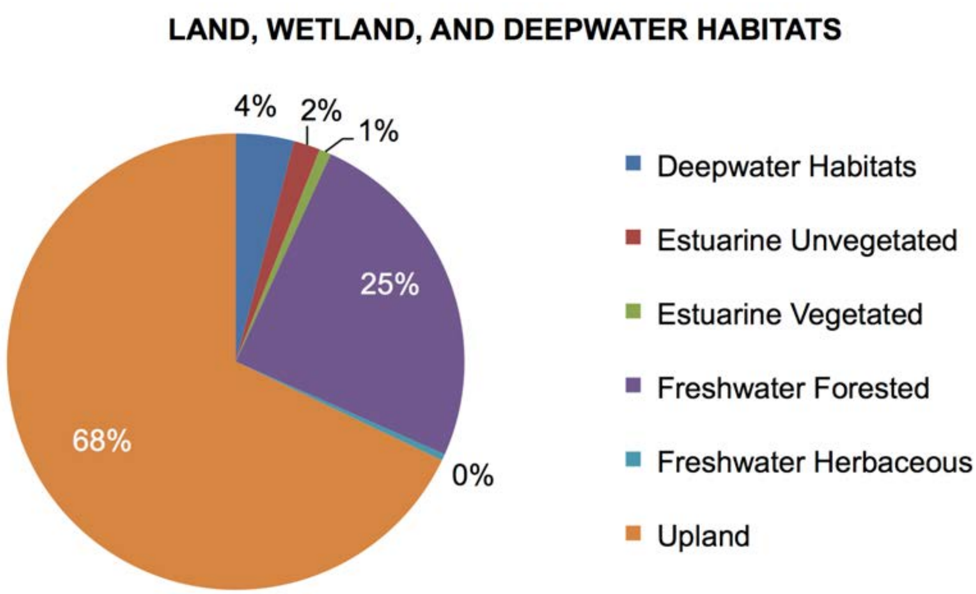


Figure 1.2 Total percentages for land, wetland, and deepwater habitats within the Lower St. Johns River Basin, Florida. (Source: SJRWMD Wetlands and Deep Water Habitats GIS Maps, 1972-1980; ***SJRWMD 2007****)*

Within the LSJRB in 2004, the dominant land covers were upland forests (35%) and wetlands (24%), and 18% was considered urban and built-up. 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 1.2.2.B.; **SJRWMD 2007**). The percentage of the region that is built-up is likely to increase in future years (**SJRWMD 2008; NRC 2010**).

1.2.3. Ecological Zones

The LSJRB is commonly divided into three ecological zones based on expected salinity differences (**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 parts per thousand (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, has an average salinity of 0.5 ppt, and experiences tidal fluctuations that are lower than those observed in the other ecological zones.

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 of dissolved and suspended components in the river are 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 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 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, such as Matthew in 2016 and Irma in 2017, tropical storms, or nor'easters, or drought events, like the droughts of the early 1970s, the early 1980s, 1989-1990, and 1999-2001 (**DEP 2010d; SJRWMD 2016a; SJRWMD 2017b**). 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 1.3).

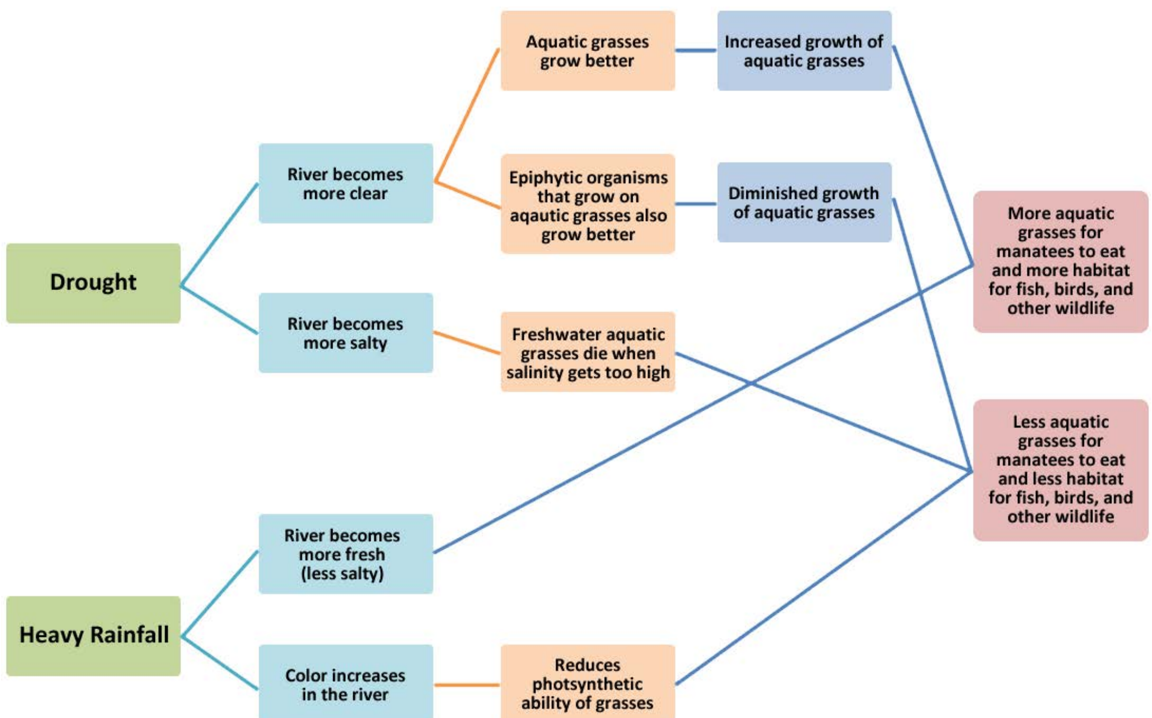


Figure 1.3 Simplified example of sequenced events that can occur in the Lower St. Johns River Basin stimulated by changes in rainfall.

The St. Johns River can be influenced by local wind direction. Surface stress of local winds upon the river plays a secondary role compared with remote winds on the ocean that affect the river's flow. However, these local winds can cause flow enhancements. 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.

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 LSJRB 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 LSJRB 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, while also engaging in traditional hunting and gathering (**Thunen 2010**). The Timucua Indians modified the land to their advantage, such as burning and clearing land for agriculture and constructing drainage ditches and large shell middens (**Milanich 1998**). 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 1.4).

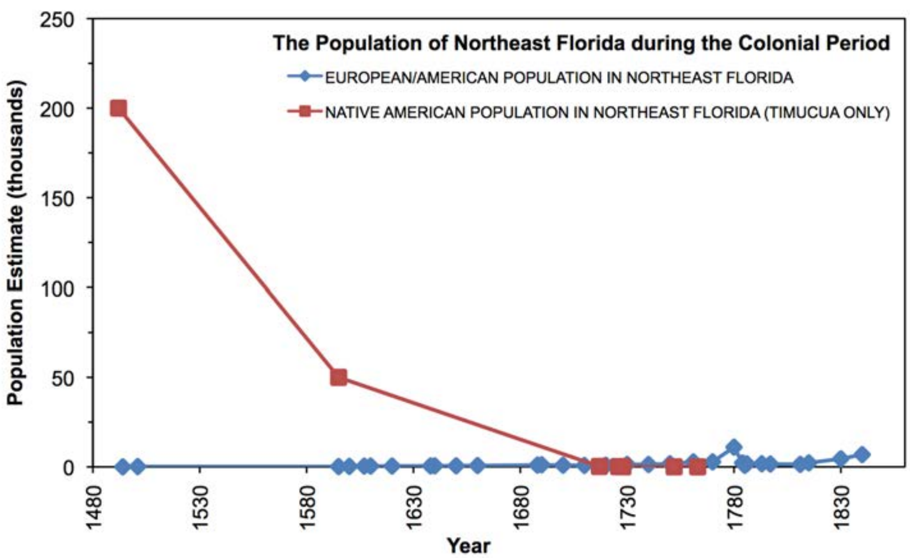


*Figure 1.4 Population of northeast Florida during the Colonial Period, 1492 to 1845. (Sources: Population estimates for the Timucua Tribe in northeast Florida were taken from **Milanich 1997**, and "Northeast Florida" is defined as all lands inhabited by Timucua Indians. Population estimates for European 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 1.3.1.*

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 1770s (**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 1.5).

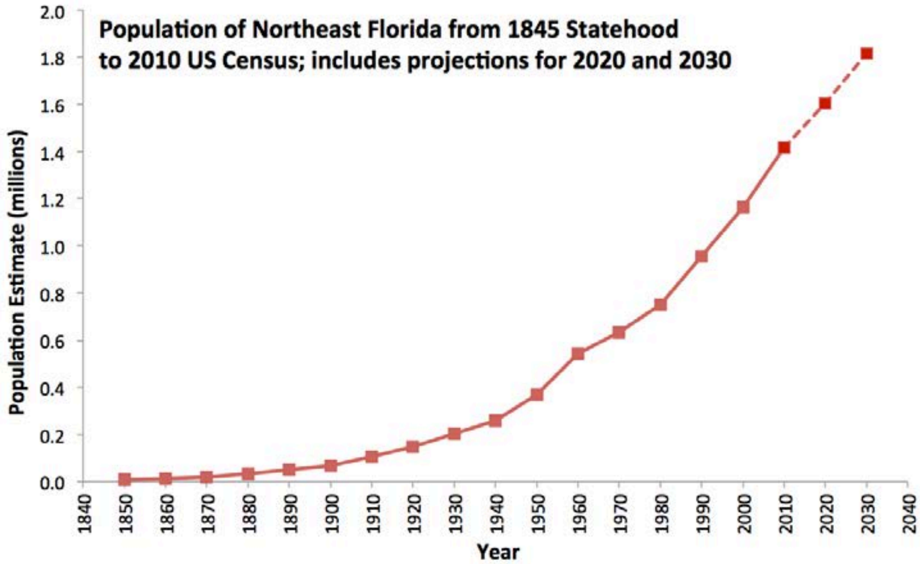


Figure 1.5. Population of northeast Florida from the time Florida was granted statehood to the 2010 U.S. Census including future population projections to 2030. ("Northeast Florida" includes population counts from Clay, Duval, Flagler, Putnam, and St. Johns counties. Sources: Population counts for the years 1850-1900 were provided by Miller 1998. Counts from 1900-1990 were extracted from ***Forstall 1995****, and 2000 and 2010 counts from the USCB. (****USCB 2000; USCB 2010****) Note: U.S. Census data were not available for Flagler County in 1900 and 1910. Population estimates for 2020 and 2030 were extracted from the Demographic Estimating Conference Database (****EDR 2015****), updated August 2014.*

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 (Figure 1.5; **USCB 2000**).

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 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 waterbodies 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 2010s.

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 2010a**).
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 LSJRB 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 2010a**).
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).
1961	City of Jacksonville completes construction of Buckman Sewage Treatment Plant (**Crooks 2004**).
1952	The Port of Jacksonville shipping channel was deepened to 34-ft (**GLD&D 2001**).
1964	Construction continued on Cross-Florida Barge Canal.

1965	U.S. Congress passes the Water Quality Act, requiring states to establish water pollution criteria (**Melosi 2008**).
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	Several federal and state environmental laws were passed. • Florida Water Resources Act: established regional water management districts and created a permit system for allocating water use (**Florida Legislature 1972b**). • Federal Clean Water Act: required that all U.S. waters be swimmable and fishable (**Congress 1972a**). • Land Conservation Act: authorized the sale of state bonds to purchase environmentally imperiled lands (**Florida Legislature 1972c**). • Environmental Land and Water Management Act: initiated the “Development of Regional Impact” program and the “Area of Critical State Concern” program (**Florida Legislature 1972c**). • Comprehensive Planning Act: called for the development of a state comprehensive plan (**Florida Legislature 1972a**). Marine Mammal Protection Act: prohibited the killing or hurting of marine mammals in U.S. waters (**Congress 1972b**).
1973	Endangered Species Act: conservation of threatened and endangered plants and animals and their habitats (**Congress 1973**).
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 LSJRB as an area in need of special protection and restoration (**SJRWMD 2008**).
1987	Water Quality Attainment Plan adopted by City of Jacksonville City Council. The plan addressed causes and remedies for non-attainment of water quality criteria.

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 2010a**).
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 2010a**).
1989	SJRWMD publishes the first 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 that 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**).
1997	The Lower St. Johns River Basin Strategic Planning Session (the "River Summit") led to the development of a 5-year "River Agenda" plan.
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 CWA (*Florida Wildlife Federation, Inc., et al. v. Browner*, (N.D. Fla. 1998) (No. 4:98CV356). In 1999 the lawsuit against EPA was settled with a Consent Decree, which required EPA and the Florida Department of Environmental Protection (DEP) to begin implementation of the TMDL provisions of the CWA. The Consent Decree required EPA to establish TMDLs if the State of Florida does not (13-year schedule to establish TMDLs).
July 30, 1998	St. Johns River is designated as an American Heritage River (**DEP 2002**).
Sept. 17, 1998	DEP submitted the 1998 303(d) list of impaired waterbodies to the EPA for approval. The 1998 303(d) list included 53 waterbodies in the LSJR. The list was approved by EPA in November 1998.
1999	Florida legislature enacted the Watershed Restoration Act (Florida Statute Section 403.067) to provide for the establishment of 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 (Case No. 01-1332R, Florida Division of Administrative Hearings), 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 mainstem 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 CWA (*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 Mainstem 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).
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 2010a**).
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 2010a**).
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 (F.A.C. 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 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 SSAC). (*St. Johns Riverkeeper, Inc., et al. v. United States Environmental Protection Agency, et al.*, No. 4:2006cv00332, 2006 (N.D. Fla.))
July 2006	The River Accord: A Partnership for the St. Johns was established.
Sept. 2006	The project collection process for the LSJR Mainstem BMAP started, which provided 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 (USACE) 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**).
Feb. 1, 2007	The Executive Committee determined the LSJR Mainstem 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	SJRWMD launched the 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 2010a**).
August 2007	Urban stormwater loads were identified and quantified by local jurisdictions for the LSJR Mainstem BMAP.
Jan. 17, 2008	EPA approves the LSJR nutrient TMDLs based on the recently adopted 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.)).
Aug. 6, 2008	The first annual "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 LSJRB 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. In October 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 TMDLs for Nutrients was adopted by the DEP for the LSJRB Mainstem. 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.
Jan. 16, 2009	EPA issued a formal determination under the CWA 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.
May 19, 2009	DEP released FINAL Drafts of the LSJRB Group 2 Cycle 2 – Verified List and Delist List of Impaired Waters. These lists update the 2004 303(d) list of waters in need of water quality restoration. The lists are submitted to EPA Region 4 as an update to the Florida 303(d) list.
July 2009	DEP adopts by rule fecal coliform TMDLs for 22 tributaries to the Lower St. Johns River.
November 2009	DEP adopts by rule several TMDLS: eight for fecal coliform, two for nutrients, five for dissolved oxygen and nutrient, one for dissolved oxygen, and two for lead.
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 2004 303(d) master list of impaired waters. The lists are submitted to EPA Region 4 as an update to the Florida 303(d) list.
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. Massive drifts of an unusual, persistent foam occurred from mid-summer through the fall. Unusually high dolphin mortalities occurred May-September. National Oceanic and Atmospheric Administration (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.
July 2010	DEP adopts by rule five fecal coliform TMDLs for tributaries to the Lower St. Johns River.
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. 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. On April 11, 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. On June 13, EPA sent an initial response to DEP's petition. In their response, EPA was prepared to withdraw the federal inland standards if DEP adopted, and EPA approved, their own protective and scientifically sound numeric standards. On 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 four months to July 6, 2012. (The extension does not affect or change the February 4, 2011 date for the SSAC provision.) This extension afforded the State additional time to finalize their own rule establishing numeric nutrient criteria for the State and submit it for EPA review. On November 30, 2012, EPA approved DEP's standards for numeric nutrient criteria in Florida's flowing waters, springs, lakes, and South Florida estuaries, and in June 2013, EPA approved DEP's criteria for estuaries, and coastal waters (**EPA 2013a**). In October 2014, EPA rescinded federally adopted criteria and DEP criteria were in effect. While this rule did not include criteria for the Lower St. Johns River Basin, it began a process for numeric criteria later applied to estuary-specific numeric nutrient criteria that do include the LSJR.
Feb. – Apr. 2011	DEP released final TMDLS for Arlington River for nutrients; Mill Creek for dissolved oxygen and nutrients; and lead in Black Creek and Peters Creek.
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.
July 2013	DEP begins an initiative to revise bacteria criteria for Florida's beaches and recreational waters. (**DEP 2014d**).
September 2013	EPA approved DEP's revised criteria for dissolved oxygen, which takes into account stream conditions and percent oxygen saturation (**DEP 2013i).**
October 2013	DEP released a final Florida Mercury TMDL (**DEP 2013c**).

November 2014	The Florida Environmental Regulation Commission (ERC) approved numeric nutrient criteria specific for several estuaries, including the Lower St. Johns River.
December 2014	RockTenn and Rayonier, two companies with facilities in the region, filed a legal challenge to the ERC's approval of the estuary-specific numeric nutrient criteria (**News4JAX 2014**).
January 2015	"St. Johns River Economic Study," edite**OSHA 2017**d by Dr. Courtney T. Hackney, is released to public (**Hackney 2015**).
January 2016	Florida Governor Rick Scott signs into law the Environmental Resources Bill, which defines flow levels for springs, creates a management plan for some South Florida watersheds, and sets guidelines for the Central Florida Water Initiative, an effort to secure water supply for Central Florida (**CBSMiami 2016**).
July 2016	Florida Environmental Regulation Commission approves changes to Florida water quality criteria.
October 2016	Legal challenges to new water quality standards are set aside by Florida administrative law judge.
January 2017	DEP releases a draft TMDL for nutrient in Crescent Lake that includes site-specific numeric interpretations of the narrative nutrient criterion.
September 2017	Hurricane Irma strikes Florida, dumping 2.2 trillion gallons of water on the region and causing major floods (**SJRWMD 2017b**).
January 2018	U.S. Federal Judge rules that the Army Corps of Engineers can begin dredging up to thirteen miles of the St. Johns River to a depth of 47 feet as part of the Jacksonville Harbor Deepening Project (**News4JAX 2018**).
February 2018	DEP is initiating rule-making to establish TMDLs for certain impaired surface waters within the Lower St. Johns River Basin.
February 2018	DEP withdraws amendment to water quality standards rule announced in July 2016. This rule would have established new water quality criteria for 39 chemicals that previously had no limits in Florida (**OSHA 2017**). It would have also updated standards on 43 other chemicals for which standards had not changed since 1992, and it would have increased allowable concentrations of some chemicals, including some released in hydraulic fracking (**DEP 2016e; Klas 2016**).

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 four decades have been marked by this oscillation between lawsuits and laws. The result has been incremental and adaptive water quality management.

An important element of protecting the St. Johns River is the possession of a good understanding of the economic impact the river has on the region. To that end, the Florida Legislature in 2013 funded a report on the river's economic value to the state of Florida (**Hackney 2015**). This report describes the economic impact of the St. Johns River in terms of a conceptual model relating natural functions with natural values, an assessment of wetland importance for flood prevention and nutrient removal, the effect on real estate values along or near the river, the importance of surface water in both water-use and water quality dimensions, and the impact of recreation and ecotourism.

In January 2016, the Environmental Resources bill was signed into law. This law addresses flow levels in springs, management plans for certain watersheds in South Florida, including Lake Okeechobee and the St. Lucie and Caloosahatchee Rivers, and guidelines for the Central Florida Water Initiative, a multi-agency effort to secure water resources for Central Florida. Business and industry groups, along with environmental groups like Audubon Florida and the Nature Conservancy, have supported its effort to advance protection of water resources. Other groups, such as the St. Johns Riverkeeper and the Florida Springs Council, have opposed the bill, citing weakened protections for land around springs and a lack of emphasis on water conservation (**Staletovich 2016**) and interbasin water transfer authority for each water management district that exceeds its jurisdictional boundaries.

Another concern is the provision that when any water management district declines a consumptive-water-use permit due to impact on river or spring flow levels, that district must submit its water supply plan to DEP for additional review and revision, thus effectively weakening the water management districts' authority over permitting (**Curry 2016**).

DEP has developed new criteria for bacteria at beaches and other recreational waters. Instead of counting the large class of fecal coliform bacteria, the new criteria will specify counts of *Escherichia coli* for freshwater and enterococci for marine waters. These species have been shown to be better predictors of bacterial contamination with human health implications. This process was initiated in July 2013 and is complete.

New changes to water quality standards were announced by the DEP in July 2016 (**DEP 2017d**). These changes would have established new water quality criteria for 39 chemicals that previously had no limits in Florida, such as beryllium, a metal used in copper alloys and the cause of chronic beryllium disease (**OSHA 2017**). The new rule also updated water quality criteria for 43 other chemicals, for which standards have existed but have not changed since 1992 (**DEP 2016d**). Some of these changes would have lowered allowable concentrations of chemicals, such as trichloroethylene, a chlorinated solvent used in degreasing applications (**Klas 2016**). Other changes would have increased allowable concentrations of chemicals, including several discharged by the hydraulic fracturing ("fracking") and pulp and paper industries (**Klas 2016**). FDEP conducted several public workshops on the proposed rule, and its scientific methods for determining human health criteria and risk factors were developed and reviewed by a group of scientists from universities within and outside Florida, as well as state and federal environmental agencies (**DEP 2016l**).

The new rule was approved in July 2016 by a 3-2 vote of the Environmental Regulation Commission (**Turner 2016**). The Environmental Regulation Commission, a seven-member board selected by the Florida Governor, had two vacant seats at the time of the vote: the seat representing the environmental community, and the seat representing local governments (**Klas 2016**). U.S. Senator Bill Nelson and several U.S. Congressmembers expressed concern in a letter to EPA Director Gina McCarthy (**Turner 2016**). Several entities formally requested a stay on the proposed rule, including the city of Miami, Martin County, the Seminole Tribe, and the Florida Pulp and Paper Association Environmental Affairs Inc. (**Saunders 2016**). The requests for a stay on the rule were rejected by Florida Administrative Law Judge Bram Kanter in October 2016 (**Saunders 2016**). Appeals were filed in the Florida First and Third District Courts of Appeal,

In 2018, the DEP formally withdrew the rule and initiated new rule making (**DEP 2018c**). The DEP states: "The Department of Environmental Protection (department) is initiating rulemaking to consider proposed revisions to the human health-based surface water quality criteria in Rule 62-302.530, Florida Administrative Code (F.A.C). The department intends to conduct a statewide fish consumption survey to accurately determine the amount and types of fish commonly eaten by Floridians in advance of criteria development and adoption. The human health-based criteria listed in Rule 62-302.530, F.A.C., will be revised based on the results of the survey and any additional relevant data and information collected by the department" (**DEP 2018d**).

1.5.1. 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 waterbodies, 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. Several TMDLs have been adopted in the LSJRB, including those for nutrients in the mainstem and fecal coliforms in the tributaries. In most cases, adoption of TMDLs is followed by development of a BMAP. 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 mainstem 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**). A progress report on the mainstem BMAP was published in 2016 (**DEP 2016m**). Updates on the tributary BMAPs were published in 2016 and progress reports on the tributary BMAPs were published in 2017.

As well, a new comprehensive statewide updated list of verified impaired waterbodies was released by DEP in 2014 and again as of April 11, 2018. (**DEP 2014f**; **DEP 2018e**).

Table 1.2 shows the number of 303(d) impairments in 2004, 2009, 2014, and as of April 11, 2018 (**DEP 2018e**). It also shows delisted impairments in 2009, 2014, and as of November 17, 2017 (**DEP 2018a**). The 2018 impairments are primarily due to fecal coliform, iron, and dissolved oxygen. Figure 1.6 illustrates the breakdown of the 2018 impairments. Table 1.2 also shows the number of 303(d) impairments that were delisted in 2009, 2014, and as of November 17, 2017. These delistings occurred for a variety of reasons, such as satisfying water quality criteria, or confirmation that natural conditions, not anthropogenic loading, caused the observed impairment, among other things (**DEP 2018a**).

Current and future efforts to improve the health of the LSJR (and other waterbodies 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 verified 303(d) 2004, 2009, 2014, 2017 and 2018 lists of LSJR impaired waterbodies or segments of waterbodies requiring TMDLs.

YEAR	# IMPAIRMENTS	# WATERBODIES WITH IMPAIRMENT	# IMPAIRMENTS DELISTED	COMMENTS
2004	153	87		
2009	123	97	67	
2014	239	151	167	Statewide mercury TMDL finalized in 2013, adding many WBIDs to impairment list.
2017			345	
2018	117	104		

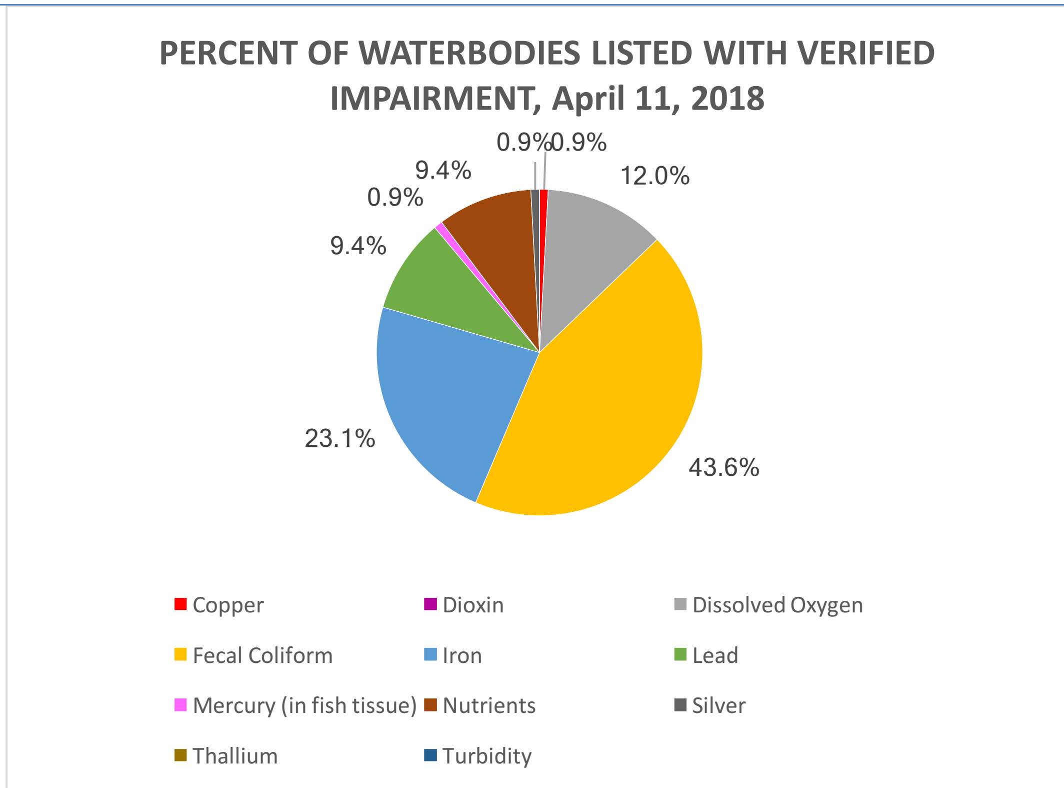


Figure 1.6 Percent of waterbodies or segments of waterbodies listed with various impairments in the Lower St. Johns River Basin in the 2018 verified list (as of April11, 2018).

1.5.2. Water Quality Credit Trading

In 2008, the Florida Legislature passed revisions to the Florida Watershed Restoration Act that established the framework for a system of water quality credit trading in the Lower St. Johns River Basin (**DEP 2010g**). This system allows individual dischargers of a pollutant, such as a local utility or a municipality, to trade credits for nutrients, which consist of total nitrogen and phosphorus. Each individual discharger has a goal for reduction of nutrients. Because some dischargers are able to control nutrients with a very different cost outlay than others, some dischargers meet and even exceed their goals, while others do not meet the goals. Thus, those that exceed their goals possess "credits" that they can sell to those who do not meet their goals.

Prior to 2014, JEA exceeded its nutrient reduction goal and accumulated credits; however, the City of Jacksonville (COJ) did not meet its goal. COJ was required by law to meet 50% of its goal by 2015, so Ordinance 2015-0105, passed by the City Council in April 2015, decreed that COJ would pay JEA approximately $2 million per year over eight years for 30.32 metric tons of credits. This ordinance also established that COJ would gain 10.15 metric tons of credits from FDOT in exchange for a 5% reduction of FDOT's obligation for nitrogen in non-point source runoff, from 10% to 5%, along with an increase in COJ's obligation rising from 90 to 95% (**Long 2018**; **COJ 2018**). However, on March 22, 2016, COJ and JEA executed a new interagency agreement by which JEA conveys its credits to COJ at no charge to COJ (**Kitchen 2016**; **Cordova 2016**). This is accompanied by an agreement between JEA and COJ to contribute $15 million each to a plan to replace septic tanks with sewer lines in existing neighborhoods.

2. Water Quality

2.1. Overview

Water quality 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 within segments of the mainstem of the LSJRB as well as among and within each tributary.

To identify characteristically similar segments in each separate water body, a unique water body identifier (WBID) number is assigned to each water body in the State. WBIDs offer an unambiguous method of referencing waterbodies within the State of Florida. The mainstem of the LSJRB is divided into multiple segments, WBIDs 2213A through 2213N, that range from marine to freshwater systems. The section we refer to as marine/estuarine in this report spans from the mouth at WBID 2213A to WBID 2213H, which contains Doctors Lake. The freshwater region extends from WBID 2213I upstream to WBID 2213N at the confluence of the Ocklawaha River (Figure 2.1).

The Clean Water Act mandates that each water body, each WBID, must be assessed for impairments for its stated uses. The LSJR is a Florida Class III water body with designated uses of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. If a water body is determined to be impaired for its designated uses, a Total Maximum Daily Load (TMDL) must be established to set maximum allowable levels of pollutants that can be discharged into it that will allow it to achieve water quality standards.

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 criteria have been established and approved for dissolved oxygen (DO) in the predominantly marine portion of the LSJRB and during certain times of the year when sensitive species may be present.

The water quality of each segment of a river or tributary is strongly impacted by the land use surrounding the water body. Thus, the segments and tributaries of the LSJR vary in water quality impacts from agricultural, industrial, urban, suburban, and rural land uses. Often, different parts of the same stream will have changes in water quality that reflect changes in land use, industry, and population along it. Identification of sources of nutrients or pollutants in the watershed of an impaired water body is part of the TMDL process and of the amount of pollutants discharged by each of these sources must be quantified.

Sources of pollutants 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. Changes to the Clean Water Act made in 1987 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 in **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 2010h**. 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 2013e**.

The LSJRB mainstem BMAP was completed in 2008 (**DEP 2008a**), and a 5-year progress report on meeting the TMDL for nutrients was recently released in 2014 (**DEP 2014a**). There have been two BMAPs completed for a total of 25 tributaries in the lower basin (**DEP 2009b; DEP 2010a**) and Phase 2 updates completed in 2016 (**DEP 2016f; DEP 2016c**).

2.2. Dissolved Oxygen

2.2.1. Description and Significance: DO and BOD

DO is defined as the concentration of oxygen that is dissolved or solubilized in water 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 by the State of Florida. Until 2013, the class III Freshwater Quality Criterion (WQC) for DO has been 5.0 mg/L (62-302.530, F.A.C.; **DEP 2013j**), requiring that normal daily and seasonal fluctuations must be maintained above 5.0 mg/L to protect aquatic wildlife. For regulatory purposes, the mouth of Black Creek divides the fresh and marine portions of the LSJR. Moving south from Black Creek (WBID I) to the city of Palatka (WBID N) is designated as the predominantly freshwater part of the LSJR. The Florida DEP developed 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. DO concentrations between 4.0 and 5.0 mg/L are considered acceptable over short time periods extending up to 55 days, provided that the DO average in a 24-hour period is not less than 5.0 mg/L (**DEP 2010c**).

In April, 2013, the U.S. EPA approved new DO and nutrient related water quality standards to be adopted by the Florida Environmental Regulation Commission (ERC). The revisions approved by the U.S. EPA include "revised statewide marine and freshwater DO criteria, anti-degradation considerations regarding any lowering of DO, protection from negative trends in DO levels, the inclusion of total phosphorus, total nitrogen, and chlorophyll *a* criteria for the Tidal Peace River, among other provisions relating to DO and nutrients". The State's revisions also require the protection of several federally listed threatened and endangered species, including three sturgeon and one mussel species.

Under the new revisions, in predominantly freshwaters of the SJR in the Peninsula bioregion, the DO should not be less than 38 percent saturation, which is equivalent to approximately 2.9 mg/L at 30°C and 3.5 mg/L at 20°C (DEP 2013b). Additionally, in the portions of the LSJR inhabited by Shortnose or Atlantic Sturgeon, the DO should not be below 53 percent saturation, which is equivalent to approximately 4.81 mg/L at 20°C, during the months of February and March. After much assessment, the FDEP supported that maintaining the 5.0 mg/L minimum DO criterion in the location where spawning would occur should "assure no adverse effects on the Atlantic and shortnose sturgeon juveniles."

For predominantly marine waters, minimum DO saturation levels shall be as follows:

> *"1. The daily average percent DO saturation shall not be below 42 percent saturation in more than 10 percent of the values; 2. The seven-day average DO percent saturation shall not be below 51 percent more than once in any twelve week period; and 3. The 30-day average DO percent saturation shall not be below 56 percent more than once per year."*

For more information, please refer to the U.S. EPA decision document (**EPA 2013b**).

Additionally, seasonal limits for Type 1 SSAC were implemented in February 2014 for certain areas of the LSJR, where the default criteria in Rule 62-302.530, F.A.C. would apply during the other times of the year. For the Amelia River, the segment between the northern mouth of the river and the A1A crossing, a SSAC for DO has been set to 3.2 mg/L as a minimum during low tide from July 1st through September 30th, and not below 4.0 mg/L during all other conditions. Likewise, Thomas Creek (including tributaries from its headwaters to the downstream predominantly marine portion) has a SSAC for DO of 2.6 mg/L, with no more than 10 percent of the individual DO measurements below 1.6 mg/L on an annual basis.

The 30-d average DO percent saturation value of 56%, which is the most conservative, was used as a reference value to compare to the data from the marine/estuarine portion of the LSJR. This value is equivalent to approximately 5.09 mg/L at 20°C and 4.28 mg/L at 30°C.

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 generally accompanied by lower DO. 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 2013j**).

Growth of bacteria and plankton requires nutrients such as carbon, nitrogen, phosphorus, and trace metals, in varying amounts. Nitrogen and phosphorus, in particular, may contribute to the overgrowth of phytoplankton, periphyton, and macrophytes, which then in turn senesce. 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*

DO reaches 100% saturation when an equilibrium between the air and water is reached. However, many factors can influence DO saturation, namely temperature, salinity, biological activity, and vertical location in the water column.

As temperature increases, the solubility of oxygen decreases (**Mortimer 1981**). Biological activities, such as respiration, microbial decomposition, and photosynthesis also influence DO saturation and are also affected by temperature. Warmer temperatures increase respiration and microbial decomposition in aquatic organisms, which are processes that require oxygen, and thus lowers the DO (Wetzel 2001). Warmer temperatures also increase metabolism and production of bacteria and phytoplankton which contribute to a higher BOD and a lower DO. Alternatively, the process of photosynthesis adds oxygen (as a waste product) into the water (Wetzel 2001). Photosynthesis can contribute to supersaturation of a water body potentially bringing the DO above 100% saturation, particularly during daytime hours in photosynthetically active water bodies.

Shallow areas and tributaries of the LSJR that are without shade have particularly elevated temperatures in the summer months and can reach 100% saturation at a lower DO concentration. Therefore, 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. Increasing salinity reduces oxygen solubility causing lower DO in aquatic systems. At a constant temperature and pressure, 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, as discussed above, it is a blackwater river, and photosynthesis by submerged aquatic vegetation 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.

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**). High TSI values can indicate high primary (plant) productivity; however, these values can also be indicative of an unbalanced ecosystem, with increased nutrients and algal biomass, which can result in large fluctuations in DO.

2.2.3. *Data Sources*

All data used for the DO and BOD analyses were from the Florida DEP STOrage and RETrieval (STORET) database. STORET is a computerized environmental data system containing water quality, biological, and physical data. From the data sets, negative values were removed. Values designated as present below the quantitation limit (QL) were replaced with the "actual value" if provided, or replaced with the average of the method detection limit (MDL) and practical

quantitation limit (PQL) if the "actual value" was not provided. For "non-detect" values, half the MDL was used; and, for values designated as "zero" the MDL was used. All samples with qualifier codes K, L, O, Q, or Y, which indicate different data quality issues, were eliminated. Data designated with a matrix of "ground water," "surface water sediment," "stormwater," or "unknown" were removed. Records with no analytical procedure listed were also removed. This section examines the data from the freshwater part of the mainstem (WBID 2213I-N), the predominantly saltwater part of the mainstem (WBID 2213A-H), the entire LSJRB (Figure 2.1) and the tributaries (discussed more 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. The data are also presented as annual mean value ± standard deviation and compared to the designated reference values.

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.

2.2.5. Current Status and Trends

Figure 2.2 shows median DO concentrations and the range of the DO values measured in the LSJR. The median DO values have been fairly stable since 1999. In 2016 and 2017, the range of DO values decreased and the minimum DO concentrations increased, particularly in the marine/estuarine sections of the LSJR mainstem (Figure 2.2). Figure 2.3 shows annual mean DO values and trendlines of the same data set. Since 2013, there have been slight fluctuations, but mostly stable DO mean concentrations in the LSJR mainstem (Figure 2.3). Furthermore, both mean and minimum values in the mainstem have been above reference values and within acceptable limits (Figures 2.2, 2.3). In the tributaries, mean DO concentrations have been at or near the marine/estuarine reference value from 1997 to 2015; however, mean values have increased (improved) over the past three years (Figure 2.3). Annual mean DO values are now within acceptable limits in the tributaries while minimum DO concentrations are below or at the freshwater and marine/estuarine reference values (Figure 2.2). Resident aquatic life may be at risk during low DO events in the tributaries of the LSJR, particularly in the marine/estuarine areas.

A seasonal trend, with the lowest concentrations observed in the summer months, was observed in the data from the entire LSJR, but not in the data from the freshwater and the saltwater areas of the mainstem (Figure 2.4A-C). This suggests that the seasonal DO fluctuation could be most problematic in the tributaries, where the lowest DO concentrations were observed. It is likely that the aquatic life inhabiting these areas will be more affected by low DO events during the summer time. Water quality conditions in tributaries will be addressed separately in Section 2.8 because DO concentrations can vary among tributaries, depending on the surrounding land use, water flow, depth, and salinity.

Since 1997, there have been slight fluctuations in the median BOD values in the LSJR mainstem (Figure 2.5). In 2016, the BOD data range decreased, including the number of high BOD values, which may be reflective of the increased minimum DO concentrations reported (Figures 2.2 and 2.5). A seasonal pattern of increased BOD values was observed in the LSJR mainstem, particularly in the freshwater areas, with the highest values observed in summer months (Figure 2.6).

Taking everything into account, the current overall STATUS for DO in the LSJR mainstem is *satisfactory* and the TREND is *unchanged*. However, the STATUS for DO in the LSJR tributaries is *unsatisfactory (dependent on location, time of day, and season)*, and the TREND is *improving*.

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 every year prior to 2015. Low DO was most problematic during summer months with many of the lowest measurements occurring in tributaries. Certain areas of the LSJR that experience 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. It is also important to note that hurricane Mathew and hurricane Irma, which impacted Jacksonville October 7th, 2016 and September 10-11, 2017, respectively, have resulted in changes in water quality in the LSJR over the past two years. In particular, massive flooding into the river has changed the salinity in some areas and could have contributed to changes in DO and other water chemistry parameters as well.

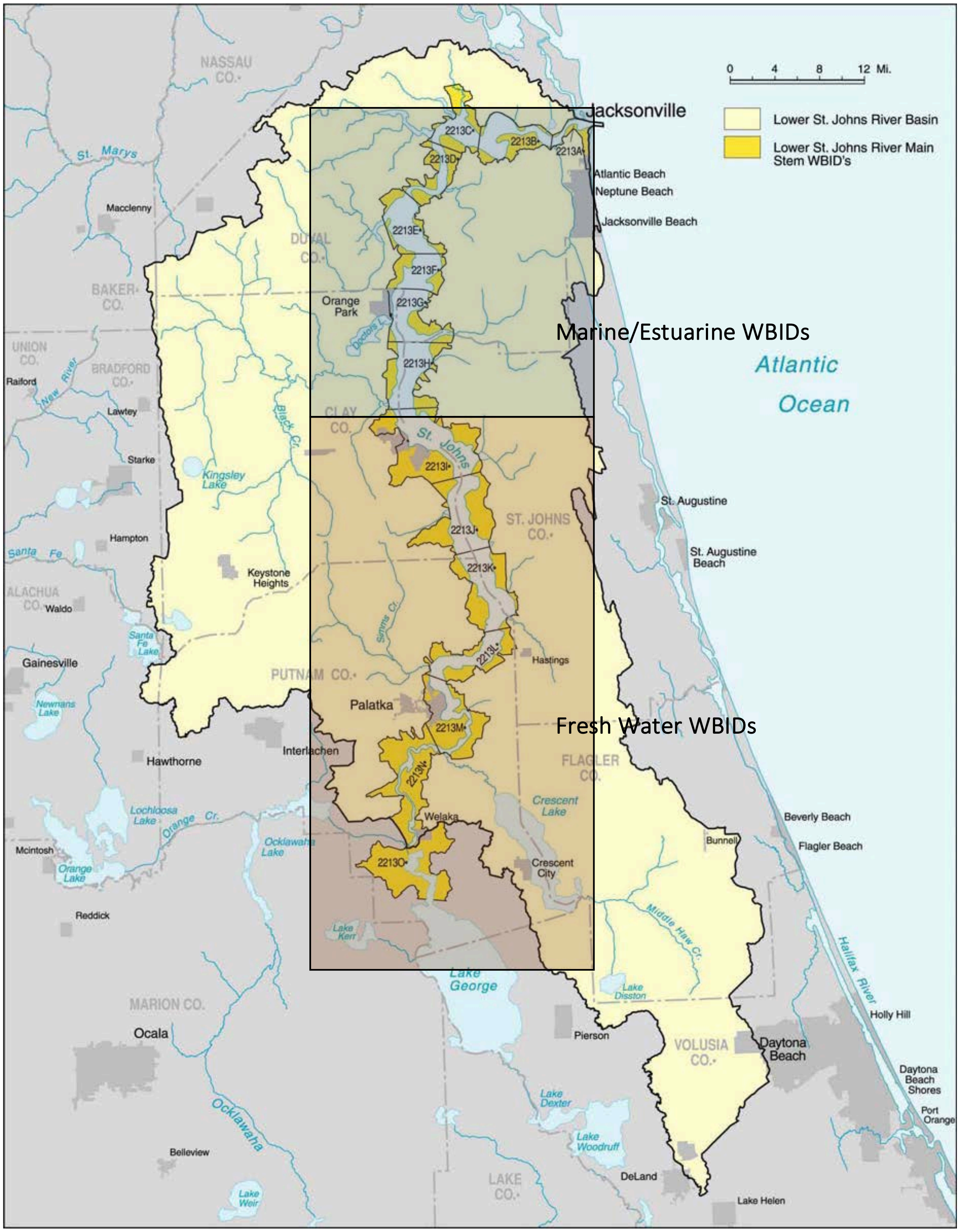


*Figure 2.1 Lower St. Johns River Mainstem Water Body Identification (WBID) Numbers (Figure 3, p. 5 in **Magley and Joyner 2008**) with designations of marine/estuarine areas (WBIDs A-H) and freshwater areas (WBIDs I-N) as used in this report.*

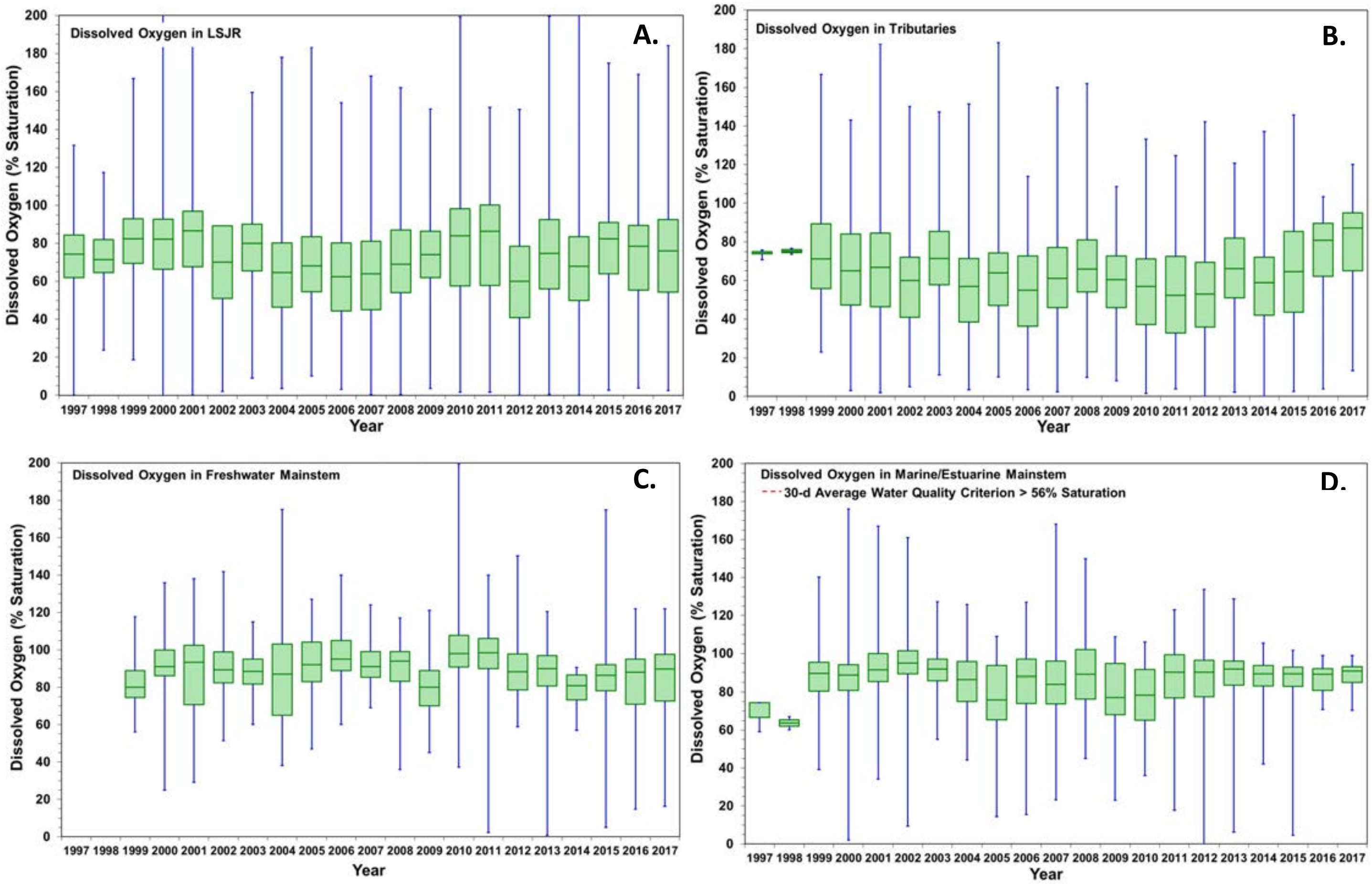


Figure 2.2 Yearly DO from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater portion of the LSJR mainstem, and D. the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating 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 water quality criterion in freshwater (>38% saturation) is equivalent to approximately 3.5 mg/L at 20°C and 2.9 mg/L at 30°C. The water quality criterion in marine/estuarine areas (>53% saturation) is equivalent to approximately 5.09 mg/L at 20°C and 4.28 mg/L at 30°C.

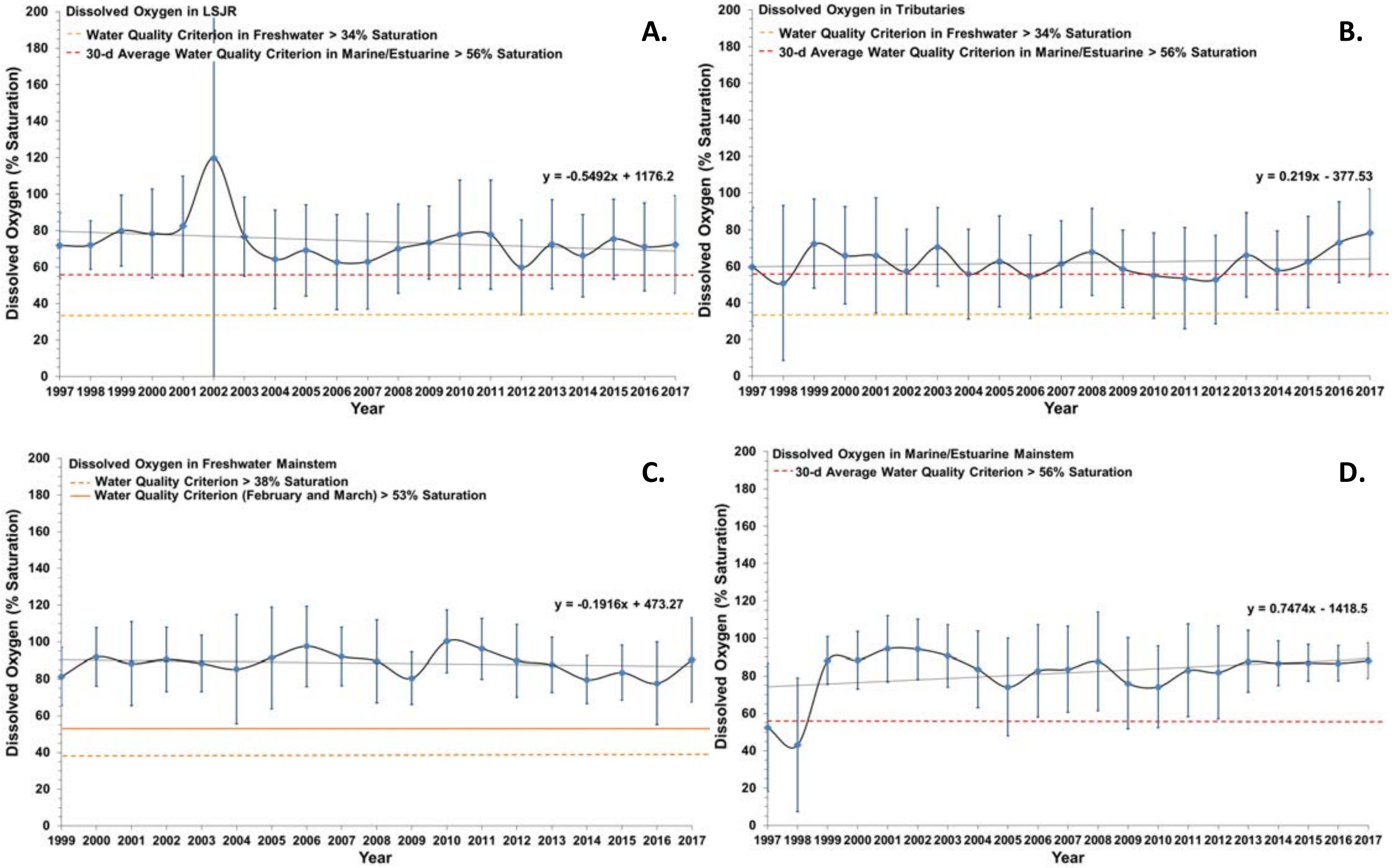


Figure 2.3 Yearly DO concentrations from 1997 to 2017 in the A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater portion of the LSJR mainstem, and D. the predominantly saltwater portion of the LSJR mainstem. Data are presented as mean ± standard deviation. The water quality criterion in freshwater (>38% saturation) is equivalent to approximately 3.5 mg/L at 20°C and 2.9 mg/L at 30°C. The water quality criterion in marine/estuarine areas (>53% saturation) is equivalent to approximately 5.09 mg/L at 20°C and 4.28 mg/L at 30°C.

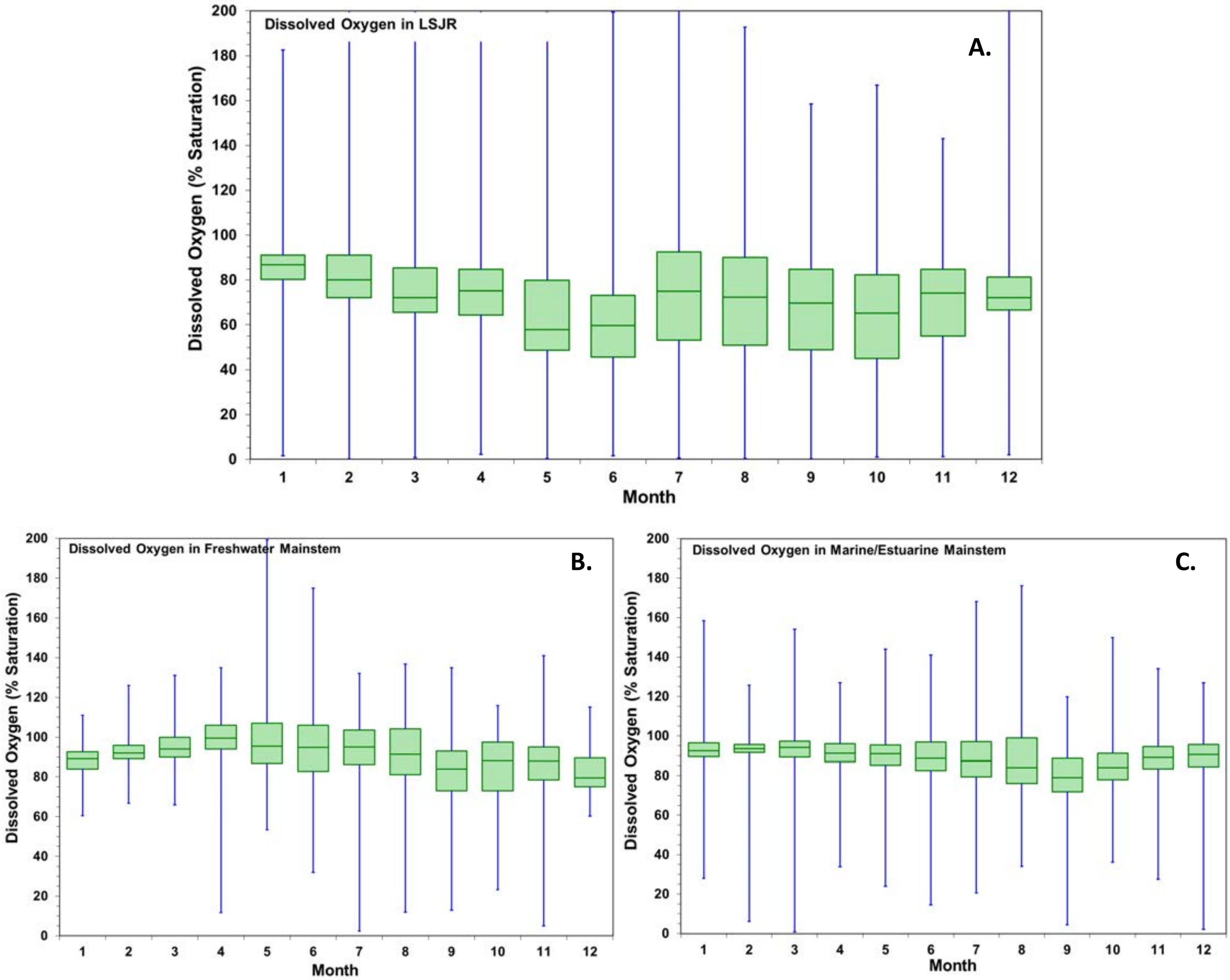


Figure 2.4 Monthly DO concentrations from 1997 to 2016 in A. the entire LSJR and its tributaries, B. the freshwater portion of the LSJR mainstem, and C. the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with green boxes indicating the median ± 25% (middle 50% of the data) and horizontal lines indicating the median values. Blue whiskers indicate the minimum and maximum values in the data set.

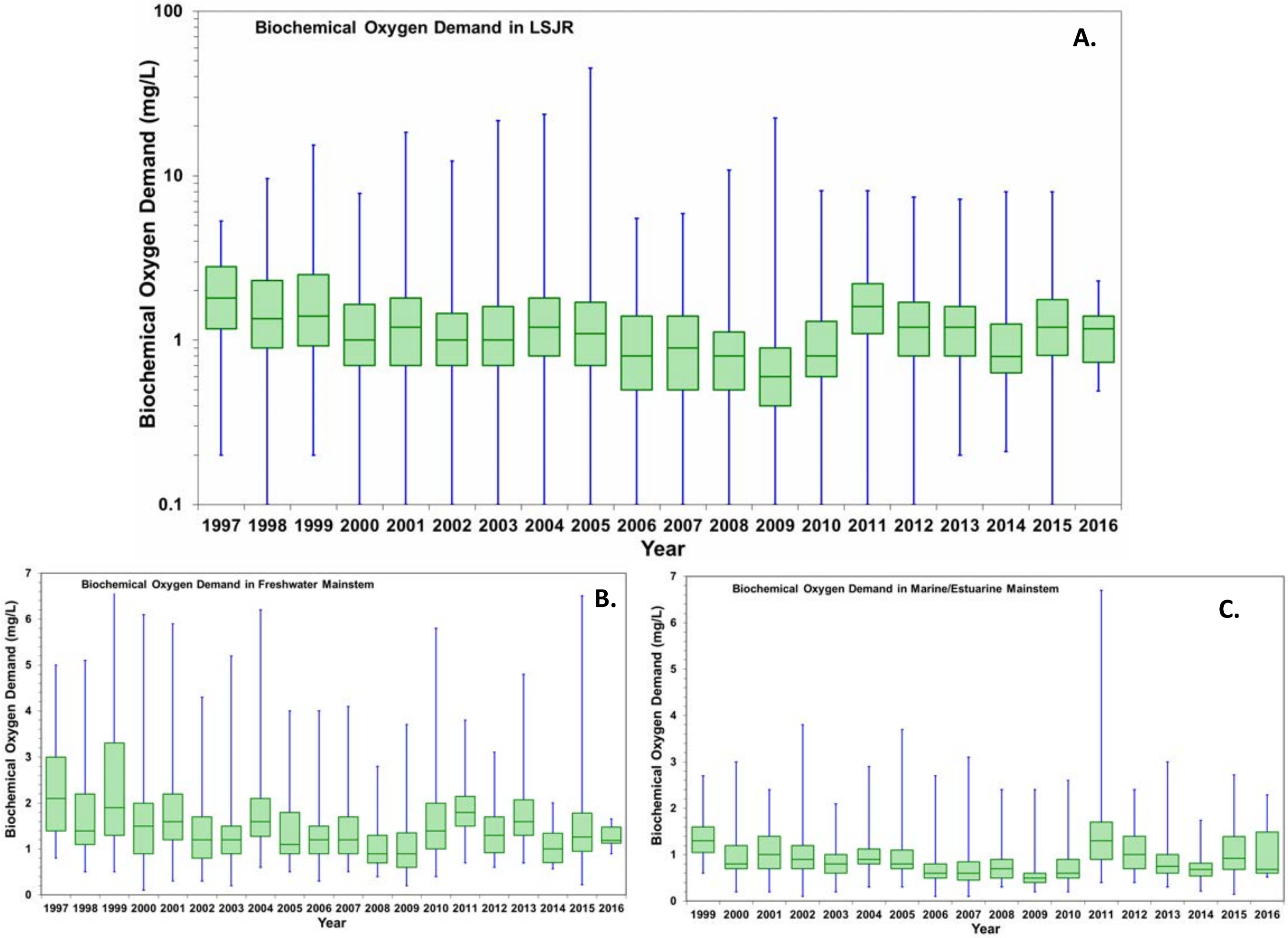


Figure 2.5 Yearly biochemical oxygen demand from 1997 to 2016 in A. the entire LSJR and its tributaries, B. the freshwater portion of the LSJR mainstem, and C. the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with green boxes indicating the median ± 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.

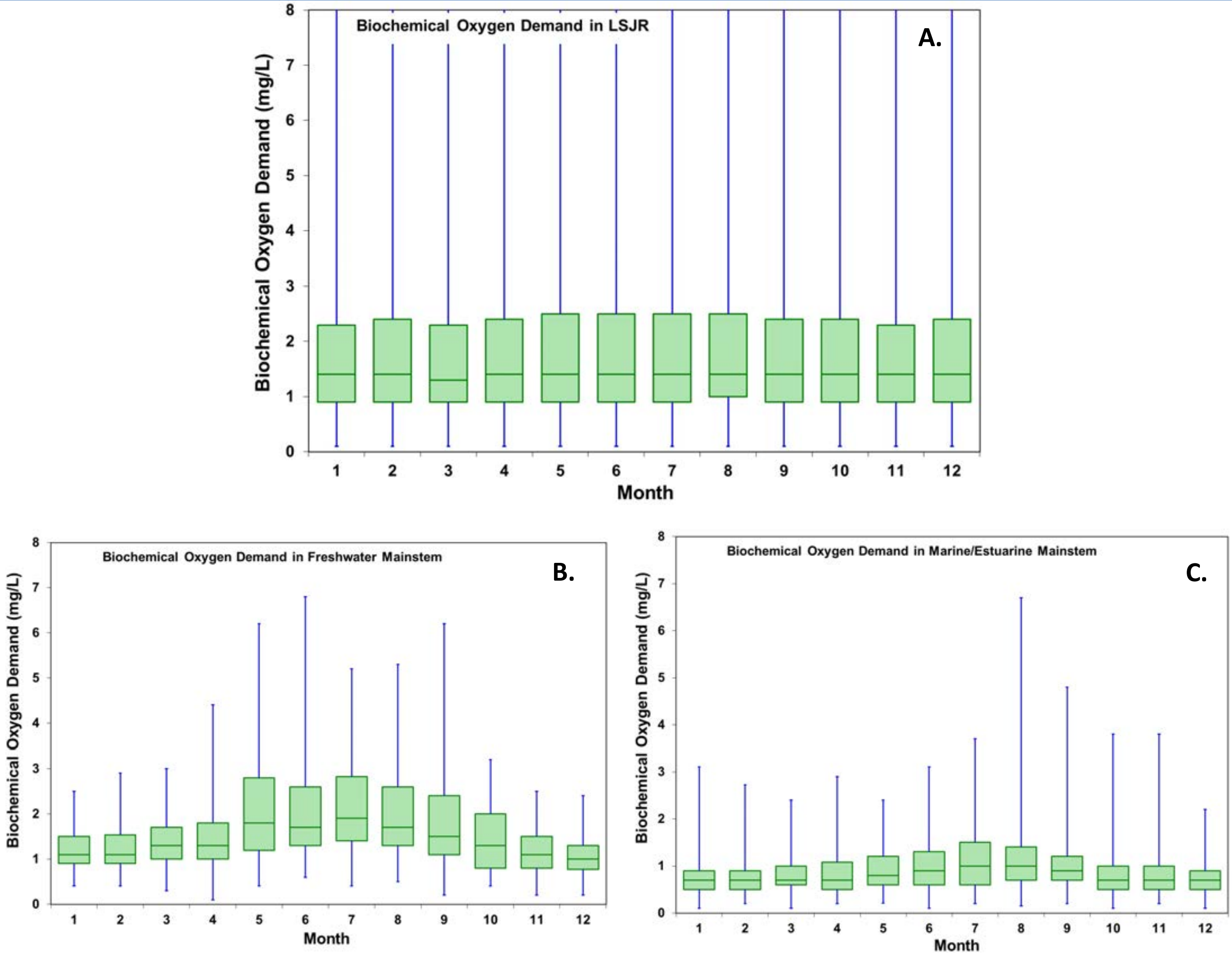


Figure 2.6 Monthly biochemical oxygen demand from 1997 to 2016 in A. the entire LSJR and its tributaries, B. the freshwater portion of the LSJR mainstem, and C. the predominantly saltwater portion of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating the 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

Phosphorus and nitrogen are important and required nutrients for terrestrial and aquatic plants, including algae. Under optimal conditions, nutrients can stimulate immediate algal growth. Alternatively, if absent, nutrients can limit algal abundance. If the nutrient concentrations in a system remain 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 can be a natural process, predominantly occurring in small, enclosed water bodies like ponds and lakes. However, anthropogenic (human-made) activities that increase the loading of nutrients into a waterway can greatly increase the level of eutrophication, even in rivers such as the LSJR and its tributaries.

2.3.1. Description and Significance: Nitrogen

Forms of nitrogen typically found in water bodies include nitrate, ammonia and organic nitrogen. These different forms convert to each other in organisms and in the environment (**Wright and Nebel 2008**). While the atmosphere contains 78% nitrogen gas by volume, this form of nitrogen is unreactive and unavailable to most organisms. An exception is "nitrogen-fixers." These bacteria take up nitrogen from the atmosphere and convert it to forms usable by other organisms. Nitrogen-fixers can add significantly to the overall nitrogen loading to a system.

Nitrate is one of the most bioavailable forms of nitrogen and can be rapidly taken up by plants. Sources of nitrate in waterbodies include atmospheric deposition, stormwater runoff containing fertilizer from agriculture and residential areas, runoff from animal operations, and treated sanitary wastewater. In particular, failing septic tanks contribute to nitrate contamination of shallow groundwater and surrounding water bodies (**Harrington et al. 2010**). Nitrite and nitrate are converted from one to the other by microbes, depending on the availability of oxygen and the pH of the environment. Under typical environmental conditions nitrite concentrations are very low compared to nitrate. Generally, both nitrate and nitrite are measured together, and the values reported as nitrate plus nitrite.

Ammonia is also taken up by phytoplankton (**Dortch 1990**) and is often converted to nitrate under the correct conditions. It 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**). Organic nitrogen such as proteins and urea, can decompose to ammonia (**Hutchinson 1944; Wetzel 2001**).

Total ammonia consists of two forms: un-ionized ammonia (NH_3) and ammonium ion (NH_4^+). They interconvert depending on environmental pH, temperature and salinity. High pH, high temperature and low salinity promote formation of the more toxic form, un-ionized ammonia. It is more toxic to aquatic organisms because of its ability to cross biological membranes.

Other human sources of nitrogen compounds primarily include industrial fixation in the manufacturing of fertilizers, and the combustion of fossil fuels which liberates nitrogen oxides into the atmosphere. The form of nitrogen that enters a waterway can give an indication of its source. However, as noted above, 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 acid-base reactions and complexation; biotic processes include nitrification, denitrification, and nitrogen fixation. Sediments may act also as a major reservoir of nitrogen, just as they do for phosphorus (**Levine and Schindler 1992**).

Unbalanced total nitrogen levels in a system can have severe impacts on the distribution of phytoplankton and the zooplankton that eat it. Excess nitrogen can markedly increase some types of phytoplankton. Nitrogen-fixers, such as some cyanobacteria, thrive in low-nitrogen conditions because they can convert inert atmospheric nitrogen to reactive nitrogen, which allows them to grow rapidly and outcompete other species (**Smith 1983**).

2.3.2. Description and Significance: Phosphorus

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 mobile particulate material; however, in the lakes and slower flowing freshwater parts of the river, phosphorus settles in sediments (**Brenner et al. 2001**). Many factors, such as wind, turbulence, DO, water hardness and alkalinity, sulfide concentration, salinity, and benthic (bottom-dwelling) organisms may potentially re-mobilize phosphorus into the water column (**Boström et al. 1982; Boström et al. 1988; Lamers et al. 1998; Wetzel 1999; Smolders et al. 2006**). When reaching the mouth of the river, sulfur may release 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 reduce 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 central 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 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, plus effluents from municipal wastewater treatment plants and other point sources may contribute to eutrophic conditions in the LSJR.

2.3.3. *Management of Nutrients*

Nutrient excesses in the LSJR have led to algal overabundance and low dissolved oxygen levels throughout the river. To address the problems, a final TMDL report was drafted in 2008 by the DEP to reduce nutrient inputs into the LSJR so that algal blooms are reduced in the freshwater regions and healthy levels of dissolved oxygen are maintained in the marine portions of the river. A TMDL is a scientific determination of the maximum amount of a given pollutant (i.e. nutrients) that a surface water body can assimilate 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 how much nutrients need to be reduced to meet water quality standards in the LSJR. Subsequent Basin Management Action Plans establish restoration strategies required to achieve the water quality standards. 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 when nontoxic. This practice has been utilized in Clay County, within the LSJRB, as well as other areas of the U.S., mostly for irrigation of urban open spaces like parks, residential lawns and golf courses. A similar practice has been used in agriculture. Wastewater treatment improvements have been implemented in Palatka, Orange Park, Neptune Beach, Jacksonville Beach, Atlantic Beach, St. Johns County, and Jacksonville.

Local utilities and government agencies have worked to reduce nutrient discharges since 2000 including a large public outreach campaign 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 can meet this goal.

In August 2013, the FDEP and the Division of Environmental Assessment and Restoration reported to the Governor and Florida legislature on the status of efforts to establish numeric nutrient standards from narrative criteria (**DEP 2013h**). In August 2013, the FDEP also submitted a plan to EPA to implement numeric nutrient standards in Florida's waters. The FDEP discussed how it developed numeric interpretations of existing State narrative criteria (**DEP 2013d**).

In this document, the site-specific numeric standards for the marine/estuarine areas of the LSJR, including marine tributaries, were expressed as TMDL loading per year, 1,376,855 kg TN/year and 412,720 kg TP/year. The numeric interpretation for chlorophyll-a is that the long-term annual averages will not exceed 5.4 μg/L. The site-specific criteria for the freshwater portion of the LSJR mainstem is 40 μg chlorophyll-a/L, not to be exceeded more than 10% of the time. For streams without site-specific interpretations required by TMDL stipulations, numeric thresholds and biological benchmarks were developed to assess nutrient status. The nutrient thresholds for peninsular Florida, based on analysis of reference streams, were 0.12 mg TP/L and 1.54 mg TN/L. These values are not to be exceeded more than once in a three-year period and are based on annual geometric means. Annual geometric means are similar to medians in that outliers (i.e., extremely high or extremely low values) influence the result less than they influence arithmetic means. Extensive biological assessment accompanies the numeric thresholds.

Progress towards meeting the TMDL goals for the LSJR mainstem has been reviewed in the 2013 LSJR Mainstem Basin Management Action Plan progress report (**DEP 2014a**) and most recently in the River Accord Status Report. In late 2014, the FDEP Environmental Regulation Commission approved slightly different numeric criteria for the LSJR (**DEP 2015b**).

2.3.4. *Data Analysis*

Because of the variability in the characteristics of the river extending from the mouth to the freshwater lakes, it is useful to examine the differences in nutrient profiles in different river regions. The section we refer to as the marine/estuarine reach

spans from the mouth at WBID 2213A to WBID 2213H which contains Doctors Lake (Figure 2.1). The section we refer to as the freshwater region extends from WBID 2213I upstream to WBID 2213N at the confluence of the Ocklawaha River.

The nutrients assessed include total nitrogen (TN), total phosphorus (TP), nitrate plus nitrite (NO_3-NO_2), ammonia, and orthophosphate (OP). The TN and TP parameters reflect total loading of nutrients into the system including different forms that are readily transformed and those that decay slowly. The sums of the dissolved and particle-bound forms are included in the TN and TP assessments. Orthophosphate, nitrate-nitrite, and ammonia are inorganic nutrients that are considered reactive because they can be taken up rapidly by biota and readily undergo chemical reactions in the environment. Chlorophyll-a is an indirect measure of biological responses to nutrient enrichment and is included in some discussions below. More detail about chlorophyll-a and its relationship to phytoplankton growth is provided in the following section on harmful algal blooms.

In this report, the numeric standards for nutrients in peninsular Florida (0.12 mg TP/L and 1.54 mg TN/L; DEP 2013d), described above in Section 2.3.3, are compared to LSJR data to generally assess the status of the LSJR. However, the water body is not regulated under those standards; numeric criteria consist of total nutrient loading rates (1,376,855 kg TN/year and 412,720 kg TP/year) that cannot be compared to actual water concentrations.

Additionally, while nitrate is regulated for springs and drinking water, neither application is appropriate for the LSJR. There is no Florida orthophosphate criterion.

In the following analyses, the current status and time trends of the four nutrients are examined in different ways. Data are displayed in annual box and whisker plots, which show the distribution of the high and low concentrations each year. These plots 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. Data are also displayed as annual means ± standard deviations. In these graphs, the peninsular Florida numeric nutrient thresholds for streams, described above, are overlaid on the charts as a general reference point to assess the status of the LSJR.

Trends over time in annual average concentrations are identified by using the Spearman Rank 1-tailed test at $p < 0.05$.

All data were obtained from the FDEP STORET. STORET is a statewide computerized environmental data system containing water quality, biological, and physical data. EPA methods 365.4 and 365.1 were used to measure total phosphorus in surface waters. Total Kjeldahl nitrogen (organic nitrogen plus ammonia), total ammonia, and nitrate plus nitrite were measured using EPA methods 351.2, 350.1 or 4500-G, and 353.2, respectively. Total nitrogen was represented by the sum of the Kjeldahl nitrogen and nitrate-nitrites in each sample. No new data beyond February 2016 was available from the FDEP STORET database for total nitrogen, because, that parameter is longer directly inputted. Therefore, TN was not updated in this year's report. Data for the entire LSJRB and tributaries were collected from FDEP STORET and culled for applicability to this study. Data were reviewed for quality and data points were discarded when samples appeared analytically compromised (contaminated blanks, poor recovery, poor replication, etc.) or were missing important information. Records with no analytical procedure listed were also removed. Negative values were removed. Values designated as present below the quantitation limit (QL) were replaced with the "actual value" if provided, or replaced with the average of the method detection limit (MDL) and practical quantitation limit (PQL) if the "actual value" was not provided. For "non-detect" values, half the MDL was used; and, for values designated as "zero" the MDL was used. All samples with qualifier codes K, L, O, Q, or Y, which indicate different data quality issues, were eliminated. Data designated with a matrix of "ground water," "surface water sediment," "stormwater," or "unknown" were removed.

2.3.5. *General Characteristics*

Nutrient profiles vary with the region of the river and depend on proximity to the mouth, rainfall, local sources, and upstream and tributary sources, as well as biological activity (Figure 2.7). The dilution of river water with lower-nutrient ocean water is evident for most nutrients because annual average concentrations sharply decrease as the river reaches the mouth in WBIDs 2213A-2213C. In most years, both forms of phosphorus and nitrate-nitrite concentrations increase as the fresh water moves downstream to estuarine areas, where it becomes diluted by ocean water. By contrast, TN gradually decreases as the river moves from freshwater to estuarine conditions (Figure 2.7). As a consequence of the different ratios

of nitrogen to phosphorus, the downstream, saltier section is generally more susceptible to nitrogen pollution, and the upstream, more riverine section is more susceptible to phosphorus pollution.

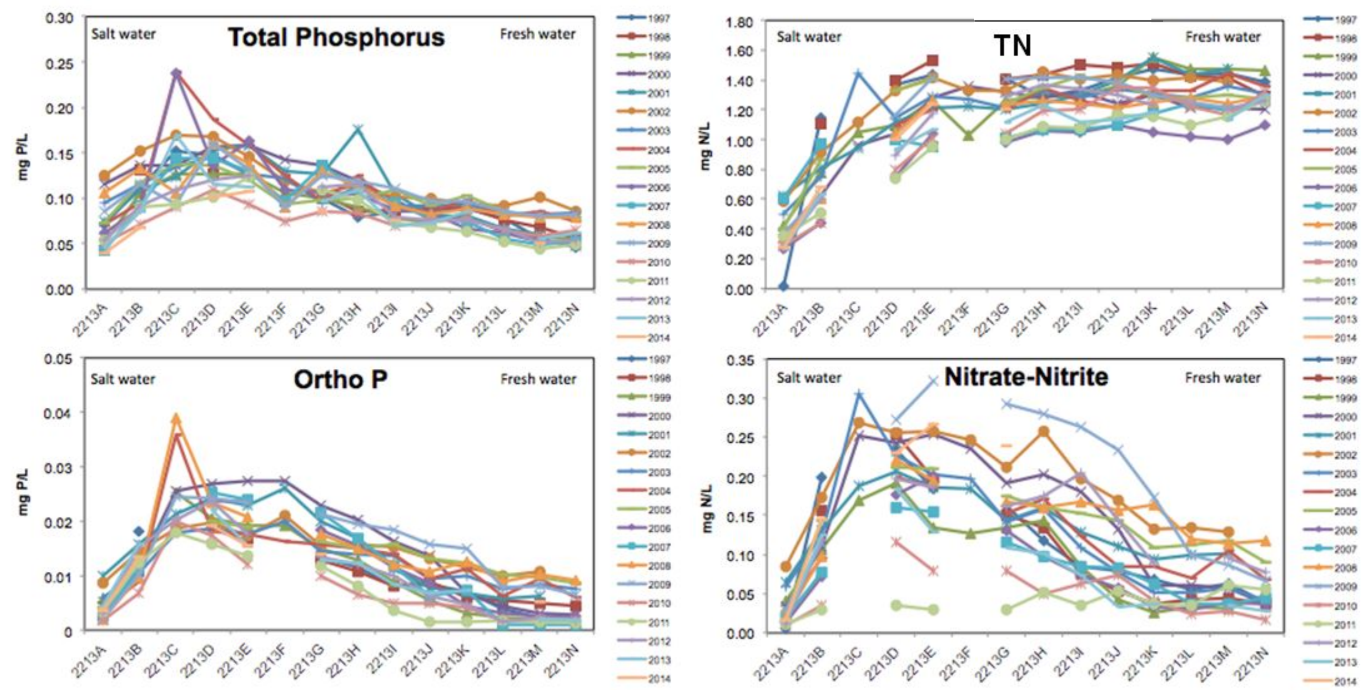


Figure 2.7 Annual averages of nutrients in the LSJR by WBID. WBIDs 2213A-H are marine/estuarine waters and WBIDs I-N are freshwater.

2.3.6. *Current Status and Trends: Total Nitrogen*

Figure 2.8 shows the median, minimum, and maximum concentrations of TN measured in the LSJR. Yearly mean TN concentrations in the LSJR are compared to the water quality reference concentration of 1.54 mg N/L (used only for the purpose of this report) in Figure 2.9. The yearly mean TN concentrations have gradually declined in both freshwater and marine/estuarine sections of the river since 1997; however, elevated TN levels were observed in 2015 and 2016 in the marine/estuarine section of the LSJR (Figure 2.9). Beginning in 2017, TN was no longer inputted into the FDEP STORET database. This parameter could be calculated in the future by addition of the various nitrogen species; however, the graphs could not be updated in this year's report. Yearly mean TN concentrations in the entire LSJR have been below the water quality reference concentration of 1.54 mg N/L since 1997; however, TN concentrations are not equally distributed in the LSJR and some areas have higher TN than others (Figures 2.8 and 2.9). The maximum values in the LSJR, particularly due to values reported in the tributaries and in saltwater areas of the mainstem, have continued to be above the TN reference value (Figure 2.8). Reductions in nitrogen loading are likely to be the primary reason for the observed decline of TN in the LSJR (**DEP 2013a**).

Relatively elevated levels of nitrogen have been frequently observed in several tributaries (see below); as well as specific locations in the mainstem 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.

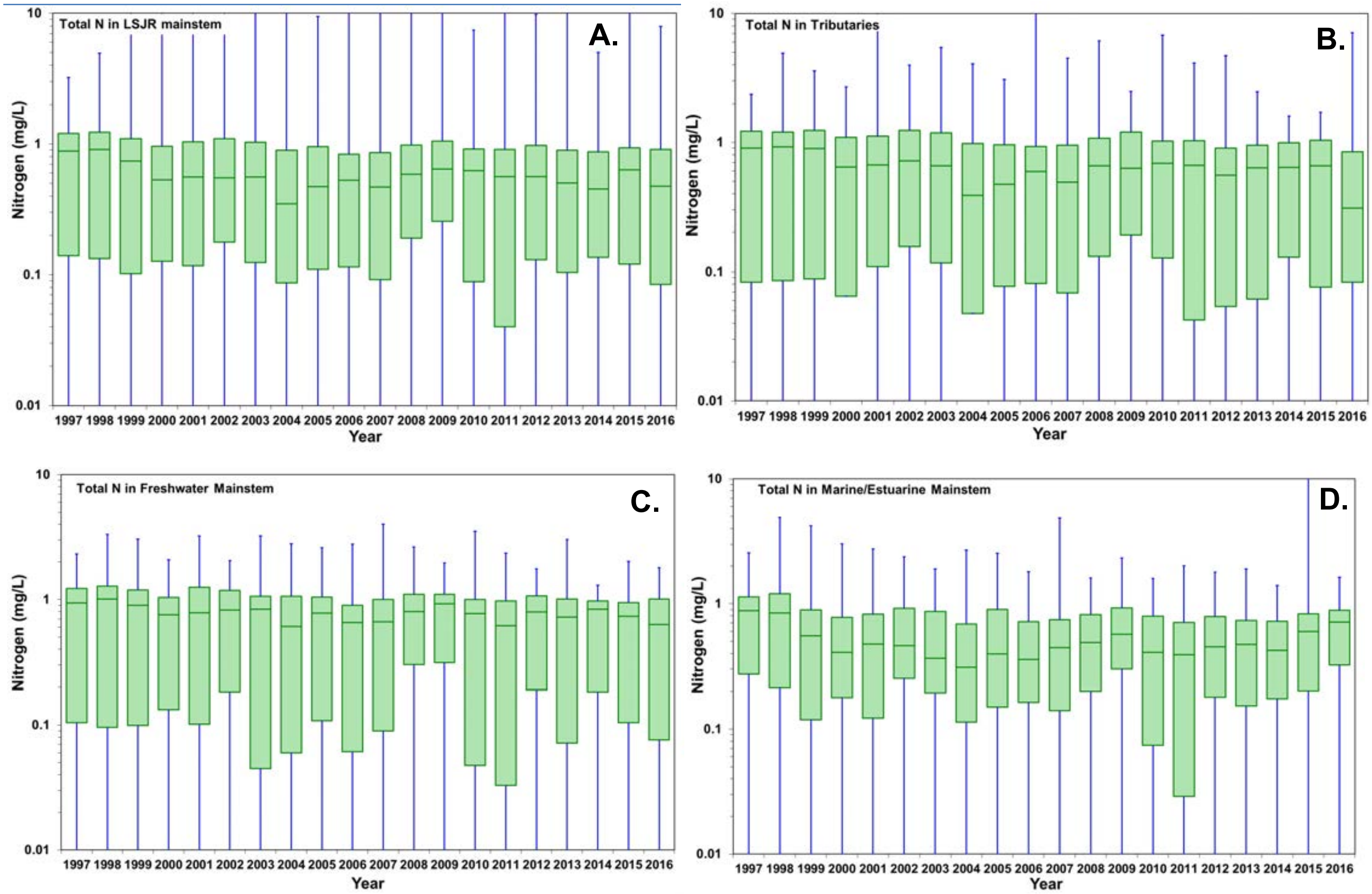


Figure 2.8 Yearly total nitrogen concentrations from 1997 to 2016 in the A. LSJR and its tributaries, B. the tributaries of the LSJR, C. the predominantly freshwater portion of the LSJR mainstem, and D. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

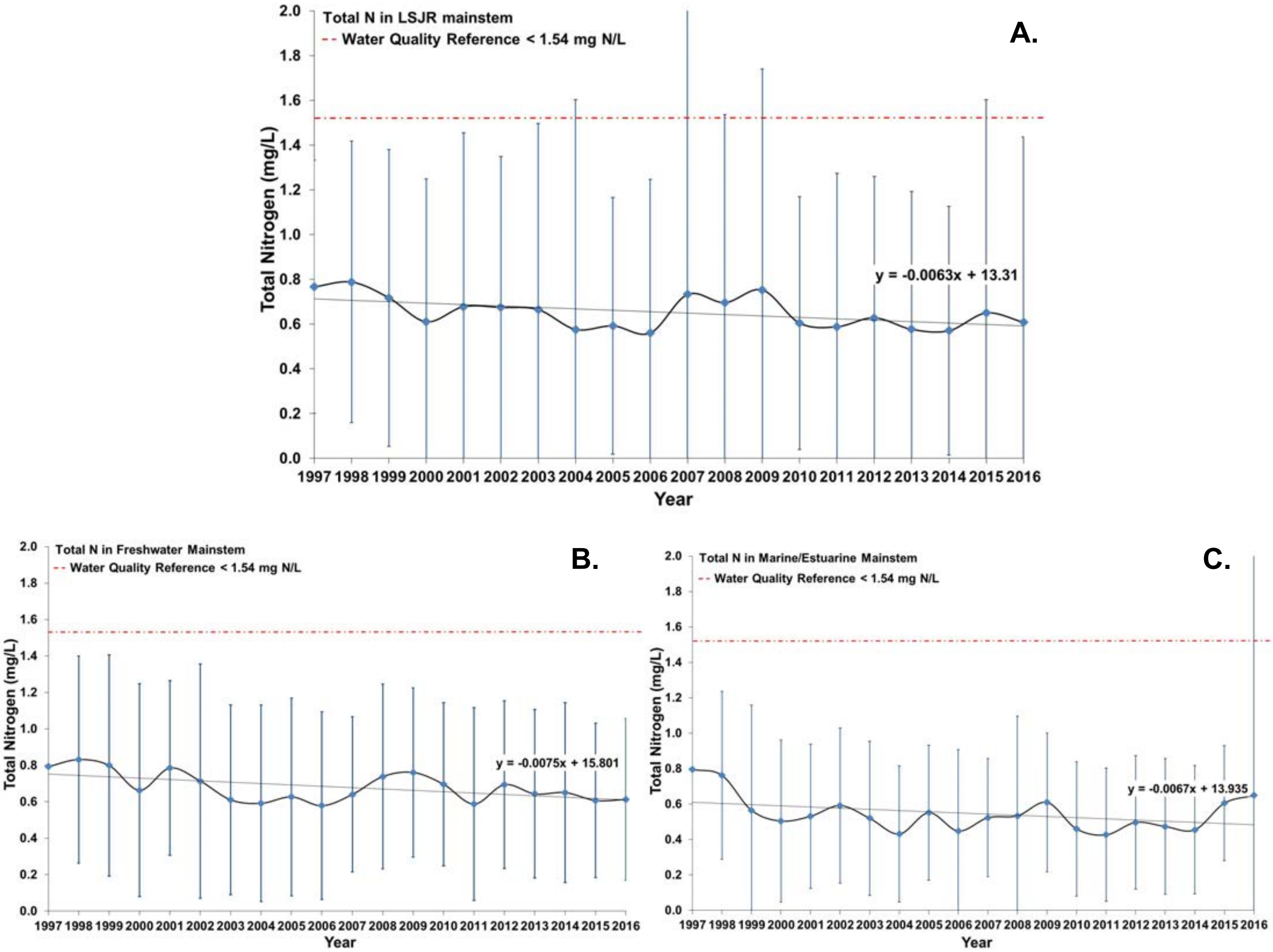


Figure 2.9 Yearly total nitrogen concentrations from 1997 to 2016 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean values ± standard deviations.

2.3.7. *Current Status and Trends: Total Phosphorus*

The median, minimum, and maximum TP concentrations in the LSJR are presented in Figure 2.10. The annual mean TP concentrations are presented in Figure 2.11. Annual mean values have been below the TP reference concentration of 0.12 mg P/L (used only for the purpose of this report) since 1997 in the mainstem (Figure 2.11B, C); with a decrease in mean TP values, since 2010 in the marine/estuarine section of the mainstem (Figure 2.11C). Mean TP values in the entire LSJR, particularly the tributaries, have fluctuated around the reference value, and maximum reported values in the tributaries have been above the reference TP value (Figures 2.10, 2.11).

Slight seasonal increases in TP concentration in the LSJR are generally observed in summer months particularly in the marine/estuarine portion of the mainstem (Figure 2.12). Fertilizers containing phosphorus are used on crops primarily during the winter; however, increased stormwater runoff during the summer adds phosphorus from soil, resulting in TP inputs into the LSJR several times throughout the year.

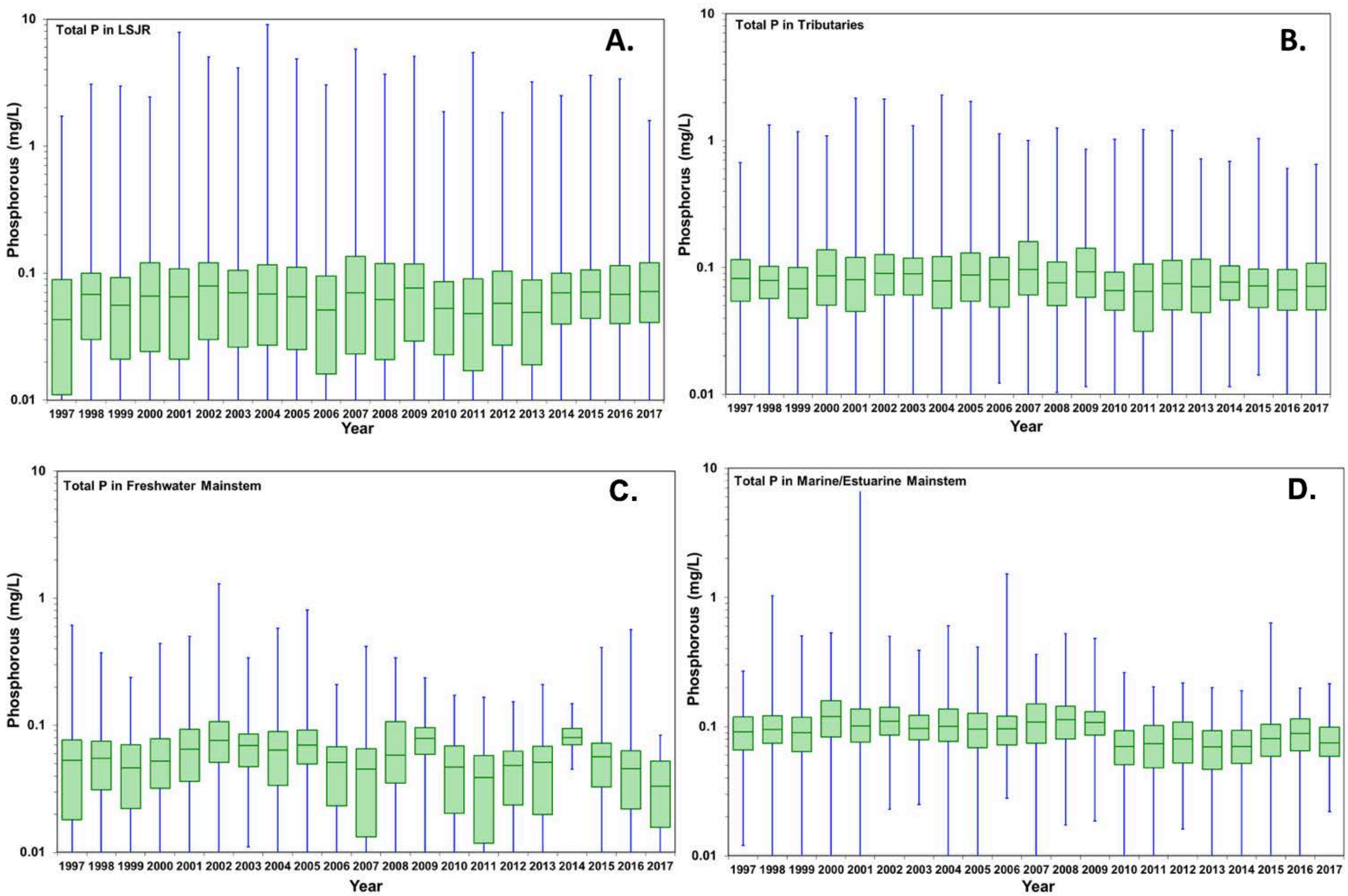


Figure 2.10 Yearly total phosphorus concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the tributaries of the LSJR, C. the predominantly freshwater portion of the LSJR mainstem, and D. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as 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. Note the log scale.

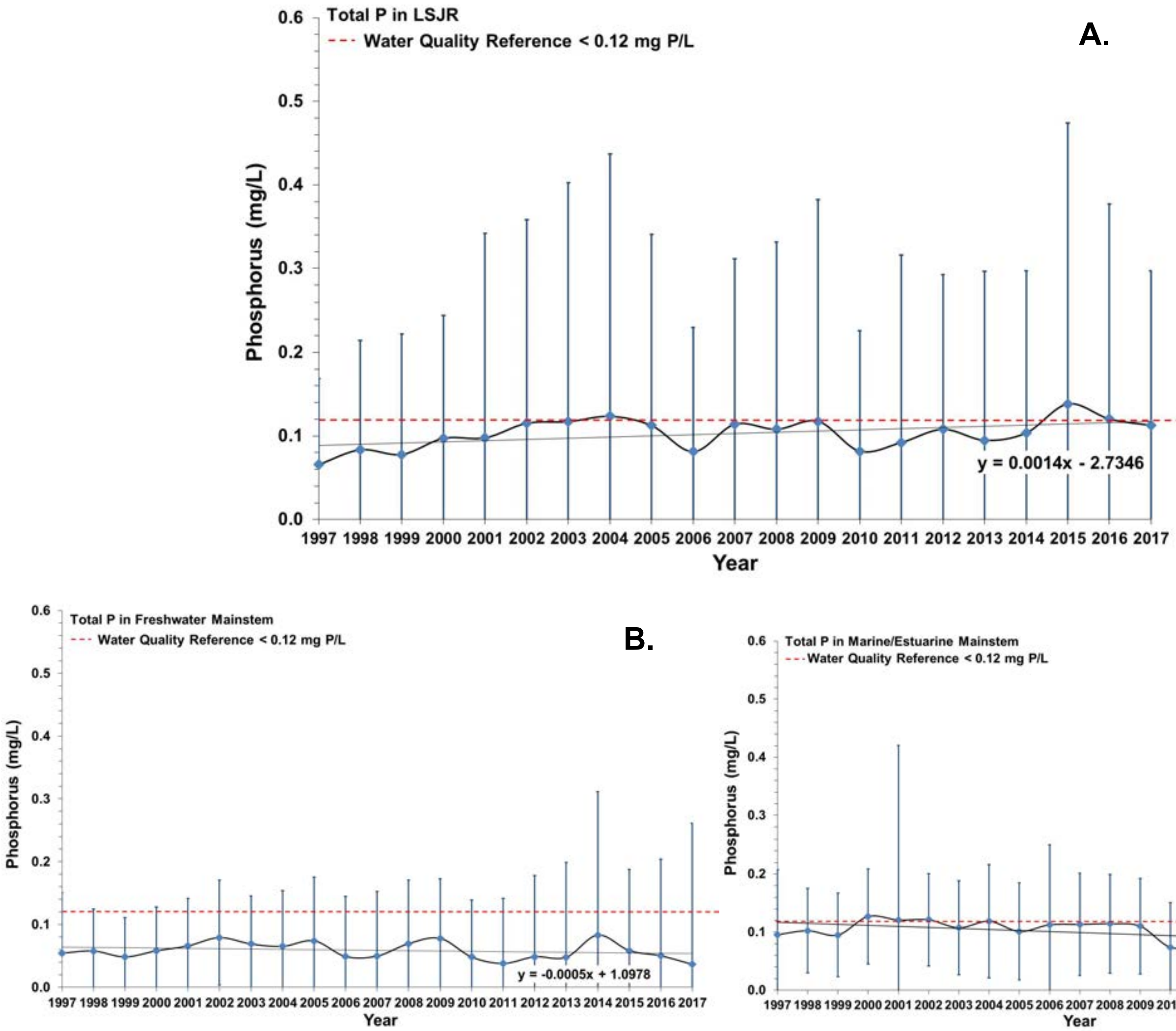


Figure 2.11 Yearly total phosphorus concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean values ± standard deviations.

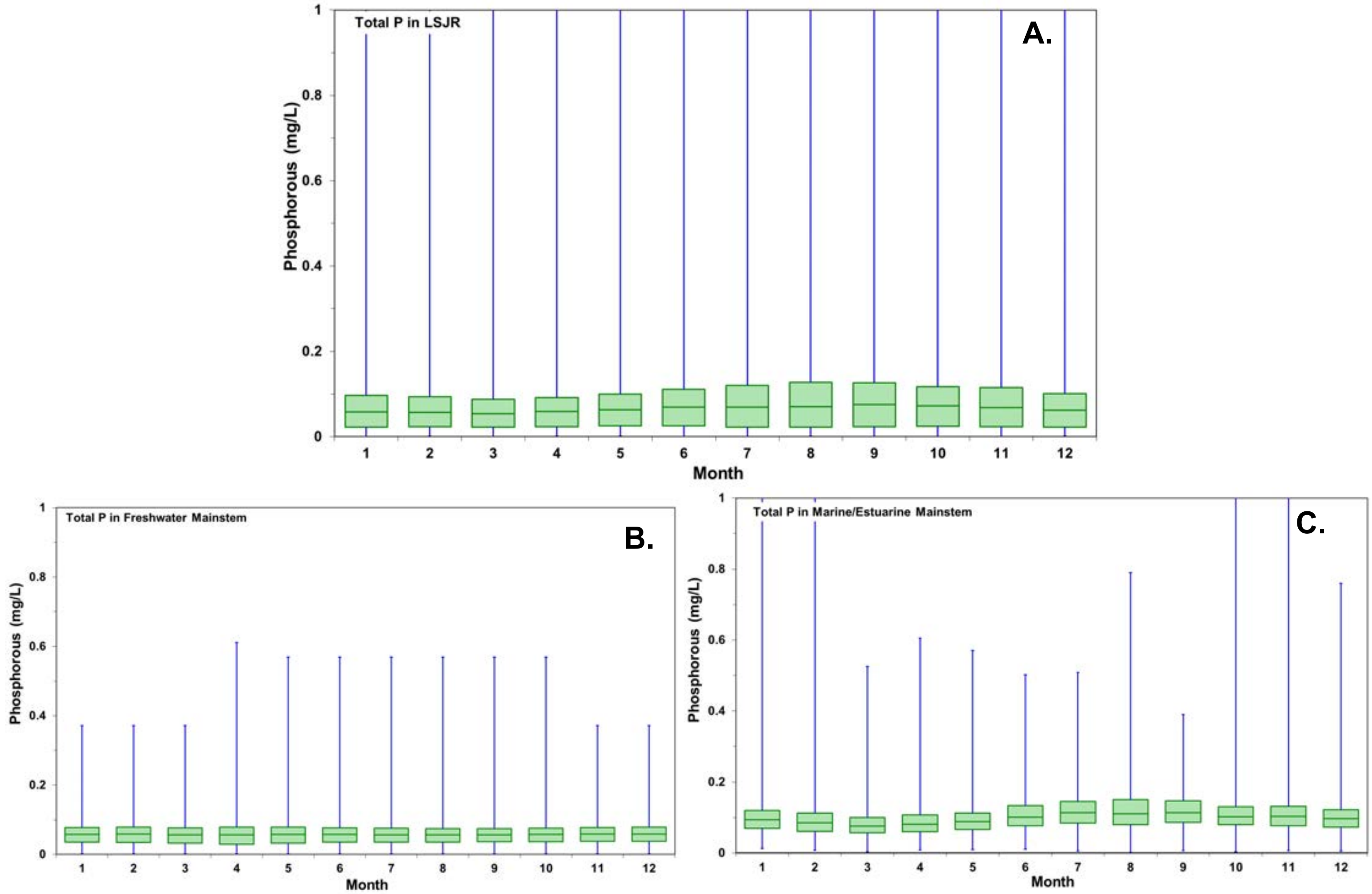


Figure 2.12 Monthly total phosphorus concentrations from 1997 to 2016 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the 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.

2.3.8. Current Status and Trends: Nitrate, Ammonia and Phosphate

The reactive inorganic nutrients ammonia, nitrate-nitrite, and orthophosphate are readily taken up by various organisms and released back into the environment. Concentrations of the nutrients vary widely with environmental conditions such as rainfall and phytoplankton growth. Median ammonia concentrations have been slightly reduced since 2014 in both the freshwater and marine/estuarine portions of the LSJR mainstem, and to some extent the entire LSJR (Figure 2.13). The median nitrate-nitrite concentrations in the LSJR have remained stable in the entire LSJR (Figure 2.14); however, since 2014, the median nitrate-nitrite concentration in the mainstem (particularly marine/estuarine) has significantly decreased (Figure 2.14). There is also a seasonal trend in the levels of nitrate-nitrite, with the highest concentrations occurring in the winter (Figure 2.15). This may be the result of limited uptake of nitrate for phytoplankton growth in winter months. Orthophosphate tends to be higher in the marine/estuarine section than in the freshwater section (Figure 2.16). The median orthophosphate concentration in the marine/estuarine sections in 2017 was over two times higher than the median in the freshwater regions of the river (Figure 2.16). Reactive inorganic nutrients were variable over time; however, some trends were evident (Figure 2.17). There was a downward trend in the mean nitrate-nitrite and in orthophosphate concentrations in the marine/estuarine sections of the LSJR; with concentrations in the freshwater areas of the mainstem remaining more stable (Figure 2.17). Alternatively, an increase in mean ammonia concentrations in the marine/estuarine sections of the mainstem and slight increases in the freshwater sections of the mainstem were observed (Figure 2.17). An interesting feature of the time series is the lower concentrations in 2010-2011 corresponding to times of intense algal blooms. Significant phytoplankton growth and die-off contribute to the fluctuations as nutrients are consumed and released.

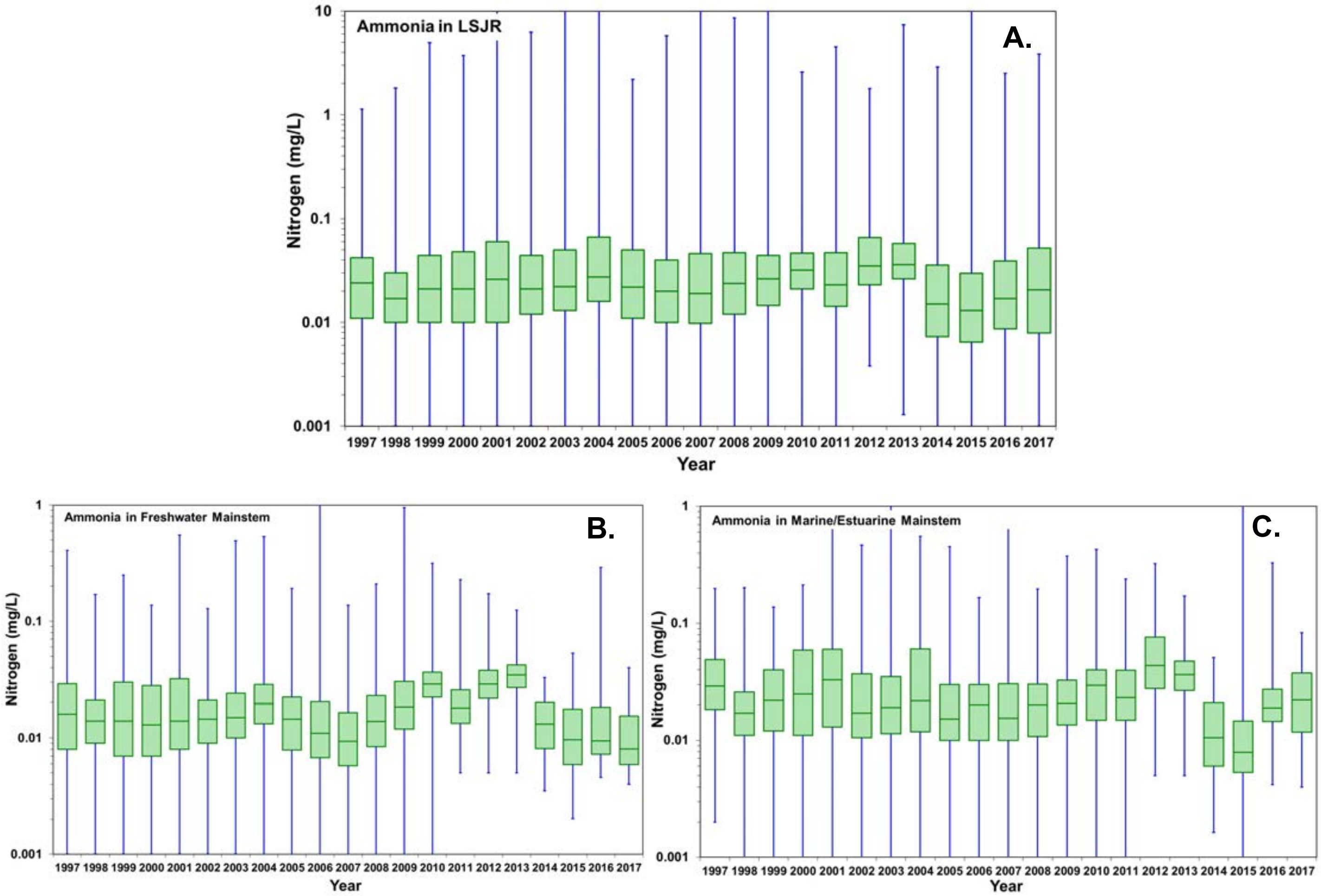


Figure 2.13 Yearly ammonia concentrations from 1997 to 2017 in the A. LSJR and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating 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.

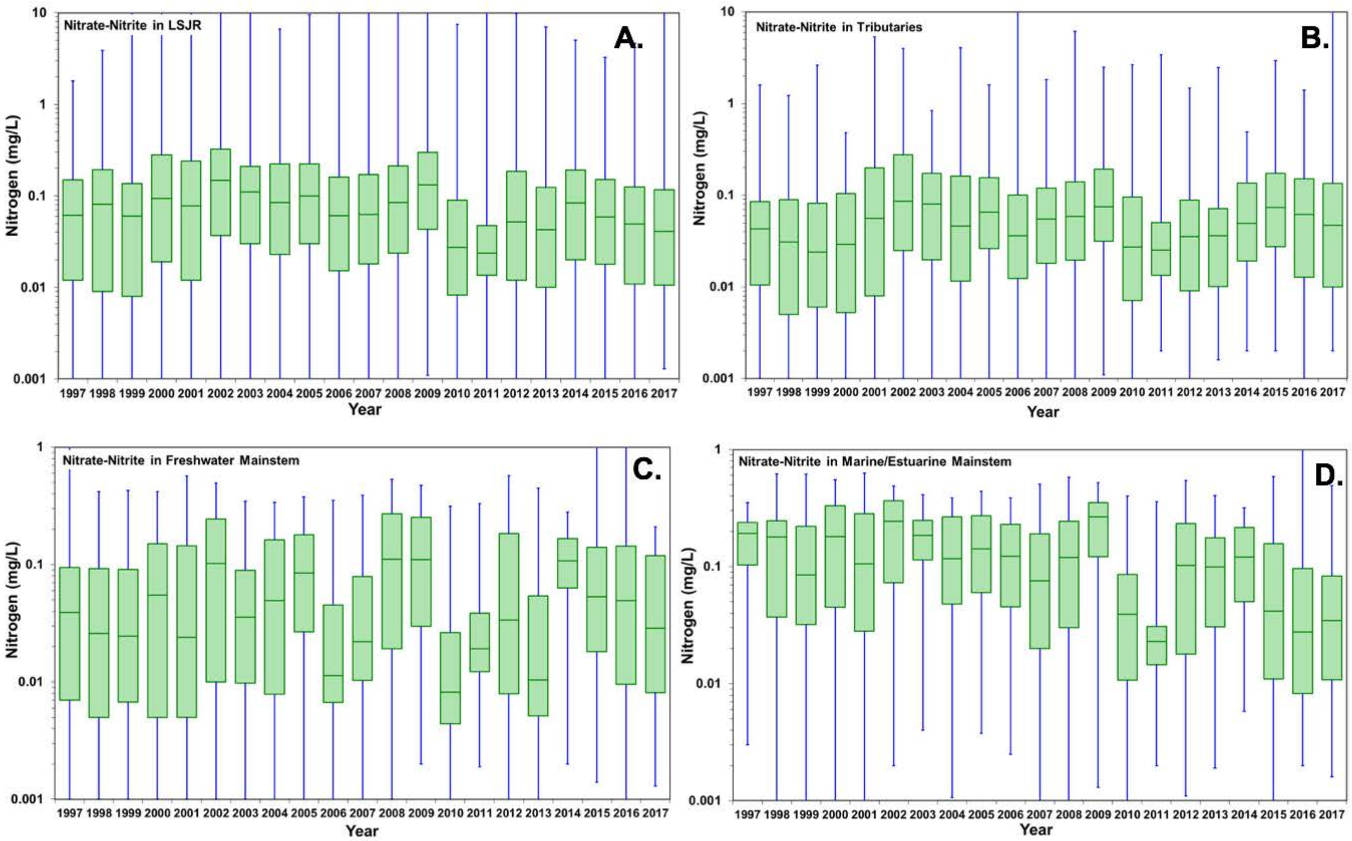


Figure 2.14 Yearly nitrate-nitrite concentrations from 1997 to 2017 in the A. LSJR and its tributaries, B. the tributaries of the LSJR, C. the predominantly freshwater portion of the LSJR mainstem, and D. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as a box-and-whiskers 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. Note the log scale.

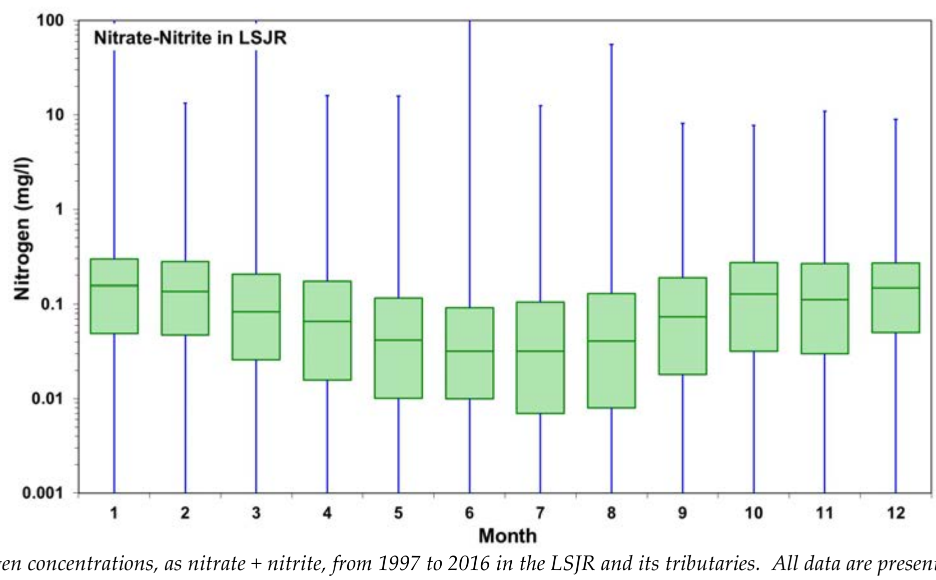


Figure 2.15 Monthly nitrogen concentrations, as nitrate + nitrite, from 1997 to 2016 in the LSJR and its tributaries. All data are presented as a box-and-whiskers plot with the green boxes indicating the median ± 25% (middle 50% of the data) and horizontal lines indicate the median values. Blue whiskers indicate the minimum and maximum values in the data set.

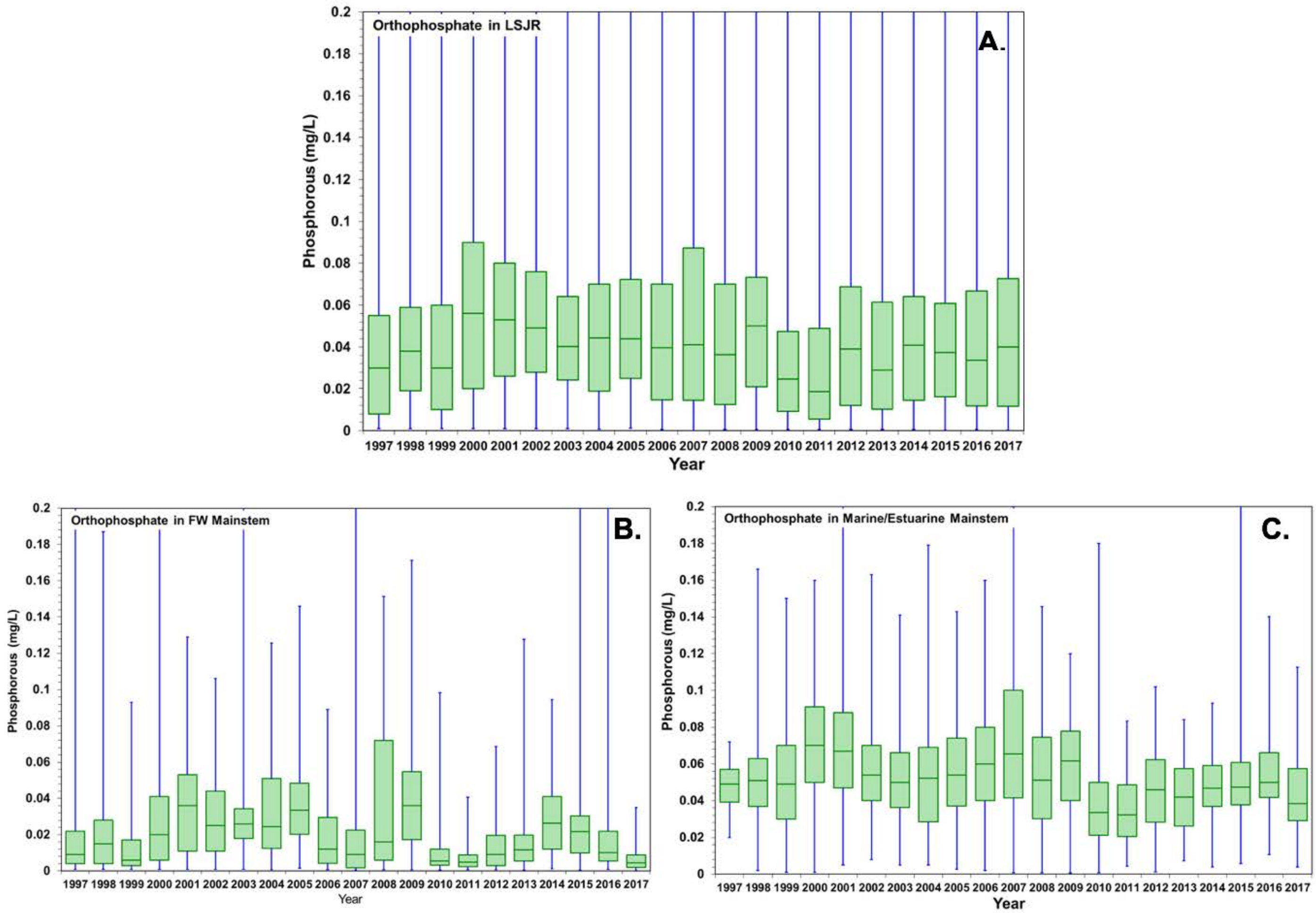


Figure 2.16 Yearly orthophosphate concentrations from 1997 to 2017 in the A. LSJR mainstem, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as a box-and-whiskers plot with the green boxes indicating 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.

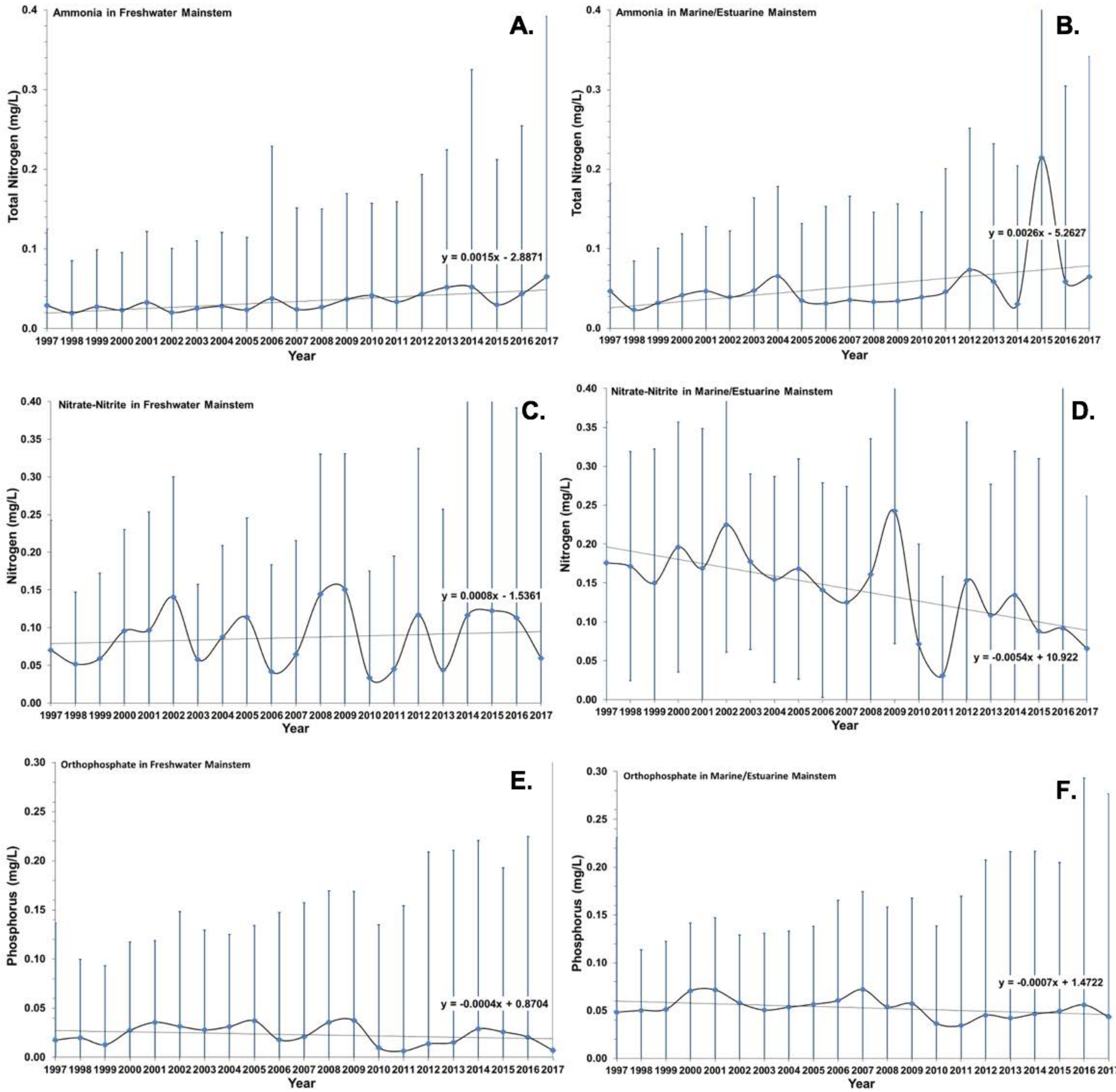


Figure 2.17 Yearly ammonia (A. and B.), nitrate-nitrite (C. and D.), and orthophosphate (E. and F.) concentrations in the freshwater section (A., C. and E.) and marine/estuarine reach (B., D., and F.) of the LSJR mainstem. Data are presented as mean values ± standard deviations.

2.3.9. *Summary and Outlook*

The annual mean TN concentrations have declined through 2016 in the mainstem; however, maximum values in the LSJR, particularly due to values reported in the tributaries, have continued to be above the TN reference value. Reductions in nitrogen loading are likely to be the primary reason for the observed decline of TN in the LSJR (**DEP 2013c**). Increased values of nitrogen, as ammonia and decreased values of nitrogen, as nitrate and nitrite, and have been observed over recent years, particularly in marine/estuarine areas. The reactive inorganic nutrients, nitrate and orthophosphate, are generally higher in the marine/estuarine section than in the freshwater section of the LSJR mainstem; however, like nitrate, mean orthophosphate concentrations have also been decreasing slightly over time.

Mean and maximum TP concentrations are below the reference value in the LSJR mainstem; however, maximum TP in the tributaries continues to be above the reference value. Areas of the LSJR with frequently elevated levels of TN or TP may have an increased propensity for algal blooms and low DO events.

Using the TN data through 2016, the overall **STATUS** of nitrogen in the mainstem and the tributaries **is *unsatisfactory***, and the **TREND** is ***improving***. However, due to no new data being added for TN in 2017, the **STATUS** and **TREND** cannot be determined in this year's report. The **STATUS** of phosphorus in the mainstem **is *satisfactory***, and the **TREND** is ***unchanged*** in the freshwater portion of the LSJR and ***improving*** in the marine/estuarine areas of the LSJR. The **STATUS** of phosphorus in the tributaries is ***unsatisfactory***, and the **TREND** in the tributaries is ***unchanged***.

There are wide fluctuations of these and other nutrients due to phytoplankton growth and die-off as well as weather conditions. As stated in section 2.1, recent hurricane activity has increased flooding into the LSJR over the past two years, which may also affect nutrient loading. Ongoing efforts to actively reduce nutrient loading into the LSJR may be lowering the concentrations of some forms of nutrients in the mainstem. Changes in nutrient concentrations typically correlate with changes in algal growth. Algal growth, as indicated by average annual chlorophyll-a levels, is discussed separately in Section 2.4.

The complex ecology of the LSJR and its highly variable characteristics and weather patterns make it difficult to assess its overall status. As a result, assessments can differ when different methods of analysis are used. It is reported in the 2013 LSJR BMAP progress report that total nitrogen is decreasing at benchmark sites in marine and freshwater areas of the river (**DEP 2014a**). Total phosphorus is unchanged at the freshwater site but could be increasing at the marine site. To date, wastewater treatment facilities in the freshwater portion of the LSJR have achieved their total nitrogen and total phosophorus TMDL-required reductions; and wastewater treatment facilities in the marine portion of the LSJR have achieved their TMDL-required total nitrogen reductions. The next few years will be critical in definitively determining when the considerable effort and expenditures to reduce nutrients in the LSJR have been successful. Robust data sets are particularly critical for assessing trends.

Numerous projects have been carried out by multiple counties and agencies in the last several years to reduce nonpoint sources of nutrients from stormwater runoff, agricultural runoff, landscape fertilizer and septic tanks, as well as point sources such as wastewater treatment plants. Projects include wastewater treatment plant upgrades, reclaimed water projects, general drainage improvement, septic tank phase-outs, and the construction of regional stormwater treatment facilities. These efforts are detailed in the 2013 LSJR Mainstem Basin Management Action Plan progress report (**DEP 2014a**). In addition, nongovernmental NPDES permit holders have also reduced the discharge of nutrients in their effluents to meet TMDL load reduction allocations. In an interesting, cost-effective restoration project in Lake Apopka, the SJRWMD is reducing the mobilization of phosphorus from sediments by harvesting gizzard shad, which disturb the sediments and release the phosphorus for uptake by algae (**DEP 2014a**). As a consequence of all of these efforts, the lower basin stakeholders have made substantial progress in meeting their targeted nutrient load reductions required by the LSJR TMDL limits, a very positive development for the river. Additionally, a similar, larger scale project has been implemented in Lake George since 2013.

To determine whether load reductions and numeric criteria have achieved a real environmental benefit, reliable and consistent data is essential. There is a very clear need for continued and increased monitoring to assess the effectiveness of the nutrient TMDLs that have been implemented for the LSJR mainstem. Responses to TMDL efforts of other water bodies in the entire St. Johns River basin, particularly upstream and tributaries also need to be monitored if benefits are to be accurately assessed. It is critical to maintain adequate monitoring capacity for nutrients, chlorophyll-a, and other water quality parameters in the LSJR mainstem so that information that is essential for effective management is available.

2.4. Algal Blooms

2.4.1. Description and Significance

Phytoplankton (microscopic algae), including cyanobacteria (also called blue-green algae) photosynthesize and serve as the base of the food chain in lakes, rivers, streams, estuaries, and oceans. Some species thrive in salt water, some in fresh water, and some tolerate wide ranges of salinity. Under certain conditions of nutrients, light, salinity and flow, these organisms can propagate rapidly and result in very high concentrations of the algae, creating what is called a "bloom", which can have significant impacts on the local ecology of a river or lake (Figure 2.18).

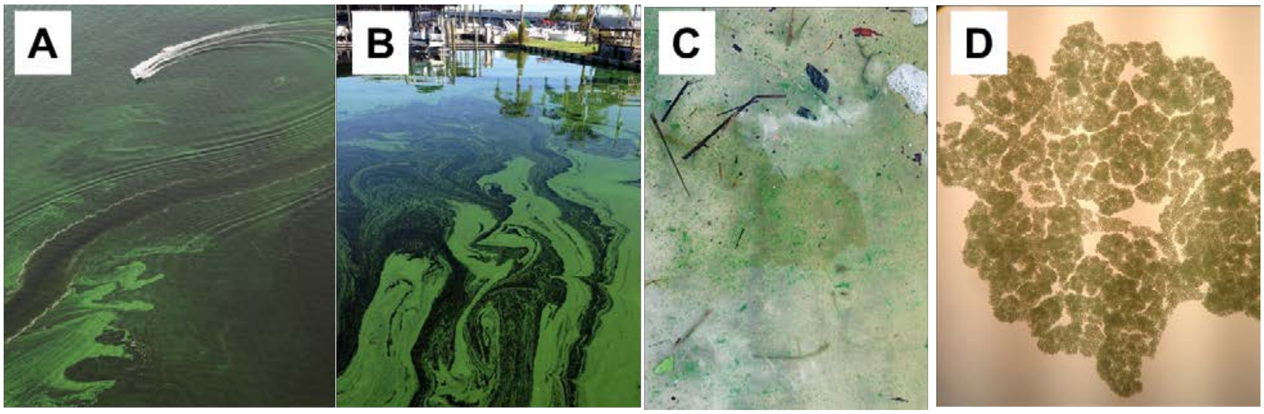


Figure 2.18 Microcystis-dominated blooms in slick form (A&B) and clump form (C). A. Ariel view of Doctors Lake in June 2016 (note the boat towards top of photo for scale). B. Ground view of Doctors Lake in October 2013. C. Shallow water close-up of St. Johns River at Arlington Lions Club Park. D. Microscope image of a Microcystis colony. Photos by Gerry Pinto (A) and Rhea Derke (B-D).

Algal blooms are often described as nuisances because of the odor and unsightliness of algal scum and the green water that often accompanies them. However, the potential impacts go well beyond being a nuisance. Blooms, in addition to being clearly visible events, often induce high oxygen production during the daylight hours (due to photosynthesis), followed at night by very low oxygen levels (due to respiration). Other effects occur when blooms are so dense that sunlight cannot reach the native submerged aquatic vegetation, reducing the plants' ability to photosynthesize and grow. Also, when the bloom biomass decays, dissolved oxygen levels are decreased. As a consequence, survival of fish and other aquatic organisms may become threatened by low oxygen and reduced food and habitat caused by algal blooms.

Some cyanobacteria species produce toxins (cyanotoxins) that can reach high levels in a bloom, potentially creating public health problems and causing widespread deaths of fish and other aquatic organisms. These incidents are known as Harmful Algal Blooms (HABs). Cyanobacteria produce three broad classes of toxins known as hepatotoxins, neurotoxins, and dermatotoxins that affect the liver, nerves, and skin, respectively (**Sivonen and Jones 1999; Williams et al. 2007; Burns Jr 2008**). In addition to toxic effects, general irritation can occur upon contact (**Chorus and Bartram 1999**). Swimmers and anglers have complained of rashes after coming into contact with blooms (**Steidinger et al. 1973**). The World Health Organization (WHO) has set a drinking water "provisional consumption" limit of 1 µg/L for one type of cyanotoxin, microcystin-LR, a toxin produced by several types of cyanobacteria, including *Microcystis* species (**Chorus and Bartram 1999**), and the U.S. EPA has issued informal health advisory guidelines for 1.6 µg/L microcystin-LR in drinking water for school aged children and adults (**EPA 2015a**).

For recreational waters, the U.S. has no guidelines, but the EPA has recently drafted recommendations for microcystins at 4 ug/L (see section 2.4.5). The WHO considers 10-20 µg/L microcystin-LR to have a moderate probability of adverse health effects for a 132-pound adult that ingests 3.4 oz. contaminated water. A 30-pound child would need to ingest less than 1 ounce for the same risk (**Chorus and Bartram 1999**). As cyanobacteria concentrations increase, so does the potential for people to ingest toxins at levels that can cause adverse effects. Scums produced by some species such as *Microcystis* and *Anabaena* are particularly hazardous. They contain high levels of toxin, so it is important for the public and their pets to avoid exposure to them (**Chorus and Bartram 1999**). Four summary references on HAB by **Steidinger et al. 1999**, **Burns Jr 2008**, **Williams et al. 2007**, and **Abbott et al. 2009** are recommended reading on this subject.

The St. Johns River and its tributaries are impacted by excess nutrients in runoff and wastewater (section 2.3). Nutrients, including nitrogen- and phosphorus-based chemicals contained in garden, lawn, and agricultural fertilizer, are common causes of impaired waters in the LSJR and are crucial contributors to freshwater algal blooms.

High levels of nutrients lead to phytoplankton growth and eutrophication, causing the ecosystem to become unbalanced with increased loading of organic matter to the system as a result (**NRC 2000**). Thus, when nutrient levels are high and other appropriate conditions exist, the possibility of harmful algal blooms increases. Cyanobacteria growth rates and species distributions in an ecosystem are highly dependent upon light, temperature, and salinity. As a consequence, proximity to the mouth of the river (due to salinity levels), temperature fluctuations, color of the water, and the presence of other phytoplankton all determine whether an algal bloom will occur and which species will predominate. Rainfall also influences HABs; periods of low flow during drought increase the likelihood of algal blooms in the freshwater reach (**Phlips et al. 2007**), while high flow and hurricane rain events increase the likelihood of less concentrated but more widespread blooms in the downstream, Jacksonville reach of the river (**Hendrickson 2013**).

Nutrients promoting algal blooms also come from leaking septic systems, livestock, industry and runoff during and after heavy rain events. However, interesting work by **Piehler et al. 2009** indicates some types of cyanobacteria can themselves increase nitrogen in waterbodies. During nitrogen fixation, a biological process, atmospheric nitrogen is taken up and used for growth by some species. The nitrogen is ultimately released into the water in forms that are more usable by biota that cannot use atmospheric nitrogen.

The question often arises about whether harmful algal blooms occurred historically and whether current blooms are a natural occurrence. Burns has this to say (**Burns Jr 2008**):

> *"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."*

Interestingly, algal blooms may have increased after successful eradication efforts to control the highly invasive water hyacinth in the 1970s and 1980s. In the past, hyacinth shaded much of the water column and limited algal growth. 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 (**Moody 1970; Hendrickson 2006; Hendrickson 2008**).

2.4.2. Cyanobacteria in Florida and the LSJR

Anabaena circinalis and *Microcystis aeruginosa* (Figure 2.17) are two of the most widely distributed freshwater cyanobacteria species in Florida that generate HABs (**Steidinger et al. 1999; Williams et al. 2007; Abbott et al. 2009**). Some of the other potentially toxic cyanobacteria that are known to bloom in Florida waters include *Cylindrospermopsis raciborskii* (reported as a possibly recent invasive species (**Chapman and Schelske 1997**)), *Anabaena flos-aquae, Aphanizomenon flos-aquae*, and *Lyngbya wollei* (**Steidinger et al. 1999; Burns Jr 2008; Abbott et al. 2009**). Extensive statewide sampling by Florida biologists in 1999-2000 showed that 88 out of 167 samples, representing 75 individual waterbodies, were found to contain potentially toxic cyanobacteria (**Williams et al. 2001; Burns Jr 2008**). Most bloom-forming cyanobacteria genera were distributed throughout the state, but waterbodies, such as Lake Okeechobee, the LSJR, the Caloosahatchee River, Lake George, Crescent Lake, Doctors Lake, and the St. Lucie River (among others) were waterbodies 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 concentrations (**Williams et al. 2001; Burns Jr 2008**). In the same 1999-2000 survey, 55% of the samples in the LSJR basin contained the genus *Anabaena*, 53.9% contained *Cylindrospermopsis raciborskii*, and 47.6% contained the genus *Microcystis* (**Williams et al. 2001**; **Burns Jr 2008**), though it should be noted that many other species reside in the LSJR.

In 2005, major blooms in the LSJR affected areas north of Crescent City to Jacksonville and caused large spikes in cyanotoxins and fish die-offs. The primary species was *Microcystis aeruginosa* (**Williams et al. 2006; Williams et al. 2007**). In an unusual series of events in the LSJR from mid-May through June of 2010, cyanobacteria blooms grew in great abundance in the freshwater reaches of the LSJR, beginning with blooms of *Aphanizomenon cf. flos-aquae*, which until then had never been recorded as the dominant species in the LSJR. With an increase in river salinity due to extended periods of reverse flow, the *Aphanizomenon* bloom decayed and was replaced by *Microcystis*, *Cylindrospermopsis*, *Anabaena*, and *Pseudoanabaena* (**FWC 2010**). Analyses for cyanotoxins, which are toxic chemicals produced by cyanobacteria, indicated large spikes of a microcystin in the river water in late May and June and elevated levels of *Cylindrospermopsis* in mid-July through September (**Hendrickson 2011**).

Other cyanobacteria identified in the LSJR in 2012 by the SJRWMD field observation team include *Anabaena spiroides Oscillatoria limosa*, in the Ocklawaha River in 2012, as well as *Planktolyngbya limnetica* and *Planktolyngbya tallingi* in Crescent Lake (**LSJR TAC 2012**).

Identification and quantitation of cyanobacteria and their toxins in the LSJR can be difficult, expensive, and time-consuming, though in recent years, there has been an expansion of different methods and approaches (**Williams et al. 2007; Burns Jr 2008**). The most consistent and complete data that reflect phytoplankton growth over many years are measurements of chlorophyll-a. Chlorophyll-a is a light-harvesting pigment used by photosynthesizing organisms. Elevated phytoplankton concentrations, including cyanobacteria, are accompanied by elevated chlorophyll-a concentrations so chlorophyll-a is often used as an indicator for HABs.

*2.4.3. Chlorophyll-*a *Thresholds and Data Analysis*

Chlorophyll-a values are used to determine relative phytoplankton abundance. Each water body is unique with respect to flow, shape, and water chemistry, all which affect phytoplankton growth and therefore also chlorophyll-a levels (**DEP 2013d**). Because salinity is a critical factor in cyanobacteria growth, it is useful to examine chlorophyll-a in different river regions. The marine/estuarine reach discussed in this report extends from the mouth at WBID 2213A to WBID 2213H, and the freshwater region extends from WBID 2213I upstream to WBID 2213N at the confluence of the Ocklawaha River (Figure 2.1).

Criteria and threshold values

Streams with chlorophyll-a concentrations that are below 3.2 µg/L are biologically healthy; however, some types of streams are stable and healthy at higher levels of chlorophyll-a/L. Therefore, a number of DEP chlorophyll-a impairment thresholds exist for Florida waterways ranging from general criteria to site-specific criteria. For example, the impairment threshold for estuaries and open coastal waters is 11 µg chlorophyll-a/L (annual geometric mean) (**DEP 2013d**). However, the marine/estuarine reach of the LSJR has an even lower, more stringent, site-specific chlorophyll-a criterion of 5.4 µg/L for long-term (7-year) annual averages (**DEP 2013h**; **DEP 2016a**). Thus, 5.4 µg/L is the threshold criterion we utilize in this report for the marine/estuarine reach (which is most appropriately compared to 7-year annual averages).

For freshwater, the general impairment threshold in Florida is 20 µg chlorophyll-a/L (not to be exceeded more than once in a three year period), based on annual geometric means (**DEP 2013d**; **DEP 2016g**). However, the DEP uses a criterion of 40 µg chlorophyll-a/L not to be exceeded more than 10% of the time (or for more than 40 days) for the chlorophyll-a threshold for the Lower St. Johns River Basin (**Magley and Joyner 2008**; **DEP 2014a**). For this River Report, both freshwater criteria are used - the general 20 µg/L annual geometric mean threshold is used for general assessment of the freshwater regions of the river, and 40 µg/L chlorophyll-a/L is used as a threshold of bloom status when discussing individual water segments (WBIDs).

In this River Report, the current status and time trends of chlorophyll-a are examined in different ways. Both the marine/estuarine and the freshwater regions are presented as annual chlorophyll-a averages for direct comparison between the two regions (Figure 2.18). The marine/estuarine data are then displayed as annual averages as well as 7-year annual averages and are compared to the 5.4 µg/L chlorophyll-a criteria (Figure 2.19A). The freshwater data are presented as annual geometric means for comparisons to the 20 µg/L chlorophyll-a threshold (Figure 2.19B). To show the spread of the data, including the high and low values, box-and-whisker plots are presented for both the marine/estuarine and freshwater regions (Figure 2.20). Trends over time of annual average concentrations were investigated by using the Spearman Rank 1-tailed test at $p < 0.05$.

Data acquisition and processing

All data were obtained from the DEP STORET. STORET is the statewide environmental data system containing water quality, biological, and physical data. Method 10200-H was used to analyze chlorophyll-a that was corrected for pheophytin, which is a form of degraded chlorophyll. Only stations in the mainstem or near the mainstem in major tributaries, such as the Ortega River and Julington Creek, were included. Data were reviewed for quality and data points were discarded when samples appeared analytically compromised (contaminated blanks, poor recovery, poor replication, etc.) or were missing important information. All samples with qualifier codes K, L, O, V, Y, or ?, which indicate different data quality issues, were eliminated. If a reported value was below the method detection limit (MDL), it was used even if flagged. One-half the MDL was used for samples reported as "nondetect." In a small number of cases, the MDL was

estimated by determining the MDL reported most frequently for other samples during the same year. When routine and integrated vertical samples were obtained at the same time, the integrated samples were used for analysis in this report.

2.4.4. Current Status and Trends

Based on annual averages, the freshwater regions have shown consistently higher concentrations of chlorophyll-a compared to the marine/estuarine regions (approximately two to seven times higher per year; Figure 2.19), which is not unexpected since the phytoplankton that cause algal blooms in the St. Johns River are freshwater species. Using aggregated WBID data, the decrease in chlorophyll-a concentrations when moving from the most upstream freshwater WBID N to the end of the St. Johns River at the Atlantic Ocean (WBID A) is evident (Fig. 2.19B).

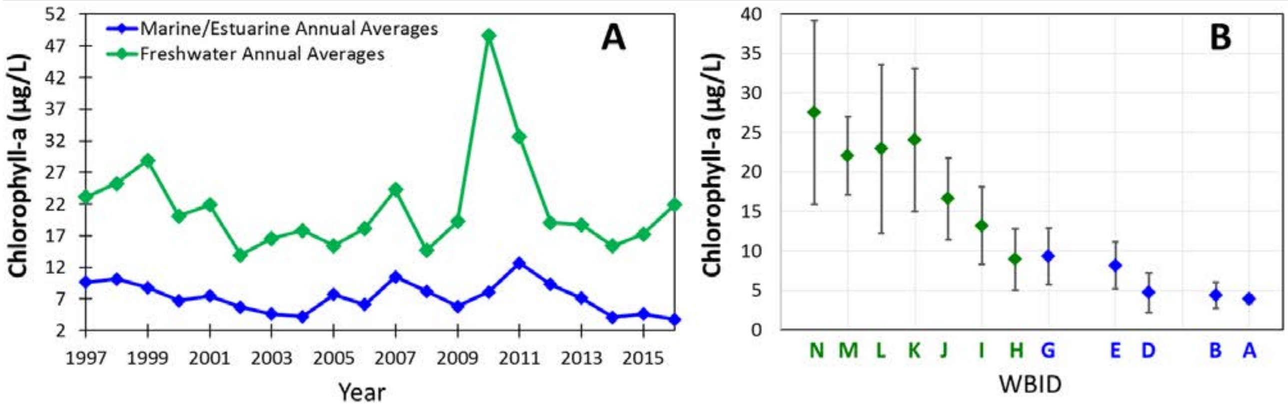


*Figure 2.19 Annual averages of chlorophyll-*a *concentrations in the freshwater section and the marine/estuarine reach for 1997-2016. Blue denotes marine/estuarine data and green denotes freshwater data. A. Annual averages per year. B. Averages of annual averages for each WBID. For each WBID, the annual averages for all years were averaged, and the error bars represent the standard deviations for each average of averages. WBIDs C and F are not included due to no data for WBID C from 2014 to present and no data for WBID F from 2009 to present.*

To assess the chlorophyll-a levels in the marine reach, the annual averages are compared to the impairment criterion value of 5.4 μg/L (Figure 2.20B). The yearly data (blue diamonds) show statistically significant decreases in chlorophyll-a concentrations over the past six years, even reaching below the 5.4 μg/L threshold the past three years. However, the 5.4 μg/L threshold is meant to be compared to long-term, 7-year averages, not individual years. The 7-year averages (black squares) have consistently been above the 5.4 μg/L threshold, thus the marine reach does not meet the chlorophyll-a criterion. Therefore, while the data have shown decreasing chlorophyll concentrations in the marine reach, which is promising, the 7-year long-term averages are all above the 5.4 μg/L target (Figure 2.20B). However, the lack of recent data for WBIDs C and F constrain the overall interpretation.

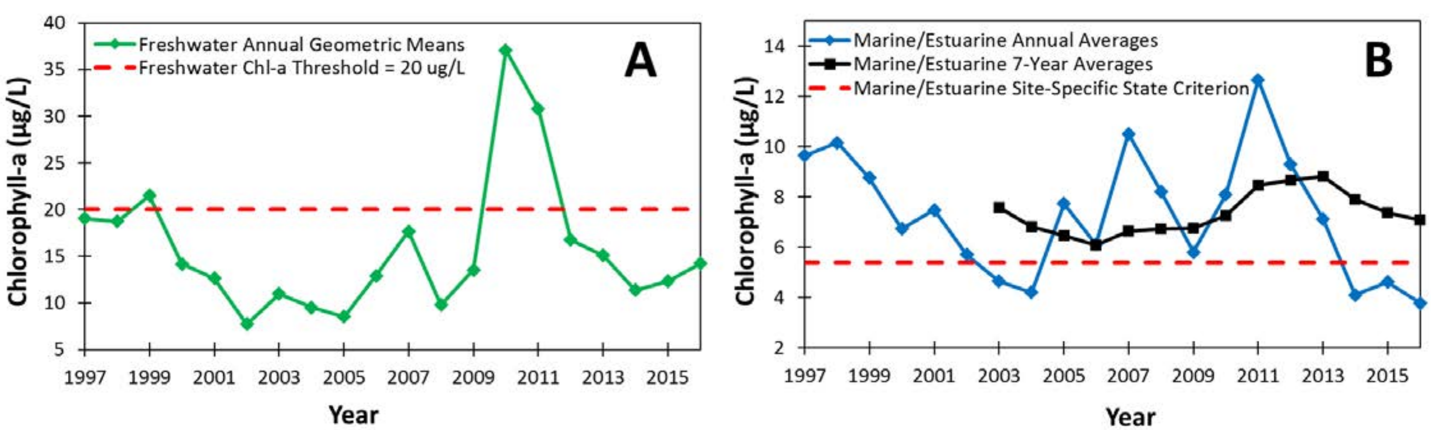


*Figure 2.20 Annual chlorophyll-*a *concentrations compared to threshold values in the Lower St. Johns River mainstem. A. Annual geometric means in the freshwater section; and B. Annual averages in the marine/estuarine reach. The dashed lines represent the chlorophyll-*a *thresholds; 5.4 μg/L for the marine and estuarine portions (State criterion), and 20 μg/L for the freshwater portions (River Report threshold).*

The freshwater annual geometric means for the five most recent years are below the 20 µg/L threshold that this River Report uses for comparison (Figure 2.20A), and these data also show a statistically significant downward trend in chlorophyll-a concentrations over the past 6 years, which looks promising regarding reduction in freshwater blooms. While Figures 2.19 and 2.20 are useful for trends and comparison to threshold values, they do a relatively poor job of representing the data sets per year. Furthermore, geometric means tend to be lower than arithmetic means (compare Figure 2.19A to 2.20A). Therefore, box and whisker plots are presented to show the spread of the data in 25% increments as well as the median value, the highest values, and the lowest values (Figure 2.21; see circled inset). The highest freshwater values for the past five years and the highest marine values for the past four years are the lowest high-values for the 20 years analyzed for each segment of the river (Figure 2.21 A and B, respectively).

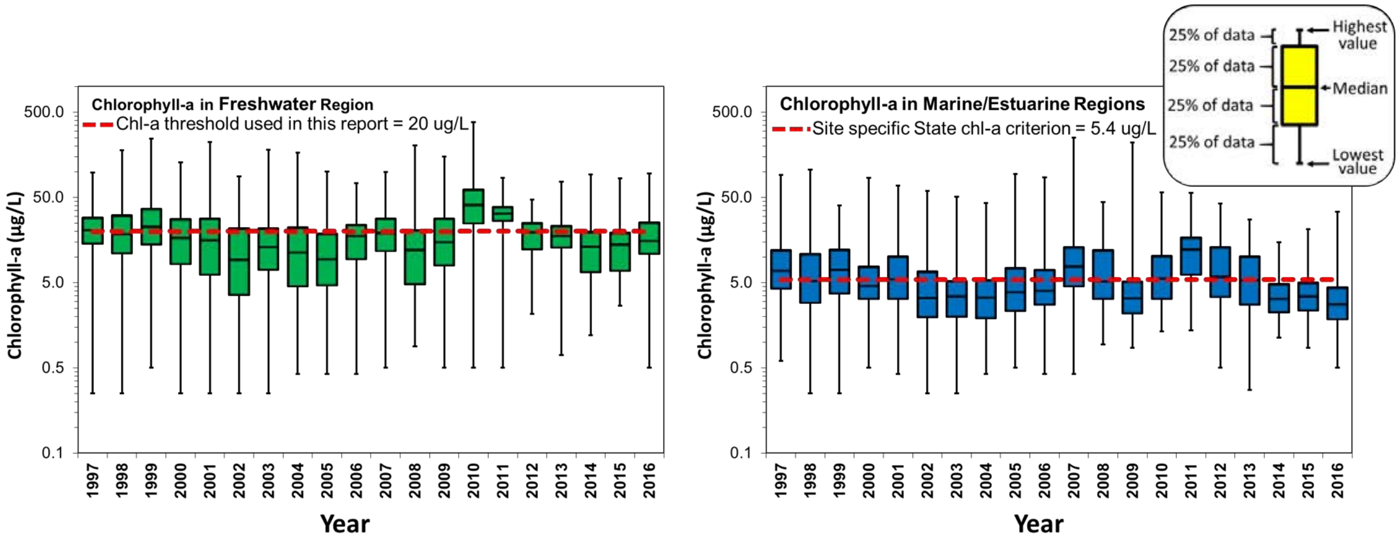


*Figure 2.21 Yearly chlorophyll-*a *concentrations with an emphasis on the spread of the data in the Lower St. Johns River mainstem for freshwater and marine/estuarine regions. The dashed red lines represent the chlorophyll-*a *thresholds. Data are presented as box-and-whiskers plots that show the data compiled into 25% intervals (inset). The median value is the number where 50% of the data is above, and 50% of the data is below, and is indicated by the horizontal line in the center of the boxes. Whiskers indicate the ranges of the highest and lowest 25% of the data, including the maximum and minimum values. Note logarithmic scale on y-axis.*

While the trend of lower chlorophyll-a concentrations is encouraging, the aggregation of the data for the large freshwater region has its limitations. Not only is the freshwater region large, but it is also complex, and there are still sections of this region (WBIDs; Figure 2.1) that are experiencing elevated chlorophyll-a levels, and therefore it is worth discussing WBID-specific information instead of strictly the aggregated data from the freshwater portion. First, figure 2.19B illustrates historic differences between the WBIDs, including among the freshwater WBIDs, with K-N noticeably higher than H-J. Second, the points below illustrate more in-depth localized analysis of data for freshwater WBIDs. These specific examples are intended to highlight issues with data limitations as well as highlight how specific regions of the freshwater portion endure particularly elevated chlorophyll-a levels, including levels which indicate blooms.

A) For 2012 and 2013, 5 of the 6 annual chlorophyll-a geometric means of freshwater WBIDs K, M, and N were above the 20 µg/L threshold.

B) Over the most recent 4 years (2013-2016), WBIDs K, M, and N combined have an almost 2- fold higher chlorophyll-a average compared to combined WBIDs H, I, J, and L.

C) For 2016, 8 of 22 samples from WBID N exceeded the site-specific chlorophyll-a criterion of 40 µg/L. These 8 samples spanned May to September, and include all 5 samples from July 13 to September 7, indicating a prolonged bloom. Furthermore, the annual geometric means for this WBID ranged from 20.4-22.7 µg/L for 2012, 2013, and 2016, slightly over the 20 µg/L threshold for each of those years. Therefore, WBID N exceeds the two different thresholds used in this River Report, including the state criteria.

D) The DEP has recently analyzed chlorophyll-a data from WBID K (Racy Point), which is a location that it considers to be a "worst-case WBID", along with nearby Dancy Point (WBID L), and reported the number of days per year that Racy Point experienced a nuisance bloom (designated as chlorophyll-a values >40 µg/L). That analysis reports a trend of decreasing days per year (from 1995-2013) when Racy Point is >40 µg/L chlorophyll-a (**DEP 2014a**). While that analysis shows a decrease in the longevity of these blooms at this location, it still has recurring blooms.

In that analysis, chlorophyll-a values derived from continuous measurements at Dancy Point (Using USGS data, which are not deposited in the DEP STORET database) are compared to the values of chlorophyll-a measured from discrete samples at Racy Point (that are in the DEP STORET database). That analysis shows many days during spring 2013 when Dancy Point (WBID L) was above the 40 μg/L threshold according to the continuous measurements, but these types of data are not in the DEP STORET database. This lack of WIBD L data for 2013 is an example of limitations of figures 2.19-2.21, and illustrates the problem of our analysis missing key algal bloom events in the river.

E) WBID K has only three data points in the database for 2016, with a high value of 43 μg/L and geometric average of 22 μg/L.

Toxic events

Chlorophyll-a data relate to abundance of all of the phytoplankton present. When high concentrations of chlorophyll-a are specifically from toxic cyanobacteria, then concerns about water toxicity are elevated. In October 2013, for example, the St. Johns Riverkeeper reported that microcystin (a cyanotoxin) concentrations in two LSJR-associated samples were >2,000 μg/L. These concentrations are more than 500 times the new USEPA draft recommendations for recreational waters (see *New EPA recommendations* section below; **EPA 2016a; EPA 2017**), and are at a level that the World Health Organization classifies as posing a *very high probability of acute health effects from recreational exposure* (**Inclan 2013; Patterson 2013; St. Johns Riverkeeper 2013a**; **EPA 2016b**). One of the toxin-sampling sites was in Doctors Lake (also see Figure 2.18 for photos of blooms in Doctors Lake), which feeds into the St. Johns River and the other was in the more estuarine region of the river (at Jacksonville University). While both of these samples had very high levels of toxins, the chlorophyll-a samples in the STORET database for Doctors Lake that same month were less than 40 μg/L, and none of the 2013 estuarine samples in the analyzed data set were >40 μg/L chlorophyll-a. Thus, there were blooms that are not evident from looking at the chlorophyll-a levels from the STORET database, which illustrates another limitation of the chlorophyll-a-based analysis in this report.

Limitations

The above discussion demonstrates that the datasets we are using have limitations in that there are recorded instances of high chlorophyll-a levels that are not captured in our analysis, and there are toxic algal bloom events that have occurred that are not represented in the chlorophyll dataset. Furthermore, the river sampling locations for chlorophyll-a are largely in the middle of the river channel, and it is known that *Microcystis* blooms can be concentrated along the shore and in coves due to the ability of these cyanobacteria to float and be pushed by the wind. Thus, some wind-driven blooms or elevated chlorophyll-a levels are missed with routine sampling at fixed locations. Sampling protocols can also miss more dense algae at the surface of the water. Finally, the geographical region analyzed also affects the interpretation. While the data here were grouped as either freshwater or marine/estuarine for the main analysis (Figures 2.19-2.21), there are individual locations in the river and its tributaries that are particularly problematic regarding algal blooms.

2.4.5. Summary and Future Outlook

The past few years have shown mean and median chlorophyll values lower than the threshold values, which is promising. However, the marine reach is still not in compliance, and for both freshwater and marine segments of the LSJR, the number of chlorophyll-a exceedances and the annual appearances of blooms (including toxic events) indicate significant impact from phytoplankton, including cyanobacteria. Therefore, the STATUS of the LSJR with respect to algal blooms is considered unsatisfactory, and the TREND is unchanged.

Nutrients

Much of the outlook for algal blooms is closely tied to that for nutrients. Reduced nutrient loading may be lowering concentrations of some forms of nutrients in the mainstem (Section 2.3), and perhaps an accompanying reduction in algal blooms is starting to be observed. However, more years of data will be needed to understand whether this is a stable trend or a short-term phenomenon. Furthermore, the number of samples obtained from the database over the past few years is reduced compared to previous years, which makes trend analysis more complicated, particularly if algal blooms are missed due to decreased sampling. The next few years will be critical in determining whether the considerable effort and expenditures to reduce nutrients in the LSJR are sufficient to limit algal blooms.

Complexity of the system

The freshwater and marine/estuarine sections analyzed above are large geographical areas and thus give a big picture view of the LSJR over time. It is important to consider the complexity of the LSJR ecology and the difficulty in establishing healthy benchmarks and natural trends in a system with physical, chemical, and biological characteristics that naturally vary so widely in space and time.

New EPA recommendations

In December 2016, the USEPA published draft recommendations for national water quality criteria for microcystins and cylindrospermopsin with the goal of protecting swimmers and others engaged in recreational activities in natural waters (**EPA 2016a; EPA 2017**). The swimming advisory levels, which are *not to be exceeded on any day*, are 4 ug/L for microcystins, and 8 ug/L for cylindrospermopsins. For assessment purposes, both toxins also have a waterbody impairment recommendation of not to exceed the above values 'more than 10% of days per recreational season up to one calendar year'. The comment period for the draft recommendations ended March 2017 with no published timeline for finalizing the recommendations.

2.4.6. Recommendations for Research

As discussed above, some bloom events are not represented in the FDEP STORET database, so our understanding of frequency, duration, and locations of blooms is not comprehensive. Additional monitoring of chlorophyll-a at locations known to have recurring blooms, combined with associated nutrient, temperature, and toxin data, could help form a clearer picture of these blooms and the extent to which they exist, how toxic they become, and determine drivers of bloom formation, such as nutrients and temperature. Laboratory, mesocosm, and *in situ* studies that analyze growth rates, toxin production, and bloom collapse of HAB cyanobacteria isolated from the LSJR as a function of varied nutrients, salinity, and temperature are essential to understanding blooms of the LSJR.

2.5. Turbidity

2.5.1. 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 mainstem 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 2009f**).*

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 2009e**).

In contrast to turbidity in freshwater, in more haline (salty) portions of the LSJR, scattering of light is dominantly from materials that 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 mainstem 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. 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 2.22 for example.

Figure 2.22 Turbid water from McCoy Creek entering the LSJR on 17 July 2008. Courtesy of Christopher Ball.

Turbidity (algal and sediment particulate) and color are the two primary light attenuating factors in the LSJR that prevent light from reaching rooted submerged plants and thus hinder 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 concentrations, 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 2.23 shows turbidity values in the LSJR since 1997. 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 mainstem (**Armingeon 2008**), and anything over 29 NTUs above background is considered to exceed Florida state standards (62-302 F.A.C.; **DEP 2013j**). 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 1997, the median value of turbidity in the LSJR has improved and is below the acceptable limit.

Algal blooms (see previous 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 planktonic or filamentous algae can reduce visible depth, affecting the rooted submerged aquatic vegetation. 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 measurement of total chlorophyll-*a* at a level greater than 40 μg/L (**SCCF 2014**). This is not an optimum, healthy state for the entire ecosystem of the water body.

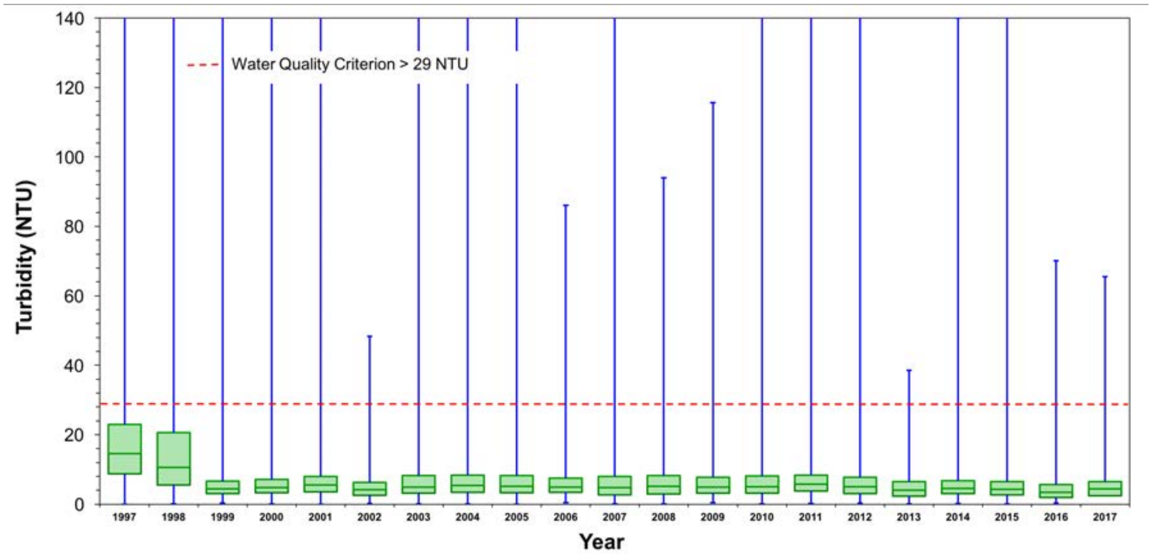


Figure 2.23 Yearly turbidity in the Lower St. Johns River Basin; 1997-2017.
Data are presented as a box-and-whiskers plot with the green boxes indicating the median value ± 25% (middle 50% of data) and the blue whiskers indicating the minimum and maximum values in the data set.

2.5.2. *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*

In 1998, under the Florida standards (62-303 F.A.C.; **DEP 2013j**), 16 waterbodies 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 mainstem of the river above the Dames Point area, at high risk of turbidity impairment, while later assessments, based on sampling in 2004, did not find turbidity impairments. 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.

2.5.4. *Current Conditions*

Based on current data available from STORET, turbidity conditions seem to be satisfactory for the LSJRB, as seen in the figure above. Reported violations of sediment control practices from work sites resulting in high turbidity events still exist, but progress is being made. In 2017, the highest turbidity value observed was 65.55 NTU. Year to year, these values vary due to rainfall events, land-disturbing activities, and other such occurrences.

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.

2.5.5. *Trend and Future Outlook*

Status: Satisfactory

Trend: Unchanged

Current management of turbidity in Duval County, for example, includes a requirement for land-disturbing activities to be overseen by a developer's certified staff, routine visits of land-disturbing sites, review of erosion control plans, and a citizen reporting mechanism. Heightened public awareness and improved engineering sediment control practices are bringing improvements in this area. Finable events over the past few years and the press they received will help keep the pressure on proper engineering practices. 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.

2.6. Bacteria (Fecal Coliform, *E. coli*, and Enterococci)

2.6.1. *Description and Significance*

Fecal bacteria, wastewater treatment, and the Clean Water Act

Fecal coliform bacteria are natural components of digestive systems of birds and mammals. They aid in digestion, and most strains are not harmful. In fact, sewage wastewater has been used to fertilize crops and replenish nutrients from depleted soils since ancient times (**Shuval et al. 1990**). But due to discoveries that sewage wastewater spreads disease, sewage wastewater is treated and released back into natural waters.

Over the last four decades, the standards for sewage treatment have become ever more stringent, particularly with the passage of the clean water act 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. The COJ passed Environmental Protection Board (EPB) Rule 3 to improve water quality in Duval County (1987), which led to a phase-out of the existing but less reliable local wastewater treatment plants, many of which were unable to meet the higher standards. Consolidation into larger regional treatment plants helped meet the higher standards.

Fecal coliform as indicator organisms

Measurement of the effectiveness of wastewater treatment has historically involved the measurement of fecal coliform bacteria, among other water quality parameters. Fecal coliform bacteria are essentially *indicator organisms* that provide evidence of whether human waste and therefore associated pathogens, such as bacteria and viruses, are being sufficiently removed by wastewater treatment. Relatively few coliform bacteria are pathogenic themselves. One shortcoming of using fecal coliform bacteria as an indicator of wastewater treatment is that some species of fecal coliform bacteria can grow and multiply in sediment long after the initial wastewater discharge occurred (**Anderson et al. 2005**), so a high fecal coliform reading may not indicate an active, current discharge of untreated wastewater.

Sources of fecal coliform bacteria in natural waters include wastewater treatment facility outflows, but these are only one type of many sources. Fecal coliform bacteria reach the river from natural sources such as wildlife. Other sources include sanitary sewer overflows, domestic animal and pet contamination, human contamination from failing septic tanks, runoff, and agricultural wastes from intensive animal farming and pasturelands. Wastewater outflows and sanitary sewer overflows 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. Nonpoint sources, in contrast, such as runoff after rain, enter the watershed from a broad area.

Fecal coliform criteria for recreational waterbodies

The mainstem and tributaries of the LSJR are designated as Class III recreational waters, suitable for 'fish consumption, recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife.' Until recently, the Florida fecal coliform exceedance criteria standards for recreational waters stated that fecal coliform counts (CFU) per 100 mL should adhere to all three of the following:

1) not exceed a monthly average of 200 (requires 10 samples in a 30-day period)
2) not exceed 400 in 10% of samples
3) not exceed 800 on any one day

These fecal coliform criteria for recreational water quality were based on 1976 EPA recommendations (**EPA 1976**), which were based on studies that found an increase in gastrointestinal illnesses after swimming in waterways that had about 400 coliform bacteria or more per 100 milliliters of water (**EPA 1986**). For protective measures, the number was halved to 200 fecal coliform bacteria per 100 milliliters as a threshold value for the monthly average value in the criteria. In 1986, based on additional studies, the EPA shifted away from fecal coliform to recommending that *E. coli* and enterococci be used as the indicator organisms for human sewage (**EPA 1986**) and in 2012 the USEPA refined the 1986 recommendations for using *E. coli* and enterococci (**EPA 2012a**). The FDEP has recently changed standards to fit the 2012 recommendations (see below).

The focus on tributaries of the LSJR

Under the FDEP "River-at-a-Glance" program through 2008, the mainstem of the LSJR (at several sites from Welaka to Arlington (in Jacksonville), was found to be largely in compliance for fecal coliform (Appendix 2.6.1). Since the tributaries were largely *not* in compliance, and the mainstem *was* in compliance, the sampling of the mainstem was discontinued and the focus became the tributaries, which is the focus of the rest of this section.

2.6.2. Current Status

Status Rating: Unsatisfactory
Trend Rating: Conditions Unchanged

Seventy-five tributaries are impaired for fecal coliform (**FDEP 2016**). Of these, thirty-six tributaries have final TMDLs for fecal coliform, and fecal coliform BMAPs are in place for twenty-five of them (Table 2.1).

Table 2.1 LSJRB Tributaries with final fecal coliform TMDLs. Tributaries with BMAPs are indicated in gray.

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 (Middle and Lower)
Cedar River	Fishing Creek	Hopkins Creek	Miramar Creek	Pottsburg Creek	Wills Branch
Cormorant Branch	Goodbys Creek	Julington Creek	Moncrief Creek	Ribault River	Williamson Creek

Percent exceedances are far from goals

As noted above, Florida statute has required that monthly averages must be calculated from at least 10 samples per 30 days. However, most impaired tributaries do not undergo fecal coliform testing that frequently. Therefore, the criterion stating that no more than 10% of samples may exceed 400 CFU/100 mL (criterion #2 above) is the metric being used by the FDEP to assess improvement. The goal is to have no more than 10% of the samples for each tributary be more than 400 fecal coliform per 100 milliliters. No tributary has reached this goal, and most are not even close (Table 2.2A), with 23% exceedance as the lowest value, and 95% as the highest value for the most recent 7.5-year period (2010-2017). When comparing the three most recent 7.5-year averages (Table 2.2A), 21 of the tributaries show no substantial changes in percent

exceedances, and 2 of the tributaries have increased by more than 10 percentage points (Table 2.2A; pink). Some progress has been made in Miramar, and Deep Bottom Creeks, which have exceedance percentages that have decreased 10 percentage points (Table 2.2A; blue), but are still far from compliance.

Magnitude of exceedances are far from goals but have made progress

While the percent exceedances for the majority of the tributaries have made no progress in declining, there has been considerable success in bringing down the magnitude of the exceedances when the 1996-2003 and 2010-2014 data sets are compared (last two columns in Table 2.2A). Ideally, the fecal coliform counts will continue to decrease to where the tributaries are no longer exceeding the 10% percent exceedance maximum as well as the single day criterion (criterion #3 above) of 800 fecal coliform on any day.

Table 2.2A Fecal coliform exceedances of LSJRB Tributaries. Percent exceedances show 7.5-year rolling averages for the last four periods, with the most recent time-period in bold. Pink indicates tributaries whose exceedances increased by at least 10 percentage points and light blue indicates tributaries that have decreased by at least 10 percentage points when comparing the first time-period to the last time-period. Exceedance median shows the magnitude of exceedances for two separate time-periods (TMDL period is 1996-2003; BMAP period is 2010-2014).

Tributary	Percent Exceedances (# Samples exceeding criteria / total number of samples)				Exceedance Median (CFU/100 mL)	
	1/1/2007 - 6/30/2014	1/1/2008 - 6/30/2015	1/1/2009 - 6/30/2016	1/1/2010 - 6/30/2017	1996 - 2003	2010 - 2014
Lower Trout River	21% (12/56)	28% (16/57)	25% (15/59)	**23% (12/53)**	1,000	721
Greenfield Creek	47% (18/38)	32% (11/34)	38% (11/29)	**47% (11/27)**	1,354	721
Middle Trout River	27% (63/235)	45%(95/211)	39% (74/188)	**35% (70/198)**	1,184	641
Sherman Creek	34% (62/181)	42% (129/306)	45% (182/407)	**45% (191/420)**	1,400	1,231
Fishing Creek	53% (110/209)	49% (155/314)	48% (174/361)	**50% (181/364)**	1,300	1,081
Cormorant Branch	52% (51/99)	45% (64/143)	48% (86/180)	**48% (89/187)**	1,500	811
Deer Creek	50% (81/163)	51% (100/195)	53% (91/171)	**53% (89/168)**	2,765	1,376
Wills Branch	57% (43/75)	61% (38/62)	54% (30/56)	**59% (80/136)**	4,000	1,000
Goodbys Creek	57% (114/199)	57%(112/197)	57% (112/196)	**56% (108/194)**	3,000	840
Pottsburg Creek	32% (33/102)	32% (23/71)	58% (31/53)	**41% (19/46)**	800	1,532
Blockhouse Creek	58% (23/40)	64% (18/28)	61% (17/28)	**65% (17/26)**	2,200	1,081
Open Creek	62% (90/146)	60% (90/151)	61% (99/161)	**63% (104/164)**	1,000	920
McCoy Creek	60% (97/161)	64% (149/234)	63% (153/244)	**63% (154/244)**	2,510	1,200
Moncrief Creek	59% (138/234)	59% (144/243)	65% (156/240)	**63% (169/269)**	2,600	1,300
Hopkins Creek	45% (36/80)	66% (172/261)	70% (234/335)	**71% (251/355)**	1,200	1,351
Miramar Creek	82% (81/99)	73% (100/137)	71% (115/162)	**72% (119/166)**	5,000	2,100
Newcastle Creek	77% (90/117)	71% (106/149)	71% (132/185)	**71% (135/189)**	2,500	1,622
Deep Bottom Creek	85% (69/81)	76% (122/161)	73% (138/188)	**75% (145/194)**	2,200	1,500
Terrapin Creek	84% (68/81)	66% (81/123)	73% (77/105)	**76% (84/111)**	1,367	920
Hogan Creek	84% (143/170)	86% (195/228)	80% (211/264)	**80% (218/273)**	5,000	1,622
Williamson Creek	85% (101/119)	85% (153/179)	83% (145/175)	**84% (163/193)**	2,400	2,300
Big Fishweir Creek	88% (250/283)	88% (245/277)	88% (261/295)	**89% (263/296)**	3,000	2,900
Miller Creek	83% (151/181)	85% (170/199)	89% (226/254)	**90% (235/262)**	5,000	5,100
Butcher Pen Creek	92% (148/161)	93% (178/191)	91% (174/191)	**91% (183/202)**	2,400	2,850
Craig Creek	93% (159/171)	93% (169/181)	94% (197/210)	**95% (198/209)**	3,000	2,550

2.6.3. Progress and Outlook

BMAPs, Walk the WBID, and activities to address fecal coliform exceedances

Generally, Basin Management Action Plans (BMAPs) lay out projects and plans intended to reduce loading of the identified pollutant, to be executed by the key responsible parties. For fecal coliform BMAPs in this set of 25 tributaries, the responsible parties are COJ, JEA, the Florida Department of Transportation, the Florida Department of Health, Naval Station Mayport, and other relevant municipalities including the Cities of Atlantic Beach, Jacksonville Beach, and Neptune Beach. FDEP also plays a role in implementation of BMAP projects. For these 25 tributaries, a coordinating body called the Tributaries Assessment Team organizes these groups in terms of information review and taking next steps.

Because the primary sources of fecal coliform are stormwater, wastewater, and septic tanks, the projects undertaken to reduce fecal coliform usually address these types of water streams. Examples of projects undertaken to reduce fecal coliform include wastewater infrastructure and treatment improvements, construction of stormwater retention ponds, removal of illicit wastewater connections to waterbodies, and septic tank phase-out and replacement by connection to municipal sewage services. Dozens of projects on these tributaries have been completed since the start of these BMAPs.

Yet, despite these projects, many of which have certainly decreased the amount of human waste entering the watershed, the above results indicate that the tributaries remain significantly impaired for fecal coliform. Stakeholders have conducted an intensive effort to investigate sources of fecal coliform. For the Tributaries I group, Maps on the Table (MOT) and Walk the WBID (WTW) exercises were conducted in 2014. MOT is a process by which stakeholders with local knowledge of the WBID (water body) meet and review a map of the WBID to identify possible sources and issues needing further study. These were followed by WTW days, in which stakeholders actually hike along the banks of the water body to observe and note potential problem areas. After these events, follow-up activities were identified, and both long-term and short-term solutions to this problem are being sought. The Tributaries II group was examined by slightly scaled-back MOT and WTW exercises in April 2015 by a coordinated inter-agency effort. During these walks, a few short-term issues were discovered and quickly addressed by the appropriate agency. Future long-term efforts generally involve maintenance activities, modified or expanded inspections, educational outreach, and basin-specific cleanup strategies.

Rule changes: Switching from fecal coliform testing to E. coli and enterococcus testing

As explained above, Florida's fecal coliform criteria are based on 1976 USEPA recommendations, which have since been updated twice by the USEPA. Recently, new bacteria criteria to replace the fecal coliform standards were developed by FDEP. These criteria adopt Recreational Water Quality Criterion (RWQC) promulgated by U.S. EPA in 2012 (**EPA 2012b**). This new RWQC is specific for *E. coli* and enterococci, rather than fecal coliform, a broader class of organisms. It was found that enterococci and *E. coli* are superior indicators of fecal contamination than simply fecal coliform, because a) the correlation between swimmer disease and bacteria levels is stronger for these specific bacteria than for the larger class of fecal coliform bacteria (**EPA 2012a**), and b) fecal coliform testing can also measure the presence of some bacteria that did not come from feces (**Jin et al. 2004**). *E. coli* will now be used for fresh waters, and enterococci will be used for saline waters.

Recent data for 10 tributaries using these new criteria are compared to data for the old criteria (Table 2.2B). Percent exceedances of fecal indicator bacteria using the new criteria are noticeably lower for 7 of the tributaries and higher for 2 of the tributaries compared to the larger fecal coliform data set (Table 2.2B). Future editions of this Report will expand on these new criteria as Florida incorporates them and as more data on *E. coli* and enterococci come available.

Table 2.2B Fecal coliform exceedances compared to *E. coli* and enterococci exceedances. Percent exceedances for old criteria encompass 1/1/2010 - 6/30/2017, and for new criteria are from 2016 and 2017 only. Pink indicates tributaries whose exceedances are at least 20 percentage points greater and light blue indicates tributaries whose exceedances are at least 20 percentage points lower when comparing the new criteria to the old criteria.

Tributary	Percent Exceedances: Old and New Criteria Comparison (# Samples exceeding criteria / total number of samples)			
	Old Criteria [Fecal coliform for marine and fresh waters] (Data from Table 2.2A)		New Criteria [Enterococci for marine waters] [*E. coli* for fresh waters]	
Sherman Creek	Fecal coliform	45% (191/420)	Enterococci	18% (4/22)
Fishing Creek	Fecal coliform	50% (181/364)	E. coli	52% (35/67)
Hopkins Creek	Fecal coliform	71% (251/355)	Enterococci	53% (10/19)
Newcastle Creek	Fecal coliform	71% (135/189)	E. coli	53% (8/15)
Big Fishweir Creek	Fecal coliform	89% (263/296)	E. coli	56% (9/16)
Miramar Creek	Fecal coliform	72% (119/166)	E. coli	62% (8/13)
Hogan Creek	Fecal coliform	80% (218/273)	E. coli	73% (16/22)
Cormorant Branch	Fecal coliform	48% (89/187)	E. coli	73% (16/22)
Miller Creek	Fecal coliform	90% (235/262)	E. coli	100% (18/18)
Deep Bottom Creek	Fecal coliform	75% (145/194)	E. coli	100% (22/22)

New tools to track the sources of fecal coliform

Since human waste has a higher health risk than wildlife, livestock, and pet wastes, FDEP and COJ have begun investigating human contributions to fecal coliform populations. This approach seeks to determine whether or not the source of the bacteria is human, using a technique called qPCR (quantitative polymerase chain reaction) to measure genetic signatures from human bacteria. FDEP also analyzes samples for sucralose and acetaminophen, to narrow down whether human sources are from a variety of human waste sources or specifically from septic tanks.

Sucralose, an artificial sweetener with common trade name Splenda, is not broken down by the body or by wastewater treatment. Therefore, the presence of sucralose in waterways indicates that the water being analyzed includes some type of wastewater effluent (septic tanks or from wastewater treatment plants), either treated or not. In contrast, most acetaminophen, a pain reliever often trade-named Tylenol, is removed from wastewater during treatment processes (septic tank or sanitary wastewater), so high concentrations of acetaminophen in a water sample indicates a *recent raw human wastewater source.*

By combining the results of the different analyses, scientists can begin to determine whether the fecal coliform bacteria in a tributary are from humans or not, whether they are from treated or untreated sewage, and whether the introduction of the fecal coliform bacteria into the waterway was recent or not. For example, if a water sample has high levels of fecal coliform, high levels of human bacteria as assessed by qPCR, and high levels of acetaminophen, then raw human wastewater is suspected, so the source must be determined and remedied. If a water sample has high levels of fecal coliform, but low levels of human bacteria as assessed by qPCR, and low levels of acetaminophen, then raw human wastewater is not suspected. In this case, the water body may not be a priority, as the source of the fecal coliform may be from wildlife, or the fecal coliform may have come from humans in the past, but is now just growing and living in the tributaries, with no associated human pathogens present, and thus is not an indication of a health risk.

This approach is much more complicated than explained here, and can include the analysis of sediments to check for fecal coliforms growing on their own as opposed to more recent introduction by human waste. These tracking methods hold much promise for determining why the tributaries continue to have such high levels of fecal coliform.

An intensive pilot study to track down the sources of human waste.

Using the new tools described above, an intensive pilot study was carried out by the FDEP in collaboration with municipalities in 2017 (**DEP 2018b**). Hopkins Creek, Miller Creek, and Butcher Pen Creek were part of the study that also included waterbodies at other locations across the state. The goal was to narrow down sources of the fecal bacteria in each water body, which is difficult for many reasons, including underground locations of many sewage pipes. Sources for Miller Creek and Hopkins were identified, but these may not be the only sources. A prioritization tool is being developed by FDEP using the results of this study. FEDP will take samples from every fecal-impaired WBID that has a BMAP, analyze them using the suite of new tools, and these results will then be analyzed with the prioritization tool to help determine which waterbodies to focus on.

2.6.4. Conclusion

Fecal bacteria are a significant problem in the tributaries of the LSJRB, and considerable effort is being made to remedy this problem by way of the state TMDL and BMAP processes. Many tributaries with elevated fecal coliform levels have undergone large reductions, which is an encouraging sign. However, despite making large reductions, actual fecal coliform levels in many tributaries are persistently higher than the current rules for the water quality criteria, and the percent exceedances are very high. Results from the new criteria where *E. coli* and enterococci are analyzed may be showing lower exceedances in some instances compared to the historic fecal coliform criteria. As agencies obtain more data with the new criteria, implement source tracking, and continue to invest in improving sewage infrastructure, our understanding of fecal bacteria in the LSJRB should become clearer, and reductions in this problem should continue to be made.

2.7. Tributaries

2.7.1. About the Tributaries

Water quality data were examined in detail for 29 tributaries in the LSJRB. Their selection was based upon several factors. First, the basin was divided into the 11 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 mainstem, and the south mainstem. Each Planning Unit is made up of several waterbodies (parts of the river system) referred to by their Waterbody Identification (WBID). 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, 2009, or 2014 (**DEP 2014f**), it was selected for analysis. Some unimpaired WBIDs were chosen because they are historically important or used frequently for recreation.

For each of these 29 tributaries, data were extracted (by characteristic) from Florida 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 (values in quotes are written as they are found in Florida STORET data fields).

- Data identified as "LEGACY STORET" (data is reported from 1997 onward).
- Data reported as "Present < PQL," where no Practical Quantitation Limit (PQL) was listed.
- Data reported as "Non-detect," where no Minimum Detection Level (MDL) was listed.
- Data with a matrix of "Ground Water," "Surface Water Sediment," and "Unknown."

Prior to the 2013 River Report, all "Non-detect" data had been removed. While seemingly a logical approach, the effect tends to bias the quartiles calculated in the data analysis on the high side. As a result, "Non-detect" data (and data reported as zero concentration) has been included in the data analysis here with a value MDL/2 (see **Helsel 2005**). In a similar manner, values listed as "Present < PQL", were included as (PQL+MDL)/2 if no "Actual value" was reported in the "Comments" field. If an "Actual value" was reported in the "Comments" field, it was used instead.

In the 'About' sections for each of the 29 tributaries below, information/data was taken from the TMDL documents about each tributary respectively, the Florida DEP comprehensive verified impaired list (**DEP 2014f**), and the final verified list (**DEP 2016j**) and delist list (**DEP 2016h**) from the recent Group 2 basins Cycle 3 assessment (**DEP 2016i**).

In the water quality data tables below, dissolved oxygen (DO) water quality criteria (WQC) where either based on Site Specific Alternate Criteria (SSAC) (**DEP 2014b**) for marine portions of the river or the new freshwater DO criteria based on DO saturation in water (DO_{sat}) (**DEP 2013l**). As both of these criteria definitions are calculation based, the WQCs indicated in the tables should be considered nominal values.

Finally, freshwater WQC's for metals were based off of 100 mg $CaCO_3$/L, the estimated hardness of the freshwater part of the LSJR (see Section 5.2.1 for more information).

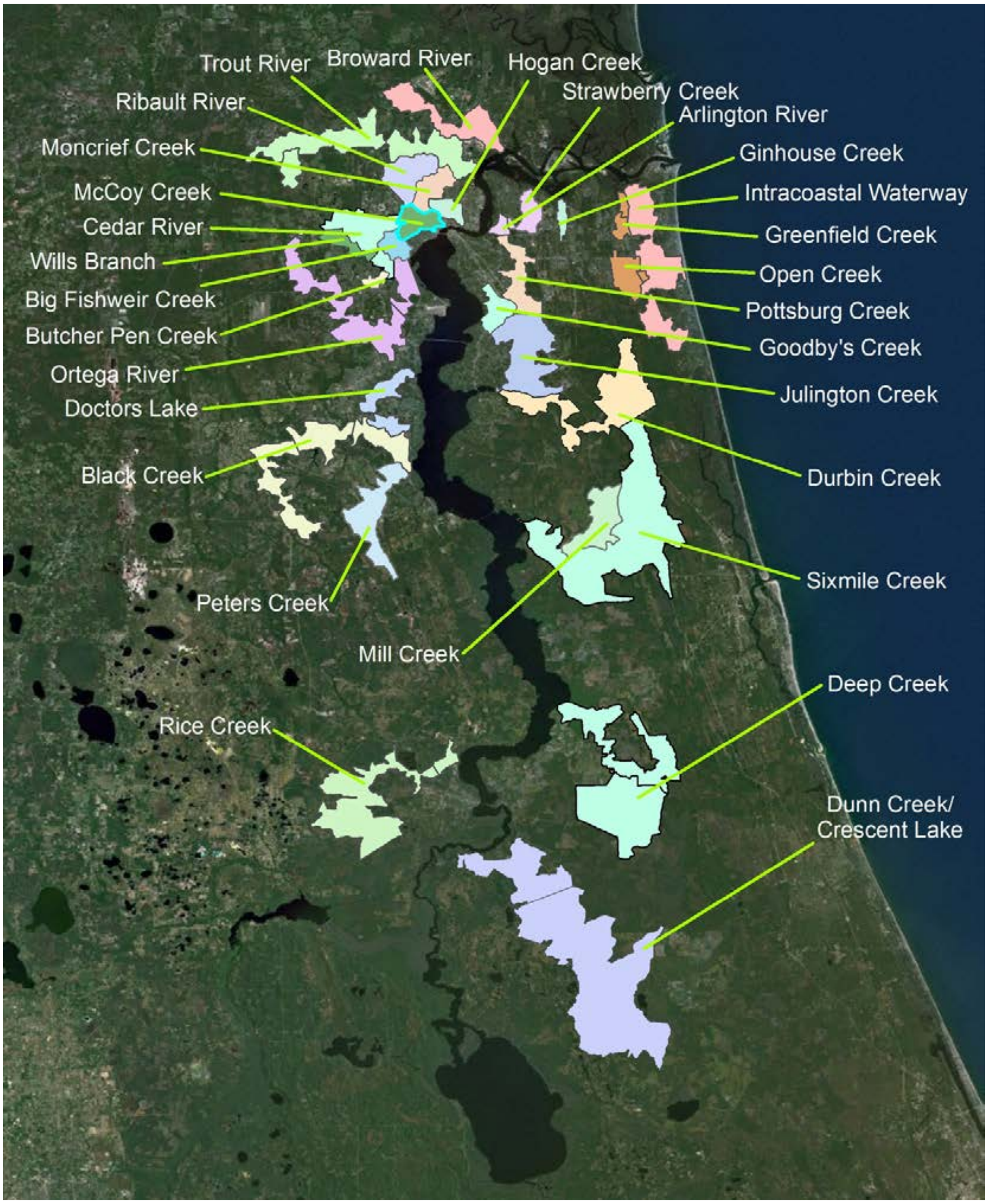


Figure 2.24 Tributaries of the Lower St. Johns River Basin.

2.7.2. Arlington River

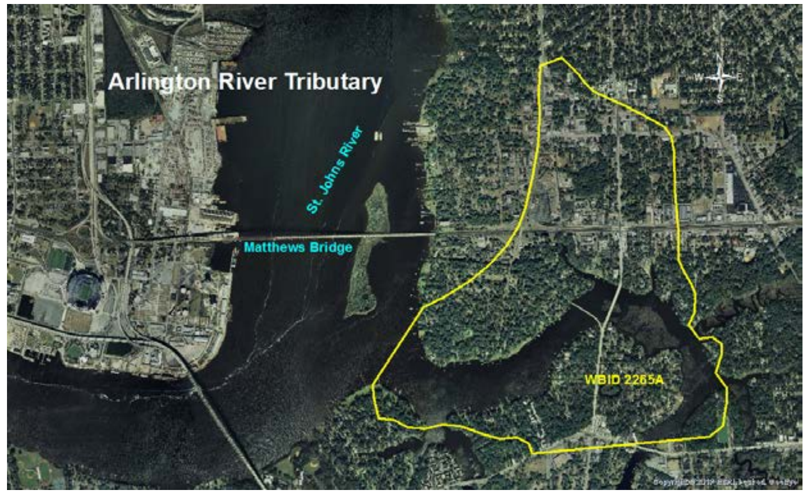


Figure 2.25 The Arlington River Tributary (WBID 2265A).

2.7.2.1. About the Arlington River

- East of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Nutrients, Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 1.6 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

2.7.2.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Arlington River WBID 2265A (**DEP 2014c**) shown above. No water quality data for the selected parameters discussed below for the Arlington River were available in STORET for 2015-2017.

2.7.2.3. Discussion

Average phosphorus levels were higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**) 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 report for nutrients was finalized in 2009 (**Magley 2009c**).

The Arlington River was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue; however, this is being delisted (**DEP 2016h**) as it has been addressed by the statewide mercury TMDL (**DEP 2013c**). The Arlington River is being delisted for chlorophyll-*a* as it has been addressed by the Nutrients TMDL (**DEP 2016h**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in the Arlington River are available in previous versions of the River Report.

2.7.3. Big Fishweir Creek

2.7.3.1. <u>About Big Fishweir Creek</u>

- West of Downtown, South of I-10
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009), Mercury
- Verified Impaired 2016 (final):
  Iron (2280A med)
- WBID Area: 3.7 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

Figure 2.26 Big Fishweir Creek (WBID 2280).

2.7.3.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Big Fishweir Creek WBID 2280, 2280A (freshwater), and 2280B (saltwater/marine) (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.3.

2.7.3.3. <u>Discussion</u>

Water quality data for Big Fishweir Creek are shown in Table 2.3. Big Fishweir Creek has been listed as Impaired for high levels of iron (**DEP 2016j**). A TMDL report (**Wainwright and Hallas 2009a**) was released in 2009 to address Fecal coliform, and Big Fishweir Creek has been delisted from the Impaired Waters list (**DEP 2016h**) (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Subsequently, a BMAP to address this issue was legally adopted (**DEP 2009b**). Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

The 2016 Annual Progress Report for this BMAP listed 16 active, ongoing projects underway by FDOT and JEA to address the BMAP in the Big Fishweir Creek watershed (**DEP 2017c**). FDEP reported improvement in the frequency of fecal coliform exceedances in the marine segment of Big Fishweir Creek, but recent fecal coliform measurements continue to show significant fecal coliform concentrations.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc

Historical water quality data for these parameters in Big Fishweir Creek are available in previous versions of the River Report.

Table 2.3 Water quality data for Big Fishweir Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	**2016**	**2017**
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	4.20 (6 of 24 samples)	3.27 (10 of 23 samples)	3.33 (7 of 16 samples)
	≥4.0 SW	3.65 (2 of 4 samples)	3.59 (1 of 1 sample)	4.14 (2 of 4 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.13 (6 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.60 (5 of 6 samples)
Chlorophyll-*a* (µg/L)	<20‡ FW	No data	No data	27.75 (4 of 4 samples)
	<5.4‡ SW	No data	No data	1.75 (0 of 2 samples)
Fecal Coliform (CFU/100 mL)	<400‡	7800 (28 of 28 samples)	3000 (24 of 25 samples)	3300 (12 of 12 samples)
Turbidity (NTU)	<29	No data	No data	4.57 (0 of 6 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.4. Black Creek

2.7.4.1. About Black Creek

- West of the St Johns River at the Clay/Duval county line
- Primary Land Use: Forested
- Current TMDL reports: Lead – 2415B, 2415C, Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 15.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

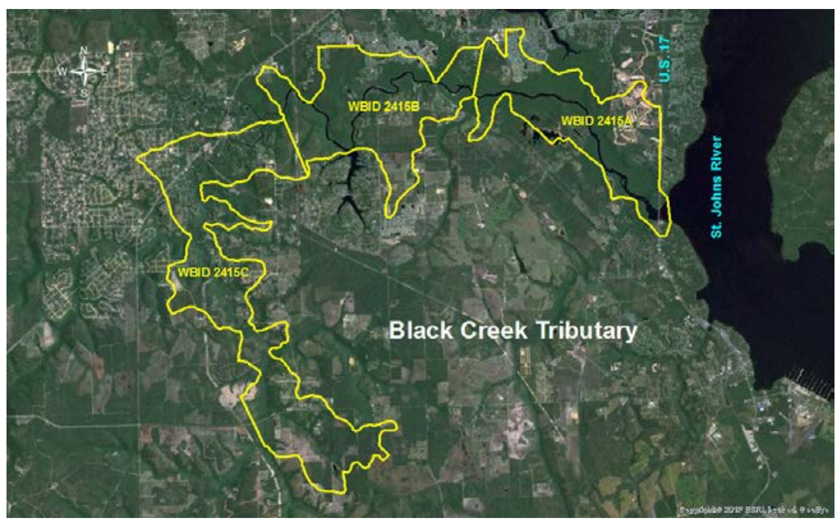


Figure 2.27 The Black Creek Tributary (WBID 2415A/B/C).

2.7.4.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Black Creek WBID 2415A/B/C (**DEP 2014c**) shown above. The aggregate (all three WBIDs) filtered dataset was used to generate Table 2.4.

2.7.4.3. Discussion

Water quality data for Black Creek are shown in Table 2.4. As compared to other tributaries in the LSJRB, Black Creek is less impacted for the majority of the assessed water quality parameters. Lead has been identified as impaired in Black Creek and a TMDL report was published in 2009 (**Lewis and Mandrup-Poulsen 2009**) to address this issue. Other metals, such as copper, nickel, and silver were detected previously at higher concentrations, but water quality data from recent years suggest that the concentrations of these metals have been reduced and controlled.

No recent measurements were available in STORET between 2015 and 2017 for the following parameter:

- Fecal coliform

Historical water quality data for this parameter in Black Creek are available in previous versions of the River Report.

Table 2.4 Water quality data for Black Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	5.62 (0 of 12 samples)	5.17 (0 of 14 samples)	5.23 (0 of 8 samples)
Nitrate-nitrite N (mg/L)§	§	0.04 (12 samples)	0.05 (13 samples)	0.06 (7 samples)
Total Phosphorus (mg/L)	<0.12‡	0.08 (1 of 8 samples)	0.08 (0 of 23 samples)	0.08 (0 of 13 samples)
Chlorophyll-*a* (µg/L)	<20‡	1.62 (0 of 12 samples)	1.70 (0 of 13 samples)	1.68 (0 of 7 samples)
Arsenic (µg/L)	≤50	0.95 (0 of 12 samples)	1.13 (0 of 12 samples)	0.99 (0 of 7 samples)
Cadmium (µg/L)	≤0.3	0.00 (0 of 12 samples)	0.03 (0 of 12 samples)	0.01 (0 of 7 samples)
Copper (µg/L)	≤9.3	0.84 (0 of 12 samples)	1.11 (0 of 12 samples)	0.85 (0 of 7 samples)
Lead (µg/L)	≤3.2	0.54 (0 of 12 samples)	0.42 (0 of 12 samples)	0.39 (0 of 7 samples)
Nickel (µg/L)	≤52	0.54 (0 of 12 samples)	0.51 (0 of 12 samples)	0.44 (0 of 7 samples)
Silver (µg/L)	≤0.07	0.00 (0 of 12 samples)	0.00 (0 of 12 samples)	0.01 (0 of 7 samples)
Zinc (µg/L)	≤120	6.87 (0 of 12 samples)	5.91 (0 of 12 samples)	3.39 (0 of 7 samples)
Turbidity (NTU)	<29	3.94 (0 of 11 samples)	2.45 (0 of 13 samples)	2.63 (0 of 6 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.5. *Broward River*

2.7.5.1. About the Broward River

- Between downtown and Jacksonville International Airport (JIA)
- Primary Land Use: Residential/Forested
- Current TMDL reports: Mercury
- Verified Impaired 2016 (final): Fecal Coliform (2191B low)
- WBID Area: 14.4 sq. mi.
- Beneficial Use: Class III M/ F (Marine - 2191B, Freshwater – 2191A)

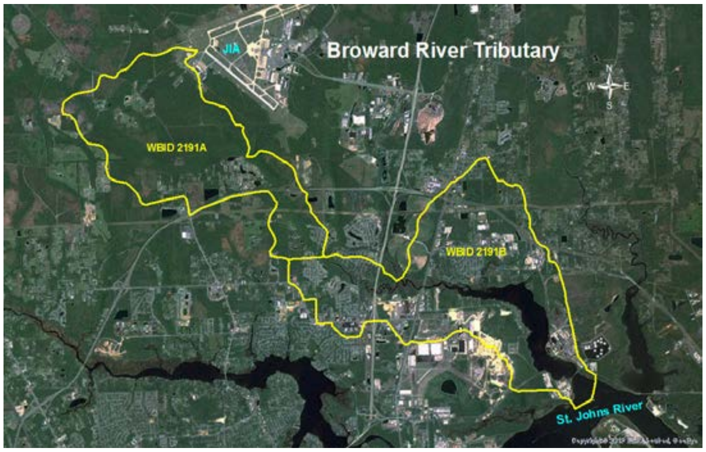


Figure 2.28 The Broward River Tributary (WBID 2191A/B).

2.7.5.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Broward River WBID 2191A/B (**DEP 2014c**) shown above. No water quality data for the selected parameters discussed below for the Broward River were available in STORET for 2015-2017.

2.7.5.3. Discussion

Historically, average phosphorus levels were higher than the 2010 updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**). Historical maximum fecal coliform level at times exceeded the WQC of 400 colony-forming-units per 100 mL, and as a result, WBID 2191B is considered impaired for fecal coliform. However, the last fecal coliform measurements reported for the Broward River date back to 2008, and no more recent data were available. The Broward River was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue; however, it is being delisted (**DEP 2016h**) as it has been addressed by the statewide mercury TMDL (**DEP 2013c**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in the Broward River are available in previous versions of the River Report.

2.7.6. Butcher Pen Creek

2.7.6.1. <u>About Butcher Pen Creek</u>

- A tributary of the Cedar River
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009), Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 1.31 sq. miles
- Beneficial Use: Class III F (Recreational – Freshwater)

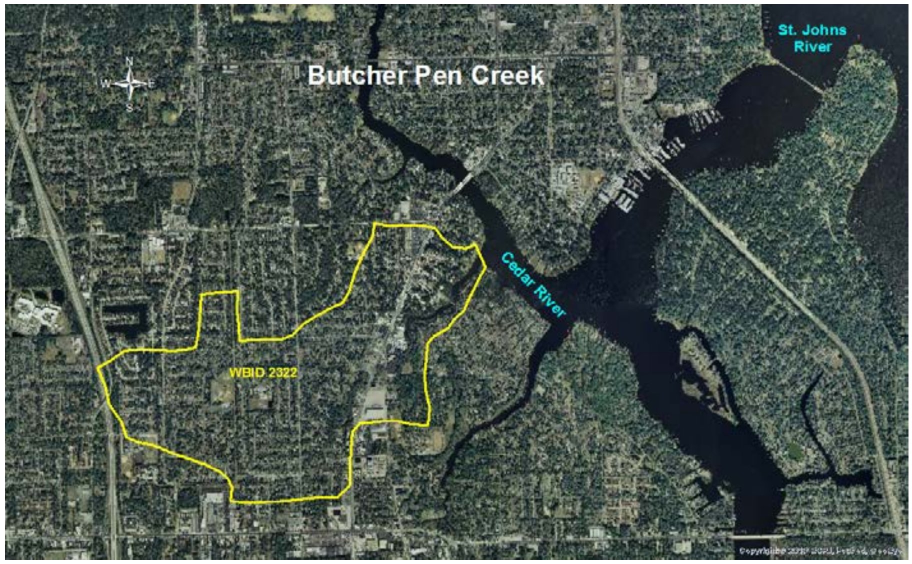


Figure 2.29 Butcher Pen Creek (WBID 2322).

2.7.6.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Butcher Pen Creek WBID 2322 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.5.

2.7.6.3. <u>Discussion</u>

Water quality data for Butcher Pen Creek are shown in Table 2.5. Historical phosphorus levels were higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**), but recent phosphorus data are lacking in STORET. The average fecal coliform level exceeded the WQC of 400 colony-forming-units per 100 mL in each of the last three years (Table 2.5). As a result, a TMDL report was published in 2005 (**Wainwright 2005a**) to address this issue. Subsequently, a BMAP to address this issue was legally adopted (**DEP 2009b**). Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

The 2016 Annual Progress Report for this BMAP listed 16 active, ongoing projects underway by FDOT and JEA to address the BMAP in the Butcher Pen Creek watershed (**DEP 2017c**). Despite these efforts, fecal coliform levels have remained high over the past three years. Butcher Pen Creek was previously impaired for chlorophyll-*a*, but annual levels have fallen below the nutrient threshold, and it has been delisted for chlorophyll-*a* (**DEP 2016h**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc

Historical water quality data for these parameters in Butcher Pen Creek are available in previous versions of the River Report.

Table 2.5 Water quality data for Butcher Pen Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	3.53 (6 of 15 samples)	3.67 (8 of 21 samples)	4.06 (5 of 16 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.09 (2 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.19 (2 of 2 samples)
Chlorophyll-*a* (μg/L)	<20‡	No data	No data	1.68 (0 of 7 samples)
Fecal Coliform (CFU/100 mL)	<400‡	10000 (15 of 15 samples)	1700 (15 of 22 samples)	3900 (11 of 12 samples)
Turbidity (NTU)	<29	No data	No data	4.90 (0 of 2 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.7. *Cedar River*

2.7.7.1. <u>About the Cedar River</u>

- At the I-10/I-295 Interchange
- Primary Land Use: Residential/Forested
- Current TMDL reports: Fecal/Total Coliform – 2262, Mercury
- Verified Impaired 2016 (final): Iron (2213P2, 2262B med)
- WBID Area: 22.8 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

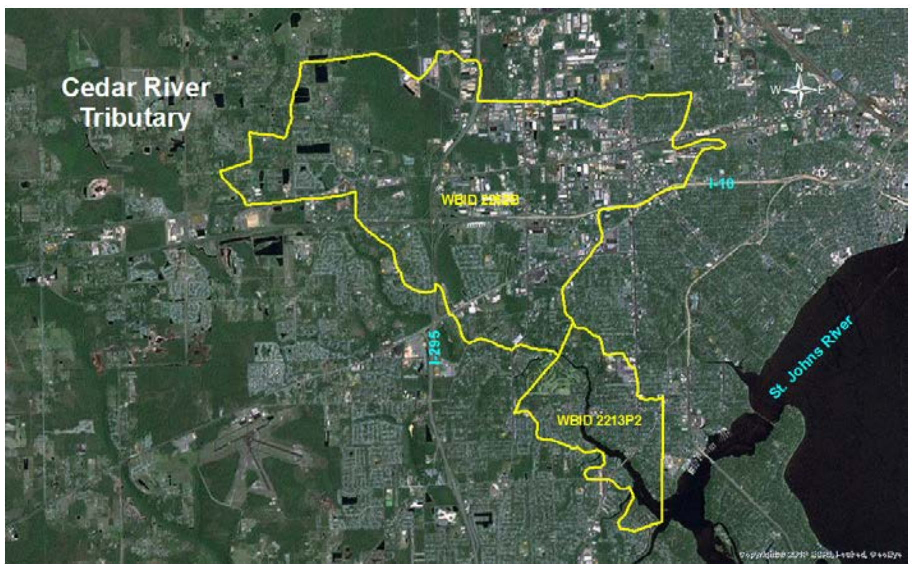


Figure 2.30 The Cedar River Tributary (WBID 2262 and 2213P2).

2.7.7.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Cedar River WBID 2262 and 2213P2 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.6.

2.7.7.3. <u>Discussion</u>

Water quality data for the Cedar River are shown in Table 2.6. 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 above the WQC and increasing over the past three years. Average total phosphorus levels have been near to or higher than

the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**). Concentrations of arsenic, copper, lead, and zinc have been decreasing over the past three years.

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 report was finalized in 2006 (**Magley 2006b**). (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Currently, a Basin Management Action Plan (BMAP) to address this impairment is under development, but the timeframe for its release is currently unknown. Additionally, no recent fecal coliform data were available in STORET for analysis.

No recent measurements were available in STORET between 2015 and 2017 for the following parameter:

- Fecal coliform

Historical water quality data for this parameter in the Cedar River are available in previous versions of the River Report.

Table 2.6 Water quality data for the Cedar River (2015-2017).

Parameters	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	6.42 (0 of 5 samples)	7.40 (0 of 6 samples)	8.09 (0 of 3 samples)
Nitrate-nitrite N (mg/L)§	§	0.16 (4 samples)	0.12 (6 samples)	0.08 (3 samples)
Total Phosphorus (mg/L)	<0.12‡	0.10 (3 of 10 samples)	0.10 (4 of 10 samples)	0.14 (4 of 6 samples)
Chlorophyll-*a* (µg/L)	<20‡	20.12 (2 of 5 samples)	14.11 (1 of 6 samples)	18.68 (2 of 3 samples)
Arsenic (µg/L)	≤50	2.17 (0 of 4 samples)	1.87 (0 of 6 samples)	1.64 (0 of 3 samples)
Cadmium (µg/L)	≤0.3	0.01 (0 of 4 samples)	0.01 (0 of 6 samples)	0.01 (0 of 3 samples)
Copper (µg/L)	≤9.3	2.28 (0 of 4 samples)	2.28 (0 of 6 samples)	1.97 (0 of 3 samples)
Lead (µg/L)	≤3.2	1.37 (0 of 4 samples)	1.09 (0 of 6 samples)	0.93 (0 of 3 samples)
Nickel (µg/L)	≤52	0.65 (0 of 4 samples)	0.56 (0 of 6 samples)	0.57 (0 of 3 samples)
Silver (µg/L)	≤0.07	0.01 (0 of 4 samples)	0.00 (0 of 6 samples)	0.02 (1 of 3 samples)
Zinc (µg/L)	≤120	8.19 (0 of 4 samples)	7.44 (0 of 6 samples)	5.98 (0 of 3 samples)
Turbidity (NTU)	<29	5.56 (0 of 4 samples)	3.01 (0 of 6 samples)	4.94 (0 of 3 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.8. Deep Creek

2.7.8.1. <u>About Deep Creek</u>

- East of the St. Johns at Palatka
- Primary Land Use: Forested, Row Crop Agriculture
- Current TMDL reports: Dissolved Oxygen – 2589, Mercury
- Verified Impaired 2016 (final): Iron (2589 med)
- WBID Area: 60.5 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

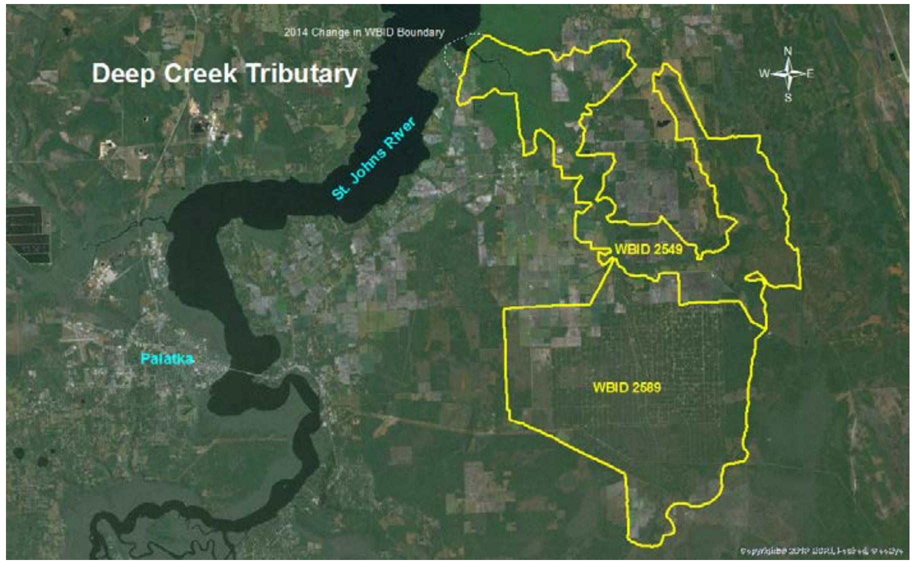


Figure 2.31 The Deep Creek Tributary (WBID 2549 and 2589).

2.7.8.2. <u>Data sources</u>

Data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Deep Creek WBIDs 2549 and 2589 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.7.

2.7.8.3. <u>Discussion</u>

Water quality data for Deep Creek are shown in Table 2.7. 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. Historical concentrations of total nitrogen were elevated but not above the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**), but recent data regarding nitrogen concentrations in the Deep Creek watershed are not available in STORET. Levels of total phosphorus were significantly above the recommended WQC (Figure 2.31). Non-point source rainwater runoff is likely the major cause of the elevated nitrogen/phosphorus concentrations in this area. Chlorophyll-*a* has been removed from the recent verified impaired list, as the annual geometric mean chlorophyll-*a* concentrations have not exceeded the WQC (20 µg/L) more than once over the past three years, but there appears to be an increasing trend in chlorophyll-*a* concentrations.

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 report for dissolved oxygen was published in 2009 (**Magley 2009d**) for WBID 2589 (Sixteen Mile Creek). Elevated concentrations of cadmium, copper, nickel, and silver were measured previously in Deep Creek, as compared to the Class III WQC for metals, but recent data suggest that these concentrations have held steady below the WQC.

No recent measurements were available in STORET from 2015 to 2017 for the following parameters:

- Nitrate-nitrite nitrogen
- Lead
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in Deep Creek are available in previous versions of the River Report.

Table 2.7 Water quality data for Deep Creek (2015-2017).

Parameters	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	4.04 (6 of 19 samples)	4.13 (8 of 17 samples)	4.65 (2 of 9 samples)
Total Phosphorus (mg/L)	<0.12‡	0.31 (22 of 31 samples)	0.27 (26 of 34 samples)	0.22 (11 of 17 samples)
Chlorophyll-*a* (µg/L)	<20‡	1.77 (0 of 18 samples)	3.11 (0 of 17 samples)	7.86 (1 of 9 samples)
Arsenic (µg/L)	≤50	0.96 (0 of 18 samples)	1.03 (0 of 17 samples)	0.72 (0 of 8 samples)
Cadmium (µg/L)	≤0.3	0.02 (0 of 18 samples)	0.01 (0 of 17 samples)	0.07 (0 of 8 samples)
Copper (µg/L)	≤9.3	1.27 (0 of 18 samples)	1.21 (0 of 17 samples)	1.06 (0 of 8 samples)
Nickel (µg/L)	≤52	0.47 (0 of 18 samples)	0.43 (0 of 17 samples)	0.46 (0 of 8 samples)
Silver (µg/L)	≤0.07	0.00 (1 of 18 samples)	0.00 (0 of 17 samples)	0.01 (1 of 8 samples)
Zinc (µg/L)	≤120	5.52 (0 of 18 samples)	9.01 (0 of 17 samples)	7.56 (0 of 8 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.9. *Doctors Lake*

2.7.9.1. About Doctors Lake

- West of the St. Johns River in Clay County
- Primary Land Use: Forested
- Current TMDL reports: Nutrient (2389), DO/Nutrient (2410), Silver (2389/2410), Mercury
- Verified Impaired 2016 (final): Nutrients (Chlorophyll-*a* 2389 med), Nutrients (Total P 2389 med)
- WBID Area: 8.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

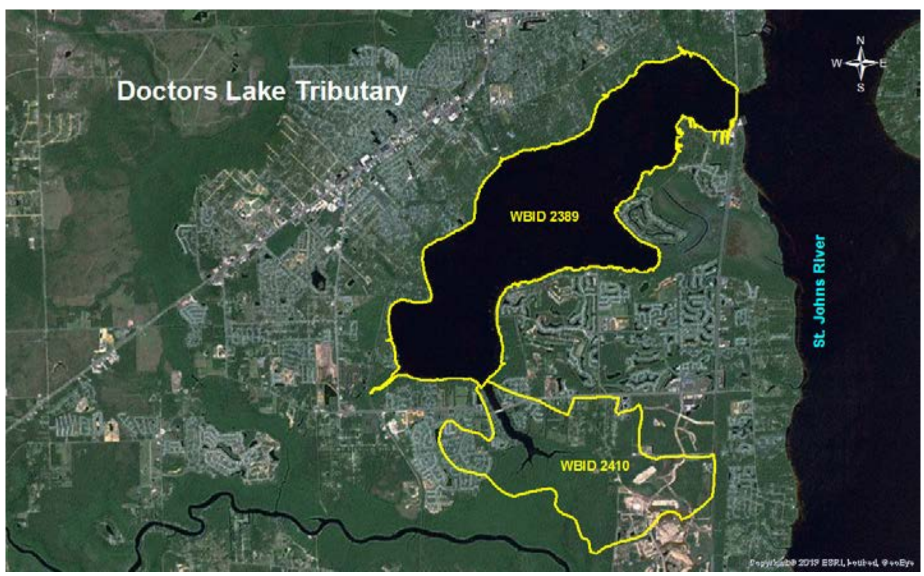


Figure 2.32 The Doctors Lake Tributary (WBID 2389 and 2410).

2.7.9.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Doctors Lake WBIDs 2389 and 2410 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.8, with freshwater stream WQC's reported. These should be regarded as guidelines only because Swimming Pen creek (2410) is accessed as a stream, Doctors Lake (2389) is accessed as a lake and has different WQC's.

2.7.9.3. Discussion

Water quality data for Doctors Lake are shown in Table 2.8. Average chlorophyll-*a* concentrations far exceeded the WQC, and this has worsened over the past three years. The average total phosphorus concentration has hovered around the

criterion value for colored lakes (0.05 mg/L) the past three years. Average dissolved oxygen levels are well above the SSAC. Thus, Doctors Lake has been identified as being impaired for nutrients (chlorophyll-*a* and total phosphorus) (**DEP 2016j**), and the final TMDL report to address this has been published (**Magley 2009e**).

Elevated maximum arsenic, cadmium, copper, nickel, silver, and zinc concentrations were previously measured in Doctors Lake, and as a result, EPA has published a Silver TMDL (**EPA 2010a**). 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. Recent data show that concentrations of these contaminants have remained roughly steady over the past three years.

No recent measurements were available in STORET from 2015 to 2017 for the following parameters:

- Nitrate-nitrite nitrogen
- Lead
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in Doctors Lake are available in previous versions of the River Report.

Table 2.8 Water quality data for Doctors Lake (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	6.87 (3 of 36 samples)	8.34 (0 of 27 samples)	7.90 (1 of 20 samples)
Total Phosphorus (mg/L)	<0.05‡	0.07 (12 of 20 samples)	0.06 (7 of 16 samples)	0.07 (7 of 14 samples)
Chlorophyll-*a* (µg/L)	<20‡	27.48 (5 of 12 samples)	23.59 (4 of 9 samples)	117.02 (5 of 8 samples)
Arsenic (µg/L)	≤50	1.75 (0 of 11 samples)	1.56 (0 of 9 samples)	2.40 (0 of 6 samples)
Cadmium (µg/L)	≤0.3	0.00 (0 of 11 samples)	0.00 (0 of 9 samples)	0.06 (0 of 6 samples)
Copper (µg/L)	≤9.3	1.01 (0 of 11 samples)	1.00 (0 of 9 samples)	0.95 (0 of 6 samples)
Nickel (µg/L)	≤52	0.25 (0 of 11 samples)	0.38 (0 of 9 samples)	0.22 (0 of 6 samples)
Silver (µg/L)	≤0.07	0.04 (0 of 11 samples)	0.00 (0 of 9 samples)	0.00 (0 of 6 samples)
Zinc (µg/L)	≤120	2.33 (0 of 11 samples)	1.39 (0 of 9 samples)	1.29 (0 of 6 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.10. Dunns Creek/Crescent Lake

Figure 2.33 The Dunns Creek/Crescent Lake Tributary (WBID 2606A/B).

2.7.10.1. About Dunns Creek/Crescent Lake

- East of the St. Johns River in Flagler County
- Primary Land Use: Forested/Wetlands
- Current TMDL reports:
  Nutrients (2606B), Mercury
- Verified Impaired 2016 (final): Fecal Coliform (2606A low), Nutrients (Chlorophyll-*a*, Total P 2606B med)
- WBID Area: 585 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

2.7.10.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Dunns Creek/Crescent Lake WBIDs 2606A/B (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.9, with freshwater stream WQC's reported. These should be regarded as guidelines only because Dunns Creek (2606A) is accessed as a stream, Crescent Lake (2606B) is accessed as a lake and has different WQC's.

2.7.10.3. Discussion

Water quality data for Dunns Creek/Crescent Lake are shown in Table 2.9. Dunns Creek (WBID 2606A) was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, however this is being delisted (**DEP 2016h**) as it has been addressed by the statewide mercury TMDL (**DEP 2013c**).

This tributary is a significant non-point-source contributor to nutrient levels in the St. Johns River (**Magley and Joyner 2008**), and a TMDL for Nutrients was adopted (**DEP 2017a**) for Crescent Lake based on its Trophic State Index (TSI), calculated from the total nitrogen (TN), total phosphorus (TP), and chlorophyll-*a* levels. Crescent Lake is listed on the final verified list for chlorophyll-*a* and total phosphorus (**DEP 2016j**). Data for total phosphorus concentrations were available for Crescent Lake (2606B) for the past three years, but no new measurements of total phosphorus in Dunns Creek were available in STORET after 2014. The average total phosphorus concentration in Crescent Lake has hovered around the criterion value for colored lakes (0.05 mg/L) the past three years.

No recent measurements were available in STORET from 2015 to 2017 for the following parameter:

- Fecal Coliform

Historical water quality data for this parameter in Dunns Creek/Crescent Lake are available in previous versions of the River Report.

Table 2.9 Water quality data for Dunns Creek/Crescent Lake (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	6.72 (4 of 81 samples)	7.62 (1 of 45 samples)	7.38 (0 of 18 samples)
Nitrate-nitrite N (mg/L)§	§	0.06 (32 samples)	0.04 (19 samples)	0.01 (6 samples)
Total Phosphorus (mg/L)	<0.05‡	0.05 (28 of 54 samples)	0.06 (19 of 33 samples)	0.04 (6 of 16 samples)
Chlorophyll-*a* (µg/L)	<20‡	19.56 (13 of 32 samples)	17.98 (5 of 20 samples)	24.96 (5 of 8 samples)
Arsenic (µg/L)	≤50	1.03 (0 of 29 samples)	0.88 (0 of 17 samples)	0.92 (0 of 8 samples)
Cadmium (µg/L)	≤0.3	0.02 (0 of 29 samples)	0.00 (0 of 17 samples)	0.06 (0 of 8 samples)
Copper (µg/L)	≤9.3	0.51 (0 of 29 samples)	0.84 (0 of 17 samples)	0.76 (0 of 8 samples)
Lead (µg/L)	≤3.2	0.40 (0 of 29 samples)	0.41 (0 of 17 samples)	0.36 (0 of 8 samples)
Nickel (µg/L)	≤52	0.29 (0 of 29 samples)	0.30 (0 of 17 samples)	0.47 (0 of 8 samples)
Silver (µg/L)	≤0.07	0.01 (0 of 29 samples)	0.00 (0 of 17 samples)	0.01 (0 of 8 samples)
Zinc (µg/L)	≤120	2.02 (0 of 29 samples)	1.29 (0 of 17 samples)	1.21 (0 of 8 samples)
Turbidity (NTU)	<29	4.21 (0 of 24 samples)	4.33 (0 of 19 samples)	8.67 (0 of 7 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.11. *Durbin Creek*

2.7.11.1. <u>About Durbin Creek</u>

- East of the St. Johns River South of I-295
- Primary Land Use: Forested
- Current TMDL reports: Fecal Coliform, Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 26.2 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

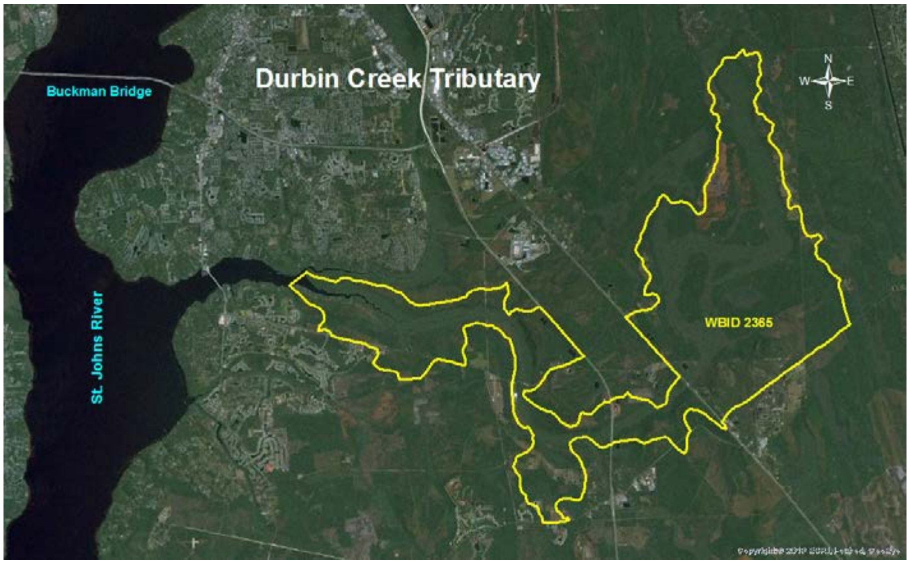


Figure 2.34 The Durbin Creek Tributary (WBID 2365).

2.7.11.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Durbin Creek WBID 2365 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.10.

2.7.11.3. Discussion

Water quality data for Durbin Creek are shown in Table 2.10. Historically, average dissolved oxygen levels in Durbin Creek were relatively low when compared to other tributaries of the LSJRB. However, no causative pollutant (specific environmental condition) has been identified, and thus no TMDL report is required as it is the "natural condition" of the water body (**DEP 2009c**). A TMDL report is available for fecal coliform in Durbin Creek (**Magley 2006a**). (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). However, the last valid measurements of fecal coliform available in STORET date back to 2008.

No recent measurements were available in STORET from 2015 to 2017 for the following parameter:

- Fecal Coliform

Historical water quality data for this parameter in Durbin Creek are available in previous versions of the River Report.

Table 2.10 Water quality data for Durbin Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	4.02 (2 of 7 samples)	3.67 (2 of 7 samples)	5.93 (0 of 3 samples)
Nitrate-nitrite N (mg/L)§	§	0.05 (7 samples)	0.07 (6 samples)	0.05 (3 samples)
Total Phosphorus (mg/L)	<0.12‡	0.11 (4 of 12 samples)	0.09 (1 of 9 samples)	0.06 (0 of 6 samples)
Chlorophyll-*a* (µg/L)	<20‡	0.88 (0 of 7 samples)	0.73 (0 of 6 samples)	0.61 (0 of 3 samples)
Arsenic (µg/L)	≤50	0.50 (0 of 4 samples)	0.41 (0 of 5 samples)	0.41 (0 of 3 samples)
Cadmium (µg/L)	≤0.3	0.03 (0 of 4 samples)	0.03 (0 of 5 samples)	0.03 (0 of 3 samples)
Copper (µg/L)	≤9.3	0.51 (0 of 4 samples)	0.49 (0 of 5 samples)	0.27 (0 of 3 samples)
Lead (µg/L)	≤3.2	0.45 (0 of 4 samples)	0.46 (0 of 5 samples)	0.26 (0 of 3 samples)
Nickel (µg/L)	≤52	0.47 (0 of 4 samples)	0.50 (0 of 5 samples)	1.06 (0 of 3 samples)
Silver (µg/L)	≤0.07	0.00 (0 of 4 samples)	0.00 (0 of 5 samples)	0.00 (0 of 3 samples)
Zinc (µg/L)	≤120	4.10 (0 of 4 samples)	6.74 (0 of 5 samples)	3.82 (0 of 3 samples)
Turbidity (NTU)	<29	4.21 (0 of 6 samples)	6.83 (0 of 6 samples)	4.98 (0 of 3 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.12. Ginhouse Creek

2.7.12.1. About Ginhouse Creek

- South of the St. Johns River just west of Craig Airfield
- Primary Land Use: Residential
- Current TMDL reports: Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 2.0 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.35 The Ginhouse Creek Tributary (WBID 2248).

2.7.12.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Ginhouse Creek WBID 2248 (**DEP 2014c**) shown above. No water quality data for the selected parameters discussed below for Ginhouse Creek were available in STORET for 2015-2017.

2.7.12.3. Discussion

No water quality data are available for Ginhouse Creek after 2014, and no data for arsenic, cadmium, copper, lead, nickel, silver, and zinc were available in STORET going back to 2005. Average fecal coliform levels were elevated and above the WQC as of 2013, but Ginhouse Creek is not currently identified as impaired. No current data regarding Fecal Coliform are available in STORET.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in Ginhouse Creek are available in previous versions of the River Report.

2.7.13. Goodbys Creek

2.7.13.1. About Goodbys Creek

- East of the St. Johns River opposite NAS Jacksonville
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009), Mercury
- Verified Impaired 2016 (final):
  None
- WBID Area: 5.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

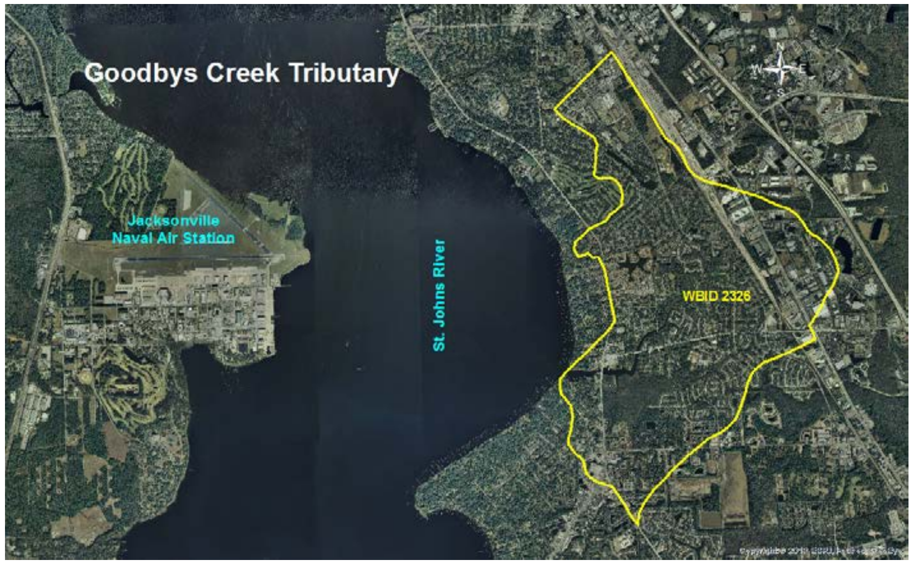


Figure 2.36 The Goodbys Creek Tributary (WBID 2326).

2.7.13.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Goodbys Creek WBID 2326, 2326A (freshwater), and 2326B ((**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.11.

2.7.13.3. Discussion

Water quality data for Goodbys Creek are shown in Table 2.11. Previous average phosphorus levels in Goodbys Creek exceeded the recently updated WQC (**EPA 2010b**), but recent data suggest that the average phosphorus levels have held roughly steady near the WQC. Average dissolved oxygen in the freshwater portion of Goodbys Creek (2326A) is above the WQC, but the limited sampling performed in the saltwater portion (2326B) indicates lower dissolved oxygen levels with a higher frequency of low dissolved oxygen measurements. Similarly, chlorophyll-*a* concentrations in the freshwater portion of Goodbys Creek were within acceptable limits, but average chlorophyll-*a* concentrations in the marine portion are at or above the WQC. There are limited data in STORET regarding water quality in general in the marine portion of Goodbys Creek.

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. A TMDL report is available for fecal coliform in Goodbys Creek (**Wainwright 2005b**). (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Subsequently, a BMAP for Goodbys Creek was legally adopted in 2009 (**DEP 2009b**). The 2016 Annual Progress Report for this BMAP listed 18 active, ongoing projects underway by FDOT and JEA to address the BMAP in the Goodbys Creek watershed (**DEP 2017c**). FDEP reported improvement in the frequency of fecal coliform exceedances in the marine segment of Goodbys Creek, and recent fecal coliform measurements agree with this assessment. Average fecal coliform concentrations appear to be trending downward and were around the WQC in 2017. Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

Table 2.11 Water quality data for Goodbys Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	4.88 (1 of 18 samples)	5.02 (3 of 12 samples)	5.14 (0 of 9 samples)
	≥4.0 SW	3.88 (6 of 9 samples)	2.40 (1 of 1 samples)	4.06 (2 of 4 samples)
Nitrate-nitrite N (mg/L)§	§	0.12 (11 samples)	No data	0.07 (6 samples)
Total Phosphorus (mg/L)	<0.12‡	0.10 (0 of 11 samples)	No data	0.13 (0 of 6 samples)
Chlorophyll-*a* (µg/L)	<20‡ FW	1.55 (0 of 6 samples)	No data	1.70 (0 of 2 samples)
	<5.4‡ SW	10.40 (2 of 5 samples)	No data	12.43 (3 of 4 samples)
Arsenic (µg/L)	≤50 FW	No data	No data	4.18 (0 of 2 samples)
Cadmium (µg/L)	≤0.3 FW	No data	No data	0.01 (0 of 2 samples)
Copper (µg/L)	≤9.3 FW	No data	No data	0.40 (0 of 2 samples)
Lead (µg/L)	≤3.2 FW	No data	No data	0.10 (0 of 2 samples)
Nickel (µg/L)	≤52 FW	No data	No data	0.35 (0 of 2 samples)
Silver (µg/L)	≤0.07 FW	No data	No data	0.01 (0 of 2 samples)
Zinc (µg/L)	≤120 FW	No data	No data	2.50 (0 of 2 samples)
Fecal Coliform (CFU/100 mL)	<400‡	580 (8 of 16 samples)	530 (7 of 13 samples)	380 (2 of 6 samples)
Turbidity (NTU)	<29	6.25 (0 of 11 samples)	No data	5.97 (0 of 6 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.14. Greenfield Creek

2.7.14.1. About Greenfield Creek

- West of the Intracoastal Waterway
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2010),
  Mercury
- Verified Impaired 2016 (final):
  None
- WBID Area: 2.9 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

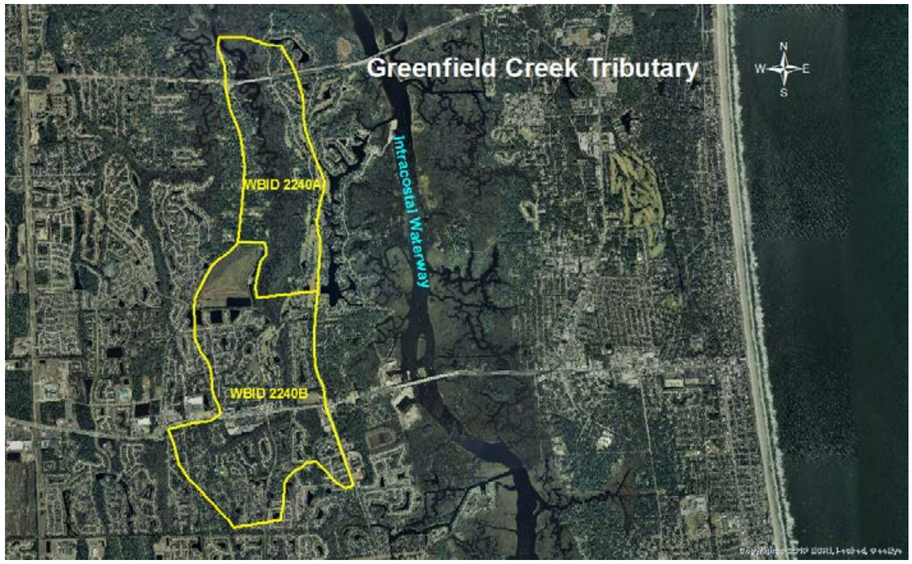


Figure 2.37 Greenfield Creek (WBID 2240A/B).

2.7.14.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Greenfield Creek WBID 2240A (marine) and 2240B (freshwater) (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.12.

2.7.14.3. Discussion

Water quality data for Greenfield Creek are shown in Table 2.12. Average phosphorus levels were historically higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**), but data from 2017 indicate that average concentrations of phosphorus, of dissolved oxygen, and of chlorophyll-*a* concentrations were within acceptable limits. However, only limited data are available in STORET for these parameters, and these measurements are all taken from the marine portion of Greenfield Creek (2240A). Dissolved oxygen had been removed from the verified impaired list (**DEP 2016j**) in Greenfield Creek. Greenfield Creek was verified impaired for mercury (**DEP 2016j**), but this has been addressed in the statewide mercury TMDL already in place (**DEP 2013c**).

A TMDL report (**Wainwright and Hallas 2009a**) was released to address fecal coliform, and a BMAP for Greenfield Creek (**DEP 2010a**) was legally adopted 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 2016 Annual Progress Report for this BMAP listed 20 active, ongoing projects underway by FDOT and JEA to address the BMAP in the Greenfield Creek watershed (**DEP 2017c**). FDEP reported improvement in the frequency of fecal coliform exceedances in the freshwater segment of Greenfield Creek, but the last fecal coliform measurements in Greenfield Creek date back to 2008. Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform

Historical water quality data for these parameters in Greenfield Creek are available in previous versions of the River Report.

Table 2.12 Water quality data for Greenfield Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	No data	No data	No data
	≥4.0 SW	No data	No data	4.87 (0 of 4 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.05 (4 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.07 (0 of 4 samples)
Chlorophyll-*a* (µg/L)	<20‡ FW	No data	No data	No data
	<5.4‡ SW	No data	No data	6.58 (0 of 4 samples)
Turbidity (NTU)	<29 SW	No data	No data	8.45 (0 of 4 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.15. Hogan Creek

2.7.15.1. <u>About Hogan Creek</u>

- Downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009),
  Mercury
- Verified Impaired 2016 (final):
  None
- WBID Area: 3.4 sq. mi.
- Beneficial Use: Class III F
  (Recreational – Freshwater)

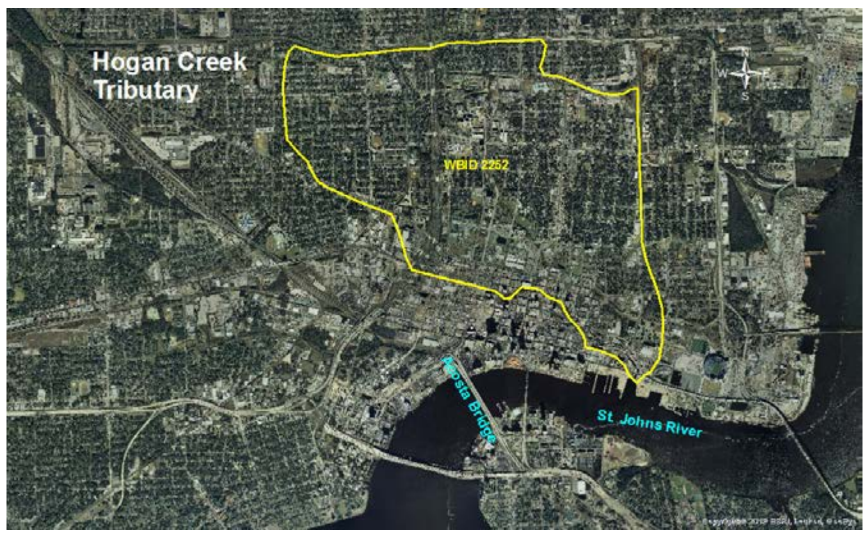


Figure 2.38 The Hogan Creek Tributary (WBID 2252).

2.7.15.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Hogan Creek WBID 2252 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.13.

2.7.15.3. <u>Discussion</u>

Water quality data for Hogan Creek are shown in Table 2.13. No data were available in STORET for 2015 or 2016, and only two measurements were performed in 2017, limiting the utility of these measurements in assessing the water quality in Hogan Creek. Historical average phosphorus levels were higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**), and the average phosphorus level in 2017 was near the WQC. Chlorophyll-*a* and dissolved oxygen concentrations appear to be within acceptable limits.

A TMDL for fecal coliform in Hogan Creek was finalized in 2006 (**Wainwright 2006d**). (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Subsequently, a BMAP for Hogan Creek was legally adopted in

December 2009 (**DEP 2009b**). Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2. The 2016 Annual Progress Report for this BMAP listed 21 active, ongoing projects underway by FDOT and JEA and 2 projects completed in 2016 (pump station rebuilding by JEA, flood improvements by COJ) to address the BMAP in the Hogan Creek watershed (**DEP 2017c**). FDEP reported improvement in the frequency of fecal coliform exceedances in the freshwater segment of Hogan Creek, but the last fecal coliform measurements in Hogan Creek available in STORET date back mainly to 2008, with a single measurement in 2011.

In 2012, COJ worked with the U.S. Army Corps of Engineers to investigate the potential to remediate and restore the aquatic ecosystem through removal of accumulated sediment, removal of exotic vegetation, and creation of wetland habitats. Fourteen sites within the Hogan Creek watershed were under consideration for restoration, but sampling of ten of these sites in 2003 revealed hazardous, toxic, and radioactive waste contamination in both the creek itself and the adjacent lands. Ash deposits dating back to the early 20th century can be found in the Hogan Creek watershed, and these are known sources of hazardous and toxic waste. Removal of these hazardous materials would prevent them from leaching into the creek and being taken up by plants and animals, but this (potentially extensive) work would need to be performed and paid for by either COJ or an organization contracted by COJ to do so. The USACE elected not to proceed with any work or action until these hazardous materials were removed, after which the project could be reconsidered (**USACE 2012a**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameter:

- Fecal Coliform

Historical water quality data for this parameter in Hogan Creek are available in previous versions of the River Report.

Table 2.13 Water quality data for Hogan Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	No data	No data	3.75 (0 of 2 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.12 (2 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.11 (0 of 2 samples)
Chlorophyll-*a* (μg/L)	<20‡	No data	No data	8.15 (0 of 2 samples)
Arsenic (μg/L)	≤50	No data	No data	1.62 (0 of 2 samples)
Cadmium (μg/L)	≤0.3	No data	No data	0.02 (0 of 2 samples)
Copper (μg/L)	≤9.3	No data	No data	1.68 (0 of 2 samples)
Lead (μg/L)	≤3.2	No data	No data	1.90 (0 of 2 samples)
Nickel (μg/L)	≤52	No data	No data	0.46 (0 of 2 samples)
Silver (μg/L)	≤0.07	No data	No data	0.01 (0 of 2 samples)
Zinc (μg/L)	≤120	No data	No data	7.80 (0 of 2 samples)
Turbidity (NTU)	<29	No data	No data	4.60 (0 of 2 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.16. Intracoastal Waterway

2.7.16.1. About the Intracoastal Waterway

- Near the mouth of the St. Johns River
- Primary Land Use: Marsh/Wetland (Land Cover)
- Current TMDL reports: Mercury
- Verified Impaired 2016 (final): Fecal Coliform (low), Iron (med)
- WBID Area: 23.9 sq. mi.
- Beneficial Use: Class III M (Recreational – Marine)

Figure 2.39 The Intracoastal Waterway Tributary (WBID 2205C).

2.7.16.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Intracoastal Waterway (ICW) WBID 2205C (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.14.

2.7.16.3. Discussion

Water quality data for the ICW are shown in Table 2.14. All parameters listed are within normal limits, although arsenic concentrations are higher compared to other tributaries. Some metals (lead, silver) have decreased in concentration over the past three years, while the others have remained steady. Based on these data, the ICW is relatively healthy and does not appear to provide a significant nutrient load to the St. Johns River. The Intracoastal Waterway was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue, which is addressed by the statewide mercury TMDL (**DEP 2013c**). The Intracoastal Waterway was also identified as being impaired for iron and fecal coliform (**DEP 2016j**); however, no new fecal coliform measurements have been reported in STORET since 2007.

No recent measurements were available in STORET between 2015 and 2017 for the following parameter:

- Fecal Coliform

Historical water quality data for this parameter in the Intracoastal Waterway are available in previous versions of the River Report.

Table 2.14 Water quality data for the Intracoastal Waterway (2015-2017).

Parameter	Water Quality Criteria (SW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥4.0	5.67 (2 of 18 samples)	6.36 (0 of 6 samples)	5.66 (1 of 14 samples)
Nitrate-nitrite N (mg/L)§	§	0.06 (9 samples)	0.11 (3 samples)	0.04 (8 samples)
Total Phosphorus (mg/L)	<5.4‡	3.53 (1 of 9 samples)	2.59 (0 of 3 samples)	4.20 (2 of 9 samples)
Chlorophyll-*a* (µg/L)	<11‡	3.53 (0 of 9 samples)	2.59 (0 of 3 samples)	4.20 (0 of 9 samples)
Arsenic (µg/L)	≤50	7.40 (0 of 16 samples)	18.19 (0 of 6 samples)	10.99 (0 of 10 samples)
Cadmium (µg/L)	≤8.8	0.06 (0 of 16 samples)	0.09 (0 of 6 samples)	0.18 (0 of 10 samples)
Copper (µg/L)	≤3.7	1.27 (0 of 16 samples)	1.19 (0 of 6 samples)	1.36 (0 of 10 samples)
Lead (µg/L)	≤8.5	0.48 (0 of 16 samples)	0.14 (0 of 6 samples)	0.11 (0 of 10 samples)
Nickel (µg/L)	≤8.3	0.30 (0 of 16 samples)	0.54 (0 of 6 samples)	0.58 (0 of 10 samples)
Silver (µg/L)	≤0.92*	0.08 (0 of 16 samples)	0.03 (0 of 6 samples)	0.01 (0 of 10 samples)
Zinc (µg/L)	≤86	3.25 (0 of 16 samples)	2.70 (0 of 6 samples)	3.02 (0 of 10 samples)
Turbidity (NTU)	<29	19.96 (2 of 9 samples)	3.96 (0 of 3 samples)	6.98 (0 of 9 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.17. *Julington Creek*

2.7.17.1. <u>About Julington Creek</u>

- East of the St. Johns River at the I-95/I-295/9A intersection
- Primary Land Use: Marsh/Wetland (Land Cover)
- Current TMDL reports: Fecal Coliform, Mercury
- Verified Impaired 2016 (final): Iron (med)
- WBID Area: 20.4 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

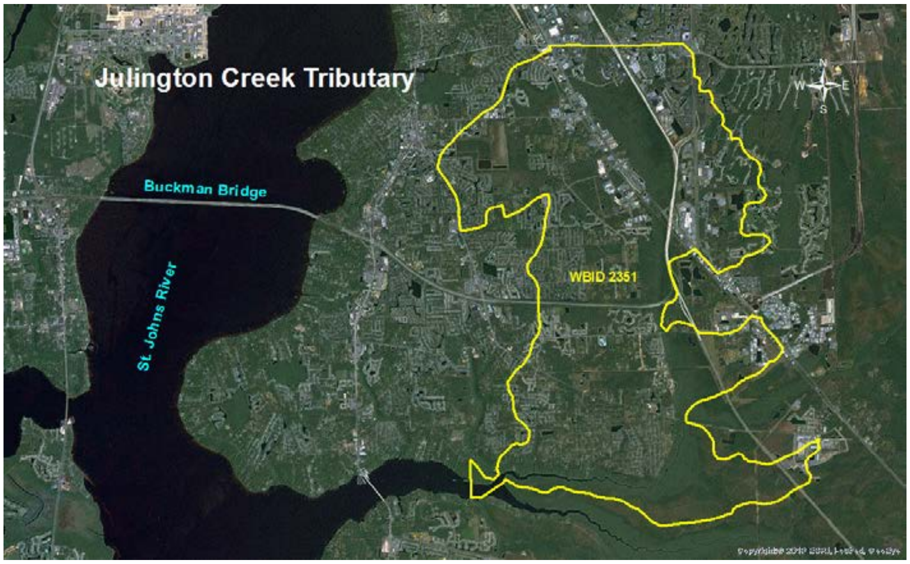


Figure 2.40 The Julington Creek Tributary (WBID 2351).

2.7.17.2. <u>Data sources</u>

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Julington Creek WBID 2351 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.15.

2.7.17.3. Discussion

Water quality data for Julington Creek are shown in Table 2.15, but the data available in STORET for Julington Creek are extremely limited, with no measurements reported for 2017. Julington Creek was identified as being impaired for iron (**DEP 2016j**).

The fecal coliform level, averaged over all the stations in Julington Creek, were historically higher than the WQC of 400 colony-forming-units (CFU) per 100 mL. Thus, a TMDL for fecal coliform was published in 2009 (**Rhew 2009c**). (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Limited measurements from 2015 and 2016 indicate fecal coliform levels that are near or slightly lower than the WQC, but no new data were reported for 2017.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Turbidity

Historical water quality data for these parameters in Julington Creek are available in previous versions of the River Report.

Table 2.15 Water quality data for Julington Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	5.97 (0 of 2 samples)	7.54 (0 of 4 samples)	No data
Fecal Coliform (CFU/100 mL)	<400‡	300 (1 of 4 samples)	400 (2 of 4 samples)	No data

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.18. McCoy Creek

2.7.18.1. About McCoy Creek

- West of the St. Johns River Downtown
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform, Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 5.34 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.41 The McCoy Creek Tributary (WBID 2257).

2.7.18.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in McCoy Creek WBID 2257 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.16.

2.7.18.3. Discussion

Water quality data for McCoy Creek are shown in Table 2.16. The fecal coliform level, averaged over all the stations in McCoy Creek, was historically above the WQC of 400 colony-forming-units (CFU) per 100 mL. Thus, a TMDL for fecal coliform was published in 2009 (**Rich-Zeisler and Kingon 2009**). (*Note: the data analysis in the TMDL is based on different criteria than that used in this report*). Subsequently, a BMAP for McCoy Creek was legally adopted in 2010 (**DEP 2010a**). The 2016 Annual Progress Report for this BMAP listed 20 active, ongoing projects underway by COJ, FDOT, and JEA and 1 completed project in 2016 (wet detention pond by COJ) to address the BMAP in the McCoy Creek watershed (**DEP 2017c**). Measurements from the past three years suggest that progress is being made. Average fecal coliform concentrations have decreased, as has the frequency of measurements that exceed the WQC. However, fecal coliform levels remain elevated. Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

Average dissolved oxygen (DO) levels are above the SSAC of 4.0 mg/L for DO in the mainstem and tributaries (**DEP 2014b**), but the average dissolved oxygen concentration has decreased over the past three years, with an increase in the frequency of measurements that fall below the WQC.

While ample data are available for dissolved oxygen, fecal coliform, and turbidity levels in McCoy Creek, very limited data can be found in STORET for nitrogen, phosphorus, and chlorophyll-*a*. No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc

Historical water quality data for these parameters in McCoy Creek are available in previous versions of the River Report.

Table 2.16 Water quality data for McCoy Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	4.51 (6 of 33 samples)	4.09 (8 of 24 samples)	4.03 (11 of 35 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.08 (2 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.08 (0 of 2 samples)
Chlorophyll-*a* (µg/L)	<20‡	No data	No data	5.55 (0 of 2 samples)
Fecal Coliform (CFU/100 mL)	<400‡	3700 (27 of 33 samples)	1800 (18 of 24 samples)	1100 (17 of 33 samples)
Turbidity (NTU)	<29	9.36 (2 of 33 samples)	10.81 (1 of 24 samples)	6.67 (0 of 35 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.19. Mill Creek

2.7.19.1. About Mill Creek

- East of the St. Johns River feeding into Sixmile Creek
- Primary Land Use: Wetlands/forest
- Current TMDL reports: Fecal Coliform, DO/Nutrient, Mercury
- Verified Impaired 2016 (final): Iron (high)
- WBID Area: 11.6 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.42 The Mill Creek Tributary (WBID 2460).

2.7.19.2. Data sources

Result data was downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Mill Creek WBID 2460 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.17.

2.7.19.3. Discussion

Water quality data for Mill Creek are shown in Table 2.17. Historically, the fecal coliform level, averaged over all the stations in Mill Creek, was above the WQC of 400 colony-forming-units (CFU) per 100 mL. Thus, a TMDL for fecal coliform was published in 2009 (**Rhew 2009b**). (*Note: the data analyses in the TMDL are based on different criteria than those used in this report*). However, the last fecal coliform measurements available in STORET date back to 2008.

In addition, Mill Creek has been identified as impaired for dissolved oxygen and associate nutrients and a TMDL addressing this was published in 2010 (**Magley 2010**). Iron has been added in the recent revised verified impaired list (**DEP 2016j**) for Mill Creek and is potentially a natural condition, common in Florida blackwater streams such as this.

Water quality data for Mill Creek are extremely limited in STORET, with only two measurements performed in 2017. No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform

Historical water quality data for these parameters in Mill Creek are available in previous versions of the River Report.

Table 2.17 Water quality data for Mill Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	No data	No data	1.45 (0 of 2 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.40 (2 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.18 (2 of 2 samples)
Chlorophyll-*a* (µg/L)	<20‡ FW	No data	No data	1.45 (0 of 2 samples)
Turbidity (NTU)	<29	No data	No data	4.40 (0 of 2 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.20. Moncrief Creek

2.7.20.1. About Moncrief Creek

- North of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Fecal/Total Coliform with BMAP (2010), Mercury
- Verified Impaired 2016 (final): Copper (2228A med), Iron (2228A med), Nutrients (Chlorophyll-*a* 228A med)
- WBID Area: 5.9 sq. mi.
- Beneficial Use: Class III F (Recreational – Marine)

Figure 2.43 The Moncrief Creek Tributary (WBID 2228).

2.7.20.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Moncrief Creek WBID 2228 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.18.

2.7.20.3. Discussion

Water quality data for Moncrief Creek are shown in Table 2.18. Historical average phosphorus levels were higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**), and the average phosphorus levels have remained slightly above the WQC over the past three years. Dissolved oxygen concentrations were within acceptable limits. Chlorophyll-*a* concentrations appear to be decreasing, but this is based on a small number of data points. Average copper concentrations were elevated relative to other tributaries, and the average copper concentrations was above the WQC in both 2015 and 2017.

A TMDL report for fecal coliform was published for Moncrief Creek in 2006 (**Wainwright 2006b**). (*Note: the data analyses in the TMDL are 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. Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

In the 2016 Annual Progress Report, 59% of Moncrief Creek fecal coliform measurements over a 7.5 year period ending June 30, 2016 exceeded the water quality criterion (400 CFU/100 mL) (**DEP 2017c**). While Moncrief Creek remains impaired for fecal coliform, the size of the exceedances has decreased since implementation of the BMAP; the median exceedance has decreased from 2,600 CFU/100 mL in the TMDL report to 1,300 CFU/100 mL in the first phase of the BMAP (2010-2014). (**DEP 2016b**). Fecal coliform measurements from the past three years show improvements in the average fecal coliform concentration as well as in the frequency of measurements that exceed the fecal coliform WQC. There were 28 projects either planned or currently underway in 2016 by COJ, JEA, and FDOT to address the BMAP in the Moncrief Creek watershed (**DEP 2017c**).

Moncrief Creek has been identified as impaired for copper and iron (**DEP 2014f**), but it has been delisted for lead (**DEP 2016h**). It was identified as being impaired for mercury, based on elevated levels of mercury in fish tissue; however, this is being delisted (**DEP 2015a**) as it has been addressed by the statewide mercury TMDL (**DEP 2013c**).

COJ has chosen Moncrief Creek as a focus watershed to monitor progress in the reduction of pollution from stormwater flows. Stormwater is the main source of the headwaters of Moncrief Creek, and there were 22 stormwater treatment ponds in the Moncrief Creek watershed in 2017. COJ plans to sample Moncrief Creek quarterly with respect to its effectiveness in stormwater treatment pollution reduction (**COJ 2017**).

Table 2.18 Water quality data for Moncrief Creek.

Parameter	Water Quality Criteria (SW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥4.0	4.93 (8 of 33 samples)	4.70 (15 of 36 samples)	5.33 (7 of 27 samples)
Nitrate-nitrite N (mg/L)§	§	0.13 (5 samples)	0.20 (4 samples)	0.10 (6 samples)
Total Phosphorus (mg/L)	<0.12‡	0.17 (4 of 10 samples)	0.13 (4 of 6 samples)	0.14 (5 of 10 samples)
Chlorophyll-*a* (µg/L)	<5.4‡	18.62 (3 of 5 samples)	7.02 (2 of 4 samples)	10.76 (3 of 7 samples)
Arsenic (µg/L)	≤50	6.98 (0 of 4 samples)	11.55 (0 of 4 samples)	7.31 (0 of 7 samples)
Cadmium (µg/L)	≤8.8	0.13 (0 of 4 samples)	0.22 (0 of 4 samples)	0.09 (0 of 7 samples)
Copper (µg/L)	≤3.7	3.33 (2 of 4 samples)	2.90 (1 of 4 samples)	4.01 (2 of 7 samples)
Lead (µg/L)	≤8.5	2.30 (0 of 4 samples)	1.27 (0 of 4 samples)	2.18 (0 of 7 samples)
Nickel (µg/L)	≤8.3	0.98 (0 of 4 samples)	0.90 (0 of 4 samples)	0.87 (0 of 7 samples)
Silver (µg/L)	≤0.92*	0.00 (0 of 4 samples)	0.03 (0 of 4 samples)	0.02 (0 of 7 samples)
Zinc (µg/L)	≤86	16.52 (0 of 4 samples)	10.92 (0 of 4 samples)	10.30 (0 of 7 samples)
Fecal Coliform (CFU/100 mL)	<400‡	5500 (20 of 28 samples)	1900 (18 of 32 samples)	810 (10 of 21 samples)
Turbidity (NTU)	<29	10.80 (0 of 4 samples)	5.57 (0 of 4 samples)	17.07 (1 of 7 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.21. Open Creek

2.7.21.1. About Open Creek

- West of the Intracoastal Waterway
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform with BMAP (2009), Mercury
- Verified Impaired 2016 (final):
  None
- WBID Area: 6.5 sq. mi.
- Beneficial Use: Class III M & F (Marine - 2299A, Freshwater - 2299B)

Figure 2.44 Open Creek (WBID 2299A/B).

2.7.21.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Open Creek WBID 2299A (marine) and 2299B (freshwater) (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.19.

2.7.21.3. Discussion

Water quality data for Open Creek are shown in Table 2.19, but the number of measurements reported in STORET is very limited. Total phosphorus, dissolved oxygen, and turbidity were in the normal range in 2017. Open Creek has been identified as impaired for mercury (**DEP 2016j**) and is addressed in the statewide mercury TMDL already in place (**DEP 2013c**).

The fecal coliform level, averaged over all the stations in Open 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. A TMDL report (**Wainwright and Hallas 2009b**) was released in 2009 to address fecal coliform. (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Subsequently, a BMAP to address this issue was legally adopted (**DEP 2009b**). Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

The 2016 Annual Progress Report for this BMAP listed 18 active, ongoing projects underway by FDOT and JEA to address the BMAP in the Open Creek watershed (**DEP 2017c**). Measurements from the past three years still show average fecal coliform concentrations around the WQC, although the frequency of measurements that exceed the WQC decreased in 2017.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc

Historical water quality data for these parameters in Open Creek are available in previous versions of the River Report.

Table 2.19 Water quality data for Open Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	No data	5.78 (0 of 9 samples)	5.69 (0 of 8 samples)
	≥4.0 SW	5.47 (2 of 12 samples)	6.00 (0 of 3 samples)	6.29 (0 of 4 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.20 (4 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.05 (0 of 4 samples)
Chlorophyll-*a* (μg/L)	<20‡ FW	No data	No data	No data
	<5.4‡ SW	No data	No data	3.20 (0 of 4 samples)
Fecal Coliform (CFU/100 mL)	<400‡	510 (7 of 12 samples)	650 (9 of 12 samples)	380 (2 of 7 samples)
Turbidity (NTU)	<29	No data	No data	2.70 (0 of 4 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.22. *Ortega River*

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

- West of NAS Jacksonville
- Primary Land Use: Residential
- Current TMDL reports:
  Fecal Coliform – 2213P1
  DO/Nutrient – 2213P1
- Verified Impaired 2016 (final): None
- WBID Area: 29.0 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

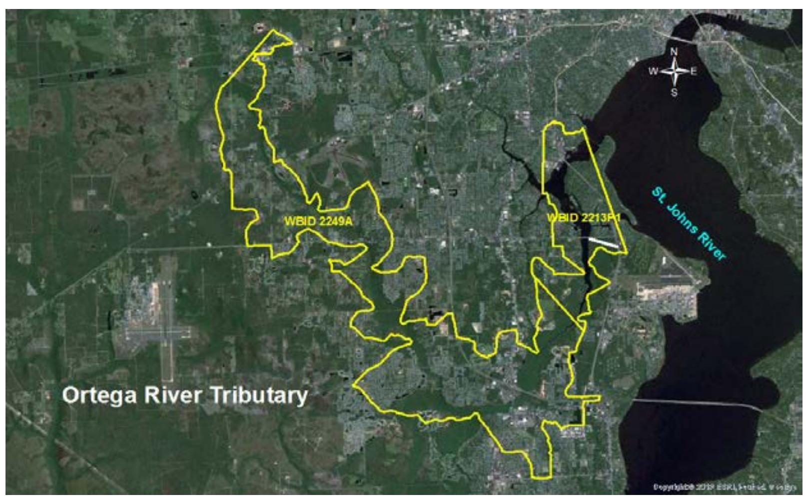


Figure 2.45 The Ortega River Tributary (WBID 2213P1 and 2249A).

2.7.22.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Ortega River WBID 2213P1 and 2249A (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.20.

2.7.22.3. <u>Discussion</u>

Water quality data for the Ortega River are shown in Table 2.20. Average total phosphorus and dissolved oxygen concentrations were within acceptable limits. Average chlorophyll-*a* concentrations have remained lower than the WQC, but there was a sharp increase in the average concentration in 2017. Concentrations of metals in the Ortega River are generally decreasing.

No valid fecal coliform measurements are available in STORET since 2013. The fecal coliform level, averaged over all the sampling sites in the Ortega River, was historically below the WQC of 400 colony-forming-units per 100 mL. The TMDL reports for fecal coliform (**Rhew 2009e**) and DO/Nutrients (**Magley 2009b**) published in 2009 referred to WBID 2213P, of which WBID 2213P1 is a subset as a result of changes to the WBID boundaries.

No recent measurements were available in STORET between 2015 and 2017 for the following parameter:

- Fecal Coliform

Historical water quality data for this parameter in the Ortega River are available in previous versions of the River Report.

Table 2.20 Water quality data for the Ortega River (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	4.05 (2 of 6 samples)	4.51 (2 of 7 samples)	4.78 (3 of 7 samples)
Nitrate-nitrite N (mg/L)§	§	0.07 (6 samples)	0.05 (7 samples)	0.03 (7 samples)
Total Phosphorus (mg/L)	<0.12‡	0.07 (1 of 11 samples)	0.05 (0 of 11 samples)	0.09 (3 of 10 samples)
Chlorophyll-*a* (µg/L)	<20‡	0.79 (0 of 6 samples)	0.57 (0 of 7 samples)	7.69 (1 of 7 samples)
Arsenic (µg/L)	≤50	1.00 (0 of 4 samples)	0.65 (0 of 7 samples)	0.61 (0 of 3 samples)
Cadmium (µg/L)	≤0.3	0.03 (0 of 4 samples)	0.03 (0 of 7 samples)	0.03 (0 of 3 samples)
Copper (µg/L)	≤9.3	1.11 (0 of 4 samples)	1.37 (0 of 7 samples)	0.81 (0 of 3 samples)
Lead (µg/L)	≤3.2	0.51 (0 of 4 samples)	0.46 (0 of 7 samples)	0.38 (0 of 3 samples)
Nickel (µg/L)	≤52	0.42 (0 of 4 samples)	0.42 (0 of 7 samples)	0.34 (0 of 3 samples)
Silver (µg/L)	≤0.07	0.00 (0 of 4 samples)	0.00 (0 of 7 samples)	0.00 (0 of 3 samples)
Zinc (µg/L)	≤120	5.11 (0 of 4 samples)	5.44 (0 of 7 samples)	4.04 (0 of 3 samples)
Turbidity (NTU)	<29	1.96 (0 of 5 samples)	1.45 (0 of 7 samples)	3.25 (1 of 7 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.23. *Peters Creek*

2.7.23.1. About Peters Creek

- Flows into Black Creek
- Primary Land Use: Forest/agriculture
- Current TMDL reports: Lead, Fecal Coliform, Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 20.5 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.46 The Peters Creek Tributary (WBID 2444).

2.7.23.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in Peters Creek WBID 2444 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.21.

2.7.23.3. Discussion

Water quality data for Peters Creek are shown in Table 2.21, but the small number of samples limits any conclusions that can be drawn. Average total phosphorus, dissolved oxygen and chlorophyll-*a* concentrations were within acceptable limits. Historical fecal coliform levels, averaged over all the sampling sites in the Peters Creek, were above the WQC of 400 colony-forming-units (CFU) per 100 mL. As a consequence, a TMDL report was published in 2009 to address this impairment (**Rhew 2009a**). However, the last fecal coliform measurements in STORET date back to 2007, and no newer data are available to assess the status of fecal coliform in Peters Creek.

Lead has been identified as impaired (high percentage of exceedances) in Peters Creek and a TMDL report was published in 2009 (**Lewis and Mandrup-Poulsen 2009**) to address this issue. However, no recent lead data were available in STORET.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform

Historical water quality data for these parameters in Peters Creek are available in previous versions of the River Report.

Table 2.21 Water quality data for Peters Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	No data	6.30 (0 of 1 sample)	7.34 (0 of 2 samples)
Nitrate-nitrite N (mg/L)§	§	No data	0.01 (1 sample)	0.05 (1 sample)
Total Phosphorus (mg/L)	<0.12‡	No data	0.05 (0 of 1 sample)	0.04 (0 of 1 sample)
Chlorophyll-*a* (µg/L)	<20‡ FW	No data	0.55 (0 of 1 sample)	0.93 (0 of 1 sample)
Turbidity (NTU)	<29	No data	1.30 (0 of 1 sample)	1.30 (0 of 1 sample)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.24. *Pottsburg Creek*

2.7.24.1. <u>About Pottsburg Creek</u>

- East of the St. Johns River at the Butler Blvd./I-95 interchange
- Primary Land Use: Residential
- Current TMDL reports: Fecal coliform with BMAP (2010), Mercury
- Verified Impaired 2016 (final): Iron (med)
- WBID Area: 9.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

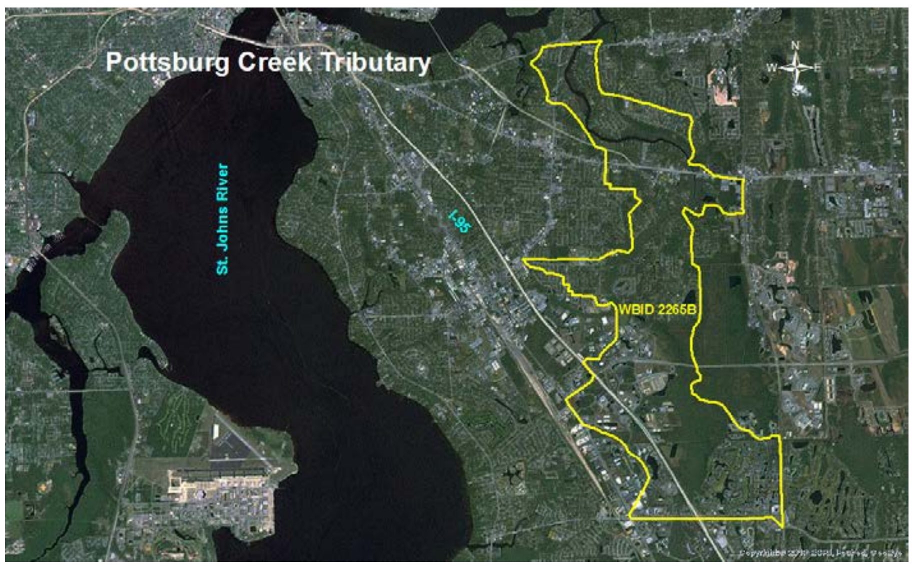


Figure 2.47 The Pottsburg Creek Tributary (WBID 2265B).

2.7.24.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Pottsburg Creek WBID 2265B, 2265C (freshwater), and 2265D (marine) (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.22.

2.7.24.3. <u>Discussion</u>

Water quality data for Pottsburg Creek are shown in Table 2.22, but only a handful of measurements are available in STORET for these parameters between 2015 and 2017. Average phosphorus levels were higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**). Historically, average dissolved oxygen and chlorophyll-*a* were within limits, although chlorophyll-*a* concentrations may also be rising.

Average fecal coliform concentrations from 1999-2012 were well above the WQC, and fecal coliform levels in this residential tributary were identified as impaired in 2004. Consequently, a TMDL for fecal coliform was published (**Rhew 2009c**). A BMAP for Pottsburg Creek (**DEP 2010a**) was legally adopted 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. Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

Annual Progress Reports for this BMAP have been published annually since 2011, listing repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT. In the 2016 Annual Progress Report, 34% of Pottsburg Creek fecal coliform measurements over a 7.5 year period ending June 30, 2016 exceeded the water quality criterion (400 CFU/100 mL) (**DEP 2017c**). Pottsburg Creek remains impaired for fecal coliform, and the size of the exceedances has increased since implementation of the BMAP; the median exceedance increased from 800 CFU/100 mL in the TMDL report to 1,532 CFU/100 mL in the first phase of the BMAP (2010-2014) (**DEP 2016b**). However, no fecal coliform data are available in STORET after 2007. There are 24 projects either planned or currently underway by COJ, JEA, and FDOT to address the BMAP in the Pottsburg Creek watershed (**DEP 2017c**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform

Historical water quality data for these parameters in Pottsburg Creek are available in previous versions of the River Report.

Table 2.22 Water quality data for Pottsburg Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Nitrate-nitrite N (mg/L)§	§	0.11 (1 sample)	No data	0.10 (4 samples)
Total Phosphorus (mg/L)	<0.12‡	0.12 (0 of 1 sample)	No data	0.15 (3 of 4 samples)
Chlorophyll-*a* (µg/L)	<5.4‡ SW	2.40 (0 of 1 sample)	No data	9.75 (1 of 4 samples)
Turbidity (NTU)	<29	6.90 (0 of 1 sample)	No data	3.45 (0 of 4 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.25. *Ribault River*

2.7.25.1. About the Ribault River

- Northwest of downtown Jacksonville
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform, Mercury
- Verified Impaired 2016 (final): Iron (med)
- WBID Area: 9.7 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

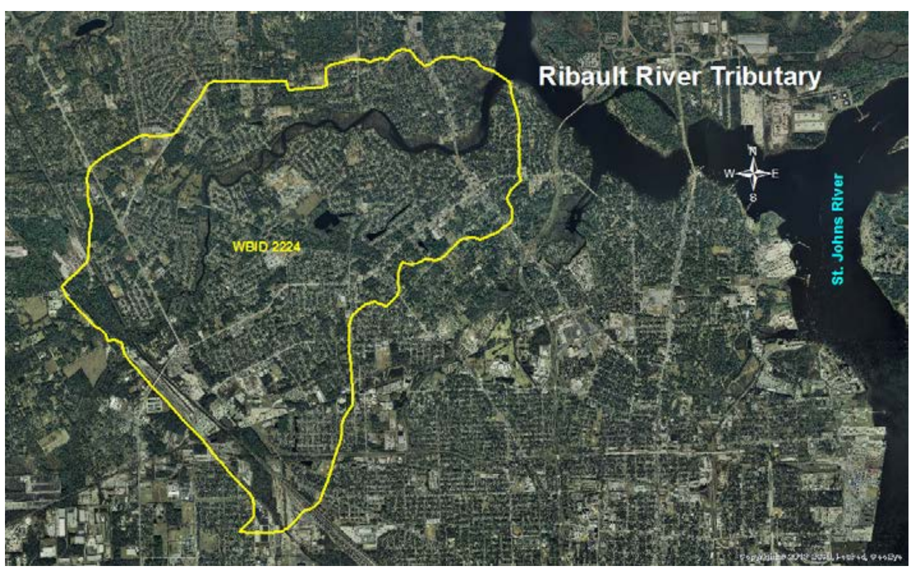


Figure 2.48 The Ribault River Tributary (WBID 2224).

2.7.25.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Ribault River WBID 2224 (**DEP 2014c**) shown above. No water quality data for the selected parameters discussed below for the Ribault River were available in STORET for 2015-2017.

2.7.25.3. Discussion

No water quality data are available for the Ribault River after 2012, and the most recent measurements of metals and phosphorus were from 2007. The Ribault River is located in a highly residential area and has historically been a contributor to elevated levels of phosphorus found in the tributary. High levels of chlorophyll-*a* have also been measured, but Ribault River has not been designated impaired (**DEP 2016h**). Iron has been added to the verified impaired list (**DEP 2016j**).

Historical fecal coliform levels, averaged over all the sampling sites in the Ribault River, were elevated. A TMDL report for fecal coliform in the Ribault River was published in 2006 (**Wainwright 2006a**), and a BMAP is under development. (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). In 2014, the City of Jacksonville implemented a monitoring program for the Ribault River as part of a bacteria pollution control plan in concert with efforts related to stormwater management (**COJ 2017**). However, the latest fecal coliform data available in STORET date back to 2012

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in the Ribault River are available in previous versions of the River Report.

2.7.26. Rice Creek

2.7.26.1. About the Rice Creek

- West of Palatka
- Primary Land Use: Forested/Wetland
- Current TMDL reports: None
- Verified Impaired 2016 (final): None
- WBID Area: 31.1 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

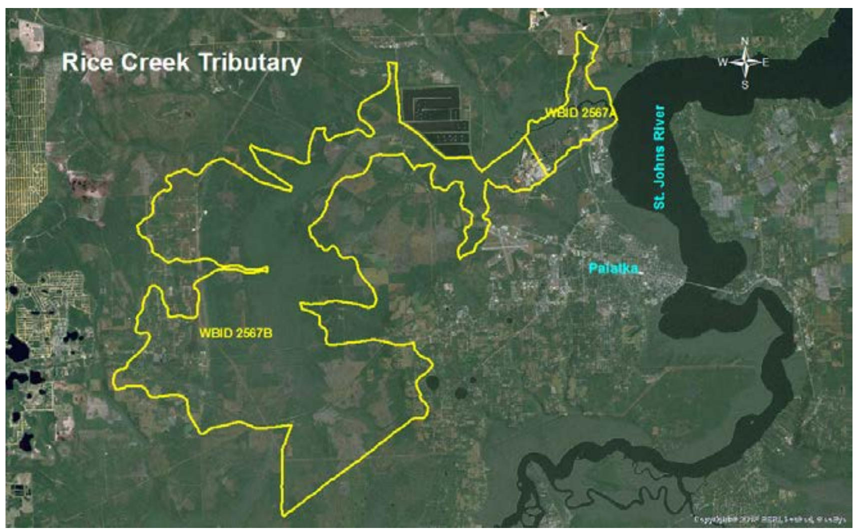


Figure 2.49 The Rice Creek Tributary (WBID 2567A/B).

2.7.26.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Rice Creek WBID 2567A/B (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.23.

2.7.26.3. Discussion

Water quality data for Rice Creek are shown in Table 2.23, although the frequency of sampling was sharply lower in 2017. Rice Creek is predominantly surrounded by wetlands, forests including The Rice Creek Wildlife Management Area and a pulp mill (Georgia-Pacific). Dissolved oxygen, total phosphorus, chlorophyll-*a*, and turbidity levels are within normal levels. Levels of certain contaminants, including arsenic and nickel, have decreased over the past three years. Rice Creek was identified as being impaired for Dioxin (**DEP 2014f**), but it is no longer listed as such.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Fecal Coliform

Historical water quality data for this parameter in Rice Creek are available in previous versions of the River Report.

Table 2.23 Water quality data for Rice Creek (2015-2017).

Parameter	Water Quality Criteria (FW)	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0)	4.44 (11 of 78 samples)	5.38 (4 of 87 samples)	5.54 (0 of 30 samples)
Nitrate-nitrite N (mg/L)§	§	0.07 (27 samples)	0.05 (29 samples)	0.03 (11 samples)
Total Phosphorus (mg/L)	<0.12‡	0.07 (0 of 37 samples)	0.05 (0 of 46 samples)	0.07 (1 of 16 samples)
Chlorophyll-*a* (µg/L)	<20‡	6.28 (4 of 27 samples)	7.50 (5 of 30 samples)	4.23 (0 of 11 samples)
Arsenic (µg/L)	≤50	0.74 (0 of 15 samples)	0.68 (0 of 18 samples)	0.58 (0 of 6 samples)
Cadmium (µg/L)	≤0.3	0.00 (0 of 15 samples)	0.00 (0 of 18 samples)	0.01 (0 of 6 samples)
Copper (µg/L)	≤9.3	0.62 (0 of 15 samples)	0.99 (0 of 18 samples)	0.86 (0 of 6 samples)
Lead (µg/L)	≤3.2	0.33 (0 of 15 samples)	0.26 (0 of 18 samples)	0.29 (0 of 6 samples)
Nickel (µg/L)	≤52	0.74 (0 of 15 samples)	0.60 (0 of 18 samples)	0.49 (0 of 6 samples)
Silver (µg/L)	≤0.07	0.00 (0 of 15 samples)	0.00 (0 of 18 samples)	0.02 (1 of 6 samples)
Zinc (µg/L)	≤120	3.24 (0 of 15 samples)	2.12 (0 of 18 samples)	2.55 (0 of 6 samples)
Turbidity (NTU)	<29	4.66 (0 of 24 samples)	2.79 (0 of 29 samples)	3.29 (0 of 11 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.27. *Sixmile Creek*

2.7.27.1. About the Sixmile Creek

- East of the St. Johns River in St. Johns County
- Primary Land Use: Forested/Wetland
- Current TMDL reports: Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 59.5 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

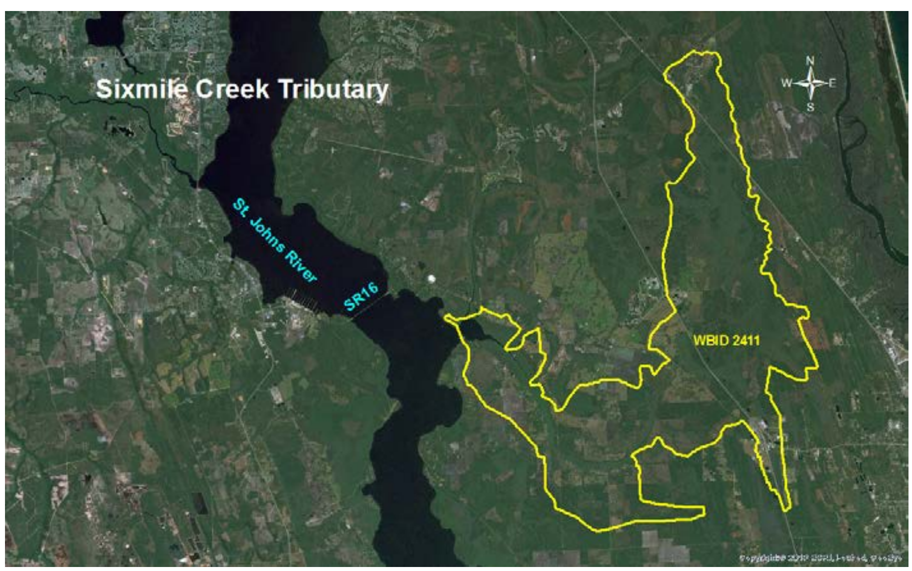


Figure 2.50 The Sixmile Creek Tributary (WBID 2411).

2.7.27.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Sixmile Creek WBID 2411 (**DEP 2014c**) shown above. The filtered dataset was used to generate Table 2.24.

2.7.27.3. Discussion

Water quality data for Sixmile Creek are shown in Table 2.24, but no new water quality data have been added to STORET since 2015. Historically, dissolved oxygen levels in Sixmile Creek were relatively low compared to other tributaries. As only one sample was reported in 2015, no adequate conclusions can be drawn regarding the condition of Sixmile Creek. Chlorophyll-*a* and silver levels exceeded WQC in the past, but both had been decreasing. No new silver measurements have been reported since 2011.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform

Historical water quality data for these parameters in Sixmile Creek are available in previous versions of the River Report.

Table 2.24 Water quality data for Sixmile Creek (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	8.00 (0 of 1 sample)	No data	No data
Nitrate-nitrite N (mg/L)§	§	0.06 (1 sample)	No data	No data
Total Phosphorus (mg/L)	<0.12‡	0.05 (0 of 1 sample)	No data	No data
Chlorophyll-*a* (µg/L)	<20‡ FW	0.59 (0 of 1 sample)	No data	No data
Turbidity (NTU)	<29	4.60 (0 of 1 sample)	No data	No data

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.28. Strawberry Creek

2.7.28.1. About the Strawberry Creek

- Flows into the Arlington River
- Primary Land Use: Residential
- Current TMDL reports: Fecal Coliform, Mercury
- Verified Impaired 2016 (final): None
- WBID Area: 4.6 sq. mi.
- Beneficial Use: Class III F (Recreational – Freshwater)

Figure 2.51 The Strawberry Creek Tributary (WBID 2239).

2.7.28.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Strawberry Creek WBID 2239 (**DEP 2014c**) shown above. No water quality data for the selected parameters discussed below for Strawberry Creek were available in STORET for 2015-2017.

2.7.28.3. Discussion

No recent water quality data were available in STORET. The most recent metals data date back to 2007, and the latest nutrient measurements date back to 2012. Historical fecal coliform levels, averaged over all the sampling sites in Strawberry Creek, were above the WQC of 400 colony-forming-units per 100 mL. Thus, a TMDL report for fecal coliform in Strawberry Creek was published in 2009 (**Rhew 2009d**). (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). However, no new fecal coliform measurements have been reported in STORET since 2012. In 2018, the City of Jacksonville plans to implement a monitoring program for Strawberry Creek as part of a bacteria pollution control plan in concert with efforts related to stormwater management (**COJ 2017**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in Strawberry Creek are available in previous versions of the River Report.

2.7.29. Trout River

2.7.29.1. About the Trout River

- North of downtown Jacksonville
- Primary Land Use: Residential/Wetland
- Current TMDL reports: Fecal coliform with BMAP (2010) DO/Nutrients (2203B), Mercury
- Verified Impaired 2016 (final): Chlorophyll-*a* (2203A, med)
- Beneficial Use: Class III M/F (Marine 2203A, Freshwater 2203/2233)

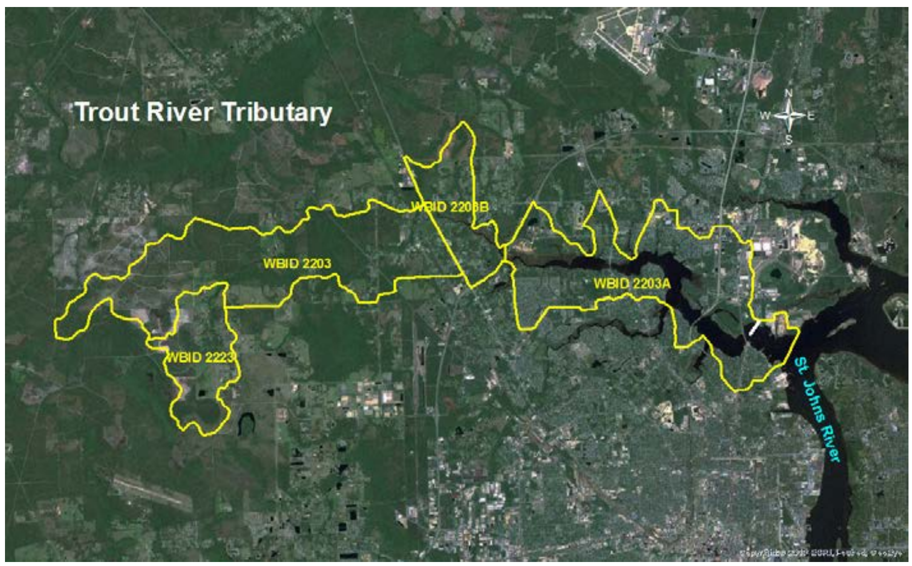


Figure 2.52 The Trout River Tributary (WBIDs 2203/2203A/2223).

2.7.29.2. Data sources

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Trout River WBIDs 2203/2203A/2203B/2223 (**DEP 2014c**) shown above. The filtered dataset was used to Table 2.25.

2.7.29.3. Discussion

Water quality data for the Trout River are shown in Table 2.25. Historically, overall (all WBIDs) average phosphorus levels were higher than the recently updated WQC (**DEP 2015c**; **DEP 2016e**; **DEP 2016k**). No phosphorus data were available in STORET from 2014 to 2016, and the average phosphorus concentration in 2017 was at the WQC. Dissolved oxygen concentrations were within acceptable limits. Nutrient levels have been found to be, on average, higher than the WQC for WBID 2203 and a TMDL report to address this issue was published in 2009 (**Magley 2009a**). The Trout River has been listed as impaired for chlorophyll-*a* (**DEP 2016j**).

The fecal coliform level, averaged over all the stations in the Trout River (Table 2.25), has been higher than the WQC of 400 colony-forming-units (CFU) per 100 mL. A TMDL for fecal coliform was published in 2009 (**Wainwright and Hallas 2009c**) for WBIDs 2203 and 2203A in the Trout River. (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Subsequently, a BMAP for the Trout River (**DEP 2010a**) was legally adopted 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 middle Trout River (2203), and the lower Trout River (2203A). Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

Annual Progress Reports for this BMAP have been published annually since 2011, listing repairs, inspections, evaluations, and other improvements conducted by JEA, the Duval County Health Department, COJ, and FDOT. In the 2016 Annual Progress Report, 32% of lower Trout River fecal coliform measurements over a 7.5 year period ending June 30, 2016 exceeded the water quality criterion (400 CFU/100 mL) (**DEP 2017c**). While the lower Trout River remains impaired for fecal coliform, the size of the exceedances has decreased since implementation of the BMAP; the median exceedance decreased from 1,000 CFU/100 mL in the TMDL report to 721 CFU/100 mL in the first phase of the BMAP (2010-2014) (**DEP 2016b**). However, fecal coliform concentrations over the past three years have remained high (although limited sampling was performed in 2017). There are 42 projects either planned or currently underway by COJ, JEA, and FDOT to address the BMAP in the Trout River watershed (**DEP 2017c**).

The Trout River (lower reach) was identified as being impaired for mercury based on elevated levels of mercury in fish tissue; however, this is being delisted (**DEP 2016h**), as it has been addressed by the statewide mercury TMDL (**DEP 2013c**). Chlorophyll-*a* has been added to the verified impaired list (**DEP 2016j**).

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc

Historical water quality data for these parameters in the Trout River are available in previous versions of the River Report.

Table 2.25 Water quality data for the Trout River (2015-2017).

Parameter	Water Quality Criteria	Average and Number of Samples°		
		2015	2016	2017
Dissolved Oxygen (mg/L)	≥34% sat. (≥3.0) FW	5.46 (6 of 20 samples)	4.96 (4 of 15 samples)	4.67 (2 of 7 samples)
	≥4.0 SW	3.96 (4 of 7 samples)	4.58 (4 of 12 samples)	4.83 (4 of 12 samples)
Nitrate-nitrite N (mg/L)§	§	No data	No data	0.09 (6 samples)
Total Phosphorus (mg/L)	<0.12‡	No data	No data	0.12 (2 of 6 samples)
Chlorophyll-*a* (µg/L)	<20‡ FW	No data	No data	No data
	<5.4‡ SW	No data	No data	7.45 (2 of 6 samples)
Fecal Coliform (CFU/100 mL)	<400‡	880 (4 of 7 samples)	330 (2 of 12 samples)	1500 (2 of 3 samples)
Turbidity (NTU)	<29	No data	No data	5.90 (0 of 6 samples)

Note: Hardness-dependent freshwater criteria for cadmium, copper, lead, nickel, and zinc were generated based on a hardness concentration of 100 mg/L.
° = Number of samples below WQC for Dissolved Oxygen, Number of samples above WQC for all other parameters
FW = freshwater; SW = saltwater (marine). Values denoted with (*) indicate a proposed criterion, which has not yet been adopted.
Values denoted with (‡) are reference values based on EPA criteria (**EPA 2010b**), but the water body is not regulated by this standard.
§ = No water quality criterion has been established for Nitrate-Nitrite nitrogen. No Total Nitrogen data were available in STORET for 2015-2017.

2.7.30. Wills Branch

2.7.30.1. <u>About the Wills Branch</u>

- West of downtown Jacksonville Flows into the Cedar River
- Primary Land Use: Residential
- Current TMDL reports: Fecal and Total Coliform with BMAP (2010), Mercury
- Verified Impaired 2016 (final): None
- Beneficial Use: Class III F (Recreational – Freshwater)

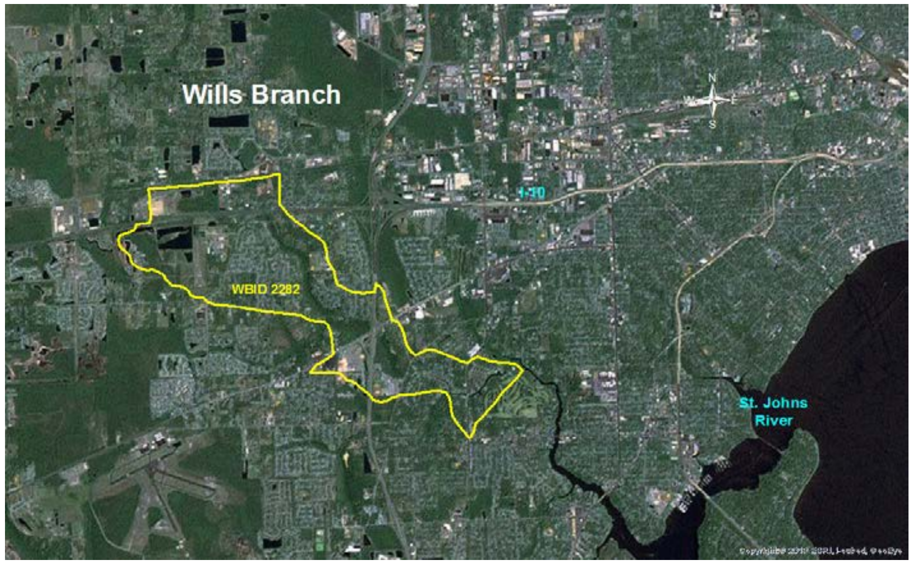


Figure 2.53 The Wills Branch Tributary (WBIDs 2282).

2.7.30.2. <u>Data sources</u>

Result data were downloaded from the FL STORET website (**DEP 2010e**) and filtered based on the stations (**DEP 2010f**) in the Wills Branch WBID 2282 (**DEP 2014c**) shown above. No water quality data for the selected parameters discussed below for Wills Branch were available in STORET for 2015-2017.

2.7.30.3. <u>Discussion</u>

Historically, average total phosphorus, dissolved oxygen and chlorophyll-*a* concentrations were within acceptable limits. The fecal coliform level, averaged over all the stations in Wills Branch, were historically above the WQC of 400 colony-forming-units (CFU) per 100 mL. As a result, a TMDL for total and fecal coliform was published in 2006 (**Wainwright 2006c**) for Wills Branch. (*Note: the data analyses in the TMDL are based on different criteria than that used in this report*). Subsequently, a BMAP for Wills Branch was legally adopted in 2010 (**DEP 2010a**). Additional information about fecal coliform in the tributaries can be found in Section 2.6 and Table 2.2.

The 2016 Annual Progress Report for this BMAP listed 20 active, ongoing projects underway by FDOT and JEA to address the BMAP in the Wills Branch watershed (**DEP 2017c**); two pump station projects were completed by JEA in 2016. However, no recent fecal coliform data are available as the last fecal coliform measurements in STORET date back to 2012.

No recent measurements were available in STORET between 2015 and 2017 for the following parameters:

- Dissolved oxygen
- Nitrate-nitrite nitrogen
- Total phosphorus
- Chlorophyll-a
- Arsenic
- Cadmium
- Copper
- Lead
- Nickel
- Silver
- Zinc
- Fecal Coliform
- Turbidity

Historical water quality data for these parameters in Wills Branch are available in previous versions of the River Report.

2.8. Salinity

2.8.1. Overview

Salinity is a measure of the amount of salt that is dissolved in a sample of water. It is measured in parts per thousand (ppt), or practical salinity units (psu), or it can be calculated from measuring the electrical conductivity of a water sample. On average, salinity ranges from about 35 parts per thousand at the ocean (full strength seawater) to about 10-18 ppt near downtown Jacksonville (brackish water), and 0-5 ppt near the Buckman Bridge (fresh water). However, depending on the offshore water levels, tide (moon phase), flow, winds locally and offshore (**Bacopoulos et al. 2009**), and weather, the salinity in the river can vary considerably at a given time and place from 1-2 day spikes to an extended duration of weeks and months. The salty waters are diluted by freshwater that enters the river primarily from precipitation (mostly June-October) and springs or other aquifer/groundwater connections. The amount of flow from springs can be significantly reduced during droughts, because the groundwater level that feeds the spring may decrease (**CFWI 2015; Beck 2018**). Salinity increases during periods of droughts, and the effects can be exacerbated if they are more frequent such as in back to back years. In addition, there are springs with high salinity that affect localized areas within the St. Johns River. For example, the input from Salt Spring (Marion County) causes elevated salinity (>5 ppt) in otherwise freshwater sections of the river because of high salts and calcium content (**Benke and Cushing 2005**).

The St. Johns River estuary also experiences significant tidal forcing which affects the salinity depending on the discharge rates at the river mouth which ranges from 2-8 billion gallons per day (**Miller 1998**). If tidal exchange is included, flow at the mouth can increase to about 14 billion gallons per day (**Sucsy 2008**). During hurricane Irma (September 2017), the river's discharge increased to about 88 billion gallons per day (**Mundy 2018**) due to increased rainfall and the river turned fresh for several months near downtown. Fishing and shrimping was significantly reduced as salt water species were likely forced to move closer to the ocean. However, at times, the St. Johns River flows backwards up to 160 miles for several weeks, as far as Lake Monroe (**Durako et al. 1988**). The main reason for these reversed flows is that the river is slow moving and flat with a mild gradient that averages about 2.2 cm/km (**Toth 1993**) and the tidal range at Mayport is large in comparison about 2 m (**McCully 2006**). Flooding is common when wind from some storms create a surge of water traveling upstream, and then later also downstream, as with hurricane Irma. This is important because salinity variations can have far-reaching effects on the ecology of the river. The flow of freshwater into an estuary, its timing and delivery, are crucial to biological productivity (**Cross and Williams 1981**). The adverse effects of reducing freshwater flowing into Apalachicola Bay, which has decimated the ability to harvest oysters, have demonstrated this (**Livingston 2008**; **Montagna et al. 2011**).

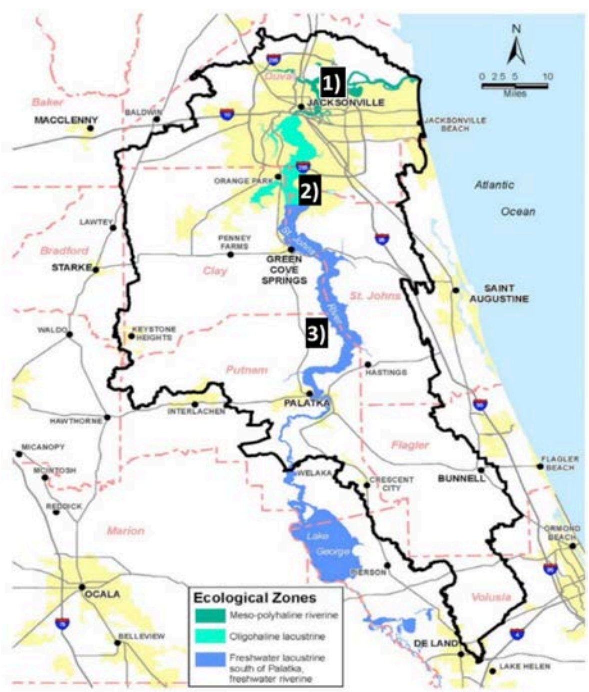


*Figure 2.54 Map of the Ecological (Salinity) Zones of the Lower St. Johns River (Source: **Hendrickson and Konwinski 1998; Malecki et al. 2004**).*

The LSJR can be divided into three ecological zones:

1) Mesohaline: Mayport to Downtown Jacksonville's Fuller Warren Bridge (0-40 km). The river is relatively narrower, deeper, fast flowing and well mixed. The salinity averages about 14.5 parts per thousand with active tidal influence.

2) Oligohaline: Downtown Jacksonville to Doctors Lake (40-75 km). The river is relatively wider, shallower, slow moving with an average salinity of 2.9 parts per thousand and moderate tidal influence.

3) Freshwater Lacustrine: Doctors Lake to Lake George (75-200 km). Here the river is wide, shallow, slow moving initially, then narrows near Palatka, and then widens into Lake George. The average salinity is 0.5 parts per thousand and the tidal influences are weak.

Interestingly, the lowest salinity occurs in the area from Green Cove south to Palatka, but then it tends to increase again because ground water entering the river has high salts and calcium content (**Benke and Cushing 2005**).

2.8.2. Biological Impacts

This sub-section covers potential biological impacts of salinity on the flora and fauna of LSJRB. Salinity increases as a result of the environment can be looked at in terms of; 1) periodic short term events like storms that result in abrupt salinity spikes for less than 14 days, 2) Intermediate term events like droughts that result in elevated salinity for some weeks, 3) Long-term changes as a result of sea levels rising over many years, 4) Human activities in the basin, such as reduced freshwater inflows to the river caused by dams, surface water withdrawals, or significant pumping of ground water. In addition, activities, such as harbor deepening, tend to increase salt water entering an estuary, thus driving up the salinity (**Sucsy 2008**).

The LSJRB supports a diverse community of living organisms that are important to the ecosystem, are affected by salinity, and have significant recreational and commercial economic value. Submerged aquatic vegetation and invertebrate bottom dwelling organisms play an important role in shaping habitat so that it is able to support fish and other wildlife. Examples of commercially valuable organisms include blue crabs, bait shrimp, and stone crabs. In 2013, Clay, Duval, Flagler, Putnam, and St. Johns Counties reported a total commercial crab harvest of 1,615,232 lbs (73%); and a fish harvest of some 570,509 lbs (**FWRI 2017a**). In general, striped mullet, whiting, and flounder have been the most caught species, but recreationally, red drum, spotted sea trout, croaker, sheepshead, flounder, largemouth bass, and blue gill are most important to anglers.

For all the species of fish and invertebrates mentioned in this report there are a few themes of importance:

- Each species plays an essential role in the ecosystem, with many interdependencies (predator, prey relationships).
- Each species requires essential habitats for an important life stage (coastal and in the river).
- Each species is of commercial and recreational value that is supported by the rest of the ecosystem, which also has value.

The most recent Supplemental Environmental Impact Statement (SEIS) by the USACE regarding dredging in the St. Johns River indicated that salinity changes, as a result of dredging, would negatively impact the distribution of Submerged Aquatic Vegetation (SAV) in LSJR. The impact would likely be from increased salinity stress on SAVs in the most northern part of their range in LSJR (Duval, Clay, and St. Johns Counties). Moreover, the report states that the 46 feet and 50 feet dredge depth scenarios would increase salinity stress by 32 and 43 acres of potential SAV habitat per day, respectively. This would most likely lead to a reduction in manatee forage habitat, essential fish habitat, benthic macro-invertebrate habitat and freshwater wetlands (**USACE 2014a**). In addition, the report states that loss of SAVs would represent a small portion of the total available SAVs in the LSJR, also that blue crabs and other marine species may benefit from any increases in salinity. In Appendix 4.1.7.1 of the report (**USACE 2014b**), the USACE pledged to monitor salinity and water quality to ensure appropriate mitigation. Furthermore, that the mitigation for SAVs lost is to be accomplished through a Corrective Action Plan that would purchase conservation lands (638 acres of freshwater wetlands, uplands, river shoreline, and saltmarshes).

In the report, the USACE states that the analysis and conclusions were based on modeling efforts that make certain assumptions about the rate of sea level rise (hydrodynamic modeling), and that salinity stress on SAVs was developed from a separate modeling analysis (**Taylor 2013a**) based on assumptions about levels of salinity stress and SAV acreages (ecological modeling). The hydrodynamic model reports (**Taylor 2011; Taylor 2013b; Taylor 2013c**) presented error statistics for the EFDC and CE-QUAL-ICM models. However, similar error statistics could not be calculated for the ecological models, and that represents an uncertain risk associated with evaluation of the ecological model results. Moreover, the report stated that, "Future condition hydrodynamic model simulations further rely on assumptions about the rate of sea level rise, quantity of water withdrawal from the middle St. Johns River, patterns of land use, and other factors. Actual conditions will deviate from those used to drive the models. These deviations introduce additional uncertainty in the models' ability to predict future conditions and impacts. These uncertainties are; however, inherent in the use of numerical models and do not represent an unknown risk" (**USACE 2014a**; Section 7.2, p. 258).

On February 19, 2016, the DEP issued a Notice of Intent to issue an Environmental Resource Permit and a Variance to allow the Army Corps of Engineers to dredge 13 miles of the St. Johns River from the mouth of the river to Brills Cut from a depth of 40 feet to up to 51 feet. The St. John RIVERKEEPER filed a Petition for Formal Administrative Hearing against DEP on April 1, 2016, based on the contention that the potential environmental impacts were not adequately addressed in the permit and important water quality standards are waived increasing the inherent risks of the proposed deep dredge. The USACE reacted by filing a Notice of Non-Participation asserting sovereign immunity and indicating that it does not plan to participate as a party in the administrative proceeding.

This is an unprecedented move, which is likely to create the potential for more risk since the USACE contends that they are immune from abiding to Florida water quality standards. On July 26, 2016 St. Johns RIVERKEEPER filed a notice withdrawing its legal challenge of the state permit due the lack of enforceability with the intent to elevate the challenge to the federal level. On Friday, April 7, 2017, St. Johns RIVERKEEPER filed a Complaint for Declaratory and Injunctive Relief in federal court against the USACE regarding the proposed St. Johns River harbor deepening project. The injunction was not upheld by the court (December 2017), and so while the legal challenge continues at the federal level, in February 2018 the USACE began to dredge an initial 3-mile section of the main St. Johns River channel near Mayport.

2.8.2.1. Macroinvertebrates

These are animals without a backbone that live in or on river bottom sediments including small crabs, snails, shrimp, clams, insects, worms, and barnacles among other species (see Section 4.3). These organisms affect oxygen levels in the sediment, as well as sediment size, which in turn affects what is able to live and grow in proximity to them. Macroinvertebrates are useful indicators of environmental stress and species change as one transitions from higher to low salinity. DEP data from 1974-1999 indicated that the northern river section was dominated by barnacles, polychaetes, and amphipods; and the southern river area was dominated by mollusks, amphipods, polychaetes, oligochaetes, and fly larvae. During the 1980s, the north section was dominated by polychaetes and barnacles, while the southern portion was mostly oligochaetes and fly larvae. In the 1990s, another shift occurred due to salinity, where the northern stations were dominated by amphipods, mollusks, polychaetes, and barnacles and the southern areas by bivalves and snails (**Evans et al. 2004; Montagna et al. 2011**).

Evans et al. 2004 states that freshwater areas of the river are affected by increasing salinity and that the concern is this will likely change the invertebrate community, the result could be significant negative impacts on the quality and quantity of freshwater fish species harvested from LSJRB. At this time, there is a lack of recent data on macroinvertebrates and how parameters, such as low dissolved oxygen, sediment quality, and toxic substances in the environment, may interact with changes in salinity levels.

2.8.2.2. Blue Crabs

The blue crab is a common benthic predator that represents the largest commercial fishery in LSJRB. Successful crab reproduction relies on a particular set of salinity conditions at specific times in the life cycle. 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 (see section 3.3.2 Fisheries). After some time adrift, wind and currents transport the megalops larvae back to the estuarine parts of the river where they settle in submerged aquatic vegetation (SAV) that serves as a nursery.

One concern that may negatively affect the recruitment of new crabs into the population is that with increasing salinity levels, the salinity transition zone will shift further south increasing the distance that female crabs with eggs will need to travel in order to reach the river mouth. This could ultimately affect recruitment.

Another concern is associated with nursery habitat. Increasing salinity further south in the river will negatively impact submerged aquatic vegetation that is required for young crabs.

Also, since the price of crustaceans in general is dependent on size, yet another concern may be diminishing size of adult crabs. There are several studies mentioned in **Tagatz 1968a** that report an inverse relationship between salinity and size. The higher the salinity of water in which growth occurs the smaller the adult sizes. This may be due to the crabs absorbing more water in lower salinity conditions when they molt (bigger crab) as opposed to them absorbing less water under higher salinity conditions (smaller crab). As a result, this could translate into lower income per pound for commercial harvesters for a particular level of fishing effort.

Ecologically speaking, blue crabs are very important in both the benthic and planktonic food webs in the St. Johns River. 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 (**White et al. 2009**).

2.8.2.3. Shrimp

Three principle shrimp species found in the area include most commonly White Shrimp (*Litopenaeus setiferus),* Brown Shrimp (*Farfantepenaeus aztecus),* and Pink Shrimp *(Farfantepenaeus duorarum).* All are omnivores feeding on worms, amphipods, mollusks, copepods, isopods and organic detritus. White shrimp spawn from April to October; pink shrimp (February to March) and brown shrimp (March to September) (**FWRI 2008d**). All species spawn offshore in deeper waters with larvae developing in the plankton and eventually settling in salt marsh tidal creeks with appropriate salinities within the estuaries. Changes in salinity will cause a change in the distribution of these early life stages that could potentially affect the number of adults returning offshore. Shrimp are important in both benthic and planktonic food webs in SJR. They affect the abundance of many small macroinvertebrates. They are also important prey for many other species. As small planktonic individuals, the shrimp post-larvae and juvenile forms provide food for other estuarine species like sheepshead minnows, insect larvae, killifish, and blue crabs. As adult shrimp, they are preyed on by finfish found within the river. The commercial shrimp fishery is one of the largest fisheries in the region, but most shrimp for human consumption are caught offshore.

2.8.2.4. Fish

The SJRWMD (**McCloud 2010**) compared current FWRI fish data with those collected by Tagatz in 1968 (**Tagatz 1968b**). The data suggested that at some areas of the river, fish communities were 50% different between 1968 and the 2001-2006 time periods. The differences in fish communities in these areas may have been the result of a transition zone between marine and freshwater moving further upstream (Figures 2.55-2.57). It is important to note that most fish are able to move from an area in response to changes in environmental factors, such as salinity, dissolved oxygen, and temperature. However, sessile species of plants and animals that are closely associated with the bottom substrate cannot move and can be impacted by such variations depending on the frequency and duration of events. Moreover, for the species that can move, there may be important life stages for these that dependent on water quality parameters being relatively stable at essential habitat areas like nursery and spawning grounds. Although fish can move, they may not be able to reproduce effectively because essential habitat has been disrupted that affects a particular life stage.

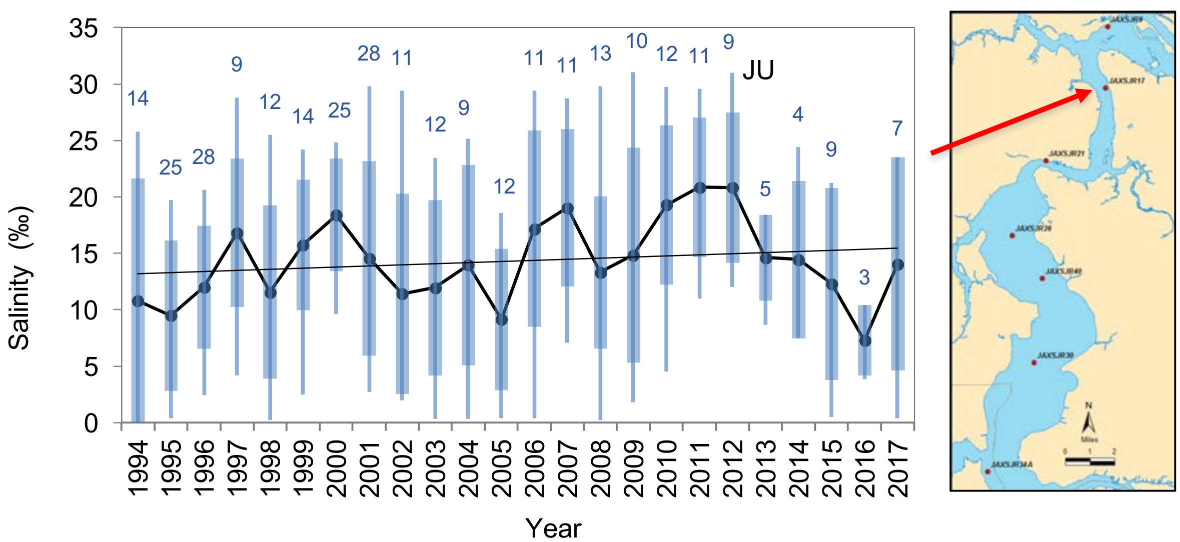


Figure 2.55 Salinity on the bottom of SJR (Station SJR17 near JU) values above the bars indicate the numbers of observations. Solid line (mean), vertical lines (maximum and minimum), and bars (Standard Deviation of the mean) (Data source: ***Karlavige 2018****). SJR17 mean 25.07‰ (SD ± 5.18) for the maxima. Note that only 5 observations were made in 2013, 4 in 2014, and 3 in 2016.*

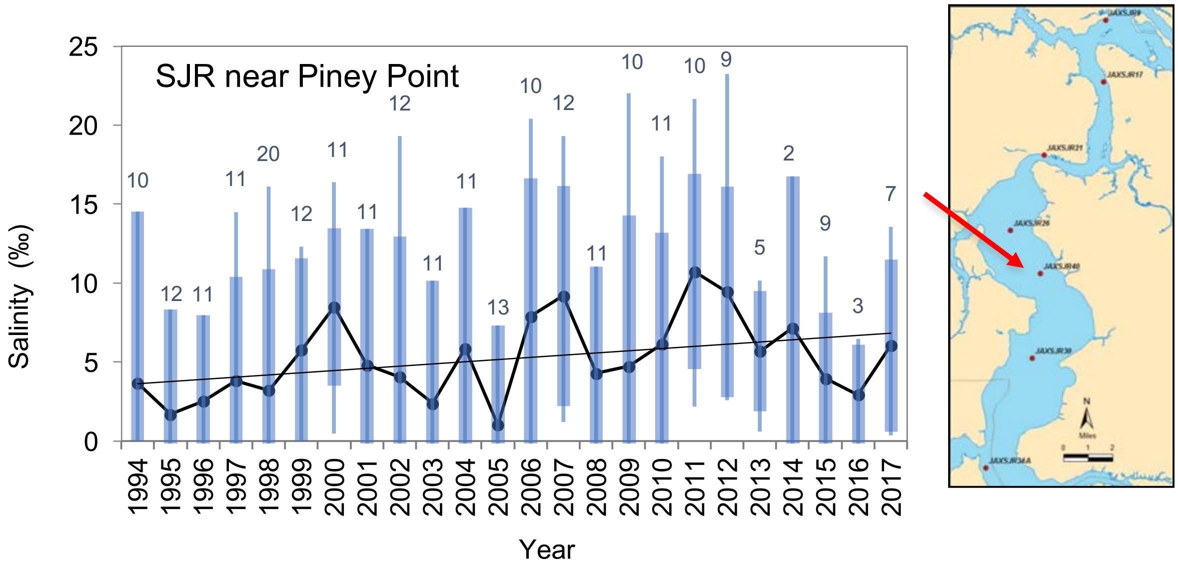


Figure 2.56 Salinity on the bottom of SJR (Mainstem Station SJR40 located mid-channel N. of Piney Pt. 100 m west of green marker 5) values above the bars indicate the numbers of observations. Solid line (mean), vertical lines (maximum and minimum), and bars (Standard Deviation of the mean) (Data source: ***Karlavige 2018****). SJR40 mean 14.03‰ (S.D. ± 5.30 for the maxima). Note that only 5 observations were made in 2013, 2 in 2014, and 3 in 2016.*

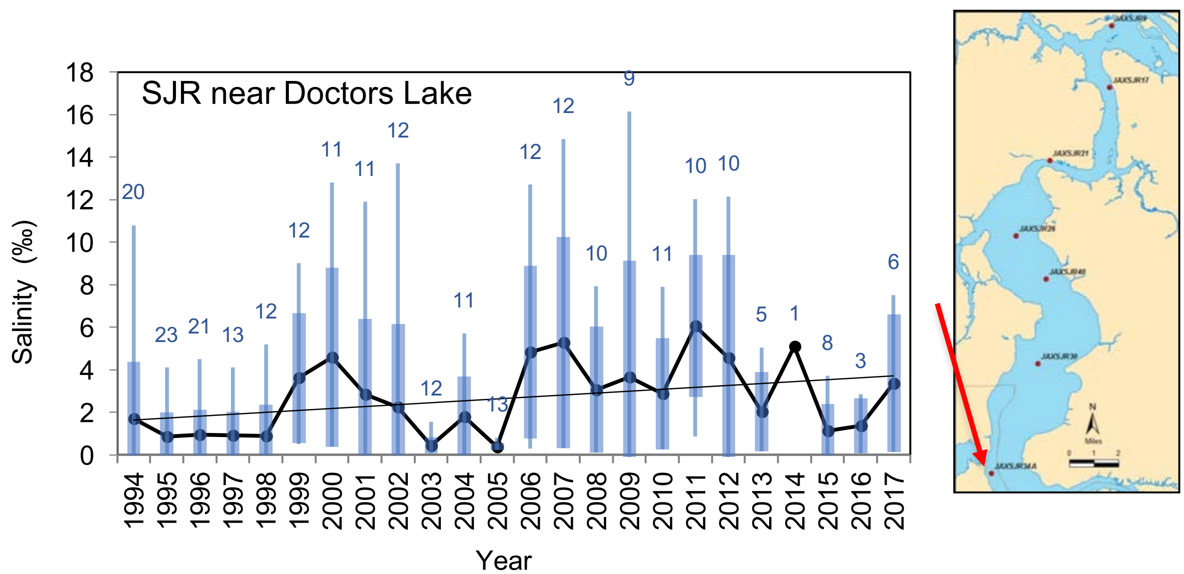


Figure 2.57 Salinity on the bottom of SJR (Station SJR34/34A located ~ 1000 m south of Doctors Lake on the west bank) values above the bars indicate the numbers of observations. Solid line (mean), vertical lines (maximum and minimum), and bars (Standard Deviation of the mean). (Data source: ***Karlavige 2018****). SJR34/34A mean 7.88‰ (SD ± 4.55) for the maxima. Note that only 5 observations were made in 2013, 1 in 2014, and 3 in 2016.*

With regard to living organisms, changes in water quality parameter averages are not as meaningful as the changes that may occur in the parameter extremes – like salinity maxima and dissolved oxygen minima. If any changes were to persist for an extended time or if they occurred too abruptly then this is likely to be detrimental to survival. Salinity changes may potentially affect the distribution of these fish within estuary creeks and the river by affecting prey distributions for different life stages. As the salinity zone shifts further south, fresh water species are likely to be more impacted than more salt tolerant species.

Red Drum *(Sciaenops ocellatus)*: Red drum is predatory fish that are found in the SJR estuary. The juveniles move into estuary creeks and rivers. Red drum is ecologically in the food web of the St. Johns River where 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; however, drum has not been commercially harvested since 1988.

Spotted Seatrout (*Cynoscion nebulosus*): The spotted seatrout is another bottom-dwelling predator common to estuaries and shallow coastal habitats. It feeds on small fish species such as anchovies, pinfish and menhaden as well as shrimp. Spotted seatrout larvae feed mostly on copepods, which are part of the plankton. There are a number of predators that feed on seatrout including Atlantic croakers, cormorants, brown pelicans, bottlenose dolphins, and sharks. These fish have significant commercial and recreational value.

Largemouth Bass *(Micropterus salmoides)*: Largemouth bass are predators in brackish to freshwater habitats in SJR, including lakes and ponds. The young feed on zooplankton, insects and crustaceans including crayfish. Adults feed on a variety of larger fish, crayfish, crabs, frogs, and salamanders. Spawning occurs from December to May, with males constructing nests and guarding young in hard-bottom areas near shorelines. Largemouth bass are aggressive predators, significantly affecting the abundance of many organisms in the area. Bass are a popular game fish in the area supporting fishing tournaments.

Channel & White Catfish (*Ictalurus punctatus & Ameiurus catus*): Channel and white catfish are omnivorous fish found in freshwater rivers, streams, ponds and lakes. During their lifetime, they may feed on insects, crustaceans (including crayfish), mollusks and fish (**DeMort 1990**). Male will build and guard the nest and fry. Both catfish species are important in benthic food webs that occur in the freshwater sections of the LSJR. Catfish are commercially and recreationally important in SJR.

Striped Mullet (*Mugil cephalus*): Striped mullet are detritivores that can live in a wide salinity range. They are abundant in most of the SJR, closely associated with bottom mud and feeding on algae, and decaying plant material. Mullet spawn offshore and their larvae drift back into the SJR estuary. They help to transfer energy from detrital matter that they feed on to their predators – 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 have significant recreational value as food and bait.

Southern Flounder (*Paralichthys lethostigma*): These are another common fish in the SJR estuary that are bottom-dwelling predators that eat shrimp, crabs, snails, bivalves and small fish. After spawning offshore in fall and winter, the larvae drift as part of the plankton eventually being transported back to the estuary to settle and grow. They are important in maintaining ecological balance in their roles as both predator and prey. They are food for sharks, marine mammals and birds. Flounders are important both commercially and recreationally in SJR.

Sheepshead (*Archosargus probatocephalus*): These fish are common to the SJR estuary and coastal waters. They prey on bivalves, crabs and barnacles. The fish spawn off shore in spring and the developing larvae are carried back to the coast by currents. The larvae enter the inlets and settle in shallow grassy areas. These fish are important in maintaining the estuarine and coastal food web as both a predator and prey. Sheepshead are prey for sharks and marine mammals. They are ecologically, recreationally and commercially important.

Atlantic Croaker (*Micropogonias undulatus*): These are bottom-dwelling predators common around rocks and pilings in the estuary. Spawning takes place in winter and spring in offshore waters, and planktonic offspring are transported back inshore to settle in vegetated shallow marsh areas. Croakers are important in the food web as both predator and particularly as prey. They feed on small invertebrates, and are fed on by fish, such as red drum, seatrout, and sharks. These fish support significant commercial and recreational fisheries in LSJR.

Baitfish (*multiple species*): There are more than two-dozen small schooling species like anchovies, menhaden, herring, killifish, sheepshead minnows, and sardines. Many baitfish species play a vital role in the ecosystem as planktivores. Others eat small crabs, worms, shrimp and fish. Most spawning occurs at inlets or offshore. Most migrate along or away from the shore. When the larvae hatch they are transported back to the estuary where they grow. Baitfish are important as prey for many larger fish species. They are also important as omnivores that recycle plant and/or animal material making that energy available to higher trophic levels. Commercial uses include bait fish, such as anchovy, menhaden, sardines, and herring which are converted into fertilizers, fishmeal, oil, and pet food (**FWC 2000**). Smaller fisheries catch killifish, sheepshead minnows, and sardines. For more information see Section 3 Fisheries and Appendix 3.1.

2.8.2.5. Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation provides nursery habitat for a variety of aquatic life, helps to reduce erosion, and limits turbidity by trapping sediment. Sunlight is vital for good growth of submerged grasses. Sunlight penetration may be reduced because of increased turbidity, pollution from upland development and/or disturbance of soils.

Deteriorating water quality, which may include unusual increases in salinity has been shown to cause a reduction in the amount of viable SAV in an area. This leads to erosion and further deterioration of water quality.

Historical accounts indicate that SAV beds existed in the river since 1773 (**Bartram 1928–** in 1955 Edition). These SAV beds have shown a gradual decline likely due to a number of cumulative impacts including routine dredging, harbor deepening, filling of wetlands, bulk heading and construction of seawalls, water withdrawals, pumping from wells, along with the contributions from chemical contamination, and sediment and nutrient loading that comes from upland development (**DeMort 1990; Dobberfuhl 2007**).

Commonly found SAV species within the salinity transition zone in LSJR include: tape grass (*Vallisneria americana*), wigeon grass (*Ruppia maritime*), and southern naiad (*Najas guadalupensis*). The greatest distribution of SAVs in Duval County is in waters south of the Fuller Warren Bridge (**Kinnaird 1983a**). There are about eight other freshwater species in LSJR (**IFAS 2007; Sagan 2007; USDA 2013**). These species are all likely to be adversely impacted by increases in salinity.

Under controlled laboratory conditions, tape grass has been shown to grow in 0 to 12 parts per thousand (ppt) of salinity and survive for short periods of time in waters with salinities up to 15-20 ppt (**Twilley and Barko 1990; Boustany et al. 2003**). However, SAV requires more light in a higher salinity environment due to increased metabolic demands (**Dobberfuhl 2007**). Evidence suggests that greater light availability can lessen the impact of high salinity on SAV (**Kraemer et al. 1999; French and Moore 2003**). What is not clearly understood is the ability of SAV to survive higher salinities when combined with environmental variables like temperature, turbidity, and excessive nutrients.

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 species, including the endangered Florida manatee (*Trichechus manatus latirostris*) (**White et al. 2002**). Manatees consume from four to 11% of their body weight in SAV daily (**Lomolino 1977; Bengtson 1981; Best 1981; Burns Jr et al. 1997**).

Commercial and recreational fisheries, including largemouth bass, catfish, blue crabs, and shrimp, are sustained by healthy SAV habitat (Watkins 1995). Fish and insects forage and avoid predation within the cover of the grass beds (**Batzer and Wissinger 1996; Jordan et al. 1996**). For example, **Jordan 2000** mentioned that SAV beds in the Lower Basin have three times greater fish abundance and 15 times greater invertebrate abundance than do adjacent sand flats.

The section of the St. Johns River north of Palatka had relatively stable trends with normal seasonal fluctuations. The availability of tape grass decreased significantly in the LSJRB during 2000-2001, because the drought caused higher than usual salinity values. In 2003, environmental conditions returned to a more normal rainfall pattern. As a result, lower salinity values favored tape grass growth again. 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**). **Sagan 2007** notes that at one of her monitoring sites, Sadler Point (the most seaward of all of her monitoring sites), SAV was present in 1998, but after a decline due to drought did not recover as did other SAV beds in the river. She cautions that long-term changes in salinity may be stressing SAV in the estuarine portions of the river. Declining SAV in the river south of Palatka and Crescent Lake is highly influenced by runoff and consequent increases in color of the water.

SAV response to drought and/or periods of reduced flow can provide crucial understanding as to how water withdrawals, harbor deepening and/or the issue of future sea level rise will likely affect the health of the ecosystem by adversely altering salinity profiles. For more information see Section 4.1 SAV and Appendix 4.1.7.1.A-D.

2.8.2.6. Florida Manatee

The Florida manatee (*Trichechus manatus latirostris*) inhabits the waters of the St. Johns River year-round. Manatees are generally most abundant in the LSJR from late April through August, with few manatees observed during the winter months (December-February). Manatees are protected under State and Federal Laws: In 1967, under a law that preceded the Endangered Species Act of 1973 the manatee was listed as an endangered species. Manatees are also protected at the Federal level under the Marine Mammal Protection Act of 1972 (**Congress 1972b**) and at the State level under the Florida Manatee Sanctuary Act of 1978 (**FWC 1978**). The current federal status of the manatee is "*Threatened*" (March 30, 2016) having just been down listed by USFWS from "*Endangered.*"

Jacksonville University has conducted aerial surveys of manatees from 1994 to 2016. Within the SJR manatees were found in greater numbers south of the Fuller Warren Bridge where their food supply is greatest relative to other areas in Duval County. The SJR provides habitat for the manatee along with supporting tremendous recreational and industrial vessel usage. 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. Also, in order to accommodate larger cargo ships more dredging by the port is expected in the future (Appendix 4.1.7.1.F Salinity). Dredging and/or deepening the channel can also affect the salinity conditions in the estuary by causing the salt water wedge to move further upstream (**Sucsy 2008**), negatively impacting biological communities like the tape grass beds on which manatees rely for food (**Twilley and Barko 1990**).

The average numbers of manatees observed on aerial surveys in the salinity transition zone area of the SJR decreased during periods of drought (1994-2000 and 2006-2009) and then increased again after the droughts (2000-2005 and 2009-2012) (Section 4.4). The reason for this was that during droughts elevated salinity leads to demise in the grasses that manatees feed on. As a result, manatees leave the study area in search for food. 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.

2.8.2.7. Data Sources & Limitations

Various sources of data were identified from DEP's STORET database, SJRWMD, USGS and COJ. Monthly data obtained from The City of Jacksonville's Environmental Quality Division "River Run" sampling program was used to determine salinity changes from 1991 to 2017. Other data sources identified include the City's Station List (122 sites) data from 1995-2009; Tributaries (105 sites) data from 1995-2010; The River Run (10 sites) in the mainstem of SJR from 1980s to 2017; The Timucuan Run (12 Sites) in the Nassau and Ft. George area sampled every other month dating back to 1997; and the recently established Basin Management Action Plan (BMAP) Tributaries sites updated in October 2010. The latter consists of 10 Tributaries (with 2-3 sites each) for a total of 30 sites beginning in 2010.

In addition, there is Water Body ID (WBID) trend data available for Jacksonville from 1994-2017. Older data includes chlorides levels collected at Main Street Bridge from 1954 to 1965 as part of the city's pollution sampling program around the time of the Buckman sewage plant coming on line (**Hendrickson 2014**).

Data obtained from The City of Jacksonville's Environmental Quality Division "River Run" sampling program was used to determine salinity changes from 1991-2017. Data is collected about twice a month at the surface (0.5 m), middle (3-5 m), and bottom (5-10 m) in the water column. However, in recent years the sampling frequency has been significantly curtailed due to budget cuts. Four sites were chosen from the regular ten sampling stations.

1) *West bank of SJR 1000 m south of Doctors Lake;*
2) *East bank of SJR 200 m north of a large apartment complex near Jacksonville University;*
3) *South bank of SJR just west of Dames Point Bridge, near the western most range marker;*
4) *Mainstem of SJR Mid channel N. of Piney Pt. 100 m west of green marker 5.*

Kendall's Tau correlation analysis revealed that salinity over time had significantly increased at the bottom, middle and surface at SJR near Doctors Lake, Piney Point mid-river, near Jacksonville University and Dames Point Bridge. For a map of the sample sites, analysis results, and graphs showing these trends, see Figures 8-20 in Appendix 4.1.7.1.F Salinity.

Monthly data are limited in that the sampling frequency is relatively low, and short-term events in weather may not be well represented. Continuous water quality data are available on the web through the USGS (**USGS 2018**). Currently active stations include the Dames Point Bridge, Buckman Bridge (Figure 2.58), and Dancy Point. Other non-active stations for which data is available include Main Street Bridge and Shands Bridge. Yet, another new source for continuous data in LSJR includes NOAA's PORTS program (**NOAA 2018**). This data has some gap years due to budget cuts preventing collection. Data at the Buckman Bridge show an increasing salinity trend in surface waters from 1995-2002 (represents a period of drought), then no data was available from 2004-2007, followed by another increasing trend from October 2008 – May 2013 (represents a period of drought). Then, this was followed by an increasing trend in salinity from June 2013 to March 2018, in spite of another data gap from April to September 2015 (representing increased rainfall initially, and then the onset of drought conditions). In 2017, there was a severe drought early in the year, followed by strong storm and precipitation activity in late 2017). These data indicate that large salinity fluctuations occurred and persisted for some time.

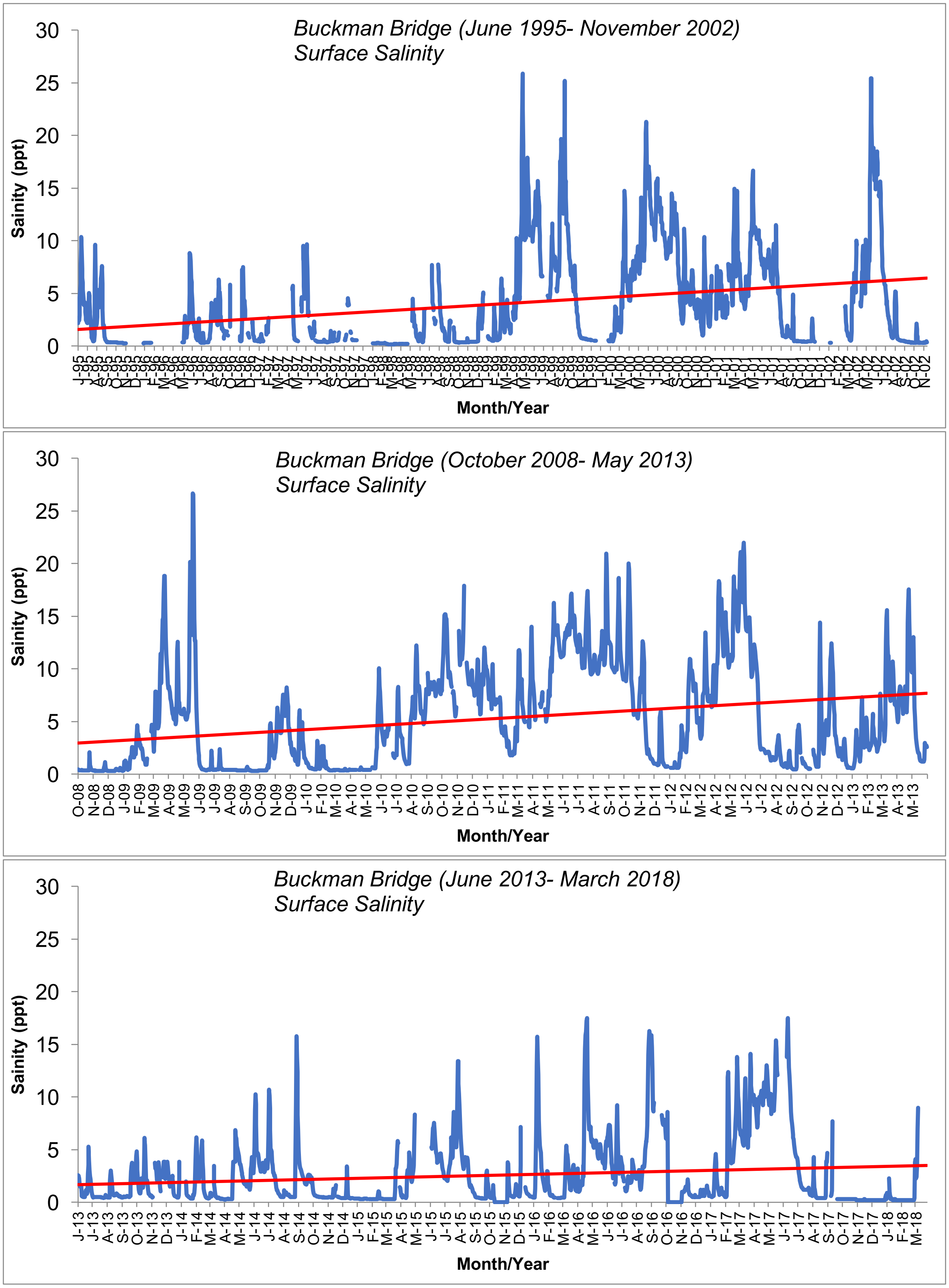


Figure 2.58 Surface salinity for June 1995- November 2002; October 2008-May 2013; and June 2013-March 2018 from USGS continuous data recording station at the Buckman Bridge.

2.8.3. Overall Assessment (Ratings of Status and Trend)

The salinity regime in the LSJRB has changed over the years due to various human activities and natural phenomena, including rising sea level. The river's ecology has been changed as a result of long-term salinity changes. In addition, there is no regulatory target for salinity in various sections of the river. However, this does not mean that we are not responsible for considering the environmental impacts of activities like surface water withdrawals and dredging, or future changes in rainfall and the amount and quality of surface water runoff given increases in population. All considered, including the historical and present values and trends in salinity, the current STATUS of salinity is rated as *unsatisfactory because of its impacts*, and the TREND of salinity is rated as *worsening because it is increasing.*

3. Fisheries

3.1. Introduction

3.1.1. General Description

The LSJRB supports a diverse finfish and invertebrate community that has significant commercial and recreational value. Blue crabs account for the majority of landings comprising 66% (1,142,824 lbs) of the total landings for 2016 (**FWRI 2018a**). Commercial finfish accounted for about 31% (546,005 lbs) of the total catch, which were predominantly striped (black) mullet (25%), flounders and sheepshead (1-3%), followed by menhaden, croakers, seatrout, and catfish (<1%). In 2013, Clay, Duval, Flagler, Putnam, and St. Johns Counties reported a total commercial crab harvest of 1,615,232 lbs (73%); and a fish harvest of some 570,509 lbs (**FWRI 2018a**). The oyster harvest represented about 3% of the total weight harvested in 2016 occurring in St. Johns County (Figure 3.1). Recreationally, the St. Johns River 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.

3.1.2. Data Sources & Limitations

All available literature was used to examine potential long-term trends (1955-2016) in fish communities via the presence or absence of species encountered in the particular study. Although, such comparisons can 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 change with time. Also, the collection methods in these studies were not the same, thus making it difficult to draw valid conclusions.

Two data sources were provided by the Florida Fish and Wildlife Research Institute (FWRI) as follows: 1) Commercial fisheries landings reports (1994-2016); and 2) data from the Fisheries Independent Monitoring (FIM) program (**FWRI 2002; FWRI 2003; FWRI 2004; FWRI 2005; FWRI 2006; FWRI 2007; FWRI 2008b; FWRI 2009; FWRI 2010; FWRI 2011; FWRI 2012b; FWRI 2013b; FWRI 2014**; **FWRI 2016**; **FWRI 2017b**; **FWRI 2018b**). 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 LSJR or the ICW. In addition, changes in fishery regulations over time limit what can be said of landings between certain time periods. For the most part, the total landings have been graphed. To best standardize comparisons of the total landings over time, we calculated landings per trip, and trends were investigated using a Kendal tau correlation analysis.

The most statistically reliable data used in this report comes from ongoing research conducted by the FWRI-FIM program. Data are presented in two forms. The first form displays for each species yearly Indices Of Abundance (IOA) for relevant age classes (young of the year, adults; or pre-fishery and slot size limits) encountered within the lower basin of the river. The second form displays the monthly length frequency diagrams for each species for the 15-years sampling period (Appendix 3.1.1). Both forms of display allow for more specific insight into temporal trends, recruitment, and the fishery (slot size limits available to fishermen). Potential trends in all these data are investigated using Kendall tau correlation analysis. Finally, scientific literature was used where appropriate to supplement these data and form conclusions about trends and status.

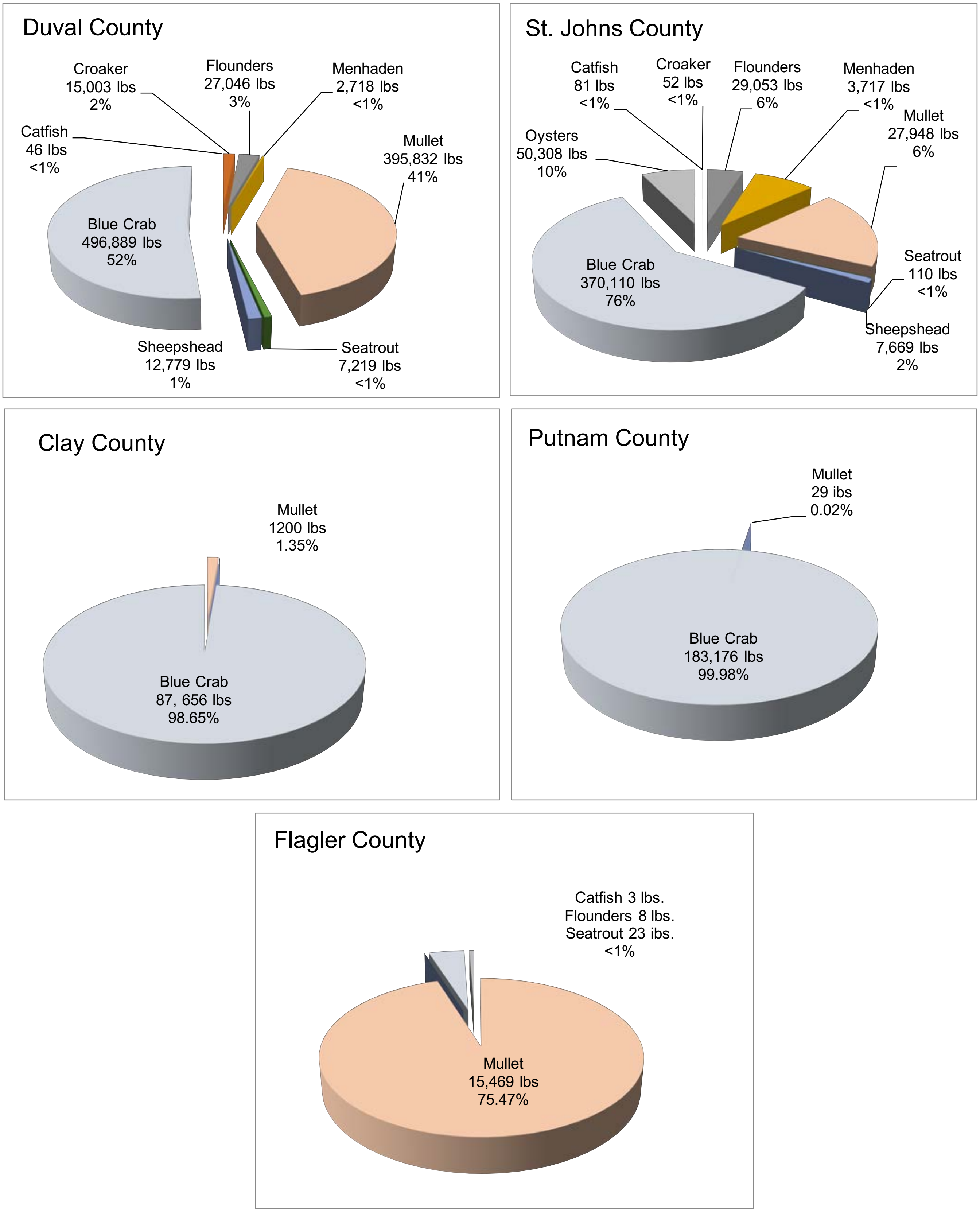


Figure 3.1 Percent comparison of commercially important fish and invertebrates caught by fisherman of five counties associated with the lower basin of the St. Johns River in 2016. These data do not differentiate between fish and invertebrates caught in the St. Johns River or the Intracoastal Waterway (ICW).

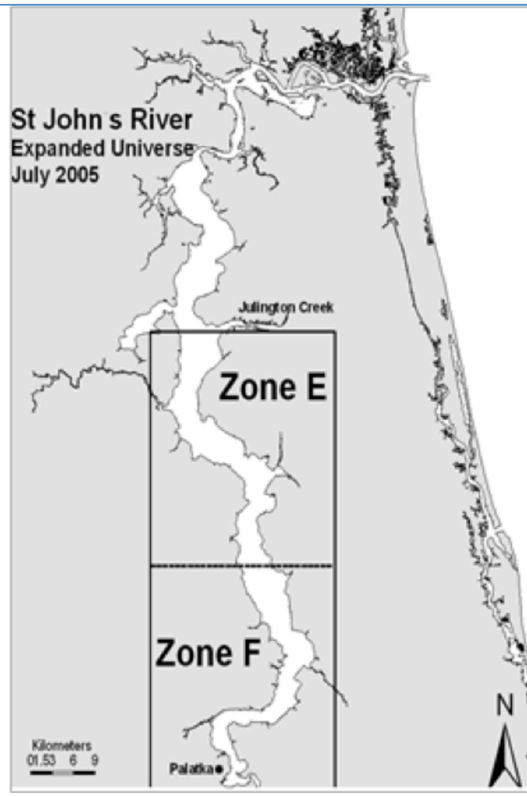


Figure 3.2 Map of areas of St. Johns River sampled by Fish and Wildlife Institute from July 2005 to December 2016 (FWC-FWRI, 2005). In this study, the north, middle, and southern river sections are FWRI areas C, D and E, F respectively.

3.1.3. *Health of Fish and Invertebrates*

There is not much information on the health of fish and invertebrates from the LSJRB. 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 69,510 (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 has data for the LSJR and the *Aphanomyces* fungus – published in part in **Sosa et al. 2007**. The latter study comprised of a statewide and historical survey of *Aphanomyces* and associated ulcerative lesions in fish. In the SJR, a number of species were confirmed with ulcerative lesions from *Aphanomyces* between 1980-2003 (time of study and retrospective analyses), including striped mullet (*Mugil cephalus*), Gulf flounder (*Paralichthys albigutta*), menhaden (*Brevoortia* sp.), weakfish (*Cynoscion regalis*), southern flounder (*Paralichthys lethostigma*), gray snapper (*Lutjanus griseus*), Atlantic croaker (*Micropogonias undulatus*), hickory shad (*Alosa mediocris*), American shad (*Alosa sapidissima*), brown bullhead (*Ameiurus nebulosus*), silver perch (*Bairdiella chrysoura*), pinfish (*Lagodon rhomboides*), sand seatrout (*Cynoscion arenarius*), and sheepshead (*Archosargus probatocephalus*). FWRI research suggested 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-aquae* followed by blooms of other algal species. Fish histopathology suggested that cyanobacteria-degrading bacteria might have played a role in this fish mortality 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* (**Sosa et al. 2007**).

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 2002; FWRI 2003; FWRI 2004; FWRI 2005; FWRI 2006; FWRI 2007; FWRI 2008b; FWRI 2009; FWRI 2010; FWRI 2011**). During this time period, the percent of fish affected by GEAs has varied between 0.001 to 0.4% (Figure 3.3). 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.

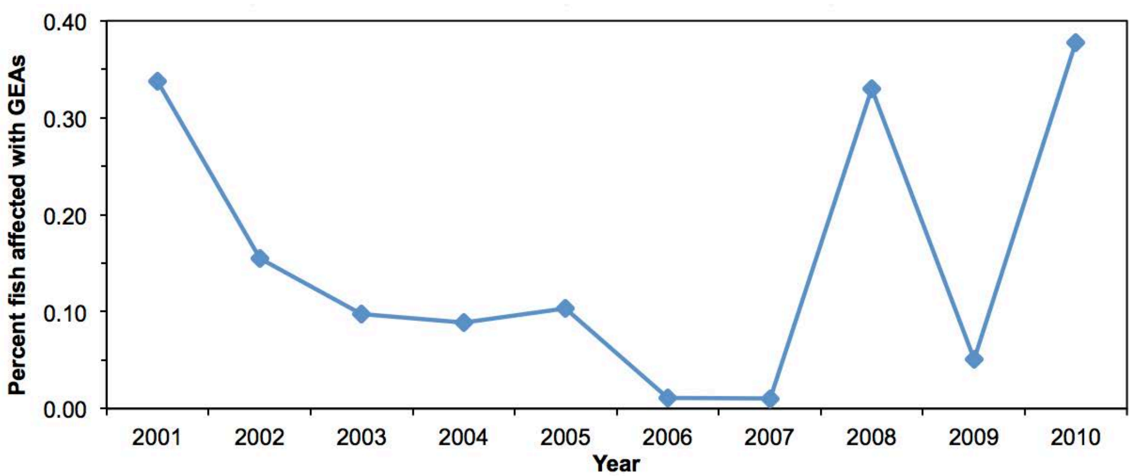


Figure 3.3 The percent of fish encountered with gross external abnormalities (GEAs) for each year of the ongoing FWRI study. A Kendall tau correlation revealed no significant trend over time (τ = -0.400; not statistically significant) in the percent fish encountered with GEAs from 2001 to 2010.

Mercury has been detected in a number of freshwater, estuarine and marine species in the state of Florida. The Florida Department of Health (FDOH) issues consumption advisories for a number of marine and estuarine fish (**FDOH 2016**). 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 LSJR, the FDOH 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 2018**). Note that more restricted consumption is recommended for children and pregnant/lactating women. For more information about consuming fish, see the FDOH website (**FDOH 2018**). 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 LSJRB 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 eels 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/redear sunfish, shad, American eels, and non-native tilapia. Of the five counties studied, Duval County had the overall highest landings (714,344 lbs. in 2014), and the generally most fish species caught per year except for flounder and menhaden mostly caught in St. Johns County (only includes fish caught within the river and ICW). Furthermore, Duval County ranks second largest among Florida counties in seafood harvested, predominantly shrimp caught in off shore coastal waters (**DACS 2014**).

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.

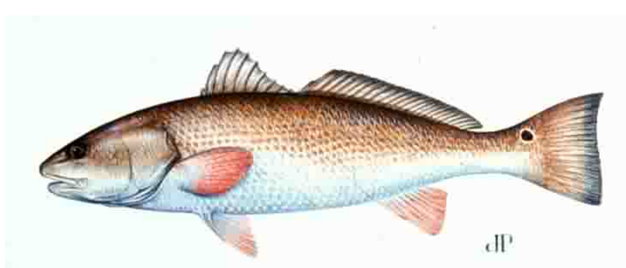
3.2.2. Long-term trends

For many years, humans have benefited from the thriving fish communities that utilize the LSJR. 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 SJR. In response to this need for more information, the FWRI 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 2008b**). 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 SJRWMD (**McCloud 2010**) compared current FWRI fish data with those collected by Tagatz in 1968 (**Tagatz 1968b**). 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 2015**) 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 45 inches.

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 2012, then a decreasing trend in adults in the last three years (2013-2015). However, 2015 only includes data from September to December and does not include January of 2016 (Figure 3.4). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ = -0.162; N.S.); adults were negatively correlated over time (τ = -0.543; p = 0.024). The Young of the Year (YOY) appear in the river from September to January and become juveniles in approximately one year (Appendix 3.2.3a).

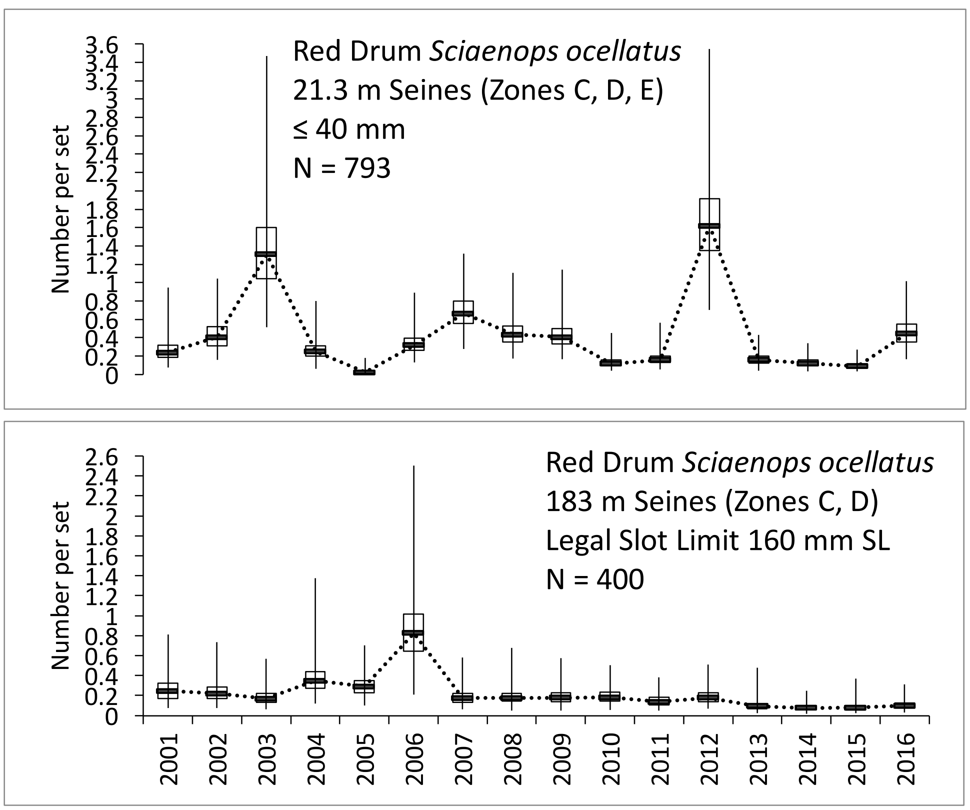


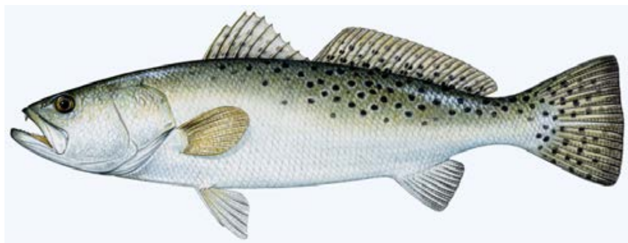
*Figure 3.4 Number of young of the year and adult red drum caught within the lower basin of the St. Johns River from 2001-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year red drum were sampled over a split year recruitment window from September to January with 21.3 m seins and a mesh size of 3.2 mm. YOY were caught in zones C, D, and E, at shallow depth (≤1.8 m). Legal sized fish were sampled from January through December with 183 m haul seins (mesh size 38 mm). Slot limit fish were caught in zones C and D along shorelines (Figure 3.2 Sampling Zone Map).*

3.2.3.4. Current Status and Future Outlook

Red drum represent an important recreational fishery in the LSJR and appear to be safe from overexploitation (**Murphy and Munyandorero 2008**). There is concern that increased fishing activity in the future may 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. Taking everything into account, the current STATUS of red drum is *satisfactory*, and the TREND is *unchanged.*

Recreationally, a maximum of two red drum may be caught per person per day throughout the year. Individual fish must be between 18 and 27 inches in length, and no red drum may be sold for profit (**FWC 2018a**).

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. 2011**). Out of this value, the LSJR (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 3.5; 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. 2011**). The FWRI data set shows consistent trends in abundance from 2001 to 2016 (Figure 3.6). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year ($\tau = 0.05$; N.S.), but there was a decreasing trend in adults ($\tau = -0.367$; $p = 0.024$; $n = 16$). In addition, there was a small peak in the number of young of the year (SL ≤ 100 mm) caught in 2007, and again in 2012. Young of the year appear in the river from May to November and become juveniles within one year (Appendix 3.2.4b).

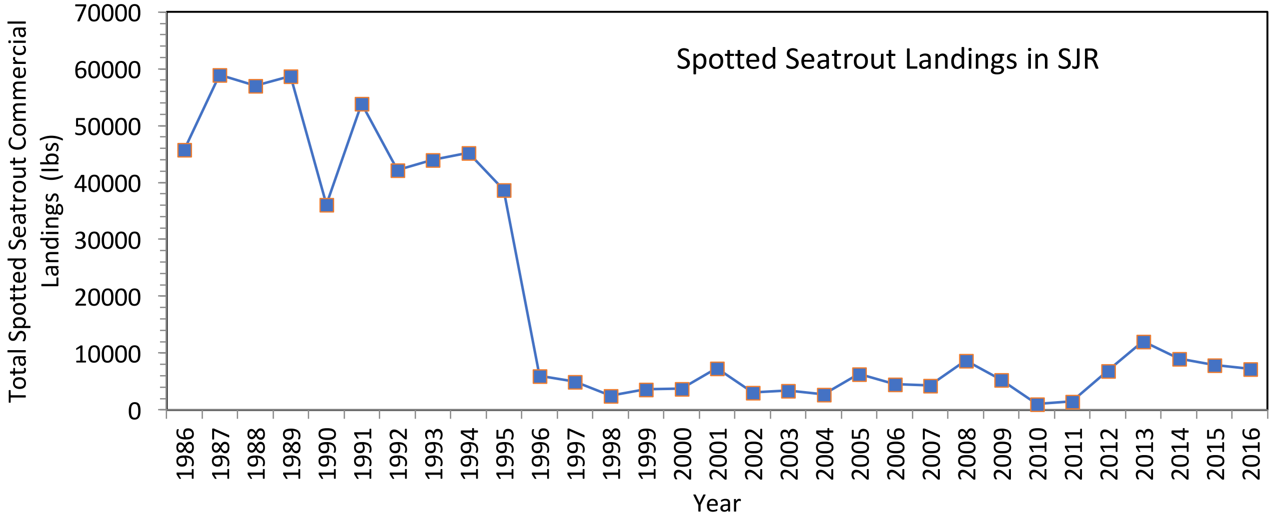


*Figure 3.5 Commercial landings (in lbs) of spotted seatrout within the lower basin of the St. Johns River from 1986 to 2016. Note that gill nets were banned in 1995 (**FWRI 2018a**).*

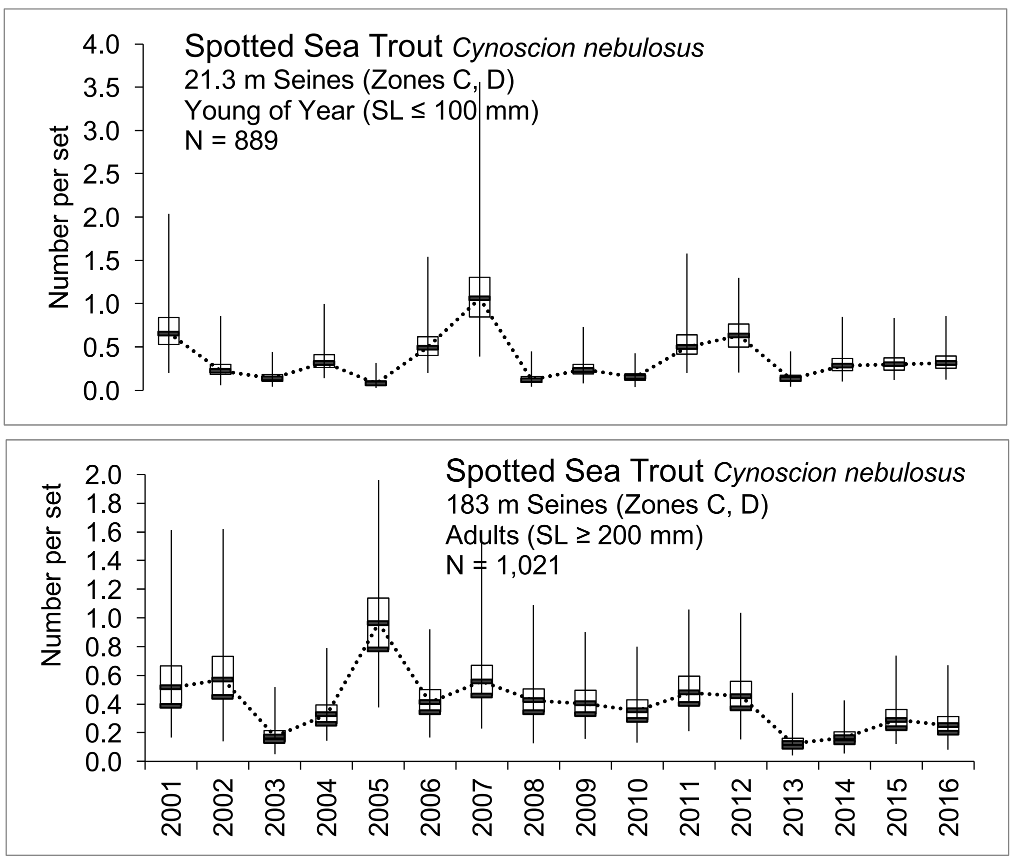


*Figure 3.6 Number of young of the year and adults of spotted seatrout caught within the lower basin of the St. Johns River from 2001-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year spotted seatrout were sampled during a recruitment window from May to November with 21.3 m seins and a mesh size of 3.2 mm. YOY were caught in zones C, D at shallow depth (≤1.8 m). Reproductively mature fish reside in zone C, but adults representing the legal slot limit of SL 325-434 mm yielded low numbers (n ≤ 110) and were not included in the analysis. Adults SL ≥ 200 mm included in the analysis yielded more numbers (n = 1,021) were used in the analysis. Adults were sampled from January through December with 183 m haul seines (mesh size 38 mm). These fish were caught in zones C and D along shorelines (Figure 3.2 Sampling Zone Map).*

3.2.4.4. Current Status & Future Outlook

The spotted seatrout recreational fishery has grown in the last 15 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 FWRI stock assessment suggests that spotted seatrout are not being overfished within the northeast Florida region (**Murphy et al. 2011**). Taking everything into account, the current STATUS of spotted seatrout is *satisfactory*, and the TREND is *unchanged*.

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 (slot limit) with a daily limit of six per person, and each person is allowed to keep one fish (included in the daily bag limit) that exceeds the slot limit of 20 inches. The season is open year round (**FWC 2018b**).

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 2016**). 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 10 years shows fairly similar yearly abundances from 2005 to 2014 (Figure 3.7). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ = -0.2; N.S.) Young of the year appear in the river from April to August and become juveniles within one year (Appendix 3.2.5a). Primary abundances occur in zones F, E, and since sufficient numbers were caught in zone D too, it was included in the analysis. Note that the analysis started in 2005 with the FWC expanded sampling zones. Also, SL ≤ 100 mm was chosen to follow the same cohort through a longer time frame. Gear used targets the small fish, and there is limited data about the adults.

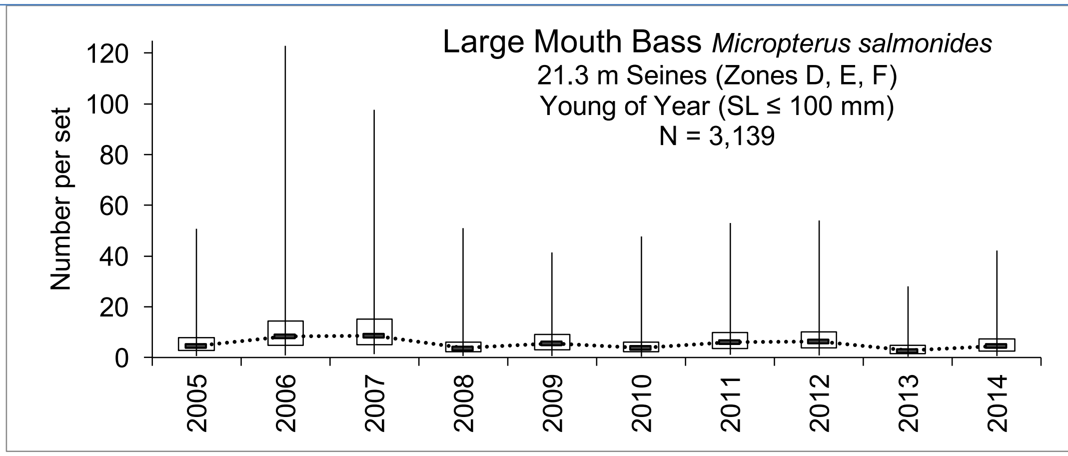


*Figure 3.7 Number of young of the year largemouth bass caught within the lower basin of the St. Johns River from 2005-2014. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year LMB were sampled during a recruitment window from April to August with 21.3 m seins and a mesh size of 3.2 mm (this gear targets the small fish). YOY were caught in zones D, E, and F at shallow depths ≤1.8 m (Figure 3.2 Sampling Zone Map).*

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. Taking everything into account, the current STATUS of Largemouth Bass is *uncertain*, and the TREND is *unchanged*.

Recreational fishermen are permitted to take largemouth bass all months of the year. As of July 2016, a daily limit of five per person is allowed with no minimum size limit and only one of the five being more than 16 inches in total length (**FWC 2018a**).

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

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

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 LSJR. 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 3.8). 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).

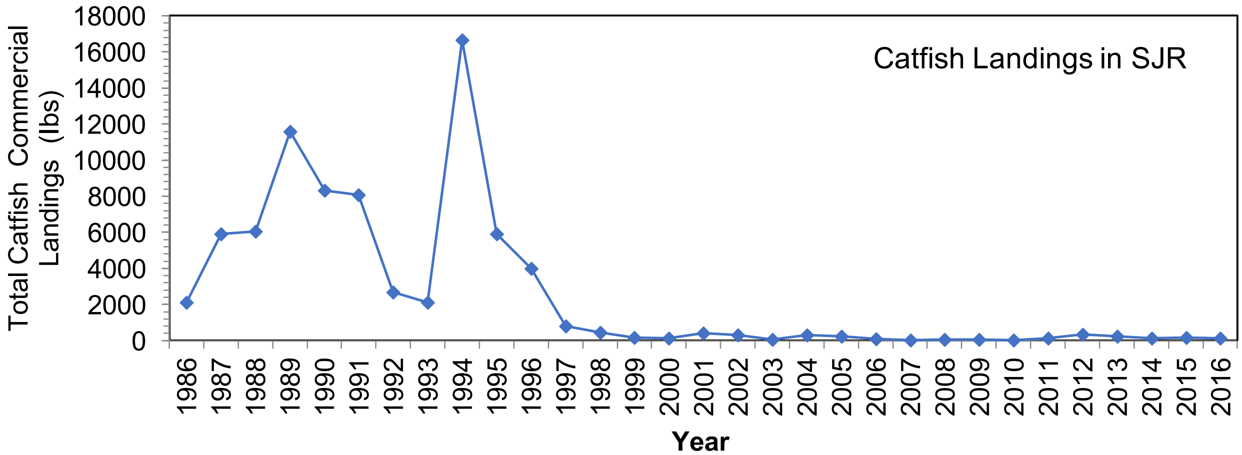


*Figure 3.8 Commercial landings (in lbs) of catfish within the lower basin of the St. Johns River from 1986 to 2016. Note that the gill net ban went into effect in 1995 (**FWRI 2018a**).*

The FWRI data set shows variable but consistent trends in abundance for both the channel and white catfish from 2005 to 2015 (Figures 3.9 and 3.10). Kendall tau correlation analyses revealed negative correlations over this time period for channel catfish in number per set for young of the year, but this was not significant (τ = -0.067; p = 0.394; n = 10). However, there did appear to be a decrease in abundance from 2005 before numbers started to become relatively similar (Figure 3.9). While somewhat variable, YOY Channel Catfish appear in the river from September to December and become juveniles in approximately one year (Appendix 3.2.6b). Primary abundances occur in zones E and F. Note that the analysis started in 2005 with the FWC expanded sampling zones. Also, SL ≤ 100 mm was chosen to follow the same cohort through a longer time frame. Gear used targets the small fish and limited data exists about the adults.

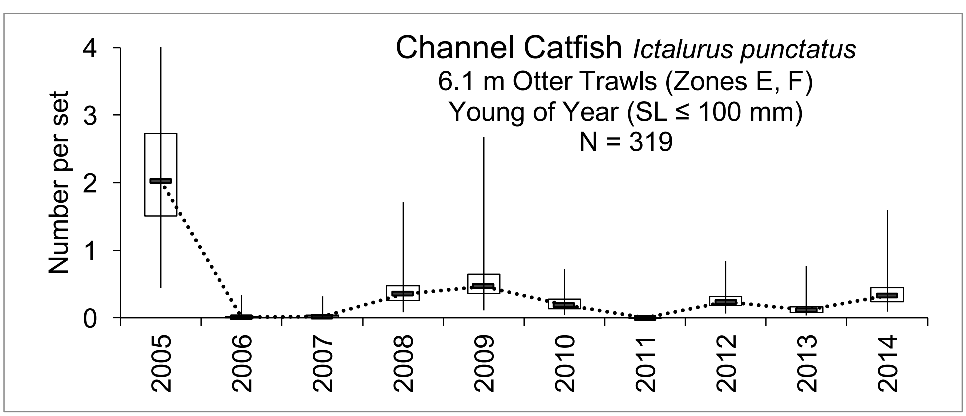


*Figure 3.9 Number of young of the year, channel catfish caught within the lower basin of the St. Johns River from 2005-2014. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year channel catfish were sampled during a recruitment window from September to December with 6.1 m otter trawls that have a cod end with a mesh size of 3.2 mm (this gear targets the small fish). YOY were caught in zones E and F (Figure 3.2 Sampling Zone Map).*

In terms of white catfish, there were also no trends observed in number per set for young of the year (τ = -0.152; p = 0.246; n = 12). However, the temporal patterns were particularly variable for young of the year with peaks encountered during 2005 and 2008/2009 and 2012. While also variable, young of the year appear in the river in June, recruit more fully from July to October, and become juveniles in approximately one year (Appendix 3.2.6c). Primary abundances occur in zones, E and F. Note that the analysis started in 2005 with the FWC expanded sampling zones. Gear used targets the small fish and limited data exists about the adults.

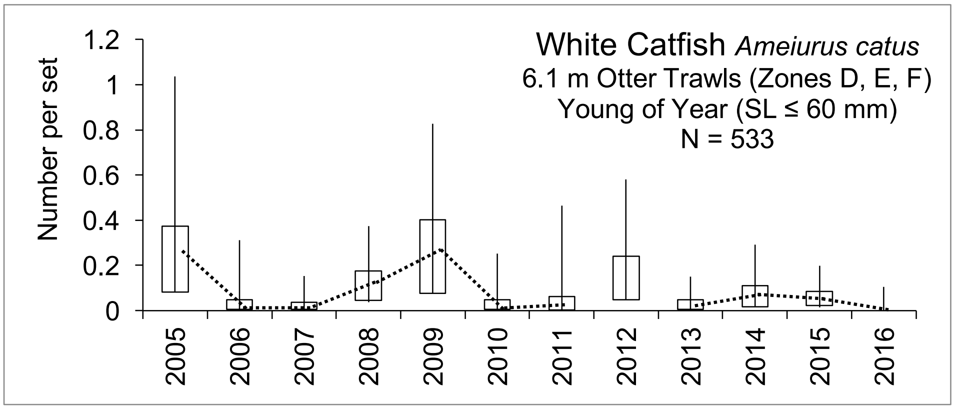


*Figure 3.10 Number of young of the year white catfish caught within the lower basin of the St. Johns River from 2005-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year white catfish were sampled during a recruitment window from July to October with 6.1 m otter trawls that have a cod end with a mesh size of 3.2 mm (this gear targets the small fish). YOY were caught in zones D, E, and F (Figure 3.2 Sampling Zone Map).*

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 and with the exception of Fish Management Areas, there is a bag limit of 6 fish per person on channel catfish, no bag limit for white catfish (**FWC 2018a**). Although there seems to be a slight increase in Young Of Year white catfish, this was not statistically significant. There are limited data about adults in general, and the commercial data suggest a decreasing trend in the northern section. Taking everything into account, the current STATUS of freshwater catfish is *uncertain*, and the TREND is *worsening*.

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 LSJR. 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 ($\tau = 0.556$; $p = 0.01$; $n = 10$) and landings per trip ($\tau = 0.689$; $p = 0.03$; $n = 10$) have been variable since the 1980s, but showed an increasing trend for the period 2007-2016 (Figure 3.11). This trend was observed in both the northern and southern sections of the river sections (Appendix 3.2.7a). The FWRI data set shows variable yearly abundances from 2006 to 2016 (Figure 3.12). Kendall tau correlation analyses revealed a negative trend in number per set for the young of the year ($\tau = -0.418$; $p = 0.037$; $n = 11$). Young of the year appear in the river from January through April and become juveniles within one year (Appendix 3.2.7b). Primary abundances occur in zones C, D, E and F. There were two observable peaks in recruitment during 2006 and 2010, possibly influenced by drought conditions in those two years. Note that the analysis started in 2006 because there was no FWC expanded sampling in zones E and F in January to April 2005. Gear used targets the small fish, and limited data exists about the adults.

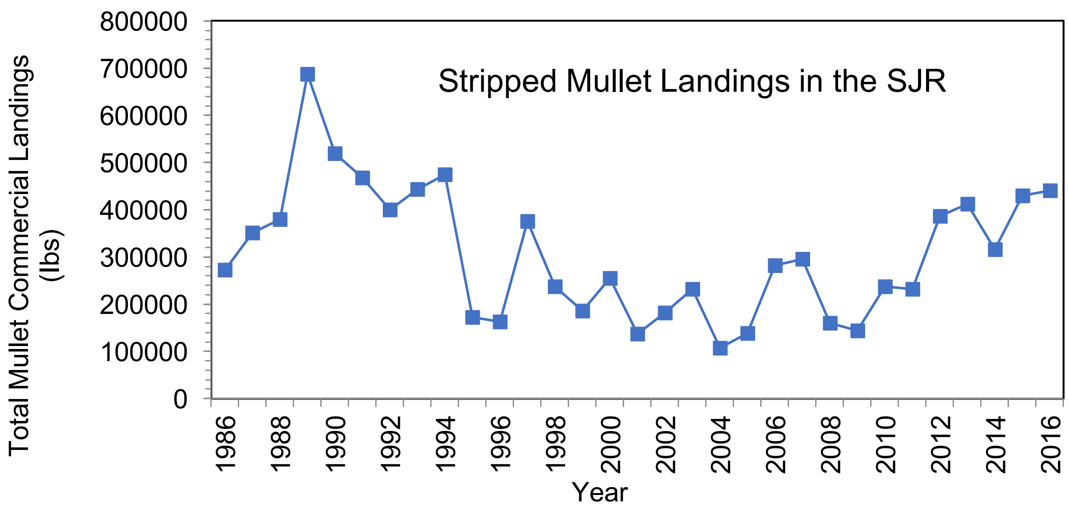


*Figure 3.11 Commercial landings (in lbs) of striped mullet within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2018a**).*

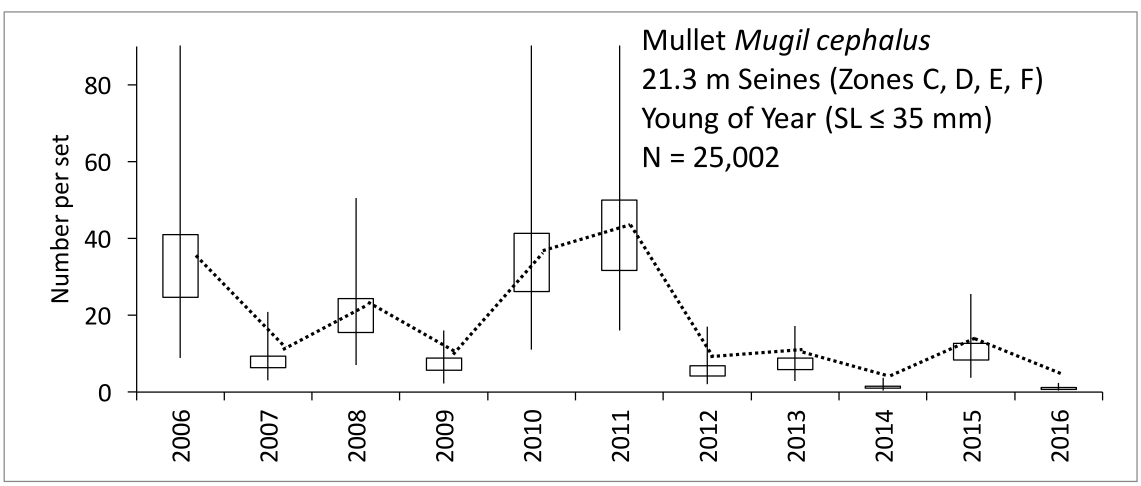


*Figure 3.12 Number of young of the year striped mullet caught within the lower basin of the St. Johns River from 2006-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year striped mullet were sampled during a recruitment window from January to April with 21.3 m seines (mesh size of 3.2 mm) that target the small fish. YOY were caught in zones C, D, E, and F (Figure 3.2 Sampling Zone Map). *Starts in 2006 due to no expansion sampling in Zones E and F in Jan-Apr 2005.*

3.2.7.4. Current Status & Future Outlook

Striped mullet in the St. Johns River continue to be important commercially and recreationally. Populations appear to be healthy and sustainable along the east coast of Florida (**Mahmoudi 2005**). Recreational fishing limitations are 50 fish per person per day (includes Striped and Silver mullet). There is a vessel limit of 50 fish (September 1st to January 31st, and 100 fish from February 1st to August 31st). There is no closed season (**FWC 2018a**). Taking everything into account, the current STATUS of Striped Mullet is *satisfactory*, and the TREND is *improving.*

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 common in and around inshore channels 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 after 1995 (Figure 3.13; Appendix 3.2.8a). Total flounder landings have decreased significantly for the north river section (τ = -0.420; p = 0.003; n = 23) and increase in the southern section of the river (τ = 0.309; p = 0.02; n = 23) (Appendix 3.2.8a).

However, the commercial catch per trip increased in the northern section of the river (τ = 0.360; p = 0.008; n = 23) and a decrease in the southern section of the river (τ = -0.494; p = 0.0005; n = 23). The mid-1990s decrease in commercial landings may be due to the impact of the gill net ban. The FWRI data set shows slight increases in young of year fish in 2003, 2005, 2010, and 2011, otherwise a relatively flat trend in abundance from 2001 to 2016 (Figure 3.14). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year using two different gear types (Seines: τ = -0.033; N.S: Trawls τ = -0.217; N.S.) Young of the year appear in the river from February to June and become juveniles within approximately one year (Appendix 3.2.8b). Primary abundances occur in zones C, D, E, and F, with a noticeable peak in recruitment during 2010, reason unknown at this time. Note that the analysis started in 2001 because there was no sampling done from January to April 2000. Both gear types used targeted the small fish, and limited data exists about the adults.

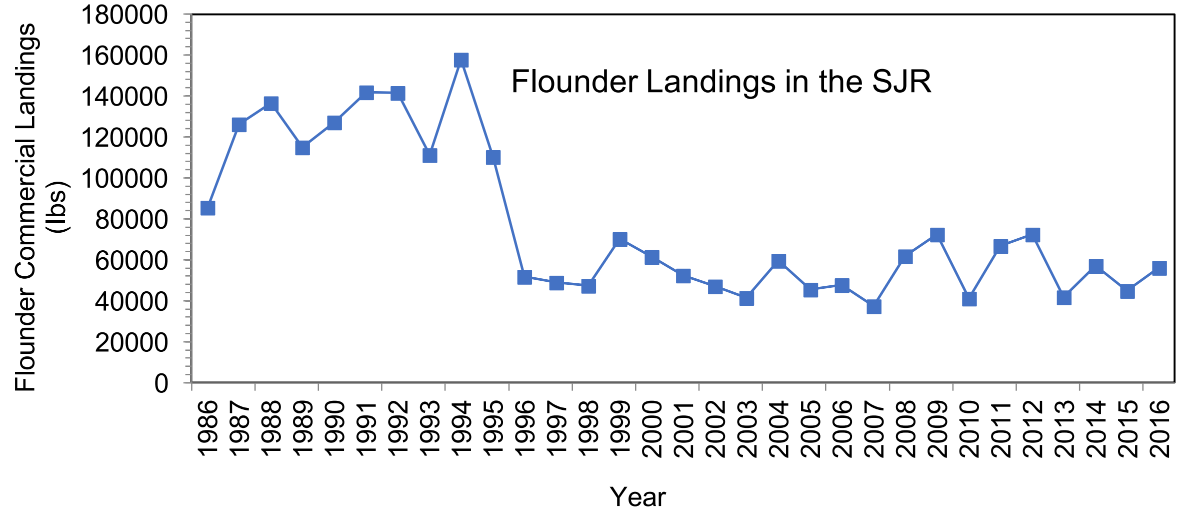


*Figure 3.13 Commercial landings (in lbs) of southern flounder within the Lower Basin of the St. Johns River from 1986-2017 (**FWRI 2018a**).*

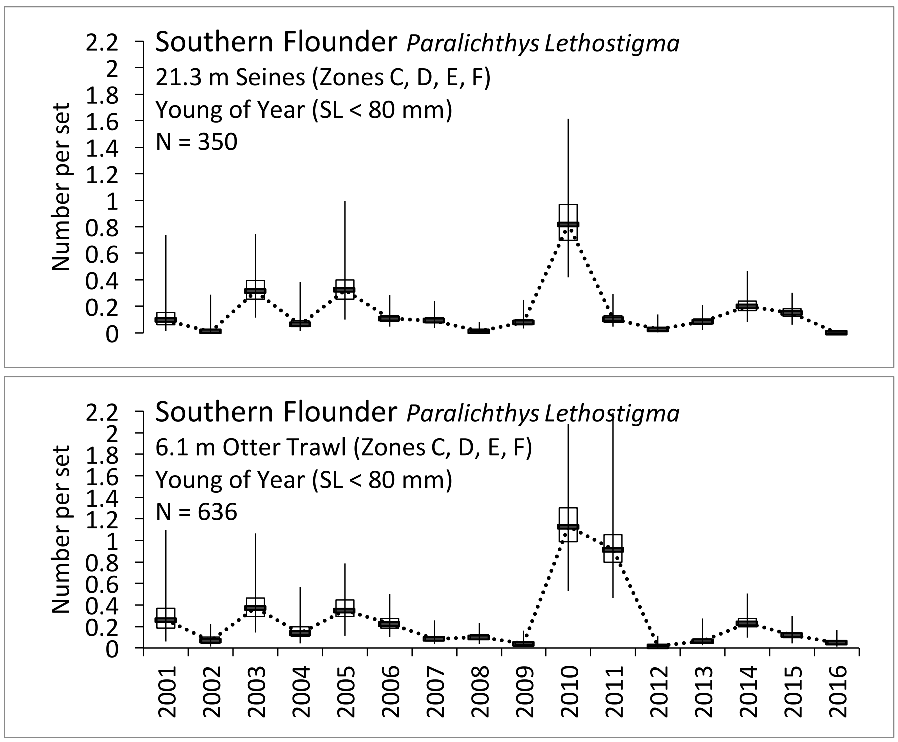


*Figure 3.14 Number of young of the year southern flounder caught within the lower basin of the St. Johns River from 2001-2016 (two gear types compared). The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year southern flounder were sampled during a recruitment window from February to June with 21.3 m seines and 6.1 m otter trawls (mesh size of 3.2 mm) that both target the small fish. YOY were caught in zones C, D, E, and F. (Figure 3.2 Sampling Zone Map).*

3.2.8.4. Current Status & Future Outlook

The southern flounder continues to be important recreationally and commercially in the LSJR. 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 2008c**). 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 limit is 12 inches with a daily limit of ten fish per person (**FWC 2018a**). Taking everything into account, the current STATUS of Southern Flounder is *uncertain*, and the TREND is *uncertain*.

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 an 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 3 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 valued by fisherman in the area for their high food value.

3.2.9.3. Trend

Commercial landings seemed stable from 1997 to 2003, then declined until 2008. Since 2008, the trend has been increasing but remains below 2003 levels (Figure 3.15). Total landings over time showed a declining trend for the north (τ = -0.394; p = 0.0009; n = 31), and whole river (τ = -0.295; p = 0.0009; n = 31) in spite of an increase in landings per trip for the north (τ = 0.402; p = 0.0007; n = 31) and whole river (τ = 0.325; p = 0.005; n = 31) (Appendix 3.2.9a). Landings and landings per trip were not significant for the southern counties. Note that data from the southern counties most likely includes a significant number of fish caught in the ICW.

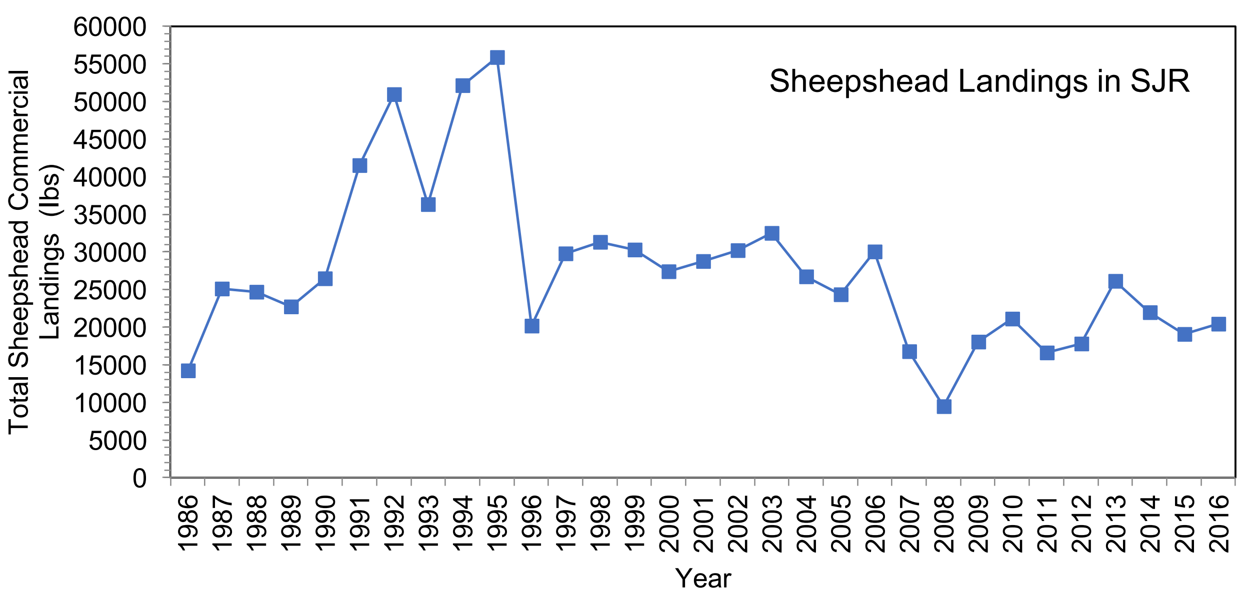


*Figure 3.15 Commercial landings (in lbs) of sheepshead within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2018a**).*

The FWRI data set shows a decreasing trend in abundance from 2001 to 2016 for harvestable fish ($\tau = -0.383$; $p=0.02$; $n=16$) (Figure 3.16). Kendall tau correlation analyses revealed that there was a negative trend in number per sets for pre-fishery fish ($\tau = -0.417$; $p = 0.01$; $n = 16$). Young of the year appear in the river in May and become juveniles within approximately one year. Unfortunately, it was not possible to analyze young of year fish due to low numbers (SL ≤ 130 mm) not being well represented in the sampling (Appendix 3.2.9b). These fish reach 1 year of age at 130 mm SL and are fully recruited to the fishery at 268 mm SL. As a result, size classes were chosen based on the FIM Annual Reports (**FWRI 2018b**) that include pre-fishery 131-267 mm SL and legally harvestable fish SL ≥ 268 mm.

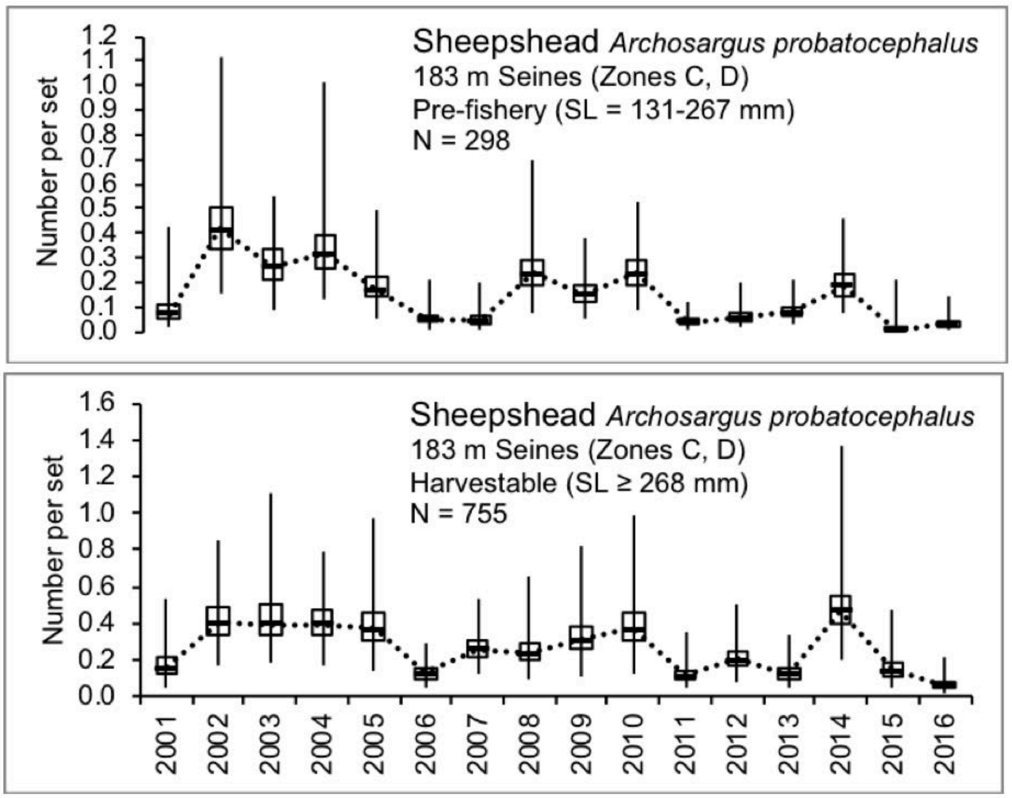


*Figure 3.16 Number of pre-fishery and harvestable sheepshead caught within the lower basin of the St. Johns River from 2001-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Sheepshead were sampled during a recruitment window from January to December with 183 m haul seines (mesh size of 38 mm) that target the larger fish. Pre-fishery and harvestable sheepshead were caught in zones C and D (Figure 3.2 Sampling Zone Map).*

3.2.9.4. Current Status & Future Outlook

Sheepshead continue to be important to both recreational fishermen and commercial fisheries. The fish are usually relatively common in the St. Johns River, although the data suggested a decreasing trend. In the past, sheepshead appeared to be abundant enough along the Florida east coast to maintain populations at the then current levels of harvest (**Munyandorero et al. 2006**). They can be caught all months of the year. Legal minimum size limit is 12 inches with a daily limit of fifteen fish per person (**FWC 2018a**). Taking everything into account, the current STATUS of Sheepshead is *uncertain*, and the TREND is *uncertain.*

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 LSJR 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 LSJR. Additionally, they are recreationally caught for their food value.

3.2.10.3. Trends

Commercially, total landings from 1986-2016 have no significant trend for the northern section of the river and whole river (τ = -0.389; NS); however, some increase occurred after 2011 to 2016 (Figure 3.17; Appendix 3.2.10a). Catch per trip had an increasing trend for the north (τ = 0.497; p = 4.32E-05; n = 31), and whole river (τ = 0.390; p = 0.001; n = 31), but this was not statistically significant for the south (τ = 0.044; NS). In both sets of commercial data, landings are lower in the southern sections of the river (Appendix 3.2.10a).

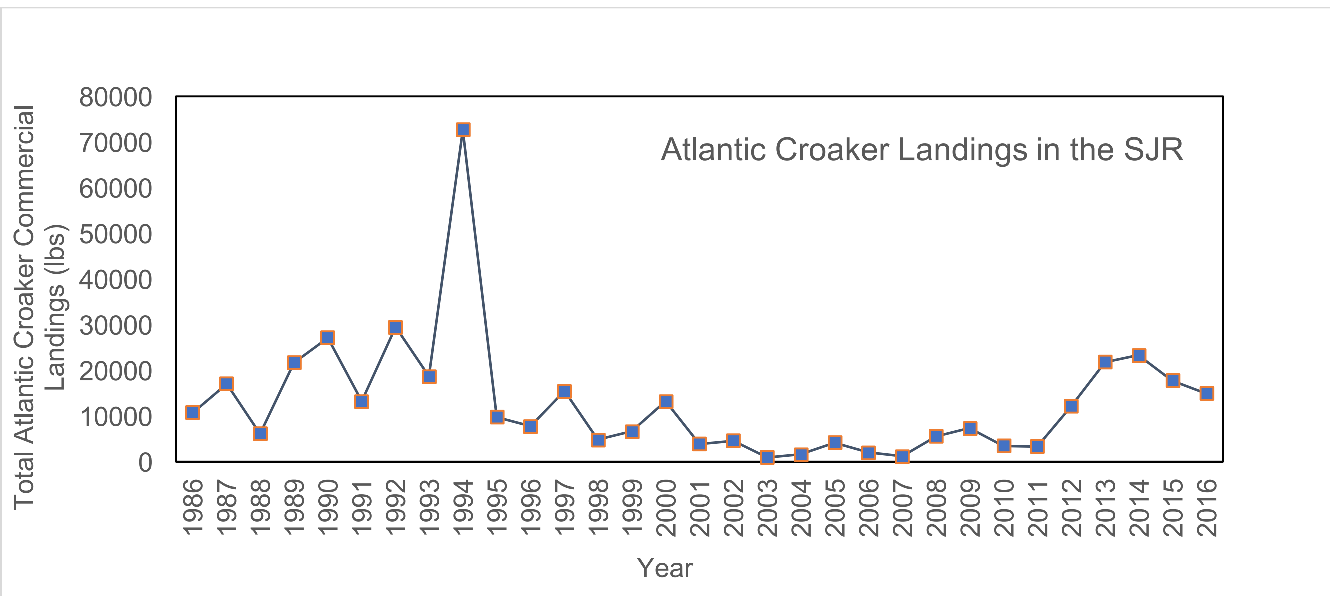


*Figure 3.17 Commercial landings (in lbs) of Atlantic croaker within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2018a**).*

The FWRI data set shows consistent trends in abundance from 2001 to 2016 (Figure 3.18). Kendall tau correlation analyses revealed no temporal trend in number per set for young of the year (τ = 0.20; N.S.) Young of the year appear in the river over a split year from October to April 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**).

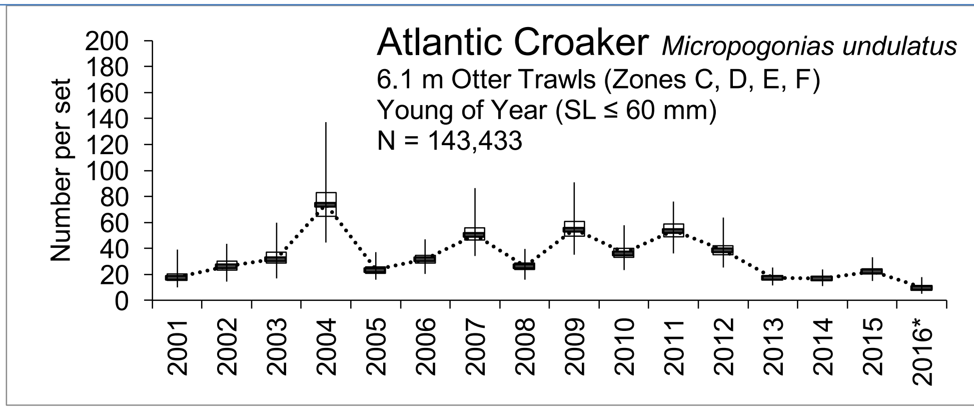


*Figure 3.18 Number of young of the year Atlantic croaker caught within the lower basin of the St. Johns River from 2001-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Young of year red drum were sampled over a split year recruitment window from October to April with 6.1 m otter trawls (cod end mesh size of 3.2 mm). Note that 2016 includes October to December but not Jan-April 2017. YOY were caught in zones C, D, E, and F. (Figure 3.2 Sampling Zone Map).*

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

Atlantic croaker are common in the LSJR 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, and there is currently no legal size limit (**FWC 2018a**). Taking everything into account, the current STATUS of Atlantic croaker is *satisfactory*, and the TREND is *unchanged*.

3.2.11. Baitfish

http://floridasportfishing.com/magazine/baifish

3.2.11.1. <u>General Life History</u>

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 LSJR. 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. <u>Significance</u>

Baitfish are very important to the LSJR because they 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. Baitfish are commercially and recreationally utilized for their bait value. Recreational use includes bait for fishing, whereas commercial uses may include 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 sporadic since (Figure 3.19; 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 landing showed significant decreasing trends for the north section of the river ($\tau = -0.286$; $p = 0.012$; $n = 31$), but was not significant for the south river section ($\tau = 0.126$; N.S.) Further, baitfish landings seem to be higher in the southern sections of the river. More recently, from 2007 to 2016, catch per trip showed significant increasing trend for the whole river ($\tau = 0.422$; $p = 0.045$; $n = 10$).

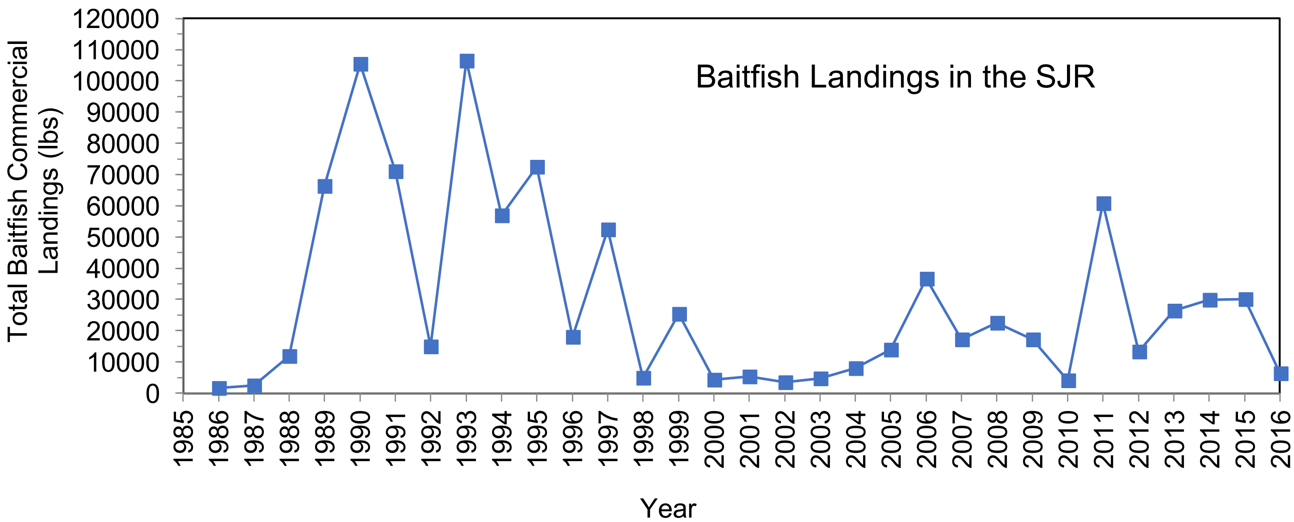


*Figure 3.19 Commercial landings (in lbs) of baitfish within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2017a**).*

3.2.11.4. Current Status & Future Outlook

Baitfish are very abundant in the LSJR 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 2018a**). Taking everything into account, the current STATUS of baitfish is *satisfactory*, and the TREND is *unchanged*.

3.3. Invertebrate Fishery

3.3.1. General description

The invertebrate community is very important to the overall ecology of the LSJRB. 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 (2007-2016), Duval County generally reported the highest catch of crabs (mean 579,768 lbs per year; SD = ± 167,038 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 2013a**) 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 2002**). 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 River. 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 LSJRB (Figure 3.1). In 2016, it accounted for 66% of commercial fisheries in the river with 1,142,824 lbs harvested. Duval County reported the highest number of crab landings (496,889 lbs), followed by St. Johns (370,110 lbs), Putnam (183,1476 lbs), Clay (87,656 lbs), and Flagler County (4,993 lbs).

3.3.2.3. Data Sources

Blue crab data were collected from commercial reports (1994 to 2015) of landings made to the state and research (2001-2015) from the FWRI. The 2014 data are finalized, whereas the 2015 data are considered preliminary.

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, but from 1986 to 2016, trended downward for north (τ = -0.230; p = 0.034; n = 31) and south (τ = -0.441; p = 0.0002; n = 31) sections of LSJR. However, from 2011 to 2012, landings increased more than over the past decade, but decreased sharply from 2013-2016 (Figure 3.20). Additionally, more landings occur in the southern versus northern section of the river (Appendix 3.3.2a). There was a significant decrease in the amount of blue crabs landed per trip over time for the north section of the river (1986-2016) (τ = -0.346; p = 0.003; n = 31), but no significant trend for the south (τ = 0.148; N.S.). From 2007 to 2016, no significant trend was observed in landings, however, catch per trip increased in the whole river (τ = 0.556; p = 0.013; n = 10), but decreased in the norther section of the river (τ = -0.689; p = 0.003; n = 10). There was a significant percent reduction in landings for blue crabs over all during the past decade (τ = -0.644; p = 0.0047; n = 10) (65% in 2016) compared to an average of 75% (range 61-86%).

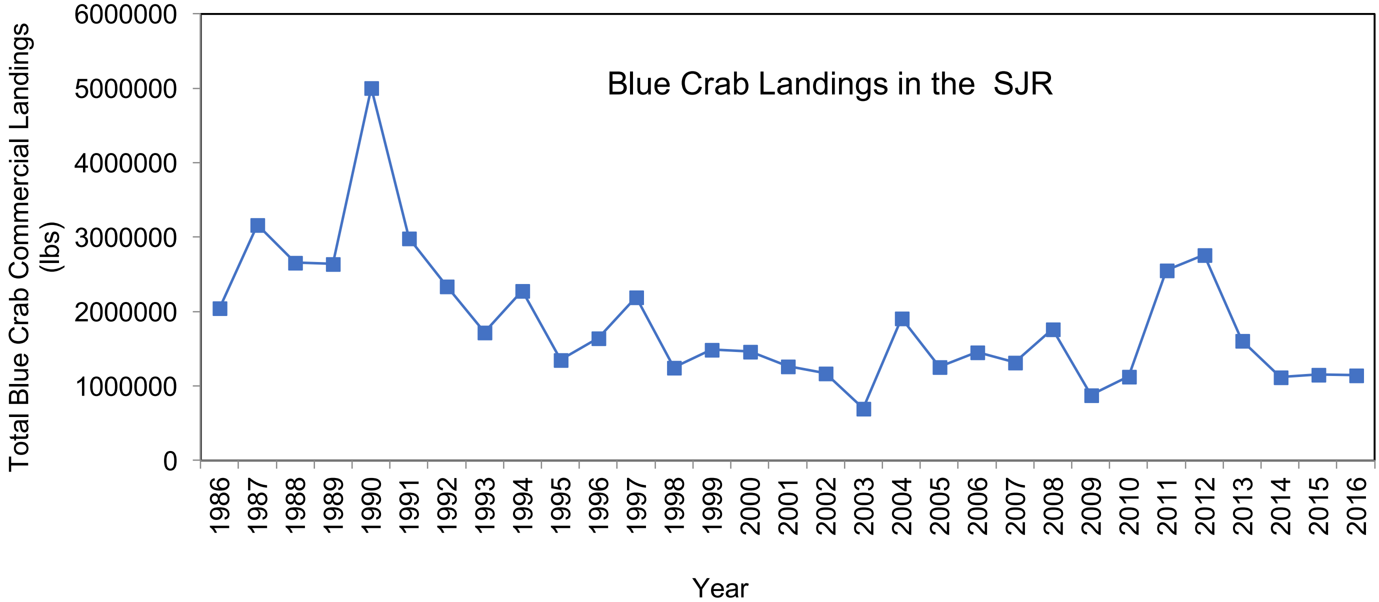


*Figure 3.20 Commercial landings (in lbs.) of blue crabs within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2018a**)*

The FWRI data set shows consistent trends in abundance from 2001 to 2016 (Figure 3.21). Kendall tau correlation analyses revealed no temporal trend in number per set for juvenile (τ = -0.067; N.S.), or adult crabs (τ = -0.133; N.S.) From trawl catch data, the abundance of juveniles seems to peak in June and is lowest in November (Appendix 3.3.2b). Blue crabs were sampled from January to December with 23.1 m seines and 6.1 m otter trawls both with a mesh size of 3.2 mm. Carapace Width (CW) size classes used follow the FIM Annual Report (**FWRI 2018b**). Blue crabs were caught in zones C, D, E, and F. Adult crabs are usually sampled with 183 m haul seines (mesh size 38 mm), but since mature crab numbers were higher in the otter trawls, this data was analyzed instead. In addition, some individuals classified as adults may still have been reproductively immature due to individual variation in growth rates and timing of maturity (**Brodie 2016**).

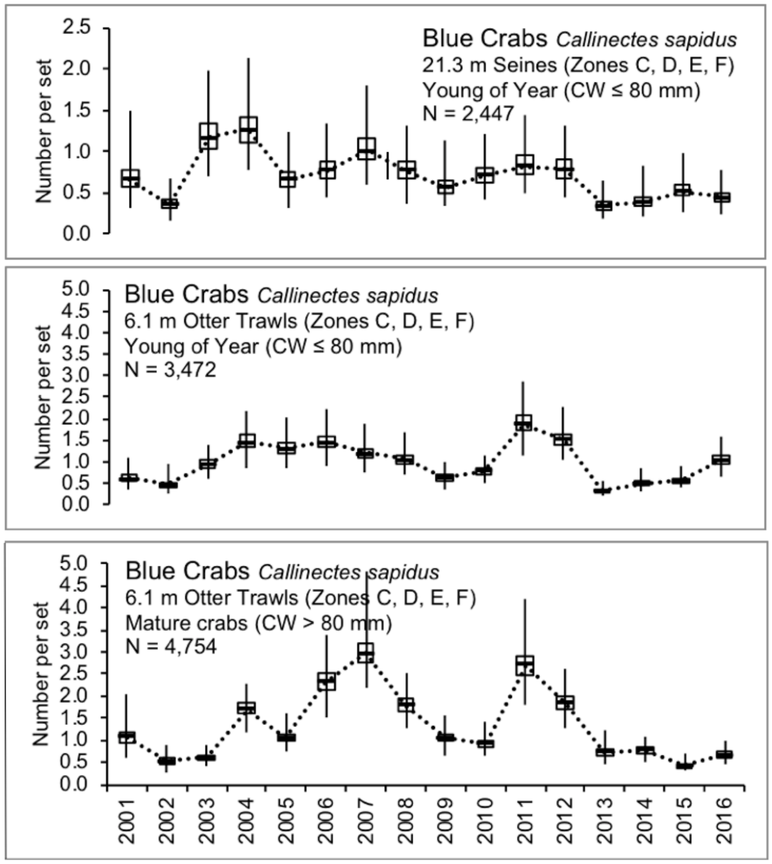


*Figure 3.21 Number of juveniles and adults of blue crabs caught within the lower basin of the St. Johns River from 2001-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). Blue crabs were sampled from January to December with 23.1 m seines and 6.1 m otter trawls both with a mesh size of 3.2 mm. Carapace Width (CW) size classes used follows the FIM Annual Report (**FWRI 2018b**). Blue crabs were caught in zones C, D, E and F. (Figure 3.2 Sampling Zone Map).*

3.3.2.6. Current Status & Future Outlook

The blue crab commercial fishery continues to be the premier invertebrate fishery within the LSJRB. 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 (ten gallons whole per harvester per day) except from January 16th to 25th on even years. Crabs can also be caught using dip nets, crab pots, and hand-lines. Although it is illegal to harvest egg-bearing females, it is not against the law to harvest non-egg bearing females; however, since female crabs are critically important to ensuring the survival of subsequent generations of crabs, releasing them helps the fishery to be more sustainable in the future. While male crabs can reproduce many times, females only mate once when mature and can store sperm for several months before actually spawning eggs (**FWC 2018a**).

> *"If a mature female is harvested, though she may not exhibit eggs, there is no certainty that she has spawned" (**FWRI 2018a**).*

The statistical analysis did not reveal any significant trend in the FWRI data for adults and Young of Year crabs. Commercial catch data indicated a decreasing trend overall (north/south sections of the river combined) and just in the north section of the river; no significant trend occurred in the southern section where most crabs are harvested. Taking everything into account, the current STATUS of blue crab is *uncertain*, and the TREND is *uncertain*.

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 2007**). 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 LSJR 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 LSJR represents a much smaller fishery.

3.3.3.3. Data Sources

Penaeid shrimp data were collected from commercial reports made to the state (1986 to 2015). These comprised of total bait shrimp landings that were generally collected within the river. 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 (2001-2016) from the FWRI.

3.3.3.4. Limitations

The primary limitation with the commercial landing data is that 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 (1986-2016) have been variable with a downward trend in the southern section of the river (τ = -0.266; p = 0.02; n = 31) (Figure 3.22). However, from 2001 to 2012, there have been drastic fluctuations among the years with peak landings occurring in 2004. Less fluctuation has occurred in recent years, but the catch per trip has also decreased significantly (τ = -0.422; p = 0.045; n = 10) particularly in the north section of the river where more bait shrimp are reported versus southern sections of the LSJR from 2007 to 2016 (Appendix 3.3.3a).

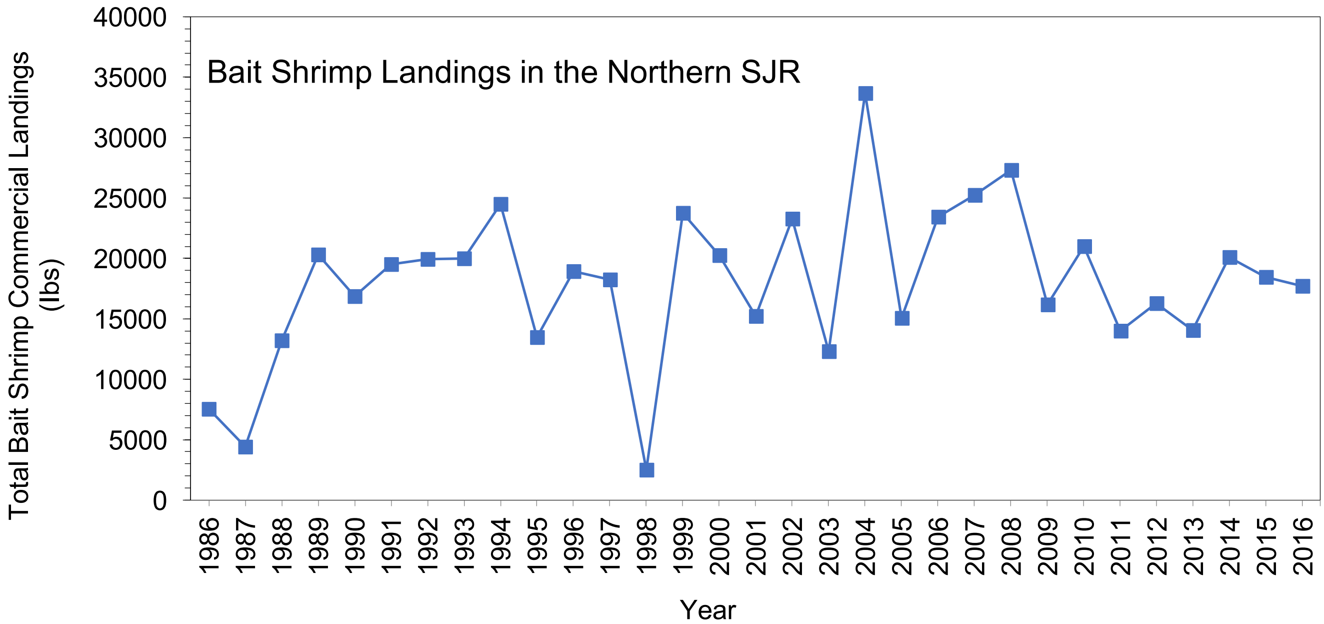


*Figure 3.22 Commercial landings (in lbs) of bait shrimp within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2018a**).*

The FWRI data set shows consistent trends in abundance for white shrimp from 2001 to 2016 (Figure 3.23). Kendall tau correlation analyses revealed no trend in the number of YOY white shrimp captured per set from seines and trawls (τ = 0.267; NS). The highest numbers of small white shrimp were encountered in the river from May to August (Appendix 3.3.3b). With seines, nearshore abundance was seen in zones C and D, and fewer numbers occurred in E and F. In contrast, with trawls, a high number was seen in all 4 zones (**Swanson 2016**).

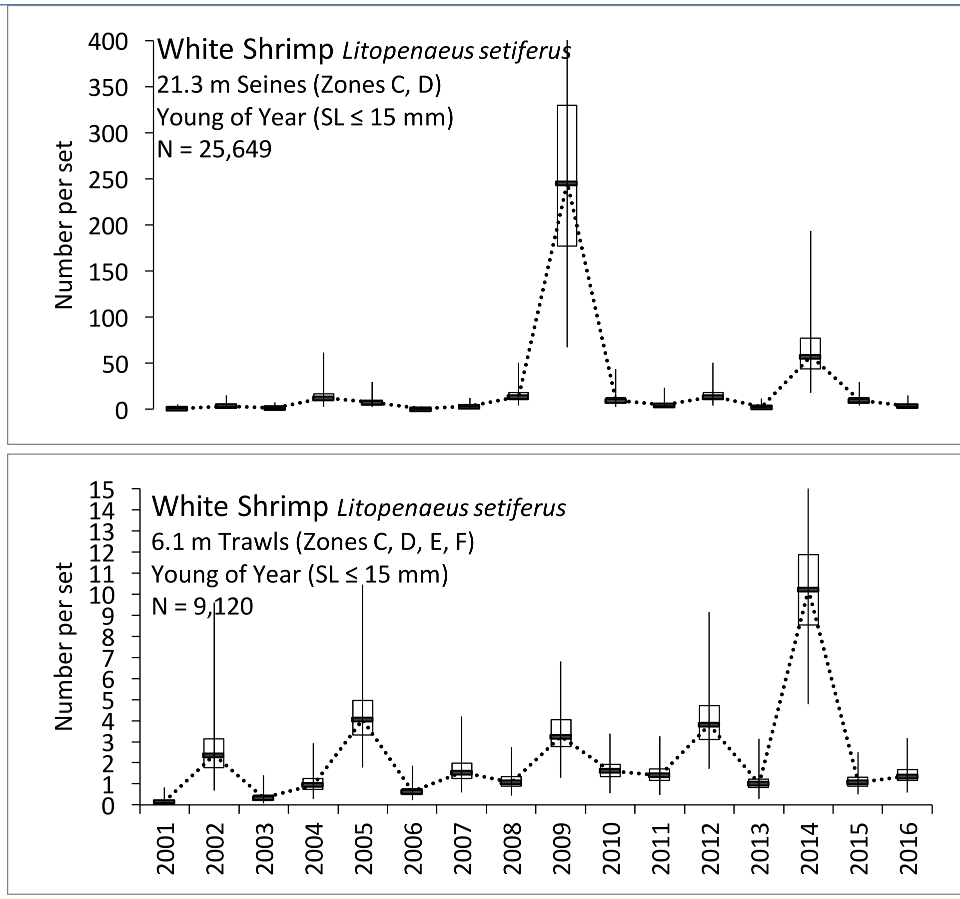


*Figure 3.23 Number of juveniles of white shrimp caught within the lower basin of the St. Johns River from 2001-2016. The N value indicates the total number of sets completed for the time period (**FWRI 2018a**). White Shrimp were sampled from May to August with 23.1 m seines and 6.1 m otter trawls both with a mesh size of 3.2 mm. White shrimp were caught in zones C, D, E and F depending on the gear type used. (Figure 3.2 Sampling Zone Map).*

3.3.3.6. Current Status & Future Outlook

Commercial harvesting of penaeid shrimp for bait is a relatively small fishery in the LSJR. The recreational fishery is probably moderately sized, although there are no available data about it. Generally, penaeid shrimp are very abundant in the region and may be at slight risk of being overfished in the south Atlantic region (see **FWRI 2008d** 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 2008d**). Recreational shrimping regulations include no size limit; however, there is a bag limit of five gallons (heads on) per person each day and a possession limit of no more than five gallons (heads on) per vessel at any time regardless of the number of people onboard. Allowable harvesting methods that comply with the FWC regulations include dip net, cast net, push net, one frame net, or beach sein. The season is closed during April and May in Nassau, Duval, St. Johns, Putnam, Flagler, and Clay Counties (**FWC 2018a**).

Statistically, there appears to be no trend in Young of Year shrimp. However, commercial data indicated a decreasing trend overall and high annual variability. Most shrimp are caught in the northern section of the river and this section has a decreasing trend for catch. In addition, the southern section of the river also exhibited a decreasing trend in catch.

Taking everything into account, the current STATUS of shrimp is *uncertain*, and the TREND is *uncertain*.

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 2007**). 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 LSJR. The highest number of claw landings within the river basin likely comes from Duval County. Claw landings from other counties of the LSJR most likely come from collections made in the ICW.

3.3.4.3. Data Sources

Stone crab data were collected from commercial reports of landings made to the State between 1986 and 2016. 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 Kendall 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 2002**). Peak landings occurred in 1994 and 1997 with generally low landings occurring from 1998 to 2006 (Figure 3.24). From 2007 to 2016, landings have increased ($\tau = 0.467$; $p = 0.03$; $n = 10$), and catch per trip was not significant.

Most landings were reported by the more southern counties of the LSJRB (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.

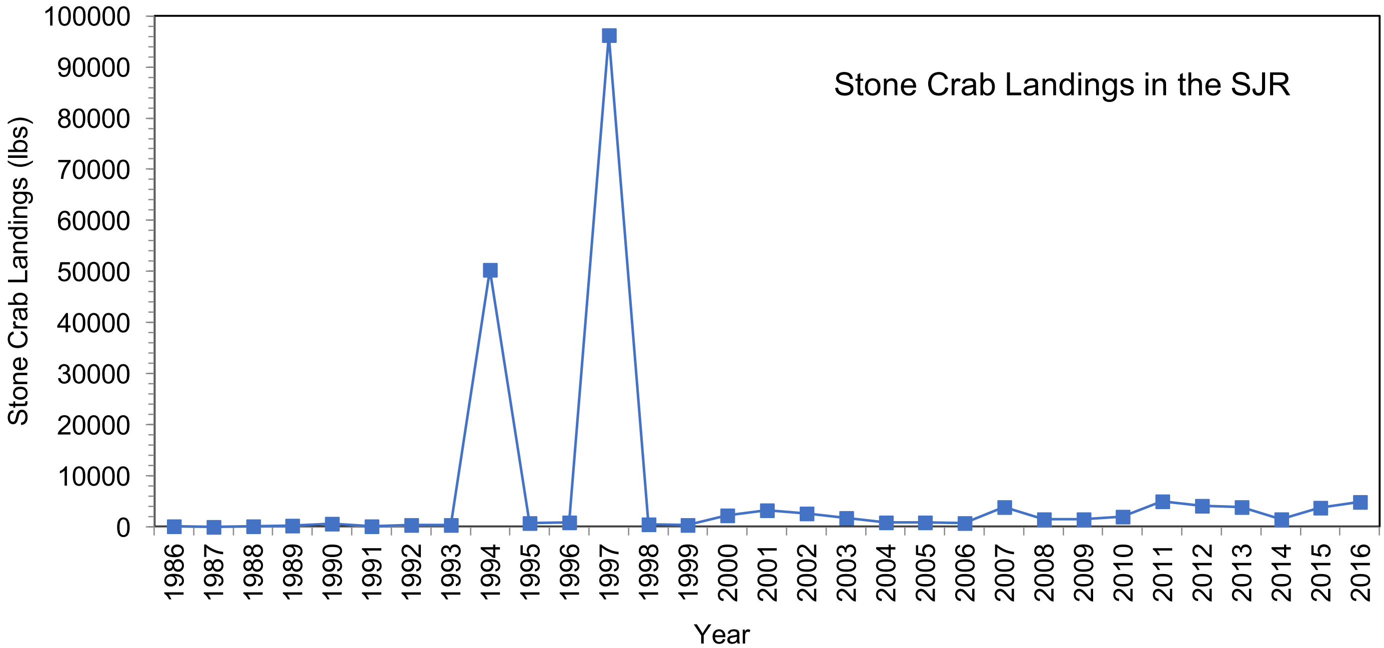


*Figure 3.24 Commercial landings (in lbs) of stone crab claws within the lower basin of the St. Johns River from 1986 to 2016 (**FWRI 2018a**).*

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 legislature implemented a crab trap reduction program in 2002. Currently, there is a daily limit of one gallon per person, or two gallons per vessel, of minimum-sized 2 ¾-inch claws (tip to elbow) to only be collected during the season from October 15 to May 15. Although it is not against the law to harvest both claws from legal sized crabs, the common practice is to leave one claw intact before returning the crab to the water. As a result, crabs can feed and defend themselves more effectively while re-growing the removed claw (**FWC 2018a**).

Taking everything into account, the current STATUS of stone crab is *satisfactory*, and the TREND is *unchanged*.

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 (**White et al. 2002; Sagan 2010)**. *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 2013**). **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
- Leaves 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 West Indian manatee *Trichechus manatu* (**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 1992**). **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 2.4 Algal 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 2012b**). On April 13, 2009, the Governing Board of the 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 would result in the withdrawal of water from the St. Johns and Ocklawaha Rivers (**St. Johns Riverkeeper 2009**). The impact of water withdrawal on salinity was investigated by a team of researchers from the SJRWMD, and the final recommended sustainable withdrawal from the Water Supply Impact Study was 155 MGD. The National Research Council peer review committee provided peer review, and the final report was made available in early 2012 (**NRC 2012**).

4.1.3. Data Sources & Limitations

The SJRWMD conducted year-round sampling of SAV from 1998 to 2011 at numerous stations (about 152 stations along line transects of St. Johns River (1.25 miles apart) (**Hart 2012**). This monitoring program, which included water quality data collected at SAV sites, was suspended due to budget cuts, so no new data were available from 2012-2014. Sampling resumed on a more limited basis in 2015/2017 to include fewer stations than before (Jacksonville to Black Creek/Hallows Cove, about 40 stations). This type of field sampling provides information about inter-annual relative changes in SAV by site and region. Data evaluated in this report is for the years 1989, 2000 through 2011, and 2000 through 2015 for the latest limited sampling program in the northern section. 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 most recent data for (1) Fuller Warren to Buckman Bridge and (2) Buckman Bridge to Hallows Cover sections have been updated in this report. The data set includes a couple of the most intense El Niño years (1998, and 2015) the former, 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 2018b**) (Figure 4.1), the National Hurricane Center (**NOAA 2018**), and the Climate

Prediction Center (**NOAA 2013**) (see Appendix 4.1.7.1.E for Rainfall, Hurricanes, and El Niño). Salinity data from 1991 to 2017 were provided by the Environmental Quality Division of the COJ. Water quality parameters are measured monthly at ten stations in the mainstem 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 are 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**, p. 5) – see a list of select findings under Section 4.1.5. Future Outlook.

4.1.4. Current Status & Trend

The status and trend was based on the significance of evaluated grass bed parameters using Kendall's Tau correlation analysis. 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 2001-2011, 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 4.1.7.2.A-B). The degree to which this occurred was greater north of the Buckman Bridge compared to south of the bridge.

<u>North of the Buckman Bridge:</u> the average grass bed length declined from 139 m (1998) to 22 m (2011). Surveys were suspended due to budget cuts from 2012 to 2014. When sampling was resumed in the area during 2015/2016, there were 12 sampling sites. In 2017, this number was reduced to 2 sampling sites, adding more uncertainty to the trend analysis: (1) the average grass bed length (includes bare patches) decreased to 50 m in 2017 from 58 m (2016). However, mean bed length (excluding bare patches) decreased to 26 m from 48 m (2016). Trends in the other grass bed parameters were: (2) total percent cover by SAV (all species) was relatively unchanged from 47 % (2015) to 53% (2016), and 55 % in 2017. Moreover, (3) *Vallisneria* percent cover increased from 61 % (2015) to 87 % in 2017 (see Table 1 in Appendix 4.1.7.2.A-B). In addition, anecdotal observations from manatee aerial surveys of the area in May and September 2017 indicated that grass bed coverage north of the Buckman Bridge (Bolles School to Buckman-east bank, and some parts from NAS JAX to Buckman-west bank) was bare. This was most likely due to the lack of rainfall over the past year, and early 2017, that resulted in increased salinity conditions in that part of the river contributing to the decline in grass bed coverage.

<u>South of the Buckman Bridge to Hallows Cove:</u> the average grass bed length was variable but showed less decline than the north from 106 m (1998) to 89 m (2011), with a maximum of 146 m in 2004 when four hurricanes skirted Florida, providing above average rainfall and fresher conditions prevailed. Surveys were suspended due to budget cuts from 2012 to 2014. When sampling was resumed in the area during 2015/2017, (1) the average grass bed length (includes bare patches) increased to 95 m from 81 m (2016). However, mean bed length (excluding bare patches) was 65 m and relatively unchanged from (2016), but less than 74 m in 2015. Trends in the other grass bed parameters were: (2) total percent cover by SAV (all species) declined from 83 % (2015) to 81% (2016), and further to 25 % in 2017. Also, (3) *Vallisneria* percent cover declined from 67 % (2015) to 59 % in 2017 (see Table 2 in Appendix 4.1.7.2.A-B). Moreover, anecdotal observations from manatee aerial surveys of the area in May and September 2017 indicated that grass bed coverage south of the Buckman Bridge (to Black Creek-east bank, and Switzerland-west bank) supported relatively lush grass beds compared to the north. This was most likely due to lower salinity and fresher conditions prevailing in this part of the river compared to the north.

Although still below 1998 levels, the 2015 and 2017 data from SJRWMD indicate that grass beds in the northern section of St. Johns River have regrown significantly compared to 2011 levels. This is likely due to fresher conditions from 2012 to 2015 when more normalized and stable rainfall conditions prevailed (Figure 4.1).

However, it is important to note that this represents just three years of data, and more years of data are required to see if the trend is sustained particularly coming out of the current El Niño season (2015) and entering into another severe period

of drought affecting the whole State of Florida. The grass beds from the Buckman Bridge to Hallows Cove do not appear to have undergone significant changes since 2011.

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. However, over the longer-term (2001-2011) there was a declining trend in grass bed length (Appendix 4.1.7.2.D-E). There was no new data for these areas of the river in 2015/2017.

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. From 2012-2015, rainfall has been near average and stable, favoring grass bed growth again in the northern sections of the river. 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**). The 2017 year was anomalous with severe drought early in the year. In September, this was followed by hurricane "Irma" that significantly affected the whole State of Florida. Taking everything into account, and particularly because of limited data and coverage in the north, the current STATUS of SAV is *unsatisfactory*, and the TREND is *uncertain*.

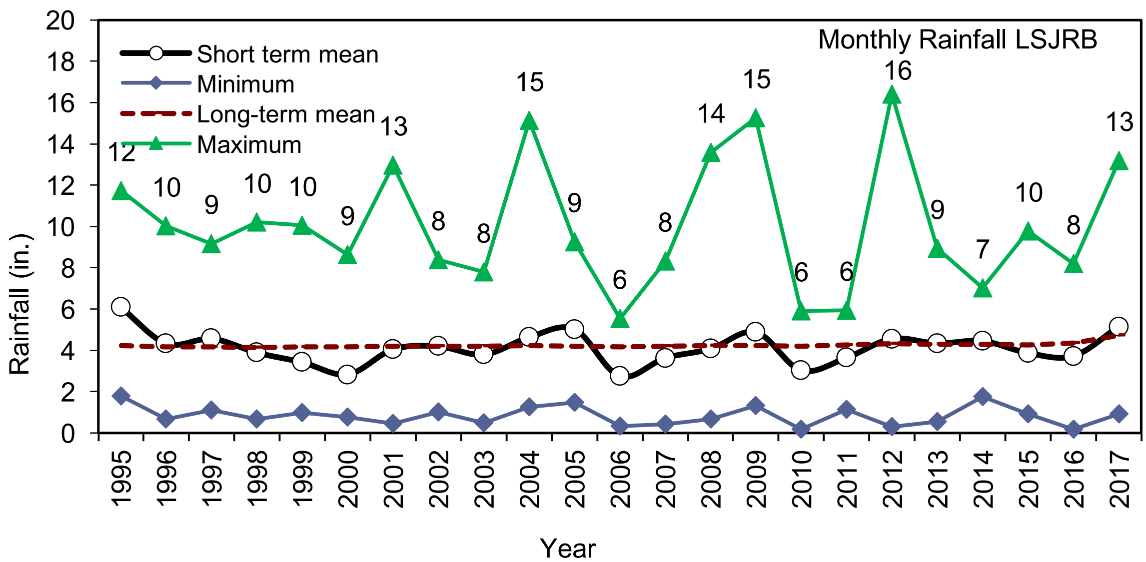


Figure 4.1 Monthly rainfall maximum, minimum, long term and short term annual means for LSJRB. Data are for the period June 1995 to December 2017 (solid lines). Average of monthly rainfall for periods 1951-1960 and 1995-2017 were not significantly different (dotted line) (Data source: ***SJRWMD 2018b****).*

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 habitat ecosystem services, fisheries and other quality-of-life indices such as aesthetics, recreation, and public health. The grass beds monitoring program should be resumed and expanded as soon as possible especially in light of efforts to further deepen the port channel, and the pending environmental and habitat changes that are likely to ensue as a result of global warming, rising sea levels, El Niño events, and storms.

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

Freshwater withdrawals, in addition to harbor deepening, have likely contribute to the changes in salinity regimes in the LSJRB over time, but the size of the most recent impacts are predicted to be minimal based on the 2012 Water Supply Impact Study (**SJRWMD 2012a**). The study found that the maximum sustainable upstream surface water withdrawal, and extent of impact to SAV in the LSJR was to be negligible relative to the normal inter-annual variation in the primary drivers of SAV colonization, water color, and salinity intrusion, which in turn are driven by precipitation and runoff. 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. As a result, 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 2012**).

Select findings of the St. Johns River Water Supply Impact Study: Final Report (**NRC 2012**):

- "The workgroups did not appear to consider the possibility of "back-to-back extreme events in their analyses, e.g., two or three years of extreme drought in a row, which the Committee considers to be reasonably likely future situations." p. 97
- "They also tended to present mean responses to perturbations of a given driver with little or no consideration of the variance in that response. Although mean values are considered the most likely responses from a statistical perspective, in analyzing potential environmental impacts of changes in driver variables it is important to consider ranges (or variances) of responses. Although such responses may be less likely than mean values, they may not have negligible probabilities and they also could be much more detrimental than the mean responses. The Committee remains concerned that the District did not consider such conditions sufficiently in their otherwise thorough analyses." p. 97
- "Several critical issues that are beyond the control of the District or were considered to be outside the boundaries of the WSIS limit the robustness of the conclusions. These issues include future sea-level rises and increased stormwater runoff and changes in surface water quality engendered by future population growth and land-use changes. As discussed in Chapter 2, the predicted effects of some of these issues on water levels and flows in the river are greater in magnitude than the effects of the proposed surface water withdrawals, but they have high uncertainties. In addition, the relatively short period (ten years) of the rainfall record used for the hydraulic and hydrodynamic modeling and the assumption that it will apply to future climatic conditions is a concern. The Committee recognizes that changing climatic conditions globally are rendering long-term historic records less and less useful in making extrapolations to future rainfall patterns, particularly for time periods in the more distant future (e.g., 25-50 years from now). The District should acknowledge this limitation in its final report and should plan to run its models with more recent rainfall records in an adaptive management mode." p. 100-101
- "The Committee continues to be somewhat concerned with the basis for the final conclusion that water withdrawals of the magnitude considered in the WSIS will not have many deleterious ecological effects. In large part, this conclusion was based on the model findings that increased flows from the upper basin projects and from changes in land use (increases in impervious urban/suburban areas) largely compensated for the impacts of water withdrawals on water flows and levels. Although the upper basin projects should be viewed as a positive influence insofar as they will return land to the basin (and water to the river) that belonged there under natural conditions, the same cannot be said about increased surface runoff from impervious urban- and suburbanization. The generally poor quality of surface runoff from such land uses is well known. Uncertainties about future conditions over which the District has no control (e.g., climate change, sea level rise, land use) also lead to concerns about the reliability of the conclusions." p. 100-101
- "The WSIS should have included a water quality workgroup that addressed the effects of changing land use on runoff and return flow water quality throughout the basin. It is clear that future needs for additional water supplies in the St. Johns River basin will be driven by population increases that also will result in land-use changes—essentially increases in urban/suburban land cover—and increases in the production of wastewater effluent. Both of these changes are highly likely to affect surface water quality in the basin. The District argued that these considerations were beyond their scope and authority and that existing regulations such as NPDES permits and stormwater regulations would be sufficient to prevent water quality degradation. Although the Committee accepts the District's argument that it lacks authority to control land use and population growth, it does not accept the view that this means

the District has no responsibility to consider these issues in a study on the environmental impacts of surface water withdrawals." p. 104

- "District scientists found that the lack of basic data (e.g., certain kinds of benthos and fish information) and the inadequacy of basic analytical tools (e.g., on wetland hydrology and biogeochemical processes) limited what they were able to achieve and conclude. Some of these deficiencies could be overcome by future work of District scientists, and these needs should be addressed in the District's medium- and long-term planning for future studies." p. 104

4.2. Wetlands

Figure 4.2 A variety of weltands can be found along the St. Johns River Basin, including 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).

4.2.1. Description

Some of the most biologically diverse and productive systems on earth, wetlands 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. ***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**). The term *wetland* also includes non-vegetated areas like tidal sand or mud flats, intertidal zones along shorelines, intermittent ponds and oyster bars. ***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 freshwater and include swampy areas that are dominated by either hardwood or coniferous trees. ***Non-forested wetlands*** can be marine, estuarine or freshwater, and include 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 SJR represents, in Florida, one of the rivers with the highest headwater to stream length ratios, with 5.3 headwaters per km of river and a total of 886 headwaters (**White and Crisman 2014**). Headwater wetlands are associated with grassland/prairie, hardwood forest, and pine flatwood habitats (**White and Crisman 2014**).

4.2.2. Significance

Wetlands perform a number of crucial ecosystem functions including assimilation of nutrients and pollutants from upland sources. The estimated nitrogen removal of 187,765 Mt per year by SJR wetlands is valued at >$400 million per year for nitrogen and the estimated phosphorous removal of 2,390 Mt per year is valued at >$500 million per year (**Craft et al. 2015**). Additionally, wetlands can help to minimize local flooding, and, thereby, reduce property loss (**Brody et al. 2007**). Basins with as little as 5% lake and wetland areas may have 40-60% lower flood peaks than comparable basins without such hydrologic features (**Novitski 1985**). In Florida between 1991 and 2003, 48% of permits issued were within the 100-year floodplain, suggesting potential costs for recovery (**Brody et al. 2008**). Wetlands also provide nursery grounds for many commercially and recreationally important fish; refuge, nesting, and forage areas 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. 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. The result has been adaptive management and evolving regulations.

Wetland mitigation 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

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 do 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.

The positive trends reported in the earlier report did not persist. The *Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States 2004 to 2009* states: "Wetland losses in coastal watersheds have continued to outdistance wetland gains, by an estimated 360,720 acres between 2004 and 2009 due primarily to silviculture and development…. **This rate of loss increased by 25 percent since the previous reporting period of 1998 to 2004**" (**Dahl and Stedman 2013**).

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 per the Compensatory Mitigation Rule (USACE, 2008a). 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**). By 2008, it was reported that mitigation banking accounted for >30% of all regulatory mitigation arising from the Section 404 permitting process (**Ruhl, et al. 2008**). This is not a surprise as the USACE actively supports the use of mitigation banks: "Mitigation banks are a "performance-based" form of wetland and stream replacement because, unlike in-lieu fee mitigation and permittee-responsible mitigation, the tradable aquatic resource restoration credits generated by banks are tied to demonstrated achievement of project goals. Thus, the rule establishes a preference for the use of credits from mitigation banks when appropriate credits are available" (**USACE 2008**). A maximum number of *potential* credits are available for purchasable mitigation banks, provided that each mitigation bank has existing documents for its milestones met in the scheduled restoration, enhancement, preservation, and/or creation plan (**SJRWMD 2010c**). Credits are *release*d as criteria for ecological performance are met, and these newly released credits are *withdrawn* from the currently *available* credits as they are sold to permit applicants (Table 4.2, **SJRWMD 2010c**).

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 may be 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, 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, the following SJRWMD mitigation basins include: Northern St. Johns River and Northern Coastal, Tolomato River and Intracoastal Nested, Sixmile and Julington Creeks Nested, Western Etonia Lakes, St. Johns River (Welaka to Bayard), and Crescent Lake (**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.

In the LSJRB, 18 mitigation banks are active with permits processed by the USACE, and 13 mitigation banks are active with permits processed by the SJRWMD (Tables 4.2 and 4.3; **DEP 2017b**; **ERDC 2017**). These mitigation banks are typically located in rural areas with palustrine habitats. In 2016, 17 mitigation banks showed permit activity (Tables 4.2 and 4.3).

Permits for Natural Resource, Sunnyside, St. Johns Co., Poa Bay, Mill Creek, Little Creek Florida, Nochaway, Normandy, and Lower St. Johns Mitigation Banks are currently pending with USACE, and St. Johns and Sandy Creek with DEP/SJRWMD.

Table 4.2 Wetland mitigation banks permitted by the USACE serving the LSJRB, Florida (Source: ERDC 2017). Values in parentheses indicate credits reported in 2016 River Report, if any changes were reported.

MITIGATION			CREDIT BALANCE			
BANK NAME	ACREAGE	CREDIT TYPE	AVAILABLE	WITHDRAWN	RELEASED	POTENTIAL
Barberville Mitigation Bank	366	Palustrine emergent, palustrine forested	2.8	13.1	15.9	63.7
Brandy Branch	762	Palustrine forested	12.6 (15.6)	3 (0)	15.6	130.5
Brick Road	2,945	Palustrine emergent, palustrine forested	62.9	1.7	64.6	504.0
Farmton	24,323	Palustrine	3882.632 (3975.2)	456.3 (363.7)	4338.9	5465.7 (5656.6)
Fish Tail Swamp	5,327	Palustrine forested	161.9 (192.8)	71.7 (40.9)	233.7	860.1
Greens Creek	1,353	Palustrine forested	38.7 (48.2)	63.6 (54.1)	102.3	291.9
Highlands Ranch	1,581	Palustrine forested	13.7 (14.4)	3.8 (3.2)	17.5	70.37
Lake Swamp	1,890	Palustrine	55.92 (31.3)	68.9 (66.2)	124.8 (96.9)	215.3
Loblolly	6,240	Palustrine forested	1586.1 (1587.3)	428.7 (427.5)	2014.8	2507.5
Longleaf	3,021	Palustrine emergent, palustrine forested	648.7 (671.0)	377.9 (355.7)	1026.7	1026.7
North Florida Saltwater Marsh	92.36	Estuarine intertidal, emergent	11.7 (7.0)	0	11.7 (7.0)	49.6
Northeast Florida Wetland	386	Palustrine	290.1 (290.1)	352.9 (352.9)	643.0	643.0
Peach Drive	57.3	Palustrine forested	27.7 (27.7)	20.0 (20.0)	47.6	47.6
Star 4	950.4	Palustrine forested	34.8 (29.3)	6.8 (6.8)	41.6 (36.1)	182.5
St. Marks Pond	935	Palustrine forested, palustrine emergent	16.8 (10.9)	6.7	23.4 (17.6)	58.5
Sundew	2,105	Palustrine emergent, palustrine forested	225.7 (91.6)	24.8 (24.6)	250.5 (116.3)	931.4
Town Branch	432	Palustrine forested	12.8 (12.8)	6.8 (6.8)	19.5	56.3
Tupelo	1,525	Palustrine forested	474.3 (489.5)	149.3 (134.1)	623.6	623.6

Table 4.3 Wetland mitigation banks permitted by SJRWMD serving the Lower St. Johns River Basin, Florida.

MITIGATION			CREDIT BALANCE		
BANK NAME	ACREAGE	CREDIT TYPE	AVAILABLE	RELEASED	POTENTIAL
Greens Creek	4,201	Forested freshwater	47.8 (69.0)	302.6 (302.6)	405.6
Highlands Ranch Mitigation	1,575	Forested freshwater	61.2	85.6	200.5
Loblolly	6,247	Forested freshwater, general wetlands	35.9 (36.9)	1375.1 (1389.4)	1650.9 (1684.0)
Longleaf	3,020	Forested freshwater	0.4 (33.1)	339.3 (334.6)	376.0 (375.0)
Lower St. Johns	990	Forested freshwater	10.3 (1.2)	126.2 (117.1)	140.1
Nochaway	4,076	Forested freshwater	93.4 (55.8)	183.9 (132.4)	459.7
Normandy	1,033	Forested freshwater, general wetlands	36.0	43.6	174.5
North Saltwater Marsh	93	Estuarine intertidal, emergent	0.01 (0.01)	7.2 (7.2)	47.7
Northeast Florida Wetland	774	General wetlands	11.4 (11.4)	395.9 (394.9)	394.9 (395.9)
St. Marks Pond	759	Forested freshwater, herbaceous freshwater	12.8 (29.7)	78.2 (53.9)	134.8
Star 4	950	Forested freshwater	18.0 (25.9)	137.4 (137.4)	171.7
Sundew	2,107	Forested freshwater, herbaceous freshwater	177.2 (182.9)	379.0 (379.0)	621.7
Tupelo	1,524	General wetlands	28.1 (28.5)	459.7	459.7

(Source: DEP 2013f; SJRWMD 2016c; DEP 2017b; and SJRWMD 2017a). Values in parentheses indicate credits reported in 2016 River Report, if any changes were reported.

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 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 wetland alterations. For example, wetland mitigation banking has led to a predominance of wetland banks in rural areas (**Ruhl and Salzman 2006**). In this case, the services provided by wetlands are taken from urban to rural environments. These services, like sediment capture, groundwater recharge, water filtration, and flood mitigation, have economic value associated with them. Calculating the dollar value of such services is a challenging, but not impossible, endeavor (Figure 4.3). The economic value of wetlands to retain storm water 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**). **Brody et al. 2007** examined wetland permits granted by the USACE in Florida between 1997 and 2001 and determined that "one wetland permit increased the average cost of each flood in Florida by $989.62."

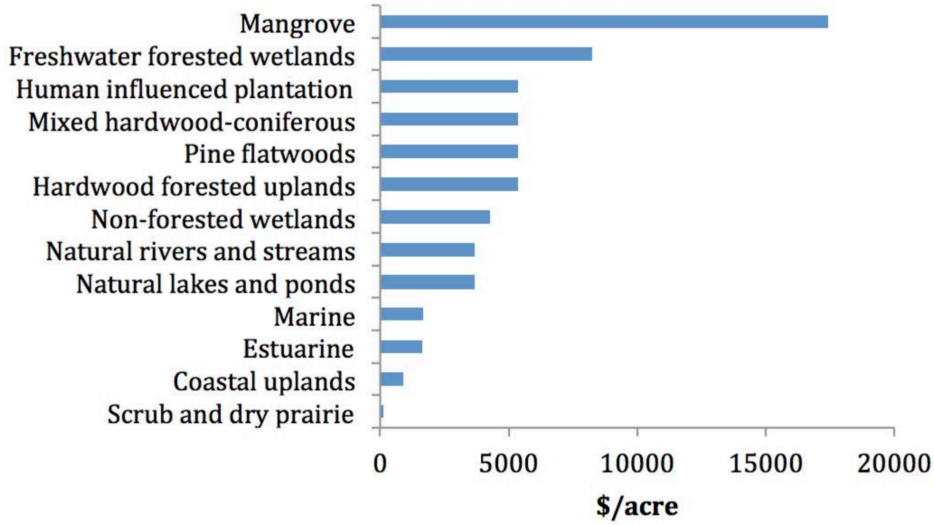


*Figure 4.3 Estimated value of ecosystem services by habitat (Source: **Brown and Shi 2014**).*

Likewise, the economic value of wetland-dependent recreation in northeast Florida is estimated 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). Based on survey results, Florida residents and tourists value outdoor recreation (>95% of 3,961 Florida residents and 2,306 tourists participated in outdoor recreation) and specifically saltwater beach activities (63%), wildlife viewing trips (49%), and fishing (46%) (**DEP 2013g**). In Florida, 2.9 million people fished, hunted, or viewed wildlife in 2006 (**USDOI and USDOC 2008**). The number of pleasure vessels recorded in Duval, St. Johns, Clay, Putnam, and Flagler is >500,000 vessels (**SRR 2012**). Bird watchers spent an estimated $3.1 billion and fishers $4.3 billion in 2006 (**USDOI and USDOC 2008**). Canoeing and kayaking have become more popular, representing 14% of recreational activities in 2002 and 26% in 2011 (**DEP 2013g**). If these kinds of services are negatively impacted, 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 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.

4.2.4. Data Sources on Wetlands in the LSJRB

4.2.4.1. Data Sources for Wetland Spatial Analyses

Ten 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 4.4). On average, wetland area represented 23.8% of total LSJRB acreage (Table 4.4).

Table 4.4 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)	455,308	1,868,003
SJRWMD Land Use/Land Cover map (based on 2009 data)	452,315	1,903,789
SJRWMD Land Use/Land Cover map (based on 2014 data)	451,689	1,938,279

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. 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 have made available a single online database to track mitigation banking activities called the *Regional Internet Bank Information Tracking System (RIBITS)* (**ERDC 2015**). Concurrently, the EPA and USACE have developed 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**).

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.

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. 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 5-20% (**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. <u>Limitations of Wetland Permit Analyses</u>

A shortcoming of the records of wetlands impacted through regulatory permitting processes is that they do not address total wetland acres in the region. Additionally, acreages 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.

4.2.6. Current Status (UNSATISFACTORY)

The current status of wetlands in Florida is considered UNSATISFACTORY, because a historical decrease in wetlands has been documented statewide. 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. 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 slightly. 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% 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). From the 2015 Florida Cooperative Land Cover Data, wetlands represented 11,069,804 acres in Florida, a reduction of 302,096 acres or 2.7% from the mid-1990s (Volk et al. 2017).

The current status of wetlands in the LSJRB is considered UNSATISFACTORY because of the continued stressors to wetlands, as indicated by the decrease of 627 acres between 2009 and 2014 data (Table 4.4). Currently, wetlands represent 23.3% of total LSJRWMD area (Table 4.4). In comparing wetland acreage between 2009 and 2014, losses >500 acres per community were for wet prairies, mixed wetland hardwoods, bay swamp, and cypress (Table 4.5). Gains > 500 acres per

community were for freshwater marshes, mixed scrub-shrub wetlands, wetland forested mixed, and emergent aquatic vegetation (Table 4.5).

Federal, state, local, and privately managed wetlands can be found in Florida conservation lands that include national parks, state forests, preserves and parks, wildlife management areas, mitigation banks, and conservation easements. For example, the North Florida Land Trust has acquired for preservation 1,500 acres this past year (**NFLT 2018**). Many of these conservation lands have swamps, marshes, and other types of wetlands. Of the 1,545,905 acres that identified as conservation areas within the LSJRB, 29% are federal lands, 68% state lands, 2% city lands, and 2% private as of September 2017 (**FNAI 2017**). State lands increased the most by 642,249 acres relative to last year, with the addition of 2312 acres for the Clay Ranch Agricultural and Conservation Easement (**FNAI 2017**). From a study of 20 conserved natural areas in Florida, ecosystem services were valued at $5,052 per acre (**Brown and Shi 2014**). For example, Pumpkin Hill Creek Preserve State Park was estimated in providing $6,169 per acre (**Brown and Shi 2014**).

Table 4.5 Comparison in wetland acreage between 2009 and 2014 - Lower St. Johns River Basin, Florida (SJRWMD 2017a).

WETLAND CATEGORY	2009 (ACRES)	2014 (ACRES)
Mixed wetland hardwoods	156,274	152,801
Wetland forested mixed	111,155	113,682
Mixed scrub-shrub wetland	68,296	70,498
Hydric pine flatwoods	30,850	30,884
Cypress	27,543	26,723
Saltwater marshes	17,965	18,074
Wet prairies	16,276	12,449
Freshwater marshes	11,271	12,097
Bay swamp	9,640	8,721
Emergent aquatic vegetation	2,271	4,960
Cabbage palm hammock	648	741
Non-vegetated wetland	121	56
Pond pine	6	4

Stressors to wetland communities include land use, nutrients, pollutants, and invasive species. In addition changes in populations of endangered/sensitive species can be indicators of stressed wetlands. Below is a discussion of these stressors affecting the LSJRB:

LAND USE. Land use is a powerful predictor of wetland condition (**Reiss and Brown 2007**). In Florida, countless non-tidal wetlands <5 ha that were formerly in agricultural fields and pasture lands have since been developed for residential and commercial uses (**Reiss and Brown 2007**). For example, in 1960, the population density was 43 people/km^2 as compared to 183 people/km^2 in 2000 near Deland, FL (**Weston 2014**). Landscape Development Intensity (LDI) is an index that associates nonrenewable energy use (electricity, fuels, fertilizers, pesticides, irrigation) to wetland condition. Palustrine wetlands surrounded by multi-family residential, high-intensity commercial, and central business district had LDI scores of 9.19 to 10.00 as compared to pine plantation, recreational open space (low intensity) and pastures of 1.58 to 4.00 (**Reiss and Brown 2007**).

High LDI values can be predicted for areas in the LSJRB with multi-family residential and commercial land use. Residential land is prevalent along waterways, representing 29% of total acreage within 50 m of a waterway. Surface drainage basins with residential land use can be plagued by low oxygen (e.g., Hogan Creek) and fecal coliform (e.g., Cedar River, Ginhouse Creek, Hogan Creek, Goodbys Creek, Moncrief Creek, Black Creek, Pottsburgh Creek, and Broward River) (**SRR 2014**). Leaking septic tanks, stormwater runoff, and wastewater treatment plants contribute to fecal coliform. Commercial activities also ranked with high LDI values (**Reiss and Brown 2007**). In the LSJRB, Georgia-Pacific, power plants, shipping and maritime activities, and the U.S. Department of Defense contribute to PAH, PCB, mercury, and nitrates in Rice Creek,

Cedar River, and Ortega River (**SRR 2016**). Additional sources of PCB contamination are from waste oil spills and accidental release of locomotive waste, such as hydraulics and lubricants into drainage ditches (**Flowe 2016**).

The extent of the surface drainage basin can exacerbate land use pressures (e.g., stormwater runoff). For example, the surface drainage basin Etonia Creek that includes the polluted Rice Creek covers 355 $miles^2$ (**Bergman 1992**). Connected surface drainage basins with a history of elevated fecal coliform levels and low oxygen include Julington Creek, Sixmile Creek, and Arlington River, covering approx. 260 $miles^2$ (**Bergman 1992**). Agriculture, although with a lower LDI (**Reiss and Brown 2007**) can contribute to nitrogen and phosphorous loading as is recorded from Deep Creek and Dunns Creek and cover approx. 100 $miles^2$ of surface drainage basin (**Bergman 1992; SRR 2014**).

NUTRIENTS. Stormwater runoff from residential and agricultural land use can contribute more nitrogen and phosphorous than other land use categories. For example, residential areas can release 2.32 mg N/L and 0.52 mg P/L as compared to agriculture (3.47 mg N/L and 0.61 mg P/L, respectively) and undeveloped/rangeland/forest (1.15 mg N/L and 0.055 mg P/L), respectively (**Harper and Baker 2007**). From a 2003-2009 study of water quality collected from 59 groundwater wells in the LSJRB, a relationship was evident between land use and groundwater (**Ouyang et al. 2012**). From the shallow groundwater system, septic tank land use had greater values of nitrate/nitrite concentrations than in agricultural lands (7.4 mg/L nitrate/nitrite and 0.04 mg/L, respectively). By comparison, calcium, sodium, chlorine, and sulfate had more than twice the values in agricultural lands (agriculture: 85.9, 148.8, 318.8, and 233.1 mg/L; septic tank land use: 34.5, 23.2, 36.5, and 58.8 mg/L, respectively; **Ouyang et al. 2014**). Managed plantations that use nitrogen and phosphorous excessively can be a source of nutrient loading to nearby tributaries that can be measured from weeks to years following application in sediments and water column (**Shepard 1994**). In addition, nutrient-laden waters from wastewater treatment spray fields can travel via the aquifer and contribute to nutrient loading far from the source, as has been recorded in Wakulla Spring from Tallahassee's wastewater reuse facility (**Kincaid et al. 2012**).

Nitrogen values remain high in a number of tributaries and sections of the LSJR (**SRR 2016**). By comparison, total phosphorous concentrations in the marine/estuarine river region were 33% lower in 2014 relative to 1997. However, estimates from the freshwater sections of the river increased by 45% (**SRR 2016**).

Sediments retain nitrogen and phosphorous. During periods of anoxic conditions due to algal blooms, Malecki et al. reported that 21% of total P load and 28% of total N load came from the sediments in the LSJR (**Malecki et al. 2004**). Dissolved reactive phosphorous released from the sediments was 37 times lower (0.13 mg per m^2 per day) than during aerobic conditions (4.77 mg per m^2 per day) (**Malecki et al. 2004**).

The presence of nutrients in combination with herbicides such as atrazine has been shown to have negative impacts on the native *Vallisneria americana* (**Dantin et al. 2010**). Submerged aquatic vegetation (SAV; e.g., *Vallisneria americana*) provides food and refuge for shrimp, blue crabs, and a variety of other fauna.

POLLUTANTS. Arsenic is present in LSJRB sediments. In Naval Station Mayport, spoils from dredging of the basin were used to fill in wetlands and low-lying areas (**Fears 2010**). These dredged materials are concentrated in arsenic (**Fears 2010**). Arsenic contamination has also been documented in golf course soils (5.3 to 250 ppm, with an average of 69.2 ppm) due to herbicide applications to turf grass (81 golf courses from the northeast, 1086 surveyed in Florida; **Ma et al. 2000**). Leaching of arsenic is further exacerbated by the presence of phosphorous, commonly applied in fertilizer. Many of these golf courses have waterbodies or are near wetlands, streams, and rivers (**Ma et al. 2000**). **Ouyang et al. 2014** reported greater arsenic values in the groundwater associated with agriculture (4.3 μg/L) and wastewater sprayfield (5.6 μg/L) land use as compared to undeveloped forest lands and septic tank land use (0.6 and 1.3 μg/L, respectively) in the LSJB.

Wading birds and other fauna that forage in wetlands are at risk of bioaccumulation of heavy metals. For example, mercury has been reported in the Broward and Trout Rivers. **Ouyang et al. 2012** estimated an average annual mercury load of 0.36 g ha^{-1} $year^{-1}$ within the Cedar and Ortega watershed (254 km^2). St. Johns River Power Park and Northside Generating Station have reduced their mercury atmospheric emissions by 71% between 2001 and 2013 (**SRR 2016**). However, an increase of 250% in metal discharge was reported for electric utility since 2001, in particular zinc, nickel, cobalt, and manganese (**SRR 2016**). Salt marshes are sinks for metals (**Leendertse et al. 1996**). **Giblin et al. 1980** found that metals in *Spartina alterniflora* detritus were taken up by fiddler crabs, and metals can be concentrated in bivalves near contaminated sites (**Leendertse et al. 1996**). **Burger et al. 1993** reported mean lead concentrations of 3,640 ppb dry weight in young wood storks from Dee Dot colony, demonstrating the availability of lead contamination and bioaccumulation from prey items.

HYDROLOGIC MANIPULATION. Many of the mitigation banks in the LSJRB were formerly pine plantations. Hydrology in forest plantations is typically modified to minimize surface waters (**Shepard 1994**) that can then impact non-tidal wetland diversity and sediment and nutrient loading to nearby waterways. Erosion in plantations adds to suspended sediments in drainage waters and connecting waterways (**Shepard 1994**). In lowland forested habitats, storm water is retained in the forest and runoff occurs after the groundwater table reaches the surface (**Sun et al. 2000**). When trees are harvested, the groundwater table rises particularly during dry periods, a phenomenon that can continue over a period of years (**Sun et al. 2000**). The decrease in evapotranspiration rates with the loss of trees is responsible for this rise in the water table (**Shepard 1994**).

Bernardes et al. 2014 raised the issue of water withdrawal affecting wetlands in northeastern Florida. Depressional wetlands are typically relict sinkholes. The Florida aquifer system is crisscrossed with fractures along which groundwater can travel. Mine pits create ponds where aquifer and groundwater accumulates and thus deprives other areas of water for recharging and supporting vegetation. Where mining-related withdrawal has occurred, wetlands in nearby mitigation banks and conservation areas have dried out with the potential of becoming sinkholes. For example, the DuPont Trail Ridge Mine is in close proximity to many of the mitigation banks listed in Table 4.2 and conservation areas (e.g., Camp Blanding, Cecil Field) that wetland permittees use to mitigate wetland alteration. Water quality, hydroperiods, and water availability would be impacted (**Bernardes et al. 2014**).

INVASIVE SPECIES. The most damaging invasive plant species have the capacity to do one or more of the following: reproduce and spread successfully, compete successfully against native species, proliferate due to the absence of herbivore or pathogen that can limit their populations, and alter a habitat (**Gordon 1998**). Invasive species can modify a wetland habitat by changing geomorphology (erosion, soil elevation, water channel), hydrology (water table depth, surface flow), biogeochemical cycling (nutrient pathways, water chemistry, nitrogen fixation), and disturbance regime. *Eichhornia crassipes* and *Pistia stratiotes* are reported to impact siltation rates, *Panicum repens* stabilizes edges of waterways, *Hydrilla verticillata* slows water flow where abundant, and *E. crassipes*, *P. stratiotes*, and *H. verticillata* alter water chemistry (dissolved oxygen, pH, phosphorous, carbon dioxide, turbidity, and water color) (**Gordon 1998**).

Where invasive plant species are dominant, native weedy species typically proliferate (**Gordon 1998**). In a 2002 study of 118 depressional non-tidal wetlands in Florida, macrophyte diversity and the percentage of native perennial species in urban environments were lower than in locations away from urban environments (**Reiss 2006**). Species that were considered the most tolerant to disturbance intensity in depressional marshes included *Alternanthera philoxeroides*, *Cynodon dactylon*, *Mikania scandens*, *Panicum repens*, and *Schinus terebinthifoilius* (**Cohen et al. 2004**). From a survey of 74 non-tidal depressional wetlands in Florida, greater plant species richness was associated with more disturbed sites and fewer species in undisturbed and oligotrophic conditions (**Murray-Hudson et al. 2012**). Ruderal or weedy species are likely to tolerate changes in the wetland-upland boundary and variability in soil saturation and water depth and extent. The authors also showed that the outer zone adjacent to the upland border of a depressional wetland with high numbers of exotics would also have a high number of exotics throughout the wetland. This pattern was true for sensitive species as well, indicating that the condition of the wetland could be predicted by the richness of suites of species along the outer band of the wetland (**Murray-Hudson et al. 2012**).

ENDANGERED/SENSITIVE SPECIES. Urbanization, habitat encroachment and increased recreational activities can negatively impact breeding populations of amphibians, reptiles, and birds. Development that alters and/or fills headwaters and streams negatively impacts habitat connectivity for many stream and wetland-dependent organism in the SJR watershed (**White and Crisman 2014**). Animals that require a variety of wetland types would be negatively impacted by chemical pollutants and turbidity that limits prey availability. Sensitive species associated with wetlands include the Striped newt (*Notophthalmus perstriatus*) that is listed as a candidate species for protection; and the flowering plants Chapman rhododendron (*Rhododendron chapmanii*), Okeechobee gourd (*Cucurbita okeechobeensis* ssp. *okeechobeensis*), and Rugel's pawpaw (*Deeringothamnus rugelii*) that are listed as endangered in counties of the LSJRB (**USFWS 2018a**). Other threatened and endangered species are found in Section 4.4. Under review, the candidate Black Creek crayfish is found in Doctors Lake and Rice Creek (**USFWS 2018a**). Doctors Lake is listed as impaired due to nutrient loading and Rice Creek is impaired to due to dioxin levels from Georgia Pacific discharge (**SRR 2016**).

Urbanization and subsequent habitat loss and alterations can result in negative interactions between humans and wildlife. For example, the Wildlife Service is called in to disperse or dispatch a variety of animals. Between the years 2006 and 2011, gulls, egrets, and herons represented 57% of the 4,407,393 animals that the agency dispersed through a variety of measures in Florida (e.g., firearms, pyrotechnics, pneumatics, and electronics) (**Levine and Knudson 2012**). **Cooper and Vanderhoff 2015** recorded greater numbers of the brown pelican at Mayport during autumn through spring months and along the river at Jacksonville University during winter and spring months, from a study conducted in September 2012 to August 2013. By comparison, numbers reported to eBird, a database monitored by the National Audubon Society and the Cornell Lab of Ornithology, were greatest during winter months. Comparing the Christmas Bird Counts in years 2000 and 2011 to 2016 from a marsh near Clapboard Creek, annual counts were generally greatest in 2011 (Table 4.6). Higher counts were recorded for the bald eagle, black skimmer, and tricolored heron (Table 4.6; **Audubon 2018**). Lower numbers were observed for the laughing gull, American oystercatcher, osprey, roseate spoonbill, and piping plover. Changes in counts may represent habitat modifications in nearby areas.

Table 4.6 Christmas bird counts of selected species from Jacksonville marsh site in 2000, 2011-2017. SSC - species of special concern; ST - state listed, threatened; FT- federal listed, threatened; FE - federal listed, endangered (Source: Audubon 2018).

SPECIES	STATUS	2000	2011	2012	2013	2014	2015	2016	2017
Brown pelican	SSC	634	2000	1250	1100	800	600	700	700
American oystercatcher	SSC	13	14	7	8	6	8	8	3
Laughing gull		512	3100	950	800	1100	1600	1700	1200
Bald eagle		18	34	35	32	21	40	36	42
Piping plover	FT	24	8	4	6	18	12	13	6
Snowy egret	SSC	307	391	175	175	400	450	342	500
Wood stork	FE	120	128	105	120	100	260	140	100
Black skimmer	SSC	8	10000	540	350	600	1000	649	4100
Tricolored heron	SSC	128	67	60	50	100	175	100	200
Little blue heron	SSC	54	93	75	80	100	200	165	300
White ibis	SSC	352	1000	400	200	900	800	1000	1000
Roseate spoonbill	SSC	1	34	5	6	13	4	5	0
Osprey	SSC	82	120	130	100	100	100	100	68

Least terns are migratory birds that require sandy or gravel habitats with little vegetation for nesting. Rooftop nesting sites have become more common due to habitat loss. Large rooftop populations have been recorded at NAS Jacksonville (**Jackson 2013**). In Florida, Wildlife Service Agency had been called upon to disperse 273 least terns in 2011, indicating negative interactions with humans (**Levine and Knudson 2012**).

Wood storks (endangered) nest in the LSJR and feed on fish among other animals, requiring 450 lbs of fish per pair during the nesting season (**SRR 2016**). They require shallow pools that dry up to help concentrate fish prey. During extended periods of drought, wood stork numbers decrease. Currently, populations are considered stable and close to carrying capacity with respect to numbers of nesting pairs. Jacksonville Zoo and Gardens (91 nests in 2015) and Dee Dot (130 nests in 2016). Pumpkin Hill nests were active in 2009 but since then data have been unavailable or the site inactive, respectively (**SRR 2016**). Between the years 2000 and 2016, numbers of wood storks were greatest in 2015 and then decreased in 2016 in a marsh near Clapboard Creek (Table 4.6). In Florida, Wildlife Service has been called upon to disperse 270 wood storks in 2008-2011, indicating negative interactions with humans (**Levine and Knudson 2012**).

4.2.7. Current Trends in Wetlands in the LSJRB (WORSENING)

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**).

- **Hefner 1986** stated 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."
- In 2012-2013, the SJRWMD reported a loss of 380.7 wetland acres as compared to 14.5 acres created, 2,268.6 acres preserved, and 660.1 acres enhanced (**DEP 2014e**).
- Duval Country is characterized with very high runoff values (57-331) mm, a ratio of urban runoff relative to county area) due to increases urbanization (**Chen et al. 2017**).

Development pressures that result in wetland loss and function indicate a WORSENING trend in total wetland acreage within the LSJRB, as indicated by changes in acreage between 2009 and 2014 (Table 4.6). For example, an increase of 3,466 residential acres was recorded between 2009 and 2014 land use maps in the LSJRB.

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.

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 4.4). Forested wetlands comprised 91% of the total wetlands in 1973, and constituted 74% of total wetlands in 2009, and 73% in 2014. **Brown and Shi 2014** estimated freshwater forested wetlands represent twice the ecosystem value as non-forested wetlands (Figure 4.4). Non-forested wetlands comprised 9% of the total wetlands in 1973, 26% in 2009, and 27% in 2014 (Figure 4.4). In the LSJRB between 2006-2013, forested wetlands represented 47-97% of permitted impacted wetland area per year (**Goldberg and Reiss 2016**).

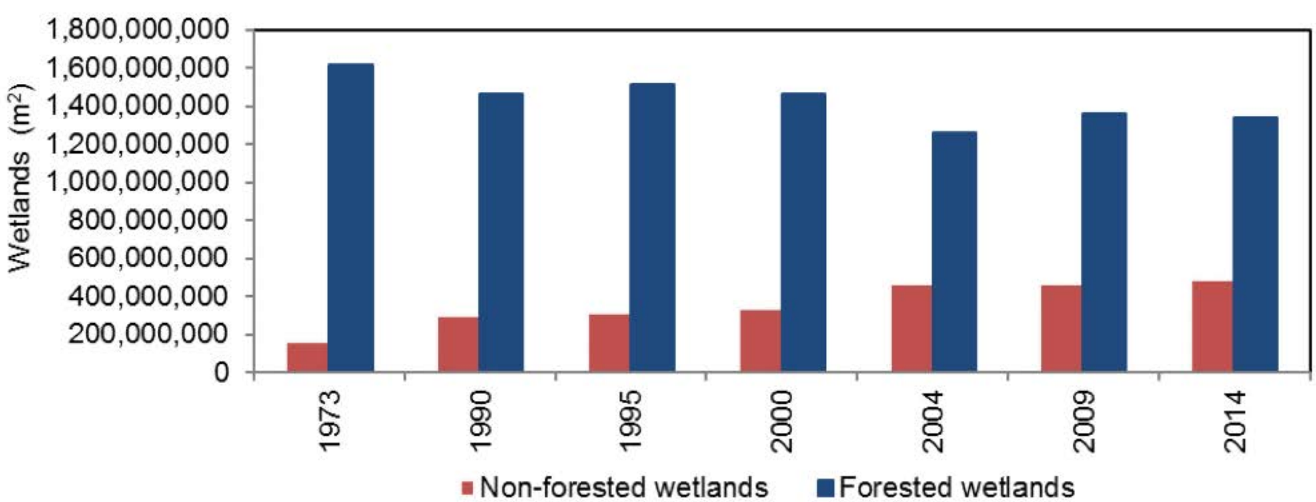


*Figure 4.4 Forested wetlands and non-forested wetlands in the Lower St. Johns River Basin based on land use/land cover maps (**SJRWMD 2017a**).*

4.2.8. Wetland Permit Trends in the LSJRB

The SJRWMD process environmental resource permits that may impact wetlands and surface waters (**SJRWMD 2017c**). In general, these projects were located in mixed hardwood wetlands. During 2017, 55 SJRWMD-processed permits were issued that required compensated mitigation, impacting 221 wetland acres with an average of 4 impacted wetland acres per permit. Between the years 2000 and 2017, the majority of issued permits was for <10 average impacted wetland acres in a project, based on SJRWMD permitting records (Figure 4.5). Incremental wetland conversions result in cumulative impacts at the landscape level.

Wetlands are fragmented across the urban landscape and different habitats occur within and surrounding project sites (**Kelly 2001**) which then impacts wetland function and community composition (**Faulkner 2004**). If wetlands are few and far between, then travelling amphibians and other animals are exposed to pollutants and death on roadways (**Faulkner 2004**). Even smaller wetlands <0.2 ha contribute to local diversity (e.g., juvenile amphibians, **Semlitsch and Bodie 1998**).

Permits for modifying small wetlands are the largest in numbers and yet the contribution of these wetlands to local diversity and function remains undocumented (Figure 4.5; **Semlitsch and Bodie 1998**). Permits are given to individuals and are site specific, but cumulative impacts due to the number of conversions at the landscape scale are not addressed. At the landscape level, these smaller and isolated wetlands are not as valued as riverine wetlands (**Brody et al. 2008**) and may not be protected by the Clean Water Act. Research is showing that these smaller wetlands can help take up nutrients via denitrification processes and thus reduce nitrogen and phosphorous, particularly in areas where there is heavy nutrient loading (e.g., agricultural and urban locations) (**Lane et al. 2015**). In addition, smaller wetlands contribute to the buffering of the local water table, in part due to the cumulative exchange along the perimeter of many smaller wetlands as compared to fewer but larger wetlands (**McLaughlin et al. 2015**).

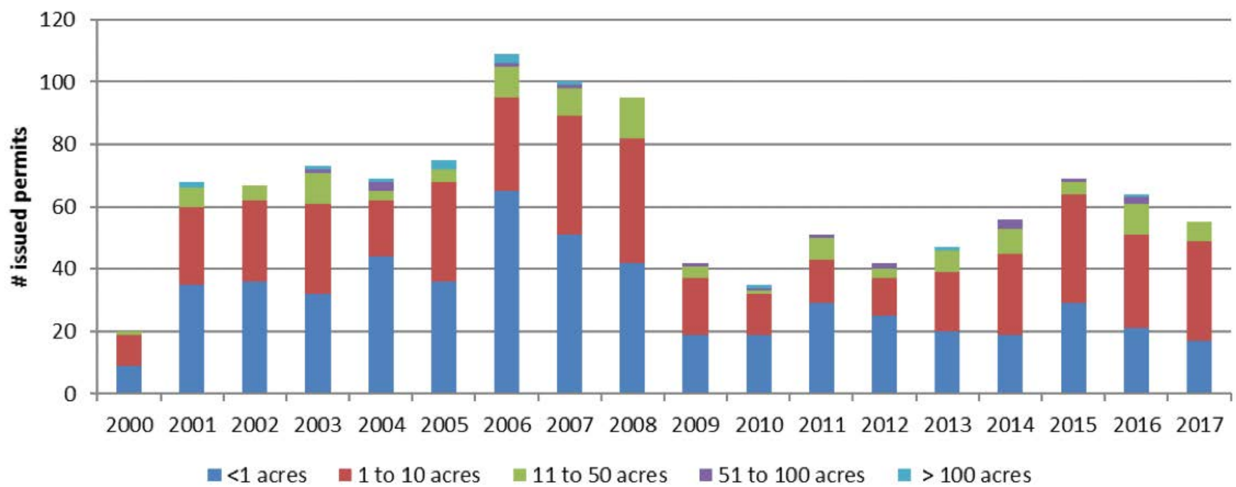


*Figure 4.5 Numbers of SJRWMD permits per project impacted wetland acreage from 2000 to 2017 (**SJRWMD 2017c**).*

Based on SJRWMD permit records, the methods used to mitigate wetlands have changed over time (Appendix 4.2.D). During the early 1990s, wetland areas were most commonly mitigated by the creation of new wetlands or through wetland restoration. During the 2000s, relatively few wetlands were created or restored with most mitigation occurring through the preservation of uplands/wetlands (Figure 4.6). In 2017, permittees of 48 projects applied for a total of 71.9 mitigation credits, and 7 projects were permitted for on-site only mitigation (**SJRWMD 2017c**). Three permittees planned for enhancement and/or restoration.

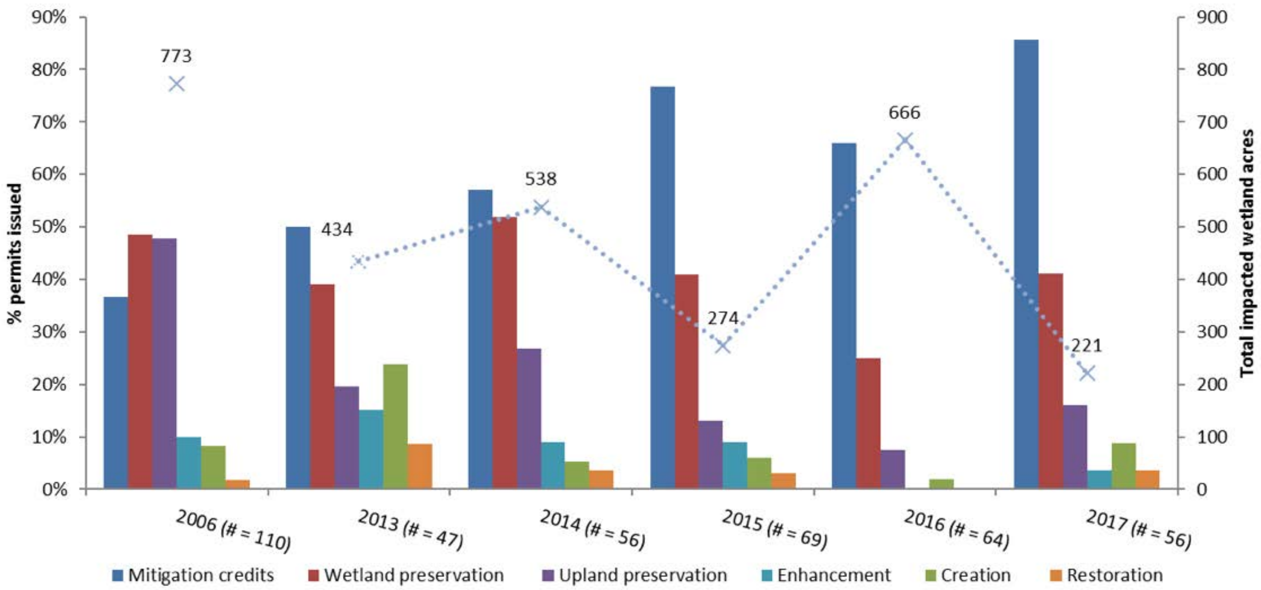


*Figure 4.6 Percentage (bars) of issued permits that opted for purchasing mitigation credits, wetland preservation, creation, upland preservation, or enhancement and total impacted wetland acres (line) in the years 2006, 2013 to 2017, indicating in parentheses the total number of permits issued for mitigated impacted wetlands. Because permittees may opt to use more than one type of mitigation for a project, total percentages per year will exceed 100% **(SJRWMD 2017c)**.*

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**).

In 2017, the trend continued for purchase of credits to offset wetland dredge and fill activities rather than for preservation, creation, enhancement, or restoration (Figure 4.6, Table 4.7). The mean ratio of mitigation credit per acreage of impacted wetland was greater in 2006 (2.1, n = 29 permits) than in 2017 (0.51, n = 31 permits) for those projects that used mitigation banks as the only type of wetland mitigation. The annual percentage of permits issued that proposed to purchase mitigation credits was lowest in 2006 and was highest in 2017 (Figure 4.6). The percentage of permitted projects that planned for wetland preservation was greatest in 2014 (Figure 4.6) with three permits in 2017 preserving >100 wetland acres in 2017.

Table 4.7 Acreage comparison in wetland mitigation for permits issued in 2006, 2013, 2015- 2017 that required mitigation (SJRWMD 2017c).

TOTAL ACREAGE	2006 110 Permits	2013 47 Permits	2015 69 Permits	2016 66 Permits	2017 56 Permits
Impacted wetlands	774	434	274	754	221
Wetland preservation	4853	691	538	2384	909
Upland preservation	1001	139	84	429	76
Creation	98	28	21	1	20
Enhancement/restoration	7539	30	11	0	15

4.2.9. Future Outlook

HIGH VULNERABILITY. The total spatial extent of wetlands negatively impacted through the SJRWMD permit process is increasing each fiscal year and is likely to increase with the improvement in the national and state economies. 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). Many remaining wetlands are susceptible to alteration and fragmentation due to growing population pressures in northeast Florida. Urbanization at the landscape level has a direct impact on wetland communities. For example, between 2006-2013, approximately 73% of the 1,046 ha of impacted wetlands were located in Mid to High Development and 18% in Mid Development parcels (**Goldberg and Reiss 2016**).

Incremental filling of depressional ponds in addition to developing along waterways have the consequence of altering local hydrology, adding nutrients and heavy metals to the sediments and water column, bioaccumulation of heavy metals up the food web, and increasing the number and coverage of nuisance and invasive species. Isolated wetlands can retain 1,619 m^3 water/ha, on average, from models developed for Alachua County, FL, wetlands (**Lane and D'Amico 2010**). The potential for flooding, hydrologic alterations, and pressures on species diversity will continue with the loss of wetlands in the LSJRB.

In addition to development and withdrawals, tidal wetlands will be impacted by sea level rise. Tidal wetlands in the river are unlikely to outpace sea level rise estimated at 3 mm/year (**Weston 2014**) due to inability of marsh vegetation to accrete organic material at faster rates. Delivery of fluvial suspended sediments is relatively low in the St Johns River, compared to other U.S. rivers (**Weston 2014**). Turbidity in the mainstem is improving, indicating that sediment export to the tidal wetlands is low (see Turbidity section; **SRR 2016**). In 2015, the maximum turbidity value in 2015 was the lowest since 1997 (**SRR 2016**). Coastal wetlands may be less impacted by sea level rise. Contrary to expectations of coastal erosion with sea level rise and disruption of longshore drift with dredging activities, shorelines along Duval and St Johns counties have been advancing since the 1800s (**Houston and Dean 2014**). On-shore sediment deposition is the likely mechanism and may help buffer erosion and sediment transport due to sea level rise in the future (**Houston and Dean 2014**).

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 close to 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 2012b**). According to the SJRWMD (**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" (**SJRWMD 2012b**, p. 10-80). 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 4.8).

Table 4.8 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	3.22 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 on average >30 miles from project site (**Brody et al. 2008**), including many acres in wetland mitigation banks. If preserved wetlands represent already functional wetlands, then they do not replace the ecosystem services lost to development. Currently, there is no accounting of the specific locations of each impacted wetland.

Restored and created wetlands generally do not reach ecosystem functioning present in reference wetlands. Based on a meta-analysis from published studies of 621 wetlands, Moreno-Mateos et al. (**Moreno-Mateos et al. 2012**) reported that ecosystem services were not returned with restoration efforts in either created or restored wetlands. The size of the wetland (>100 ha) recovered more quickly than smaller wetlands (0.1, 1, and 10 ha). Wetlands only reached on average 74% of biogeochemical functioning **after 100 years**. In addition, plants and vertebrate diversities in restored/created wetlands remained lower than reference wetlands after 100 years. By comparison, macroinvertebrates reached references assemblages between 5 and 10 years. In comparing different types of wetlands, riverine and tidal wetlands recovered more quickly (up to 30 years) as compared to depressional wetlands that did not reach reference conditions (**Moreno-Mateos et al. 2012**).

Wetlands at the mitigation banks are not necessarily reaching a measure of success relative to reference conditions. Difficulties in restoring wetlands may be related to past activities on the property and indirect effects due to surrounding land use. For example, land use at Loblolly, Tupelo, and Sundew mitigation banks were previously agricultural, managed pasturelands, and mixed agriculture and/or low intensity urban, respectively (**Reiss et al. 2014**). **Reiss et al. 2007** investigated success and compliance of 29 wetland mitigation banks in Florida. Barberville, Loblolly, Sundew, and Tupelo were included in their study (Tables 4.3 and 4.4). These mitigation banks did not include a target for success criteria or a reference condition (either a reference database and/or comparison sites, **Reiss et al. 2009**) to measure success (e.g., wildlife needs). With respect to exotic and nuisance cover, final success criteria for state permit requires <10% exotic and nuisance cover (except for Barberville: 5% exotic, 10% nuisance). **Reiss et al. 2007** recommend that monitoring should also encompass flora and fauna, and not just exotic and nuisance species. At the time of their study, Barberville was a 'long ways off' from final success due to pines having to be replanted. Loblolly and Tupelo had started plantings and was described as not communicating so well in providing the monitoring and management status reports. Sundew was also described as not communicating so well with reports (**Reiss et al. 2007**). **Reiss et al. 2007** argue that functional equivalency in wetland mitigation banking remains questionable without a clear method to assess ecosystem function. LDI scores within the mitigation banks indicate that wetland function may be impossible to achieve (**Reiss et al. 2014**).

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. Given the connectivity of aquifer and ground water via fracture lines, those activities that uptake water in one location may prevent the watershed from being recharged during precipitation events and exacerbate drought effects on wetland systems (**Bernardes et al. 2014**).

Partial restoration of riparian corridors can have fairly immediate and positive impacts on nutrient levels and diversity of local flora and fauna (**Rossi et al. 2010**). The authors had planted riparian species of trees, shrubs, grass, and forbs to increase structural complexity in areas 3 x 9.5 m along first-order tributaries of the LSJR. After three months, sampling was conducted for two years. Macroinvertebrate diversity increased (Coleoptera and Lepidoptera), dominance of pollution-tolerant taxa decreased, and pollution-intolerant taxa (Odonta and Ephemeroptera) increased as compared to non-restored sites. In addition, soil nitrate was significantly less in the restoration sites than control sites and soil phosphorous decreased over time in restored sites due to nutrient uptake by the plants. The authors recommend incorporating restoration areas along urban stretches of the river to promote ecosystem function (**Rossi et al. 2010**). The Lasalle Bioswale Project showcases another way to minimize contaminants from entering waterways. Bioswales are vegetated areas that collect stormwater runoff. Plants and soil communities take up the pollutants and thereby treat pollutants found in stormwater runoff. This particular project was accomplished by the St. Johns Riverkeeper and partners (**St. Johns Riverkeeper 2013b**). The City of Jacksonville is exploring ways to mitigate flood-prone areas in the Jacksonville area, including, Jacksonville Landing, northern San Marco, St. Johns Quarter (Riverside), Avondale, areas along Hogan Creek, McCoy Creek, Trout River and Ribault River **(MetroJacksonville 2017)**. For example, they have approached homeowners in the South Shores area to purchase 73 properties with the intention of converting the area to wetlands **(MetroJacksonville 2017)**.

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. Given the continued trend of mitigation via purchase of mitigation credits and off-site conservation areas in place of on-site mitigation, the outlook for local wetlands in the LSJRB does not look promising.

4.3. Macroinvertebrates

4.3.1. Description

Benthic macroinvertebrates include invertebrates (animals without a backbone) that live on or in the sediment and can be seen with the naked eye. They include a large variety of organisms such as sponges, crabs, shrimp, clams, oysters, barnacles, insect larvae, and worms. Almost 400 species from 10 phyla have been identified in the LSJRB.

4.3.1.1. Sponges (Phylum Porifera)

Sponges are stationary filter feeding organisms consisting of over 5,000 species with about 150 freshwater species. They do not have organs or tissues, but the cells specialize in different functions. They reproduce both sexually and asexually (**Myers 2001c**). In the LSJRB, five taxa have been recorded and are found in fresh, marine, and estuarine waters (i.e., *Spongilla fragilis* and *Craniella laminaris*) (**Mattson et al. 2012**).


Sponge. Photo by Kimberly Mann

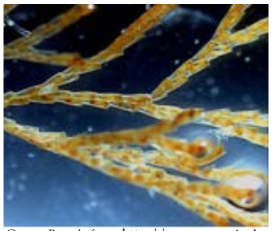
4.3.1.2. Sea Stars and Sea Cucumbers (Phylum Echinodermata)


Brittle Star (Family *Ophioderma*)
Photo by Christina Adams.


Sea Cucumber (*Cucumaria frondosa*)
http://www.sealifebase.fisheries.ubc.ca

There are approximately 7000 marine species. They can range in size from 1 cm to 2 m. Food habits vary among the different species, anything from filter feeders to scavengers to predators. Sea stars can regenerate missing arms, and sea cucumbers and urchins are also able to regenerate certain parts of their anatomy (**Mulcrone 2005**).

4.3.1.3. "Moss Animals" (Phylum Bryozoa)


Genus *Bugula* from http://www.serc.si.edu

This group of animals lives in colonies (**Collins 1999**). They have tentacles which they use to filter phytoplankton out of the water (**Bullivant 1968**). Five non-native species have been recorded in the LSJRB (see Section 4.5 Non-native Aquatic Species; **Mattson et al. 2012**).

4.3.1.4. Jellyfish, Sea Anemones, and Hydrozoans (Phylum Cnidaria)

All the species in this phylum have stinging cells called nematocysts. They have two basic body forms – medusa and polyp. Medusae are the free-moving, floating organisms, such as jellyfish. Polyps are benthic organisms such as the hydrozoans (**Myers 2001a**). In the LSJRB, hydrozoans are more common than jellyfish and sea anemones. Eight taxa have been recorded in the LSJRB, with three taxa found in freshwater including *Corylophora lacustris* (**Mattson et al. 2012**). The non-native freshwater jellyfish *Craspedacusta sowerbyi* has been recorded in the LSJRB (see Section 4.5 Non-native Aquatic Species).


Tubularian Hydroid (*Tubularia crocea*) Photo by Bob Michelson from http://stellwagen.noaa.gov


Sea Anemone (Order Actiniaria) from http://digitalmedia.fws.gov


Jellyfish (Class Scyphozoa) from http://digitalmedia.fws.gov

4.3.1.5. Ribbon Worms (Phylum Nemertea)

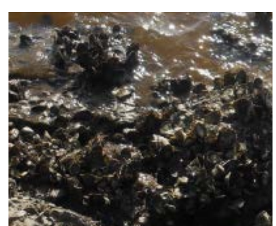

Ribbon Worm (Genus *Tubulanus*) Photo by Kare Telnes from http://www.seawater.no/fauna/nemertea/

The common name "ribbon worm" relates to the length of many species with one species being 30 m. Marine species are more common than freshwater species (**Collins 2001**). Besides long length, these worms have an elongated appendage from the head called a proboscis that they use to capture prey. (**Collins 2001; Graf 2013**). One ribbon worm was recorded by **Evans et al. 2004** that was salt and pollution tolerant.

4.3.1.6. Snails, Mussels, and Clams (Phylum Mollusca)

The Mollusca are very diverse with >50,000 species, ranging in size from less than a millimeter to more than twenty meters long (giant squids). Over 150 taxa have been identified in the SJRB, including more than 3 invasive taxa (see Section 4.5 Non-native Aquatic Species) and others endemic to the SJR drainage (Elimia sp.) (**Mattson et al. 2012**). Representative taxa include *Mytilopsis leucophaeata*, *Gemma gemma*, *Littoridinops*, *Boonea impressa*, *Nassarius obsoletus*, and the non-native *Rangia cuneata* (**Cooksey and Hyland 2007**). Six taxa were recorded by **Evans et al. 2004** from 2002-2003 collections in the LSJRB. Each taxon was pollution tolerant and two taxa were gastropods and the other four were bivalves.


Snails (Class Gastropoda) Photo by Kimberly Mann


American oyster (*Crassotrea virginica*) Photo by Kimberly Mann


Mussel (Class Bivalvia) from http://digitalmedia.fws.gov

4.3.1.7. "Peanut Worms" (Phylum Sipuncula)


Peanut Worm (Phylum Sipuncula) from http://www.ucmp.berkeley.edu l

The common name "peanut worm" relates to their shape. Over 320 marine species have been described and they are found in sand, mud, and crevices in rocks and shells (**Collins 2000**).

4.3.1.8. "Horseshoe worm" (Phylum Phoronida)


Genus Phononpsis, Copyright Peter Wirtz peterwirtz2004@yahoo.com l

Approximately 12 marine species have been identified with some species having horseshoe-shaped tentacles (**Collins 1995**). They are most common in shallow sediments. *Phoronis* has been recorded from Clapboard Creek (**Cooksey and Hyland 2007**).

4.3.1.9. Insect larvae (Phylum Arthropoda, Supbphylum Crustacea, Class Insecta)


Insect larvae (Class Insecta) from http://digitalmedia.fws.govl

Most insect larval forms look differently from their adult stage. Those larvae associated with aquatic habitats can be found under rocks and in the mud (**Myers 2001b**). Representative genera include *Coelonypus* and *Chrionomus* (**Cooksey and Hyland 2007**). Sixteen taxa were recorded by **Evans et al. 2004** from 2002-2003 collections in the LSJRB. These taxa were found in freshwater, and six were pollution tolerant.

4.3.1.10. Isopods, Amphiphods, and "shrimp-like" crustaceans (Phylum Arthropoda, Subphylum Crustacea, Class Malacostraca, Superorder Peracarida)


Left: Isopod, photo by A. Slotwinski, from http://www.imas.utas.edu.au
Middle: Amphipod, photo by A. Slotwinkski, from http://www.imas.utas.edu.au
Right: Mysid ("shrimp-like"), photo by A. Slotwinski, from http://www.imas.utas.edu.au

It has been estimated that there are over 54,000 species in this group (**Kensley 1998**). They all possess a single pair of appendages (maxillipeds) extending from their chest (thorax) and mandibles. The maxillipeds assist in getting food to their mouth. For this superorder, the carapace (the exoskeleton protecting the head and some to all of the thorax is reduced in size and does not cover all of the thorax. The carapace is also used to brood eggs (**UTAS 2013**). Over 60 taxa have been recorded in the LSJRB (**Mattson et al. 2012**). In the LSJRB, eleven taxa were recorded, of which all were salt-tolerant, and four taxa were pollution-intolerant (**Evans et al. 2004**). Example taxa are *Paracaprella pusilla*, *Apocorophium lacustre*, and *Protohaustroius wigleyi* (**Cooksey and Hyland 2007**). Two species are non-native to the SJRB (see Section 4.5 Non-native Aquatic Species).

4.3.1.11. Crabs and Shrimp (Phylum Arthropoda, Subphylum Crustacea, Class Malacostraca, Order Decapoda)

Blue Crab (*Callinectes sapidus*) from http://digitalmedia.fws.gov

Shrimp (Order Decapoda) Photo by Kimberly Mann

This is one of the most well-known groups since many people eat crabs, shrimps, and lobsters. Decapoda refers to the five pairs of legs. This group has an exoskeleton, which they periodically have to shed (molt) so they can continue to grow. Their body is divided into three sections – the head, thorax and abdomen. The head and thorax are fused together and covered by the carapace. In crabs, the abdomen is curved under the carapace (**Humann and Deloach 2011**). Approximately 55 taxa of crabs and shrimp have been reported in estuarine, marine, and freshwater in the LSJRB (Appendix 3.3.2a-3.3.3b). In the SJRB, five species are commercially and/or recreationally (**Mattson et al. 2012**) harvested. In 2002-3, **Evans et al. 2004** recorded two taxa in salt waters, of which *Rhithropanopeus harrisii* was pollution intolerant. Four species are non-native to the SJRB (see Section 4.5 Non-native Aquatic Species).

4.3.1.12. Barnacles (Phylum Arthropoda, Subphylum Crustacea, Class Malacostraca, Infraclass Cirripedia)

Gooseneck Barnacles, http://www.digitalmedia.fws.gov l

There are approximately over 1,400 species. Size can range from a few centimeters to slightly greater than 10 cm. Barnacles are attached to a hard substrate or other organisms. The carapace completely encloses their soft body. They do not possess compound eyes or appendages. For most, their habitat is along rocky shoreline in the intertidal zone (**Newman and Abbott 1980**). Two taxa were recorded by **Evans et al. 2004** that were salt and pollution tolerant in the LSJRB. Five non-native taxa have been recorded in the LSJRB (see Section 4.5 Non-native Aquatic Species).

4.3.1.13. Worms (Class Polychaeta, Phylum Annelida)

Limnodrilus hoffmeisteri (Subclass Oligochaeta) from http://www.fcps.edu

Class Polychaete, Photo by Kimberly Mann

This phylum consists of worms that have segmented bodies, including earthworms. Polychaete means "many bristles" and members of this class look like feathered worms. Over 200 taxa have been recorded in the SJRB (**Mattson et al. 2012**). Example taxa are *Streblospio benedicti*, *Mediomastus*, *Neanthes succinea*, *Nereis*, *Sabellaria vulgaris*, *Paraonis fulgens*, *Nephtys picta* (**Cooksey and Hyland 2007**). *Streblospio benedicti* and *N. succinea* are pollution tolerant and representative of impaired environmental conditions (**Cooksey and Hyland 2007**). Seventeen taxa were recorded by **Evans et al. 2004**, of which two taxa were pollution intolerant (*Orginiidae* sp. and *Scolopolos rubra*) and another two species that were freshwater tolerant (*Aulodrilus pigueti* and *Limnodrilus hoffmeisteri*) (**Evans et al. 2004**).

4.3.2. Significance

Benthic macroinvertebrates 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. Benthic activities in the sediment or bioturbation can result in sediment turnover, changes in oxygen and nutrient availability, and distribution of grain size. The presence of stress-tolerant species can serve as an indicator of river health (Table 4.2; **Pearson and Rosenberg 1978; Gray et al. 1979**). For more information on pollution in benthic invertebrates, see Section 5 Contaminants.

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) from 1973-2000 with supplemental data from DEP's "Fifth Year Assessments" (**DEP 2013k**). No dataset has been compiled within the past three years.

4.3.4. Current Status (UNCERTAIN)

The current status is rated as UNCERTAIN due to lack of data.

4.3.5. Trend (UNCERTAIN)

Community shifts are expected in response to the natural changes in water quality, salinity, and temperature in addition to biological factors that can include recruitment and predation variability (**Cooksey and Hyland 2007**). 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 current trend is rated as UNCERTAIN. The lack of recent surveys and monitoring of benthic macroinvertebrates makes it difficult to identify trends, especially since microhabitat variability can be as high as site variability. Yet, low species richness, diversity, and abundance are representative of impaired benthic conditions (**Cooksey and Hyland 2007**). The health of the SJR is linked to the health of benthic macroinvertebrates. A potential concern is if macroinvertebrate communities change in a large area within the river, and then 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 2018b**). These animals are protected under the Endangered Species Act of 1973 (**Congress 1973**). The West Indian manatee, bald eagle, and wood stork discussed here 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 (although included in past reports, the latter three have not be included in this report). In addition, other endangered or threatened 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 human 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 (133 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 (delisted 2016, current status: Threatened)

Photo by Chelsea Bohaty, Blue Springs State Park.

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 1972b**), and by the State under the Florida Manatee Sanctuary Act of 1978 (**FWC 1978**). More recently, because manatees are no longer considered to be in imminent danger of extinction, the U.S. Fish and Wildlife Service announced that the West Indian manatee was reclassified from endangered to threatened status on March 30, 2016. This action does not affect federal protections currently enforced under the Endangered Species Act (**USFWS 2018b**).

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 ft 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 2018**). In 1989, Florida's Governor and Cabinet identified 13 “key” counties experiencing excessive watercraft-related mortality of manatees and mandated that these counties develop a Manatee Protection Plan (MPP). The following counties have state-approved MPPs: Brevard, Broward, Citrus, Collier, Dade, Duval, Indian River, Lee, Martin, Palm Beach, Sarasota, St. Lucie, and Volusia (**FWC 2014b**). 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 2014.

Jacksonville University has conducted some 759 aerial surveys with over 18,375 manatee sightings (1994-2017). These 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 2014**).

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 about 485 manatees from the Blue Springs area (**Hartley 2018**) of which numbers visiting the LSJRB are not known (**Ross 2018**). 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 3,731 animals in 2018 along the entire east coast of Florida, and 2,400 along the west coast for a total of 6,131 manatees (**FWRI 2018d**). State synoptic surveys were not conducted in some years (1993, 1994, 2008, 2012, and 2013) because weather conditions were not preferable. The warm winters meant that manatees did not aggregate well at warm water sources for counting. The Florida counts have grown significantly over time as the population has increased from an average of 1,530 manatees in the early 1990's; to 2,376 manatees (1995-2007); 4,635 manatees (2009-2015); and more recently 6,266 manatees (2014-2018). Considerable coordination and effort by FWRI is involved, for example 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 total of 4,834 (Figure 4.7). In general, few animals were observed in the LSJRB because of the cold weather, although, some animals were found at artificial warm water sources. No animals were observed in the northeast Florida synoptic survey area in 2011, 2015, and 2016. In 2010 and 2014, two animals were observed and in 2017, the previous record count was surpassed with 3,488 animals on the east coast, and 3,132 on the west coast of Florida, for a total of 6,620 manatees (on this occasion 6 animals were observed in the northeast synoptic survey area (**FWRI 2018c**).

*"Synoptic" can be defined as a general statewide view of the number of manatees in Florida. The FWC uses these surveys to obtain a general count of manatees statewide by coordinating 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 2015, the counts have been conducted 29 times (**FWRI 2018e**).*

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 second highest count ever recorded at that time with 2,780 animals on the east coast, and 2,296 animals on the west coast for a sum total of 5,076 animals (**FWRI 2018e**).

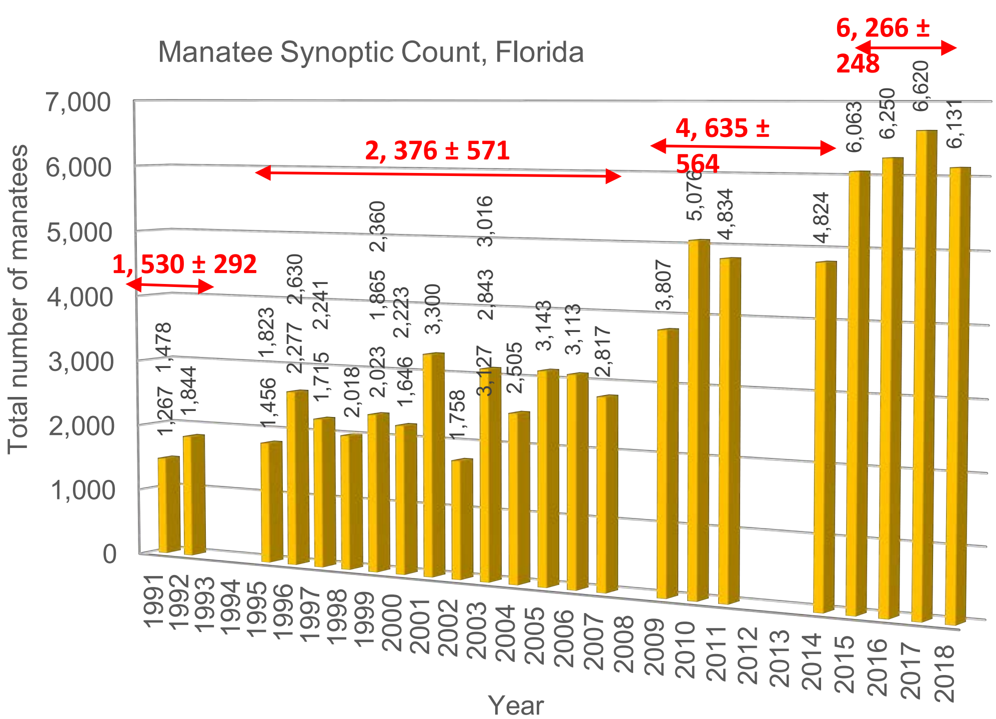


Figure. 4.7. Synoptic aerial counts of manatees in Florida 1991-2018. Vertical numbers above bars indicate totals for the east and west coast (grey); Horizontal numbers show mean and standard deviation, and arrows indicate the period averaged (red). Source: FWRI 2018c

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 LSJR 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. Since 2000, a total of 7 animals: 4 recovered in Duval County (2006, 2008, 2010, and 2012); 2 from Clay County (2011, and 2013); and 1 from St. Johns County (2010), were recovered in the northeast Florida area, that were identified as animals that came from the Blue Springs sub-population (**Beck 2018**).

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 2017, pleasure boats have increased the most and represent about 97% of all vessels. St. Johns, Clay, and Flagler Counties experienced an increasing trend in the number of vessels. Duval and Putnam Counties experienced a decreasing trend in vessels. 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 2017**) records show that there were 34,483 registered boaters in Duval County in 2002. This number increased to 34,494 by 2007 and has since fallen from 28,519 in 2012 to 26,060 in 2016. Duval County had the most vessels (45%) followed by St. Johns and Clay (18%) then Putnam (12%) and Flagler (7%). Port statistics indicated that as many as 4,166 vessel passages occurred to and from the Port in 2012, and that these decreased to 3,312 in 2017 year (**JAXPORT 2018**). 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 2009-2017 the number of passages averaged 155. Large commercial vessel calls and departures are projected to increase significantly in the future (**JAXPORT 2007**). Also, in order to accommodate larger ships, the JAXPORT dredged turning basins in 2008 and began to deepen the channel near the mouth of the SJR in December of 2017. 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 1994-2018, and Clay County 2002-2003) were used in addition to historic surveys by FWC (Putnam 1994-1995). Ground survey data came from Blue Springs State Park (1970-2017). The FWRI provided manatee mortality data from 1975-2017. Other data sources include the USGS Sirenia Project's radio and satellite tracking program, manatee photo identification 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 or Robinson R44 helicopter at altitudes of 500-1,000 ft. (**JU 2018**) 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, the 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 prior to 2012 averaged 19 ± 3.5 SD (range 11-26/yr). Since then, funding for aerial surveys was significantly reduced due to budget cuts, which resulted in a lower survey frequency of 3-5 surveys/yr. This includes additional assistance with surveys from the USCG Air Auxiliary Unit. The reduced survey effort has significantly reduced the power to predict trends and represents a further limitation in the data.

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. Updated salinity data were provided by Bill Karlavige (Environmental Quality Division, City of Jacksonville). Water quality parameters are measured monthly at ten stations in the mainstem of the St. Johns River at the bottom (5.0 m), middle (3.0 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 Niño), and salinity data for specific SAV monitoring sites came from SJRWMD (Appendix 4.1.7.1.F Salinity). Regarding the salinity data associated with SAV sites and including grass beds information, these data were not available for 2012 to 2014 because that program (encompassing 152 sites) was suspended due to budget cuts. Sampling resumed on a more limited basis in 2015/17 to include fewer stations than before (Jacksonville to Black Creek/Hallows Cove, about 40 stations).

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 4.8). Since 2009, manatee numbers have begun to increase again. The longer-term trend (1994-2017) appears to be relatively stable, when excluding the variation caused by the droughts. Data points from 2013 to 2017 are likely to be significantly affected by reduced sampling frequency.

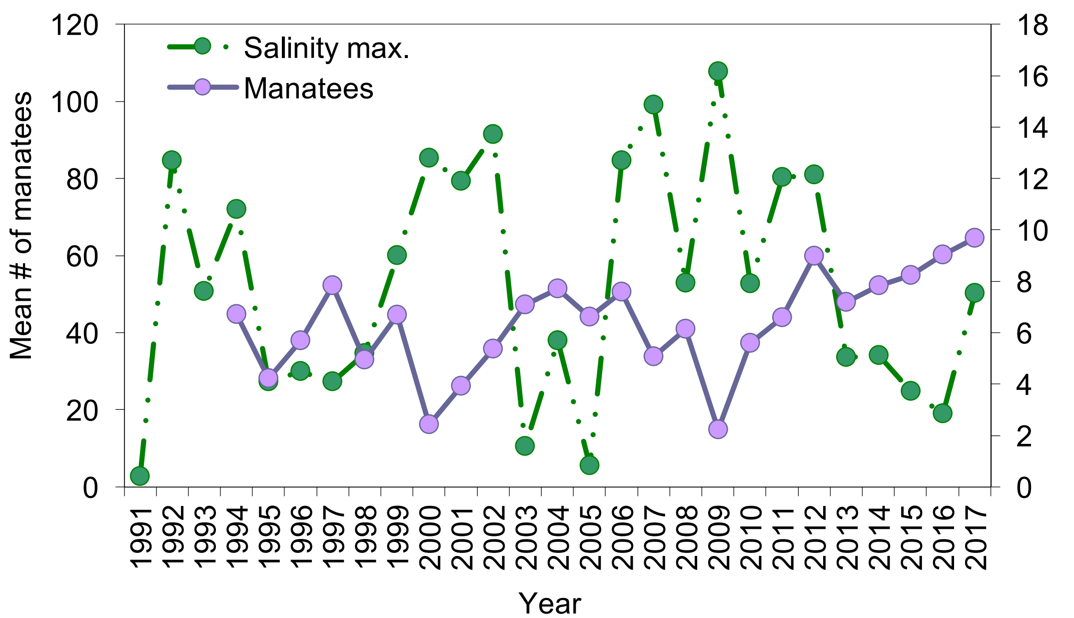


Figure 4.8 Mean numbers of manatees per survey in Duval Co., FL and adjacent waters 1994-2017.
Data source: Jacksonville University and City of Jacksonville (Appendix 4.4.1.A).

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 4.9). A second dip in numbers (2005-2009) occurred as a result of another series of droughts. In 2010, manatee numbers began to increase again and in 2012 a high count of 177 manatees was recorded. In 2016, this was surpassed by another higher count of 192 manatees. Data points from 2013 to 2017 are likely to be significantly affected by reduced sampling frequency. In addition, 2017 was an anomalous year with severe drought in spring and summer, and tremendous storm activity later in September (Hurricane Irma).

"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.

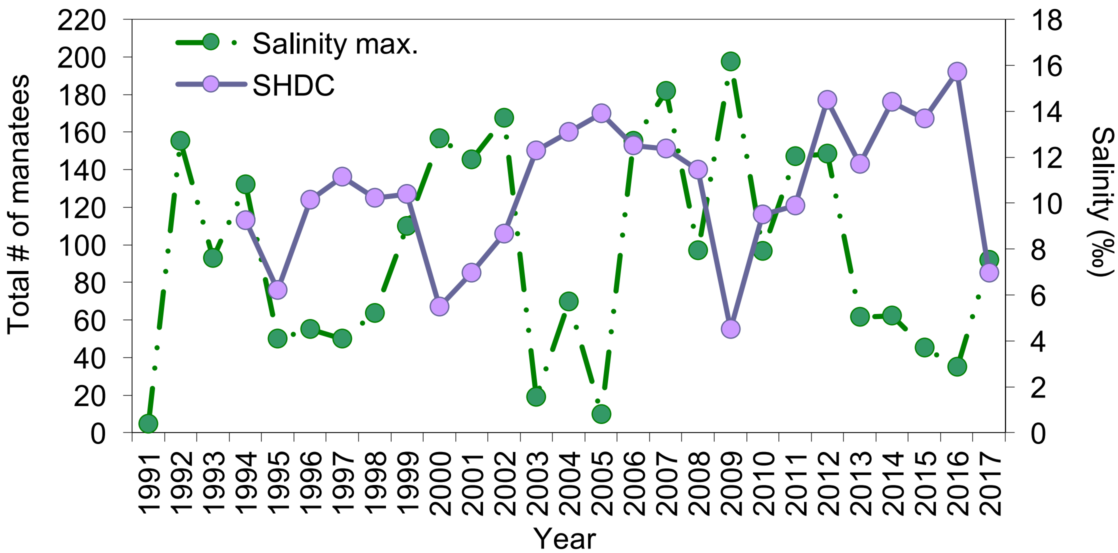


Figure 4.9 Single highest day count per year of manatees in Duval Co., FL 1994-2017.
Data source: Jacksonville University and City of Jacksonville (Appendix 4.4.1.A).

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 six-year average for total number of manatees seen has increased from 6% (1994-2003) to 22% (2004-2016); note also that most of these animals stay in the vicinity of Blue Springs and that calves represent about 7% of the total number sighted (Figure 4.10).

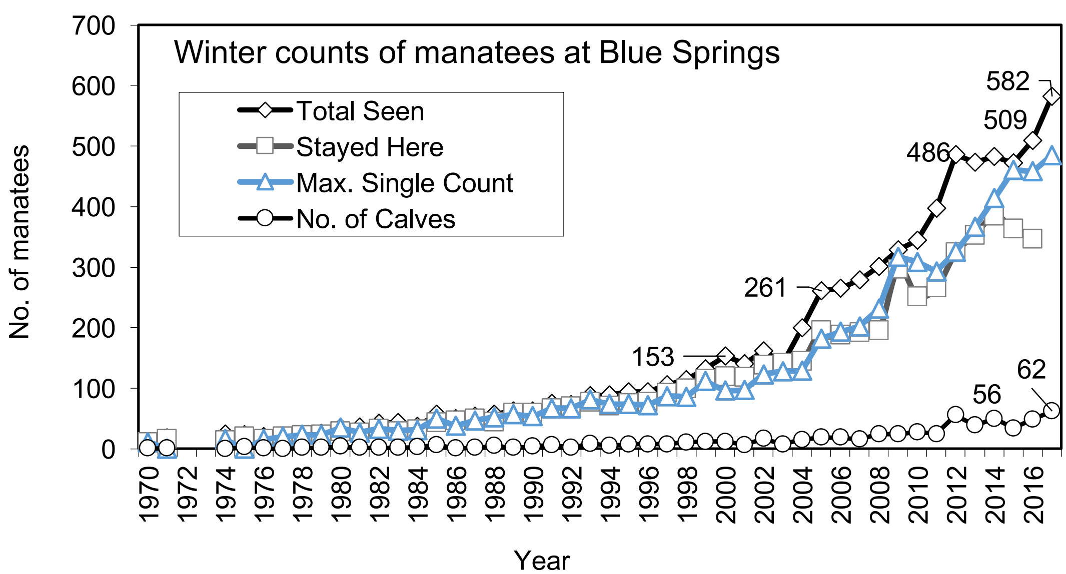


Figure 4.10 Winter counts of Florida manatees identified at the winter aggregation site in Blue Springs State Park, Volusia Co., FL 1970-2017. Maximum single day counts and animals that stayed at the site are also indicated (Data source: ***Hartley 2018****).*

Total Mortality: There were a total of 758 manatee deaths in the LSJRB from 1980-2017 (Figure 4.11), of which a total of 198 were caused by watercraft (26% of total manatee deaths), 14 were from other human related causes, 124 were of a perinatal nature, 134 were from cold stress, 41 from other natural causes and 201 were from undetermined causes. The total number of manatee mortalities (from all causes) increased towards the mouth of the SJR with Duval County being associated with 55% of all deaths, followed by St. Johns (15%), Putnam (12%), Clay (10%), and finally Flagler County with 7% (**FWRI 2018c**).

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*

Watercraft Mortality: Watercraft-related mortalities in 2017, as a percentage of the total mortality by-county, were highest in Duval (34%) followed by Putnam (20%), Clay (19%), Flagler (14%) and then St. Johns 13%. Since most deaths in the basin occurred in Duval County, watercraft deaths in Duval County were compared in five-year increments beginning 1980 through 2014. (Note that in Figure 4.11, the large drop represents just three years of data for 2015/17 and was not considered in any statistical analysis). These times were picked because they represent uniform periods either side of 1994 when the Interim Duval County MPP regulations were implemented. From 1980 to 2004, watercraft deaths of manatees in Duval County averaged 31% of total deaths, and from 2005 to 2009, watercraft deaths were 52% of total deaths. For the 5-year period from 2010 to 2014, watercraft-caused mortality decreased to 24% of total manatee mortalities in LSJRB. For the last three years from 2015 to 2017, it averaged 21% (Appendix 4.4.1.A).

In comparison, the average watercraft death rate for the state was similar for the same period 20% (± s. d. = 0.6%). Mortalities from watercraft in LSJRB showed an upward trend since the mid-1990s, with most reported in Duval County. In the last five years, watercraft deaths of manatees have decreased. The watercraft mortality for the LSJRB was 26% of total mortality in 2017, and the state watercraft mortality rate was 20%. In 2016, it was 28% for LSJRB and 20% for the state (**FWRI 2018d**).

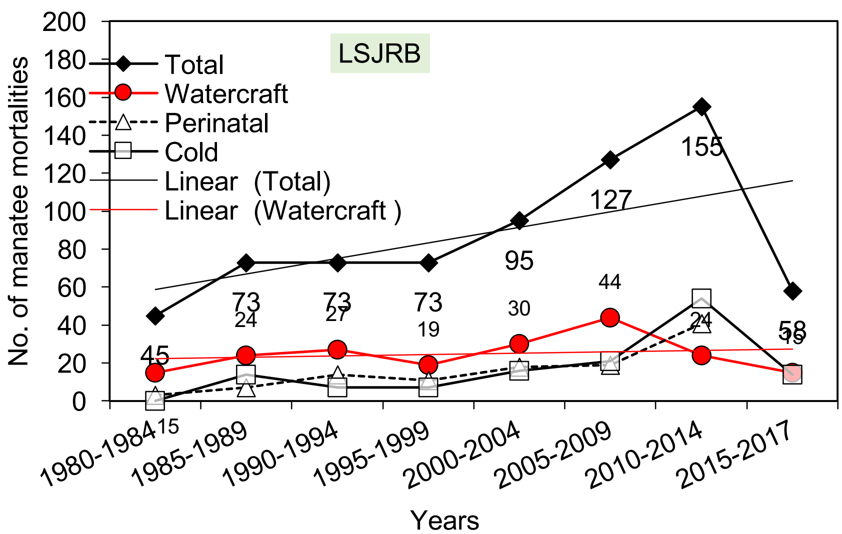


Figure 4.11 Summary of total (large numbered diamonds), watercraft (small numbered circles/red), perinatal, and cold stress manatee mortalities by county in LSJRB (five-year intervals from 1980-2014). Note: 2015-2017 represents an average of only the last three years.

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 (see below on the snout) or abscesses, fat depletion, dehydration, constipation and other gastrointestinal disorders, internal abscesses, and secondary infections. The manatee in the picture below was recovering well from severe cold stress (April 2018) at the Manatee Critical Care Center, Jacksonville Zoo.

Photo by G. Pinto

Cold-stress mortalities were particularly elevated throughout Florida during the period January to March 2010 (Figure 4.11). This period included the coldest 12-days 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. Florida manatees rely on warm-water refuges to survive winter and extended cold periods, which are of particular concern because the long-term survival of these animals will be dependent on access to warm water springs as power plant outfalls throughout the Florida peninsula are shut down (**Laist et al. 2013**). In LSJRB there were 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, that sought to down list manatees from endangered to threatened status. Currently, manatees are considered threatened at the federal level. Taking everything into account, the current STATUS of the Florida Manatee is *satisfactory*, and the TREND is *improving.*

4.4.1.5. Future Outlook

Manatees in the LSJRB are likely to continue to increase as more manatees move north because of population increase, decreases in manatee habitat and its quality in south Florida. Although threats still exist, manatees do not appear to be in imminent danger of extinction. As a result, the U.S. Fish and Wildlife Service has ruled that the manatee status be upgraded to "threatened" without affecting federal protections currently enforced under the ESA (**USFWS 2018a**).

Recovery from the most recent drought cycle (2009-2012) 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 2007b**). In 2013, the aerial survey budget was significantly reduced to the point that useful information about population trends is more limited. In light of that issue, the USCG Auxiliary Air Unit stepped up to offer assistance in providing flights, when possible. Just like in Lee County, Florida (**Semeyn et al. 2011**) the manatee count and distribution information in the form of maps is discriminated to local, state and federal law enforcement, maritime industry groups, the port, and the media so that efforts can be focused on raising public awareness through education. The focus on education is primarily so that manatee deaths from watercraft can be reduced. In May of 2013, the area experienced significant rainfall and algae blooms in the mains stem of SJR near Doctors Lake. There has been a spatial shift over the last fifteen years in that fewer manatees are seen in areas north of the Buckman Bridge for extended periods of time, and more tend to congregate further south. This correlates with more suitable habitat to the south verses the north. There appears to be a decreasing trend in watercraft-caused deaths for the LSJRB from 2010-2017, though if this trend is sustained or not remains unclear (**FWRI 2018c**). Although there is a decreasing trend in registered vessels in Duval and Putnam Counties, significant increases in vessel traffic in the LSJRB are projected to occur over the next decade as human population increases and commercial traffic increases. 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 known 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, 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**). Important monitoring programs have been reduced or eliminated due to budget cuts in the last few years. Fewer data impacts the ability of planners to gauge the effectiveness of programs that have the goal of improving environmental conditions in the river and may lead to additional costs in the future.

> *"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 Menken, 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 had increased from just under 500 (1960) to over 10,000 (2007).

As a result of this tremendous recovery, bald eagles were delisted June 28, 2007 (**USFWS 2007a; USFWS 2008a; USFWS 2008d; AEF 2016**). 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 (**Scott 2003b; Jacksonville Zoo 2018a**). 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 2018**). 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 (**Scott 2003b; AEF 2016; Jacksonville Zoo 2016; Jacksonville Zoo 2018a**). 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 2018**).

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 fewer nests, because of a change in survey protocol starting November 2008 (**Gipson 2014**). After a hiatus of two years, bald eagle nests were surveyed again in 2013 and numbers of active nests had not changed significantly from 2010 (**Gipson 2014**) (Figure 4.12).

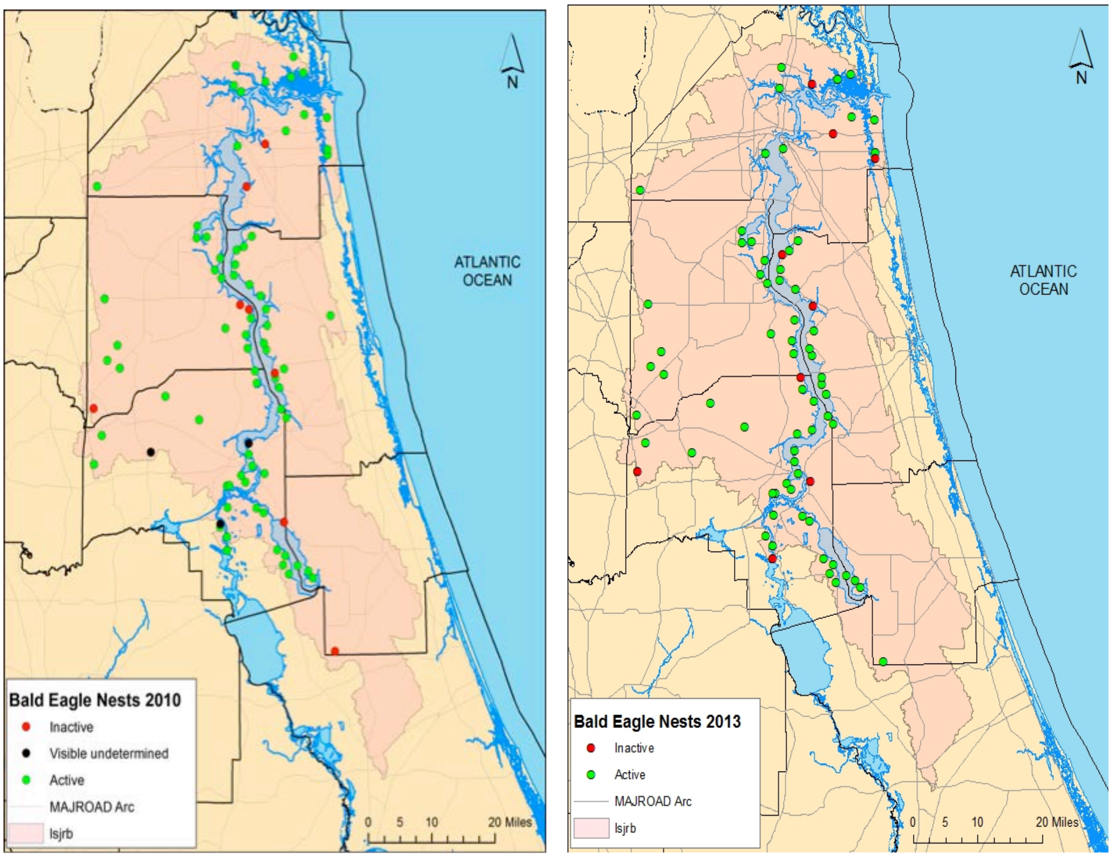


Figure 4.12 Bald eagle nesting sites in LSJRB 2010 and 2013 (Source data: ***Gipson 2014****).*

4.4.2.3. Data Sources & Limitations

Data came from a variety of sources: Audubon Society winter bird counts, FWC, Jacksonville Zoo and Gardens, USFWS and various books and web sites. No new data for the LSJRB area was available from FWCC for 2011/2013 and 2014/2015/2016/2017. Various groups conduct periodic surveys and the state has a five-year management plan (**FWC 2008**) to monitor the eagle's continued welfare (**FWC 2008**; **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 2008**).

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 2018a**). 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 2014**; **USFWS 2008b; USFWS 2008c**). According to Jacksonville winter bird counts by the Duval Audubon Society, numbers sighted (1981-2017) have increased significantly ($\tau = 0.799$; $p = 7.29E\text{-}12$; $n = 35$) since the pesticide DDT was banned in the 1960s (Figure 4.13). Taking everything into account, the current STATUS of the Bald Eagles is *satisfactory*, and the TREND is *improving*.

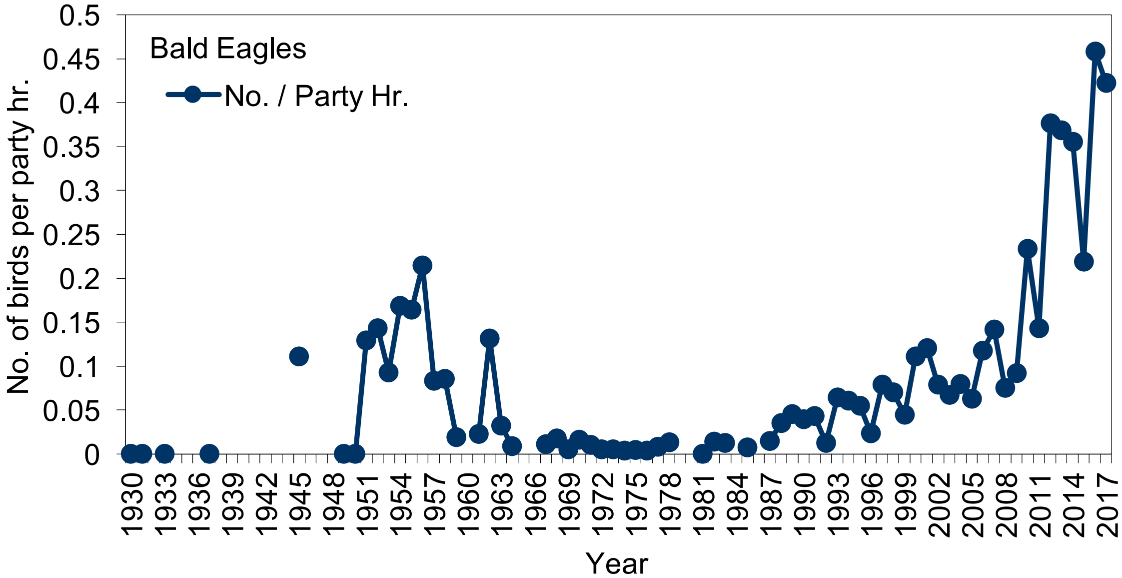


*Figure 4.13 Long-term trend in the number of bald eagles counted during winter bird surveys (1929-2017) in Jacksonville, FL (Source data: **Audubon 2018**) (Appendix 4.4.2.A).*

In a recent Kendall tau correlation analysis of rainfall for the LSJRB, count data for Audubon count circle in Jacksonville was negatively correlated to rainfall, but not significant ($\tau = -0.12$; $p = 0.203$; $n = 23$). The analysis indicated increase in numbers of eagles over time with respect to party hours of effort ($\tau = 0.668$; $p = 4.03E\text{-}06$; $n = 23$) and raw numbers ($\tau = 0.684$; $p = 2.43E\text{-}06$; $n = 23$), respectively (Figures 4.14 and 4.15).

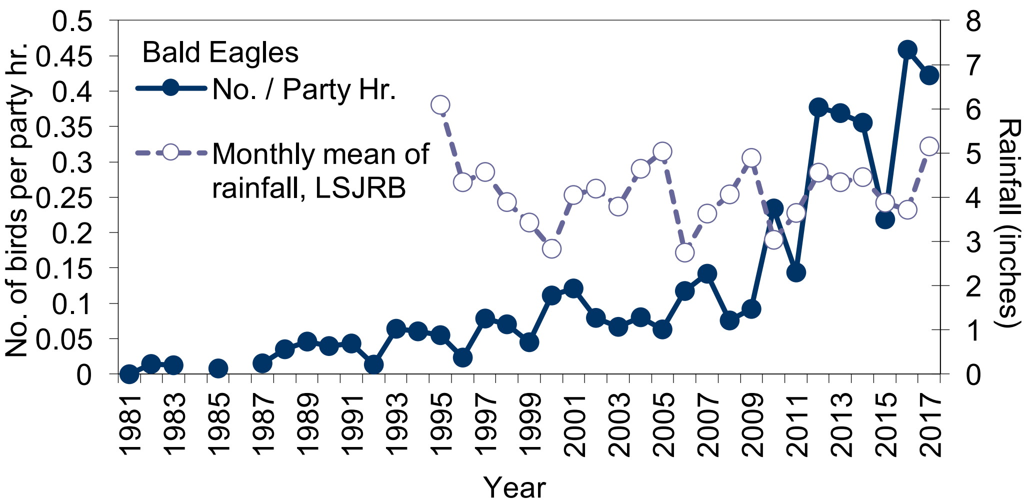


*Figure 4.14 Long-term trend in the number of bald eagles counted per party hour and mean monthly rainfall (1981-2017) in Jacksonville, FL (Source data: **Audubon 2018**; **SJRWMD 2018b**) (Appendix 4.4.2.A).*

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.

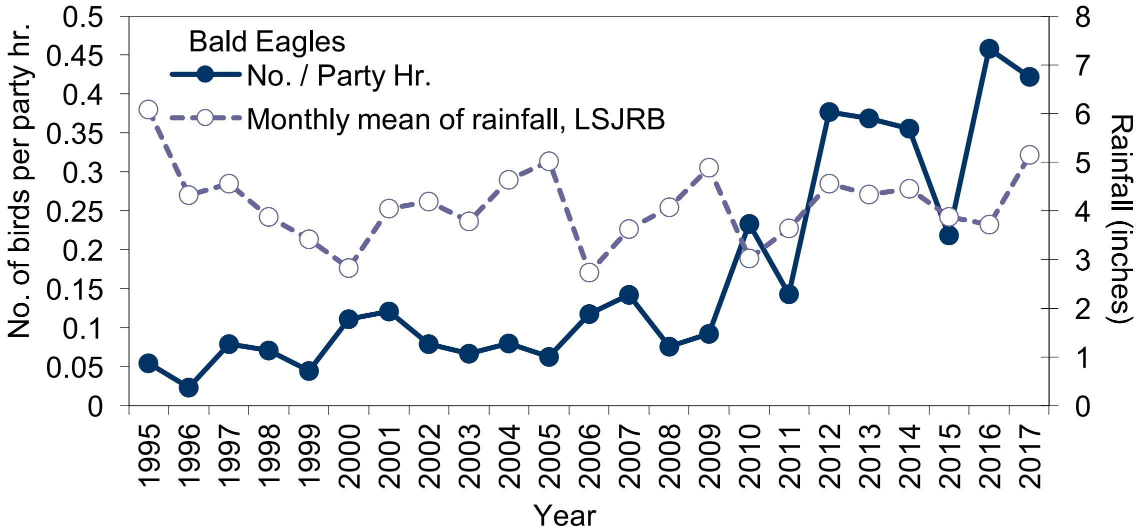


*Figure 4.15 Recent trends in the number of bald eagles counted per party hour and mean monthly rainfall (1995-2017) in Jacksonville, FL (Source data:: **Audubon 2018**; **SJRWMD 2018b**) (Appendix 4.4.2.A).*

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. In 2010, rainfall and the number of bald eagles increased. The dip in eagle numbers in 2010/2011 may have been caused by the unusually cold weather experienced at the time. In 2012, eagle numbers remained at an all-time high with only a slight dip in 2013/2014. In 2015, there was a significant decrease in eagle numbers, but in 2016/2017, following a period of drought bald eagle numbers increased again so that the overall trend remains upward (see Appendix 4.1.7.1.E Rainfall, Hurricanes, and El Niño).

4.4.2.5. Future Outlook

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 from endangered to threatened, it is imperative that everyone does their 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. Ongoing 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 being the most significant (**FWC 2008; USFWS 2008a**; **AEF 2018**).

4.4.3. Wood Stork (down listed 2014, current status: Threatened)

Photos by G. Pinto, Jacksonville Zoo Colony

4.4.3.1. Description

The wood stork *(Mycteria americana)* was listed as endangered in 1984 and is America's only native stork. The reason for the Endangered Species Act (ESA) listing was declining numbers of nesting pairs from about 20,000 (1930s) to 3,000-5,000 pairs in the 1970s (**Jacksonville Zoo 2018b**). Wood storks originally recommended to be down listed (**USFWS 2007c**) were upgraded to threatened status in June 2014 (**USFWS 2018a**). 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). (**USFWS 2002**; **Scott 2003c**). Feather analysis of the banded chicks at Jacksonville Zoo suggests that the primary food sources being fed to the chicks is fresh water prey items not zoo food items or estuarine prey. Satellite tracking data to date supports this foraging pattern, with adults feeding primarily on an estuarine prey base prior to nesting, switching to fresh water prey base during chick rearing, and then return to an estuarine diet after chick fledging and during the rest of the year (**Jacksonville Zoo 2018b**). 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 2003c**).

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 is one cause of nesting failures, as has been reported in the Everglades (**Scott 2003c**).

4.4.3.3. Data Sources & Limitations

Data came from Audubon Society winter bird counts from 1962-2017, USFWS surveys and *Southeast U.S. Wood Stork Nesting Effort Database*, FWC/FWRI collaborative work in the SJRWMD area, and Donna Bear-Hull of the Jacksonville Zoo and Gardens from 2000-2017. The Audubon winter bird count area consists of a circle with a radius of ten miles surrounding Blount Island in Jacksonville, FL. 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 4.16 and Appendix 4.4.3.A).

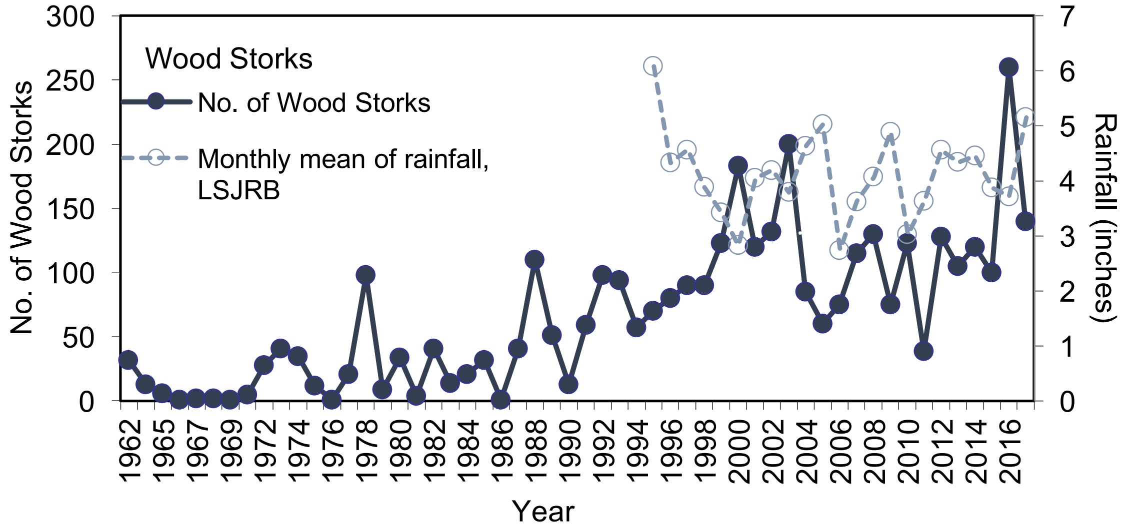


*Figure 4.16 Long-term trend of the number of Wood Storks counted during winter bird surveys (1961-2017) and mean monthly rainfall in Jacksonville, FL (Source data:: **Audubon 2018**; **SJRWMD 2018b**) (Appendix 4.4.3.A).*

Rainfall appears to affect wood stork status in several different ways. In the short term (1995-2017), rainfall for the LSJRB was negatively correlated with numbers of wood storks (τ = -0.235; p = 0.058; n = 23) (Figure 4.17). 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, following a prolonged cold winter, another cycle of drought began, and wood storks began to increase. Rainfall in the last few years increased close to normal levels again for the area and the wood stork population rebounded. However, in 2016 and early 2017, there was a severe drought which caused a large increase in wood storks. Then in late 2017, numbers fell sharply probably due to storm impacts to wood stork colonies from Hurricane Irma (see Appendix 4.1.7.1.E Rainfall, Hurricanes, and El Niño). Taking everything into account, the current STATUS of the Wood Storks is *satisfactory*, and the TREND is *improving.*

Rainfall data for LSJRB (1995-2017) was negatively correlated with Wood storks when party hours of effort were considered, but this was not significant (τ = -0.162; p = 0.139; n = 23) (Figure 4.17).

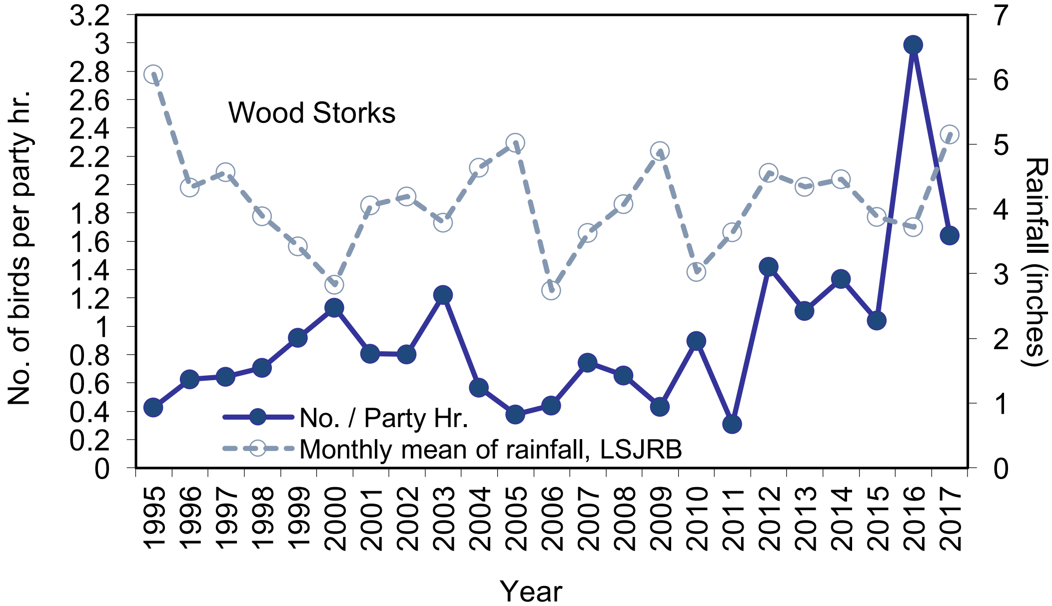


Figure 4.17 Recent trends in the number of wood storks counted per party hour and mean monthly rainfall (1995-2017) in Jacksonville, FL (Source data: ***Audubon 2018****;* ***SJRWMD 2018b****) (Appendix 4.4.2.A).*

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 4.18.

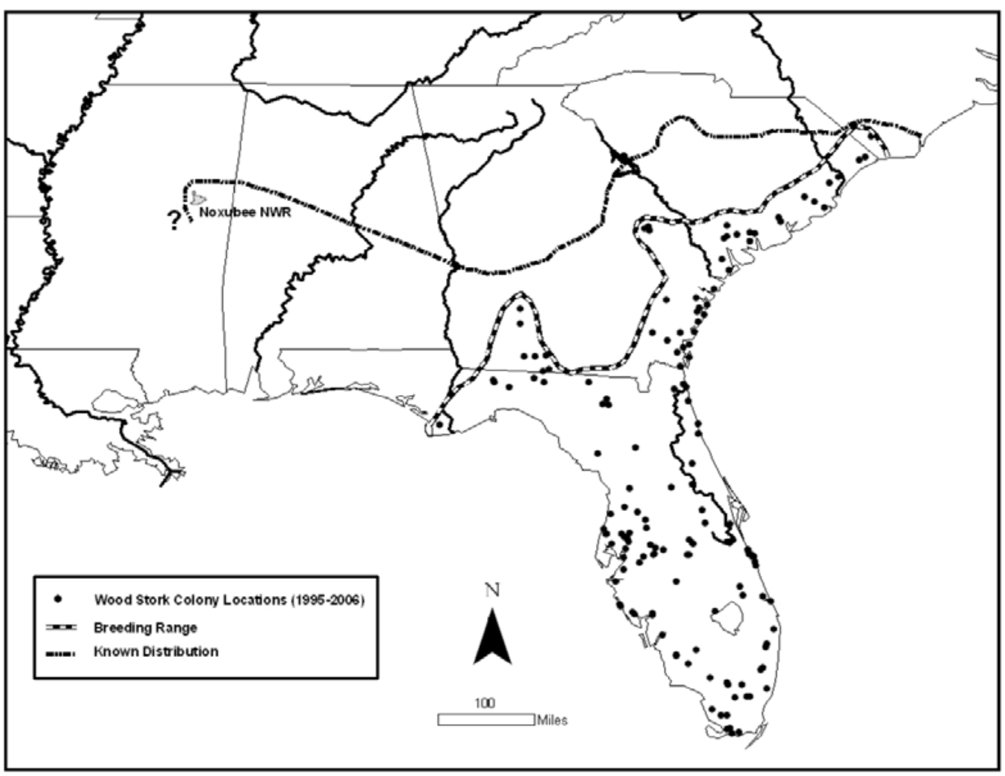


*Figure 4.18 Distribution of wood stork colonies and current breeding range in the southeastern U.S. (****USFWS 2007c****).*

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:

Jacksonville Zoo and Gardens: This colony was formed in 1999 and has continued to persist strongly with growth leveling off in recent years. This group continues to have the highest number and productivity of birds in central and north Florida (**Rodgers Jr et al. 2008a**) (Figures 4.19 and 4.20; Appendix 4.4.3.B). It is considered the most important recently-established rookery in Duval County (**Brooks 2018**). 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 86 pairs (181 fledged chicks) (**USFWS 2004; Bear-Hull 2018**). In 2009, the nesting and fledgling rates were similar 88 pairs, but 124 fledged chicks (**USFWS 2018c**). In 2010, the number of wood storks increased to 107 pairs and 276 fledged chicks. From 2011 to 2013 there was a significant decline in the numbers of fledglings to a low of 35 fledglings from 90 pairs in 2013 (2011: 105 pairs and 213 fledged chicks; 2012: 106 pairs and 147 fledged chicks. Currently this population appears to be close to carrying capacity, and with stabilizing numbers of nests (2017: 70 nests, 81% success rate; 2016: 101 nests, 78% success rate; 2015: 91 nests, 81% success rate; 2014: 88 nests, 74% success rate; 2013: 90 nests, 30% success rate; 2012: 106 nests, 76% success rate) (**Bear-Hull 2018**).

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 9 adults. In addition, four adults have been fitted with satellite monitoring tags. The 9 banded adults returned every year to the zoo site until 2007, some did not perhaps going to other rookeries. Satellite tracking data to date supports this foraging pattern, with adults feeding primarily on an estuarine prey base prior to nesting, switching to fresh water prey base during chick rearing, and then return to an estuarine diet after chick fledging and during the rest of the year (**Jacksonville Zoo 2018b**).

A success is defined as at least one successful hatch. The mean success rate of nests at the zoo increased from 90% (2009) to 98% (2010); then decreased to 72% (2012), and further to 31% (2013), but then increased again to 74% (2014), 81% (2015), 78% 2016, and 81% in 2017.

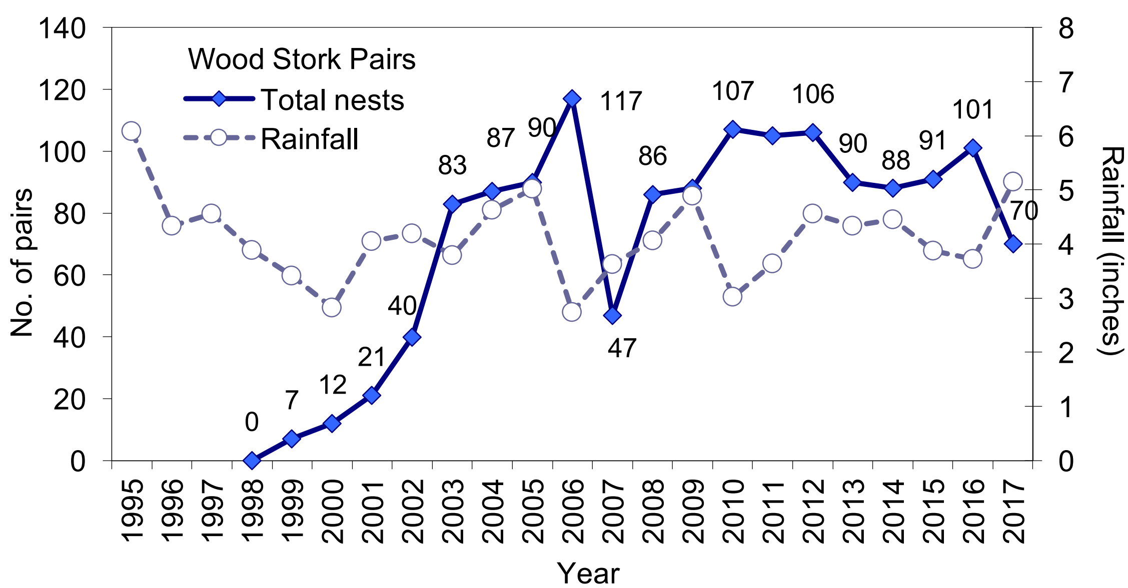


*Figure 4.19 Number of wood stork nests at Jacksonville Zoo (2003-2017) (Source data: (**USFWS 2018c**; **SJRWMD 2018b**; **Bear-Hull 2018**).*

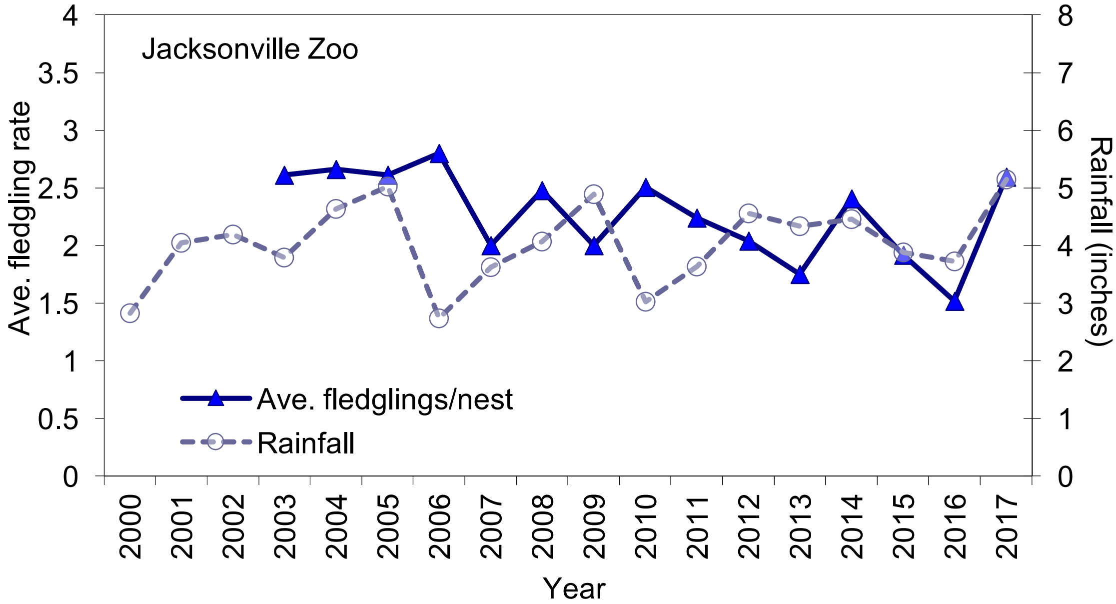


*Figure 4.20 Wood stork productivity chicks/nest/year at Jacksonville Zoo (2003-2017) and mean monthly rainfall (Source data: **USFWS 2005; USFWS 2007c; Rodgers Jr. 2011; Bear-Hull 2018**; **SJRWMD 2018b**; **USFWS 2018c**).*

(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 2007c**). 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; although the colony was active (determined by aerial survey), data on wood storks numbers were unavailable for 2009-2013 (Figures 4.21 and 4.22). In 2014, the colony consisted of 170 active wood stork nests, determined from aerial photographs and in 2015, there were in excess of 130 nests. In 2016, 100 nest were reported with 28 successes and 81 chicks fledged (2.85 chicks/nest); Increased storm activity in 2017 probably led to a significant decrease in nests, totaling 43 (**Bear-Hull 2018**; **USFWS 2018c**).

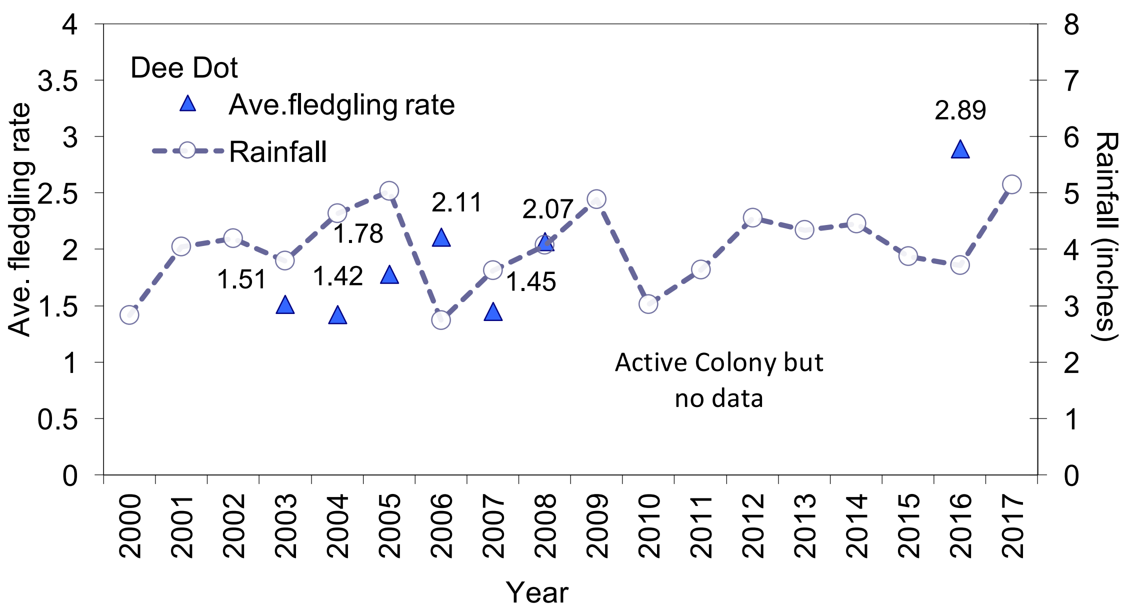


*Figure 4.21 Wood stork productivity (chicks/nest/year) at Dee Dot (2003-2008, 2016) and mean monthly rainfall (2000-2017) (Source data: **USFWS 2005; USFWS 2007c; Rodgers Jr et al. 2008b; SJRWMD 2018b; USFWS 2018c; Bear-Hull 2018**).*

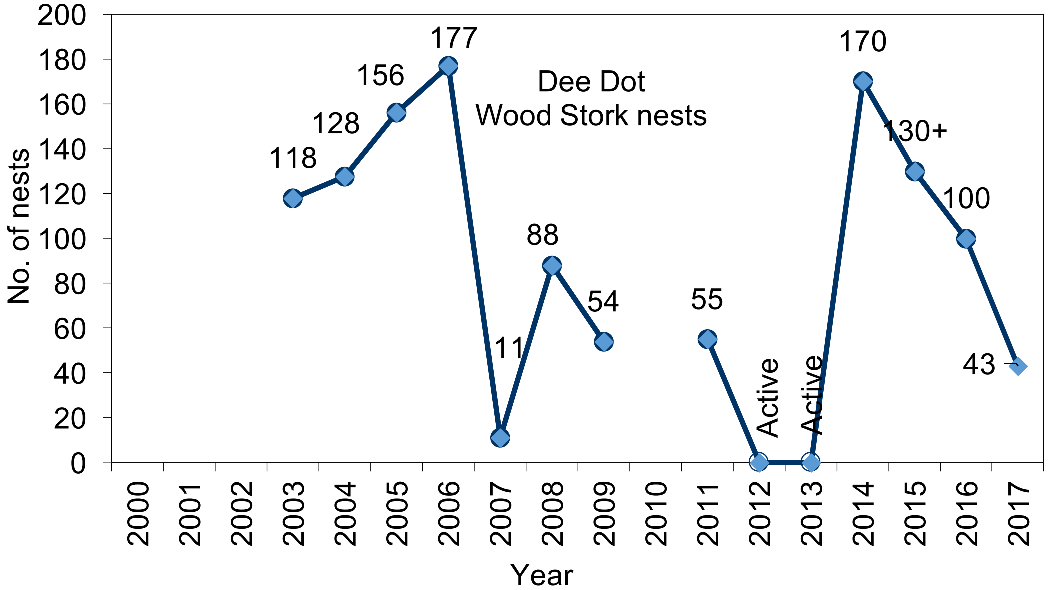


Figure 4.22 Number of wood stork nests at Dee Dot (2003-2017) Note: there were no data for 2010, 2012, and 2013 (Source data: ***Rodgers Jr et al. 2008a; Rodgers Jr et al. 2008b; USFWS 2018c; Bear-Hull 2018****).*

(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 2018; USFWS 2018c**). This site was inactive during 2010 to 2016, and no data were available for 2017 (Figures 4.23 and 4.24).

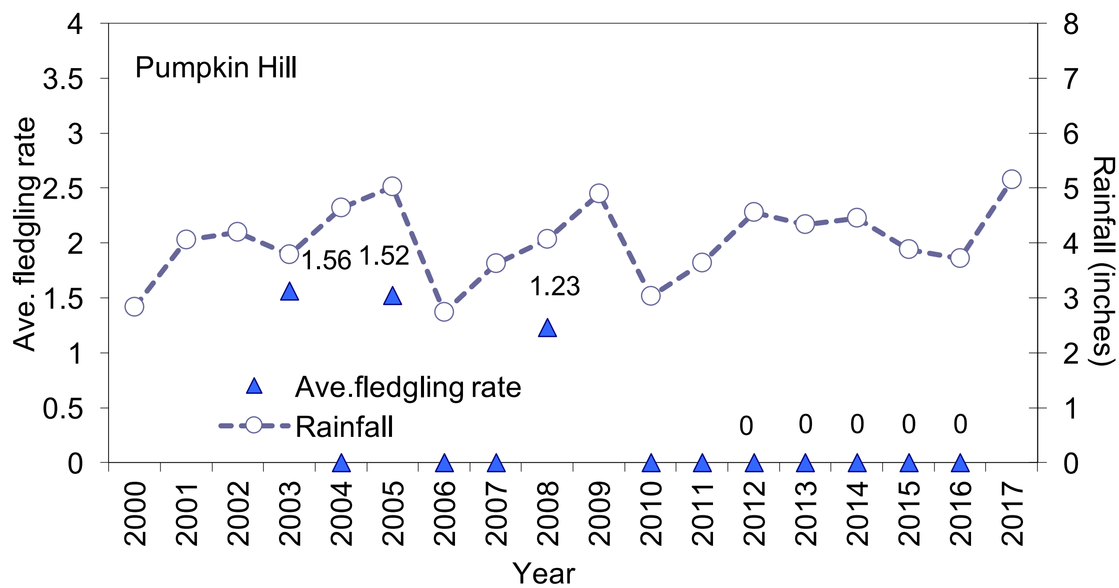


Figure 4.23 Wood stork productivity (chicks/nest/year) at Pumpkin Hill (2003-2016) and mean monthly rainfall. There are two colonies at this site, which is characterized by cypress-dominated domes. In 2004, the period 2006 to 2007, and from 2010-2016 no wood stork activity has been documented at this site (no data in 2017). In 2009, the colony was described as being active, but no data was available (Source data: ***Rodgers Jr et al. 2008a; Rodgers Jr et al. 2008b; SJRWMD 2016b; USFWS 2018c****).*

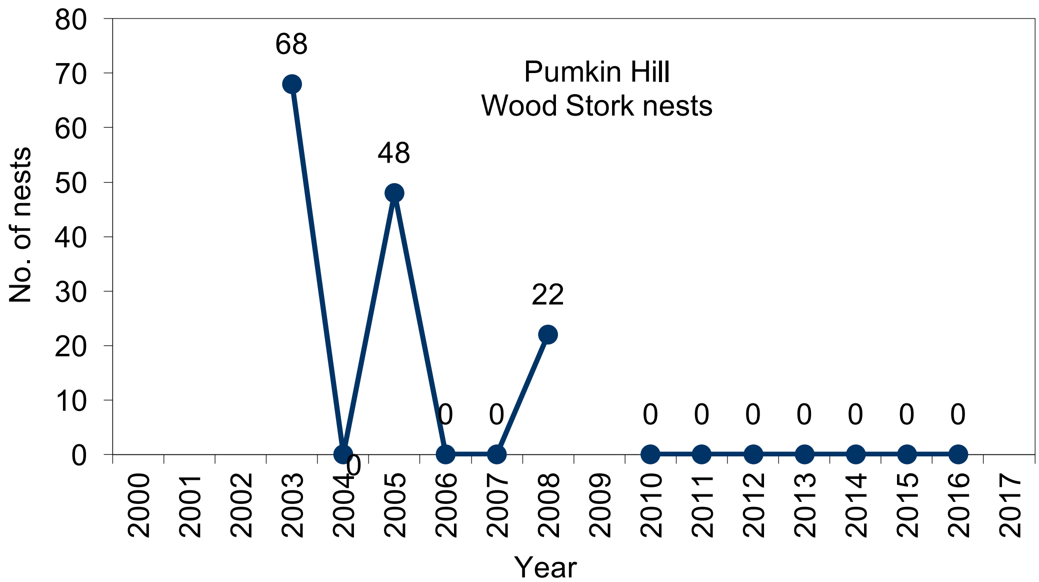


Figure 4.24 Number of wood stork nests at Pumpkin Hill (2003-2016). In 2004, the period 2006 to 2007, and from 2010-2016 no wood stork activity has been documented at this site (no data in 2017). In 2009, the colony was described as being active, but no data was available (Source data: ***Rodgers Jr et al. 2008a; Rodgers Jr et al. 2008b; USFWS 2016; USFWS 2018c****).*

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 2007c**). The U.S. Fish and Wildlife Service upgraded the status for wood storks from endangered to threatened because of the success of conservation efforts over the last 30 years (**USFWS 2016**).

4.4.4. Shortnose Sturgeon (Endangered)

Source: USFWS

4.4.4.1. Description

The shortnose sturgeon *(Acipenser brevirostrum)* is a native species historically associated with rivers along the east coast of U.S. from Canada, south to Florida. The fish tend to be found in larger populations in more northerly rivers. The Shortnose sturgeon 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. 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 1980s and 1990s culminated in the Shortnose Sturgeon Recovery and Management Plan of 1998 (**NMFS 1998; FWRI 2018f**).

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

4.4.4.2. 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**).

4.4.4.3. Data Sources & Limitations

Information on shortnose sturgeon in literature is limited to a few specimen capture records. Information sources included books, reports and web sites. Shortnose sturgeons have been encountered in the St. Johns River since 1949 in Big Lake George and Crescent Lake (**Scott 2003a**). 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 FWC. 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 FWRI 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 2018f**).

4.4.4.4. Current Status

The species is likely to be declining or almost absent in the LSJRB (**FWRI 2018f**). Population estimates are not available for the following river systems: Penobscot, Chesapeake Bay, Cape Fear, Winyah Bay, Santee, Cooper, Ashepoo Combahee Edisto 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**).

4.4.4.5. 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 USFWS for breeding and conservation stocking.

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 1996b**; **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**).

Protection from and management of aquatic species occurs at the federal and state levels. At the federal level, impairment by invasive species is not recognized under the Clean Water Act (**ELI 2008**). USACE in Jacksonville leads invasive species management with the Aquatic Plant Control Operations Support Center and the Removals of Aquatic Growth Program. The U.S. Department of Agriculture Animal and Plant Health Inspection Services is charged with protection from invasive species (**ELI 2008**).

In Florida, management of invasive species is coordinated by Florida Fish and Wildlife Commission's Aquatic Plant Management Program. In 1994, Florida Department of Environment (DEP) included a TMDL water body impairment category of "WEED-exotic and nuisance aquatic plants density impairing water body" (**ELI 2008**).

However, DEP has yet to develop a TMDL for this category. FWC regulates import of vertebrate and invertebrate aquatic species, Florida Department of Agriculture and Consumer Services (FDACS) contributes to prevention of invasive species with importation regulation. Water management districts also contribute with control and restoration programs (**ELI 2008**). Non-profit organizations, such as the First Coast Invasive Working Group, organize invasive species removal events and education outreach.

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 2015**). 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 growing throughout months of lower light (**Gordon 1998**). 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**).

Eutrophic conditions due to excessive nitrate conditions can contribute to proliferation of *H. verticillata* in historically oligotrophic waters (**Kennedy et al. 2009**). In an aquaria experiment with low and high nitrate treatments (0.2 and 1.0 mg nitrate per L, respectively), *H. verticillata* more than doubled its weight in the high nitrate treatment (547 g dry weight) as compared to the low nitrate treatment (199 g dry weight). By comparison, the native species *Sagittaria kurziana* and *Vallisneria americana* did not have a significant difference in weight despite the addition of nitrates. This study suggests that *H. verticillata* will outgrow native aquatic plants as nitrates continue to increase (**Kennedy et al. 2009**).

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 2015**). 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 2015**). 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. Recently, the vermiculated sailfin catfish has been eradicated from the Rainbow River following removal of 28 individuals by hand and spear, demonstrating that early removal of invasive species is possible (**Hill and Sowards 2015**).

Urbanization can contribute to the altering of flow regimes and water quality in the LSJRB (**Chadwick et al. 2012**) that may enable invasive organisms to survive. As compared to rural streams where the flow is typically intermittent, urban streams may have perennial flow due to irrigation, leaky sewage tanks and perhaps storm water that was not diverted to retention ponds. The invasive clam *Corbicula fluminea* contributes significant biomass in two urban perennial streams (**Chadwick et al. 2012**). *Rangia cuneata* was also common on silt-sand substrates near Sixmile Creek and northward in the main river channel to near Cedar River (**Mason Jr 1998**).

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 et al. 1990**; **Hallegraeff and Bolch 1991**; **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 (**Kling 2004**; **Jones and Sauter 2005**). *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

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

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 (**Frank and Lee 2008**). 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.

Just as importantly, yet often overlooked, non-native species can be serious nuisances on a small scale. They foul recreational boats, docks, 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.

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. Resources to investigate distributions of non-native plants include EDDMAPS, USDA, and the Atlas of Florida Vascular Plants. Additional records and information were obtained from agency reports, books, published port surveys, and personal communication data.

4.5.4. Limitations

We expect that many more non-native species are found within the LSJRB, but have not been recognized or recorded, either because they are *naturalized*, *cryptogenic,* or lack of the taxonomic expertise to identify foreign species, subspecies, or hybrids.

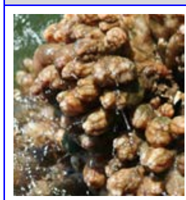
*A naturalized species is any non-native species that has adapted and grows or multiplies as if native (**Horak 1995**).*

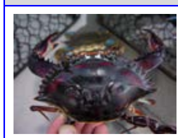
*A cryptogenic species is an organism whose status as introduced or native is not known (**Carlton 1987**).*

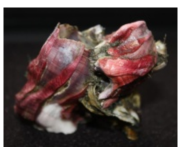
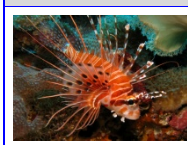
4.5.5. *Current Status*

The current status is rated as UNSATISFACTORY. Approximately 87 non-native aquatic species are documented and believed to be established in the LSJRB (Table 4.9). Non-native species recorded in the Lower Basin include floating or submerged aquatic plants, molluscs, fish, crustaceans, amphibians, jellyfish, mammals, reptiles, tunicates, bryozoans, and blue-green algae (Table 4.9). Freshwater species represent >65% of the species introduced into the LSJRB. Non-native aquatic species originate from the Central and South America, the Caribbean, Asia, and Africa (Table 4.9).

Table 4.9 Non-native aquatic species recorded in the Lower St. Johns River Basin.

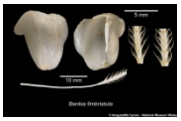
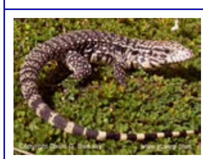
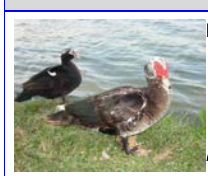
LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
AMPHIBIANS								
	Cane toad *Photo: USGS NAS*	*Rhinella marina*	Freshwater, Brackish	1987	South and Central America	Humans, range expansion from South Florida populations	Clay, 1987	**USGS 2015**
	Cuban treefrog *Photo: USGS NAS*	*Osteopilus septentrionalis*	Terrestrial, Freshwater (springs, lakes, ponds)	1991	Caribbean	Dispersing northward from S. Florida populations, floating vegetation/debris, humans, vehicles, bulk freight/cargo, plant or parts of plants	Clay, 1991; Duval, 2002; Flagler, 2004; St. Johns, 2006; Volusia, 2012	**CISEH 2014; USGS 2015**
TUNICATES								
	Pleated (or rough) sea squirt *Photo: SERTC/SC DNR*	*Styela plicata*	Marine	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	Offshore Jacksonville, 1940	**De Barros et al. 2009; GBIF 2012d**
ECTOPROCTS - BRYOZOANS								
	Brown bryozoan	*Bugula neritina*	Marine, Brackish	mid-1900s.	Native range is unknown - probably Mediterranean Sea (1758 record).	Ship/boat hull fouling		**Eldredge and Smith 2001; NEMESIS 2014**
		Celleporaria pilaefera	Marine	2001	Indo-Pacific	Ship/boat hull fouling, aquaculture	Duval (SJR), 2001	**McCann et al. 2007; NEMESIS 2014**
		Arbopercula bengalensis	Marine	2001	India and tropical, subtropical coast of China		Duval (SJR), 2001	**McCann et al. 2007; NEMESIS 2014**
		Hippoporina indica	Marine	2001	Western Pacific	Ship/boat hull fouling	Duval (SJR), 2001	**McCann et al. 2007; NEMESIS 2014**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
		Sinoflustra annae	Marine	2001	Indo-Pacific		Duval (SJR), 2001	**McCann et al. 2007; NEMESIS 2014**
POLYCHAETE								
		*Ficopomatus uschakovi*	Marine	2002	Indo-Pacific	Ship/boat hull fouling, ballast water	Duval (SJR), 2002	**NEMESIS 2014**
		*Hydroides diramphus*	Marine	2002	Western Atlantic and/or Indo-Pacific	Ship/boat hull fouling, ballast water	Duval (Mayport), 2002	**NEMESIS 2014**
JELLYFISH								
	Freshwater jellyfish *Photo: USGS NAS*	*Craspedacusta sowerbyi*	Freshwater (ponds, lake)	1980	Asia	Aquaculture stock, other live animal, plant or parts of plants	Duval, 1999; Putnam, 1980	**USGS 2015**
CRUSTACEANS								
	Bocourt swimming crab *Photo: Big Bend Brian*	*Callinectes bocourti*	Marine, Brackish	2002	Caribbean and South America	From the Caribbean via major eddies in Gulf Stream or southern storm events	Duval, 2002; Flagler, 2014	**CISEH 2015; USGS 2015**
	Indo-Pacific swimming crab *Photo: SC DNR*	*Charybdis hellerii*	Marine-offshore	Unknown	Indo-Pacific	Ship ballast water/sediment, or drift of juveniles from Cuba		**USGS 2015**
	Green porcelain crab *Photo: D. Knott*	*Petrolisthes armatus*	Marine, Brackish	Unknown	Caribbean and South America	Natural range expansion, ship ballast water/sediment, importation of mollusk cultures		**Power et al. 2006**
	Slender mud tube-builder amphipod *Photo: VIMS*	*Corophium lacustre*	Freshwater, Brackish	1998	Europe and Africa	Ship ballast water/sediment from Europe	St. Johns River, 1998	**Power et al. 2006; GBIF 2012b**
	Skeleton shrimp *Photo: D. Knott*	*Caprella scaura*	Marine	2001	Indian Ocean	Ship/boat hull fouling, ship ballast water/sediment	St. Johns River, 2001	**Foster et al. 2004; GBIF 2012a**
	Asian tiger shrimp *Photo: David Scott SERTC*	*Penaeus monodon*	Marine	2008	East Africa, South Asia, Southeast Asia, the Philippines, and Australia	Accidental release	Duval, 2008; Putnam, 2013	**USGS 2015**

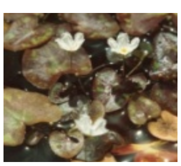
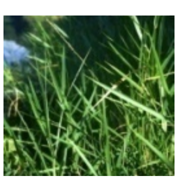
LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Wharf roach *Photo: Ruppert and Fox (1998)*	*Ligia exotica*	Marine	Unknown	Northeast Atlantic and Mediterranean Basin	Bulk freight/cargo, ship ballast water/sediment, shipping material from Europe		**Power et al. 2006**
	Striped barnacle *Photo: A. Cohen*	*Balanus amphitrite*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling		**Power et al. 2006**
	Triangular barnacle *Photo: D. Elford*	*Balanus trigonus*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling		**GSMFC 2010**
	Barnacle *Photo: C. Baike*	*Balanus reticulatus*	Marine	Unknown	Indo-Pacific	Ship/boat hull fouling		**GSMFC 2010**
	Titan acorn barnacle *Photo: H. McCarthy*	*Megabalanus coccopoma*	Marine	2004	Pacific Ocean	Ship/boat hull fouling	Duval, 2004; Mayport, 2008	**Frank and Lee 2008**
	Mediterranean acorn barnacle *Photo: H. McCarthy*	*Megabalanus antillensis* *(also known as M. tintinnabulum)*	Marine	Unknown	Europe (Mediterranea n Sea)	Ship/boat hull fouling		**Masterson 2007; McCarthy 2011**
	Asian tiger shrimp *Photo: M. Watkins, FWRI-Jacksonville*	*Penaeus monodon*	Marine, Brackish	2008.	Australasia	Aquaculture stock	Duval, 2008; St. Johns, 2011; Volusia, 2010	**CISEH 2014; USGS 2015**
FISH								
	Lionfish *Photo: A. Baeza*	*Primarily Pterois volitans (red lionfish) with a small number of Pterois miles (devil firefish)*	Marine-offshore	2001	Indo-Pacific	Humans: aquarium releases or escapes	Offshore Jacksonville, 2001	**USGS 2015**
	Goldfish *Photo: USGS NAS*	*Carassius auratus*	Freshwater	1974	Eurasia	Intentional release, ornamental purposes, stocking, aquarium trade, escape from confinement, landscape/fauna "improvement"	Clay, 1991; Putnam, 1974	**USGS 2015**, 2018
	Unidentified cichlids *Photo: USGS NAS*	*Cichlidae spp.*	Freshwater	2001-2006	Africa	Humans		**GSMFC 2010**; **Brodie 2008**; **USGS 2015**
	Blue tilapia *Photo: USGS NAS*	*Oreochromis aureus*	Freshwater (pond, lake)	1986	Europe and Africa	Humans: intentional fish stocking	Clay, 1991; Duval, 1984; Putnam, 1984; St. Johns 1986	**GSMFC 2010**; **Brodie 2008**; **USGS 2015**
	Mozambique tilapia *Photo: USGS NAS*	*Oreochromis mossambicus*	Freshwater, Brackish	2001-2006	Africa	Humans: stocked, intentionally released, escapes from fish farms, aquarium releases		**GSMFC 2010**; **Brodie 2008**; **USGS 2015**

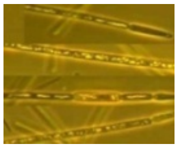
LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Unidentified tilapia *Photo: USGS NAS*	*Tilapia spp.*	Freshwater (pond)	2001-2006	Africa	Humans		**GSMFC 2010**; **Brodie 2008**
	Unidentified Pacu *Photo: USGS NAS*	*Colossoma or Piaractus sp.*	Freshwater, Brackish (tributary, creek)	1989	South America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)	Duval, 1989	**USGS 2015**
	Brown Hoplo *Photo: USGS NAS*	*Hoplosternum littorale*	Freshwater	2005	South America	Humans	Duval, 2005; Flagler, 2008; Putnam 2008	**CISEH 2015; USGS 2015**
	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 (pond, lake), Brackish, Marine	1992	Artificial Hybrid	Humans: intentional fish stocking	Duval and Clay, 1992	**USGS 2015**
	White bass *Photo: Thomas, Bonner, and Whiteside*	*Morone chrysops*	Freshwater, Marine	1980	Northern and Central USA	Intentional introduction	Putnam, 1980	**USGS 2015**
	Unidentified armored catfish *Photo: USGS NAS*	*Loricariidae spp.*	Freshwater	2001- 2006.	South and Central America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)		**FWRI 2006**; **Brodie 2008**
	Suckermouth catfish *Photo: L. Smith*	*Hypostomus sp.*	Freshwater	1974, 2003	South and Central America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)		**USGS 2015**
	Southern sailfin catfish *Photo: K.S. Cummings*	*Pterygoplichthys anisitsi*	Freshwater (river)	2007	South America	Humans: likely aquarium release	St. Johns, 2007	**USGS 2015**
	Vermiculated sailfin catfish *Photo: USGS NAS*	*Pterygoplichthys disjunctivus*	Freshwater (river)	2003	South America	Aquaculture stock (fish farm escapes or releases), humans (aquarium releases)	Duval, 2015; Putnam, 2003	**USGS 2015**, 2018
	Orinoco sailfin catfish	*Pterygoplichthys multiradiatus*	Freshwater	2009	Tropical America	Aquaculture stock (fish farm escapes and/or releases)	Duval, 2013; Putnam, 2009	**USGS 2015**
	Walking catfish *Photo: USGS NAS*	*Clarias batrachus*	Freshwater	2015	Southeastern Asia	Aquaculture stock (fish farm escapes and/or releases)	Clay, 2015	**USGS 2015**
	Flathead catfish *Photo: Garold Sneegas*	*Pylodictis olivaris*	Freshwater	1979	Northern and Central USA	Introductions	Duval, 1979	**USGS 2015**
	Redtail catfish *Photo: Monika Betley commons.wikimedia.or*	*Phractocephalus hemioliopterus*	Freshwater, Brackish	2007	Tropical America	Humans (aquarium releases)	Clay, 2014	**News4JAX 2015; USGS 2015**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
MAMMALS								
	Nutria *Photo: USGS NAS*	*Myocaster coypus*	Freshwater (retention pond, drainage ditch), Terrestrial	1957	South America	Humans: escaped or released from captivity	Duval, 1963; Putnam, 1957	**CISEH 2014; USGS 2015**, 2018
	Capybara *Photo: USGS NAS*	*Hydrochoerus hydrochaeris*	Freshwater	2015	South America	Pet escapee	Clay, 2015	**USGS 2016**
MOLLUSCS								
	Asian clam *Photo: USGS NAS*	*Corbicula fluminea*	Freshwater (stream, lake)	1990	Asia and Africa	Humans, live seafood, bait, aquaculture stock, water	Clay, 2006; Duval, 2003; Flagler, 2008; Putname, 2008; Volusia 1990	**Frank and Lee 2008; Lee 2008; CISEH 2014; USGS 2015**
	Charua mussel *Photo: H. McCarthy*	*Mytella charruana*	Marine	1986	South America	Ship ballast water/sediment	Duval, 1986; Flagler, 2006	**Boudreaux and Walters 2006; Power et al. 2006; Frank and Lee 2008; Spinuzzi et al. 2012; CISEH 2014; USGS 2015**
	Green mussel *Photo: H. McCarthy*	*Perna viridis*	Marine, Brackish (river)	2002	Indo-Pacific	Ship ballast water/sediment, ship/boat hull fouling, humans	Duval, 2003; St. Johns, 2009; Volusia, 2002	**Power et al. 2006; Frank and Lee 2008; Spinuzzi et al. 2012; CISEH 2015**
	Paper pondshell *Photo: B. Frank*	*Utterbackia imbecillis*	Freshwater (lake)	1990	North America: Native in Mississippi River and Great Lakes	Other live animal, plant or parts of plants, ship/boat	Duval, 1990	**Frank and Lee 2008; Lee 2008**
	Red-rim melania *Photo: B. Frank*	*Melanoides tuberculata*	Freshwater (river)	1976	Asia and Africa	Other live animal, plant or parts of plants, ship/boat	Duval, 1976; Volusia, 2005	**Frank and Lee 2008; Lee 2008; CISEH 2014; USGS 2015**
	Fawn melania *Photo: B. Frank*	*Melanoides* cf. *turricula*	Freshwater	2006	North America: Native in western U.S. and Canada	Other live animal, plant or parts of plants, ship/boat	Duval, 2006; St. Johns, 2006	**Frank and Lee 2008**
	Spiketop applesnail *Photo: B. Frank*	*Pomacea diffusa*	Freshwater (pond, drainage ditch)	2006	South America	Humans: probable aquarium releases	Duval, 2006; Clay, 2011	**Rawlings et al. 2007; Frank 2008; CISEH 2014**
	Channeled applesnail *Photo: Georgia DNR*	*Pomacea canaliculata*	Freshwater (retention pond)	2005	South America	Humans: probable aquarium releases	Duval, 2005; St. Johns, 2005	**Rawlings et al. 2007; Frank 2008; CISEH 2014; USGS 2015**
	Island applesnail *Photo: B. Frank*	*Pomacea (maculatum) insularum*	Freshwater (lake, creek, drainage ditch, river)	2005	South America	Humans: probable aquarium releases	Duval, 2005; St. Johns, 2005; Volusia, 2005	**Rawlings et al. 2007; Frank 2008; CISEH 2014; USGS 2015**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Mouse-ear marshsnail *Photo: B. Frank*	*Myosotella myosotis*	Marine	Unknown	Europe	Bulk freight/cargo, ship ballast water/sediment,		**Frank and Lee 2008**
	Striped falselimpet *Photo: B. Frank*	*Siphonaria pectinata*	Marine (Mayport), Brackish (Sisters Creek)	2008	Europe and Africa (Mediterranea n Sea)	Bulk freight/cargo, ship ballast water/sediment, ship/boat hull fouling, humans	Duval 2008; Mayport 2011	**Frank and Lee 2008; McCarthy 2008**
	Fimbriate shipworm *Photo: A. Cymru (Nat'l Museum of Wales)*	*Bankia fimbriatula*	Marine	Unknown	Pacific?	Ship/boat hull fouling, humans		**Frank and Lee 2008**
	Striate piddock shipworm *Photo: J. Wooster*	*Martesia striata*	Marine	Unknown	Indo-Pacific?	Ship/boat hull fouling, humans		**Frank and Lee 2008**
	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		**Carlton 1992; Foltz et al. 1995; Verween et al. 2006; Carlton 2012; GBIF 2012c; Lee 2012b; NEMESIS 2014**
REPTILES								
	Red-eared slider *Photo: USGS NAS*	*Trachemys scripta elegans*	Freshwater (drainage ditch), Brackish	1991	North America: U.S. midwestern states to northeastern Mexico	Humans: pet releases and escapes	Duval, 1991; Clay, 2012; Volusia, 2000	**CISEH 2014; USGS 2015**
	Razorback Musk Turtle *Photo: R.C. Thomson*	*Sternotherus carinatus*	Freshwater (drainage ditch) Brackish	1958	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	Putnam, 1958	**Lindeman 2008; Krysko et al. 2011; USGS 2015**
	Black and White Tegu	*Tupinambis merianae*		2012			Duval, 2013; Volusia, 2012	**CISEH 2015; JHS 2014**
BIRDS								
	Muscovy duck *Photo: FWC*	*Cairina moschata*	Freshwater	1967	Central and South America	Humans: pet releases and escapes	Clay, 1986; Duval, 1991; Flagler, 1991; Putnam, 1991; St. Johns, 1991; Volusia, 1991	**CISEH 2014; FWC 2014c**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
AQUATIC PLANTS								
	Alligator-weed *Photo: USGS NAS*	*Alternanthera philoxeroides*	Freshwater	1983	South America	Ship ballast water/sediment	Duval, 1984; Clay, 1983; Flagler, 1984; Putnam, 1984; St. Johns, 1984; Volusia, 1984	**McCann et al. 1996; USDA 2013; CISEH 2014; USGS 2015**
	Para grass *Photo: F. & K. Starr*	*Urochloa (Brachiaria) mutica*	Freshwater	2003	Africa	Humans: intentional release for agriculture	Flagler, 2009; Putnam, 2003; Volusia, 2004	**CISEH 2015; McCann et al. 1996; FCCDR 2008; USGS 2015**
	Water spangles *Photo: IFAS Univ. of Florida*	*Salvinia minima*	Freshwater (lakes, ponds)	1940	South and Central America	Ship ballast water/sediment, humans, aquarium trade	Clay, 1982; Duval, 1949; Flagler, 1940; Putnam 1940; St. Johns, 1982; Volusia, 1930	**McCann et al. 1996; CISEH 2014; USGS 2015**
	Hydrilla *Photo: USGS NAS*	*Hydrilla verticillata*	Freshwater (lake, creek, river)	1967	Asia	Debris associated with human activities, ship/boat, aquarium trade, garden waste disposal	Duval, 1982; Clay, 1967; Flagler, 2010; Putnam, 1967; St. Johns, 1967; Volusia, 2007	**McCann et al. 1996; CISEH 2014; USGS 2015**
	Water-hyacinth *Photo: USGS NAS*	*Eichhornia crassipes*	Freshwater (pond, lake, ditch, canal, river)	1890	South America	Humans, aquarium trade, garden escape	Duval, 1982; Clay 1900; Flagler, 1982; Putnam, 1890; St. Johns, 1900; Volusia 1963	**McCann et al. 1996; CISEH 2014; USGS 2015**
	Water-lettuce *Photo: USGS NAS*	*Pistia stratiotes*	Freshwater	1766	South America	Ship ballast water/sediment	Duval, Clay, 1982; Flagler, 2003; Putnam, 1982; St. Johns, 1982; Volusia, 1766	**CISEH 2015; McCann et al. 1996; FCCDR 2008; USGS 2015**
	Brazilian waterweed *Photo: USGS NAS*	*Egeria densa*	Freshwater	1969	South America	Humans: accidental aquarium releases, intentional release for control of mosquito larvae	Duval, 1995; Putnam, 1969; St. Johns, 1983; Volusia, 1990	**McCann et al. 1996; FCCDR 2008; CISEH 2014; USGS 2015**
	Watersprite *Photo: A. Murray*	*Ceratopteris thalictroides*	Freshwater	1984	Australasia	Humans	Duval, 2010; Clay, 2002; Flagler, 1990; Putnam, 1990; St. Johns, 1984; Volusia; 2014	**CISEH 2015; McCann et al. 1996; FCCDR 2008; USGS 2015**
	Wild taro *Photo: K. Dressler*	*Colocasia esculenta*	Freshwater (ditch, stream, lakeside, floodplain swamp, baygall)	1971	Africa	Humans	Duval, 2006; Clay, 1985; Flagler, 2003; Putnam, 1971; St. Johns, 1999; Volusia, 1995	**McCann et al. 1996; CISEH 2014; USGS 2015**
	Miramar weed	*Hygrophila polysperma*	Freshwater	2006	East Indies, India, Malaysia, Taiwan	Aquarium trade	Duval, 2006	**FLEPPC 2016; USGS 2016**
	Umbrella flatsedge	*Cyperus involucratus*	Freshwater	1984	Africa	Escaped cultivation	Duval, 2010; Clay, 1984	**CISEH 2016; Langeland et al. 2008; USGS 2016**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
	Cuban bulrush	*Cyperus blepharoleptos*	Freshwater	1982	South America and West Indies	Ship ballast, migratory birds	Clay, 2002; Duval, 2004; Flagler, 1982; Putnam 1988; St. Johns, 1982; Volusia, 1984;	**CISEH 2016; USGS 2018**
	Papyrus	*Cyperus papyrus*	Freshwater, Brackish	2011			Putnam, 2011	**USGS 2018**
	Eurasian watermilfoil *Photo: USGS NAS*	*Myriophyllum spicatum*	Freshwater	1999	Europe, Asia, and Northern Africa	Aquarium, aquatic nursery trade, intentional	Flagler, 1999	**USGS 2018**
	Large-flower primrose-willow	*Ludwigia grandiflora*	Freshwater	1998	South America	Humans	Clay, 1998	**USGS 2016**
	West Indian marsh grass	*Hymenachne amplexicaulis*	Freshwater	2008	West Indies, tropical Central and South America	Humans and/or migratory birds, forage	St. Johns, 2008	**Diaz et al. 2015** **USGS 2016**
	Uruguay water-primrose *Photo: Washington State Noxious Weed Control Board*	*Ludwigia uruguayensis*	Freshwater	1998	South America	Humans	Clay, 1998	**McCann et al. 1996; CISEH 2014; USGS 2015**
	Marsh dewflower *Photo: L. Lee*	*Murdannia keisak*	Freshwater	1960	Asia	Humans	Duval, 1960	**CISEH 2014; USGS 2015**
	Parrot-feather *Photo: USGS NAS*	*Myriophyllum aquaticum*	Freshwater (slough)	1940	South America	Humans	Clay, 1940; Duval, 1983; St. Johns, 1983; Flagler, 1940; Putnam, 1983; Volusia, 1986	**McCann et al. 1996; FCCDR 2008; CISEH 2014; USGS 2015**
	Brittle naiad *Photo: USGS NAS*	*Najas minor*	Freshwater (lake)	1983	Eurasia	Humans	Putnam, 1983	**McCann et al. 1996; FCCDR 2008; CISEH 2014; USGS 2015**
	Crested floating-heart *Photo: C. Jacono*	*Nymphoides cristata*	Freshwater	2010	Asia	Humans	St. Johns, 2010	**CISEH 2015; FCCDR 2008; USGS 2015**
	Water-cress *Photo: WI DNR*	*Nasturtium officinale*	Freshwater	1995	Eurasia	Humans	Duval, 1995; Clay, 1995; Putnam, 1995; St. Johns	**McCann et al. 1996; FCCDR 2008; CISEH 2014; USGS 2015**
	Torpedo grass *Photo: V. Ramey*	*Panicum repens*	Freshwater (adjacent to waterways)	2002	Europe	Humans	Duval, 2004; Clay, 2005; Flagler, 2003; Putnam, 2002; St. Johns, 2003; Volusia, 2003	**McCann et al. 1996; FCCDR 2008; CISEH 2014; USGS 2015**

LIFEFORM	COMMON NAME	SCIENTIFIC NAME	HABITAT REALM	DATE	ORIGIN	PROBABLE VECTORS	COUNTY- FIRST REPORTED	REF
BLUE-GREEN ALGAE								
	Blue-green alga *Photo: Umwelt Bundes Amt*	*Cylindrospermopsis raciborskii*	Freshwater	1950s First ID in the U.S.; 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)		**Dyble et al. 2002**

4.5.6. *Trend*

The cumulative number of non-native aquatic species introduced into the LSJRB has been increasing at an exponential rate since records were kept prior to 1900 (Figure 4.25). 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. For this reason, the current status has been assigned as *unsatisfactory*.

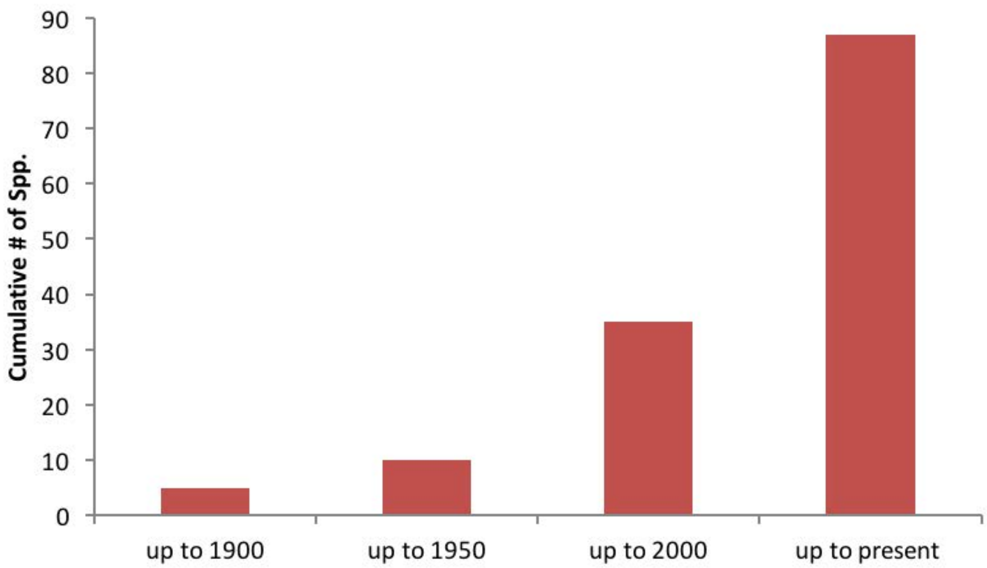


Figure 4.25 Cumulative number of non-native aquatic species introduced into the Lower St. Johns River Basin, Florida since the turn of the 20th century.

Non-native plants and animals arrive in the St. Johns River watershed by various means. Common vectors of transport have been humans, ship ballast consisting of water and/or sediment, ship/boat hull fouling, and mariculture/aquaculture activities. For example, JAXPORT imported >18,000 50-pound bushels of oysters (**JAXPORT 2017**), which have the potential to carry non-native organisms. 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.

4.5.7. *Future Outlook*

IRREVERSIBLE IMPACTS. Once a 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.

HIGH RISK. There is a high probability that future invasions of non-native aquatic species will continue to occur in the LSJRB. Human population growth in northeast Florida is projected to more than double by 2060 (**Zwick and Carr 2006**). Significant vectors for transporting non-native organisms are imported products and ship ballast, and these vectors are expected to contribute to the likelihood for additional and potentially more frequent introductions.

The number of ships visiting the Port of Jacksonville has increased since 2002 (Figure 4.26) and is expected to increase further with the increases from the Asian container trade with 19% growth from 2016 and represents 40% of total cargo container business (**JAXPORT 2017**). The port reported a record number of 1.3 million containers being moved through the port and more than any other container port in the state of Florida (Figure 4.26). The port is planning to expand its auto and vehicle handling capacity by 25% and looks to take advantage of channel dredging to 47 ft (**JAXPORT 2017**).

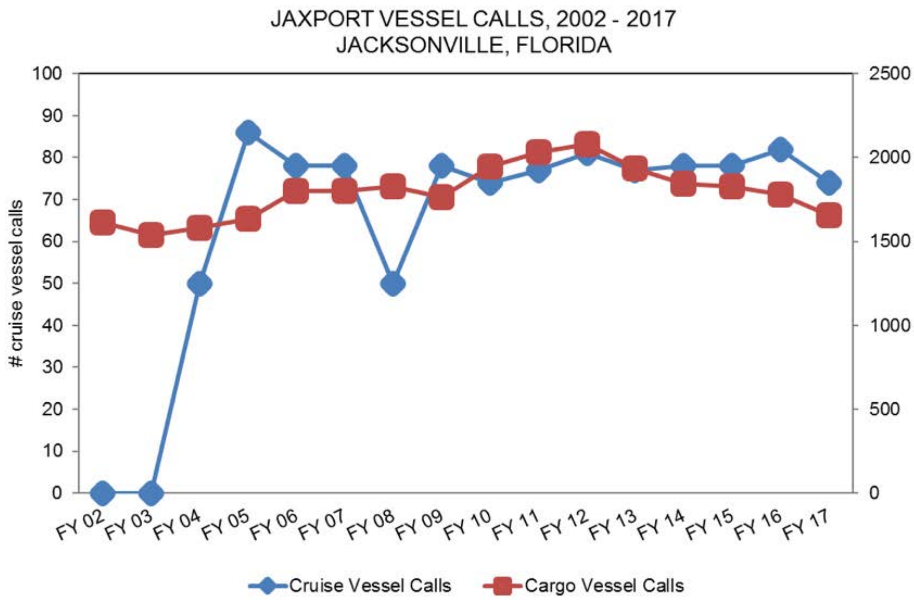


*Figure 4.26 Number of cruise ships and cargo ships calling on Port of Jacksonville, FL (JaxPort) terminals between fiscal year 2002 and 2018. Fiscal year (FY) begins Oct 1 (**JAXPORT 2018**).*

Additional invasions into the Lower St. Johns River Basin are expected from adjacent or interconnected waterbodies. For example, 19 non-native aquatic species not found in the LSJRB have been recorded in the Upper St. Johns River Drainage Basin (**USGS 2015**). These species may disperse into the LSJRB. In addition, 85% of living non-native plants that are received into the U.S. come from the Port of Miami (**ELI 2008**).

Rising global temperatures may also contribute to a northward expansion in the range of non-native species from Central and south Florida. For example, the old world climbing fern and Cuban treefrog were recorded in St. Johns and Duval counties in 2016, species spreading from southern Florida (**CISEH 2014**). There is concern that the Cuban treefrog can spread as tadpoles in fresh and brackish water with ~80% survival at 12 ppt and were able to survive 14 ppt for up to 24 hours (**Johnson and McGarrity 2013**). The habitat for the most northern record of Cuban treefrog tadpoles was described as ponds created after Hurricane Matthew (**CISEH 2016**). **Gilg et al. 2014** studied dispersal of the green mussel near the Matanzas, St. Augustine and Ponce de Leon Inlet. Mussel spat density was positively correlated with temperature and likely to be correlated with phytoplankton availability. Larvae settled within 10 km of source population located in the Intracoastal Waterway. The authors suggest that populations at the mouth of the SJR may be connected to the more southern populations due to transport along the coast, but that persistence is due to localized recruitment (**Gilg et al. 2010**).

Invasive species are often caught by local recreational fishers and researchers. A predatory redtail catfish was caught in Clay County from a local pond (**News4JAX 2015**). The aquarium fish was likely released and can reach 80 kg in weight (**News4JAX 2015; USGS 2015**). A foot-long Asian tiger shrimp was netted in July 2015 (**FCN 2015**). In addition, significant numbers of tilapia and sailfin catfish were collected within 10 km of the mouth of Rice Creek (**Gross and Burgess 2015**). Other species raising concern is the Muscovy duck that can transmit disease to and can interbreed with Florida's native waterfowl (**FWC 2014c**). In addition, the Black and white tegu has been observed in Avondale and have the potential to enter gopher tortoise holes for mice and tortoise eggs (**JHS 2014; CISEH 2015**).

Given the devastating impacts of lionfish on coastal communities, Florida Fish and Wildlife Conservation Commission have waived the recreational license requirement if using designated spearing devices and have also waived bag limits harvesting lionfish (**FWC 2014a**). To date, lionfish have only been recorded off shore of northeast Florida and not in the SJR. Johnson and Swenarton (2016) developed a length-based age-structured model for lionfish from >2,000 individuals caught

by spear fishermen off the coast of northeastern Florida in 2013-2015. The authors reported that larger lionfish are culled, or are moving to deeper waters. Recruitment events are occur during early summer, and growth rates are much greater than recorded from their native ranges (**Johnson and Swenarton 2016**). In 2016, Patrick McCarver and Dan Lindley had harvested 1,266 of the 3,478 lionfish speared from the month-long Fifth Annual Northeast Florida Lionfish Blast (**NFLB 2017**).

Another point of concern is the public's lack of knowledge regarding invasive species in Florida. A recent survey by UF/IFAS Center for Public Issues Education in Agricultural and Natural Resources (PIE Center) indicated 62% of 515 Florida residents to be slightly or not knowledgeable of invasive species in general, 63% were slightly or not knowledgeable of the types of invasive species in Florida, and 66% were slightly or not knowledgeable of how to prevent invasions from entering Florida (**Dodds et al. 2014**). Yet, 79% of respondents were likely to pay attention to a story covering invasive species, with >70% preferring to learn about invasive species from the television, websites, videos, fact sheets, and newspapers. This survey highlights the importance of educational outreach and the interest of the public in learning about invasive species (**Dodds et al. 2014**).

5. Contaminants

5.1. Background

Contaminants are chemicals that are found at elevated concentrations in any environment. Some are produced solely by human activity, but many are also produced naturally in small quantities. Both anthropogenic (human-made) and naturally occurring compounds may become contaminants when they are introduced into ecosystems at elevated concentrations, often as a result of human activity (examples are polyaromatic hydrocarbons, or PAHs, and metals). Concentrations of naturally-occurring 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 and 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.

Contaminants can also reside in sediments and in the water. They will partition between biota, sediments and water in ratios that depend on the chemical and the conditions. The sediments of rivers often serve as reservoirs for chemical contaminants. 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 potentially exposed to contaminated water and sediments, so assessments of their toxic responses to contaminants are particularly important in determining overall river health.

Figure 5.1 Sediment at Talleyrand, LSJR

5.1.1. Assessments of Status and Trends

Chemicals in four environmentally significant categories are evaluated in this report. 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. Each of the categories is discussed separately.

Sediment contaminants are examined in terms of frequency of occurrence, the concentrations present, and whether any trends up or down exist. The cumulative impact of the chemicals is estimated as well as the relative toxic impact of the different classes in different regions. Methods we used to determine toxic impact are discussed in the next section. It is important to note that most of these data end in 2007.

Water column concentrations of metals are included because more of these compounds will reside in the water column than the other classes of chemicals. The distributions of the metal data are compared to Florida ambient water quality standards. These parameters are regularly monitored and data are current.

The rate at which chemicals are released into the environment clearly affects their potential environmental impact. In addition to examining concentrations of contaminants found in the LSJR sediments and water, we examined the status and trends of reported chemical releases into the atmosphere and waterways of the LSJR using the Toxics Release Inventory database (**EPA 2015d; EPA 2015b**) and the Risk Screening Environmental Indicators model (**EPA 2013e**), both provided by the EPA. Releases of all chemicals are discussed in Section 5.4 and releases of the metals and PAHs are discussed in their respective sections.

5.2. Data Sources and Analysis

5.2.1. Water

All data were obtained from the Florida DEP STORET database. STORET is a computerized environmental data system containing water quality, biological, and physical data. Total metal concentrations 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.

The LSJR varies in salinity, with the mainstem 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, lead, 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. Data are also presented as yearly mean values and compared to the designated reference values. Graphs are presented for the entire LSJR (including tributaries), the freshwater and saltwater portions of LSJR mainstem, as well as for the tributaries in some cases. Data used from the Florida DEP STORET database are of higher quality but are less abundant than data from the EPA STORET. Only total metal concentrations were used in this report, rather than the preferred dissolved metal concentrations, which are used in calculation of water quality criterion values. Total values were used because the dissolved metal concentrations were not reported to a large extent, and in many cases dissolved values only accounted for less than 5% of the total data reported. Additionally, negative values were removed and values designated as present below the quantitation limit (QL) were replaced with the average of the method detection limit (MDL) and practical quantitation limit (PQL). For "non-detect" values, half the MDL was used; and, for values designated as "zero" the MDL was used. Data were rejected and not used if they had the value qualifier code of K, L, O, or Y. Data designated with a matrix of "ground water", "surface water sediment," "stormwater," or "unknown" were removed. Records with no analytical procedure listed were also removed.

5.2.2. Sediment

5.2.2.1. Sediment Data Sources

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. 2013**) 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 the EPA (modern) and DEP were included as well. 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 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. 2013**).

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, 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.

5.2.2.2. 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. The effects on ecosystems and aquatic organisms are the focus of our assessment of contaminants in the LSJR although human health effects from mercury in fish are discussed.

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.

5.2.2.3. 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 sediment 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 mainstem, which includes urban Jacksonville and extends down to Julington Creek.

The southernmost region in the LSJR, Area 4 or the south mainstem, 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.

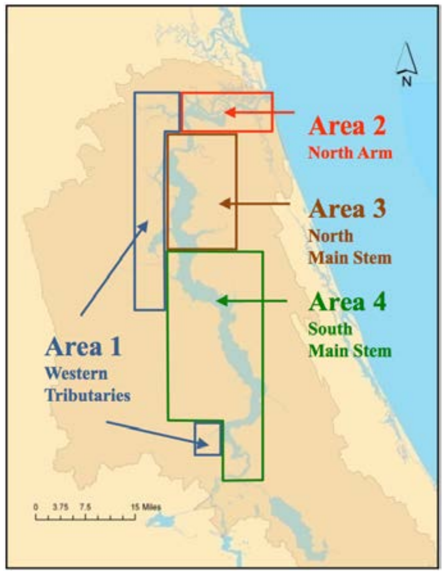


Figure 5.2 Areas of the LSJR studied for sediment contamination: Area 1 – western tributaries (including Trout River, Moncrief Creek, Ribault River, Long Branch Creek, Cedar-Ortega Basin, and Rice Creek); Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See Appendix 5.2.E for additional 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 2015d**). 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 2013f**).

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 2013 using data from EPA's TRI-NET database (**EPA 2015b**). 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 5.1). 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 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. The Risk-Screening Environmental Indicators (RSEI) is a companion EPA program that uses TRI data to screen for overall toxicity (**EPA 2013e**).

Quantities of chemicals, their individual toxicity, their fate in the environment, and their proximity to people are used to determine discharges of toxicity, rather than pounds. The relative importance of major emissions and discharges to chronic human health is addressed using the results of the RSEI model, although data are only available until 2011. It is important to note that the RSEI analysis does not indicate that there is a human health risk. It only indicates which emissions and discharges in our local environment are the most likely to have chronic human health risks associated with them.

Table 5.1 Reported Releases of Chemicals by Industries in the LSJR Basin (EPA 2015d).

Releases of Chemicals to the Atmosphere[1]				
Year	Total Tons	No. Chemicals[2]	No. Industries	No. Facilities
2001	7,928	69	21	79
2002	8,016	69	21	80
2003	7,697	67	21	78
2004	7,736	68	21	75
2005	7,258	62	21	73
2006	6,898	61	21	71
2007	6,236	6	20	71
2008	5,883	60	21	76
2009	3,774	53	21	70
2010	3,965	55	21	71
2011	3,055	56	21	74
2012	2,179	54	21	71
2013	2,176	59	21	78
Releases of Chemicals to the LSJR and Tributaries[3]				
Year	Total Tons	No. Chemicals[2]	No. Industries	No. Facilities
2001	152	28	10	15
2002	168	34	11	16
2003	233	30	10	14
2004	261	22	7	10
2005	302	23	8	11
2006	136	24	6	10
2007	216	28	7	11
2008	188	30	9	12
2009	278	27	8	11
2010	162	29	8	11
2011	205	30	7	11
2012	269	29	7	10
2013	203	26	6	9

1 Chemical releases from facilities emitting into the atmosphere in nine counties of the LSJR watershed
2 Number of unique chemicals or chemical classes released.
3 Chemical releases from facilities discharging to the surface waters of 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 91% of their waste into the atmosphere. These numbers do not include the on-site releases to landfills and surface impoundments.

Between 2001 and 2013, the reported annual release of chemicals to the atmosphere declined by over 70% to 4.4 million pounds (Figures 5.3 and 5.4). Reductions in emissions of hydrochloric and sulfuric acids 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 with a 6.2 million pound or 79% reduction over 13 years. Emissions declined for 58 of the 83 reported chemicals between 2001 and 2013. Ammonia, hexane and phenol were major exceptions with increases of 63%, 159% and 595%, respectively.

Despite the substantial reductions in acid gas emissions (sulfuric, hydrochloric and hydrofluoric acids), they still comprised 63% percent of the chemicals reported to be released to the LSJR region atmosphere in 2013, mostly released by electric utilities. Of the total atmospheric releases in 2013, 30% were composed of methanol, ammonia and styrene that were emitted primarily by electric utilities and the transportation equipment and paper industries. The remaining chemicals released into the atmosphere were organic and inorganic compounds, such as polyaromatic hydrocarbons and metals discussed in more detail in Sections 5.4 and 5.5.

In 2011 (the most recent year for which the RSEI model has data), regular emissions of sulfuric acid had the highest potential for chronic human health risk of all reported atmospheric releases, followed by cobalt, arsenic, and chromium, which were all emitted by the electric utilities. An accidental release of ethylene oxide by BAE Shipyards was also significant in 2011. Releases of formaldehyde by Georgia-Pacific and benzene by BP Products were also among the top ten atmospheric releases that had the highest potential for human health risks (**EPA 2013e**).

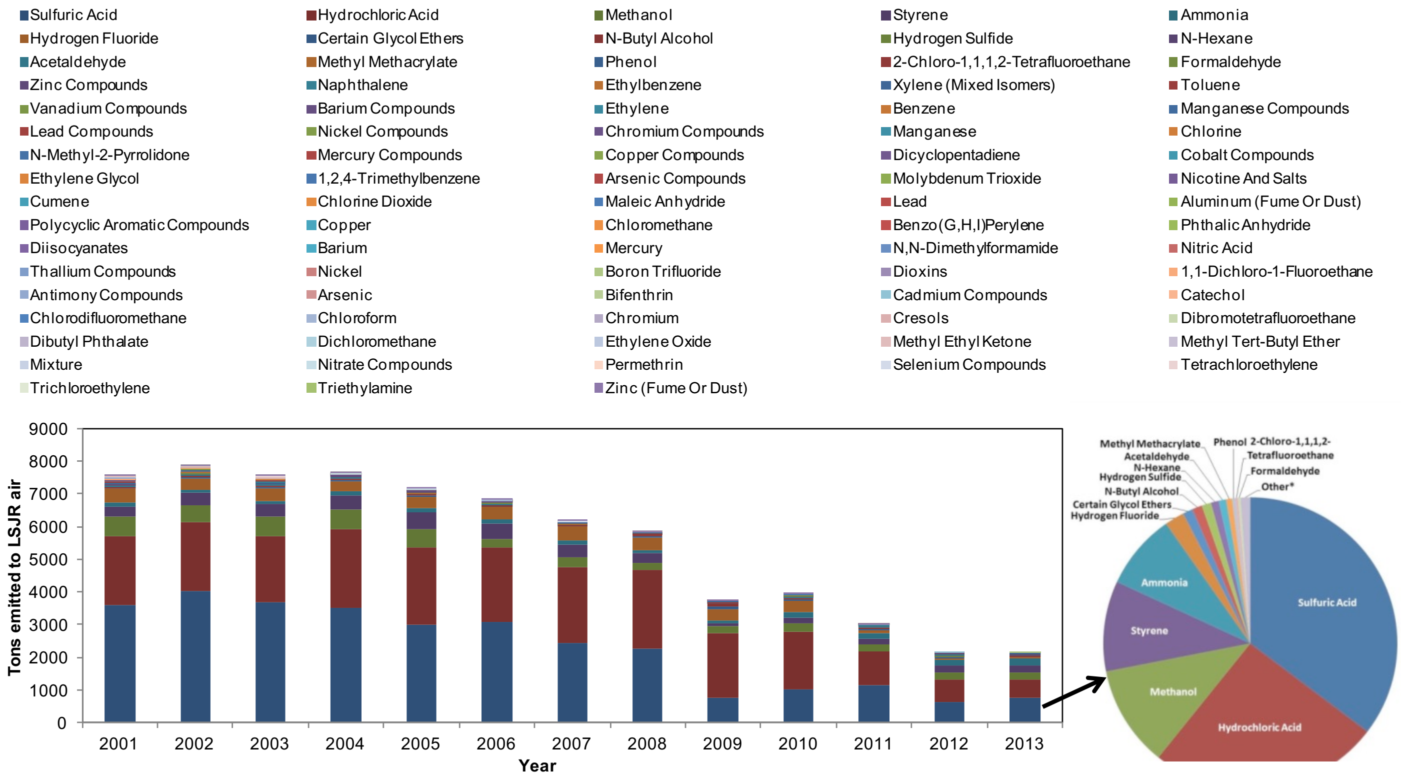


*Figure 5.3 Trends and status of 83 chemicals released to the atmosphere by industries in the nine-county LSJR basin as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the distribution of 2,176 tons of chemicals emitted in 2013. The Other category in the inset is composed of 44 chemicals ranging from 3.3 tons of zinc to 40 milligrams of dioxins.*

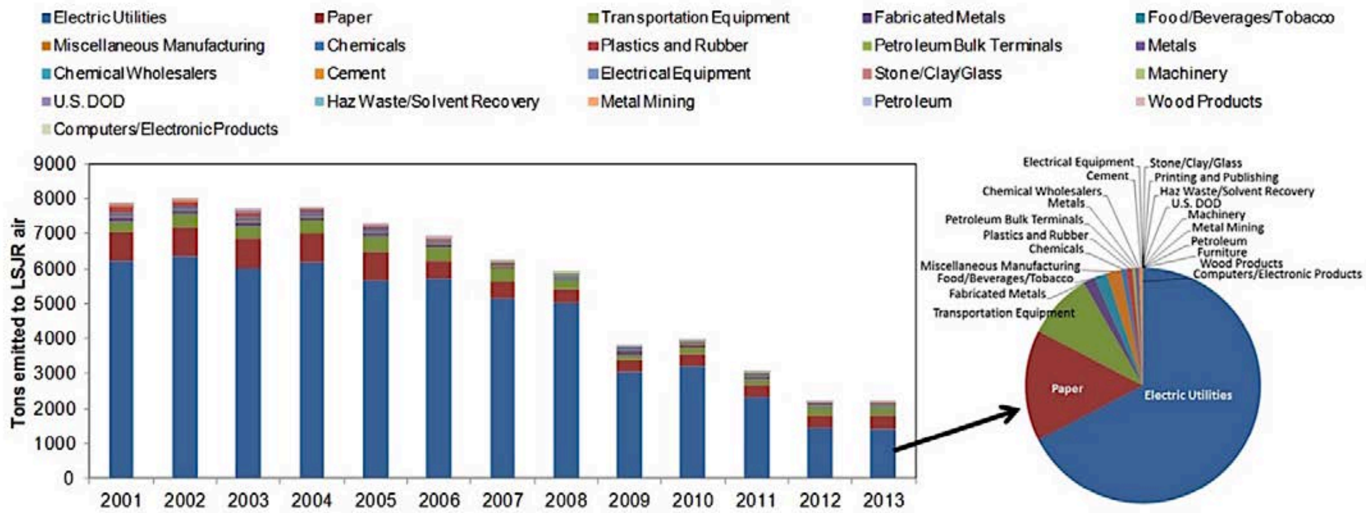


*Figure 5.4 Trends and status of 23 industries releasing chemicals to the atmosphere in the nine-county LSJR basin as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the major industries emitting 2,176 tons of chemicals in 2013.*

Unlike atmospheric emissions, surface water discharges into the LSJR did not decline between 2001 and 2013, but have increased by 34%. Fluctuations in the extremely large discharges of nitrate and manganese by the paper industry and U.S. DOD affected overall SJR loading during the decade (Figures 5.5 and 5.6). Of the chemicals reported to be released into surface water in 2013, 12 were discharged at greater rates since 2001 and 12 chemicals were discharged at lower rates. The electric utility industry experienced an increase of 186% (nearly 15,000 pounds) in total annual chemicals discharged between 2001 and 2013, much of it in the form of nickel, barium, and cobalt compounds.

In 2013, 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 (over 318,000 lbs.) and manganese by the pulp and paper industry (51,000 lbs.). The paper industry reported no nitrate discharges in 2013, in contrast to 2013 when 105,000 pounds were reported. The nitrate and manganese discharges represented 91% of the total quantity of chemicals released into the LSJR in 2013 (Figures 5.5 and 5.6).

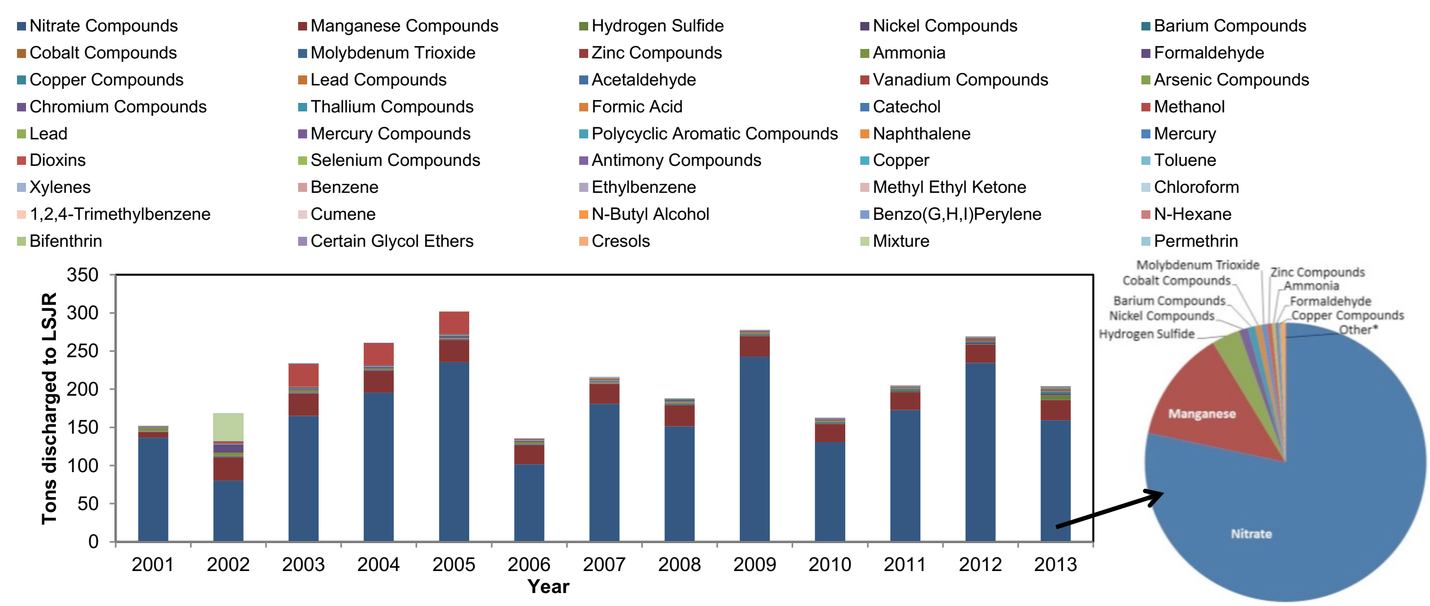


*Figure 5.5 Trends and status of 46 chemicals released to the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the distribution of over 400,000 pounds of chemicals discharged in 2013. The Other category in the inset is composed of 15 chemicals ranging from 510 pounds of lead compounds to a few milligrams of dioxins.*

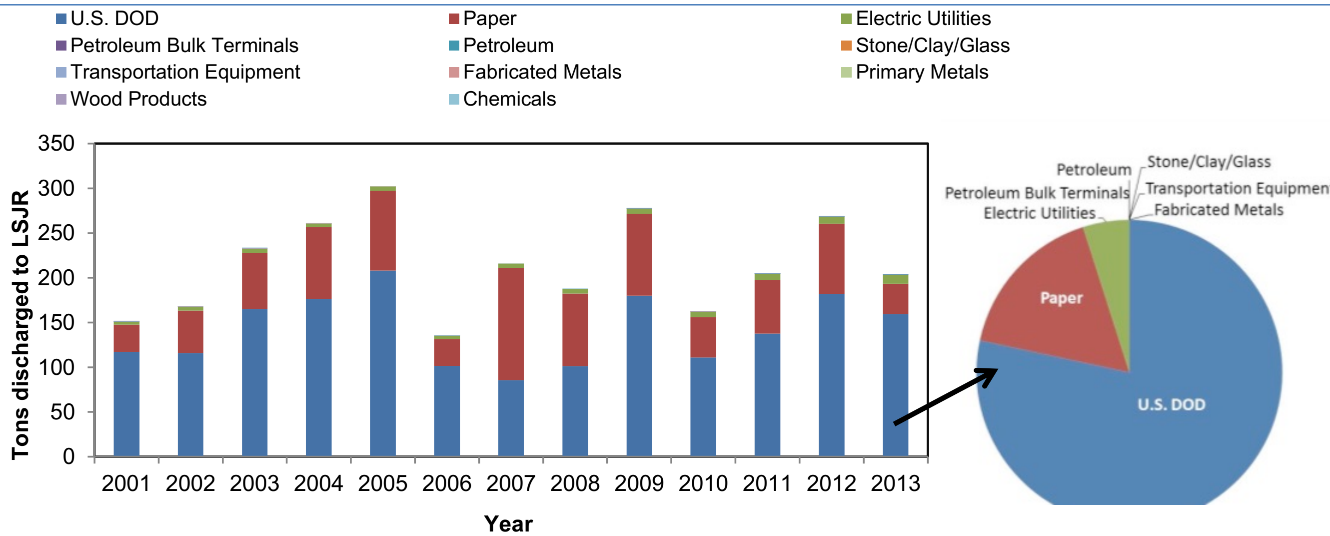


*Figure 5.6 Trends and status of 11 industries releasing chemicals into the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the major industries discharging over 400,000 pounds of chemicals in 2013.*

An analysis of toxicity loading into the LSJR surface waters by industries is greatly hindered by the fact the St. Johns River Power Park/Northside Generating Station, a major discharger, is not included in the EPA RSEI model because there is insufficient or questionable information about the segment of the river where it discharges its effluents. This may result from the reverse flow of the river causing difficulties with the model accuracy or due to inadequate flow information about the region from the National Hydrography Dataset used in the model (**EPA 2013c**). However, of the remaining discharges in 2013, arsenic, mercury, copper and polyaromatic hydrocarbons released by the other electric utilities contributed most of the total toxicity along with lead, mercury and dioxins discharged by the pulp and paper industries. The major pathway to exposure was found to be fish ingestion.

In summary, industries in the LSJR region reported the release of 4.8 million pounds of chemicals into the air and into the river and its tributaries in 2013, with 91% released into the air. Local emissions to the atmosphere, mostly from electric utilities, are primarily composed of acid gases followed by methanol, styrene, and ammonia. Air emissions have declined by more than two-thirds between 2001 and 2013, which is similar to the rest of the state (**EPA 2015c**). The LSJR surface waters received over 400,000 pounds of chemicals in 2013, 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 2013 is 34% greater than in 2001 while the rest of the state discharged 24% less since 2001.

Of all atmospheric emissions in the LSJR region in 2011, sulfuric acid and metals emitted into the atmosphere by electric utilities were most likely to cause chronic human health effects. Of surface water discharges in the LSJR in 2011, metals, polyaromatic hydrocarbons and dioxins discharged by electric utilities and the paper industry had the highest potential for human health risk. It is important to note that this does not mean that there is a human health risk. It means simply that of all the chemicals released into our local environment by industry, these are the most likely to be the most significant in terms of human health.

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 2013d**). 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.

The **STATUS** of point sources of toxics emitted into the atmosphere is ***satisfactory*** because the rate of emissions is similar to the rest of the state and the **TREND** is ***improving***. The **STATUS** of point sources of toxics discharged into the LSJR surface waters is ***unsatisfactory*** because the rate of discharges exceeds the rest of the state, and the **TREND** is ***unchanged***.

5.4. Polyaromatic Hydrocarbons (PAHs)

5.4.1. Background and Sources: PAHs

Polyaromatic hydrocarbons are a class of over 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 indicate 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 mainstem 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.

5.4.2. Fate: PAHs

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**). Once they are in the water, the PAHs tend to settle into the sediments fairly quickly, 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**).

The 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.

5.4.3. Toxicity: PAHs

Although PAH accumulation does occur in organisms from all trophic levels (**Carls et al. 2006; Cailleaud et al. 2009**), 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. 2002; Barron et al. 2004**). Specifically, the narcosis occurs due to PAH accumulation in the lipid bilayer of a biological cell membrane, which at elevated concentrations may disrupt the membrane integrity and function, leading to depression of the central nervous system (**Van Wezel and Opperhuizen 1995; Barron et al. 2002; Escher et al. 2002; Escher and Hermens 2002; Barron et al. 2004).** Although narcosis is reversible, depending on the PAH concentration, it may result in erratic swimming, 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**).

5.4.4. Current Status: PAHs in Sediments

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.

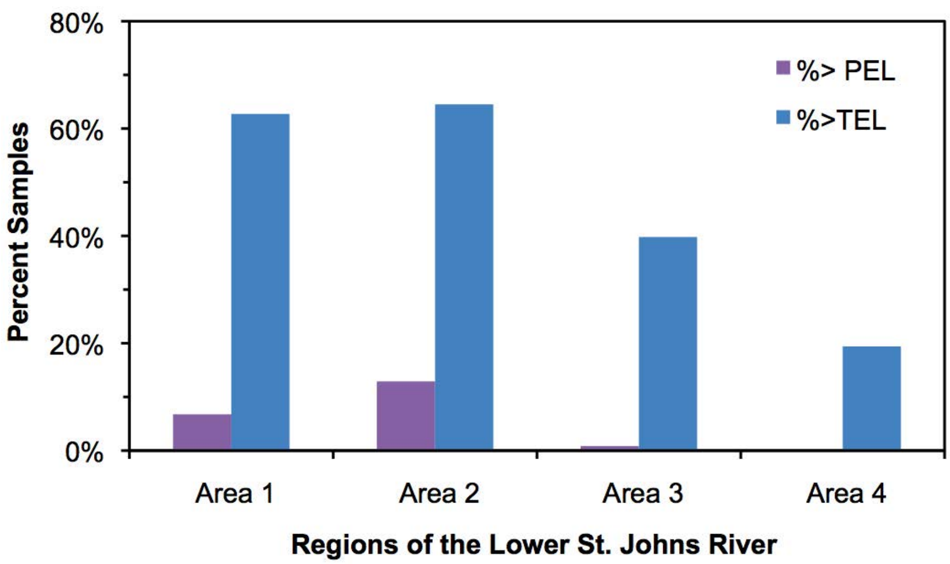


Figure 5.7 Percentage of samples from 2000-2007 with PAH concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for one or more PAHs. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data 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 mainstem 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 mainstem.

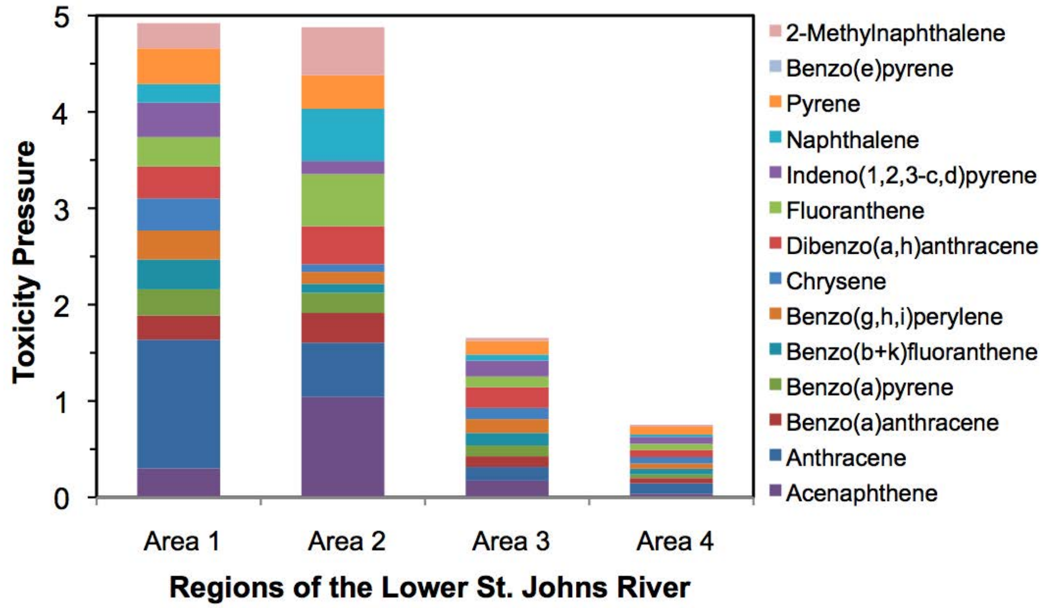


Figure 5.8 Average toxicity pressure of PAHs in sediments from 2000-2007 in the four areas of the LSJR. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data sources.

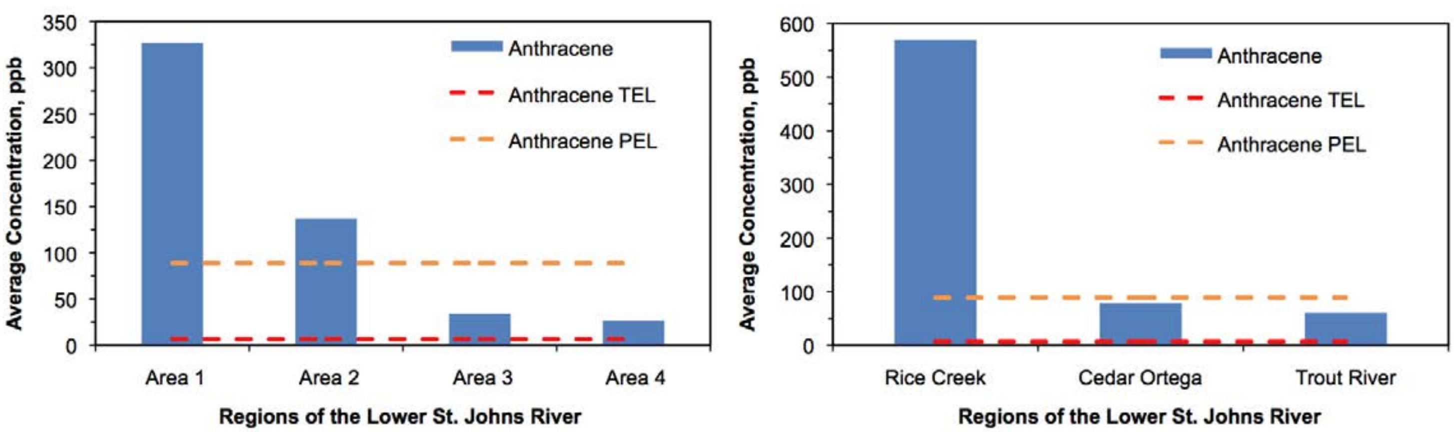


Figure 5.9 Average concentrations of anthracene in sediments from 2000-2007 in the four areas of the LSJR and in three streams in Area 1. Sediment quality guidelines for anthracene are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data sources.

5.4.5. Trends: PAHs in Sediments

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 mainstem, 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 mainstem 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.

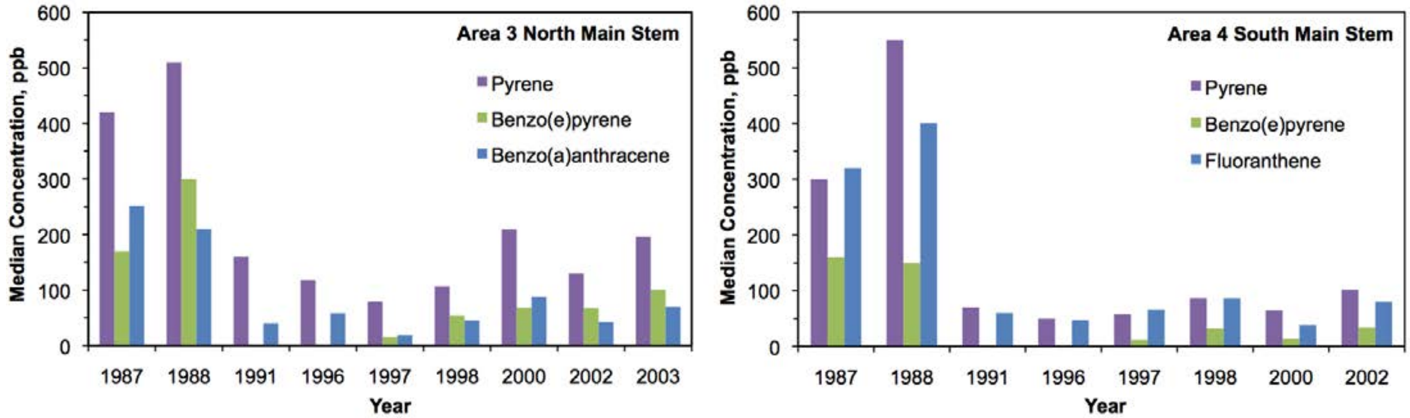


Figure 5.10 Median concentrations of PAHs in sediments from 2000-2007 in Area 3 (north mainstem) and Area 4 (south mainstem). Note that years are not continuous. See text in Section 5.2 for data sources.

However, since the 1990s, several PAH levels may be slowly rising in the mainstem. 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.

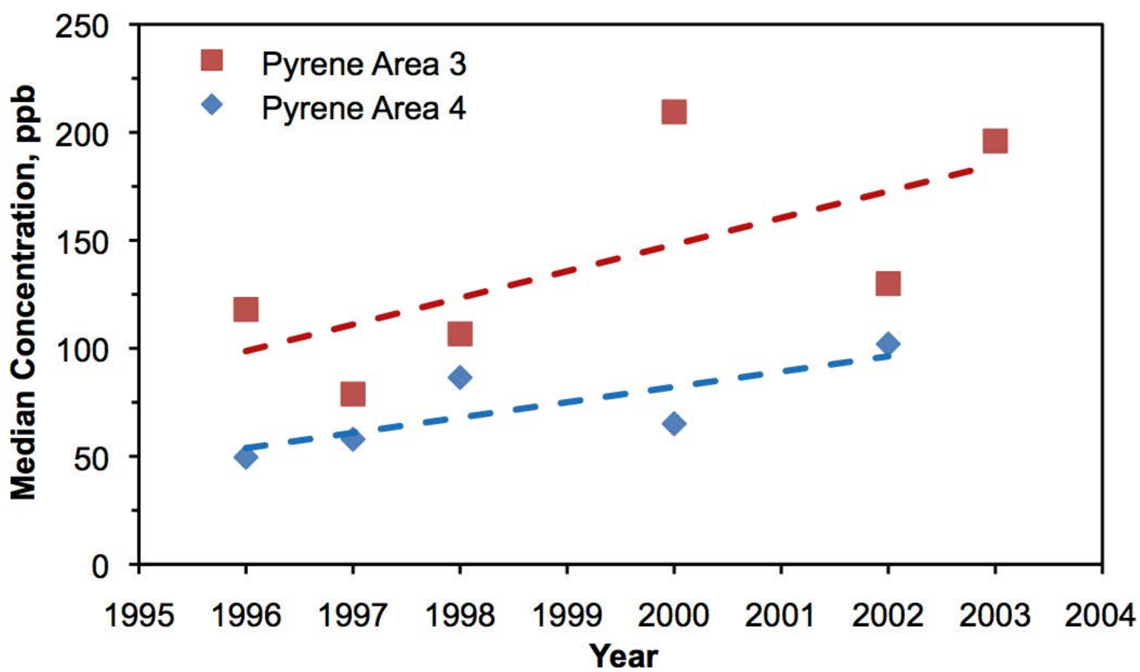


Figure 5.11 Apparent rise of median concentrations of pyrene in LSJR sediments since 1996 in Area 3 (north mainstem) and Area 4 (south mainstem). Dashed lines represent trend lines. See text in Section 5.2 for data sources.

5.4.6. 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.

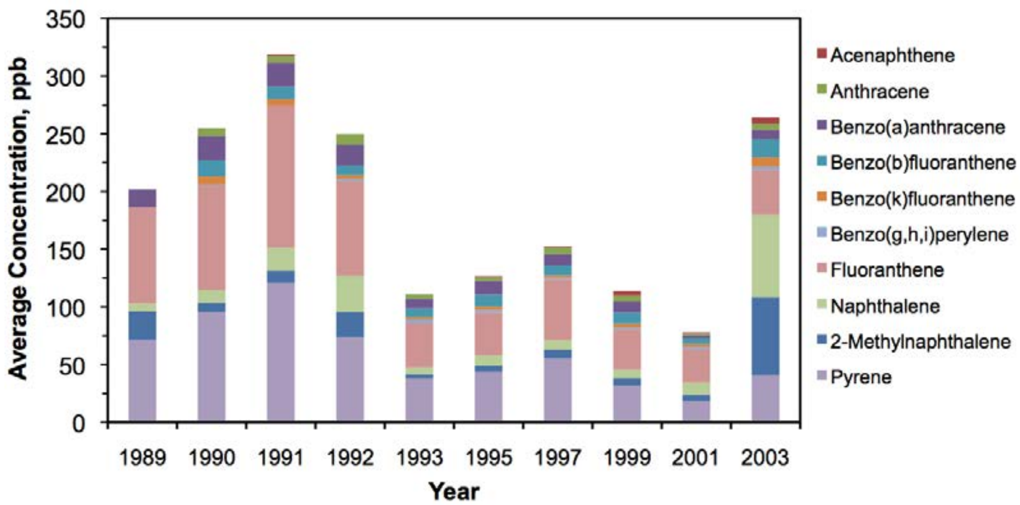


Figure 5.12 Concentration of select PAHs in oysters in Chicopit Bay, LSJR (Area 2 – north arm). Note that years are not continuous. See text in Section 5.2 for data sources.

5.4.7. *Point Sources of PAHs and related compounds in the LSJR Region*

Reported PAH emissions to the LSJR region atmosphere have dropped by 83% over the last decade, mainly due to reductions in emissions by electric utilities (**EPA 2015b**). In 2013 the total emitted PAHs was 112 pounds, 100 pounds of which came from the paper industry. Direct surface water discharges of PAHs have declined from nearly 20 pounds in 2001 to a pound in 2013, all of which is now released by electric utilities. Despite the decline in surface water discharges, PAHs represent one of the top ten chemicals that have the highest potential for human health risk of all discharges in the LSJR basin (**EPA 2013e**).

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 2013. Several industries have shared in reducing the overall aromatic hydrocarbon loading to the region.

5.4.8. *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 the north mainstem, 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 mainstem portion of the river, which may be beginning to suffer the same stress from urban impact that the north mainstem 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 affect a gradual improvement in the next few years if the emission rates remain stable or decrease. In the previous report, the **STATUS** of PAHs in sediments **was *unsatisfactory*** while the **TREND** in the north marine/estuarine section was ***improving***, and the **TREND** in the south fresh water section was ***worsening***. The **STATUS** and **TREND** of PAHs in this year's report were not updated because of lack of data.

5.5. Metals

5.5.1. Background

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 and water bodies also vary naturally. Sediments in the mainstem 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 can be difficult to 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**). However, anthropogenic contributions of excess metals in aquatic environments are generally much greater than natural contributions (**Eisler 1993**).

Metals may enter aquatic systems via industrial effluent, agricultural and stormwater runoff, sewage treatment discharge, fossil fuel combustion, ore smelting and refining, mining processes, and due to leachate from metal-based antifouling paints (**Reichert and Jones 1994; Kennish 1997; Evans et al. 2000; Voulvoulis et al. 2000; Echols et al. 2009**). Coal and oil combustion represent a substantial release of atmospheric metals, often fated for future deposition into water bodies. Metals are only present in these fuels in small quantities; however, massive amounts of fuel are combusted. 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**). Naturally occurring trace metals such as copper, zinc, and nickel are essential micronutrients required by all organisms; however, in excess, these metals, as well as non-essential metals, such as arsenic, cadmium, lead, silver, and mercury may cause adverse biological effects in aquatic organisms (**Bryan and Hummerstone 1971; Dallinger and Rainbow 1993; Bury et al. 2003; Bielmyer et al. 2005a; Bielmyer et al. 2006a**).

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 (**Bielmyer-Fraser et al. 2017)**. Copper enters aquatic 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**). Copper is also a constituent of several pesticides commonly used to control algae. 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; Eisler 1988b; Hoang et al. 2004**). 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**). In the past, lead has also been used to a large extent in corrosion prevention, but legislation in the 1980s has limited the content of lead in paints, reduced the lead in gasoline, and eliminated the use of lead shot nationwide (**Eisler 1988a**). Current concerns about lead contamination in aquatic environments are mainly due to point-source discharges from mining, smelting, and refining processes, mostly for use in the production of batteries (**Eisler 1988a; WHO 1995**). Natural sources of lead such as erosion and atmospheric deposition from volcanoes and forest fires also contribute to the lead found in aquatic environments (**WHO 1995**). Elevated silver concentrations in aquatic animals occur near sewage outfalls, electroplating plants, mine waste sites, or areas where 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**); however, over the last decade the use of silver, as silver nanoparticles, has substantially increased, particularly for applications in catalysis, optics, electronics, biotechnology and bioengineering, water treatment, and silver-based consumer products. Arsenic and many of its compounds are especially potent poisons, especially to insects, thereby making arsenic 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**).

5.5.1.1. 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 over time, as has occurred in the LSJR; however, metals may be remobilized into the interstitial water by both physical and chemical disturbances.

Metal concentrations in saltwater 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 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; Jarvis et al. 2013**). Lead concentrations in natural waters generally range from 0.02 to 36 μg/L, with the highest concentrations found in the sediment interstitial waters, due to the high affinity of this metal for sediment (**Eisler 1988a**).

Benthic biota 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.

5.5.1.2. 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 (**Bury et al. 2003; Bielmyer et al. 2006b**). 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; Bielmyer et al. 2012b**). 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. 2013** 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**), nickel (**Bielmyer et al. 2013**) and cadmium (Bielmyer, unpublished work) 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. 2013**). 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. 2012b**). 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**). Lead (Pb) can exist as an organometal and has a higher partition coefficient than the other metals discussed here; therefore, Pb would be preferentially distributed in more hydrophobic compartments (**Eisler 1988a**). Lead has been shown to exert toxic effects on a variety of aquatic organisms with sensitivity of some invertebrates as low as 4 μg/L (**Grosell et al. 2006**). Chronic lead toxicity in fish includes neurological and hematological dysfunctions (**Davies et al. 1976; Hodson et al. 1978; Mager and Grosell 2011**).

5.5.2. Current Status and Trends of Metals in Water and Sediments

5.5.2.1. Metals in Water

Generally, since 2010, a pattern of stabilized or reduced metal concentrations, particularly the maximum values, has been observed, as compared to previous years, in the LSJR mainstem. This reduction in metal concentration may reflect the recent efforts associated with TMDLs. However, the data set for metals in the water column has been substantially reduced over the years, which may contribute error in the data trend analyses. Each metal is discussed in turn below.

Arsenic With all but one exception (elevated maximum value) in 2000, the arsenic minimum, median, and maximum values in the LSJR mainstem and tributaries have been below the WQC of 50 μg/L since 1997 (Figure 5.13). Past exceedances of the WQC have mainly occurred in Cedar River, Doctors Lake, Durban Creek, and Moncrief Creek (Figure 5.20A). Mean arsenic values have decreased over time in the mainstem with the exception of a spike in 2016 (Figure 5.14). Median and maximum cadmium values in the LSJR have fluctuated since 1997 (Figure 5.15).

Cadmium Mean cadmium concentrations have generally decreased, and have been below WQC (with the assumed hardness value of 100 mg/L) in the entire LSJR since 2009 and in the mainstem since 2001 (Figure 5.16). Maximum values are now at or below WQC as well (Figure 5.15). In the past, cadmium exceedances in the tributaries have occurred specifically in Hogan Creek, as well as Cedar River, McCoy Creek, and Moncrief Creek to some degree (Figure 5.27).

Copper Copper was one of the more commonly found metals in the LSJR, based on this data set. Since 1997, maximum copper concentrations in the predominantly saltwater regions of the LSJR mainstem and tributaries have exceeded the WQC; however, since 2016 all maximum copper concentrations in the LSJR were below the WQC and within acceptable limits (Figure 5.17; 5.27). Overall, maximum copper concentrations have decreased since 2010 in the LSJR and median values have been stable (Figure 5.17). Mean copper values have significantly decreased in the saltwater regions of the LSJR mainstem since 1997 and in the freshwater regions of the mainstem since 2012 (Figure 5.18). Copper has been most problematic in the tributaries, where many exceedances have been documented (Figure 5.17; 5.27).

Lead Since 2008, maximum lead concentrations have decreased in the LSJR (Figure 5.19), with significantly decreased mean values over time in the entire LSJR, particularly the saltwater areas (Figure 5.20). In several tributaries, including Big Fishweir Creek, McCoy Creek, and Moncrief Creek, lead concentrations (median and maximum values) exceeding both freshwater and saltwater criteria have been documented, as have the maximum lead concentrations in several other tributaries; however, since 2016, all lead concentrations were below the WQC values (Figure 5.27).

Nickel Maximum nickel concentrations in the entire LSJR have decreased and remained stable since 2009, with concentrations below the saltwater and freshwater criteria of 8.3 μg/L and 52 μg/L, respectively (Figure 5.21). Additionally, mean nickel concentrations have significantly decreased over time (Figure 5.22). Since 1997, maximum nickel concentrations have been reported above WQC in several tributaries, particularly Doctors Lake, Dunns Creek, and Sixmile Creek; however, as of 2016, all nickel concentrations have been reported below WQC (Fig. 5.27).

Silver Median and maximum silver concentrations in the LSJR mainstem have fluctuated since 1997, with decreased median silver concentrations observed from 2015 until the present time (Figure 5.23). From 2006-2014, mean silver concentrations in the freshwater portion of the LSJR mainstem were elevated above the WQC of 0.07 μg/L; however, the mean silver concentrations were below the WQC since 2015 (Figure 5.24). Maximum silver concentrations within several tributaries were above both freshwater and saltwater WQC since 1997; however, as of 2016, the maximum values are at or below the WQC (Figure 5.23; 5.27).

Zinc Median and mean zinc concentrations in the entire LSJR were below the WQC and within acceptable limits since 1997, and maximum zinc concentrations were below WQC since 2008 (Figure 5.25; Figure 5.26). In the past, elevated maximum zinc concentrations were reported in Doctor's Lake, Dunns Creek, McCoy Creek, and Butcher Pen Creek; however, current reported zinc concentrations are within acceptable limits (Figure 5.27). The metals analyzed in this report are widely used and therefore continue to enter the LSJR through point and nonpoint sources. The majority of the metal concentrations in the water column of the LSJR mainstem were at or below WQC for the last three years. The metal concentrations in the tributaries were generally the highest and therefore most problematic.

For these reasons, the current overall **STATUS** of metals in the water column that were evaluated in this study (including arsenic, copper, cadmium, lead, nickel, silver, and zinc) in the mainstem of the LSRJ is *satisfactory* with a **TREND** of *improving*. The **STATUS** and **TREND** of metal concentrations in the tributaries of the LSJR cannot be determined because of the lack of data, and is therefore *uncertain*.

Data Limitations It should be noted that the data set has decreased tremendously. For example, in 2007, there were 397 data points for nickel concentrations in the tributaries, and, there were only 54 data points for 2017. Additionally, these ratings are for the water column only; sediments act as a reservoir and may still contain high metal concentrations (see below). If sediments are disturbed by dredging or other activities, metals may be remobilized into the water column and may negatively impact aquatic life in the LSJR. Environment Florida's recently released Troubled Waters report shows that US Naval Station Mayport has had more than 12 exceedances of various parameters, including nickel and copper, during a 21-month span between January 2016 and September 2017. The magnitude of potential impact is dependent on many concurring abiotic and biotic factors.

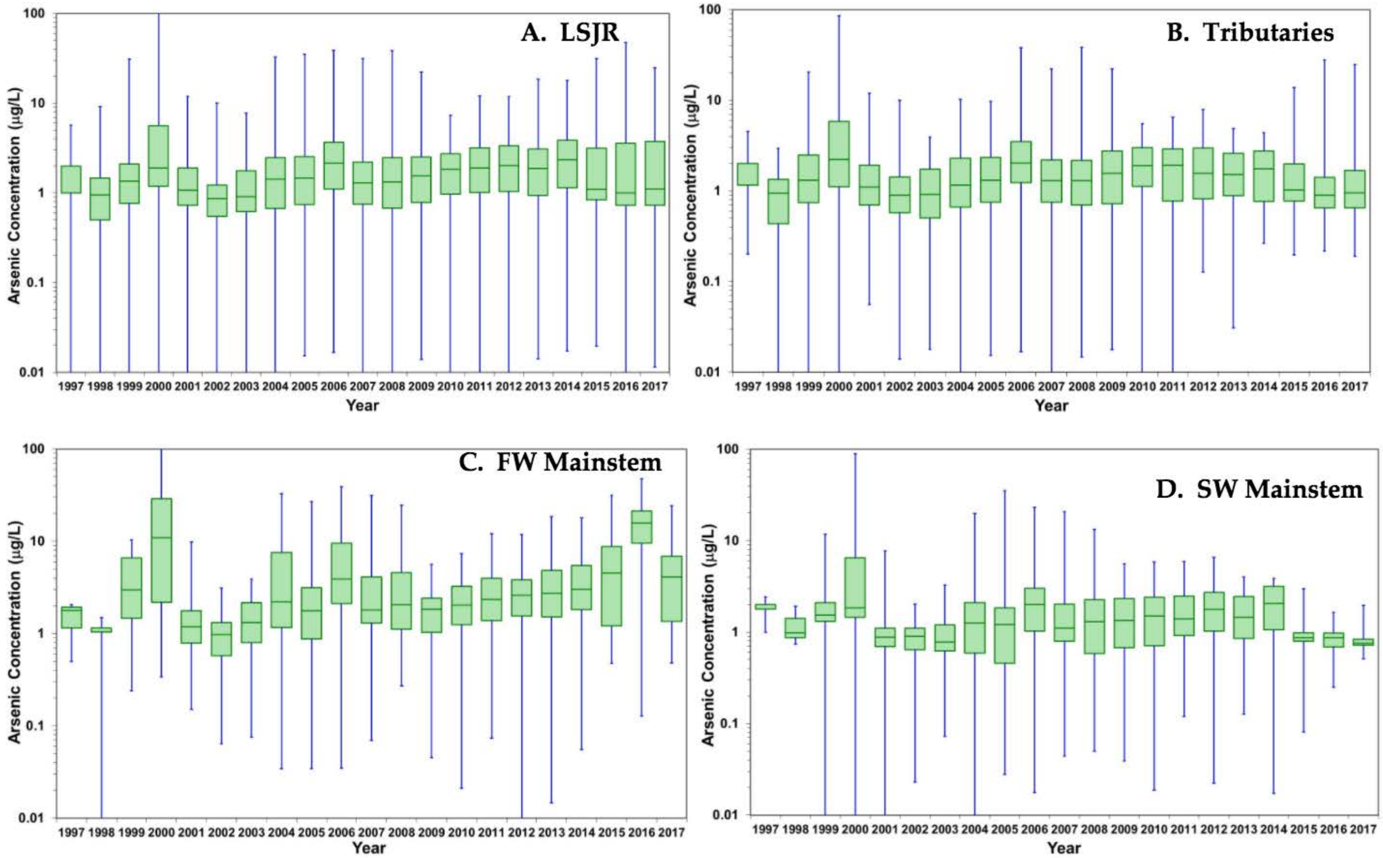


Figure 5.13 Yearly arsenic concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

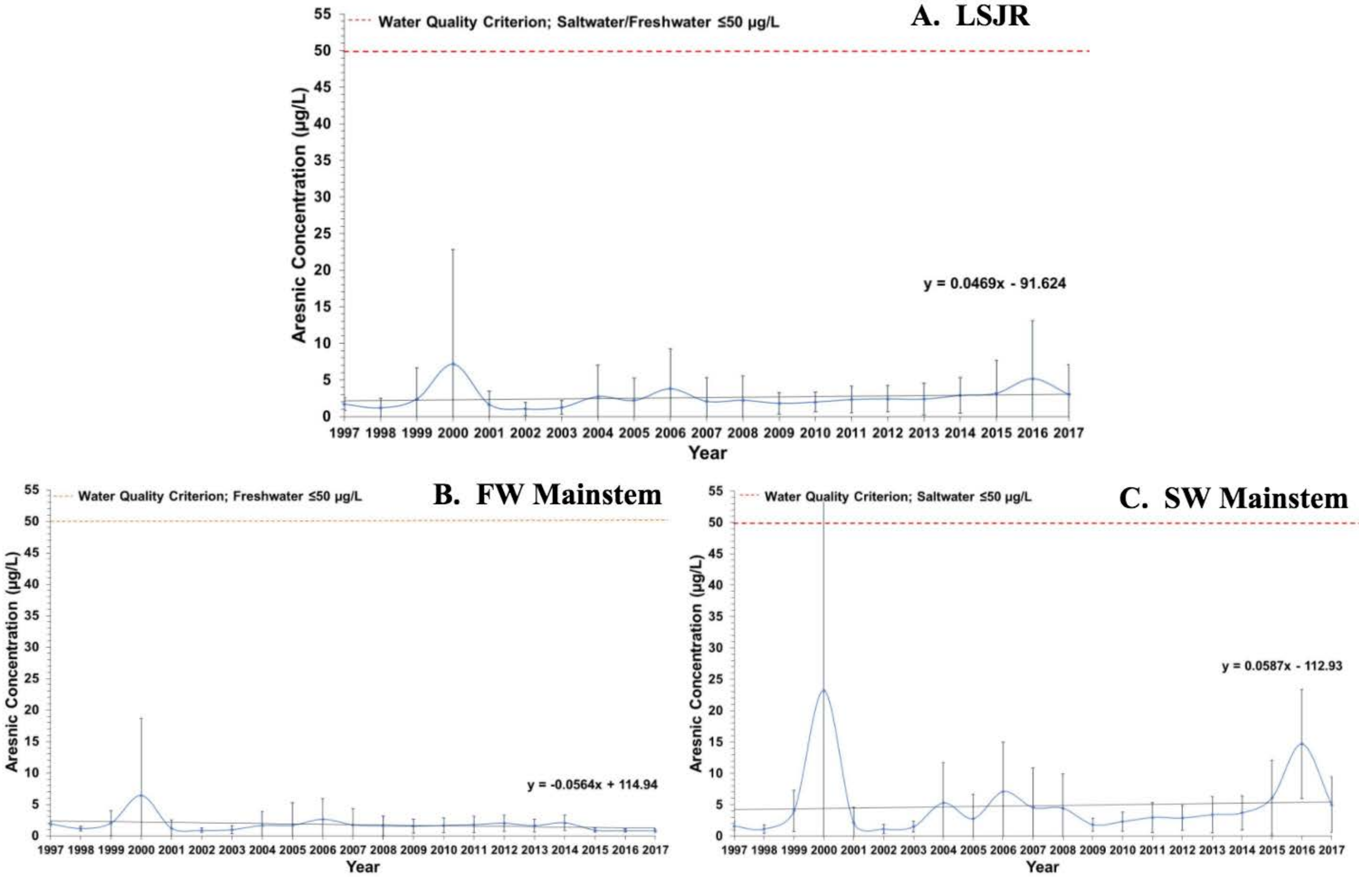


Figure 5.14 Yearly arsenic concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line (not shown due to the scale) indicates the class III water quality criterion for both marine waters and freshwaters.

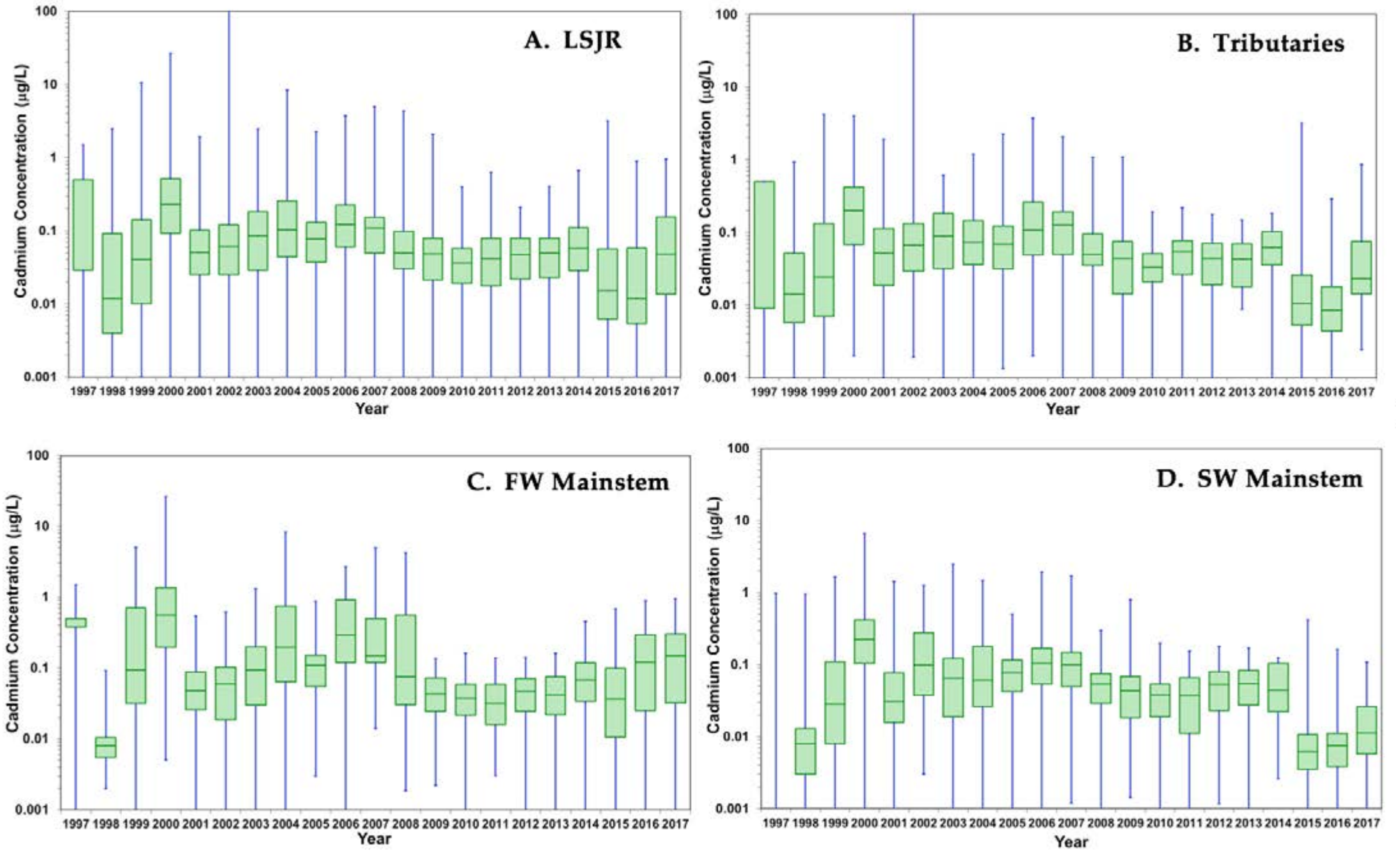


Figure 5.15 Yearly cadmium concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

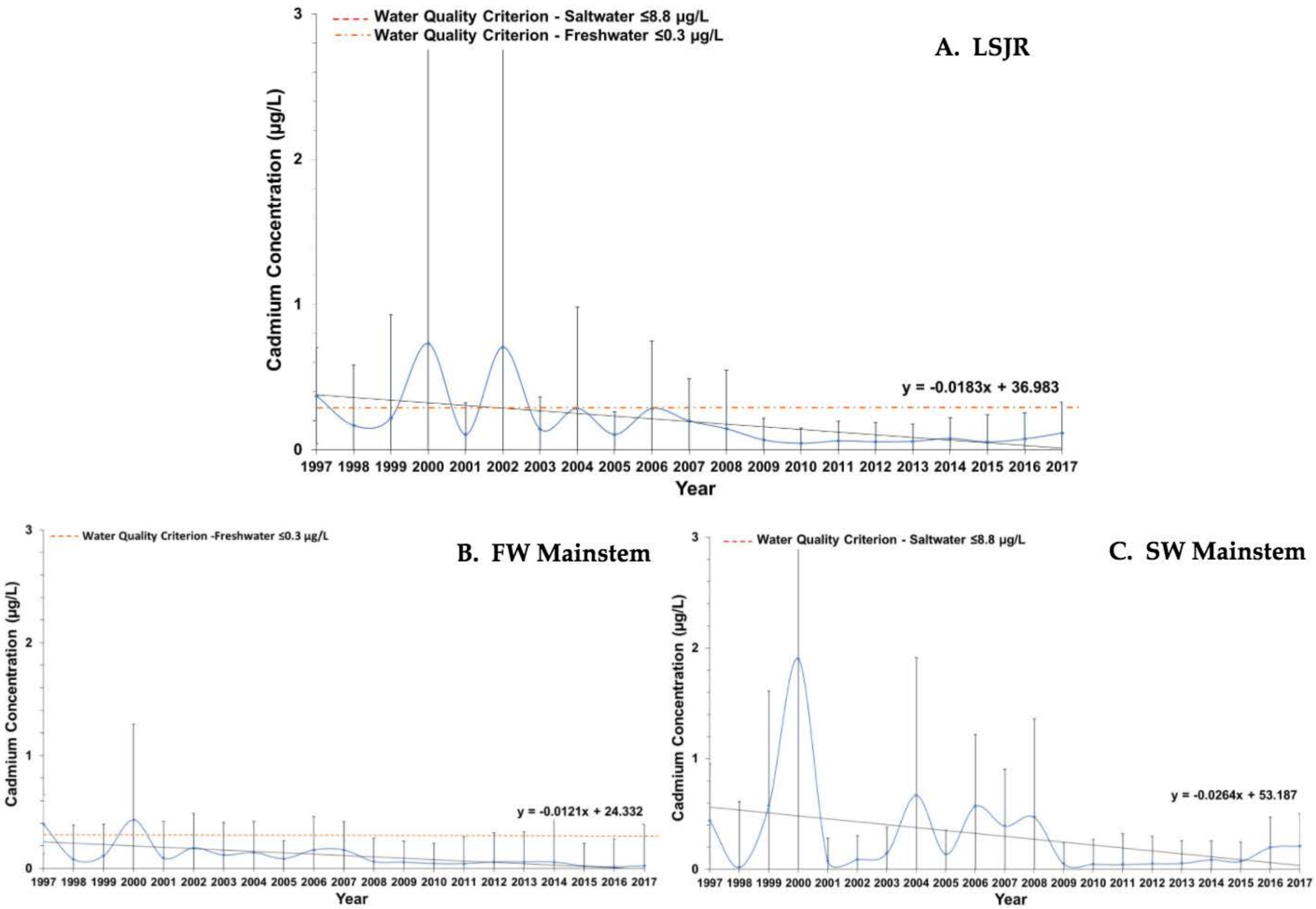


Figure 5.16 Yearly cadmium concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line indicates the class III water quality criterion for marine/estuarine waters and the dotted orange line indicates the class III water quality criterion for freshwaters.

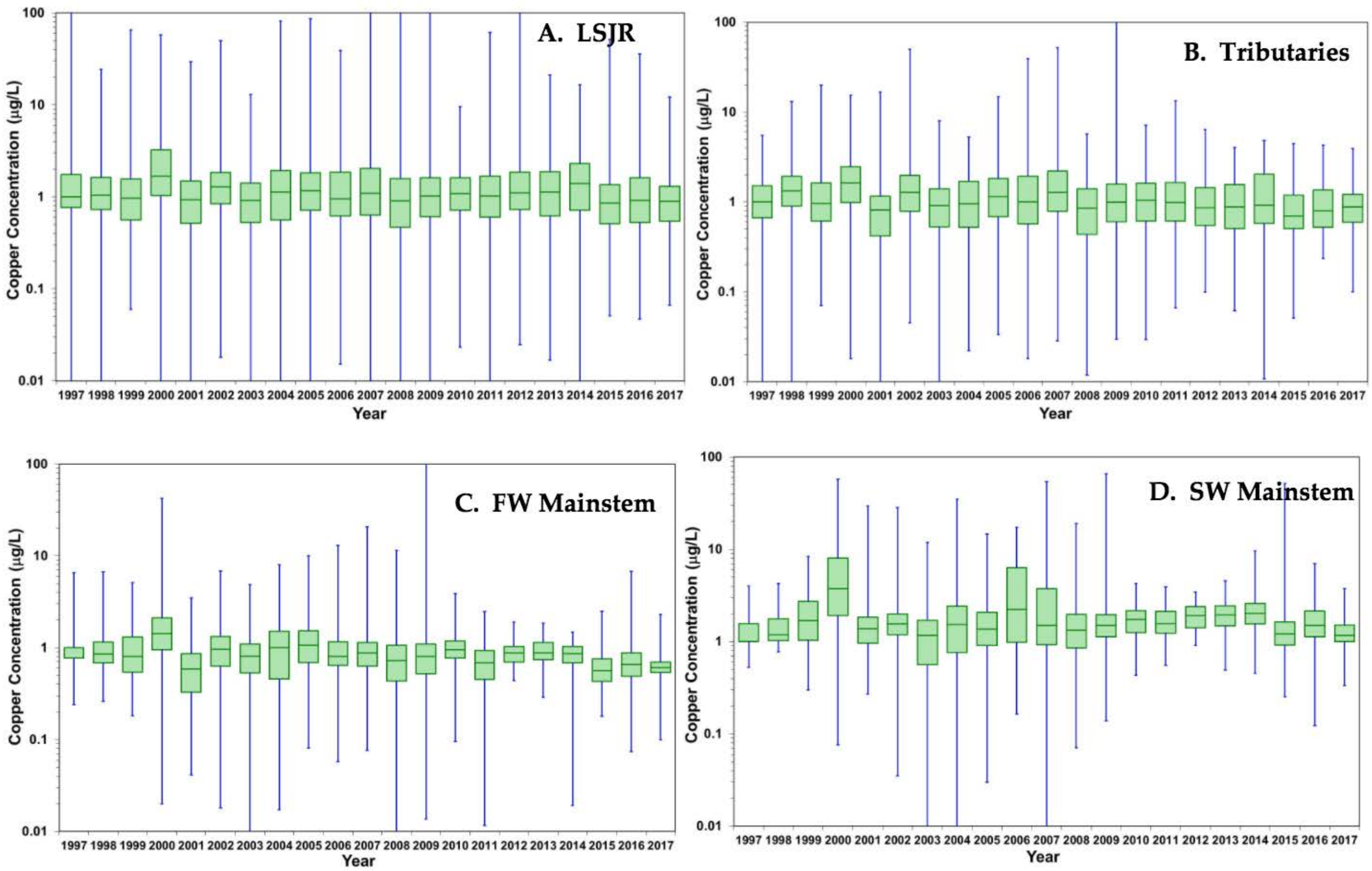


Figure 5.17 Yearly copper concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

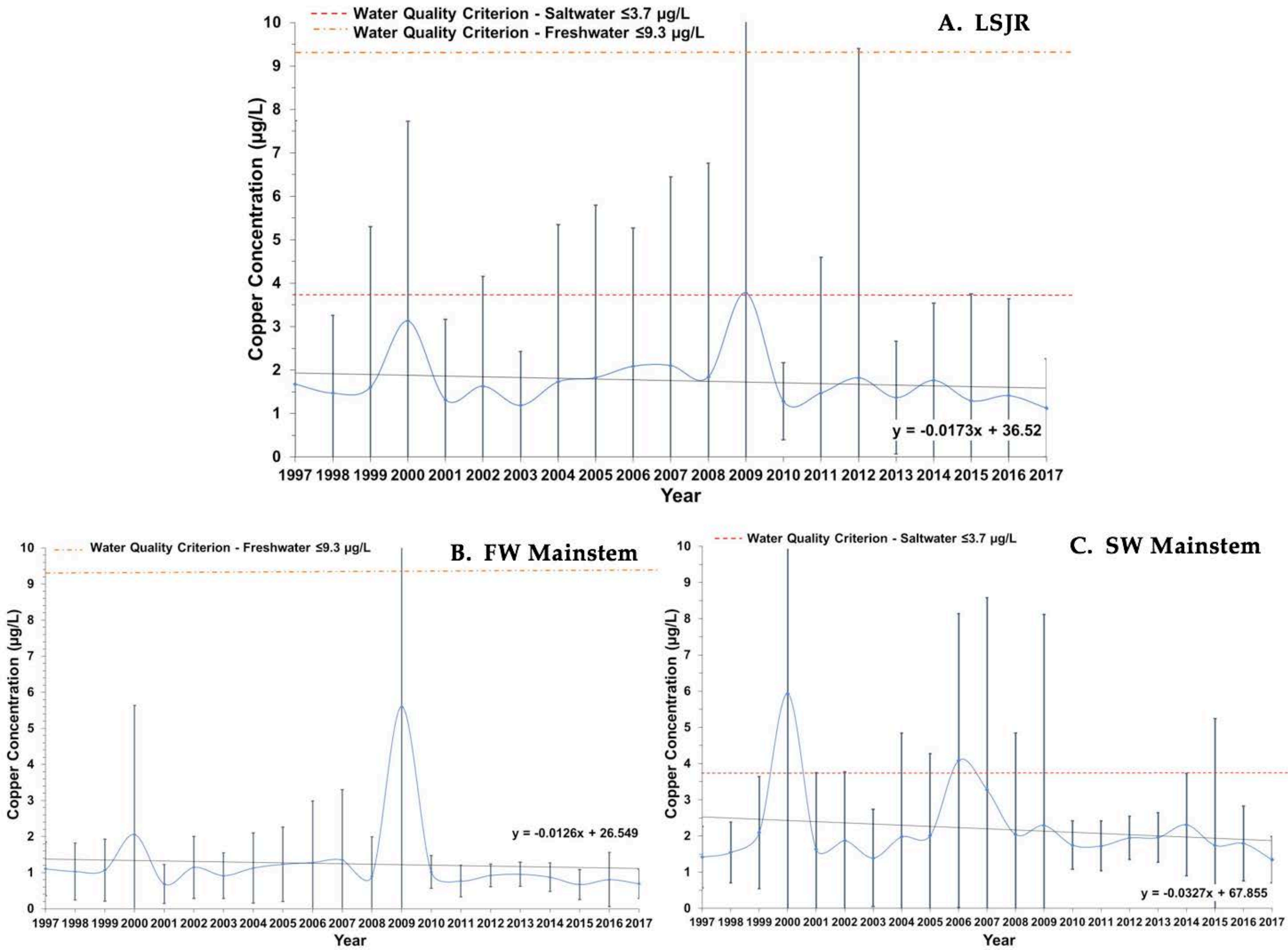


Figure 5.18 Yearly copper concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line indicates the class III water quality criterion for marine/estuarine waters and the dotted orange line indicates the class III water quality criterion for freshwaters.

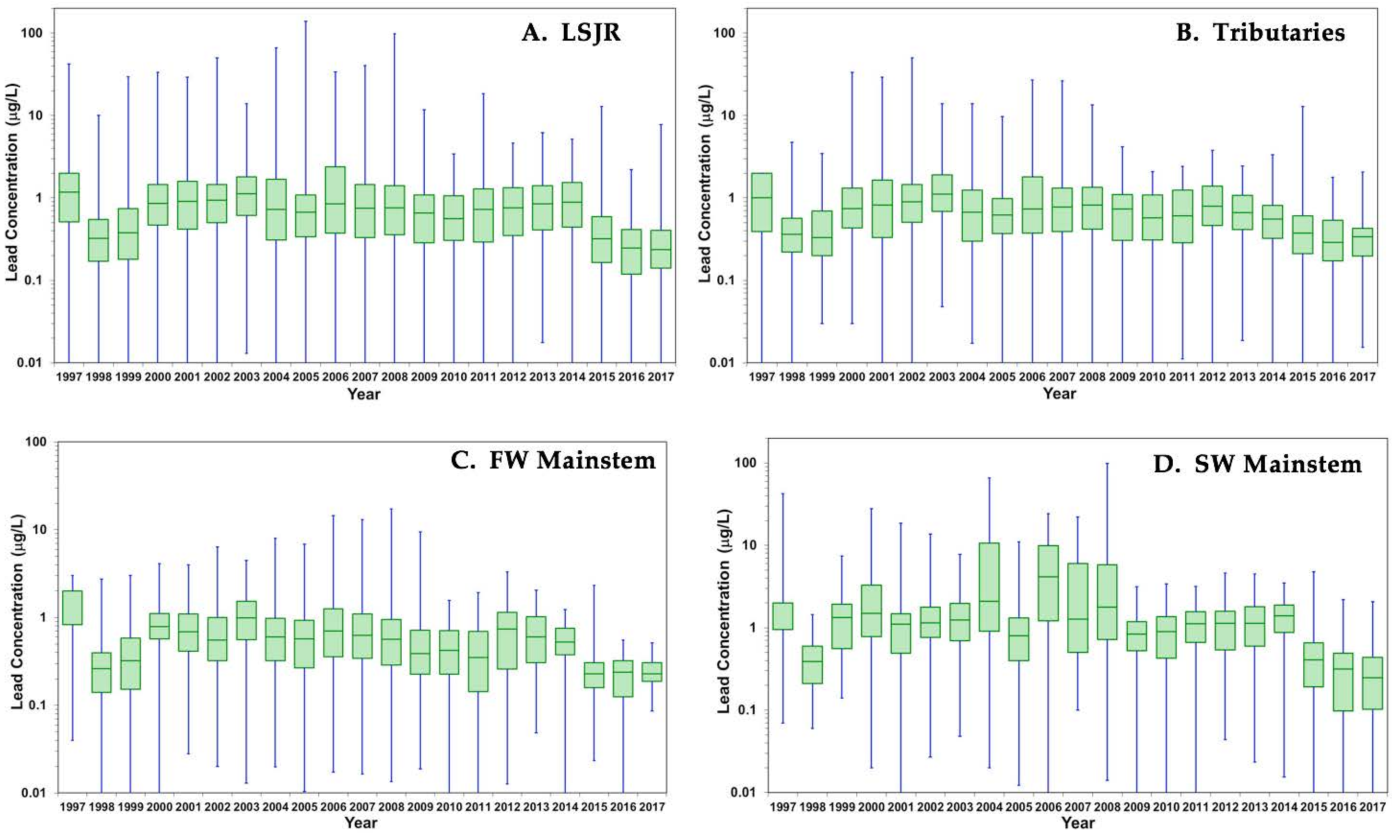


Figure 5.19 Yearly lead concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

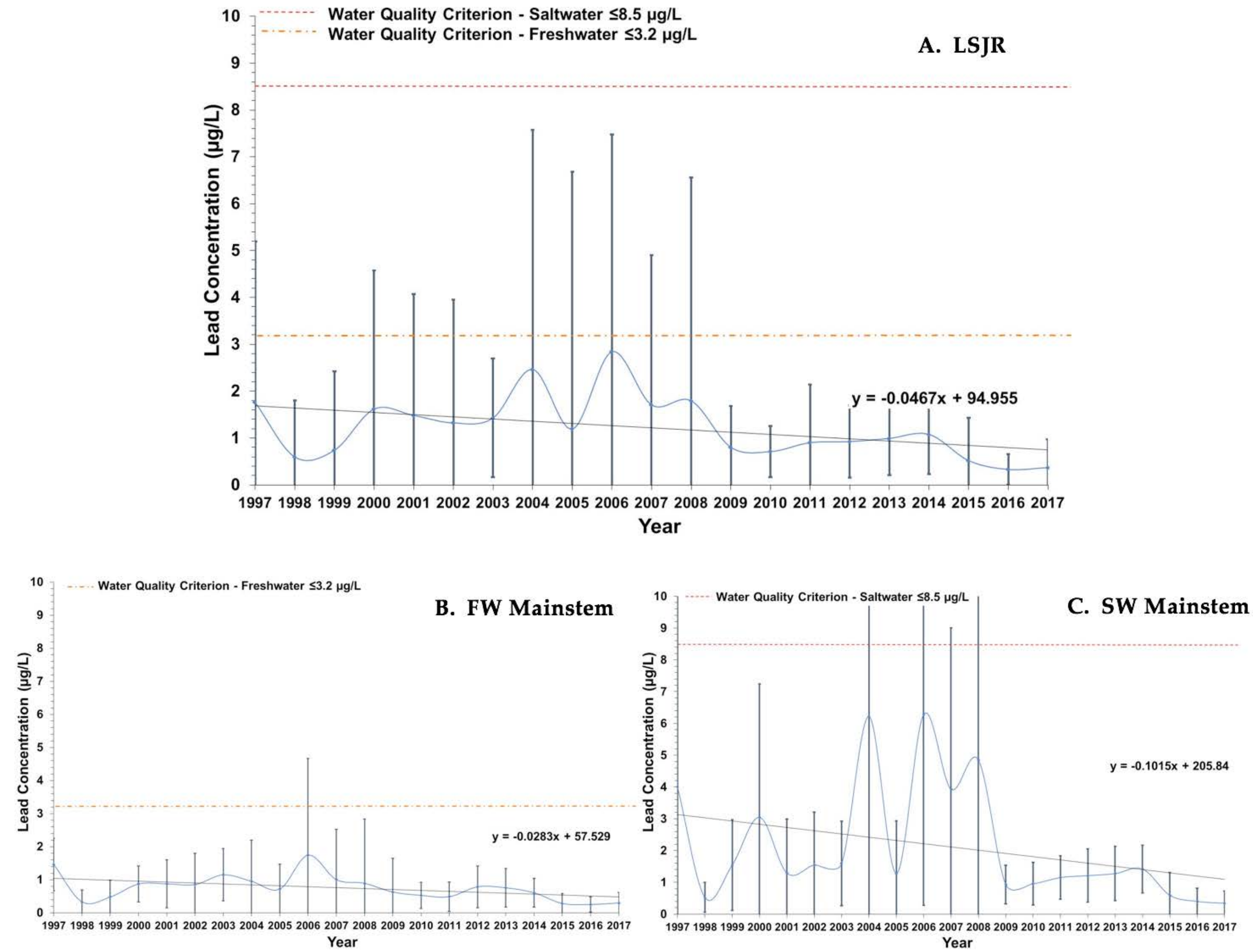


Figure 5.20 Yearly lead concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line indicates the class III water quality criterion for marine/estuarine waters and the dotted orange line indicates the class III water quality criterion for freshwaters.

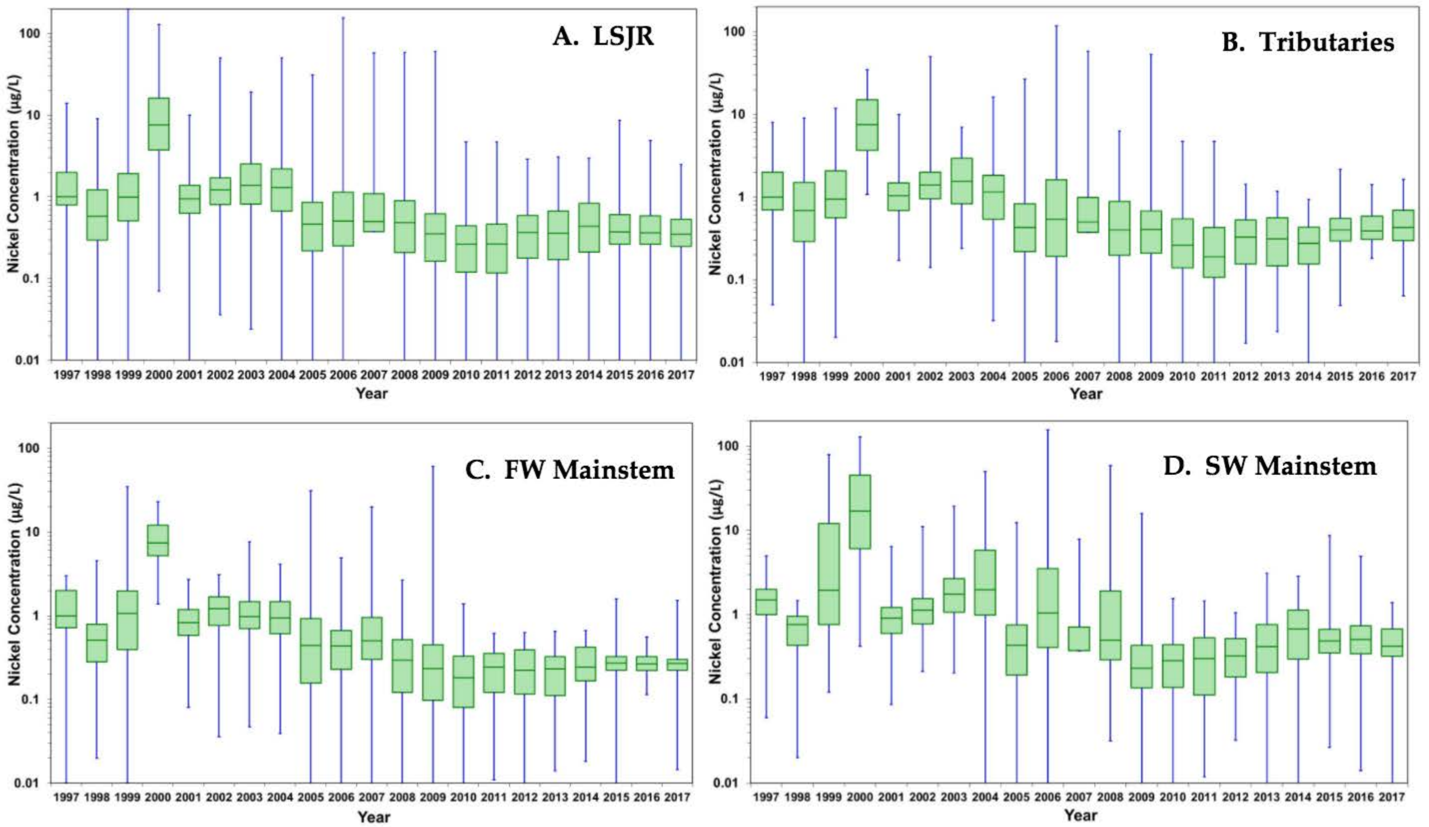


Figure 5.21 Yearly nickel concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

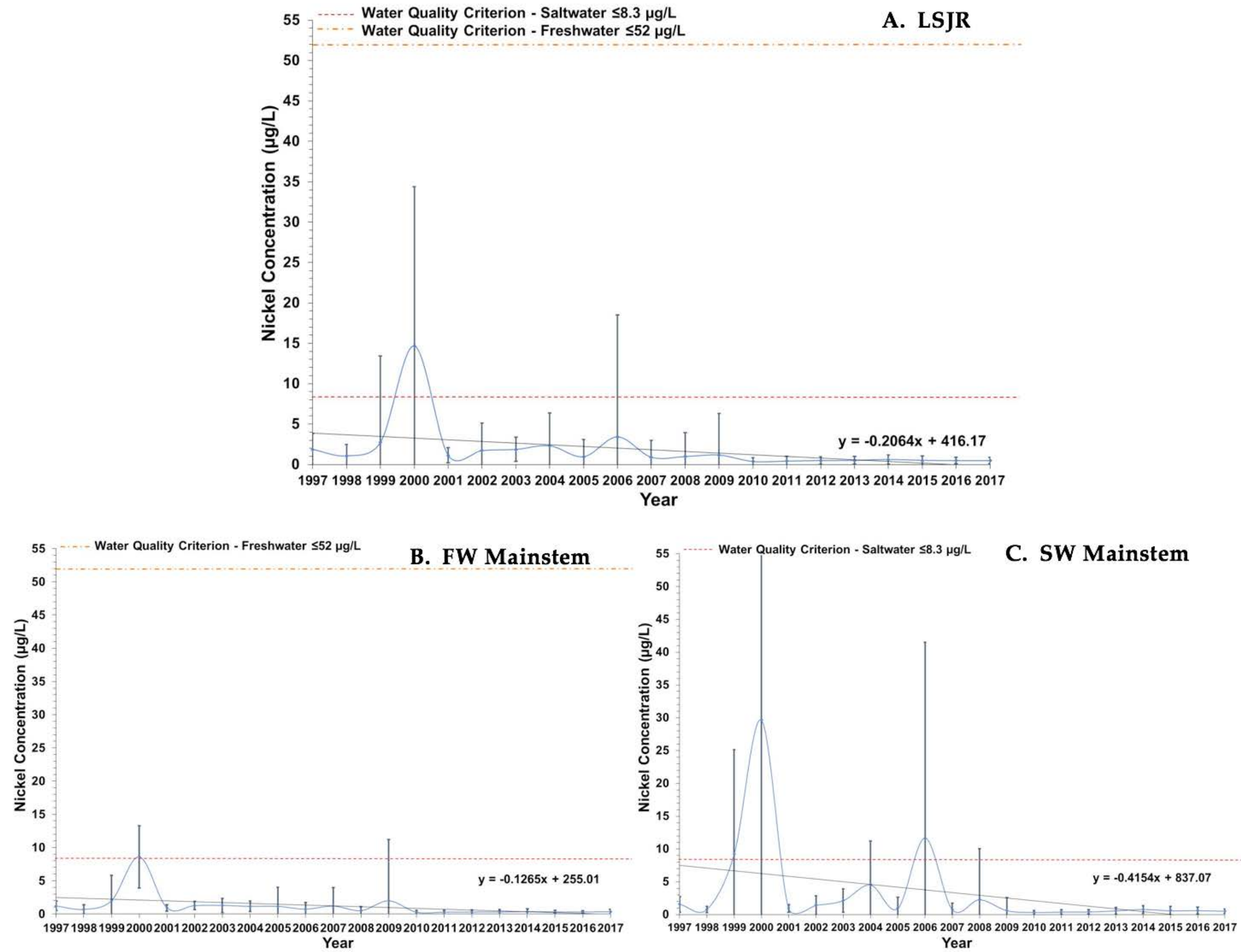


Figure 5.22 Yearly nickel concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line indicates the class III water quality criterion for marine/estuarine waters and the dotted orange line indicates the class III water quality criterion for freshwaters.

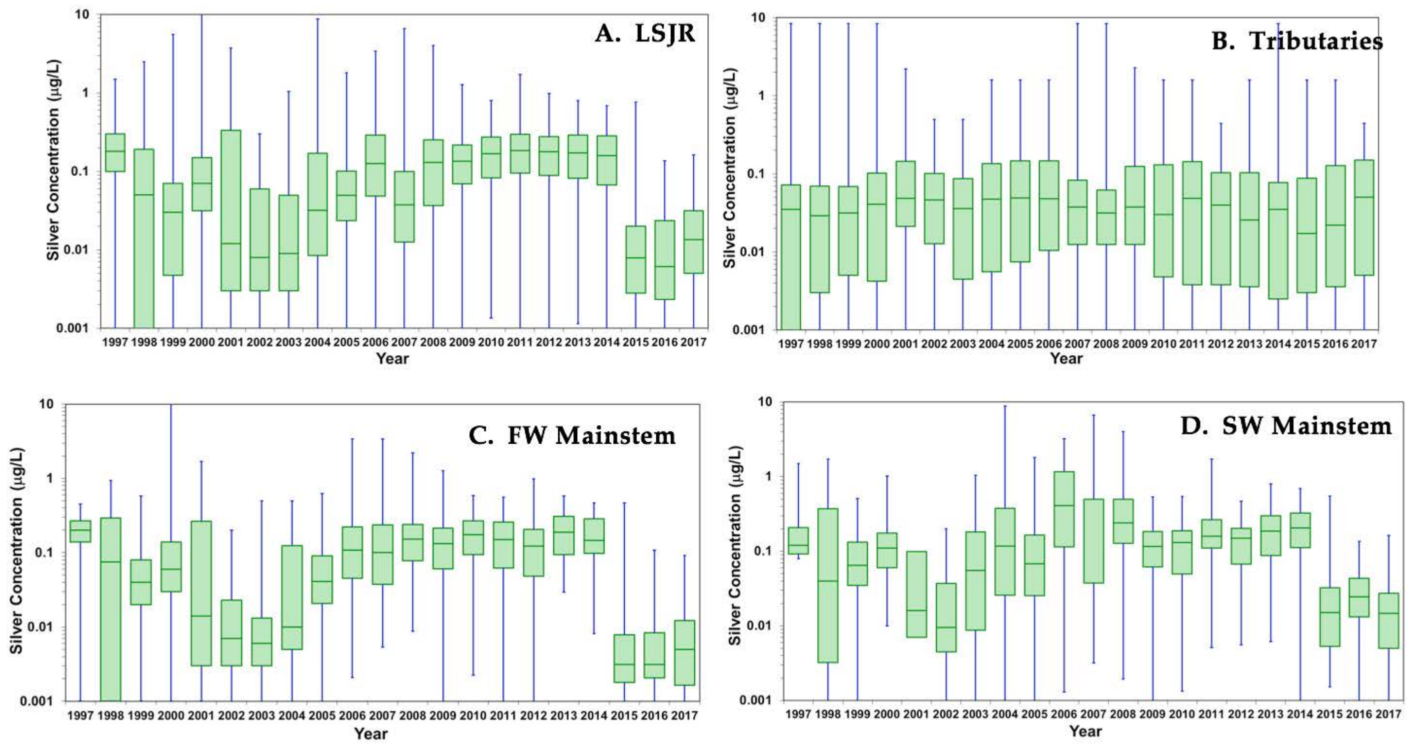


Figure 5.23 Yearly silver concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

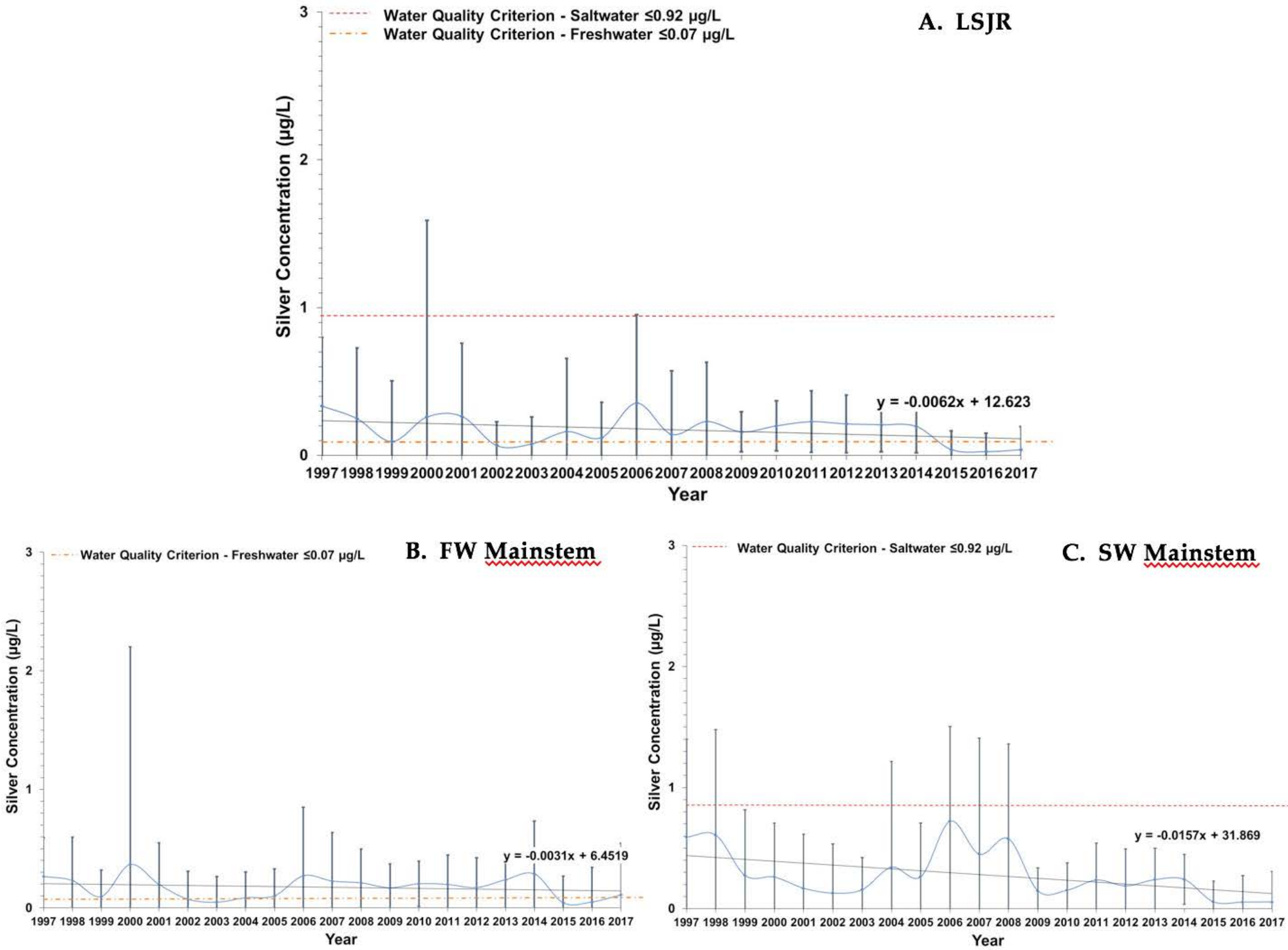


Figure 5.24 Yearly silver concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line indicates the class III water quality criterion for marine/estuarine waters and the dotted orange line indicates the class III water quality criterion for freshwaters.

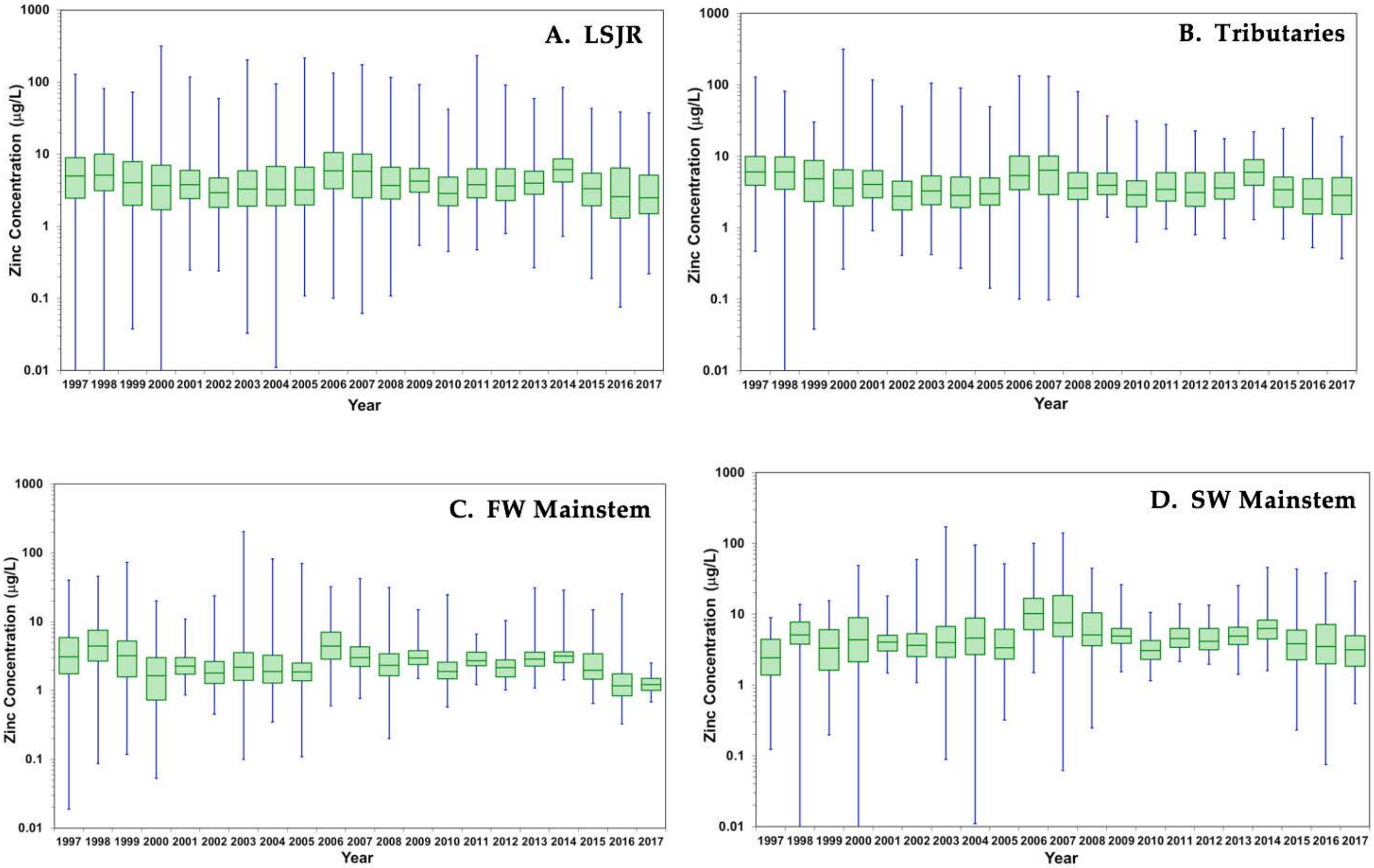


Figure 5.25 Yearly zinc concentrations (µg/L) from 1997 to 2017 in A. the entire LSJR and its tributaries, B. the tributaries of the LSJR, C. the freshwater (FW) portion of the LSJR mainstem, and D. the predominantly saltwater (SW) portion of the LSJR mainstem. Data are presented as a box-and-whiskers 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.

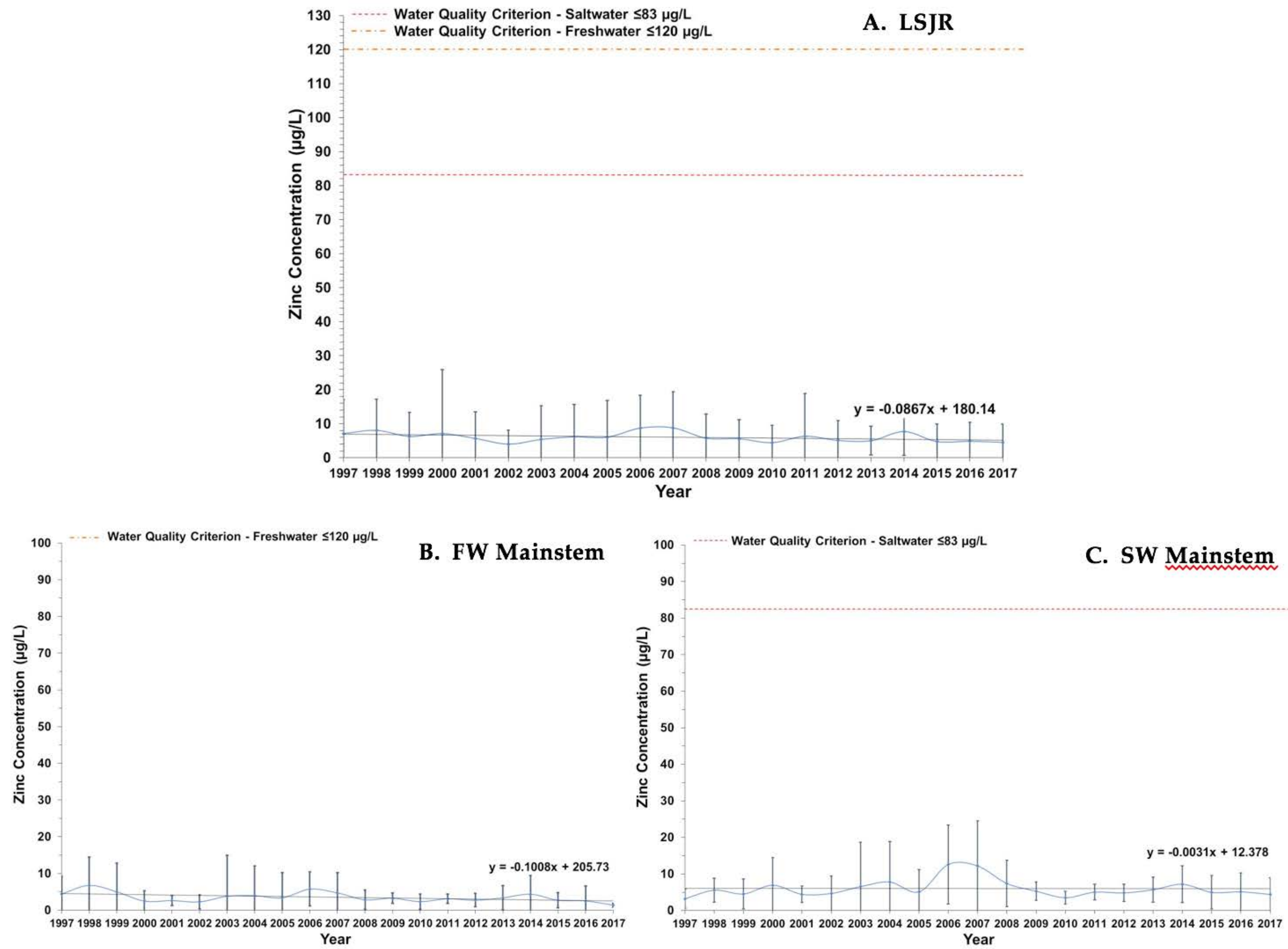
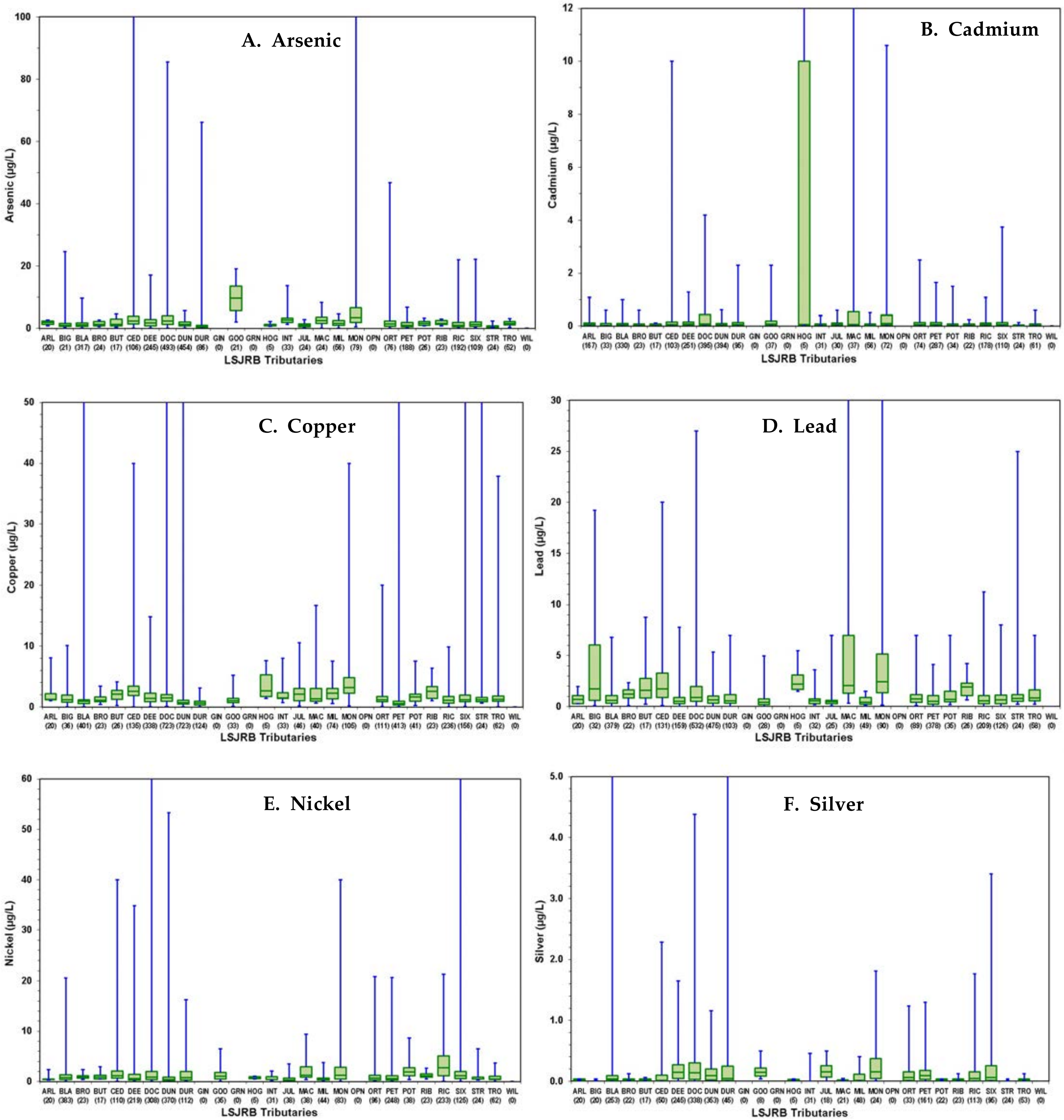
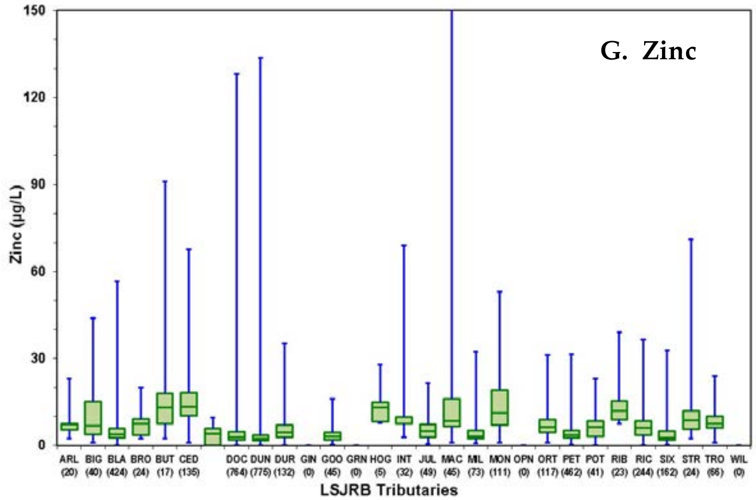


Figure 5.26 Yearly zinc concentrations from 1997 to 2017 in the A. LSJR mainstem and its tributaries, B. the predominantly freshwater portion of the LSJR mainstem, and C. the predominantly marine/estuarine region of the LSJR mainstem. Data are presented as mean ± standard deviation. The dotted red horizontal line indicates the class III water quality criterion for marine/estuarine waters and the dotted orange line indicates the class III water quality criterion for freshwaters.


A. Arsenic
Arsenic (µg/L)
LSJRB Tributaries
B. Cadmium
Cadmium (µg/L)
LSJRB Tributaries
C. Copper
Copper (µg/L)
LSJRB Tributaries
D. Lead
Lead (µg/L)
LSJRB Tributaries
E. Nickel
Nickel (µg/L)
LSJRB Tributaries
F. Silver
Silver (µg/L)
LSJRB Tributaries



Tributary Comparison Key

ARL – Arlington River
BIG – Big Fishweir Creek
BLA – Black Creek
BRO – Broward River
BUT – Butcher Pen Creek
CED – Cedar River
DEE – Deep Creek
DOC – Doctors Lake
DUN – Dunns Creek
DUR – Durbin Creek
GIN – Ginhouse Creek
GOO – Goodbys Creek
GRN – Greenfield Creek
HOG – Hogan Creek
INT – Intracoastal
JUL – Julington Creek
MAC – McCoy Creek
MIL – Mill Creek
MON – Moncrief Creek
OPN – Open Creek
ORT – Ortega River
PET – Peters Creek
POT – Pottsburg Creek
RIB – Ribault River
RIC – Rice Creek
SIX – Sixmile Creek
STR – Strawberry Creek
TRO – Trout River
WIL – Wills Branch

Figure 5.27 Water column variation in A. arsenic, B. cadmium, C. copper, D. lead, E. nickel, F. silver, and G. zinc in over 29 tributaries of the Lower St. Johns River Basin (see key for tributary codes). 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. Values in brackets below the tributary codes represent the number of data points for each tributary.

5.5.2.2. Metals in Sediments

The metals in sediments that we have evaluated in this study include arsenic, mercury, lead, cadmium, copper, silver, zinc, nickel, and chromium. Metals in general have been elevated over natural background levels in sediments all throughout the LSJR for more than two decades (Table 5.2) and continue to do so today. Many 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)

From the 1980s to 2003, different metals exhibit slightly different trends with time, but none appear to be significantly declining in any area. 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, suggesting that the metals found throughout the LSJR individually exert a low-level stress during that time period. Metals in Area 3, the north mainstem, have increased since 1983, but the rate of increase has slowed since the mid-1990s (Figure 5.28). Although a decrease in lead concentrations were not observed 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**).

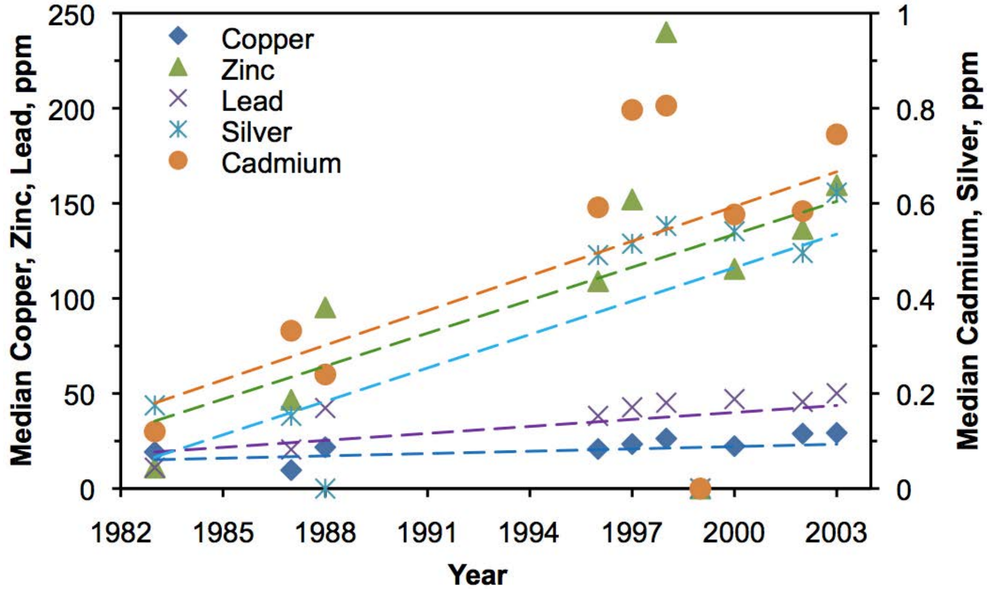


Figure 5.28 Median concentrations of copper, zinc, lead, silver, and cadmium in sediments in Area 3, the north mainstem. Trend lines are shown as dashed lines. See text in Section 5.2 for data sources.

From 2005 to 2016, despite some hot spots, mean metal concentrations in sediments are generally present at concentrations near their TELs; however, for most metals, values above TELs have been reported (Figure 5.29). In particular, lead and mercury continue to be problematic in the LSJR (Figure 5.29). Individually, metals may exert pressure to aquatic life; however, exposure to all metals together may cause synergistic toxic effects, constituting an important class of stressor to the river. It should be noted that the number of sediment samples analyzed for metals has decreased over the past five years by more than 10-fold in some cases. In 2016, there were less than 5 samples for some metals.

For these reasons, the **STATUS** of metals in sediments is ***unsatisfactory,*** and the **TREND** is ***unchanged***.

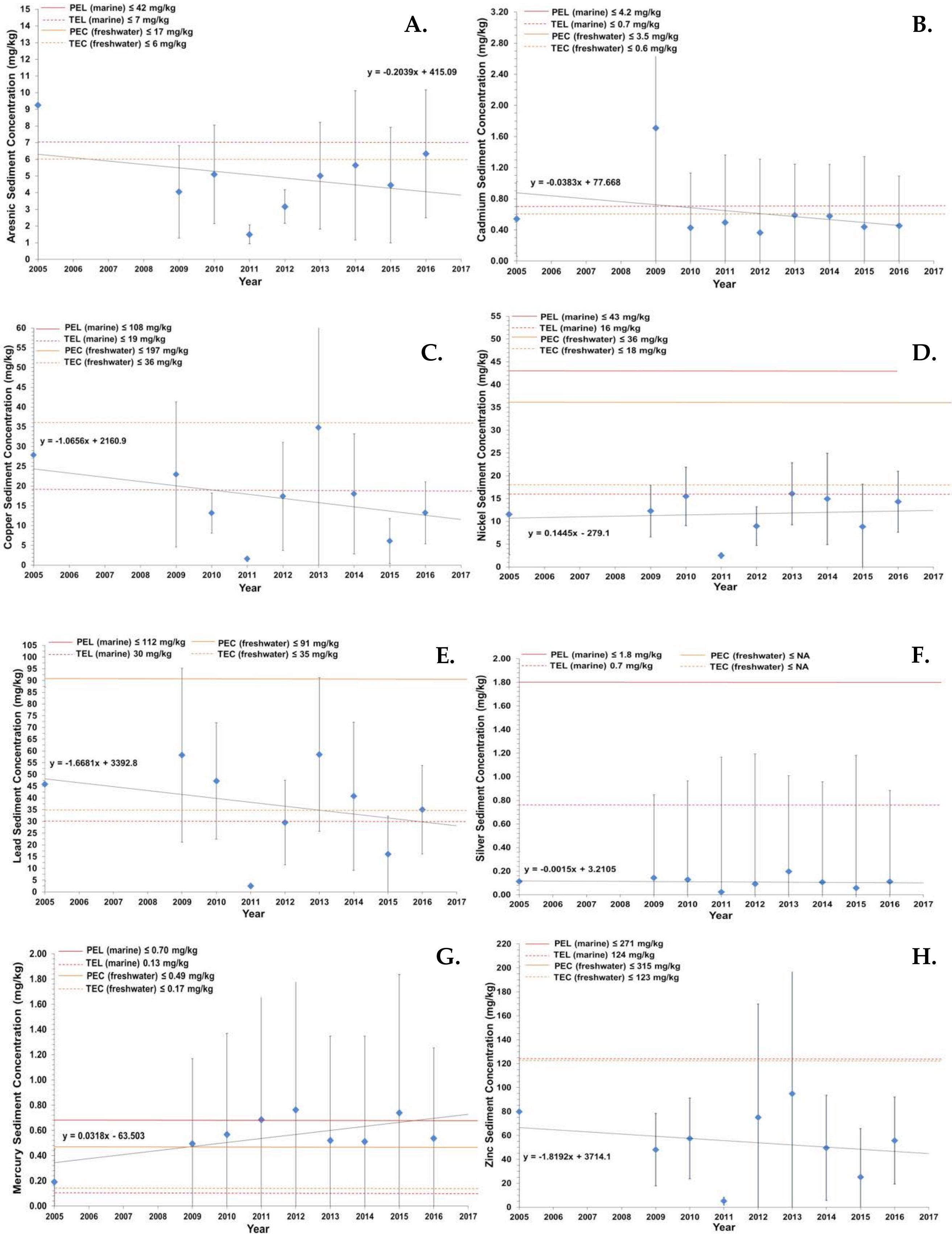


Figure 5.29 Annual Mean Concentrations of A. arsenic, B. cadmium, C. copper, D. nickel, E. lead, F. silver, G. zinc, and H. mercury in the Lower St. Johns River Basin. The dotted red horizontal line indicates the Threshold Effects Level, TEL, for freshwater (sensitive species may be affected); the solid red line indicates the Probable Effects Level, PEL, for freshwater, (some species affected); the dotted orange horizontal line indicates the Threshold Effects Level, TEL, for saltwater (sensitive species may be affected); the solid red line indicates the Probable Effects Level, PEL, for saltwater (some species affected).

5.5.3. Point Sources of Metals in the LSJR Region

Most metals emitted to the atmosphere declined significantly between 2001 and 2013, with a 97% reduction in vanadium released by electric utilities accounting for much of the decline (Figures 5.30 and 5.31). In addition, zinc, nickel, copper and cobalt emissions declined significantly from 2002 to 2013 (Figure 5.30). In 2013, releases of 14 different metals to the atmosphere in the LSJR basin were reported. Zinc was the most abundant and comprised about 35% of all metal releases.

In contrast to atmospheric emissions, surface water discharges of metals increased by over 230% to a total of 71,000 pounds between 2001 and 2013. The paper industry released most total metals into the LSJR in 2013 because of the extremely large quantity of manganese that was reported (51,000 pounds). Additional metals discharged by that industry were lead (415 pounds) and mercury (0.26 pounds). Excluding manganese, electric utilities discharged about 50 times more metals than the paper industry and had more diverse effluents with 13 different metals. The metals released by electric utilities totaled 19,712 pounds in 2013 with the top five being barium, cobalt, molybdenum, nickel, and zinc.

Much of the overall increase in metals released to the LSJR is due to the electric utilities, which has had an increase of 250% in its metal discharges since 2001, despite that industry's significant reduction in its air emissions (Figures 5.32 and 5.33). Seven of the 13 metals that were reported in 2013 by the utilities have higher release rates than in 2001. Zinc and nickel increased sharply between 2011 and 2012, while cobalt and barium increased significantly between 2007 and 2008 and have steadily increased since. Reported discharges of mercury and vanadium have decreased since 2001.

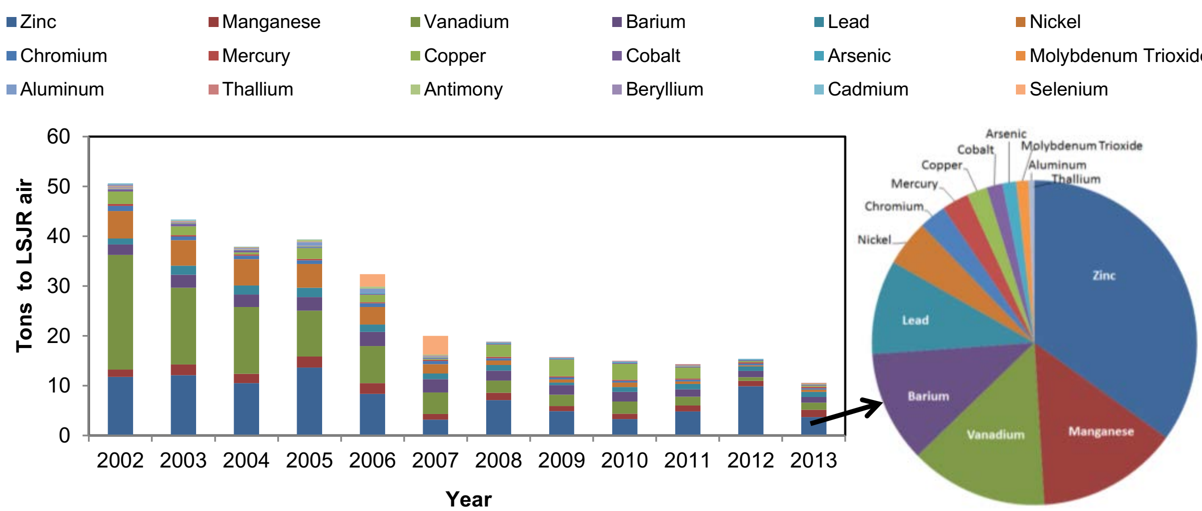


Figure 5.30 Trends and status of 18 metals released into the atmosphere of the nine-county LSJR region as reported in the Toxics Release Inventory ***EPA 2015d****). Inset shows the distribution of 10 tons of metals emitted in 2013.*

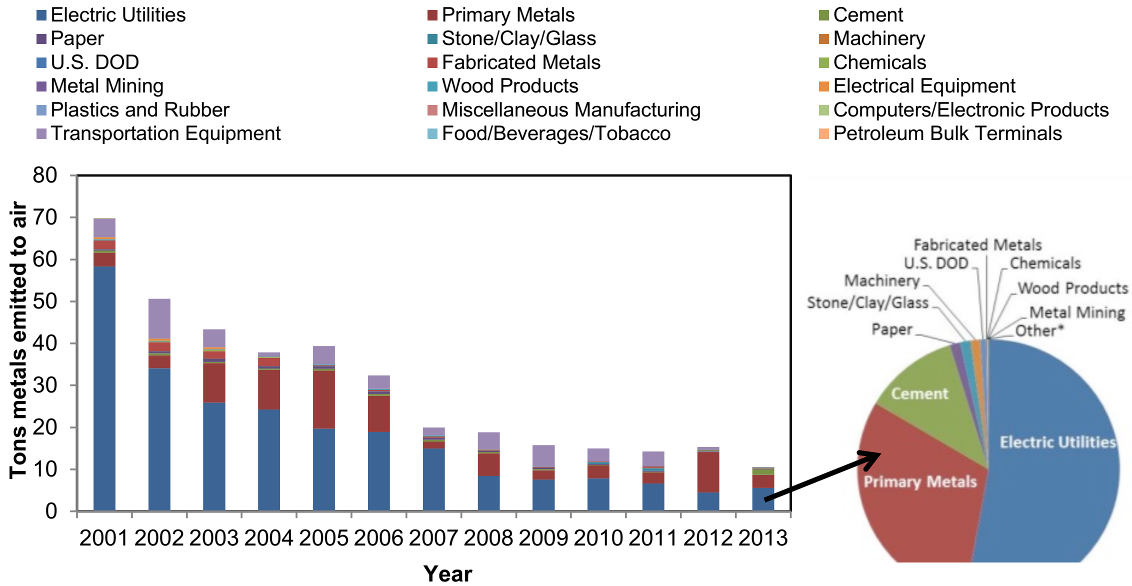


*Figure 5.31 Trends and status of 18 industries releasing metals into the atmosphere of the nine-county LSJR region as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the major industries emitting 10 tons of metals in 2013. Other* industries consist of electrical equipment, plastics and rubber, computers/electronic products, and miscellaneous manufacturing which together emitted 4 pounds of metals in 2013.*

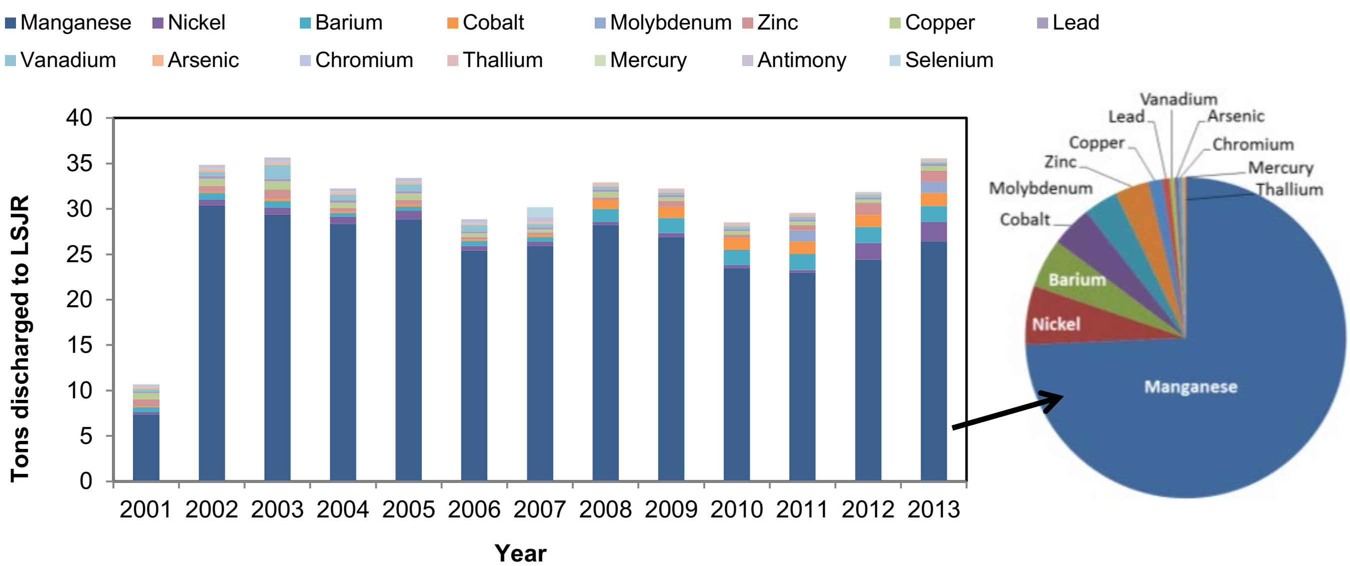


*Figure 5.32 Trends and status of 15 metals released to the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the distribution of 71,000 pounds of metals discharged in 2013.*

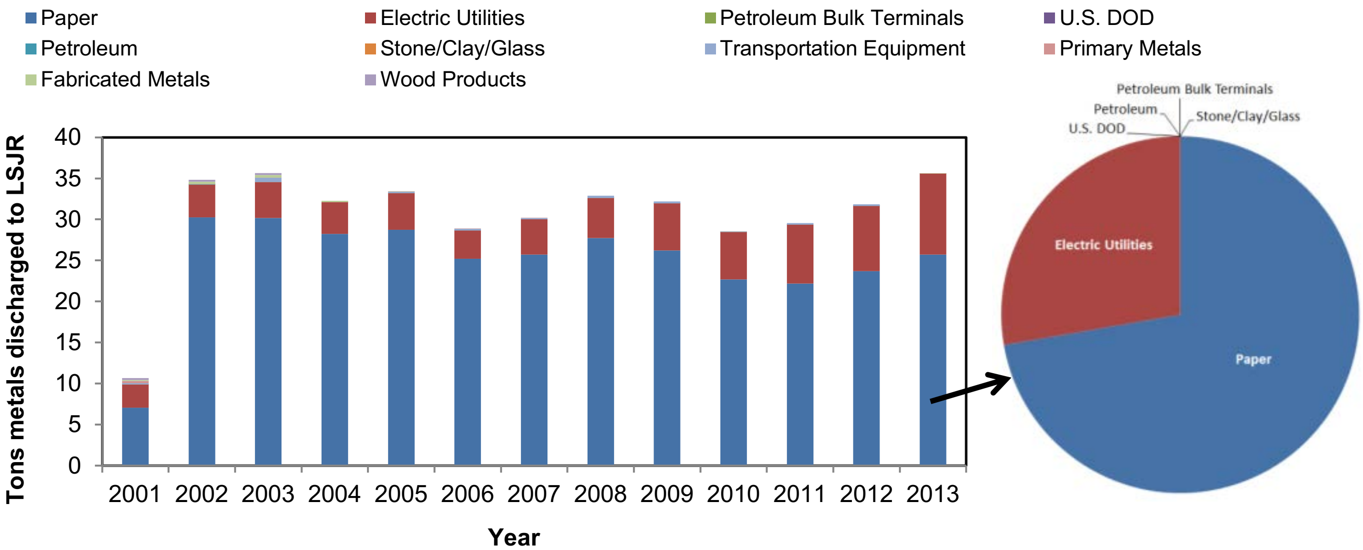


*Figure 5.33 Trends and status of 10 industries releasing metals into the LSJR and its tributaries as reported in the Toxics Release Inventory (**EPA 2015d**). Inset shows the major industries discharging 71,000 pounds of metals in 2013.*

5.5.4. Mercury in the LSJR

5.5.4.1. 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, the EPA determined that approximately 60% of the mercury deposited in the U.S. 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 5.34).

The LSJR emissions reflect national trends in that most waste mercury is emitted from coal power plants (**EPA 1997a**).

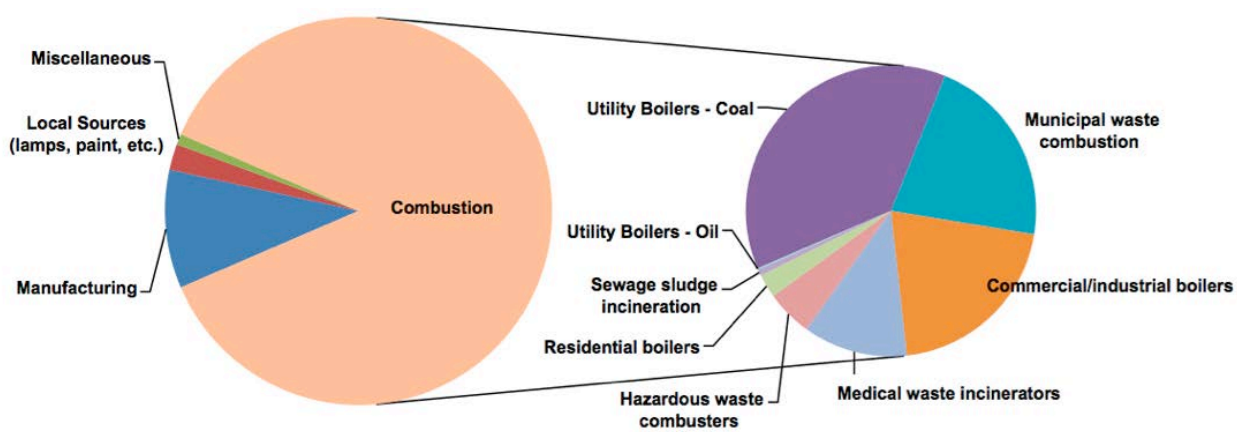


*Figure 5.34 National emissions of mercury in the US totaled 158 tons in 1994-1995. Combustion is responsible for the large majority (left graph) with coal combustion the most important type (right graph) (**EPA 1997a**).*

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 5.35).

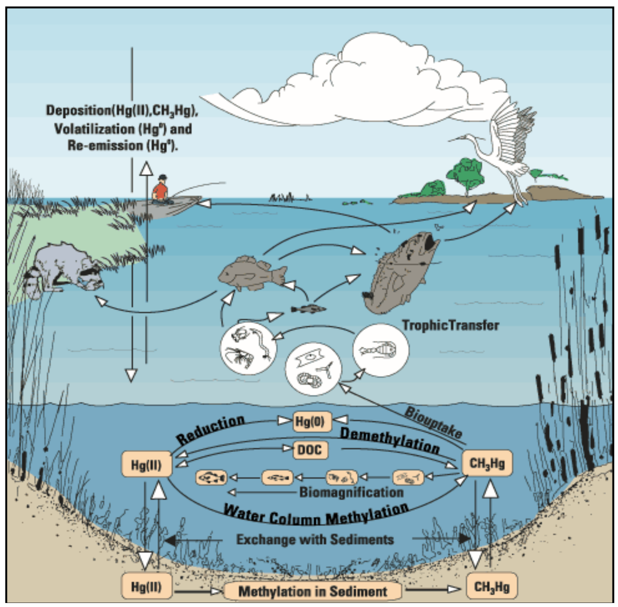


Figure 5.35 The mercury cycle. Mathematical models must accurately describe each step to predict the effect of mercury sources on fish tissue.
Source: ***USGS 2004****.*

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 the 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 2016**). 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 childbearing 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 2016**). 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).

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 childbearing 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.

The FL DEP issued its final report for the statewide mercury TMDL in October 2013 (see Section 1 in this report for additional information on TMDLs). The ultimate goal of the TMDL effort is to reduce the levels of mercury in fish in State waterways to safe levels where fish consumption advisories have been issued. The elements of the multi-year study to establish mercury load limits included measuring the amount of mercury that is present in Florida waterways (in fish, water and sediment), and identifying sources and fates of mercury in the State through atmospheric monitoring and modeling.

Intensive monitoring of atmospheric mercury, along with other metals and air quality parameters, was undertaken at seven sites from 2008-2010. Wet deposition of mercury was monitored at all sites and in Jacksonville, Pensacola, Tampa and Davie dry deposition was also monitored. In addition to atmospheric monitoring, extensive analysis of mercury in fish, primarily largemouth bass, and water quality was undertaken in over 100 freshwater lakes and 100 streams. The selected sites varied in acidity, trophic status and color, all parameters that were thought to 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 were developed as well as models to predict the concentrations in fish with different mercury loading rates and in different aquatic environments. Estimating exposure to mercury by different populations and establishing a safe level of consumption was another significant effort in the project (**DEP 2007; DEP 2011; DEP 2013c**). Results of the studies indicate that the vast majority of the man-made sources of mercury in Florida waters has global sources and that aquatic lakes and streams vary more because of their geochemistry than because of atmospheric loading. The TMDL report indicates significant reductions in mercury emissions have occurred in the last two decades.

No additional reductions will be required of local coal fired power plants due to recent large reductions arising from federal regulation (**EPA 2013d**) and the global nature of the sources in State waters. NPDES permit-holders will have no additional mercury limits imposed beyond currently enforced water quality criteria because of the limited impact of local atmospheric and point sources, and because of anticipated impending EPA regulations (**EPA 2015b**).

5.5.4.2. 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 mainstem, 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.

Mean mercury concentrations in sediments collected from various sites along the LSJR Sites are given in Table 5.3. The distribution of mercury, the TEL, PEL, and hot spots in various years is shown in Figure 5.36. Mercury levels that exceed natural background levels and the most protective environmental guidelines are found throughout the mainstem. 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.

Because of the high degree of toxicity pressure due to mercury, the high numbers of sites that have mercury in sediments greater than background levels, and the high degree of potential human risk, the **STATUS** of mercury in sediments is ***unsatisfactory***, and the **TREND** is *unchanged*.

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)

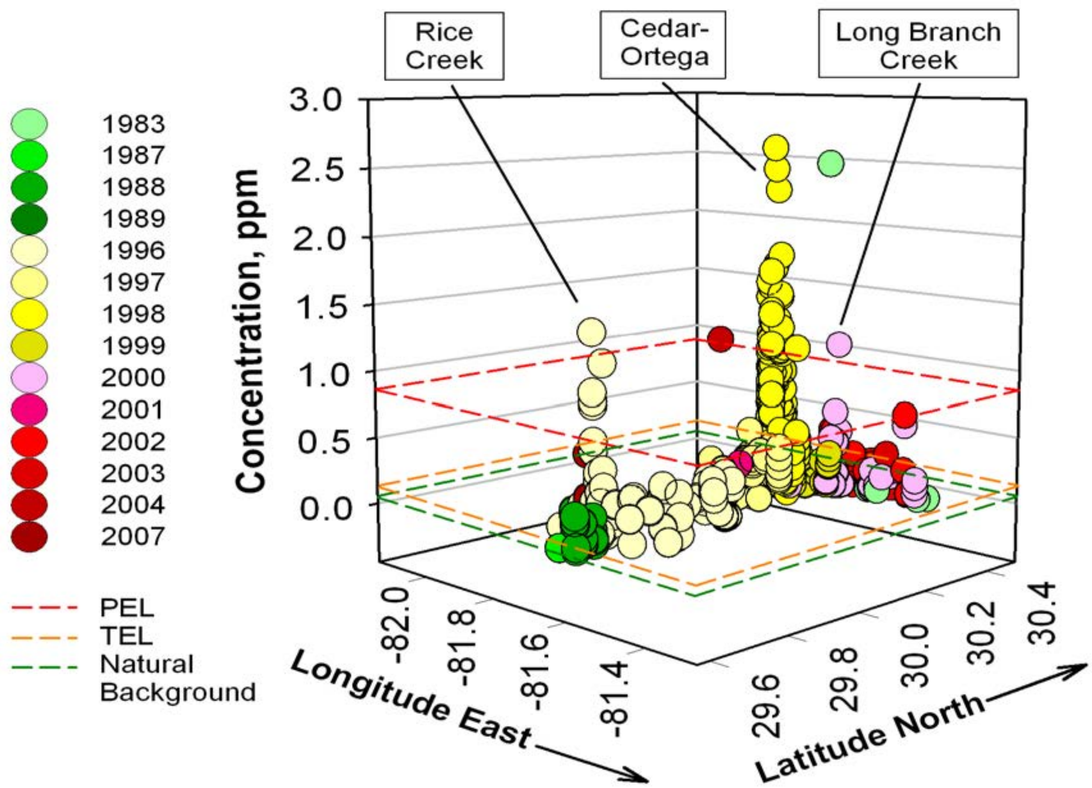


Figure 5.36 Mercury Sediment Quality Guidelines and LSJR sediment hot spots (scale of mercury concentrations does not show Rice Creek 2007 maxima). See text in Section 5.2 for data sources.

5.5.4.3. 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 5.37, 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. Those data, collected throughout Florida's coastal and offshore waters, resulted in impaired designations for the marine and estuarine mainstem 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 2016**). 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 mainstem, tributaries, and large connected lakes, fish have been extensively sampled in the last 10 years (Figure 5.38). 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 mainstem, 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**).

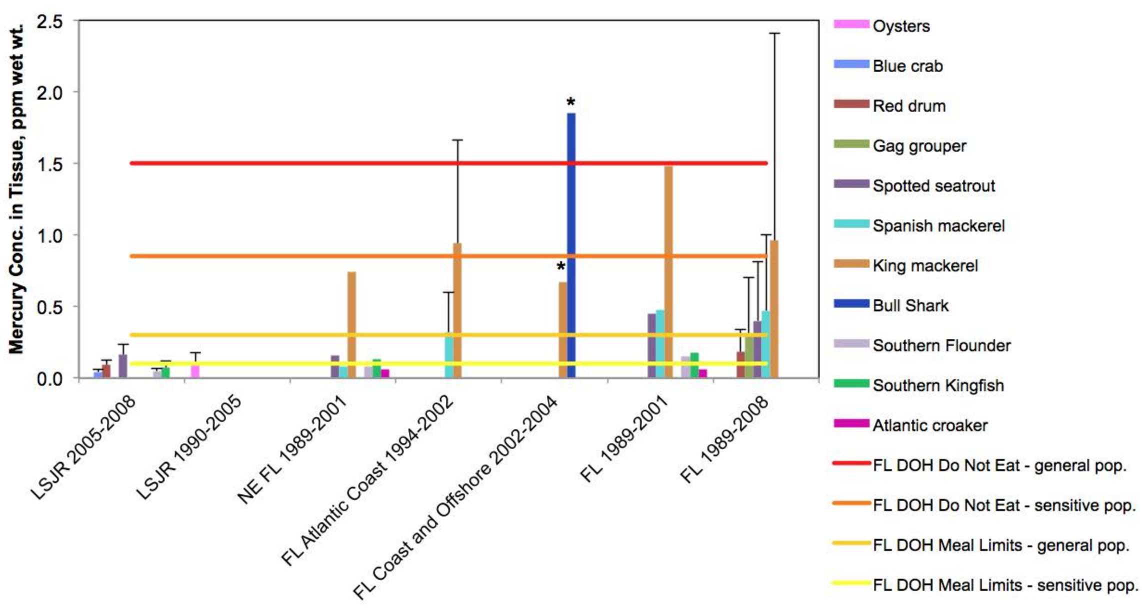


Figure 5.37 Average mercury concentrations in estuarine and marine invertebrates and fish caught in coastal waters, offshore, and in the LSJR north of Doctors Lake. An asterisk means the data set was used for 2009 303(d) impaired water listing for the marine/estuarine mainstem and 7 tributaries north of Doctors Lake. Standard deviation bars are shown. Data sources include ***Adams et al. 2003; Adams and McMichael Jr 2007; NOAA 2007b; Brodie 2008; Axelrad 2010; Goff 2010****.*

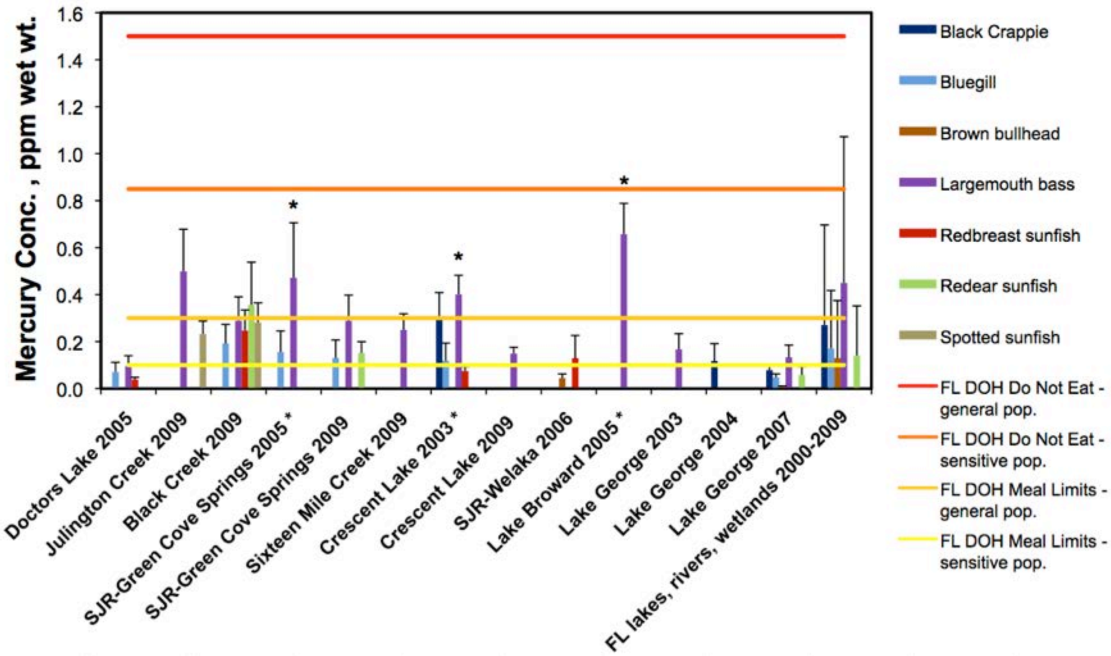


*Figure 5.38 Average mercury concentrations in freshwater fish caught in the LSJR mainstem and tributaries south of Doctors Lake, as well as other Florida waterways. An asterisk means the data set was used for 2009 303(d) impaired water listing for the indicated water bodies in the LSJRB. Data sources include **Axelrad 2010; Goff 2010; Lange 2010**.*

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.

5.5.4.4. Point Sources of Mercury in the LSJR Region

In 2013, 558 pounds of atmospheric mercury emissions in the LSJR region were from four primary industries, including stone/clay/glass (30%), electric utilities (30%), primary metals (25%), and cement (15%). Emissions from gypsum and steel production have grown since 2008, offsetting reductions by the electric utility industry (Figure 5.39). St. Johns River Power Plant and Northside Generating Station reduced their mercury emissions by 71% between 2001 and 2013 (Figure 5.33). While 10 facilities reported mercury emissions, five were responsible for 99% of total atmospheric mercury emissions in 2013 (Figure 5.40).

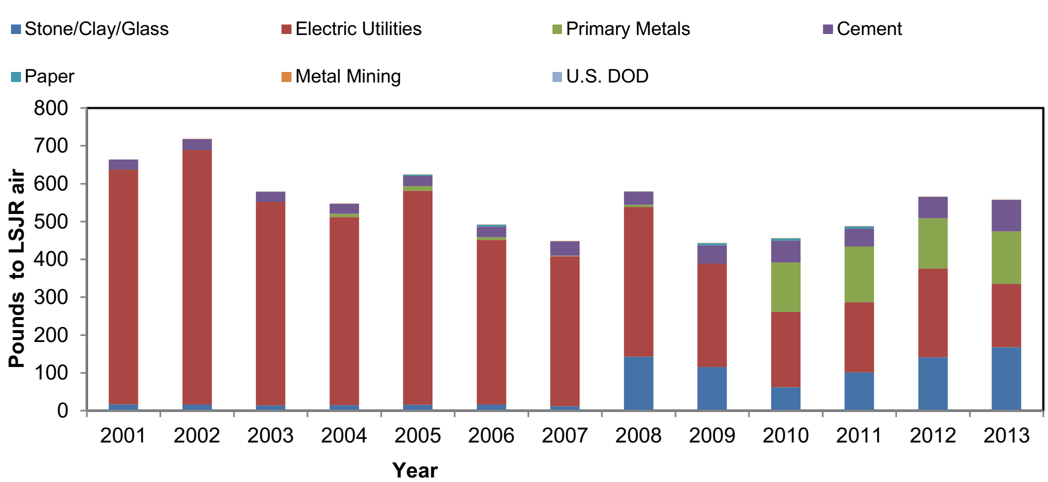


*Figure 5.39 Trends and status of emissions of mercury into the atmosphere of the nine-county LSJR basin by industry as reported in the Toxics Release Inventory (**EPA 2015d**).*

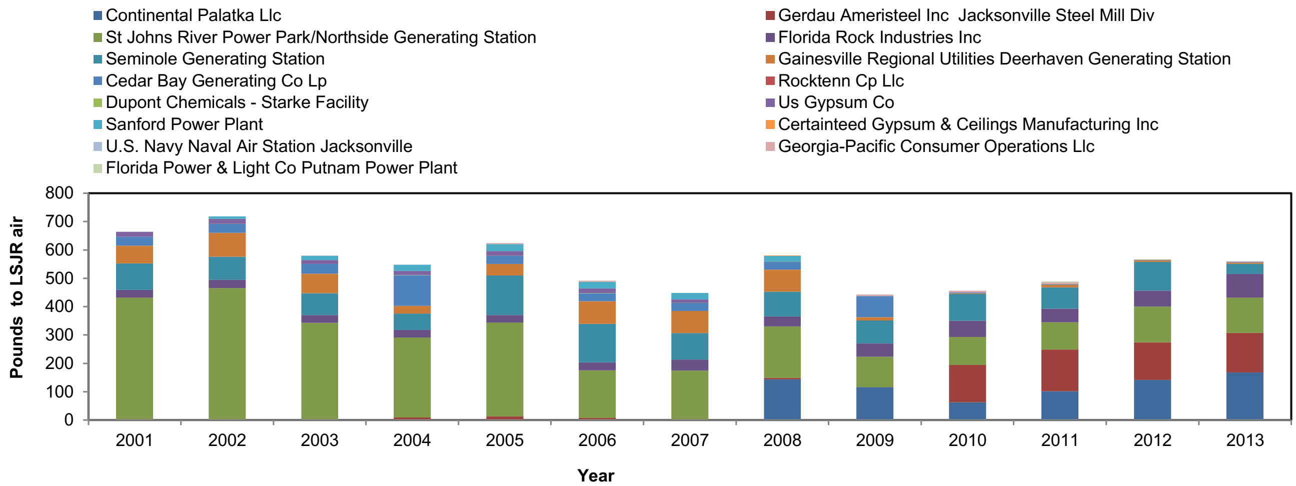


*Figure 5.40 Trends and status of emissions of mercury into the atmosphere of the nine-county LSJR basin by the facilities (**EPA 2015d**).*

Mercury releases into the LSJR and tributaries significantly dropped in 2004 with Seminole Generating station dramatically reducing its output of mercury. Coincident with reductions in atmospheric emissions since 2006, St. Johns River Power Park and Northside Generating Station steadily increased their discharges of mercury into surface water until 2011. However, in the subsequent two years there was a dramatic decrease in mercury discharges by that facility. Total discharges of mercury into the LSJR have been reduced by nearly 75% since 2001 (Figure 5.41). The RSEI model of chronic human health toxicity indicates that mercury releases to water by Seminole Electric is among the top potential risks compared to all releases in the region (**EPA 2013e**). However, we are unable to fully assess the importance of mercury because St. Johns River Power Park/Northside Generating Station, a major discharger, is not included in the RSEI modeling (see Section 5.3).

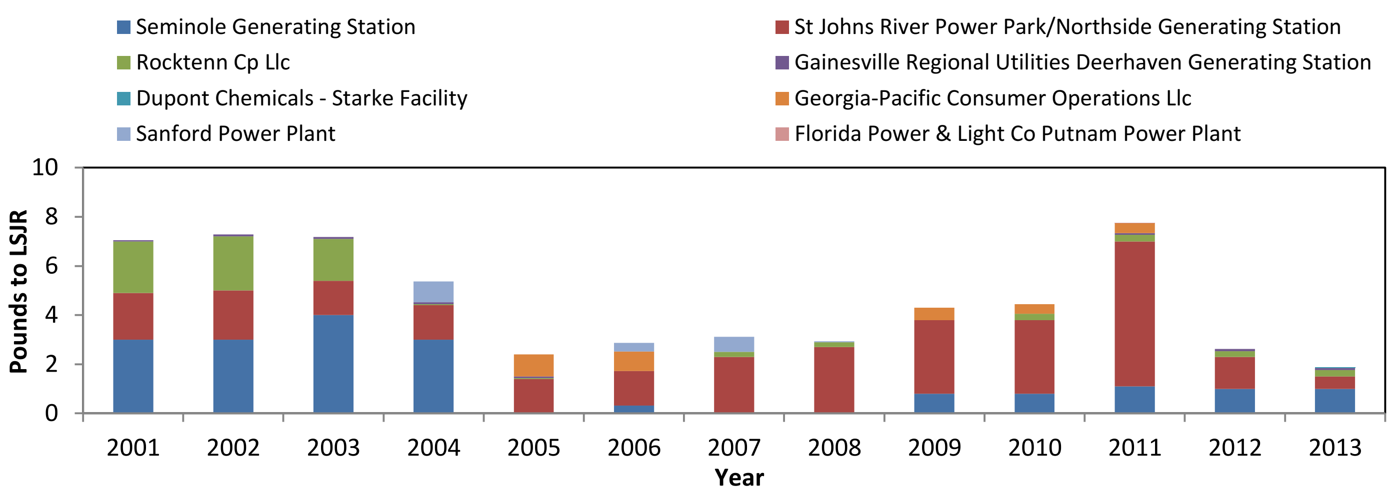


*Figure 5.41 Trends and status of discharges of mercury into the LSJR and its tributaries by facility as reported by the Toxics Release Inventory (**EPA 2015d**).*

5.6. Polychlorinated Biphenyls (PCBs)

5.6.1. Background and Sources: 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 the EPA (**EPA 1979**). In the 1980s, Jacksonville was the site of several electrical testing and service businesses which intentionally and unintentionally dispersed PCB-contaminated fluids (i.e., waste oil) into or near the LSJR. Waste oil uses and spills from locomotive wastes has also contributed PCBs near the LSJR. 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. 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. 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. Fate: PCBs

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.

5.6.3. Toxicity: PCBs

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 that 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 (**Fisk et al. 2001; Cailleaud et al. 2009**) 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. However, **Sepulveda et al. 2004** also recently reported thiamine deficiency in Florida alligators as another potential cause of the population declines.

Due to their endocrine-disrupting properties, PCBs may threaten aquatic ecosystems at both the individual and the population level.

5.6.4. Current Status: PCBs in Sediments

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 5.42). 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**).

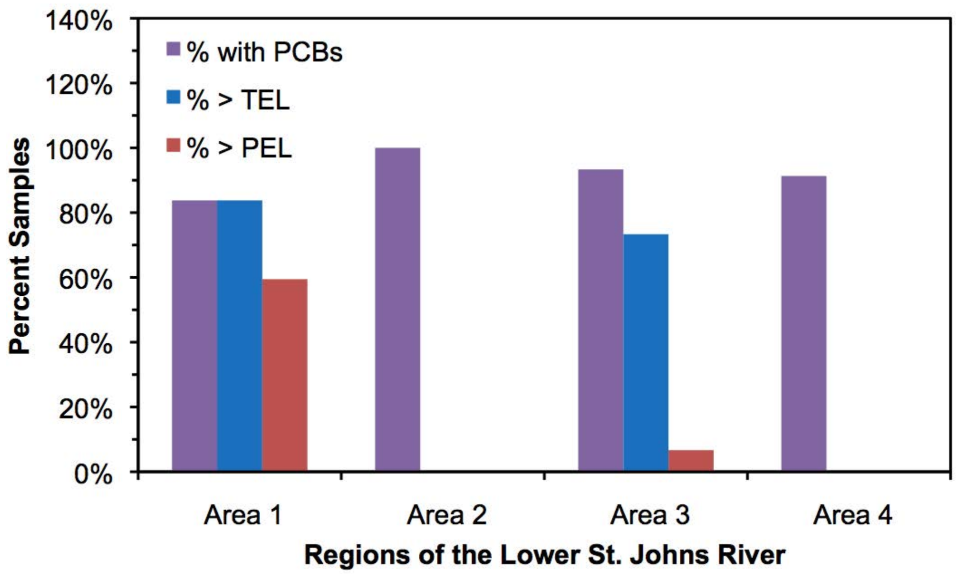


Figure 5.42 Percentage of sediment samples from 2000-2007 that contain PCBs and have PCBs concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for PCBs. See text in Section 5.2 for data sources.

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 mainstem 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 5.43).

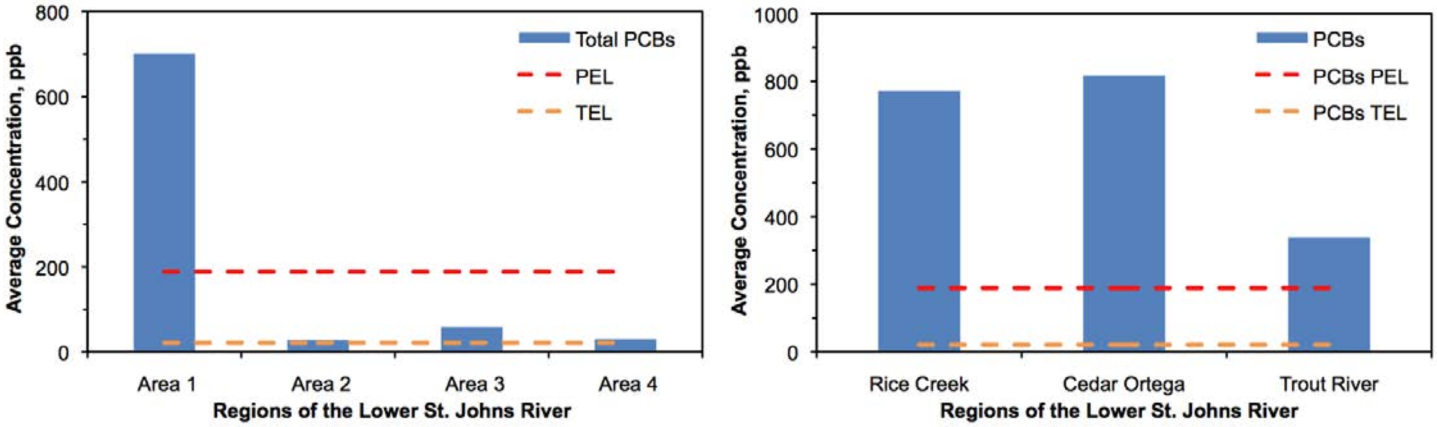


Figure 5.43 Average concentrations of PCBs in sediments from 2000-2007 in the four areas of the LSJR and in three streams in Area 1. Sediment quality guidelines for PCBs are shown as dashed lines. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data sources.

5.6.5. *Trends: PCBs in Sediments*

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.

5.6.6. *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. Previously, the **STATUS** of PCBs in sediments was ***unsatisfactory***, and the **TREND** was ***unchanged***; however, PCBs were not evaluated in this year's report.

5.7. Pesticides

5.7.1. *Background and Sources: Pesticides*

Pesticides are diverse, primarily including insecticides, herbicides, fungicides and rodenticides. 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 different 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 (OC's; 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. 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 2012b**). 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 dichlorodiphenyltrichloroethane (DDT) and its degradation products, dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD) are also reviewed.

5.7.2. *Fate: Pesticides*

OCs, such as 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, DDE and DDD. This class of insecticides proved to be highly effective and persistent, which was ideal for remediating target pests, but resulted in very long term environmental impacts. These chemicals also have broad spectrum toxicity, meaning they can affect a variety of species, including non-target species. Additionally, like PCBs they can biomagnify up the food chain and resist chemical breakdown in the environment (**Woodwell et al. 1967**). Because of their chemical structure, OCs primarily partition into the fat tissue of biota and primarily the organic fraction of sediment. A biomagnification assessment in the Carman's 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 can 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.

5.7.3. *Toxicity: Pesticides*

Due to their prevalence in the LSJR and toxicity, this review will focus on insecticides. 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. 1994; Guillette Jr. et al. 1999**). 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.

5.7.4. Status and Trends: Pesticides in Sediments

Organochlorine pesticides have been found all throughout the LSJR sediments for years (Figure 5.44), 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 5.45).

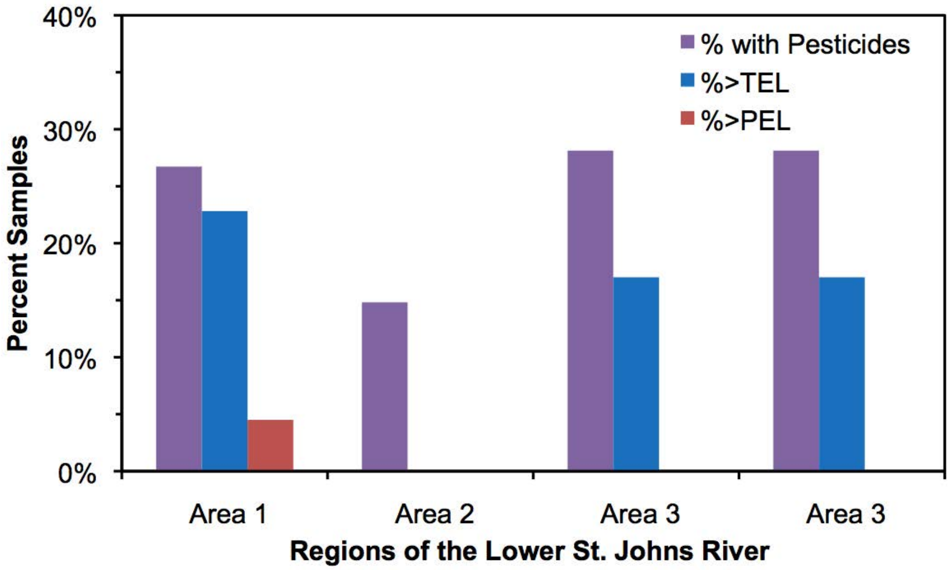


Figure 5.44 Percentage of sediment samples from 2000-2007 that contain organochlorine pesticides and have concentrations that exceed Threshold Effects Levels (TEL) and Probable Effects Levels (PEL) for one or more pesticides. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data sources.

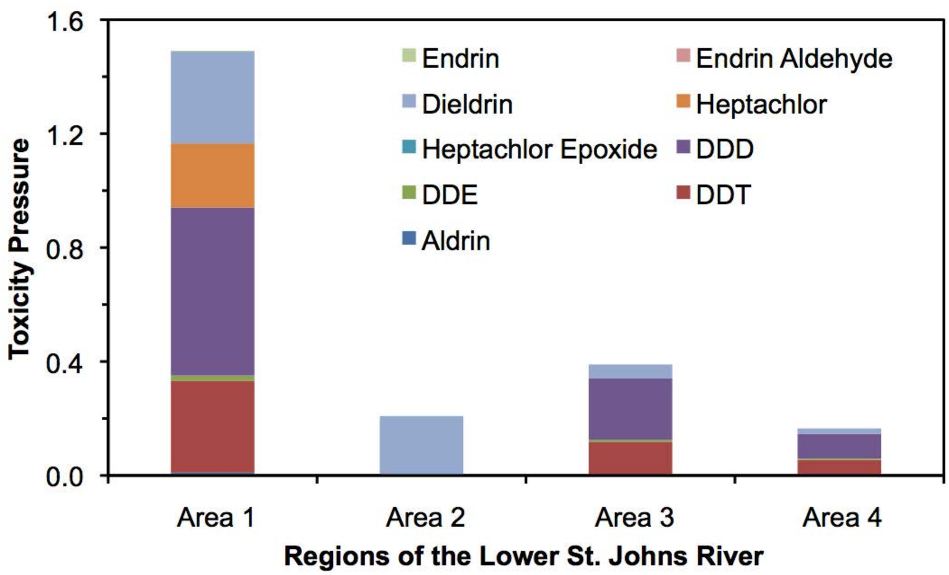


Figure 5.45 Toxicity pressure from different organochlorine pesticides and their degradation products. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data sources.

5.7.5. *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. Previously, the **STATUS** of organochlorine pesticides in sediments was ***unsatisfactory*** while the **TREND** was ***unchanged***; however, pesticides were not evaluated in this year's report.

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 5.46). 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 sediments 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.

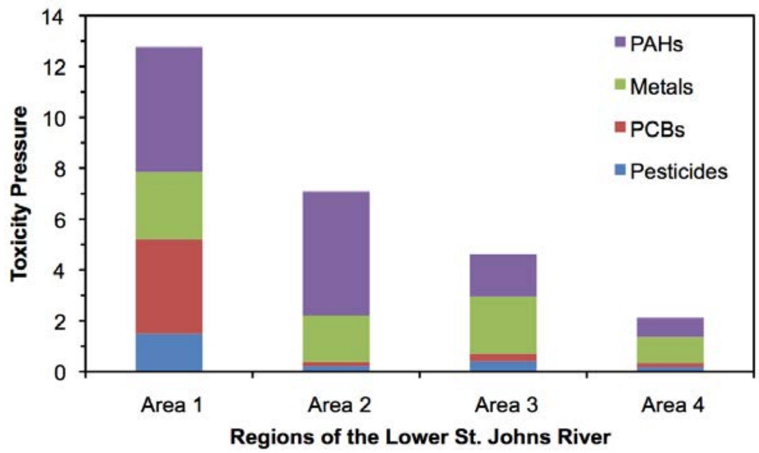


Figure 5.46 Average cumulative toxicity pressures of contaminants in sediments in different areas of the LSJR from 2000 – 2007. Area 1 – western tributaries; Area 2 – north arm; Area 3 – north mainstem; Area 4 – south mainstem. See text in Section 5.2 for data sources.

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. Relocation of the discharge of a pulp and paper mill effluent from the creek to the mainstem in 2013 will have an unknown impact on the sediment contaminants discussed. 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 mainstem portion of the LSJR has contamination that may affect sensitive organisms.

Overall, the mass of contaminants released to the atmosphere from point sources in the LSJR region has significantly declined over a decade. However, little change in surface water discharges has occurred and there have been significant increases in discharges of some metals. Water concentrations of several metals have generally declined in the last few years in the mainstem and are generally below water quality criteria, though exceptions are copper and silver. Continued efforts are needed to reduce pollutant loadings through stormwater control projects, permitting and best management practices.

6. 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 which 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 DEP

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 duration of twenty-four hours

Drainage basin - the area of land which 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 which 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 which 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 which 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

Mainstem - 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 which 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 which originated from its current habitat

Naturalized - an adapted, non-native species which grows or multiplies as if native

Nemerteans - flatworms

Nestling - bird too young to leave the nest

Neurotoxin - substance which 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 which 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 which 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 which 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 which 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 which flows into the mainstem 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 which 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

7. References

The references below have been checked for accuracy as part of the preparation of the report and all URLs contained within them were live as of July 20th, 2018. Each reference that is available online has also been added to the SJR Digital Archive (SJRDA) available at https://sjrda.unf.edu to ensure that the materials are permanently available. Those entries with a URL starting with http://sjrda.unf.edu/items/view have already disappeared from their original links and are thus only available online in the SJRDA. References where the URL starts with http://sjrda.unf.edu/items/forward are still available online, however due to problems with some URLs in PDF files, they do not link correctly when converted to PDF, so the forwarding function at the SJRDA site is used avoid this problem.

Abbott, G., J. H. Landsberg, A. R. Reich, K. A. Steidinger, S. Ketchen and C. Blackmore. 2009. Resource Guide for Public Health Response to Harmful Algal Blooms in Florida. Tallahassee (FL): http://research.myfwc.com/publications/publication_info.asp?id=58596 Accessed July 15, 2015.

Ackerman, B. B. 1995. Aerial Surveys of Manatees: A Summary and Progress Report. (In Population Biology of the Florida Manatee (*Trichechus manatus latirostris*)). T. J. O'Shea, B. B. Ackerman and H. F. e. Percival (Eds). Washington (DC): National Biological Service (NBS). 13-33. https://www.fort.usgs.gov/sites/default/files/products/publications/2364/2364.pdf Accessed July 15, 2015.

Adams, D. H. and R. H. McMichael Jr. 2001. Mercury Levels in Marine and Estuarine Fishes of Florida. St. Petersburg (FL): http://f50006a.eos-intl.net/ELIBSQL12_F50006A_Documents/Techincal Report TR-6_R.pdf Accessed July 15, 2015.

Adams, D. H. and R. H. McMichael Jr. 2007. Mercury in King Mackerel, *Scomberomorus cavalla*, and Spanish Mackerel, *S. maculatus*, From Waters of the South-eastern USA: Regional and Historical Trends. Marine and Freshwater Research; 58(2):187-193. 10.1071/MF06096 http://dx.doi.org/10.1071/MF06096 Accessed July 15, 2015.

Adams, D. H., R. H. McMichael Jr and G. E. Henderson. 2003. Mercury Levels in Marine and Estuarine Fishes of Florida 1989-2001. St. Petersburg (FL): http://f50006a.eos-intl.net/ELIBSQL12_F50006A_Documents/Technical Report TR-9_R.pdf Accessed July 15, 2015.

Adamus, C., D. Clapp and S. Brown. 1997. Surface Water Drainage Basin Boundaries of the St. Johns River Water Management District: A Reference Guide. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/TP/SJ97-1.pdf Accessed July 15, 2015.

AEF. 2016. More About Bald Eagles. Pigeon Forge (TN): The American Eagle Foundation (AEF). http://www.eagles.org/programs/eagle-facts/more-about-bald-eagles.php Accessed April 1, 2016

AEF. 2018. More About Bald Eagles. Pigeon Forge (TN): The American Eagle Foundation (AEF). http://www.eagles.org/programs/eagle-facts/more-about-bald-eagles.php Accessed April 10, 2018

Alexander, C. R., R. G. Smith, F. D. Calder, S. J. Schropp and H. L. Windom. 1993. The Historical Record of Metal Enrichment in Two Florida Estuaries. Estuaries and Coasts; 16(3B):627-637. 10.2307/1352800 http://dx.doi.org/10.2307/1352800 Accessed July 15, 2015.

Alsop, D. H. and C. M. Wood. 2000. Kinetic Analysis of Zinc Accumulation in the Gills of Juvenile Rainbow Trout: Effects of Zinc Acclimation and Implications for Biotic Ligand Modeling. Environmental Toxicology and Chemistry; 19(1911-1918. 10.1002/etc.5620190728 http://dx.doi.org/10.1002/etc.5620190728 Accessed July 15, 2015.

Anderson, K., J. Whitlock and V. Harwood. 2005. Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. Applied and Environmental Microbiology; 71(6):3041-3048. http://aem.asm.org/content/71/6/3041.full Accessed June 14, 2016.

Anderson, W. and D. A. Goolsby. 1973. Flow and Chemical Characteristics of the St. Johns River at Jacksonville, Florida. Tallahassee (FL): http://www.aquaticcommons.org/1212/1/anderson_flow.pdf Accessed July 15, 2015.

Armingeon, N. 2008. *Personal Communication* to P. Welsh.

Ashley, K. H. 2010. Mocama Archaeology. Jacksonville (FL): University of North Florida Archaeology Laboratory. http://www.unf.edu/~kashley/Mocama.html Accessed July 15, 2015

ATSDR. 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons. Atlanta (GA): http://www.atsdr.cdc.gov/toxprofiles/tp69.pdf Accessed July 15, 2015.

ATSDR. 1999. Toxicological Profile for Mercury. Atlanta (GA): http://www.atsdr.cdc.gov/toxprofiles/tp46.pdf Accessed July 15, 2015.

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (PCBs). Atlanta (GA): http://www.atsdr.cdc.gov/ToxProfiles/tp17.pdf Accessed July 15, 2015.

Audubon. 2018. The 117th Christmas Bird Count. New York (NY): National Audubon Society. http://www.audubon.org/conservation/science/christmas-bird-count/ Accessed March 10, 2018

Axelrad, D. 2010. *Personal Communication* to L. Sonnenberg.

Bacopoulos, P., Y. Funakoshi, S. C. Hagen, A. T. Cox and V. J. Cardone. 2009. The Role of Meteorological Forcing on the St. Johns River (Northeastern Florida). Journal of Hydrology; 369(1-2):55-70. 10.1016/j.jhydrol.2009.02.027 http://dx.doi.org/10.1016/j.jhydrol.2009.02.027 Accessed July 15, 2015.

Baird, C. 1995. Titlle. (Eds). ISBN: 978-0716731535. New York (NY): W.H. Freeman and Company. http://www.amazon.com/dp/0716731533 Accessed July 15, 2015.

Barron, M. G., M. G. Carls, R. Heintz and S. D. Rice. 2004. Evaluation of Fish Early Life-stage Toxicity Models of Chronic Embryonic Exposures to Complex Polycyclic Aromatic Hydrocarbon Mixtures. Toxicological Sciences; 78(1):60-67. 10.1093/toxsci/kfh051 http://dx.doi.org/10.1093/toxsci/kfh051 Accessed July 15, 2015.

Barron, M. G., J. A. Hansen and J. Lipton. 2002. Association Between Contaminant Tissue Residues and Effects in Aquatic. (In OrganismsReviews of Environmental Contamination and Toxicology). G. W. e. Ware (Eds). ISBN: 978-0387953397. Springer-Verlag. 1-37. http://www.springer.com/us/book/9780387953397 Accessed July 15, 2015.

Bartram, W. 1928. Titlle. M. Van Doren and editor (Eds). ISBN: 978-0486200132. New York (NY): Dover Publications. http://store.doverpublications.com/0486200132.html Accessed July 15, 2015.

Bartram, W. 1998. Titlle. (Eds). ISBN: 978-0820320274. Athens (GA): University of Georgia Press. http://www.ugapress.org/index.php/books/travels_of_william_bartram/ Accessed July 15, 2015.

Baskaran, S., R. S. Kookana and R. Naidu. 1999. Degradation of Bifenthrin, Chlorpyrifos and Imidacloprid in Soil and Bedding Materials at Termiticidal Application Rates. Pesticide Science; 55(12):1222-1228. 10.1002/(SICI)1096-9063(199912)55:12<1222::AID-PS83>3.0.CO;2-7 http://onlinelibrary.wiley.com/resolve/openurl?genre=article&title=Pesticide%20Science&date=1999&volume=55&issue=12&spage=1222 Accessed July 15, 2015.

Batzer, D. P. and S. A. Wissinger. 1996. Ecology of Insect Communities in Nontidal Wetlands. Annual Review of Entomology; 41(1):75-100. 10.1146/annurev.en.41.010196.000451 http://dx.doi.org/10.1146/annurev.en.41.010196.000451 Accessed July 15, 2015.

Baussant, T., S. Sanni, G. Jonsson, A. Skadsheim and J. F. Børseth. 2001a. Bioaccumulation of Polycyclic Aromatic Compounds: 1. Bioconcentration in Two Marine Species and in Semipermeable Membrane Devices During Chronic Exposure to Dispersed Crude Oil. Environmental Toxicology and Chemistry; 20(6):1175-1184. 10.1002/etc.5620200606 http://dx.doi.org/10.1002/etc.5620200606 Accessed July 15, 2015.

Baussant, T., S. Sanni, A. Skadsheim, G. Jonsson, J. F. Børseth and B. Gaudebert. 2001b. Bioaccumulation of Polycyclic Aromatic Compounds: 2. Modeling Bioaccumulation in Marine Organisms Chronically Exposed to Dispersed Oil. Environmental Toxicology and Chemistry; 20(6):1185-1195. 10.1002/etc.5620200607 http://dx.doi.org/10.1002/etc.5620200607 Accessed July 15, 2015.

Bear-Hull, D. 2018. *Personal Communication* to G. Pinto.

Beck, C. A. 2018. *Personal Communication* to G. Pinto.

Beck, C. A. and J. P. Reid. 1998. An Automated Photo-Identification Catalog for Studies of the Life History of the Florida Manatee. (In Population Biology of the Florida Manatee (*Trichechus manatus latirostris*)). T. J. O'Shea, B. B. Ackerman and H. F. e. Percival (Eds). Washington (DC): National Biological Service (NBS). 120-134. http://gcmd.nasa.gov/records/GCMD_usgsbrdfcscsirenia.html Accessed July 15, 2015.

Bengtson, J. L. 1981. Ecology of Manatees (*Trichechus manatus*) in the St. Johns River, Florida. Ph.D.; University of Minnesota. http://prime2.oit.umn.edu/primo_library/libweb/action/dlDisplay.do?vid=TWINCITIES&docId=UMN_ALMA21376681770001701 Accessed July 15, 2015.

Benke, A. C. and C. E. Cushing. 2005. Titlle. (Eds). ISBN: 978-0080454184. Burlington (MA): Elsevier/Academic Press. http://store.elsevier.com/product.jsp?isbn=9780080454184 Accessed July 15, 2015.

Bergeron, J. M., D. Crews and J. A. McLachlan. 1994. PCBs as Environmental Estrogens: Turtle Sex Determination as a Biomarker of Environmental Contamination. Environmental Health Perspectives; 102(9):http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1567153/ Accessed July 15, 2015.

Bergman, M. J. 1992. Volume 2 of the Lower St. Johns River Basin Reconnaissance: Surface Water Hydrology. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/TP/SJ92-1.pdf Accessed July 15, 2015.

Bernardes, S., J. He, S. T. Bacchus, M. Madden and T. Jordan. 2014. Mitigation Banks and Other Conservation Lands at Risk from Preferential Groundwater Florw and Hydroperiod Alterations by Existing and Proposed Northeast Florida Mines. Journal of Sustainable Development; 7(4):225-261. 10.5539/jsd.v7n4p225 http://dx.doi.org/10.5539/jsd.v7n4p225 Accessed July 15, 2015.

Best, R. C. 1981. Food and Feeding Habits of Wild and Captive Sirenia. Mammal Review; 11(1):3-29. 10.1111/j.1365-2907.1981.tb00243.x http://dx.doi.org/10.1111/j.1365-2907.1981.tb00243.x Accessed July 15, 2015.

Bielmyer, G. K., K. V. Brix, T. R. Capo and M. Grosell. 2005a. The Effects of Metals on Embryo-larval and Adult Life Stages of the Sea Urchin, *Diadema antillarum*. Aquatic Toxicology; 74(3):254-268. 10.1016/j.aquatox.2005.05.016 http://dx.doi.org/10.1016/j.aquatox.2005.05.016 Accessed July 15, 2015.

Bielmyer, G. K., J. B. Bullington, C. A. DeCarlo, S. J. Chalk and K. Smith. 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; 52(6):753-760. 10.1093/icb/ics045 http://dx.doi.org/10.1093/icb/ics045 Accessed July 15, 2015.

Bielmyer, G. K., C. A. DeCarlo, C. Morris and T. Carrigan. 2013. The Influence of Salinity on Acute Nickel Toxicity to the Two Euryhaline Fish Species, *Fundulus heteroclitus* and *Kryptolebias marmoratus*. Environmental Toxicology and Chemistry; 32(6):1354-1359. 10.1002/etc.2185 http://dx.doi.org/10.1002/etc.2185 Accessed July 15, 2015.

Bielmyer, G. K., D. Gatlin, J. J. Isely, J. R. Tomasso and S. J. Klaine. 2005b. Responses of Hybrid Striped Bass to Waterborne and Dietary Copper in Freshwater and Saltwater. Comparative Biochemistry and Physiology - Part C: Toxicology & Pharmacology; 140(1):131-137. 10.1016/j.cca.2005.01.014 http://dx.doi.org/10.1016/j.cca.2005.01.014 Accessed July 15, 2015.

Bielmyer, G. K. and M. Grosell. 2011. Emerging Issues in Marine Metal Toxicity. (In Surface Chemistry, Bioavailability and Metal Homeostasis in Aquatic Organisms: An Integrated Approach). N. Bury and R. e. Handy (Eds). ISBN: 978-1907491023. London (England): Kings College. 129-158. http://www.sebiology.org/publications/Book_Series.html Accessed July 15, 2015.

Bielmyer, G. K., M. Grosell and K. Brix. 2006a. Toxicity of Silver, Zinc, Copper, and Nickel to the Copepod *acartia tonsa* Exposed via a Phytoplankton Diet. Environmental Science and Technology; 40(6):2063-2068. 10.1021/es051589a http://dx.doi.org/10.1021/es051589a Accessed July 15, 2015.

Bielmyer, G. K., M. Grosell, P. R. Paquin, R. Mathews, K. B. Wu, R. C. Santore and K. V. Brix. 2007. Validation Study of the Acute Biotic Ligand Model for Silver. Environmental Toxicology and Chemistry; 26(10):2241-2246. 10.1897/06-634R.1 http://dx.doi.org/10.1897/06-634R.1 Accessed July 15, 2015.

Bielmyer, G. K., T. A. Jarvis, B. T. Harper, B. Butler, L. Rice, S. Ryan and P. McLoughlin. 2012b. Metal Accumulation From Dietary Exposure in the Sea Urchin, *Strongylocentrotus droebachiensis*. Archives of Environmental Contamination and Toxicology; 63(1):86-94. 10.1007/s00244-012-9755-6 http://dx.doi.org/10.1007/s00244-012-9755-6 Accessed July 15, 2015.

Bielmyer, G. K., J. R. Tomasso and S. J. Klaine. 2006b. Physiological Responses of Hybrid Striped Bass to Aqueous Copper in Freshwater and Saltwater. Archives of Environmental Contamination and Toxicology; 50(4):531-538. 10.1007/s00244-005-0131-7 http://dx.doi.org/10.1007/s00244-005-0131-7 Accessed July 15, 2015.

Bielmyer-Fraser, G. K., M. N. Waters, C. G. Duckworth, P. Patel, B. Webster, A. Blocker, C. H. Crummey, A. Duncan, S. Nwokike, C. Picariello, J. T. Ragan, E. L. Schumacher, R. Tucker, E. Tuttle and C. Wiggins. 2017. Assessment of metal contamination in the biota of four rivers experiencing varying degrees of human Impact. Environmental Monitoring and Assessment; 189(23. DOI:10.1007/s10661-016-5738-9 https://link.springer.com/article/10.1007/s10661-016-5738-9 Accessed March 10, 2017.

Blake, N. M. 1980. Titlle. (Eds). ISBN: 978-0813006420. Tallahassee (FL): University Press of Florida. http://florida.theorangegrove.org/og/items/626e4cf0-0156-898a-745c-76b32eeab65e/1/ Accessed July 15, 2015.

Boothman, W. S., D. J. Hansen, W. J. Berry, D. L. Robson, A. Helmstetter, J. M. Corbin and S. D. Pratt. 2001. Biological Response to Variation of Acid-Volatile Sulfides and Metals in Field-exposed Spiked Sediments. Environmental Toxicology and Chemistry; 20(2):264-272. 10.1002/etc.5620200206 http://dx.doi.org/10.1002/etc.5620200206 Accessed July 15, 2015.

Borgert, C. J., T. S. Gross, P. D. Guiney, T. G. Osimitz, B. Price and C. Wells. 2004. Interactive Effects of p,p'-Dichlorodiphenyldichloroethylene and Methoxychlor on Hormone Synthesis in Largemouth Bass Ovarian Cultures. Environmental Toxicology and Chemistry; 23(8):1947-1956. 10.1897/03-424 http://dx.doi.org/10.1897/03-424 Accessed July 15, 2015.

Boström, B., J. M. Anderson, S. Fleischer and M. Jansson. 1988. Exchange of Phosphorus Across the Sediment-water Interface. Hydrobiologia; 170(1):229-244. 10.1007/BF00024907 http://dx.doi.org/10.1007/BF00024907 Accessed July 15, 2015.

Boström, B., M. Jansson and C. Forsberg. 1982. Phosphorus Release from Lake Sediments. (In Nutrient Remobilization from Sediments and its Limnological Effects). H. e. Bernhardt (Eds). ISBN: 978-3510470167. Stuttgart (Germany): E.

Schweizerbart'sche Verlagsbuchhandlung. 5-59. http://www.schweizerbart.de/publications/detail/isbn/3510470168 Accessed July 15, 2015.

Boudreaux, M. L. and L. J. Walters. 2006. *Mytella Charruana* (Bivalvia: Mytilidae): A New, Invasive Bivalve in Mosquito Lagoon, Florida. The Nautilus; 120(1):34-36. http://www.shellmuseum.org/nautilus/nautilus_contents_120.html Accessed July 15, 2015.

Boustany, R. G., T. C. Michot and R. F. Moss. 2003. Environmental Factors Affecting the Distribution and Health of Submersed Aquatic Plants in the Lower St. Johns River: Phase V - Final Report: Effect of Nutrients and Salinity Pulse on Biomass and Growth on *Vallisneria americana* in Lower St. Johns River, FL, USA. Palatka (FL): Accessed NA.

Bowman, R. D. 2009. *Personal Communication* to H. McCarthy.

Bradbury, S. P. and J. R. Coats. 1989. Toxicokinetics and Toxicodynamics of Pyrethroids Insecticides in Fish. Environmental Toxicology and Chemistry; 8(5):10.1002/etc.5620080503 http://dx.doi.org/10.1002/etc.5620080503 Accessed July 15, 2015.

Brenner, M., C. L. Schelske and L. W. Keenan. 2001. Historical Rates of Sediment and Nutrient Accumulation in Marshes of the Upper St. Johns River Basin, Florida, USA. Journal of Paleolimnology; 26(3):10.1023/A:1017578330641 http://dx.doi.org/10.1023/A:1017578330641 Accessed July 15, 2015.

Brodie, R. 2008. *Personal Communication* to H. McCarthy.

Brodie, R. 2009. *Personal Communication* to D. McCarthy.

Brodie, R. 2016. *Personal Communication* to G. Pinto.

Brody, R. W. 1994. Volume 6 of the Lower St. Johns River Basin Reconnaissance: Biological Resources. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/TP/SJ94-2.pdf Accessed July 15, 2015.

Brody, S. D., S. Zahran, W. E. Highfield, H. Grover and A. Vedlitz. 2008. Identifying the Impact of the Built Environment on Flood Damage in Texas. Disaster; 32(1):10.1111/j.1467-7717.2007.01024.x http://dx.doi.org/10.1111/j.1467-7717.2007.01024.x Accessed July 15, 2015.

Brody, S. D., S. Zahran, P. Maghelal, H. Grover and W. E. Highfield. 2007. The Rising Costs of Floods: Examining the Impact of Planning and Development Decisions on Property Damage in Florida. Journal of the American Planning Association; 73(3):10.1080/01944360708977981 http://dx.doi.org/10.1080/01944360708977981 Accessed July 15, 2015.

Broman, D., C. Näuf, I. Lundbergh and Y. Zebühr. 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. Environmental Toxicology and Chemistry; 9(4):10.1002/etc.5620090404 http://dx.doi.org/10.1002/etc.5620090404 Accessed July 15, 2015.

Brooks, B. 2018. *Personal Communication* to G. Pinto.

Brooks, W. B. and T. F. Dean. 2008. Measuring the Breeding Status of the Southeast U.S. Population of Wood Storks. Waterbirds; 31(SP1):10.1675/1524-4695(2008)31[50:MTBSOT]2.0.CO;2 https://sjrda.unf.edu/items/forward/sjrda:65 Accessed July 15, 2015.

Brown, A. and P. Shi. 2014. Valuing the Economic Benefits of Florida's Conservation Lands. Durham (NC): http://hdl.handle.net/10161/8571 Accessed July 15, 2015.

Bruland, K. W. 1980. Oceanographic Distributions of Cadmium, Zinc, Nickel and Copper in the North Pacific. Earth and Planterary Science Letters; 47(2):10.1016/0012-821X(80)90035-7 http://www.sciencedirect.com/science/article/pii/0012821X80900357 Accessed July 15, 2015.

Bruland, K. W. 1983. Trace Elements in Seawater. (In Chemical Oceanography). J. P. Riley and R. e. Chester (Eds). ISBN: 978-0125886086. New York (NY): Academic Press. 157-220. http://www.amazon.com/dp/012588608X Accessed July 15, 2015.

Bryan, G. W. 1976. Some Aspects of Heavy Metal Tolerance in Aquatic Organisms. (In Effects of Pollutants on Aquatic Organisms). A. P. M. e. Lockwood (Eds). ISBN: 0521211034. Cambridge (England): University Press. 7-34. http://www.amazon.com/dp/0521211034 Accessed July 15, 2015.

Bryan, G. W. and L. G. Hummerstone. 1971. Adaptations of the Polychaete *Nereis diversicolor* to Estuarine Sediments Containing High Concentrations of Heavy Metals. I. General Observations and Adaptations to Copper. Journal of the Marine Biological Association U.K.; 51(4):10.1017/S0025315400018014 http://dx.doi.org/10.1017/S0025315400018014 Accessed July 15, 2015.

Buker, G. E. 1992. Titlle. (Eds). ISBN: 978-0872497900. Columbia (SC): University of South Carolina Press. http://ufdc.ufl.edu/NF00000148/00001 Accessed July 15, 2015.

Bullard, R. D. 1990. Titlle. (Eds). Oxford: Westview Press. Accessed April 1, 2018.

Bullivant, J. S. 1968. The Rate of Feeding of the Bryozaoan, *Zoobotryon verticillatum*. New Zealand Journal of Marine and Freshwater Research; 2(1):10.1080/00288330.1968.9515230 http://dx.doi.org/10.1080/00288330.1968.9515230 Accessed July 15, 2015.

Burger, J., J. A. Rodgers Jr. and M. Gochfeld. 1993. Heavy Metal and Selenium Levels in Endangered Wood Storks from Nesting Colonies in Florida and Costa Rica. Archives of Environmental Contamination and Toxicology; 24(4):10.1007/BF01146155 http://dx.doi.org/10.1007/BF01146155 Accessed July 15, 2015.

Burns Jr, J. W. 2008. Chapter 5. Toxic Cyanobacteria in Florida Waters. (In Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs). H. K. e. Hudnell (Eds). ISBN: 978-0387758640. New York (NY): Springer-Verlag. 127-137. http://dx.doi.org/10.1007/978-0-387-75865-7_5 Accessed July 15, 2015.

Burns Jr, J. W., A. D. Chapman, E. Messer and J. Konwinski. 1997. Submerged Aquatic Vegetation of the Lower St. Johns River. Palatka (FL): https://sjrda.unf.edu/items/view/sjrda:77 Accessed July 15, 2015.

Bury, N. R., P. A. Walker and C. N. Glover. 2003. Nutritive Metal Uptake in Teleost Fish. Journal of Experimental Biology; 206(1):10.1242/jeb.00068 http://dx.doi.org/10.1242/jeb.00068 Accessed July 15, 2015.

Cailleaud, K., H. Budzinski, K. Le Menach, S. Souissi and J. Forget-Leray. 2009. Uptake and Elimination of Hydrophobic Organic Contaminants in Estuarine Copepods: An Experimental Study. Environmental Toxicology and Chemistry; 28(2):10.1897/07-664.1 http://dx.doi.org/10.1897/07-664.1 Accessed July 15, 2015.

Campbell, D. 2009. *Personal Communication* to H. McCarthy.

Campbell, P. G. C. 1995. Interactions Between Trace Metals and Aquatic Organisms: A Critique of the Free-ion Activity Model. (In Metal Speciation and Bioavailability in Aquatic Systems). A. Tessier and D. R. e. Turner (Eds). ISBN: 978-0471958307. New York (NY): Wiley Interscience. 45-102. http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471958301.html Accessed July 15, 2015.

Campbell, P. G. C., P. R. Paquin, W. J. Adams, K. V. Brix, D. R. Juberg, R. C. Playle, C. J. Ruffing and R. S. Wentsel. 2000. Risk Assessment. (In Silver in the Environment: Transport, Fate, and Effects). A. W. Andren and T. W. e. Bober (Eds). ISBN:

978-1880611449. Pensacola (FL): Society of Environmental Toxicology and Chemistry (SETAC). 97-134. https://www.setac.org/store/ViewProduct.aspx?id=1037388 Accessed July 15, 2015.

Carls, M. G., J. W. Short and J. Payne. 2006. Accumulation of Polycyclic Aromatic Hydrocarbons by Neocalanus copepods in Port Valdez, Alaska. Marine Pollution Bulletin; 52(11):10.1016/j.marpolbul.2006.05.008 http://dx.doi.org/10.1016/j.marpolbul.2006.05.008 Accessed July 15, 2015.

Carlton, J. T. 1987. Patterns of Transoceanic Marine Biological Invasions in the Pacific Ocean. Bulletin of Marine Science; 41(2):None http://openurl.ingenta.com/content?genre=article&issn=0007-4977&volume=41&issue=2&spage=452&epage=465 Accessed July 15, 2015.

Carlton, J. T. 1992. Introduced Marine and Estuarine Mollusks of North America: An End-of-the-20th-Century Perspective. Journal of Shellfish Research; 11(2):http://www.biodiversitylibrary.org/page/15141774 Accessed July 15, 2015.

Carlton, J. T. 2012. *Personal Communication* to H. Lee and H. McCarthy.

Carlton, J. T. and J. B. Geller. 1993. Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms. Science; 261(5117):10.1126/science.261.5117.78 http://dx.doi.org/10.1126/science.261.5117.78 Accessed July 15, 2015.

CBSMiami. 2016. Former Governor Calls on Scott to Stop Water Bill. Miami (FL): CBS Miami. http://miami.cbslocal.com/2016/01/20/former-governor-calls-on-scott-to-stop-water-bill/ Accessed April 5, 2016

CCSSI. 2012. Titlle. (Eds). Washington (DC): National Governors Association, Common Core State Standards Initiative (CCSSI). http://www.p12.nysed.gov/ciai/common_core_standards/pdfdocs/ccssi_ela_standards.pdf Accessed April 1, 2018.

CEQ. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal. Washington (DC): http://georgewbush-whitehouse.archives.gov/ceq/wetlands/2008/index.html Accessed July 15, 2015.

CFWI. 2015. Central Florida Water Initiative. Orlando (FL): Central Florida Water Initiative (CFWI). http://cfwiwater.com/ Accessed

Chadwick, M. A., J. E. Thiele, A. D. Huryn, B. A. C. and D. R. Dobberfuhl. 2012. Effects of Urbanization on Macroinvertebrates in Tributaries of the St. Johns River, Florida, USA. Urban Ecosystems; 15(2):10.1007/s11252-011-0217-0 http://dx.doi.org/10.1007/s11252-011-0217-0 Accessed July 15, 2015.

Chapman, A. D. and C. L. Schelske. 1997. Recent Appearance of *Cylindrospermopsis* (Cyanobacteria) in Five Hypereutrophic Florida Lakes. Journal of Phycology; 33(2):10.1111/j.0022-3646.1997.00191.x http://dx.doi.org/10.1111/j.0022-3646.1997.00191.x Accessed July 15, 2015.

Chen, J., L. Theller, M. W. Gitau, B. A. Engel and J. M. Harbor. 2017. Urbanization Impacts On Surface Runoff Of The Contiguous United States. Journal of Environmental Management; 187(0):470-481. http://www.sciencedirect.com/science/article/pii/S0301479716308933 Accessed March 17, 2017.

Chorus, I. and J. e. Bartram (Eds). 1999. Toxic Cyanobacteria in Water. A Guide to their Public Health Consequences, Monitoring and Management. Bury St Edmunds, Suffolk, England: World Health Organization. http://www.who.int/water_sanitation_health/resourcesquality/toxicyanbact/en/ Accessed July 15, 2015.

CISEH. 2014. Early Detection & Distribution Mapping System (EDDMapS). Tifton, GA: University of Georgia (UGA), Center for Invasive Species and Ecosystem Health (CISEH). http://www.eddmaps.org/ Accessed July 15, 2015

CISEH. 2015. Early Detection & Distribution Mapping system (EDDMapS). Tifton, GA: University of Georgia (UGA), Center for Invasive Species and Ecosystem Health (CISEH). http://www.eddmaps.org/ Accessed December 20, 2015

CISEH. 2016. Early Detection & Distribution Mapping System (EDDMapS). Tifton, GA: University of Georgia (UGA), Center for Invasive Species and Ecosystem Health (CISEH). http://www.eddmaps.org/ Accessed March 17, 2017

Clesceri, L. S. 1989. Titlle. (Eds). ISBN: 978-0875531618. Baltimore (MD): American Public Health Association (APHA). http://www.standardmethods.org/ Accessed July 15, 2015.

Cohen, M. J., S. Carstenn and C. R. Lane. 2004. Floristic Quality Indices for Biotic Assessments of Depressional Marsh Condition in Florida. Ecological Applications; 14(3):10.1890/02-5378 http://dx.doi.org/10.1890/02-5378 Accessed July 15, 2015.

COJ. 2010. Environmental Compliance Department Mosquito Control FAQ. Jacksonville (FL): City of Jacksonville (COJ), Environmental and Compliance Department. http://www.coj.net/departments/regulatory-compliance/mosquito-control/frequently-asked-questions.aspx Accessed July 1, 2008

COJ. 2017. Assessment Plan Part V. B. Jacksonville (FL): N/A Accessed April 1, 2018.

COJ. 2018. City of Jacksonville Bill Information. City of Jacksonville (COJ) http://cityclts.coj.net/coj/COJBillList.asp?Bill=2015-0105 Accessed July 11, 2018

Collins, A. G. 1995. Introduction to Phoronida. Berkeley, CA: University of California Museum of Paleontology. http://www.ucmp.berkeley.edu/brachiopoda/phoronida.html Accessed July 15, 2015

Collins, A. G. 1999. Introduction to the Bryozoa: Moss Animals. Berkeley, CA: University of California Museum of Paleontology. http://www.ucmp.berkeley.edu/bryozoa/bryozoa.html Accessed July 15, 2015

Collins, A. G. 2000. Introduction to the Sipuncula: The Peanut Worms. Berkeley, CA: University of California Museum of Paleontology. http://www.ucmp.berkeley.edu/sipuncula/sipuncula.html Accessed July 15, 2015

Collins, A. G. 2001. Introduction to the Nemertini: Tied Up in Knots…. Berkeley, CA: University of California Museum of Paleontology. http://www.ucmp.berkeley.edu/nemertini/nemertini.html Accessed July 15, 2015

Congress. 1972a. Clean Water Act of 1972 ((33 U.S.C. § 1251 et seq.)). Washington (DC): 92nd Congress. http://www.epw.senate.gov/water.pdf Accessed July 15, 2015.

Congress. 1972b. Marine Mammal Protection Act of 1972 ((16 U.S.C. § 1531 et seq.)). Washington (DC): 92nd Congress. http://www.nmfs.noaa.gov/pr/pdfs/laws/mmpa.pdf Accessed July 15, 2015.

Congress. 1973. Endangered Species Act of 1973 ((16 U.S.C. § 1361 et seq.)). Washington (DC): 93rd Congress. http://www.nmfs.noaa.gov/pr/pdfs/laws/esa.pdf Accessed July 15, 2015.

Cooksey, C. and J. L. Hyland. 2007. Sediment Quality of the Lower St. Johns River, FL: An Integrative Assessment of Benthic Fauna, Sediment-Associated Stressors, and General Habitat Characteristics. Marine Pollution Bulletin; 54(1):10.1016/j.marpolbul.2006.09.007 http://dx.doi.org/10.1016/j.marpolbul.2006.09.007 Accessed July 15, 2015.

Cooper, K. and E. N. Vanderhoff. 2015. Survey of Brown Pelicans (Pelecanus occidentalis) in Jacksonville, Florida. Florida Field Naturalist; 43(2):69-78. http://www.fosbirds.org/sites/default/files/FFNs/FFNv43n2p69-78.pdf Accessed March 14, 2016.

Cordova, E. 2016. *Personal Communication* to R. Pyati.

Craft, C., J. Ehman and S. Perry. 2015. Chapter 3. Removal of Phosphorous and Nitrogen by Wetlands along the St. Johns River: An Economic Perspective. (In St. Johns River Economic Study). C. T. Hackney (Eds). Jacksonville (FL): University of North Florida (UNF), Coastal Biology Program. 145-167. http://floridaswater.com/stjohnsriver/pdfs/St._Johns_River_Economic_Study.pdf Accessed July 15, 2015.

Crain, D. A., L. J. Guillette Jr., D. B. Pickford, H. F. Percival and A. R. Woodward. 1998. Sex-Steroid and Thyroid Hormone Concentrations in Juvenile Alligators (Alligator mississippiensis) from Contaminated and Reference Lakes in Florida. Environmental Toxicology and Chemistry; 17(3):10.1002/etc.5620170315 http://dx.doi.org/10.1002/etc.5620170315 Accessed July 15, 2015.

Crooks, J. B. 2004. Titlle. (Eds). ISBN: 978-0813027081. Gainesville (FL): University Press of Florida. http://www.upf.com/book.asp?id=CROOKS04 Accessed July 15, 2015.

Cross, R. and D. L. Williams. 1981. Proceedings of the National Symposium on Freshwater Flow to Estuaries. Washington (DC): Accessed March 10, 2018.

CSA. 1988. A Final Report for St. Johns River Ichthyofaunal Survey. Jupiter (FL): https://sjrda.unf.edu/items/view/sjrda:101 Accessed July 15, 2015.

Curry, C. 2016. Environmental groups want water-bill veto. Gainesville (FL): The Gainesville Sun. http://www.gainesville.com/article/20160115/ARTICLES/160119737?p=1&tc=pg Accessed April 6, 2016

DACS. 2014. Florida Seafood and Aquaculture Overview and Statistics. Tallahassee (FL): Florida Department of Agriculture and Consumer Services (DACS). http://www.freshfromflorida.com/Divisions-Offices/Marketing-and-Development/Education/For-Researchers/Florida-Seafood-and-Aquaculture-Overview-and-Statistics Accessed July 15, 2015

Dadswell, M. J., B. D. Taubert, T. S. Squiers, D. Marchette and J. Buckley. 1984. Synopsis of Biological Data on Shortnose Sturgeon, *Acipenser brevirostrum* LeSueur 1818. Washington (DC): http://www.nmfs.noaa.gov/pr/pdfs/species/shortnosesturgeon_biological_data.pdf Accessed July 15, 2015.

Dahl, T. E. 2000. Status and Trends of Wetlands in the Conterminous United States 1986 to 1997. Washington (DC): http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-in-the-Conterminous-United-States-1986-to-1997.pdf Accessed July 15, 2015.

Dahl, T. E. 2005. Florida's Wetlands: An Update on Status and Trends 1985 to 1996. Washington (DC): http://www.fws.gov/wetlands/Documents/Floridas-Wetlands-An-Update-on-Status-and-Trends-1985-to-1996.pdf Accessed July 15, 2015.

Dahl, T. E. 2006. Status and Trends of Wetlands in the Conterminous United States 1998 to 2004. Washington (DC): http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-in-the-Conterminous-United-States-1998-to-2004.pdf Accessed July 15, 2015.

Dahl, T. E. and C. E. Johnson. 1991. Wetlands Status and Trends in the Conterminous United States, Mid-1970's to Mid-1980's. Washington (DC): http://www.fws.gov/wetlands/Documents/Wetlands-Status-and-Trends-in-the-Conterminous-United-States-Mid-1970s-to-Mid-1980s.pdf Accessed July 15, 2015.

Dahl, T. E. and S.-M. Stedman. 2013. Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States 2004 to 2009. Washington (DC): http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-In-the-Coastal-Watersheds-of-the-Conterminous-US-2004-to-2009.pdf Accessed July 15, 2015.

Dallinger, R. and P. S. Rainbow (Eds). 1993. Ecotoxicology of Metals in Invertebrates. 978-0873717342. Boca Raton (FL): CRC Press. https://www.crcpress.com/Ecotoxicology-of-Metals-in-Invertebrates/Dallinger-Rainbow/9780873717342 Accessed July 15, 2015.

Dame, R., M. Alber, D. Allen, M. A. Mallin, C. Montague, A. Lewitus, A. Chalmers, R. Gardner, C. Gilman, B. Kjerfve, J. Pinckney and N. Smith. 2000. Estuaries of the South Atlantic Coast of North America: Their Geographical Signatures. Estuaries and Coasts; 23(6):10.2307/1352999 http://dx.doi.org/10.2307/1352999 Accessed July 15, 2015.

Dames and Moore. 1983. Deepwater Ports Maintenance Dredging Study; Results, Interpretations and Recommendations - Ports of Jacksonville, Tampa, Manatee and Pensacola. Tallahassee (FL): http://www.gpo.gov/fdsys/pkg/CZIC-tc224-f6-d36-1983-v-ii/pdf/CZIC-tc224-f6-d36-1983-v-ii.pdf Accessed July 15, 2015.

Dantin, D. D., R. G. Boustany, M. A. Lewis, S. J. Jordan, R. F. Moss and T. C. Michot. 2010. Effects of Nutrient Pre-Exposure on Atrazine Toxicity to *Vallisneria americana* Michx. (Wild Celery). Archives of Environmental Contamination and Toxicology; 58(3):10.1007/s00244-009-9399-3 http://dx.doi.org/10.1007/s00244-009-9399-3 Accessed July 15, 2015.

Daskalakis, K. D. and T. P. O'Connor. 1995. Distribution of Chemical Concentrations in US Coastal and Estuarine Sediment. Marine Environmental Research; 40(4):10.1016/0141-1136(94)00150-N http://www.sciencedirect.com/science/article/pii/014111369400150N Accessed July 15, 2015.

Davies, P. H., J. P. Goettl, J. R. Sinley and N. F. Smith. 1976. Acute and Chronic Toxicity of Lead to Rainbow Trout *Salmo gairdneri*, in Hard and Soft Water. Water Research; 10(3):10.1016/0043-1354(76)90128-7 http://www.sciencedirect.com/science/article/pii/0043135476901287 Accessed July 15, 2015.

Davis, J. E. and R. Arsenault (Eds). 2005. Paradise Lost? This Environmental History of Florida. 978-0813028262. Gainesville (FL): University Press of Florida. http://www.upf.com/book.asp?id=DAVISF05 Accessed July 15, 2015.

Davis, T. F. 1925. Titlle. (Eds). 978-0935259063. St. Augustine (FL): The Florida Historical Society and The Record Company. http://ufdc.ufl.edu/NF00000013/00001 Accessed July 15, 2015.

De Barros, R. C., R. M. Da Rocha and M. R. Pie. 2009. Human-Mediated Global Dispersion of *Styela plicata* (Tunicata, Ascidiacea). Aquatic Invasions; 4(1):10.3391/ai.2009.4.1.4 http://dx.doi.org/10.3391/ai.2009.4.1.4 Accessed July 15, 2015.

Delfino, J. J., J. A. Coates, W. M. Davis, K. L. Garcia, M. W. Jacobs, K. J. Marincic and L. L. Signorella. 1991a. Toxic Pollutants in Discharges, Ambient Waters, and Bottom Sediments: Final Report. Tallahassee (FL): Accessed

Delfino, J. J., J. A. Coates, W. M. Davis, K. L. Garcia and L. L. Signorella. 1991b. Toxic Organic Pollutant Content of Sediments Within the SJRWMD Non-Swim Areas. Palatka (FL): https://sjrda.unf.edu/items/view/sjrda:118 Accessed July 15, 2015.

Delfino, J. J., J. A. Coates, K. L. Garcia and L. L. Signorella. 1992. Toxic Organic Pollutant Content of Sediments Within the SJRWMD Non-Swim Areas. Palatka (FL): https://sjrda.unf.edu/items/view/sjrda:119 Accessed July 15, 2015.

DeMort, C. L. 1990. Chapter 7. The St. Johns River System. (In The Rivers of Florida). R. J. e. Livingston (Eds). ISBN: 978-0387973630. New York (NY): Springer-Verlag. 97-120. http://www.springer.com/us/book/9780387973630 Accessed July 15, 2015.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom and R. A. Batiuk. 1993. Assessing Water Quality with Submersed Aquatic Vegetation: Habitat Requirements as Barometers of Chesapeake Bay Health. BioScience; 43(2):10.2307/1311969 http://dx.doi.org/10.2307/1311969 Accessed July 15, 2015.

DEP. 2002. Basin Status Report: Lower St. Johns. Tallahassee (FL): https://sjrda.unf.edu/items/view/sjrda:123 Accessed July 15, 2015.

DEP. 2004. Adopted Verified Lists of Impaired Waters for the Group 2 Basins: Lower St. Johns River. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Division of Water Resource Management. https://sjrda.unf.edu/items/forward/sjrda:124 Accessed July 1, 2008

DEP. 2007. Plan for Development of a Statewide Total Maximum Daily Load for Mercury (Mercury TMDL). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/mercury/merc-tmdl-plan-draft.pdf Accessed July 15, 2015.

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 Mainstem. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/docs/bmap/adopted-lsjr-bmap.pdf Accessed July 15, 2015.

DEP. 2008b. Integrated Water Quality Assessment for Florida: 2008 305(b) Report and 303(d) List Update. Tallahassee (FL): http://www.dep.state.fl.us/water/docs/2008_Integrated_Report.pdf Accessed July 15, 2015.

DEP. 2008c. Surface Water Improvement and Management Program (SWIM). Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://www.dep.state.fl.us/water/watersheds/swim.htm Accessed July 15, 2015

DEP. 2009a. Adopted Verified Lists of Impaired Waters for the Group 2 Basins: Lower St. Johns River. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/adopted/cycle2/lsjr-verified-c2.xls Accessed July 15, 2015.

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): http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-tribs-fecal-bmap.pdf Accessed July 15, 2015.

DEP. 2009c. Final Delist List of Impaired Waters: Lower St. Johns River (Cycle 2). Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/adopted/cycle2/lsjr-delist-c2.xls Accessed July 15, 2015.

DEP. 2009d. Final Verified Lists of Impaired Waters: Group 2 (Cycle 2). 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 July 15, 2015

DEP. 2009e. Florida's NPDES Stormwater Program. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://www.dep.state.fl.us/water/stormwater/npdes/index.htm Accessed July 1, 2008

DEP. 2009f. Northwest District Water Quality Outlook. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://www.dep.state.fl.us/northwest/Ecosys/waterquality/outlook.htm Accessed July 15, 2015

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 (II). Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/docs/bmap/bmap-lsjt2.pdf Accessed July 15, 2015.

DEP. 2010b. Basin Management Action Plans. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. http://www.dep.state.fl.us/water/watersheds/bmap.htm Accessed July 15, 2015

DEP. 2010c. Classification of Surface Waters, Usage, Reclassification, Classified Waters (62-302.400). Tallahassee (FL): Florida Department of State (FDOS). https://www.flrules.org/gateway/ruleno.asp?id=62-302.400 Accessed July 15, 2015.

DEP. 2010d. Florida Drought Conditions. Tallahassee (FL): Florida Department of Environmental Protection (DEP). Accessed July 15, 2015

DEP. 2010e. Florida STORET: Search Water Data. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://survey.dep.state.fl.us/DearSpa/default.do?page=waterdata Accessed July 15, 2015

DEP. 2010f. Florida STORET: Station Search. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://survey.dep.state.fl.us/DearSpa/default.do?page=stations Accessed July 15, 2015

DEP. 2010g. The Pilot Water Quality Credit Trading Program for the Lower St. Johns River: A Report to the Governor and Legislature. Tallahassee (FL): http://www.dep.state.fl.us/water/wqssp/docs/WaterQualityCreditReport-101410.pdf Accessed July 15, 2015.

DEP. 2010h. Watershed Management. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. http://www.dep.state.fl.us/water/watersheds/ Accessed July 15, 2015

DEP. 2011. DRAFT Plan for Development of a Statewide Total Maximum Daily Load for Mercury. Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://sjrda.unf.edu/items/forward/sjrda:156 Accessed July 15, 2015

DEP. 2013a. 2012 Progress Report for the Lower St. Johns River Mainstem Basin Management Action Plan. Tallahassee (FL): http://www.dep.state.fl.us/northeast/stjohns/2012_progress_report_lsjr_bmap.pdf Accessed July 15, 2015.

DEP. 2013b. Dissolved Oxygen Criteria for Class I, Class II, and Class III-Limited Waters (62-302.533). Tallahassee (FL): Florida Department of State (FDOS). https://www.flrules.org/gateway/ruleno.asp?id=62-302.533 Accessed July 15, 2015.

DEP. 2013c. Final Report: Mercury TMDL for the State of Florida. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/mercury/Mercury-TMDL.pdf Accessed July 15, 2015.

DEP. 2013d. Implementation of Florida's Numeric Nutrient Standards. Tallahassee (FL): http://www.dep.state.fl.us/secretary/news/2013/03/NNC_Implementation_3-11-13.pdf Accessed July 15, 2015.

DEP. 2013e. Lower St. Johns River Basin TMDL. Tallahassee (FL): Florida Department of Environmental Protection (DEP), Watershed Assessment Section. http://www.dep.state.fl.us/northeast/stjohns/TMDL/tmdl.htm Accessed July 15, 2015

DEP. 2013f. Mitigation Banks Permitted Under 373.4135, F.S. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://www.dep.state.fl.us/water/wetlands/docs/mitigation/mitbanks-all.xlsx Accessed July 15, 2015

DEP. 2013g. Outdoor Recreation in Florida 2013: Florida's Statewide Comprehensive Outdoor Recreation Plan (SCORP). Tallahassee (FL): http://www.dep.state.fl.us/parks/outdoor/files/FLSCORP_Draft2013.pdf Accessed July 15, 2015.

DEP. 2013h. Report to the Governor and Legislature: Status of Efforts to Establish Numeric Interpretations of the Narrative Nutrient Criterion for Florida Estuaries and Current Nutrient Conditions of Unimpaired Waters. Tallahassee (FL): https://sjrda.unf.edu/items/view/sjrda:631 Accessed July 15, 2015.

DEP. 2013i. Surface Water Triennial Review of State Surface Water Quality Standards. Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://www.dep.state.fl.us/water/wqssp/trirev.htm Accessed July 15, 2015

DEP. 2013j. Table: Surface Water Quality Criteria (62-302.530). Tallahassee (FL): Florida Department of State (FDOS). https://www.flrules.org/gateway/ruleno.asp?id=62-302.530 Accessed July 15, 2015.

DEP. 2013k. Technical Reports: Fifth Year Assessments. Jacksonville (FL): Florida Department of Environmental Protection (DEP), Bureau of Laboratories. http://www.dep.state.fl.us/labs/cgi-bin/reports/results.asp Accessed July 15, 2015

DEP. 2013l. Technical Support Document: Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tsd-do-criteria-aquatic-life.pdf Accessed July 15, 2015.

DEP. 2014a. 2013 Five-Year Assessment Report. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-bmap-FiveYearProgressReport-2013.pdf Accessed July 15, 2015.

DEP. 2014b. Alternate Surface Water Quality Standards: Waters with Site Specific Alternative Criteria. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://www.dep.state.fl.us/water/wqssp/ssac-list.htm Accessed July 15, 2015

DEP. 2014c. Basin Downloads: Waterbody ID Run 49. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://www.dep.state.fl.us/water/watersheds/assessment/docs/basin411/WBID_Run49.zip Accessed July 15, 2015

DEP. 2014d. DEP Takes a Major Step to Better Protect Florida's Beaches. Tallahassee (FL): Florida Department of Environmental Protection (DEP). http://content.govdelivery.com/accounts/FLDEP/bulletins/8482f5 Accessed July 15, 2015

DEP. 2014e. Integrated Water Quality Assessment for Florida: 2014 Sections 303(d), 305(b) Report and 314 Report and Listing Update. Tallahassee (FL): A. 2014. http://www.dep.state.fl.us/water/docs/2014_integrated_report.pdf Accessed July 15, 2015.

DEP. 2014f. Statewide Comprehensive Verified List of Impaired Waters. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/Comp-Verified-List-2014.xlsx Accessed July 15, 2015.

DEP. 2015a. Draft Delist List of Impaired Waters: Lower St. Johns River (Cycle 3). Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/cycle3/vldl/g2c3-lsj-dl-draft.xlsx Accessed July 15, 2015.

DEP. 2015b. Estuary-Specific Numeric Interpretations of the Narrative Nutrient Criterion (62-302.532). Tallahassee (FL): Florida Administrative Code, State of Florida. https://www.flrules.org/Gateway/View_notice.asp?id=16034893 Accessed July 15, 2015.

DEP. 2015c. List of Nutrient TMDLs that are Hierarchy 1 Interpretations under Rule 62-302.531(2)(a), F.A.C. Tallahassee (FL): http://www.dep.state.fl.us/water/wqssp/docs/swqdocs/nutrient-tmdl-list.pdf Accessed June 18, 2016.

DEP. 2016a. Estuary-Specific Numeric Interpretations of the Narrative Nutrient Criterion (62-302.532). Tallahassee (FL): Florida Administrative Code, State of Florida. https://www.flrules.org/gateway/ruleno.asp?id=62-302.532 Accessed June 14, 2016.

DEP. 2016b. Final Lower St. Johns River Tributaries BMAP I Progress Report. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr-tribs1-bmap-apr-2014.pdf Accessed

DEP. 2016c. Final Lower St. Johns River Tributaries BMAP II Update. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr_tribs2-bmap-update.pdf Accessed May 2, 2017.

DEP. 2016d. Human Health Criteria: Frequently Asked Questions. Tallahassee (FL): https://depnewsroom.files.wordpress.com/2016/06/human-health-criteria-faq-0725161.pdf Accessed May 2, 2017.

DEP. 2016e. Lower St. Johns River Basin TMDLs (62-304.415). Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://www.flrules.org/gateway/RuleNo.asp?ID=62-304.415 Accessed June 18, 2016.

DEP. 2016f. Lower St. Johns River Tributaries I BMAP Update, Phase 2. Tallahassee (FL): http://publicfiles.dep.state.fl.us/DEAR/DEARweb/BMAP/Lower St. Johns River LSJR Tributaries/LSJR_Tribs_BMAP_I_Update_07-30-15_Distribution.pdf Accessed May 2, 2017.

DEP. 2016g. Numeric Interpretations of Narrative Nutrient Criteria (62-302.531). Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://www.flrules.org/gateway/ruleno.asp?id=62-302.531 Accessed June 14, 2016.

DEP. 2016h. Revised Delist of Impaired Waters: Lower St. Johns River (Cycle 3). Tallahassee (FL): http://dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/cycle3/vldl/g2c3-lsj-dl-rev.xlsx Accessed April 4, 2016.

DEP. 2016i. Revised List of Assessments in the Group 2 (Cycle 3) Basins for the Verified List of Impaired Waters, Delist, and Study Lists. Tallahassee (FL): http://dep.state.fl.us/water/watersheds/assessment/g2c3.htm Accessed April 4, 2016.

DEP. 2016j. Revised Verified List of Impaired Waters: Lower St. Johns (Cycle 3). Tallahassee (FL): http://dep.state.fl.us/water/watersheds/assessment/docs/303d/group2/cycle3/vldl/g2c3-lsj-vl-rev.xlsx Accessed April 4, 2016.

DEP. 2016k. Table: Surface Water Quality Criteria (62-302-530). Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://www.flrules.org/gateway/ruleno.asp?id=62-302.530 Accessed April 2, 2016.

DEP. 2016l. Technical Support Document: Derivation of Human Health Criteria and Risk Impact Statement. Tallahassee (FL): Technical support document: derivation of human health criteria and risk impact statement Accessed May 2, 2017.

DEP. 2017a. Final TMDL Report Nutrient TMDLs for Crescent Lake (WBID 2606B). Tallahassee (FL): https://floridadep.gov/sites/default/files/Crescent_Lake_FINAL_052017_0.pdf Accessed April 1, 2018.

DEP. 2017b. Mitigation and Mitigation Banking. Tallahassee (FL): Florida Deparment of Environmental Protection (DEP). https://floridadep.gov/water/submerged-lands-environmental-resources-coordination/content/mitigation-and-mitigation-banking Accessed March 10, 2018

DEP. 2017c. Progress Report for the Lower St. Johns River Tributaries Basin Management Action Plans I and II. Tallahassee (FL): http://publicfiles.dep.state.fl.us/DEAR/DEARweb/BMAP/Lower St. Johns River LSJR Tributaries/Final LSJR Tribs Progress Report__2016.pdf Accessed July 14, 2017.

DEP. 2017d. Surface Water Quality Standards. Tallahassee (FL): F. D. o. E. Protection. http://www.dep.state.fl.us/water/wqssp/ Accessed May 2, 2017.

DEP. 2018a. Comprehensive Delist List. Tallahassee (FL): F. D. o. E. P. (DEP). https://floridadep.gov/dear/quality-assurance/documents/comprehensive-delist-list Accessed April 21, 2018.

DEP. 2018b. Lower St. Johns River (LSJR) Tributaries Basin Management Action Plans (BMAPs) I and II Annual Meeting. Jacksonville (FL): Accessed May 5, 2018.

DEP. 2018c. Notice of Change/Withdrawal (Table: Surface Water Quality Criteria) (62-302.530). Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://www.flrules.org/gateway/RuleNo.asp?ID=62-302.530 Accessed April 12, 2018.

DEP. 2018d. Notice of Development of Rulemaking (62-302.530). Tallahassee (FL): Florida Department of Environmental Protection (DEP). https://www.flrules.org/gateway/RuleNo.asp?ID=62-302.530 Accessed April 12, 2018.

DEP. 2018e. Statewide Comprehensive List of Impaired Waters. Tallahassee (FL): F. D. o. E. P. (DEP). https://floridadep.gov/dear/watershed-assessment-section/documents/statewide-comprehensive-verified-list-impaired-waters Accessed April 21, 2018.

DETR. 1998. Digest of Environmental Statistics No. 20. London (England): http://webarchive.nationalarchives.gov.uk/20130822084033/http://www.defra.gov.uk/statistics/files/pas-summary-1997.pdf Accessed July 15, 2015.

Deutsch, C. J., J. P. Reid, R. K. Bonde, D. E. Easton, H. I. Kochman and T. J. O'Shea. 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): http://www.aquaticcommons.org/1067/ Accessed July 15, 2015.

Deutsch, C. J., J. P. Reid, R. K. Bonde, D. E. Easton, H. I. Kochman and T. J. O'Shea. 2003. Seasonal Movements, Migratory Behavior, and Site Fidelity of West Indian Manatees Along the Atlantic Coast of the United States. Wildlife Monographs; 151(http://www.jstor.org/stable/3830830 Accessed July 15, 2015.

Di Toro, D. M., H. E. Allen, H. L. Bergman, J. S. Meyer, P. R. Paquin and R. C. Santore. 2001. Biotic Ligand Model of the Acute Toxicity of Metals. 1. Technical Basis. Environmental Toxicology and Chemistry; 20(10):10.1002/etc.5620201034 http://dx.doi.org/10.1002/etc.5620201034 Accessed July 15, 2015.

Ding, Y., D. P. Weston, J. You, A. K. Rothert and M. J. Lydy. 2010. Toxicity of Sediment-Associated Pesticides to Chironomus dilutus and Hyalella azteca. Archives of Environmental Contamination and Toxicology; 61(1):10.1007/s00244-010-9614-2 http://dx.doi.org/10.1007/s00244-010-9614-2 Accessed July 15, 2015.

Dobberfuhl, D. R. 2002. Distribution of Submerged Aquatic Vegetation in the Lower St. Johns River, 1998 Atlas. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/PP/SJ2002-PP1.pdf Accessed July 15, 2015.

Dobberfuhl, D. R. 2007. Light Limiting Thresholds for Submerged Aquatic Vegetation in a Blackwater River. Journal of Aquatic Botany; 86(4):10.1016/j.aquabot.2007.01.003 http://dx.doi.org/10.1016/j.aquabot.2007.01.003 Accessed July 15, 2015.

Dobberfuhl, D. R. 2009. *Personal Communication* to G. Pinto.

Dobberfuhl, D. R. and N. Trahan. 2003. Distribution of Submerged Aquatic Vegetation in the Lower St. Johns River, 2001 Atlas. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/PP/SJ2003-PP1.pdf Accessed July 15, 2015.

Dodds, N. M. W., M. H. Miller and A. J. Lamm. 2014. Floridians' Perceptions of Invasive Species. Gainesville (FL): http://edis.ifas.ufl.edu/wc186 Accessed December 28, 2015.

Donkin, P., J. Widdows, S. V. Evans, C. M. Worrall and M. Carr. 1989. Quantitative Structure-activity Relationships for the Effect of Hydrophobic Organic Chemicals on Rate of Feeding by Mussels *(Mytilus edulis)*. Aquatic Toxicology; 14(3):10.1016/0166-445X(89)90021-0 http://www.sciencedirect.com/science/article/pii/0166445X89900210 Accessed July 15, 2015.

Dortch, Q. 1990. The Interaction Between Ammonium and Nitrate Uptake in Phytoplankton. Marine Ecology Progress Series; 61(1):http://www.int-res.com/articles/meps/61/m061p183.pdf Accessed July 15, 2015.

Dunn, A. E., D. R. Dobberfuhl and D. A. Casamatta. 2008. A Survey of Algal Epiphytes from *Vallisneria americana* Michx. (Hydrocharitaceae) from the Lower St. Johns River, Florida. Southeastern Naturalist; 7(2):10.1656/1528-7092(2008)7[229:ASOAEF]2.0.CO;2 http://www.bioone.org/doi/abs/10.1656/1528-7092%282008%297%5B229%3AASOAEF%5D2.0.CO%3B2 Accessed July 15, 2015.

Durako, M. J., M. D. Murphy and K. D. Haddad. 1988. Assessment of Fisheries Habitat: Northeast Florida. St. Petersburg (FL): http://f50006a.eos-intl.net/ELIBSQL12_F50006A_Documents/FMRP045ocr.pdf Accessed July 15, 2015.

Durell, G. S., J. S. Fredriksson and J. C. Higman. 2004. Sediment Quality of the Lower St. Johns River and Cedar-Ortega River Basin: Chemical Contaminant Characteristics. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/SP/SJ2004-SP43.pdf Accessed July 15, 2015.

Durell, G. S., J. C. Higman, J. S. Fredriksson and J. Neff. 2005. Chemical Contamination of Sediments in the Cedar-Ortega River Basin. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/SP/SJ2005-SP5.pdf Accessed July 15, 2015.

Durell, G. S., J. A. Seavey and C. D. Hunt. 1997. Status of Sediment Quality in the St. Johns River Water Management District: Physical and Chemical Characteristics. Revised. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/SP/SJ98-SP5.pdf Accessed July 15, 2015.

Dyble, J., H. W. Paerl and B. A. Neilan. 2002. Genetic Characterization of *Cylindrospermopsis raciborskii* (Cyanobacteria) Isolates from Diverse Geographic Origins Based on *nifH* and *cpcBA*-IGS Nucleotide Sequence Analysis. Applied and Environmental Microbiology; 68(5):10.1128/AEM.68.5.2567-2571.2002 http://dx.doi.org/10.1128/AEM.68.5.2567-2571.2002 Accessed July 15, 2015.

Earthjustice. 2008. Complaint for Declaractory and Injuctive Relief. Oakland (CA): http://earthjustice.org/news/press/2008/earthjustice-files-federal-lawsuit-to-stop-toxic-algae-blooms Accessed July 15, 2015.

Echols, K. R., J. C. Meadows and C. E. Orazio. 2009. Pollution of Aquatic Ecosystems II: Hydrocarbons, Synthetic Organics, Radionuclides, Heavy Metals, Acids, and Thermal Pollution. (In Encyclopedia of Inland Waters). G. E. Likens (Eds). 978-0123706263. Elsevier/Academic Press. 120-128. http://dx.doi.org/10.1016/B978-012370626-3.00223-4 Accessed July 15, 2015.

EDR. 2015. Bill Number: Demographic Estimating Conference Database. Code(Code The Florida Legislature, Office of Economic and Demographic Research (EDR). http://edr.state.fl.us/Content/conferences/population/index.cfm Accessed July 15, 2015.

Ehrenfeld, D. W. 1970. Titlle. (Eds). 978-0030800498. New York (NY): Holt, Rinehart and Winston. http://www.amazon.com/dp/0030800498 Accessed July 15, 2015.

Eisler, R. 1988a. Lead Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel (MD): http://www.pwrc.usgs.gov/eisler/CHR_14_Lead.pdf Accessed July 15, 2015.

Eisler, R. 1988b. Nickel Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel (MD): http://www.pwrc.usgs.gov/eisler/CHR_34_Nickel.pdf Accessed July 15, 2015.

Eisler, R. 1993. Zinc Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel (MD): http://www.pwrc.usgs.gov/eisler/CHR_26_Zinc.pdf Accessed July 15, 2015.

Eisler, R. 1996. Silver Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. Laurel (MD): http://www.pwrc.usgs.gov/eisler/CHR_32_Silver.pdf Accessed July 15, 2015.

Eldredge, L. G. and C. M. Smith. 2001. A Guidebook of Introduced Marine Species in Hawaii. Manoa, HI: http://www2.bishopmuseum.org/HBS/invertguide/species_pdf/guide.pdf Accessed July 15, 2015.

ELI. 2008. The Role of Aquatic Invasive Species in State Listing of Impaired Waters and the TMDL Program: Seven Case Studies. Washington (DC): http://www.eli.org/sites/default/files/eli-pubs/d18__14.pdf Accessed July 15, 2015.

Elton, C. S. 1958. Titlle. (Eds). ISBN: 978-0226206387. Chicago (IL): The University of Chicago Press. http://press.uchicago.edu/ucp/books/book/chicago/E/bo3614808.html Accessed July 15, 2015.

EPA. 1976. Quality Criteria for Water. Washington (DC): E. P. A. (EPA). http://www.waterboards.ca.gov/water_issues/programs/tmdl/records/state_board/2008/ref2689.pdf Accessed April 1, 2017.

EPA. 1979. Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions. Federal Register; 44(106):https://sjrda.unf.edu/items/view/sjrda:563 Accessed July 15, 2015.

EPA. 1986. Ambient Water Quality Criteria for Bacteria - 1986. Washington (DC): http://water.epa.gov/scitech/swguidance/standards/upload/2009_04_13_beaches_1986crit.pdf Accessed July 15, 2015.

EPA. 1997a. Mercury Study Report to Congress; Volume I: Executive Summary. Washington (DC): http://www.epa.gov/ttn/oarpg/t3/reports/volume1.pdf Accessed July 15, 2015.

EPA. 1997b. Mercury Study Report to Congress; Volume II: An Inventory of Anthropogenic Mercury Emissions in the United States. Washington (DC): http://www.epa.gov/ttn/oarpg/t3/reports/volume2.pdf Accessed July 15, 2015.

EPA. 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury. Washington (DC): https://sjrda.unf.edu/items/forward/sjrda:566 Accessed July 15, 2015.

EPA. 2002a. Methods for Estimating the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. Washington (DC): http://water.epa.gov/scitech/methods/cwa/wet/upload/2007_07_10_methods_wet_disk2_atx.pdf Accessed July 15, 2015.

EPA. 2002b. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Washington (DC): http://water.epa.gov/scitech/methods/cwa/wet/upload/2007_07_10_methods_wet_disk3_ctf.pdf Accessed July 15, 2015.

EPA. 2007. Integrated Risk Information System (IRIS) Substance List. 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 July 15, 2015

EPA. 2008. Clean Water Act History. Washington (DC): Environmental Protection Agency (EPA). http://www2.epa.gov/laws-regulations/history-clean-water-act Accessed July 1, 2008

EPA. 2010a. Total Maximum Daily Loads for the Doctors Lake, Swimming Pen Creek, Six Mile Creek, Black Creek, Black Creek South Fork, Peters Creek and Lake Harney Watersheds - WBIDS: 2389, 2410, 2411, 2415B, 2415C, 2444, 2964A: Silver. Atlanta (GA): http://www.epa.gov/waters/tmdldocs/38333_38333_silver.pdf Accessed July 15, 2015.

EPA. 2010b. Water Quality Standards for Florida's Lakes and Flowing Waters. EPA-HQ-OW-2009-0596. Federal Register; 75(233):http://federalregister.gov/a/2010-29943 Accessed July 15, 2015.

EPA. 2012a. 2012 Recreational Water Quality Criteria. Washington (DC): https://www.epa.gov/sites/production/files/2015-10/documents/rwqc2012.pdf Accessed July 1, 2014.

EPA. 2012b. Microbial (Pathogen)/Recreational Water Quality Criteria. Washington (DC): http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/factsheet2012.pdf Accessed July 15, 2015.

EPA. 2013a. Approval of Florida's Numeric Nutrient Standards. Washington (DC): https://sjrda.unf.edu/items/view/sjrda:759 Accessed July 15, 2015.

EPA. 2013b. Decision Document of the United States Environmental Protection Agency Determination Under§ 303(c) of the Clean Water Act Review of a Portion of Florida's 2013 Triennial Review of Changes to Rules 62-302 and 62-303. Tallahassee (FL): F. D. o. E. P. (DEP). https://sjrda.unf.edu/items/view/sjrda:761 Accessed July 15, 2015.

EPA. 2013c. EPA's Risk-Screening Environmental Indicators (RSEI) methodology: RSEI Version 2.3.2. Washington (DC): http://www.epa.gov/oppt/rsei/pubs/rsei_methodology_v2_3_2.pdf Accessed July 15, 2015.

EPA. 2013d. Mercury and Air Toxics Standards (MATS). Washington (DC): Environmental Protection Agency (EPA). http://www.epa.gov/mats/ Accessed July 15, 2015

EPA. 2013e. Risk-Screening Environmental Indicators (RSEI). Washington (DC): U.S. Environmental Protection Agency (EPA). http://www.epa.gov/oppt/rsei/pubs/get_rsei.html Accessed July 15, 2015

EPA. 2013f. Technology Transfer Network: Clearinghouse for Inventories & Emissions Factors. Washington (DC): Environmental Protection Agency (EPA). http://www.epa.gov/ttn/chief/ap42/ Accessed July 15, 2015

EPA. 2015a. 2015 Drinking Water Health Advisories for Two Cyanobacterial Toxins. Washington (DC): https://www.epa.gov/sites/production/files/2015-06/documents/cyanotoxins-fact_sheet-2015.pdf Accessed June 15, 2016.

EPA. 2015b. Bill Number: Toxics Release Inventory (TRI) Program. Code(Code Washington (DC): Environmental Protection Agency (EPA). http://www2.epa.gov/toxics-release-inventory-tri-program Accessed July 15, 2015.

EPA. 2015c. TRI Explorer Releases: Trends Report, Toxics Release Inventory. Washington (DC): Environmental Protection Agency (EPA). https://sjrda.unf.edu/items/forward/sjrda:571 Accessed July 15, 2015

EPA. 2015d. TRI.NET. Washington (DC): Environmental Protection Agency (EPA). http://www2.epa.gov/toxics-release-inventory-tri-program/trinet Accessed July 15, 2015

EPA. 2016a. Fact Sheet: Draft Human Health Recreational Ambient Water Quality Criteria/Swimming Advisories for Microcystins and Cylindrospermospin. Washington (DC): O. o. W. Environmental Protection Agency (EPA). https://www.epa.gov/sites/production/files/2016-12/documents/draft-hh-rec-ambient-water-swimming-factsheet.pdf Accessed March 10, 2017.

EPA. 2016b. Nutrient Policy Data: Guidelines and Recommendations. Washington (DC): E. P. A. (EPA). https://www.epa.gov/nutrient-policy-data/guidelines-and-recommendations - what3 Accessed June 15, 2016.

EPA. 2017. Microbial (Pathogen)/Recreational Water Quality Criteria. Washington (DC): E. P. A. (EPA). https://www.epa.gov/wqc/microbial-pathogenrecreational-water-quality-criteria - swimming Accessed March 10, 2017.

ERDC. 2015. Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS). Washington (DC): https://ribits.usace.army.mil/ribits_apex/f?p=107:2 Accessed July 15, 2015.

ERDC. 2017. Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS). Washington (DC): https://ribits.usace.army.mil/ribits_apex/f?p=107:2 Accessed March 10, 2018.

Escher, B. I., R. I. L. Eggen, U. Schreiber, Z. Schreiber, E. Vye, B. Wisner and R. P. Schwarzenbach. 2002. Baseline Toxicity (Narcosis) of Organic Chemicals Determined by in Vitro Membrane Potential Measurements in Energytransducing Membranes. Environmental Science and Technology; 36(9):10.1021/es015844c http://dx.doi.org/10.1021/es015844c Accessed July 15, 2015.

Escher, B. I. and J. L. M. Hermens. 2002. Modes of Action in Ecotoxicology: Their Role in Body Burdens, Species Sensitivity, QSARs, and Mixture Effects (Critical Review). Environmental Science and Technology; 36(20):10.1021/es015848h http://dx.doi.org/10.1021/es015848h Accessed July 15, 2015.

Evans, D. L., D. G. Strom, J. C. Higman, E. Hughes, E. A. Hoover and L. M. Line. 2004. An Evaluation of Benthic Macroinvertebrate Data from 20 Surface Water Sites Within the Lower St. Johns River Basin, 2002-2003. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/SP/SJ2004-SP41.pdf Accessed July 15, 2015.

Evans, S. M., A. C. Birchenough and M. S. Brancato. 2000. The TBT Ban: Out of the Frying Pan into the Fire? Marine Pollution Bulletin; 40(3):10.1016/S0025-326X(99)00248-9 https://sjrda.unf.edu/items/forward/sjrda:763 Accessed July 15, 2015.

Faulkner, S. 2004. Urbanization Impacts on the Structure and Function of Forested Wetlands. Urban Ecosystems; 7(2):10.1023/B:UECO.0000036269.56249.66 http://dx.doi.org/10.1023/B:UECO.0000036269.56249.66 Accessed July 15, 2015.

FCCDR. 2008. Atlas of Florida Vascular Plants. Tampl, FL: University of South Florida (USF), The Florida Center for Community Design + Research (FCCDR). http://www.florida.plantatlas.usf.edu/ Accessed July 15, 2015

FCN. 2015. Foot-long Asian tiger shrimp caught on the First Coast. Jacksonville (FL): First Coast News (FCN). http://legacy.firstcoastnews.com/story/news/weird/2015/07/09/asian-tiger-shrimp---st-johns-river--jacksonville/29945025/ Accessed February 3, 2016

FDEP. 2016. Basin Management Action Plan for the Implementation of Total Daily Maximum Loads for Fecal Coliforms in the Lower St. Johns River Basin Tributaries I. Tallahassee (FL): http://www.dep.state.fl.us/water/watersheds/docs/bmap/lsjr_tribs1-bmap-update.pdf Accessed April 2, 2016.

FDHSMV. 2017. Vessel Owner Statistics. Tallahassee (FL): Florida Department of Highway Safety and Motor Vehicles (FDHSMV). https://www.flhsmv.gov/pdf/vessels/vesselstats2016.pdf Accessed March 10, 2017

FDOE. 2010. Next Generation Sunshine State Standards. Tallahassee (FL): http://casamples.com/downloads/FL-stams2010.pdf Accessed April 10, 2018.

FDOH. 2005. News Release: Health Alert for Duval, St. Johns, and Clay Counties. Tallahassee (FL): https://sjrda.unf.edu/items/view/sjrda:199 Accessed July 15, 2015.

FDOH. 2016. Your Guide to Eating Fish Caught in Florida (2015). Tallahassee (FL): http://www.floridahealth.gov/programs-and-services/prevention/healthy-weight/nutrition/seafood-consumption/_documents/2013-advisory-brochure.pdf Accessed April 1, 2016.

FDOH. 2018. Seafood Consumption. Tallahasee (FL): http://www.floridahealth.gov/programs-and-services/prevention/healthy-weight/nutrition/seafood-consumption/quick-facts.html Accessed March 10, 2018.

Fears, D. R. 2010. Arsenic in the Groundwater at Naval Station Mayport; Geochemical Processes or Anthropogenically Caused? Gainesville (FL): https://sjrda.unf.edu/items/view/sjrda:678 Accessed July 15, 2015.

Fernald, E. A. and D. J. Patton. 1984. Titlle. (Eds). 978-0960670819. Tallahassee (FL): Florida State University. http://www.amazon.com/dp/0960670815 Accessed July 15, 2015.

Fisk, A. T., G. A. Stern, K. A. Hobson, W. J. Strachan, M. D. Loewen and R. J. Norstrom. 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. Marine Pollution Bulletin; 43(1-6):10.1016/S0025-326X(01)00038-8 http://www.sciencedirect.com/science/article/pii/S0025326X01000388 Accessed July 15, 2015.

Florida Legislature. 1972a. Florida Statute: Chapter 163 - Intergovernmental Programs Tallahassee (FL): State of Florida. http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&URL=0100-0199/0163/0163ContentsIndex.html Accessed July 15, 2015.

Florida Legislature. 1972b. Florida Statute: Chapter 373 - Water Resources Tallahassee (FL): State of Florida. http://www.leg.state.fl.us/Statutes/index.cfm?App_mode=Display_Statute&URL=0300-0399/0373/0373ContentsIndex.html Accessed July 15, 2015.

Florida Legislature. 1972c. Florida Statute: Chapter 380 - Land and Water Management Tallahassee (FL): State of Florida. http://www.leg.state.fl.us/Statutes/index.cfm?App_mode=Display_Statute&URL=0300-0399/0380/0380ContentsIndex.html Accessed July 15, 2015.

Flowe, J. 2016. *Personal Communication* to N. Goldberg.

FNAI. 2017. FNAI GIS Data. Tallahasse (FL): Florida Natural Assets Inventory (FNAI). http://www.fnai.org/gisdata.cfm Accessed March 10, 2018

Foltz, D. W., S. K. Sarver and A. W. Hrincevich. 1995. Genetic Structure of Brackish Water Clams (*Rangia spp.*). Biochemical Systematics and Ecology; 23(3):223-233. 10.1016/0305-1978(95)00012-J http://www.sciencedirect.com/science/article/pii/030519789500012J Accessed July 15, 2015.

Forstall, R. L. 1995. Florida Population of Counties by Decennial Census: 1900 to 1990. Washington (DC): http://www.census.gov/population/cencounts/fl190090.txt Accessed July 15, 2015.

Fossi, M. C. and L. Marsili. 2003. Effects of Endocrine Disruptors in Aquatic Mammals. Pure and Applied Chemistry; 75(11-12):10.1351/pac200375112235 http://dx.doi.org/10.1351/pac200375112235 Accessed July 15, 2015.

Foster, J. M., R. W. Heard and D. M. Knott. 2004. Northern Range Extensions for *Caprella Scaura* Templeton, 1836 (Crustacea: Amphipoda: Caprellidae) on the Florida Gulf Coast and South Carolina. Gulf and Caribbean Research; 16(1):http://aquila.usm.edu/gcr/vol16/iss1/9/ Accessed July 15, 2015.

Frank, B. 2008. *Personal Communication* to H. McCarthy.

Frank, B. and H. Lee. 2008. Jacksonville Shells. Jacksonville (FL): Jacksonville Shell Club. http://www.jaxshells.org/ Accessed July 15, 2015

Frayer, W. E., T. Monahan, D. C. Bowden and F. A. Graybill. 1983. Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States, 1950's to 1970's. St. Petersburg (FL): http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-and-Deepwater-Habitats-in-the-Conterminous-United-States-1950s-to-1970s.pdf Accessed July 15, 2015.

French, G. T. and K. A. Moore. 2003. Interactive Effects of Light and Salinity Stress on the Growth, Reproduction, and Photosynthetic Capabilities of *Vallisneria americana* (Wild Celery). Estuaries and Coasts; 26(5):10.1007/BF02803628 http://dx.doi.org/10.1007/BF02803628 Accessed July 15, 2015.

Friedland, K. D. and B. Kynard. 2004. IUCN Red List of Threatened Species (2007) *Acipenser brevirostrum*. Cambridge (England): International Union for Conservation of Nature and Natural Resources (IUCN). http://www.iucnredlist.org/details/222/0 Accessed July 15, 2015

FWC. 1978. The Florida Manatee Sanctuary Act (68C-22). Tallahassee (FL): Florida Department of State (FDOS). https://www.flrules.org/gateway/ChapterHome.asp?Chapter=68C-22 Accessed July 15, 2015.

FWC. 2000. Sea Stats: Baitfish. St. Petersburg (FL): http://research.myfwc.com/products/product_info.asp?id=1442 Accessed July 15, 2015.

FWC. 2007. Florida Manatee Management Plan: *Trichechus manatus latirostris*. Tallahassee (FL): http://myfwc.com/media/415297/Manatee_MgmtPlan.pdf Accessed July 15, 2015.

FWC. 2008. Bald Eagle Management Plan: *Haliaeetus leucocephalus*. St. Petersburg (FL): http://myfwc.com/media/427567/Eagle_Plan_April_2008.pdf Accessed July 15, 2015.

FWC. 2010. FWC Determines Fungus Caused St. Johns Fish Kill. Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). http://preview.myfwc.com/news/news-releases/2010/november/09/fish-kill/ Accessed July 15, 2015

FWC. 2014a. Lionfish Recreational Regulations. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). http://myfwc.com/fishing/saltwater/recreational/lionfish/ Accessed July 15, 2015

FWC. 2014b. Manatee Protection Plans. Tallahassee (FL): Florida Fish and Wildlife Conservation Commission (FWC). http://www.myfwc.com/wildlifehabitats/managed/manatee/protection-plans/ Accessed July 15, 2015

FWC. 2014c. Nonnatives - Muscovy Duck. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). http://myfwc.com/wildlifehabitats/nonnatives/birds/muscovy-duck/ Accessed July 15, 2015

FWC. 2016. Species Profile - Largemouth Bass. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). http://myfwc.com/wildlifehabitats/profiles/freshwater/largemouth-bass/ Accessed April 1, 2016

FWC. 2018a. Florida Freshwater Fishing Regulations 2017 St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). http://www.eregulations.com/florida/fishing/freshwater/ Accessed March 10, 2018.

FWC. 2018b. Florida Saltwater Recreational Fishing Regulations 2018 St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC). http://www.eregulations.com/florida/fishing/saltwater/ Accessed March 10, 2018.

FWRI. 2002. Fisheries-Independent Monitoring Program 2001 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2001_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2003. Fisheries-Independent Monitoring Program 2002 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2002_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2004. Fisheries-Independent Monitoring Program 2003 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2003_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2005. Fisheries-Independent Monitoring Program 2004 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2004_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2006. Fisheries-Independent Monitoring Program 2005 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2005_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2007. Fisheries-Independent Monitoring Program 2006 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2006_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2008a. Atlantic Croaker, *Micropogonias undulates* (Linnaeus, 1766). St. Petersburg (FL): http://myfwc.com/media/194607/atlantic_croaker.pdf Accessed July 15, 2015.

FWRI. 2008b. Fisheries-Independent Monitoring Program 2007 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2007_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2008c. Flounders, *Paralichthys* spp. St. Petersburg (FL): http://myfwc.com/media/194673/flounders.pdf Accessed July 15, 2015.

FWRI. 2008d. Penaeid Shrimp. St. Petersburg (FL): http://myfwc.com/media/195867/penaeid_shrimps.pdf Accessed July 15, 2015.

FWRI. 2009. Fisheries-Independent Monitoring Program 2008 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2008_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2010. Fisheries-Independent Monitoring Program 2009 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2009_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2011. Fisheries-Independent Monitoring Program 2010 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2010_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2012a. Cold-Related Mortality Event Winter 2009-2010. St. Petersburg (FL): http://myfwc.com/research/manatee/rescue-mortality-response/mortality-statistics/cold-related-2009-2010/ Accessed July 15, 2015.

FWRI. 2012b. Fisheries-Independent Monitoring Program 2011 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2011_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2013a. Blue Crab, *Callinectes sapidus* Rathbun, 1896. St. Petersburg (FL): http://myfwc.com/media/195795/ihr_2013-014_blue_crab_2013.pdf Accessed July 15, 2015.

FWRI. 2013b. Fisheries-Independent Monitoring Program 2012 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2012_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2014. Fisheries-Independent Monitoring Program 2013 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2013_Annual_Report.pdf Accessed July 15, 2015.

FWRI. 2015. Red Drum, *Scianops ocellatus* (Linnaeus, 1766). St. Petersburg (FL): http://myfwc.com/media/194654/red-drum.pdf Accessed April 1, 2016.

FWRI. 2016. Fisheries-Independent Monitoring Program 2015 Annual Data Summary Report. St. Petersburg (FL): http://www.lsjr.org/pdf/FIM_2015_Annual_Report.pdf Accessed April 1, 2016.

FWRI. 2017a. Commercial Fisheries Landings in Florida. 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 March 3, 2017

FWRI. 2017b. Fisheries-Independent Monitoring Program 2016 Annual Data Summary Report. St. Petersburg (FL): F. a. W. R. I. F. Florida Fish and Wildlife Conservation Commission (FWC).

https://www.dep.state.fl.us/northeast/stjohns/TMDL/docs/Feb2017/LSJR_Main_Stem_BMAP_2016_progress_report021617.docx Accessed March 10, 2017.

FWRI. 2018a. Commercial Fisheries Landings in Florida. 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 March 3, 2018

FWRI. 2018b. Fisheries-Independent Monitoring Program 2016 Annual Data Summary Report. St. Petersburg (FL): F. a. W. R. I. F. Florida Fish and Wildlife Conservation Commission (FWC). https://floridadep.gov/northeast Accessed March 10, 2018.

FWRI. 2018c. Florida Manatee. St. Petersburg (FL): F. a. W. R. I. F. Florida Fish and Wildlife Conservation Commission (FWC). http://myfwc.com/research/manatee/ Accessed April 10, 2018.

FWRI. 2018d. Manatee Mortality Search. St. Petersburg (FL): Florida Department of Agriculture. http://research.myfwc.com/manatees/ Accessed April 10, 2018

FWRI. 2018e. Manatee Population Monitoring. St. Petersburg (FL): Florida Fish and Wildlife Conservation Commission (FWC), Fish and Wildlife Research Institute (FWRI). http://myfwc.com/research/manatee/research/population-monitoring/synoptic-surveys/ Accessed April 10, 2018

FWRI. 2018f. Shortnose Sturgeon Population Evaluation in the St. Johns River, Florida. 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 April 10, 2018

Gallegos, C. L. 2005. Optical Water Quality of a Blackwater River Estuary: The Lower St. Johns River, Florida, USA. Estuarine, Coastal and Shelf Science; 63(1-2):10.1016/j.ecss.2004.10.010 http://dx.doi.org/10.1016/j.ecss.2004.10.010 Accessed July 15, 2015.

GBIF. 2012a. Occurrence Records for *Caprella scaura* (Templeton, 1836). Copenhagen, Denmark: http://data.gbif.org/species/5178082/ Accessed July 15, 2015.

GBIF. 2012b. Occurrence Records for *Corophium lacustre* (Vanhöffen, 1911). Copenhagen, Denmark: http://data.gbif.org/species/2217325/ Accessed July 15, 2015.

GBIF. 2012c. Occurrence Records for *Rangia cuneata* (G. B. Sowerby I, 1831). Copenhagen, Denmark: http://data.gbif.org/species/5188971/ Accessed July 15, 2015.

GBIF. 2012d. Occurrence Records for *Styela plicata* (Lesueur, 1823). Copenhagen, Denmark: http://data.gbif.org/species/2331954/ Accessed July 15, 2015.

Gelsleichter, J., C. J. Walsh, N. J. Szabo and L. E. L. Rasmussen. 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):10.1016/j.chemosphere.2005.09.011 http://dx.doi.org/10.1016/j.chemosphere.2005.09.011 Accessed July 15, 2015.

Gerstein, E. R., J. E. Blue, G. F. Pinto and S. Barr. 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): https://sjrda.unf.edu/items/view/sjrda:279 Accessed July 15, 2015.

Giblin, A. E., A. Bourg, I. Valiela and J. M. Teal. 1980. Uptake and Losses of Heavy Metals in Sewage Sludge by a New England Salt Marsh. American Journal of Botany; 67(7):http://www.jstor.org/stable/2442198 Accessed July 15, 2015.

Gilg, M. R., R. Howard, R. Turner, M. Middlebrook, M. Abdulnour, E. Lukaj, P. Sheng, T. Liu and B. Tutak. 2014. Estimating the dispersal capacity of the introduced green mussel, *Perna viridis* (Linnaeus, 1758), from field collections and oceanographic modeling. Journal of Experimental Marine Biology and Ecology; 461(10.1016/j.jembe.2014.08.004 http://dx.doi.org/10.1016/j.jembe.2014.08.004 Accessed July 15, 2015.

Gilg, M. R., E. Lukaj, M. Abdulnour, E. Gonzalez, M. Middlebrook, R. Turner and R. Howard. 2010. Spatio-Temporal Settlement Patterns of the Non-native Titan Acorn Barnacle, *Megabalanus coccopoma*, in Northeastern Florida. Journal of Crustacean Biology; 30(1):10.1651/09-3148.1 http://dx.doi.org/10.1651/09-3148.1 Accessed July 15, 2015.

Gilliom, R. J., J. E. Barbash, C. G. Crawford, P. A. Hamilton, J. D. Martin, N. Nakagaki, L. H. Nowell, J. C. Scott, P. E. Stackelberg, G. P. Thelin and D. M. Wolock. 2006. Pesticides in the Nation's Streams and Ground Water, 1992-2001 (Revised February 2007). Washington (DC): http://pubs.usgs.gov/circ/2005/1291/pdf/circ1291.pdf Accessed July 15, 2015.

Gipson, J. 2014. *Personal Communication* to G. Pinto.

GLD&D. 2001. Future Opportunities: $31.6-million Deepening Funded for Jacksonville. Oak Brook (IL): https://sjrda.unf.edu/items/view/sjrda:283 Accessed July 15, 2015.

Goff, K. 2010. *Personal Communication* to L. Sonnenberg.

Goldberg, N. and K. C. Reiss. 2016. Accounting for Wetland Loss: Wetland Mitigation Trends in Northeast Florida 2006-2013. Wetlands; 36(2):73-384. Accessed May 25, 2016.

Gordon, D. 1997. Sodium Channels as Targets for Neurotoxins: Mode of Action and Interaction of Neurotoxins with Receptor Sites on Sodium Channels. (In Toxins and Signal Transduction). (Eds). 978-9057020780. Amsterdam: Harwood. 119-149. https://www.crcpress.com/Toxins-and-Signal-Transduction/Gutman-Lazarovici/9789057020780 Accessed July 15, 2015.

Gordon, D. R. 1998. Effects of Invasive, Non-Indigenous Plant Species on Ecosystem Processes: Lessons Learned from Florida. Ecological Applications; 8(4):10.1890/1051-0761(1998)008[0975:EOINIP]2.0.CO;2 http://www.esajournals.org/doi/abs/10.1890/1051-0761%281998%29008%5B0975%3AEOINIP%5D2.0.CO%3B2 Accessed July 15, 2015.

Graf, D. L. 2013. Phylum Nemertea. Stevens Point, WI: University of Wisconsin-Stevens Point. http://winvertebrates.uwsp.edu/Nemertea.html Accessed July 15, 2015

Granberry, J. 1956. Timucua I: Prosodics and Phonemics of the Mocama Dialect. International Journal of American Linguistics; 22(2):http://www.jstor.org/stable/1263585 Accessed July 15, 2015.

Granberry, J. 1993. Titlle. (Eds). ISBN: 978-0817307042. Tuscaloosa (AL): The University of Alabama Press. https://sjrda.unf.edu/items/forward/sjrda:286 Accessed July 15, 2015.

Gray, J. S., M. Waldichuk, A. J. Newton, R. J. Berry, A. V. Holden and T. H. Pearson. 1979. Pollution-Induced Changes in Populations. Philosophical Transactions of the Royal Society of London B.; 286(1015):10.1098/rstb.1979.0045 http://dx.doi.org/10.1098/rstb.1979.0045 Accessed July 15, 2015.

Green, E. J. and D. E. Carritt. 1967. New Tables for Oxygen Saturation of Seawater. Journal of Marine Research; 25(2):Accessed July 15, 2015.

Groom, M. J., G. K. Meffe and C. R. Carroll. 2006. Titlle. (Eds). ISBN: 978-0-878-93518-5. Sunderland (MA): Sinauer Associates, Inc. http://www.sinauer.com/catalog/biology/principles-of-conservation-biology.html Accessed July 15, 2015.

Grosell, M., J. Blanchard, K. V. Brix and R. Gerdes. 2007. Physiology is Pivotal for Interactions Between Salinity and Acute Copper Toxicity to Fish and Invertebrates. Aquatic Toxicology; 84(2):10.1016/j.aquatox.2007.03.026 http://dx.doi.org/10.1016/j.aquatox.2007.03.026 Accessed July 15, 2015.

Grosell, M., R. Gerdes and K. V. Brix. 2006. Influence of Ca, Humic acid and pH on Lead Accumulation and Toxicity in the Fathead Minnow During Prolonged Water-borne Lead Exposure. Comparative Biochemistry and Physiology - Part C: Toxicology & Pharmacology; 143(4):10.1016/j.cbpc.2006.04.014 http://dx.doi.org/10.1016/j.cbpc.2006.04.014 Accessed July 15, 2015.

Gross, T. S. and O. T. Burgess. 2015. Lower St. Johns River Biological Community Monitoring - Post Discharge Relocation Report. Accessed April 1, 2016.

GSMFC. 2010. Non-Native Aquatic Species in the Gulf of Mexico and South Atlantic Regions. Ocean Springs (MS): Gulf States Marine Fisheries Commission (GSMFC). http://www.gsarp.org/ Accessed July 15, 2015

Guillette Jr., L. J., J. W. Brock, A. A. Rooney and A. R. Woodward. 1999. Serum Concentrations of Various Environmental Contaminants and Their Relationship to Sex Steroid Concentrations and Phallus Size in Juvenile American Alligators. Archives of Environmental Contamination and Toxicology; 36(4):10.1007/PL00006617 http://dx.doi.org/10.1007/PL00006617 Accessed July 15, 2015.

Guillette Jr., L. J., T. S. Gross, G. R. Masson, J. M. Matter, H. F. Percival and A. R. Woodward. 1994. Developmental Abnormalities of the Gonads and Abnormal Hormone Concentrations in Juvenile Alligators from Contamined and Control Lakes in Florida. Environmental Health Perspectives; 102(8):http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1567320/ Accessed July 15, 2015.

Guzman, H. M. and C. E. Jimenez. 1992. Contamination of Coral Reefs by Heavy Metals Along the Caribbean Coast of Central America (Costa Rica and Panama). Marine Pollution Bulletin; 24(11):10.1016/0025-326X(92)90708-E http://www.sciencedirect.com/science/article/pii/0025326X9290708E Accessed July 15, 2015.

Hackney, C. T. 2015. St. Johns River Economic Study. Jacksonville (FL): http://floridaswater.com/stjohnsriver/pdfs/St._Johns_River_Economic_Study.pdf Accessed July 15, 2015.

Hallegraeff, G. M. and C. J. Bolch. 1991. Transport of Toxic Dinoflagellate Cysts via Ships' Ballast Water. Marine Pollution Bulletin; 22(1):10.1016/0025-326X(91)90441-T http://www.sciencedirect.com/science/article/pii/0025326X9190441T Accessed July 15, 2015.

Hallegraeff, G. M., C. J. Bolch, J. Bryan and B. Koerbin. 1990. Microalgal Spores in Ship's Ballast Water: A Danger to Aquaculture. Fourth International Conference on Toxic Marine Phytoplankton, Lund (Sweden): Elsevier. http://www.amazon.com/dp/044401523X Accessed July 15, 2015.

Hankla, D. 2007. U.S. Fish and Wildlife Service Announces Availability of the Wood Stork Five-Year Review. 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 July 15, 2015

Harper, H. H. and D. M. Baker. 2007. Evaluation of Current Stormwater Design Criteria within the State of Florida. Orlando (FL): http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/SW_TreatmentReportFinal_71907.pdf Accessed July 15, 2015.

Harrington, D., G. Maddox and R. Hicks. 2010. Florida Springs Initiative Monitoring Network Report and Recognized Sources of Nitrate. Tallahassee (FL): http://www.dep.state.fl.us/springs/reports/files/springs_report_102110.pdf Accessed July 15, 2015.

Hart, C. 2012. *Personal Communication* to G. Pinto.

Hartley, W. 2018. *Personal Communication* to G. Pinto.

Hefner, J. M. 1986. Wetlands in Florida: 1950's to 1970's. Managing Cumulative Effects in Florida Wetlands, Madison (WI): Omnipress. https://www.fws.gov/wetlands/Documents/Wetlands----of----Florida----1950s----to----1970s.pdf Accessed

Helsel, D. 2005. More Than Obvious: Better Methods for Interpreting Nondetect Data. Environmental Science and Technology; 39(20):10.1021/es053368a http://dx.doi.org/10.1021/es053368a Accessed July 15, 2015.

Hendrickson, J. 2006. The St. Johns River: Water Resource and Pollution Issues. A Seminar for Journalists. Palatka (FL): https://sjrda.unf.edu/items/view/sjrda:301 Accessed July 15, 2015.

Hendrickson, J. 2008. *Personal Communication* to P. Welsh.

Hendrickson, J. 2011. *Personal Communication* to L. Sonnenberg.

Hendrickson, J. 2013. *Personal Communication* to L. Sonnenberg.

Hendrickson, J. 2014. *Personal Communication* to G. Pinto.

Hendrickson, J. and J. Konwinski. 1998. Seasonal Nutrient Import-Export Budgets for the Lower St. Johns River, Florida. Palatka (FL): http://waterinstitute.ufl.edu/WorkingGroups/TCAA/downloads/Hendrickson_and_Konwinski_1998.pdf Accessed July 15, 2015.

Higman, J. C., C. Hart, J. Tallerico, S. Baird and D. Campbell. 2013. The Lower St. Johns River Basin Sediment Quality Atlas: Riverbed Sediment Characteristics and Contaminant Concentrations. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/SP/SJ2013-SP4.pdf Accessed July 15, 2015.

Hill, J. E. and J. Sowards. 2015. Successful eradication of the non-native loridcariid catfish Pterygoplichthys disjunctivus from the Rainbow River, Florida. Managemt Biol.l Inv.; 6(311-317. http://www.reabic.net/journals/mbi/2015/Accepted/MBI_2015_Hill_Sowards_correctedproof.pdf Accessed July 15, 2015.

Hoang, T. C., J. R. Tomasso and S. J. Klaine. 2004. Influence of Water Quality and Age on Nickel Toxicity to Fathead Minnows (*Pimephales promelas*). Environmental Toxicology and Chemistry; 23(1):10.1897/03-11 http://dx.doi.org/10.1897/03-11 Accessed July 15, 2015.

Hodson, P. V., B. R. Blunt and D. J. Spry. 1978. Chronic Toxicity of Water-borne and Dietary Lead to Rainbow Trout (*Salmo gairdneri*) in Lake Ontario Water. Water Research; 12(10):10.1016/0043-1354(78)90039-8 http://www.sciencedirect.com/science/article/pii/0043135478900398 Accessed July 15, 2015.

Horak, D. 1995. Native and Nonnative Fish Species Used in State Fisheries Management Programs in the United States. American Fisheries Society Symposium on Uses and Effects of Cultured Fishes in Aquatic Ecosystems, Albuquerque (NM): American Fisheries Society. http://www.amazon.com/dp/0913235911 Accessed July 15, 2015.

Hough, P. and M. Robertson. 2009. Mitigation Under Section 404 of the Clean Water Act: Where it Comes From, What it Means. Wetlands Ecology and Management; 17(1):10.1007/s11273-008-9093-7 http://dx.doi.org/10.1007/s11273-008-9093-7 Accessed July 15, 2015.

Houston, J. R. and R. G. Dean. 2014. Shoreline Change on the East Coast of Florida. Journal of Coastal Research; 30(4):10.2112/JCOASTRES-D-14-00028.1 http://dx.doi.org/10.2112/JCOASTRES-D-14-00028.1 Accessed July 15, 2015.

Humann, P. and N. Deloach. 2011. Titlle. (Eds). ISBN: 978-1878348319. Jacksonville (FL): New World Publications. http://www.fishid.com/nwp/index.php?main_page=product_info&cPath=1&products_id=3 Accessed July 15, 2015.

Hutchinson, G. E. 1944. Nitrogen in the Biogeochemistry of the Atmosphere. American Scientist; 32(3):http://www.jstor.org/stable/29773619 Accessed July 15, 2015.

Hyland, J. L., R. F. Van Dolah and T. R. Snoots. 1999. Predicting Stress in Benthic Communities of Southeastern U.S. Estuaries in Relation to Chemical Contamination of Sediments. Environmental Toxicology and Chemistry; 18(11):10.1002/etc.5620181124 http://dx.doi.org/10.1002/etc.5620181124 Accessed July 15, 2015.

IFAS. 2007. UF/IFAS Center for Aquatic and Invasive Plants. Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS). http://plants.ifas.ufl.edu/ Accessed July 15, 2015

IFAS. 2009. Trophic States of Florida Lakes. Gainesville (FL): University of Florida, Institute of Food and Agricultural Sciences (IFAS). http://plants.ifas.ufl.edu/manage/overview-of-florida-waters/introduction Accessed July 15, 2015

Incardona, J. P., T. K. Collier and N. L. Scholz. 2004. Defects in Cardiac Function Precede Morphological Abnormalities in Fish Embryos Exposed to Polycyclic Aromatic Hydrocarbons. Toxicology and Applied Pharmacology; 196(2):10.1016/j.taap.2003.11.026 http://dx.doi.org/10.1016/j.taap.2003.11.026 Accessed July 15, 2015.

Inclan, L. 2013. Algae Bloom in St. Johns River Causes Health Concerns. Jacksonville (FL): Action News Jacksonville. https://sjrda.unf.edu/items/view/sjrda:773 Accessed July 15, 2015

Jackson, T. 2013. *Personal Communication* to N. Goldberg.

Jacksonville Zoo. 2016. Biofacts: Bald Eagle. Jacksonville (FL): Jacksonville Zoo and Gardens. http://www.jacksonvillezoo.org/listingDetails.aspx?listingID=6983&pageID=15580 Accessed April 1, 2016

Jacksonville Zoo. 2018a. Biofacts: Bald Eagle. Jacksonville (FL): Jacksonville Zoo and Gardens. http://www.jacksonvillezoo.org/listingDetails.aspx?listingID=6983&pageID=15580 Accessed April 10, 2018

Jacksonville Zoo. 2018b. Wood Stork Conservation. Jacksonville (FL): Jacksonville Zoo and Gardens. http://www.jacksonvillezoo.org/woodstorkconservation Accessed April 10, 2018

Jacoby, C. A. 2011. *Personal Communication* to G. Pinto.

Jarvis, T. A., R. J. Miller, H. S. Lenihan and G. K. Bielmyer. 2013. Toxicity of ZnO Nanoparticles to the Copepod *Acartia tonsa*, Exposed Through a Phytoplankton Diet. Environmental Toxicology and Chemistry; 32(6):10.1002/etc.2180 http://dx.doi.org/10.1002/etc.2180 Accessed July 15, 2015.

JAXPORT. 2007. JAXPORT Begins Construction of New TraPac Terminal. Jacksonville (FL): Jacksonville Port Authority (JAXPORT). http://www.freightnet.com/release/1228.htm Accessed July 1, 2008

JAXPORT. 2008. Harbor Deepening. Jacksonville (FL): Jacksonville Port Authority (JAXPORT). http://www.jaxport.com/corporate/major-growth-projects/harbor-deepening Accessed July 15, 2015

JAXPORT. 2017. Cargo Statistics. Jacksonville (FL): Jacksonville Port Authority (JAXPORT). https://www.jaxport.com/newsroom/cargo-statistics Accessed March 10, 2017

JAXPORT. 2018. Cargo Statistics. Jacksonville (FL): Jacksonville Port Authority (JAXPORT). https://www.jaxport.com/newsroom/cargo-statistics Accessed March 10, 2018

JHS. 2014. Reptile Found in Ocala Forest Concerns Experts. Ocala, FL: Ocala Star Banner. http://www.ocala.com/article/20100516/ARTICLES/5161015 Accessed July 15, 2015

Jin, G., A. Englande, H. Bradford and H. Jeng. 2004. Comparison of E.Coli, Enterococci, and Fecal Coliform as Indicators for Brackish Water Quality Assessment. Water Environment Research; 76(3):245-255. http://www.ingentaconnect.com/content/wef/wer/2004/00000076/00000003/art00008 Accessed

Johnson, E. G. and M. K. Swenarton. 2016. Age, Growth And Population Structure Of Invasive Lionfish (Pterois volitans Miles) In Northeast Florida Using A Length-Based, Age-Structured Population Model. Journal; DOI 10.7717/peerj.2730 https://peerj.com/articles/2730.pdf Accessed Access Date.

Johnson, S. and M. McGarrity. 2013. Science: Tadpole Salinity Tolerance. The Invader Update; 5(4):http://ufwildlife.ifas.ufl.edu/InvaderUpdater/pdfs/InvaderUpdater_Winter2013.pdf Accessed July 15, 2015.

Jones, R. J. 1997. Zooxanthellae Loss as a Bioassay for Assessing Stress in Corals. Marine Ecology Progress Series; 149(1):10.3354/meps149163 http://dx.doi.org/10.3354/meps149163 Accessed July 15, 2015.

Jones, W. W. and S. Sauter. 2005. Distribution and Abundance of *Cylindrospermopsis raciborskii* in Indiana Lakes and Reservoirs. Bloomington (IN): https://sjrda.unf.edu/items/forward/sjrda:323 Accessed July 15, 2015.

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): https://sjrda.unf.edu/items/view/sjrda:325 Accessed July 15, 2015.

Jordan, F., M. Bartolini, C. Nelson, P. E. Patterson and H. L. Soulen. 1996. Risk of Predation Affects Habitat Selection by the Pinfish *Logodon rhomboids* (Linaeus). Journal of Experimental Marine Biology and Ecology; 208(1-2):10.1016/S0022-0981(96)02656-1 http://www.sciencedirect.com/science/article/pii/S0022098196026561 Accessed July 15, 2015.

JU. 2018. Jacksonville University Manatee Research Center Online (MARCO). Jacksonville (FL): Jacksonville University (JU). http://www.ju.edu/marco/ Accessed March 10, 2018

Karami-Mohajeri, S. and M. Abdollahi. 2011. Toxic Influence of Organophosphate, Carbamate, and Organochlorine Pesticides on Cellular Metabolism of Lipids, Proteins, and Carbohydrates: A Systematic Review. Human & Experimental Toxicology; 30(9):10.1177/0960327110388959 http://dx.doi.org/10.1177/0960327110388959 Accessed July 15, 2015.

Karen, D. J., B. M. Joab, J. M. Wallin and K. A. Johnson. 1998. Partitioning of Chlorpyrifos Between Water and an Aquatic Macrophyte *(Elodea densa)*. Chemosphere; 37(8):10.1016/S0045-6535(98)00141-6 http://www.sciencedirect.com/science/article/pii/S0045653598001416 Accessed July 15, 2015.

Karen, D. J., S. J. Klaine and P. E. Ross. 2001. Further Considerations of the Skeletal System as a Biomarker of Episodic Chlorpyrifos Exposure. Aquatic Toxicology; 52(3-4):10.1016/S0166-445X(00)00164-8 http://www.sciencedirect.com/science/article/pii/S0166445X00001648 Accessed July 15, 2015.

Karickhoff, S. W. 1981. Semi-Empirical Estimation of Sorption of Hydrophobic Pollutants on Natural Sediments and Soils. Chemosphere; 10(8):10.1016/0045-6535(81)90083-7 http://www.sciencedirect.com/science/article/pii/0045653581900837 Accessed July 15, 2015.

Karlavige, B. 2018. *Personal Communication* to G. Pinto.

Katagi, T. 2010. Bioconcentration, Bioaccumulation, and Metabolism of Pesticides in Aquatic Organisms. (In Reviews of Environmental Contamination and Toxicology). D. M. Whitacre (Eds). 978-1441914408. New York (NY): Springer-Verlag. 1-132. http://dx.doi.org/10.1007/978-1-4419-1440-8_1 Accessed July 15, 2015.

Kelly, N. M. 2001. Changes to the Landscape Pattern of Coastal North Carolina Wetlands Under the Clean Water Act, 1984–1992. Landscape Ecology; 16(1):10.1023/A:1008168322720 http://dx.doi.org/10.1023/A:1008168322720 Accessed July 15, 2015.

Kennedy, T. L., L. A. Horth and D. E. Carr. 2009. The Effects of Nitrate Loading on the Invasive Macrophyte *Hydrilla verticillata* and Two Common, Native Macrophytes in Florida. Aquatic Botany; 91(3):10.1016/j.aquabot.2009.06.008 http://dx.doi.org/10.1016/j.aquabot.2009.06.008 Accessed July 15, 2015.

Kenney, W. F., M. N. Waters, C. L. Schelske and M. Brenner. 2002. Sediment Records of Phosphorus-Driven Shifts to Phytoplankton Dominance in Shallow Florida Lakes. Journal of Paleolimnology; 27(3):10.1023/A:1016075012581 http://dx.doi.org/10.1023/A:1016075012581 Accessed July 15, 2015.

Kennish, M. J. 1997. Titlle. (Eds). Boca Raton (FL): CRC Press. https://www.crcpress.com/Pollution-Impacts-on-Marine-Biotic-Communities/Kennish/9780849384288 Accessed July 15, 2015.

Kensley, B. 1998. Estimates of Species Diversity of Free-living Isopod Crustaceans on Coral Reefs. Coral Reefs; 17(1):10.1007/s003380050100 http://dx.doi.org/10.1007/s003380050100 Accessed July 15, 2015.

Keppner, S. M. 1995. U.S. Fish and Wildlife Service: National and Regional Responses to Non-Indigenous Aquatic Species. Proceedings of the Northeast Conference on Non-Indigenous Aquatic Nuisance Species, Cromwell (CT): Connecticut Sea Grant College Program. Accessed July 15, 2015.

Kiker, C. F. and A. W. Hodges. 2002. Economic Benefits of Natural Land Conservation: Case Study in Northeast Florida. Gainesville (FL): U. o. Florida. http://www.fred.ifas.ufl.edu/economic-impact-analysis/pdf/NE-Fla-Project-Final-Report.pdf Accessed July 15, 2015.

Kincaid, T., G. Davies, C. Werner and R. DeHan. 2012. Demonstrating the interconnection between a wastewater application facility and a first magnitude spring in a karstic watershed: Tracer study of the Southeast Farm Wastewater Reuse Facility, Tallahassee, Florida. Tallahassee (FL): http://ufdcimages.uflib.ufl.edu/AA/00/01/68/94/00001/AA00016894.pdf Accessed July 15, 2015.

Kinnaird, M. F. 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): http://www.aquaticcommons.org/1085/ Accessed July 15, 2015.

Kinnaird, M. F. 1983b. Site-Specific Analysis of Factors Potentially Influencing Manatee Boat/Barge Mortality. Site-Specific Reduction of Manatee Boat/Barge Mortality. Gainesville (FL): http://ufdc.ufl.edu/UF00073786/00001 Accessed August 15, 2015.

Kitchen, S. 2016. JEA, city of Jacksonville to spend $30 million to reduce septic tanks. Jacksonville (FL): Florida Times Union. http://jacksonville.com/news/metro/2016-04-04/story/jea-city-jacksonville-spend-30-million-reduce-septic-tanks Accessed April 4, 2016

Klas, M. E. 2016. Regulators Want to Allow More Toxic Chemicals in Florida's Water. Tallahassee (FL): http://www.miamiherald.com/news/local/environment/article91731227.html Accessed May 2, 2017.

Kling, H. J. 2004. *Cylindrospermopsis Raciborskii* (Nostocales, Cyanobacteria): A Brief Historic Overview and Recent Discovery in the Assiniboine River (Canada). Fottea; 9(1):http://www.fottea.cz/pdfs/fot/2009/01/02.pdf Accessed July 15, 2015.

Kozelka, P. B. and K. W. Bruland. 1998. Chemical Speciation of Dissolved Cu, Zn, Cd, Pb in Narragansett Bay, Rhode Island. Marine Chemistry; 60(3-4):10.1016/S0304-4203(97)00107-2 http://www.sciencedirect.com/science/article/pii/S0304420397001072 Accessed July 15, 2015.

Kraemer, G. P., R. H. Chamberlain, P. H. Doering, A. D. Steinman and M. D. Hanisak. 1999. Physiological Responses of Transplants of the Freshwater Angiosperm *Vallisneria Americana* Along a Salinity Gradient in the Caloosahatchee Estuary (Southwestern Florida). Estuaries and Coasts; 22(1):10.2307/1352934 http://dx.doi.org/10.2307/1352934 Accessed July 15, 2015.

Kramer, J. R., G. Benoit, K. C. Bowles, D. M. DiToro, R. T. Herrin, G. W. Luther III, H. Manolopoulos, K. A. Robillard, M. M. Shafer and J. R. Shaw. 2000. Environmental Chemistry of Silver. (In Silver in the Environment: Transport, Fate, and Effects). A. W. Andren and T. W. Bober (Eds). 978-1880611449. Pensacola (FL): Society of Environmental Toxicology and Chemistry (SETAC). 1-25. https://www.setac.org/store/ViewProduct.aspx?id=1037388 Accessed July 15, 2015.

Krysko, K. L., J. P. Burgess, M. R. Rochford, C. R. Gillette, D. Cueva, K. M. Enge, L. A. Somma, J. L. Stabile, D. C. Smith, J. A. Wasilewski, G. N. Kieckhefer III, M. C. Granatosky and S. V. Nielsen. 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(http://www.flmnh.ufl.edu/museum-voices/kenney-krysko/files/2014/05/2011_Krysko_et_al_Verified_herps_in_Florida.pdf Accessed July 15, 2015.

Laane, R. W. P. M., W. W. C. Gieskes, G. W. Kraay and A. Eversdijk. 1985. Oxygen Consumption from Natural Waters by Photo-Oxidizing Processes. Netherlands Journal of Sea Research; 19(2):10.1016/0077-7579(85)90016-X http://www.sciencedirect.com/science/article/pii/007775798590016X Accessed July 15, 2015.

Laist, D. W., C. Taylor and J. E. Reynolds III. 2013. Winter Habitat Preferences for Florida Manatees and Vulnerability to Cold. PLoS ONE; 8(3):10.1371/journal.pone.0058978 http://dx.doi.org/10.1371/journal.pone.0058978 Accessed July 15, 2015.

Lamers, L. P. M., H. B. M. Tomassen and J. G. M. Roelofs. 1998. Sulfate-Induced Eutrophication and Phytotoxicity in Freshwater Wetlands. Environmental Science and Technology; 32(2):10.1021/es970362f http://dx.doi.org/10.1021/es970362f Accessed July 15, 2015.

Lane, C. R., B. C. Autrey, T. Jicha, L. Lehto, C. Elonen and L. Siefert-Monson. 2015. Denitrification Potential in Geographically Isolated Wetlands of North Carolina and Florida, USA. Wetlands; 35(3):459-471. http://link.springer.com/article/10.1007/s13157-015-0633-7 Accessed December 28, 2015.

Lane, C. R. and E. D'Amico. 2010. Calculating the Ecosystem Service of Water Storage in Isolated Wetlands using LiDAR in North Central Florida, USA. Wetlands; 30(5):10.1007/s13157-010-0085-z http://dx.doi.org/10.1007/s13157-010-0085-z Accessed July 15, 2015.

Lange, T. 2010. *Personal Communication* to L. Sonnenberg.

Leal, D. R. and R. E. Meiners (Eds). 2002. Government vs. Environment. 978-0742521803. Lanham (MD): Rowman & Littlefield Publishers. http://www.rowmanlittlefield.com/ISBN/074252180X Accessed July 15, 2015.

Lee, H. 2008. *Personal Communication* to H. McCarthy.

Lee, H. 2012a. Mytella Charruana (d'Orbigny, 1846) Charrua Mussels in Duval Co., Florida. Jacksonville (FL): Jacksonville Shell Club. http://www.jacksonvilleshells.org/012509.htm Accessed July 15, 2015

Lee, H. 2012b. *Personal Communication* to H. McCarthy.

Leendertse, P. C., M. C. T. Scholten and J. T. Van Der Wal. 1996. Fate and Effects of Nutrients and Heavy Metals in Experimental Salt Marsh Ecosystems. Environmental Pollution; 94(1):10.1016/S0269-7491(96)00104-2 http://www.sciencedirect.com/science/article/pii/S0269749196001042 Accessed July 15, 2015.

Levine, N. and T. Knudson. 2012. Interactive Graphic: Animals Killed by Wildlife Services Nationwide. Sacramento, CA: The Sacramento Bee. http://www.sacbee.com/news/investigations/wildlife-investigation/article2574588.html Accessed July 15, 2015

Levine, S. N. and D. W. Schindler. 1992. Modification of the N:P Ratio in Lakes by in Situ Processes. Limnology and Oceanography; 37(5):http://www.aslo.org/lo/toc/vol_37/issue_5/0917.pdf Accessed July 15, 2015.

Lewis, N. and J. Mandrup-Poulsen. 2009. Final TMDL Report: Lead TMDLs for Black Creek (WBIDs 2415B and 2415C) and Peters Creek (WBID 2444). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/black-peters-lead-tmdl.pdf Accessed July 15, 2015.

Lindeman, P. V. 2008. *Sternotherus Carinatus* (Gray 1856) - Razorback Musk Turtle, Razor-Backed Musk Turtle. Lunenberg, MA: A. G. J. Rhodin. http://dx.doi.org/10.3854/crm.5.012.carinatus.v1.2008 Accessed July 15, 2015.

Livingston, R. J. 2008. Importance of River Flow to the Apalachicola River-Bay System. Tallahassee (FL): http://mayorvanjohnson.com/files/Livingston_Report.pdf Accessed March 10, 2018.

Lomolino, M. V. 1977. The Ecological Role of the Florida Manatee (*Trichechus manatus latirostris*) in Water Hyacinth-Dominated Ecosystems. M.S.; University of Florida. http://uf.catalog.fcla.edu/permalink.jsp?20UF020568919 Accessed July 15, 2015.

Long, E. R., D. D. MacDonald, S. L. Smith and F. D. Calder. 1995. Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. Environmental Management; 19(1):10.1007/BF02472006 http://dx.doi.org/10.1007/BF02472006 Accessed July 15, 2015.

Long, M. 2018. *Personal Communication* to

LSJR TAC. 2012. 2012 SJRWMD Field Science Team Field Osbervations. Jacksonville (FL): Lower St. Johns River (LSJR) Technical Advisory Committee (TAC). http://www.lsjr.org/AlgalBloomInfo.html Accessed July 15, 2015

Ma, L. Q., W. G. Harris and J. Sartain. 2000. Environmental Impacts of Lead Pellets at Shooting Ranges & Arsenical Herbicides On Golf Courses in Florida. Gainesville (FL): http://soils.ifas.ufl.edu/lqma/Publication/MA-00-R.pdf Accessed July 15, 2015.

MacDonald, D. D. 1994. Chapter 6. Numerical Sediment Quality Assessment Guidelines for Florida Coastal Waters. Approach to the Assessment of Sediment Quality. (In Approach to the assessment of sediment quality in Florida coastal waters). (Eds). Tallahassee (FL): Florida Department of Environmental Protection (DEP). 48-75. http://www.dep.state.fl.us/water/monitoring/docs/seds/vol1/chapter6.pdf Accessed July 15, 2015.

Mager, E. M. and M. Grosell. 2011. Effects of Acute and Chronic Waterborne Lead Exposure on the Swimming Performance and Aerobic Scope of Fathead Minnows (*Pimephales promelas*). Comparative Biochemistry and Physiology - Part C: Toxicology & Pharmacology; 154(1):10.1016/j.cbpc.2011.03.002 http://dx.doi.org/10.1016/j.cbpc.2011.03.002 Accessed July 15, 2015.

Magley, W. 2006a. TMDL Report: Fecal and Total Coliform TMDLs for Durbin Creek (WBID 2365). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2365.pdf Accessed July 15, 2015.

Magley, W. 2006b. TMDL Report: Fecal and Total Coliform TMDLs for the Cedar River (WBID 2262). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2262A.pdf Accessed July 15, 2015.

Magley, W. 2009a. Final TMDL Report: Dissolved Oxygen and Nutrient TMDLs for Trout River (WBID 2203). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/MiddleTroutRiver-DO_TMDL.pdf Accessed July 15, 2015.

Magley, W. 2009b. Final TMDL Report: DO and Nutrient TMDLs for the Ortega River (WBID 2213P). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/OrtegaDONutTMDL.pdf Accessed June 17, 2016.

Magley, W. 2009c. Final TMDL Report: Nutrient TMDL for Arlington River, WBID 2265A. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/arlington-river-nutr-tmdl.pdf Accessed July 15, 2015.

Magley, W. 2009d. TMDL Report: Dissolved Oxygen TMDL for Sixteen Mile Creek, WBID 2589. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/SixteenMileCreek-DO-TMDL.pdf Accessed July 15, 2015.

Magley, W. 2009e. TMDL Report: DO and Nutrient TMDLs for Swimming Pen Creek (WBID 2410) and Nutrient TMDL for Doctors Lake (WBID 2389). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/SwimmingPenDoctors-DONut-TMDL.pdf Accessed July 15, 2015.

Magley, W. 2010. Final TMDL Report: Dissolved Oxygen and Nutrient TMDLs for Mill Creek (WBID 2460). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/millcreek-donut-tmdl.pdf Accessed July 15, 2015.

Magley, W. and D. Joyner. 2008. TMDL Report: Total Maximum Daily Load for Nutrients for the Lower St. Johns River. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/lower-stjohns-nutrients.pdf Accessed July 14, 2016.

Mahmoudi, B. 2005. A 2005 Update of the Stock Assessment for the Striped Mullet, *Mugil cephalus*, in Florida. St. Petersburg (FL): http://myfwc.com/media/203452/stripedmullet_2005asse_1327.pdf Accessed July 15, 2015.

Malecki, L. M., J. R. White and K. R. Reddy. 2004. Nitrogen and Phosphorus Flux Rates from Sediment in the Lower St. Johns River Estuary. Journal of Environmental Quality; 33(4):10.2134/jeq2004.1545 http://dx.doi.org/10.2134/jeq2004.1545 Accessed July 15, 2015.

Mason Jr, W. T. 1998. Macrobenthic Monitoring in the Lower St. Johns River, Florida. Environmental Monitoring and Assessment; 50(2):10.1023/A:1005802229832 http://dx.doi.org/10.1023/A:1005802229832 Accessed July 15, 2015.

Masterson, J. 2007. Indian River Lagoon Inventory: *Megabalanus coccopoma*, Titan Acorn Barnacle. Fort Pierce (FL): Smithsonian Marine Station. http://www.sms.si.edu/irlspec/Megabalanus_coccopoma.htm Accessed July 15, 2015

Mattson, R. A., K. W. Cummins, R. W. Merritt, P. A. Montagna, T. Palmer, J. Mace, J. Slater and C. A. Jacoby. 2012. St. Johns River Water Supply Impact Study: Chapter 11 - Benthic Macroinvertebrates. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/TP/SJ2012-1_Chapter11.pdf Accessed July 15, 2015.

McBride, R. S. 2000. Florida's Shad and River Herrings (*Alosa* species): A Review of Population and Fishery Characteristics. St. Petersburg (FL): http://f50006a.eos-intl.net/ELIBSQL12_F50006A_Documents/Technical Report TR-5_R.pdf Accessed July 15, 2015.

McCann, J. A., L. N. Arkin and J. D. Williams. 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): http://plants.ifas.ufl.edu/manage/sites/default/files/McCann_Arkin_Williams_1996-Nonindigenous.pdf Accessed July 15, 2015.

McCann, L. D., N. G. Hitchcock, J. E. Winston and G. M. Ruiz. 2007. Non-native Bryozoans in Coastal Embayments of the Southern United States: New Records for the Western Atlantic. Bulletin of Marine Science;

80(2):http://openurl.ingenta.com/content?genre=article&issn=0007-4977&volume=80&issue=2&spage=319&epage=342 Accessed July 15, 2015.

McCarthy, D. 2008. *Personal Communication* to H. McCarthy.

McCarthy, H. (2011). Unpublished Data.

McCloud, L. 2010. *Personal Communication* to D. McCarthy.

McCully, J. G. 2006. Titlle. (Eds). ISBN: 978-9812566447. Hackensack (NJ): World Scientific Publishing. http://dx.doi.org/10.1142/9789812774330 Accessed July 15, 2015.

McLane, W. M. 1955. The Fishes of the St. Johns River System. Ph.D.; University of Florida. http://uf.catalog.fcla.edu/permalink.jsp?20UF000543250 Accessed July 15, 2015.

McLaughlin, D. L., D. A. Kaplan and M. J. Cohen. 2015. A significant nexus: Geographically isolated wetlands influence landscape hydrology. Water Resources Research; 50(9):7153-7166. 10.1002/2013WR015002 http://www.watershedecology.org/uploads/1/2/7/3/12731039/mclaughlin_et_al._2014.pdf Accessed December 28, 2015.

Meindl, C. F. 2005. Chapter 5: Water, Water Everywhere. (In Paradise Lost? An Environmental History of Florida). J. E. Davis and R. e. Arsenault (Eds). ISBN: 978-0813028262. Gainesville (FL): University Press of Florida. 113-140. http://www.upf.com/book.asp?id=DAVISF05 Accessed July 15, 2015.

MetroJacksonville. 2017. South Shores: A historic neighborhood near its end? . Jacksonville (FL): Metro Jacksonville. https://www.metrojacksonville.com/article/2017-nov-south-shores-a-historic-neighborhood-near-its-end Accessed March 10, 2018

Meybeck, M. 1982. Carbon, Nitrogen, and Phosphorus Transport by World Rivers. American Journal of Science; 282(4):10.2475/ajs.282.4.401 http://dx.doi.org/10.2475/ajs.282.4.401 Accessed July 15, 2015.

Meybeck, M. 1993. Natural Sources of C, N, P, and S. (In Interactions of C, N, P and S Biogeochemical Cycles and Global Change). R. Wollast, F. T. Mackenzie and L. e. Chou (Eds). ISBN: 978-3642760662. Berlin (Germany): Springer-Verlag. 163-193. http://www.springer.com/earth+sciences+and+geography/geography/book/978-3-642-76066-2 Accessed July 15, 2015.

Milanich, J. T. 1995. Titlle. (Eds). ISBN: 978-0813016368. Gainesville (FL): University Press of Florida. http://www.upf.com/book.asp?id=MILANF95 Accessed July 15, 2015.

Milanich, J. T. 1996. Titlle. (Eds). ISBN: 978-0631218647. Hoboken (NJ): Wiley-Blackwell. http://www.wiley.com/WileyCDA/WileyTitle/productCd-0631218645.html Accessed July 15, 2015.

Milanich, J. T. 1997. Missions, Timucuans, and the Aucilla. Aucilla River Times; X(1):None http://www.flmnh.ufl.edu/vertpaleo/aucilla10_1/missions.htm Accessed July 15, 2015.

Milanich, J. T. 1998. Titlle. (Eds). ISBN: 978-0813015989. Gainesville (FL): University Press of Florida. http://www.upf.com/book.asp?id=MILANF98 Accessed July 15, 2015.

Miller, J. J. 1998. Titlle. (Eds). ISBN: 978-0813016009. Gainesville (FL): University Press of Florida. http://www.upf.com/book.asp?id=MILLES98 Accessed July 15, 2015.

Mitchelmore, C. L., E. A. Verde, A. H. Ringwood and V. M. Weis. 2003. Differential Accumulation of Heavy Metals in the Sea Anemone *Anthopleura elegantissima* as a Function of Symbiotic State. Aquatic Toxicology; 64(3):10.1016/S0166-445X(03)00055-9 http://www.sciencedirect.com/science/article/pii/S0166445X03000559 Accessed July 15, 2015.

Mitsch, W. J. and J. G. Gosselink. 2000. The Value of Wetlands: Importance of Scale and Landscape Setting. Ecological Economics; 35(200):10.1016/S0921-8009(00)00165-8 http://www.sciencedirect.com/science/article/pii/S0921800900001658 Accessed July 15, 2015.

Miyamoto, J. and M. Matsuo. 1990. Environmental Health Criteria No 94: Permethrin. Geneva (Switzerland): http://www.inchem.org/documents/ehc/ehc/ehc94.htm Accessed July 15, 2015.

Montagna, P. A., T. A. Palmer and J. B. Pollack. 2011. St. Johns Estuary: Estuarine Benthic Macroinvertebrates Phase 2. A Final Report Submitted to the St. Johns River Water Management District. Palatka (FL): H. R. I. f. G. o. M. Studies. http://floridaswater.com/technicalreports/pdfs/SP/SJ2012-SP4.pdf Accessed July 15, 2015.

Monteiro, P. R. R., M. A. Reis-Henriques and J. Coimbra. 2000. Plasma Steroid Levels in Female Flounder (*Platichthys flesus*) after Chronic Dietary Exposure to Single Polycyclic Aromatic Hydrocarbons. Marine Environmental Research; 49(5):http://dx.doi.org/10.1016/S0141-1136(99)00085-9 http://www.sciencedirect.com/science/article/pii/S0141113699000859 Accessed July 15, 2015.

Moody, H. L. 1970. Factors in the Decline of the Fishery of the St. Johns River, Florida: Report to the Florida Department of Air and Water Pollution Control Board. Tallahassee (FL): Accessed July 15, 2015.

Moreno-Mateos, D., M. E. Power, F. A. Comin and R. Yockteng. 2012. Structural and Functional Loss in Restored Wetland Ecosystems. PLoS Biology; 10(1):10.1371/journal.pbio.1001247 http://dx.doi.org/10.1371/journal.pbio.1001247 Accessed July 15, 2015.

Morris IV, F. W. 1995. Volume 3 of the Lower St. Johns River Basin Reconnaissance: Hydrodynamics and Salinity of Surface Water. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/TP/SJ95-9.pdf Accessed July 15, 2015.

Mortimer, C. H. 1981. Titlle. (Eds). ISBN: 978-3510520220. Stuttgart (Germany): Schweizerbart Science Publishers. http://www.schweizerbart.de/publications/detail/isbn/351052022X Accessed July 15, 2015.

Moskowitz, H., R. Herrmann, E. Zlotkin and D. Gordon. 1994. Variability Among Insect Sodium Channels Revealed by Binding of Selective Neurotoxins. Insect Biochemical and Molecular Biology; 24(1):10.1016/0965-1748(94)90118-X http://www.sciencedirect.com/science/article/pii/096517489490118X Accessed July 15, 2015.

Mulcrone, R. S. 2005. Animal Diversity Web: Echinodermata - Sea Stars, Sea Urchins, Sea Cucumbers, and Relatives. Ann Arbor, MI: University of Michigan. http://animaldiversity.org/accounts/Echinodermata/ Accessed July 15, 2015

Muller, R. G., T. M. Bert and S. D. Gerhart. 2006. The 2006 Stock Assessment Update for the Stone Crab, *Menippe* spp., Fishery in Florida. St. Petersburg (FL): http://myfwc.com/media/203200/sa_stone_crab_2006_0856.pdf Accessed July 15, 2015.

Mundy, C. 2018. Hydrologic Conditions Report - March 2018, Agenda Item 2 (PowerPoint Presentation). Palatka (FL): S. J. R. W. M. D. (SJRMD). Accessed April 13, 2018.

Munyandorero, J., M. D. Murphy and T. C. MacDonald. 2006. An Assessment of the Status of Sheepshead in Florida Waters Through 2004. St. Petersburg (FL): https://sjrda.unf.edu/items/forward/sjrda:465 Accessed July 15, 2015.

Murphy, M. D., D. Chagaris and D. Addis. 2011. An Assessment of the Status of Spotted Seatrout in Florida Waters Through 2009. St. Petersburg (FL): http://myfwc.com/media/1355905/Spotted_seatrout.pdf Accessed July 15, 2015.

Murphy, M. D., A. L. McMillen-Jackson and B. Mahmoudi. 2007. A Stock Assessment for the Blue Crab, *Callinectes sapidus*, in Florida Waters. St. Petersburg (FL): http://myfwc.com/media/200959/bc_2007.pdf Accessed July 15, 2015.

Murphy, M. D. and J. Munyandorero. 2008. A Stock Assessment of Red Drum, *Sciaenops ocellatus*, in Florida: Status of Stocks Through 2007. St. Petersburg (FL): http://myfwc.com/media/1353540/red-drum.pdf Accessed July 15, 2015.

Murphy, M. D. and R. G. Taylor. 1990. Tag/Recapture and Age Validation of Red Drum in Florida. St. Petersburg (FL): http://myfwc.com/media/1353540/red-drum.pdf Accessed July 15, 2015.

Murray-Hudson, M., C. R. Lane, S. North and B. M.T. 2012. Macrophyte Species Distribution, Indices of Biotic Integrity, and Sampling Intensity in Isolated Florida Marshes. Wetlands; 32(3):10.1007/s13157-012-0278-8 http://dx.doi.org/10.1007/s13157-012-0278-8 Accessed July 15, 2015.

Myers, P. 2001a. Animal Diversity Web: Cnidaria - Corals, Sea Anemones, Jellyfish, and Relatives. Ann Arbor, MI: University of Michigan. http://animaldiversity.org/accounts/Cnidaria/ Accessed July 15, 2015

Myers, P. 2001b. Animal Diversity Web: Insecta - Insects. Ann Arbor, MI: University of Michigan. http://animaldiversity.org/accounts/Insecta Accessed July 15, 2015

Myers, P. 2001c. Animal Diversity Web: Porifera - Sponges. Ann Arbor, MI: University of Michigan. http://animaldiversity.org/accounts/Porifera/ Accessed July 15, 2015

Myers, R. L. and J. J. Ewel (Eds). 1990. Ecosystems of Florida. 978-0813010229. Orlando (FL): University Press of Florida. http://www.upf.com/book.asp?id=MYERSF90 Accessed July 15, 2015.

Naumann, E. 1929. The Scope and Chief Problems of Regional Limnology. International Review of Hydrobiology; 22(1):10.1002/iroh.19290220128 http://dx.doi.org/10.1002/iroh.19290220128 Accessed July 15, 2015.

Neff, J. M. and W. A. Burns. 1996. Estimation of Polycyclic Aromatic Hydrocarbon Concentrations in the Water Column Based on Tissue Residues in Mussels and Salmon: An Equilibrium Partitioning Approach. Environmental Toxicology and Chemistry; 15(12):10.1002/etc.5620151218 http://dx.doi.org/10.1002/etc.5620151218 Accessed July 15, 2015.

NEMESIS. 2014. Bill Number: National Exotic Marine and Estuarine Species Information System. Code(Code Edgewater, MD: Smithsonian Environmental Research Center (SERC). http://invasions.si.edu/nemesis/index.jsp Accessed July 15, 2015.

Newbold, J. D. 1992. Cycles and Spirals of Nutrients. (In The Rivers Handbook. I. Hydrological and Ecological Principles). P. Calow and G. E. Petts (Eds). 978-0632028327. Oxford (England): Blackwell Science Publishers. 379-408. http://www.limnology.uni-muenster.de/etc/experieco/lit/respiration/newbold_1992.pdf Accessed July 15, 2015.

Newman, W. A. and D. P. Abbott. 1980. Cirripedia: The Barnacles. (In Intertidal Invertebrates of California). R. H. Morris, D. P. Abbott and E. C. Haderlie (Eds). 978-0804710459. Stanford (CA): Stanford University Press. 504-535. http://www.amazon.com/dp/0804710457 Accessed July 15, 2015.

News4JAX. 2014. DEP challenged over St. Marys water standards. Jacksonville (FL): News Service of Florida. http://www.news4jax.com/news/florida/nassau-county/dep-challenged-over-st-marys-water-standards Accessed June 27

News4JAX. 2015. Local boys catch their own 'River Monster'. Jacksonville (FL): News4JAX. http://www.news4jax.com/news/local-boys-catch-their-own-river-monster/29821620 Accessed July 15, 2015

News4JAX. 2018. Work begins on $484M St. Johns River dredging project. Jacksonville (FL): News4JAX. https://www.news4jax.com/news/local/jacksonville/work-begins-on-billion-st-johns-river-dredging-project Accessed April 13, 2018

NFLB. 2017. 5th Annual Northeast Florida Lionfish Blast. Jacksonville (FL): https://www.lionfishblast.com/ Accessed March 3, 2017

NFLT. 2018. Land acquired by North Florida Land Trust along the Ortega River has been named for donors. Jacksonville (FL): http://www.northfloridalandtrust.org/pressreleases/ Accessed March 10, 2018.

Nixon, S. W. 1995. Coastal Marine Eutrophication: A Definition, Social Causes, and Future Concerns. Ophelia; 41(1):10.1080/00785236.1995.10422044 http://www.tandfonline.com/doi/abs/10.1080/00785236.1995.10422044 Accessed July 15, 2015.

NMFS. 1998. Recovery Plan for the Shortnose Sturgeon (*Acipenser brevirostrum*). Washington (DC): http://www.nmfs.noaa.gov/pr/pdfs/recovery/sturgeon_shortnose.pdf Accessed July 15, 2015.

NOAA. 2007a. Bill Number: National Center for Coastal Monitoring and Assessment: Monitoring Data - Benthic Surveillance. Code(Code National Oceanic and Atmospheric Administration (NOAA). http://ccma.nos.noaa.gov/about/coast/nsandt/benthic_surveillance.aspx Accessed July 15, 2015.

NOAA. 2007b. Bill Number: National Center for Coastal Monitoring and Assessment: Monitoring Data - Mussel Watch. Code(Code National Oceanic and Atmospheric Administration (NOAA). http://ccma.nos.noaa.gov/about/coast/nsandt/musselwatch.aspx Accessed July 15, 2015.

NOAA. 2008. Screening Quick Reference Tables. Seattle (WA): http://response.restoration.noaa.gov/sites/default/files/SQuiRTs.pdf Accessed July 15, 2015.

NOAA. 2013. Download Environmental Sensitivity Index (ESI) Maps and GIS Data. Washington (DC): National Oceanic and Atmospheric Administration (NOAA), Office of Response and Restoration. http://response.restoration.noaa.gov/maps-and-spatial-data/download-esi-maps-and-gis-data.html - Florida Accessed July 1, 2014

NOAA. 2018. 2017 Atlantic Hurricane Season. Miami (FL): National Oceanic and Atmospheric Administration (NOAA), National Hurricane Center. https://www.nhc.noaa.gov/data/tcr/index.php?season=2017&basin=atl Accessed April 10, 2018

Novitski, R. P. 1985. The Effects of Lakes and Wetlands on Flood Flows and Base Flows in Selected Northern and Eastern States. Wetlands Of The Chesapeake, Easton (MD): Environmental Law Institute. Accessed July 15, 2015.

NRC. 1995. Titlle. (Eds). ISBN: 978-0309083973. Washington (DC): National Academies Press (NAP), National Research Council (NRC). http://www.nap.edu/catalog/4923/understanding-marine-biodiversity Accessed July 15, 2015.

NRC. 1996a. National Science Education Standards. Washington (DC): Accessed April 10, 2018.

NRC. 1996b. Titlle. (Eds). ISBN: 978-0309055376. Washington (DC): National Academies Press, National Research Council (NRC). http://www.nap.edu/catalog/5294/stemming-the-tide-controlling-introductions-of-nonindigenous-species-by-ships Accessed July 15, 2015.

NRC. 2000. Titlle. (Eds). ISBN: 978-0309069489. Washington (DC): National Academies Press, National Research Council (NRC). http://www.nap.edu/catalog/9812/clean-coastal-waters-understanding-and-reducing-the-effects-of-nutrient Accessed July 15, 2015.

NRC. 2001. Titlle. (Eds). ISBN: 978-0309074322. Washington (DC): National Academies Press (NAP), National Research Council (NRC). http://www.nap.edu/catalog/10134/compensating-for-wetland-losses-under-the-clean-water-act Accessed July 15, 2015.

NRC. 2002. Titlle. (Eds). ISBN: 978-0309082648. Washington (DC): National Academies Press (NAP), National Research Council (NRC). http://www.nap.edu/catalog/10259/predicting-invasions-of-nonindigenous-plants-and-plant-pests Accessed July 15, 2015.

NRC. 2010. Review of the St. Johns River Water Supply Impact Study: Report 3 (2010). Washington (DC): https://www.nap.edu/read/13052/chapter/1 Accessed April 12, 2018.

NRC. 2011. Titlle. (Eds). ISBN: 978-0309225670. Washington (DC): National Academies Press (NAP), National Research Council (NRC). http://www.nap.edu/catalog/13314/review-of-the-st-johns-river-water-supply-impact-study Accessed July 15, 2015.

NRC (2012). Review of the St. Johns River Water Supply Impact Study: Final Report). Washington (DC), National Academis Press (NAP), National Research Council (NRC).

NRC. 2013. Titlle. (Eds). Washington (DC): National Academies Press (NAP), National Research Council (NRC). Accessed April 1, 2018.

Nriagu, J. O. 1980. Global Cycle and Properties of Nickel. (In Nickel in the Environment). (Eds). ISBN: 9780471058854. New York (NY): Wiley Interscience. 1-26. http://www.amazon.com/dp/0471058858 Accessed July 15, 2015.

O'Connor, T. P. and G. G. Lauenstein. 2006. Trends in Chemical Concentrations in Mussels and Oysters Collected Along the U.S. Coast: Update to 2003. Marine Environmental Research; 62(4):10.1016/j.marenvres.2006.04.067 http://dx.doi.org/10.1016/j.marenvres.2006.04.067 Accessed July 15, 2015.

OSHA. 2017. Beryllium. Washington (DC): https://www.osha.gov/SLTC/beryllium/ Accessed May 2, 2017.

Ouyang, Y., J. C. Higman and J. Hatten. 2012. Estimation of Dynamic Load of Mercury in a River with BASINS-HSPF Model. Journal of Soils and Sediments; 12(2):10.1007/s11368-011-0426-4 http://dx.doi.org/10.1007/s11368-011-0426-4 Accessed July 15, 2015.

Ouyang, Y., P. Nkedi-Kizza, R. S. Mansell and J. Y. Ren. 2003. Spatial Distribution of DDT in Sediments from Estuarine Rivers of Central Florida. Journal of Environmental Quality; 32(5):10.2134/jeq2003.1710 http://dx.doi.org/10.2134/jeq2003.1710 Accessed July 15, 2015.

Ouyang, Y., P. Nkedi-Kizza, Q. T. Wu, D. Shinde and C. H. Huang. 2006. Assessment of Seasonal Variations in Surface Water Quality. Water Research; 40(20):10.1016/j.watres.2006.08.030 http://dx.doi.org/10.1016/j.watres.2006.08.030 Accessed July 15, 2015.

Ouyang, Y., J. E. Zhang and L. Cui. 2014. Estimating Impacts of Land Use on Groundwater Quality Using Trilinear Analysis. Environmental Monitoring and Assessment; 186(9):10.1007/s10661-014-3784-8 http://dx.doi.org/10.1007/s10661-014-3784-8 Accessed July 15, 2015.

Pane, E. F., J. G. Richards and C. M. Wood. 2003. Acute Waterborne Nickel Toxicity in the Rainbow Trout (*Oncorhynchus mykiss*) Occurs by a Respiratory Rather Than Ionoregulatory Mechanism. Aquatic Toxicology; 63(1):10.1016/S0166-445X(02)00131-5 http://dx.doi.org/10.1016/S0166-445X%2802%2900131-5 Accessed July 15, 2015.

Patterson, S. 2013. Riverkeeper: Stay Away from the St. Johns. Jacksonville (FL): Florida Times Union. http://jacksonville.com/news/premium-news/2013-10-09/story/st-john-river-tests-show-algae-toxins-far-above-un-standards Accessed July 15, 2015

Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic Succession in Relation to Organic Enrichment and Pollution of The Marine Environment. (In Oceanography and Marine Biology. An Annual Review). (Eds). Boca Raton (FL): CRC Press. 229-311. http://www.researchgate.net/publication/243785865 Accessed July 15, 2015.

Phillips, B. M., B. S. Anderson, J. P. Voorhees, J. W. Hunt, R. W. Holmes, A. Mekebri, V. Connor and R. S. Tjeerdema. 2010. The Contribution of Pyrethroid Pesticides to Sediment Toxicity in Four Urban Creeks in California, USA. Journal of Pesticide Science; 35(3):10.1584/jpestics.G10-34 http://dx.doi.org/10.1584/jpestics.G10-34 Accessed July 15, 2015.

Phlips, E. J., E. Bledsoe, M. Cichra, S. Badylak and J. Frost. 2002. The Distribution of Potentially Toxic Cyanobacteria in Florida. Proceedings of Health Effects of Exposure to Cyanobacteria Toxins: State of the Science, Sarasota (FL): Mote Marine Laboratory. https://sjrda.unf.edu/items/view/sjrda:493 Accessed July 15, 2015.

Phlips, E. J., M. Cichra, F. J. Aldridge, J. Jembeck, J. Hendrickson and R. W. Brody. 2000. Light Availability and Variations in Phytoplankton Standing Crops in a Nutrient-rich Blackwater River. Limnology and Oceanography; 45(4):10.4319/lo.2000.45.4.0916 http://www.aslo.org/lo/pdf/vol_45/issue_4/0916.pdf Accessed July 15, 2015.

Phlips, E. J., J. Hendrickson, E. L. Quinlan and M. Cichra. 2007. Meteorological Influences on Algal Bloom Potential in a Nutrient-rich Blackwater River. Freshwater Biology; 52(11):10.1111/j.1365-2427.2007.01844.x http://dx.doi.org/10.1111/j.1365-2427.2007.01844.x Accessed July 15, 2015.

Piehler, M. F., J. Dyble, P. H. Moisander, A. D. Chapman, J. Hendrickson and H. W. Paerl. 2009. Interactions Between Nitrogen Dynamics and Phytoplankton Community in Lake George. Lake and Reservoir Management; 25(1):10.1080/07438140802714288 http://dx.doi.org/10.1080/07438140802714288 Accessed July 15, 2015.

Pierce, R. H., L. K. Dixon, R. C. Brown and G. Rodrick. 1988. Characterization of Baseline Conditions of the Physical, Chemical and Microbiological Environments in the St. Johns River Estuary. Sarasota (FL): https://dspace.mote.org:8443/dspace/bitstream/2075/23/1/128.pdf Accessed July 15, 2015.

Power, A., M. A. Mitchell, R. Walker, M. Posey, T. Alphin and C. Belcher. 2006. Baseline Port Surveys for Introduced Marine Molluskan, Crustacean and Polychaete Species in the South Atlantic Bight. Savannah (GA): http://georgiaseagrant.uga.edu/images/uploads/media/Port_Survey.pdf Accessed July 15, 2015.

Purdum, E. D. 2002. Florida Waters: A Water Resources Manual from Florida's Water Management Districts. Palatka (FL): http://www.swfwmd.state.fl.us/publications/files/floridawaters.pdf Accessed July 15, 2015.

Rahman, F. A., D. L. Allan, C. J. Rosen and M. J. Sadowsky. 2004. Arsenic Availability From Chromated Copper Arsenate (CCA)-Treated Wood. Journal of Environmental Quality; 33(1):10.2134/jeq2004.1730 http://dx.doi.org/10.2134/jeq2004.1730 Accessed July 15, 2015.

Rao, D. V., S. A. Jenab and D. A. Clapp. 1989. Rainfall Analysis of Northeast Florida. Part III: Seasonal Rainfall Data. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/TP/SJ89-1.pdf Accessed July 15, 2015.

Rauschenberger, R. H., M. S. Sepúlveda, J. J. Wiebe, N. J. Szabo and T. S. Gross. 2004. Predicting Maternal Body Burdens of Organochlorine Pesticides from Eggs and Evidence of Maternal Transfer in *Alligator mississippiensis*. Environmental Toxicology and Chemistry; 23(12):10.1897/03-584.1 http://dx.doi.org/10.1897/03-584.1 Accessed July 15, 2015.

Rawlings, T. A., K. A. Hayes, R. H. Cowie and T. M. Collins. 2007. The Identity, Distribution, and Impacts of Non-native Apple Snails in the Continental United States. BMC Evolutionary Biology; 7(1):10.1186/1471-2148-7-97 http://dx.doi.org/10.1186/1471-2148-7-97 Accessed July 15, 2015.

Reichert, A. J. and G. B. Jones. 1994. Trace Metals as Tracers of Dredging Activity in Cleveland Bay - Field and Laboratory Studies. Australian Journal of Marine and Freshwater Research; 45(7):10.1071/MF9941237 http://dx.doi.org/10.1071/MF9941237 Accessed July 15, 2015.

Reid, J. P., R. K. Bonde and T. J. O'Shea. 1995. Reproduction and Mortality of Radio-Tagged and Recognizable Manatees on the Atlantic Coast of Florida. (In Population Biology of the Florida Manatee (*Trichechus manatus latirostris*)). T. J. O'Shea, B. B. Ackerman and H. F. Percival (Eds). Washington (DC): National Biological Service (NBS). 171-191. https://www.fort.usgs.gov/sites/default/files/products/publications/2364/2364.pdf Accessed July 15, 2015.

Reiss, K. C. 2006. Florida Wetland Condition Index for Depressional Forested Wetlands. Ecological Indicators; 6(2):10.1016/j.ecolind.2005.03.013 http://dx.doi.org/10.1016/j.ecolind.2005.03.013 Accessed July 15, 2015.

Reiss, K. C. and M. T. Brown. 2007. Evaluation of Florida Palustrine Wetlands: Application of USEPA Levels 1, 2, and 3 Assessment Methods. EcoHealth; 4(2):10.1007/s10393-007-0107-3 http://dx.doi.org/10.1007/s10393-007-0107-3 Accessed July 15, 2015.

Reiss, K. C., E. Hernandez and M. T. Brown. 2007. An Evaluation of the Effectiveness of Mitigation Banking in Florida: Ecological Success and Compliance with Permit Criteria. Tallahassee (FL): http://www.dep.state.fl.us/water/wetlands/docs/mitigation/Final_Report.pdf Accessed July 15, 2015.

Reiss, K. C., E. Hernandez and M. T. Brown. 2009. Evaluation of Permit Success in Wetland Mitigation Banking: A Florida Case Study. Wetlands; 29(3):10.1672/08-148.1 http://dx.doi.org/10.1672/08-148.1 Accessed July 15, 2015.

Reiss, K. C., E. Hernandez and M. T. Brown. 2014. Application of the Landscape Development Intensity (LDI) Index in Wetland Mitigation Banking. Ecological Modelling; 271(10):10.1016/j.ecolmodel.2013.04.017 http://dx.doi.org/10.1016/j.ecolmodel.2013.04.017 Accessed July 15, 2015.

Rhew, K. 2009a. Final TMDL Report: Fecal Coliform TMDL for Little Black Creek (WBID 2368), Peters Creek (WBID 2444), and Greene Creek (WBID 2478). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/fecaltmdl_2368_2444_2478.pdf Accessed July 15, 2015.

Rhew, K. 2009b. Final TMDL Report: Fecal Coliform TMDL for Mill Creek (WBID 2460). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/fecaltmdl_millcreek.pdf Accessed July 15, 2015.

Rhew, K. 2009c. Final TMDL Report: Fecal Coliform TMDL for Pottsburg Creek (WBID 2265B) and Julington Creek (WBID 2351). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/fecaltmdl_2265b_2351.pdf Accessed July 15, 2015.

Rhew, K. 2009d. Final TMDL Report: Fecal Coliform TMDL for Strawberry Creek (WBID 2239). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/fecaltmdl_strawberryc.pdf Accessed July 15, 2015.

Rhew, K. 2009e. Final TMDL Report: Fecal Coliform TMDL for the Ortega River (WBID 2213P). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/fecaltmdl_ortegarive.pdf Accessed July 15, 2015.

Rich-Zeisler, J. and K. Kingon. 2009. Final TMDL Report: Fecal Coliform TMDL for McCoy Creek, WBID 2257. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/mcoycreekfecalfinal.pdf Accessed July 15, 2015.

Rodgers Jr, J. A., M. Barrett and R. S. Butryn. 2010. Productivity and Habitat Modeling of Wood Storks *Mycteria Americana* Nesting in North and Central Florida. Final Performance Report. St. Petersburg (FL): https://sjrda.unf.edu/items/view/sjrda:499 Accessed July 15, 2015.

Rodgers Jr, J. A., S. T. Schwikert, G. A. Griffin and D. Bear-Hull. 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): https://sjrda.unf.edu/items/view/sjrda:498 Accessed July 15, 2015.

Rodgers Jr, J. A., S. T. Schwikert, G. A. Griffin, W. B. Brooks, D. Bear-Hull, P. M. Elliott, K. J. Ebersol and J. Morris. 2008b. Productivity of Wood Storks (*Mycteria americana*) in North and Central Florida. Waterbirds; 31(SP1):10.1675/1524-4695(2008)31[25:POWSMA]2.0.CO;2 http://www.bioone.org/doi/abs/10.1675/1524-4695%282008%2931%5B25%3APOWSMA%5D2.0.CO%3B2 Accessed July 15, 2015.

Rodgers Jr., J. A. 2011. *Personal Communication* to G. Pinto.

Ross, M. 2018. *Personal Communication* to G. Pinto.

Rossi, A. M., D. C. Moon, D. Casamatta, K. Smith, C. Bentzien, J. McGregor, A. Norwich, E. Perkerson, R. Perkerson, J. Savinon, K. Stokes and D. Doebberfuhl. 2010. Pilot Study on the Effects of Partially Restored Riparian Plant Communities on Habitat Quality and Biodiversity along First-Order Tributaries of the Lower St. Johns River. Journal of Water Resource and Protection; 2(9):10.4236/jwarp.2010.29090 http://dx.doi.org/10.4236/jwarp.2010.29090 Accessed July 15, 2015.

Ruckelshaus, M. H. and C. G. Hays. 1997. Chapter 6. Conservation and Management of Species in the Sea. (In Conservation Biology: For the Coming Decade). F. P. L. and P. M. e. Kareiva (Eds). ISBN: 978-0412096617. New York (NY): Springer-Verlag. 112-156. http://www.springer.com/environment/nature+conservation+-+biodiversity/book/978-0-412-09661-7 Accessed July 15, 2015.

Ruhl, J. B. and J. Salzman. 2006. The Effects of Wetland Mitigation on People. National Wetlands Newsletter; 28(2):http://papers.ssrn.com/sol3/papers.cfm?abstract_id=878331 Accessed July 15, 2015.

Ruhl, J. B., J. Salzman and I. Goodman. 2008. Implementing the New Ecosystem Services Mandate of the Section 404 Compensatory Mitigation Program: A Catalyst for Advancing Science and Policy. Stetson Law Review; 38(2):http://ssrn.com/abstract=1281048 Accessed July 15, 2015.

Runge, M. C., C. A. Langtimm and W. L. Kendall. 2004. A Stage-Based Model of Manatee Population Dynamics. Marine Mammal Science; 20(3):10.1111/j.1748-7692.2004.tb01167.x http://dx.doi.org/10.1111/j.1748-7692.2004.tb01167.x Accessed July 15, 2015.

Rutheford, F. J. and A. Ahgren. 1990. Titlle. (Eds). New York (NY): Oxford University Press. Accessed April 10, 2018.

Sagan, J. J. 2004. SAV Bed Architecture: Water Depth Distribution and Cover of *Najas guadalupensis*, *Ruppia maritime*, and *Vallisneria americana*. Palatka (FL): https://sjrda.unf.edu/items/view/sjrda:504 Accessed July 15, 2015.

Sagan, J. J. 2006. A Reanalysis of Data Related to Submerged Aquatic Vegetation Within the Lower St. Johns River: 1996-2005. Palatka (FL): https://sjrda.unf.edu/items/view/sjrda:505 Accessed July 15, 2015.

Sagan, J. J. 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): https://sjrda.unf.edu/items/view/sjrda:506 Accessed July 15, 2015.

Sagan, J. J. 2010. *Personal Communication* to G. Pinto.

Salzman, J. and J. B. Ruhl. 2005. 'No Net-Loss' - Instrument Choice in Wetlands Protection. Durham (NC): http://ssrn.com/abstract=796771 Accessed July 15, 2015.

Saunders, J. 2016. Judge Refuses to Block Changes to Florida's Water Quality Standards. Orlando (FL): http://www.orlandoweekly.com/Blogs/archives/2016/10/12/judge-refuses-to-block-changes-to-floridas-water-quality-standards Accessed May 2, 2017.

Scarlatos, P. D. 1993. A Review of Sediment Analysis, Management Techniques and Sediment Quality Data for the Lower St. Johns River Basin: Vol. 5. Palatka (FL): http://floridaswater.com/technicalreports/pdfs/SP/SJ94-SP16.pdf Accessed July 15, 2015.

SCCF. 2014. Chlorophyll-*a*. Sanibel, FL: Sanibel-Captiva Conservation Foundation. http://recon.sccf.org/definitions/chlorophyll.shtml Accessed July 15, 2015

Schafer, D. L. 2007. New World in a State of Nature; British Plantations and Farms on the St. Johns River, East Florida, 1763-1784. Jacksonville (FL): University of North Florida (UNF), Florida Online History. http://www.unf.edu/floridahistoryonline/Plantations/ Accessed July 15, 2015

Schropp, S. J. and H. L. Windom. 1988. A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments. Tallahassee (FL): http://www.dep.state.fl.us/water/monitoring/docs/seds/estuarine.pdf Accessed July 15, 2015.

Scott, C. 2003a. Shortnose Sturgeon (*Acipenser brevirostrum*). (In Endangered and Threatened Animals of Florida and Their Habitats). (Eds). ISBN: 978-0292705296. Austin (TX): University of Texas Press. 253-259. http://utpress.utexas.edu/index.php/books/scoend Accessed July 15, 2015.

Scott, C. 2003b. Southern Bald Eagle (*Haliaeetus leucocephalus leucocephalus*). (In Endangered and Threatened Animals of Florida and Their Habitats). (Eds). ISBN: 978-0292705296. Austin (TX): University of Texas Press. 177-180. http://utpress.utexas.edu/index.php/books/scoend Accessed July 15, 2015.

Scott, C. 2003c. Wood Stork (*Mycteria americana*). (In Endangered and Threatened Animals of Florida and Their Habitats). (Eds). ISBN: 978-0292705296. Austin (TX): University of Texas Press. 168-171. http://utpress.utexas.edu/index.php/books/scoend Accessed July 15, 2015.

Scudder, B. C., L. C. Chasar, D. A. Wentz, N. J. Bauch, M. E. Brigham, P. W. Moran and D. P. Krabbenhoft. 2009. Mercury in Fish, Bed Sediment, and Water from Streams Across the United States, 1998-2005. Reston (VA): http://pubs.usgs.gov/sir/2009/5109/pdf/sir20095109.pdf Accessed July 15, 2015.

Semeyn, D. J., C. C. Cush, K. M. Scolardi, J. Hebert, J. D. McBride, D. Grealish and J. E. Reynolds III. 2011. Aerial Surveys of Manatees (*Trichechus manatus*) in Lee County, Florida, Provide Insights Regarding Manatee Abundance and Real Tme Information for Managers and Enforcement Officers. Journal of Coastal Conservation; 15(4):10.1007/s11852-011-0146-3 http://dx.doi.org/10.1007/s11852-011-0146-3 Accessed July 15, 2015.

Semlitsch, R. D. and J. R. Bodie. 1998. Are Small, Isolated Wetlands Expendable? Conservation Biology; 12(5):10.1046/j.1523-1739.1998.98166.x http://dx.doi.org/10.1046/j.1523-1739.1998.98166.x Accessed July 15, 2015.

Sepúlveda, M. S., W. E. Johnson, J. C. Higman, N. D. Denslow, T. R. Schoeb and T. S. Gross. 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):10.1016/S0048-9697(01)01029-4 http://www.sciencedirect.com/science/article/pii/S0048969701010294 Accessed July 15, 2015.

Sepulveda, M. S., J. J. Wiebe, D. C. Honeyfield, H. R. Rauschenberger, J. P. Hinterkopf, W. E. Johnson and T. S. Gross. 2004. Organochlorine Pesticides and Thiamine in Eggs of Largemouth Bass and American Alligators and Their Relationship with Early Life-stage Mortality. Journal of Wildlife Diseases; 40(4):10.7589/0090-3558-40.4.782 http://dx.doi.org/10.7589/0090-3558-40.4.782 Accessed July 15, 2015.

Shabecoff, P. 1988. Most Sewage Plants Meeting Latest Goal of Clean Water Act. New York (NY): New York Times. http://www.nytimes.com/1988/07/28/us/most-sewage-plants-meeting-latest-goal-of-clean-water-act.html Accessed July 1, 2008

Shepard, J. P. 1994. Effects of Forest Management on Surface Water Quality in Wetland Forests. Wetlands; 14(1):10.1007/BF03160618 http://dx.doi.org/10.1007/BF03160618 Accessed July 15, 2015.

Shuval, H. I., A. Adin, B. Fattal, E. Rawitz and P. Yekutiel. 1990. Integrated Resource Recovery. Wastewater Irrigation in Developing Countries - Health Effects and Technical D|Solutions. Washington (DC): http://documents.worldbank.org/curated/en/1986/05/440564/integrated-resource-recovery-wastewater-irrigation-developing-countries-health-effects-technical-solutions Accessed July 15, 2015.

Shyn, A., S. J. Chalk, K. Smith, N. L. Charnock and G. K. Bielmyer. 2012. Zinc Distribution in the Organs of Adult *Fundulus heteroclitus* After Waterborne Zinc Exposure in Freshwater and Saltwater. Archives of Environmental Contamination and Toxicology; 63(4):10.1007/s00244-012-9805-0 http://dx.doi.org/10.1007/s00244-012-9805-0 Accessed July 15, 2015.

Simberloff, D., D. C. Schmitz and T. C. Brown (Eds). 1997. Strangers in Paradise: Impact and Management of Nonindigenous Species in Florida. 978-1559634298. Washington (DC): Island Press. http://works.bepress.com/daniel_simberloff/1/ Accessed July 15, 2015.

Sivonen, K. and G. Jones. 1999. Cyanobacterial Toxins. (In Toxic Cyanobacteria in Water. A Guide to their Public Health Consequences, Monitoring and Management). I. Chorus and J. Bartram (Eds). Bury St Edmunds, Suffolk, England: World Health Organization. http://www.who.int/water_sanitation_health/resourcesquality/toxicyanbact/en/ Accessed July 15, 2015.

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): https://sjrda.unf.edu/items/view/sjrda:515 Accessed July 15, 2015.

SJRWMD. 2005. Blue-Green Algae in Florida Waters: Effects on Water Quality. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://floridaswater.com/algae/bluegreen.html Accessed July 15, 2015

SJRWMD. 2007. Bill Number: Geographic Information Systems (GIS) Database: Wetland and Deep Water Habitat Map. Code(Code Palatka (FL): St. Johns River Water Management District (SJRWMD). ftp://secure.sjrwmd.com/disk3/wetlands/habitats/ Accessed July 15, 2015.

SJRWMD. 2008. Surface Water Improvement and Management (SWIM) Plan: Lower St. Johns River Basin. Palatka (FL): http://floridaswater.com/SWIMplans/2008_LSJRB_SWIM_Plan_Update.pdf Accessed July 15, 2015.

SJRWMD. 2010a. Florida Water Management History. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://floridaswater.com/history/index.html Accessed July 15, 2015

SJRWMD. 2010b. GIS Download Library. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://floridaswater.com/gisdevelopment/docs/themes.html Accessed July 15, 2015

SJRWMD. 2010c. SJRWMD Mitigation Banking. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://webapub.sjrwmd.com/agws10/mt/ Accessed July 15, 2015

SJRWMD. 2010d. Watershed Facts: Cedar River. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://floridaswater.com/watershedfacts/factPages/20030083.html Accessed July 15, 2015

SJRWMD. 2012a. The St. Johns River Water Supply Impact Study. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://floridaswater.com/surfacewaterwithdrawals/impacts.html Accessed July 15, 2015

SJRWMD. 2012b. St. Johns River Water Supply Impact Study. Palatka (FL): http://floridaswater.com/technicalreports/tpubs1.html Accessed July 15, 2015.

SJRWMD. 2016a. One week after Matthew, SJRWMD looks back at impacts, forward to recovery. Palatka (FL): https://www.sjrwmd.com/2016/10/one-week-after-matthew-sjrwmd-looks-back-at-impacts-forward-to-recovery/ Accessed April 12, 2018.

SJRWMD. 2016b. Radar Rainfall Data. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://webapub.sjrwmd.com/agws10/hdsnew/map.html Accessed April 1, 2016

SJRWMD. 2016c. Regulatory Permit Search. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://webapub.sjrwmd.com/agws10/sjrwmdpermit/ Accessed March 10, 2017

SJRWMD. 2017a. Geographic information system (GIS) development program. Palatka (FL): St. Johns River Water Management District (SJRWMD). https://www.sjrwmd.com/data/gis/ - natural-resources Accessed March 10, 2018

SJRWMD. 2017b. Hurricane Irma spreads 2.2 trillion gallons of water across the district. Palatka (FL): https://www.sjrwmd.com/2017/10/hurricane-irma-spreads-2-2-trillion-gallons-of-water-across-the-district/ Accessed April 12, 2018.

SJRWMD. 2017c. Regulatory Permit Search. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://webapub.sjrwmd.com/agws10/sjrwmdpermit/ Accessed March 10, 2018

SJRWMD. 2018a. Geopolitical Map of the St. Johns River. Palatka (FL): St. Johns River Water Management District (SJRWMD). https://www.sjrwmd.com/static/waterways/SJR-Lower-Basin-map.pdf Accessed March 12, 2018

SJRWMD. 2018b. Radar Rainfall Data. Palatka (FL): St. Johns River Water Management District (SJRWMD). http://webapub.sjrwmd.com/agws10/radrain/ Accessed March 10, 2018

SLES. 1988. Chemical and Physical Characteristics of Water, Sediments and Sediment Elutriates for the Port of Jacksonville, Florida. Savannah (GA): https://sjrda.unf.edu/items/view/sjrda:584 Accessed July 15, 2015.

Smith, V. H. 1983. Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue-Green Algae in Lake Phytoplankton. Science; 221(4611):10.1126/science.221.4611.669 http://dx.doi.org/10.1126/science.221.4611.669 Accessed July 15, 2015.

Smolders, A. J. P., L. P. M. Lamers, E. C. H. E. T. Lucassen, G. Van der Velde and J. G. M. Roelofs. 2006. Internal Eutrophication: How It Works and What To Do About It – A Review. Chemistry and Ecology; 22(2):10.1080/02757540600579730 http://dx.doi.org/10.1080/02757540600579730 Accessed July 15, 2015.

Sosa, E. R., J. H. Landsberg, C. M. Stephenson, A. B. Forstchen, M. W. Vandersea and R. W. Litaker. 2007. *Aphanomyces invadans* and Ulcerative Mycosis in Estuarine and Freshwater Fish in Florida. Journal of Aquatic Animal Health; 19(1):10.1577/H06-012.1 http://dx.doi.org/10.1577/H06-012.1 Accessed July 15, 2015.

Spinuzzi, S., K. Schneider, L. Walters, E. Nash, S. Wei and E. Hoffman. 2012. Tracking the Distribution of Non-native Marine Species, *Mytella charruana*, *Perna viridis*, and *Megabalanus coccopoma*, Along the Southeastern United States Coastline. Orlando (FL): http://biology.cos.ucf.edu/hoffman/wp-content/uploads/2013/09/Spinuzzi-et-al.-2013.pdf Accessed July 15, 2015.

SRR. 2012. State of the River Report for the Lower St. Johns River Basin, Florida: Water Quality, Fisheries, Aquatic Life, Contaminants, and Aquatic Toxicology 2012. Jacksonville (FL): http://sjrreport.com/media/pdf/sjrreport2012.pdf Accessed July 15, 2015.

SRR. 2014. State of the River Report for the Lower St. Johns River Basin, Florida: Water Quality, Fisheries, Aquatic Life, and Contaminants 2014. Jacksonville (FL): http://sjrreport.com/media/pdf/sjrreport2014.pdf Accessed July 15, 2015.

SRR. 2016. State of the River Report for the Lower St. Johns River Basin, Florida: Water Quality, Fisheries, Aquatic Life, Contaminants, and Aquatic Toxicology 2012. Jacksonville (FL): http://www.sjrreport.com/ Accessed March 17, 2017.

St. Johns Riverkeeper. 2009. Central Florida's Thirst Threatens River. Jacksonville (FL): St. Johns Riverkeeper. http://www.stjohnsriverkeeper.org/thirstthreatens.asp Accessed July 15, 2015

St. Johns Riverkeeper. 2013a. Alarming Levels of Algal Toxins in St. Johns. Jacksonville (FL): St. Johns Riverkeeper. http://www.stjohnsriverkeeper.org/blog/alarming-levels-of-algal-toxins-in-st-johns/ Accessed July 15, 2015

St. Johns Riverkeeper. 2013b. Pollution Soutions: Lasalle Bioswale Project. Jacksonville (FL): St. Johns Riverkeeper. http://www.stjohnsriverkeeper.org/blog/lasalle-bioswale-project/ Accessed July 15, 2015

Staletovich, J. 2016. Environmental groups want Scott to veto water bill. Miami (FL): Miami Herald. http://www.miamiherald.com/news/local/environment/article54961190.html Accessed April 6, 2016

Stedman, S.-M. and T. E. Dahl. 2008. Status and Trends of Wetlands in the Coastal Watersheds of the Eastern United States 1998 to 2004. Washington (DC): 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 July 15, 2015.

Steidinger, K. A., M. A. Burklew and R. M. Ingle. 1973. The Effects of *Gymnodinium breve* Toxin on Estuarine Animals. (In Marine Pharmacognosy: Action of Marine Toxins at the Cellular Level). D. F. Martin and G. M. Padilla (Eds). New York (NY): Academic Press. 179-202. http://dx.doi.org/10.1016/B978-0-12-474550-6.50011-7 Accessed July 15, 2015.

Steidinger, K. A., J. H. Landsberg, C. R. Tomas and J. W. Burns Jr. 1999. Harmful Algal Blooms in Florida. St. Petersburg (FL): http://myfwc.com/research/redtide/task-force/reports-presentations/white-paper/ Accessed July 15, 2015.

Steinbrecher, P. 2008. *Personal Communication* to H. McCarthy.

Stewart, I., A. A. Seawright, P. J. Schulter and G. R. Shaw. 2006. Primary Irritant and Delayed-Contact Hypersensitivity Reactions to the Freshwater Cyanobacterium *Cylindrospermopsis raciborskii* and its Associated Toxin Cylindrospermopsin. BMC Dematology; 6(10.1186/1471-5945-6-5 http://dx.doi.org/10.1186/1471-5945-6-5 Accessed July 15, 2015.

Stork, W. 1769. Titlle. (Eds). London (England): Nicoll and Jefferies. http://www.amphilsoc.org/exhibits/nature/stork.htm Accessed July 15, 2015.

Stumm, W. and J. J. Morgan. 1996. Titlle. (Eds). ISBN: 978-0471511854. New York (NY): John Wiley & Sons. http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471511854.html Accessed July 15, 2015.

Sucsy, P. V. 2008. *Personal Communication* to G. Pinto.

Sun, G., H. Riekerk and L. V. Kornhak. 2000. Ground-Water-Table Rise after Forest Harvesting on Cypress-Pine Flatwoods in Florida. Wetlands; 20(1):10.1672/0277-5212(2000)020[0101:GWTRAF]2.0.CO;2 http://link.springer.com/article/10.1672/0277-5212%282000%29020%5B0101%3AGWTRAF%5D2.0.CO%3B2 Accessed July 15, 2015.

Swanson, C. 2016. *Personal Communication* to GP.

Tagatz, M. E. 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): http://archive.org/download/specialscientifi501usfi/specialscientifi501usfi_bw.pdf Accessed July 15, 2015.

Tagatz, M. E. 1968a. Biology of the Blue Crab, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. Fishery Bulletin; 67(1):http://fishbull.noaa.gov/67-1/tagatz.pdf Accessed July 15, 2015.

Tagatz, M. E. 1968b. Fishes of the St. Johns River, Florida. Quarterly Journal Florida Academy of Sciences; 30(1):http://ufdc.ufl.edu/UF00000193/00001 Accessed July 15, 2015.

Tagatz, M. E. 1968c. Growth of Juvenile Blue Crabs, *Callinectes sapidus* Rathbun, in the St. Johns River, Florida. Fishery Bulletin; 67(2):http://fishbull.noaa.gov/67-2/tagatz.pdf Accessed July 15, 2015.

Taylor. 2011. EFDC Salinity Modeling for Jacksonville Harbor GRRII Deepening Project Phase 1. Draft Report prepared for USACE Jacksonville District. Jacksonville (FL): http://www.saj.usace.army.mil/Portals/44/docs/Planning/EnvironmentalBranch/EnvironmentalDocs/FINAL_Jacksonville_ Accessed June 14, 2016.

Taylor. 2013a. Ecological Modeling for Jacksonville Harbor Deepening GRRII. Draft report prepared for USACE Jacksonville District. Jacksonville (FL): http://www.saj.usace.army.mil/Portals/44/docs/Planning/EnvironmentalBranch/EnvironmentalDocs/FINAL_Jacksonville_ Accessed June 14, 2016.

Taylor. 2013b. EFDC Hydrodynamic Modeling for Water Quality Model Input for the Jacksonville Harbor GRRII Deepening Project. Draft report prepared for USACE Jacksonville Distric. Jacksonville (FL): http://www.saj.usace.army.mil/Portals/44/docs/Planning/EnvironmentalBranch/EnvironmentalDocs/FINAL_Jacksonville_ Accessed June 14, 2016.

Taylor. 2013c. EFDC Salinity Modeling for Jacksonville Harbor GRRII Deepening Project, Phase 2. Draft report prepared for USACE Jacksonville District. Jacksonville (FL): http://www.saj.usace.army.mil/Portals/44/docs/Planning/EnvironmentalBranch/EnvironmentalDocs/FINAL_Jacksonville_ Accessed June 14, 2016.

Thayer, G. W., W. J. Kenworthy and M. S. Fonseca. 1984. The Ecology of Eelgrass Meadows of the Atlantic Coast: a Community Profile. Beaufort (NC): http://www.nwrc.usgs.gov/techrpt/84-02.pdf Accessed July 15, 2015.

Thunen, R. L. 2010. Archaeological Excavations at the Cedar Point West site in Jacksonville, Florida. Jacksonville (FL): University of North Florida Archaeology Laboratory. http://www.unf.edu/~rthunen/fieldwork09/Field_Photos.html Accessed July 15, 2015

Toth, D. J. 1993. Lower St. Johns River Basin Reconnaissance – Hydrogeology. Palatka (FL): http://floridagroundwater.dep.state.fl.us/floridabasins/LowerStJohns.pdf Accessed

Turner, D. R., M. Whitfield and A. G. Dickson. 1981. The Equilibrium Speciation of Dissolved Components in Freshwater and Seawater at 25°C and 1 Atm Pressure. Geochimica et Cosmochimica Acta; 45(6):10.1016/0016-7037(81)90115-0 http://www.sciencedirect.com/science/article/pii/0016703781901150 Accessed July 15, 2015.

Turner, J. 2016. State Regulators Approve Sweeping Changes in Water-quality Standards. Jacksonville (FL): http://jacksonville.com/news/florida/2016-07-27/story/state-regulators-approve-sweeping-changes-water-quality-standards Accessed May 2, 2017.

Twilley, R. R. and J. W. Barko. 1990. The Growth of Submersed Macrophytes Under Experimental Salinity and Light Conditions. Estuaries and Coasts; 13(3):10.2307/1351922 http://dx.doi.org/10.2307/1351922 Accessed July 15, 2015.

Udall, S. L. 1967. Native Fish and Wildlife: Endangered Species. Federal Register; 32(48):http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1051&context=endangeredspeciesbull Accessed July 15, 2015.

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. Federal Register; 72(71):http://www.gpo.gov/fdsys/pkg/FR-2007-04-13/pdf/07-1835.pdf Accessed July 15, 2015.

USACE. 2008. Compensatory Mitigation for Losses of Aquatic Resources. Federal Register; 73(70):http://www.gpo.gov/fdsys/pkg/FR-2007-04-13/pdf/07-1835.pdf Accessed July 15, 2015.

USACE. 2012a. Hogan's Creek: Draft Detailed Project Report. Jacksonville (FL): J. D. U.S. Army Corps of Engineers (USACE). http://groundworkjacksonville.org/wp-content/uploads/2015/02/draft__hogan_creek_dpr_08_15_2012.pdf Accessed April 1, 2018.

USACE. 2012b. Invasive Species Control on the St. Johns River. Jacksonville (FL): U.S. Army Corps of Engineers (USACE), Jacksonville District. http://www.saj.usace.army.mil/Missions/Environmental/InvasiveSpecies/OperationsSpraySchedules.aspx Accessed July 15, 2015

USACE. 2014a. Jacksonville Harbor Navigational Study, Duval County, Florida: Final Integrated General Reevaluation Report II and Supplemental Environmental Impact Statement
. Jacksonville (FL): http://cdm16021.contentdm.oclc.org/cdm/ref/collection/p16021coll7/id/2118 Accessed June 14, 2016.

USACE. 2014b. Jacksonville Harbor Navigational Study, Duval County, Florida: Final Integrated General Reevaluation Report II and Supplemental Environmental Impact Statement. Appendix E. USACOE. 2014. Jacksonville Harbor Navigational Study, Duval County, Florida: Final Integrated General Reevaluation. Jacksonville (FL): Accessed June 14, 2016.

USCB. 2000. Population Statistics for Clay, Duval, Flagler, Putnam, and St. Johns County, Florida. Washington (DC): U.S. Census Bureau (USCB). http://quickfacts.census.gov/qfd/states/12000lk.html Accessed July 1, 2008

USCB. 2010. 2010 Census Interactive Population Search. Washington (DC): U.S. Census Bureau (USCB). http://www.census.gov/2010census/popmap/ipmtext.php?fl=12 Accessed July 1, 2015

USDA. 2013. Bill Number: The PLANTS Database. Code(Code Washington (DC): U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). http://plants.usda.gov/java/ Accessed July 15, 2015.

USDOI and USDOC. 2008. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Washington (DC): http://www.census.gov/prod/2008pubs/fhw06-fl.pdf Accessed July 15, 2015.

USFWS. 2001. Florida Manatee Recovery Plan (*Trichechus manatus latirostris*), Third revision. Atlanta (GA): https://sjrda.unf.edu/items/forward/sjrda:535 Accessed July 15, 2015.

USFWS. 2002. Wood Stork Report. Washington (DC): https://sjrda.unf.edu/items/view/sjrda:536 Accessed July 15, 2015.

USFWS. 2004. Wood Stork Report. Washington (DC): https://sjrda.unf.edu/items/view/sjrda:537 Accessed July 15, 2015.

USFWS. 2005. Wood Stork Report. Washington (DC): https://sjrda.unf.edu/items/view/sjrda:538 Accessed July 15, 2015.

USFWS. 2007a. Bald Eagle Soars off Endangered Species List. Washington (DC): U.S. Fish and Wildlife Service (USFWS). http://www.fws.gov/news/ShowNews.cfm?ID=72A15E1E-F69D-06E2-5C7B052DB01FD002 Accessed July 1, 2008

USFWS. 2007b. West Indian Manatee (*Trichechus Manatus*). 5-Year Review: Summary and Evaluation. Washington (DC): http://www.fws.gov/northflorida/Manatee/2007 5-yr Review/2007-Manatee-5-Year-Review-Final-color-signed.pdf Accessed July 15, 2015.

USFWS. 2007c. Wood Stork (*Mycteria americana*) 5-Year Review: Summary and Evaluation. Jacksonville (FL): http://www.fws.gov/northflorida/WoodStorks/2007-Review/2007-Wood-stork-5-yr-Review.pdf Accessed July 15, 2015.

USFWS. 2008a. Bald Eagle. Washington (DC): U.S. Fish and Wildlife Service (USFWS), Division of Migratory Bird Management. http://www.fws.gov/migratorybirds/baldeagle.htm Accessed July 1, 2008

USFWS. 2008b. Bald Eagle Breeding Pairs 1990 - 2006. Washington (DC): U.S. Fish and Wildlife Service (USFWS), Midwest Region. http://www.fws.gov/midwest/eagle/population/nos_state_tbl.html Accessed July 15, 2015

USFWS. 2008c. Bald Eagle Management Guidelines and Conservation Measures. Washington (DC): U.S. Fish and Wildlife Service (USFWS), Midwest Region. http://www.fws.gov/midwest/eagle/conservation/recreation.html Accessed July 1, 2008

USFWS. 2008d. Species Profile: Bald Eagle (*Haliaeetus leucocephalus*). 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 July 15, 2015

USFWS. 2016. Endangerd and Threatened Wildlife and Plants; Reclassification of the U.S. Breeding Population of the Wood Stork from Endangered to Threatened. Washington (DC): U.S. Fish and Wildlife Service (USFWS). https://www.federalregister.gov/articles/2014/06/30/2014-14761/endangered-and-threatened-wildlife-and-plants-reclassification-of-the-us-breeding-population-of-the Accessed July 1, 2015

USFWS. 2018a. Endangered Species. Jacksonville (FL): https://www.fws.gov/endangered/species/index.html Accessed March 10, 2018.

USFWS. 2018b. Manatee Reclassified from Endangered to Threatened as Habitat Improves and Population Expands – Existing Federal Protections Remain in Place. Jacksonville (FL): https://www.fws.gov/northflorida/manatee/manatees.htm Accessed March 30, 2018.

USFWS. 2018c. Bill Number: Southeast US Wood Stork Nesting Database. Code(Code http://www.wec.ufl.edu/faculty/frederickp/woodstork/ Accessed March 10, 2017.

USGS. 1992. Application of Satellite Data for Mapping and Monitoring Wetlands. Reston (VA): http://www.gpo.gov/fdsys/pkg/CZIC-ta595-5-u55-a66-1992/pdf/CZIC-ta595-5-u55-a66-1992.pdf Accessed July 15, 2015.

USGS. 2004. Aquatic Cycling of Mercury in the Everglades. Washington (DC): U.S. Geological Survey (USGS). http://sofia.usgs.gov/projects/index.php?project_url=evergl_merc Accessed July 15, 2015

USGS. 2015. Bill Number: Non-Indigenous Aquatic Species (NAS) Database. Code(Code Reston (VA): U.S. Geological Survey (USGS). http://nas.er.usgs.gov/ Accessed July 15, 2015.

USGS. 2018. Florida Drought Watch. Animation of flood and high flow condition maps for September 2017. Reston (VA): U.S. Geological Survey (USGS). https://waterwatch.usgs.gov/index.php?ym=201709&id=ww_animation_flood Accessed April 18, 2018

UTAS. 2013. Peracarida. Hobart, Tasmania, Australia: University of Tasmania (UTAS), Institute for Marine and Antarctic Studies (IMAS). http://www.imas.utas.edu.au/zooplankton/image-key/malacostraca/peracarida Accessed July 15, 2015

Valiela, I. 1995. Titlle. (Eds). ISBN: 978-0387943213. New York (NY): Springer-Verlag. http://www.springer.com/life+sci/ecology/book/978-0-387-94321-3 Accessed July 15, 2015.

Van Wezel, A. P. and A. Opperhuizen. 1995. Narcosis Due to Environmental Pollutants in Aquatic Organisms: Residue-Based Toxicity, Mechanisms, an Membrane Burdens. Critical Reviews in Toxicology; 25(3):10.3109/10408449509089890 http://dx.doi.org/10.3109/10408449509089890 Accessed July 15, 2015.

Verween, A., F. Kerckhof, M. Vincx and S. Degraer. 2006. First European Record of the Invasive Brackish Water Clam *Rangia cuneata* (G.B. Sowerby I, 1831) (Mollusca: Bivalvia). Aquatic Invasions; 1(4):10.3391/ai.2006.1.4.1 http://www.aquaticinvasions.net/2006/AI_2006_1_4_Verween_etal.pdf Accessed July 15, 2015.

Voulvoulis, N., M. D. Scrimshaw and J. N. Lester. 2000. Occurrence of Four Biocides Utilized in Antifouling Paints, as Alternatives to Organotin Compounds, in Waters and Sediments of a Commercial Estuary in the UK. Marine Pollution Bulletin; 40(11):10.1016/S0025-326X(00)00034-5 http://www.sciencedirect.com/science/article/pii/S0025326X00000345 Accessed July 15, 2015.

Wainwright, D. 2005a. TMDL Report: Fecal Coliform TMDL for Butcher Pen Creek, WBID 2322. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/butcher-pen-creek-fecal-tmdl.doc Accessed July 15, 2015.

Wainwright, D. 2005b. TMDL Report: Fecal Coliform TMDL for Goodbys Creek (WBID 2326). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2326.pdf Accessed July 15, 2015.

Wainwright, D. 2006a. TMDL Report: Fecal and Total Coliform TMDLs for the Ribault River (WBID 2224). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2224.pdf Accessed July 15, 2015.

Wainwright, D. 2006b. TMDL Report: Fecal Coliform and Total Coliform TMDL for Moncrief Creek (WBID 2228). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2228.pdf Accessed July 15, 2015.

Wainwright, D. 2006c. TMDL Report: Fecal Coliform and Total Coliform TMDL for Wills Branch (WBID 2282). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2282.pdf Accessed July 15, 2015.

Wainwright, D. 2006d. TMDL Report: Fecal Coliform TMDL for Hogan Creek (WBID 2252). Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/tmdl_document2252.pdf Accessed July 15, 2015.

Wainwright, D. and J. F. Hallas. 2009a. Final TMDL Report: Fecal Coliform TMDL for Big Fishweir Creek, WBID 2280. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/bigfishwircreekfecalfinal.pdf Accessed July 15, 2015.

Wainwright, D. and J. F. Hallas. 2009b. Final TMDL Report: Fecal Coliform TMDL for Open Creek, WBID 2299. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/opencreekfecalfinal.pdf Accessed July 15, 2015.

Wainwright, D. and J. F. Hallas. 2009c. Final TMDL Report: Fecal Coliform TMDLs for Trout River, WBIDs 2203A and 2203. Tallahassee (FL): http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp2/troutriverfinfecal.pdf Accessed July 15, 2015.

Wang, W.-X. and L. Guo. 2000. Bioavailability of Colloid-Bound Cd, Cr, and Zn to Marine Plankton. Marine Ecology Progress Series; 202(1):10.3354/meps202041 http://dx.doi.org/10.3354/meps202041 Accessed July 15, 2015.

Warren, C. 2005. Chapter 7: 'Nature's Navels' - An Overview of the Many Environmental Histories of Florida Citrus. (In Paradise Lost? An Environmental History of Florida). J. E. Davis and R. Arsenault (Eds). 978-0-813-02826-2. Gainesville (FL): University Press of Florida. 177-200. http://www.upf.com/book.asp?id=DAVISF05 Accessed July 15, 2015.

Watkins, B. 1992. Florida Governor's Nomination of the Lower St. Johns River Estuary to the National Estuary Program. Washington (DC): https://sjrda.unf.edu/items/view/sjrda:555 Accessed July 15, 2015.

Weiss, R. F. 1970. The Solubility of Nitrogen, Oxygen, and Argon in Water and Seawater. Deep Sea Research; 17(4):10.1016/0011-7471(70)90037-9 http://www.sciencedirect.com/science/article/pii/0011747170900379 Accessed July 15, 2015.

Welsh, P. 2008. *Personal Communication* to H. McCarthy.

Weston, N. B. 2014. Declining Sediments and Rising Seas: an Unfortunate Convergence for Tidal Wetlands. Estuaries and Coasts; 37(1):10.1007/s12237-013-9654-8 http://dx.doi.org/10.1007/s12237-013-9654-8 Accessed July 15, 2015.

Wetzel, R. G. 1999. Biodiversity and Shifting Energetic Stability Within Freshwater Ecosystems. Archiv für Hydrobiologie: Special Issues of Advanced Limnology; 54(1):None Accessed July 15, 2015.

Wetzel, R. G. 2001. Chapter 9 - Oxygen. (In Limnology: Lake and River Ecosystems). (Eds). ISBN: 978-0127447605. San Diego (CA): Elsevier/Academic Press. 205-286. http://www.elsevierdirect.com/product.jsp?isbn=9780127447605 Accessed July 15, 2015.

Wetzel, R. G. and G. E. Likens. 2000. Titlle. (Eds). ISBN: 978-0387989280. New York (NY): Springer-Verlag. http://www.springer.com/life+sci/ecology/book/978-0-387-98928-0 Accessed July 15, 2015.

White, A. Q. and G. F. Pinto. 2006a. The Clay County Manatee Protection Plan. Green Cove Springs (FL): http://www.claycountygov.com/home/showdocument?id=652 Accessed July 15, 2015.

White, A. Q. and G. F. Pinto. 2006b. The Duval County Manatee Protection Plan. Jacksonville (FL): http://www.coj.net/city-council/jacksonville-waterways-commission/jwc-mpp.aspx Accessed July 15, 2015.

White, A. Q. and G. F. Pinto. 2014. Annual Update on the Duval County Manatee Protection Plan. Jacksonville (FL): http://www.coj.net/departments/planning-and-development/docs/community-planning-division/manatee/2014-08-14-final-jax-mpp-3rd.aspx Accessed July 15, 2015.

White, A. Q., G. F. Pinto and M. L. Luther. 2009. St. Johns River-In the Balance. Jacksonville (FL): Accessed July 15, 2015.

White, A. Q., G. F. Pinto and A. P. Robison. 2002. Seasonal Distribution of Manatees, *Trichechus manatus latirostris*, in Duval County and Adjacent Waters, Northeast Florida. Florida Scientist; 65(3):https://sjrda.unf.edu/items/view/sjrda:559 Accessed July 15, 2015.

White, W. R. and T. L. Crisman. 2014. Headwater Streams of Florida: Types, Distributions and a Framework for Conservation. River Research and Applications; Early View(10.1002/rra.2845 http://dx.doi.org/10.1002/rra.2845 Accessed July 15, 2015.

WHO. 1991. Environmental Health Criteria No 118: Inorganic Mercury. Geneva (Switzerland): World Health Organization (WHO). http://www.inchem.org/documents/ehc/ehc/ehc118.htm Accessed July 15, 2015

WHO. 1995. Environmental Health Criteria No 165: Inorganic Lead. Geneva (Switzerland): World Health Organization (WHO). http://www.inchem.org/documents/ehc/ehc/ehc165.htm Accessed July 15, 2015

Williams, C. D., M. T. Aubel, A. D. Chapman and P. E. D'Aiuto. 2007. Identification of Cyanobacterial Toxins in Florida's Freshwater Systems. Lake and Reservoir Management; 23(2):10.1080/07438140709353917 http://dx.doi.org/10.1080/07438140709353917 Accessed July 15, 2015.

Williams, C. D., J. W. Burns, A. D. Chapman, L. Flewelling, M. Pawlowicz and W. Carmichael. 2001. Assessment of Cyanotoxins in Florida's Lakes, Reservoirs, and Rivers. Final Report. Palatka (FL): https://sjrda.unf.edu/items/forward/sjrda:459 Accessed July 15, 2015.

Williams, C. D., J. W. Burns, A. D. Chapman, M. Pawlowicz and W. Carmichael. 2006. Assessment of Cyanotoxins in Florida's Surface Waters and Associated Drinking Water Resources. Final Report. Palatka (FL): https://www.researchgate.net/publication/268058092_Assessment_of_Cyanotoxins_in_Florida%27s_Surface_Waters_and_Associated_Drinking_Water_Resources Accessed July 15, 2015.

Woodwell, G. M., C. F. Wurster Jr. and P. A. Isaacson. 1967. DDT Residues in an East Coast Estuary: A Case of Biological Concentration of a Persistent Insecticide. Science; 156(3776):10.1126/science.156.3776.821 http://dx.doi.org/10.1126/science.156.3776.821 Accessed July 15, 2015.

Worth, J. E. and D. H. Thomas. 1995. Titlle. (Eds). ISBN: 978-0820317458. New York (NY): American Museum of Natural History. http://hdl.handle.net/2246/270 Accessed July 15, 2015.

Wright, R. T. and B. J. Nebel. 2008. Section 3.3 - The Cycling of Matter in Ecosystems. (In Environmental Science). R. T. Wright (Eds). ISBN: 978-0-132-30265-4. Upper Saddle River (NJ): Prentice Hall. 67-70. http://www.pearsonhighered.com/academic/product?ISBN=0132302659 Accessed July 15, 2015.

Zlotkin, E. 1999. The Insect Voltage-Gated Sodium Channel as Target of Insecticides. Annual Review of Entomology; 44(10.1146/annurev.ento.44.1.429 http://dx.doi.org/10.1146/annurev.ento.44.1.429 Accessed July 15, 2015.

Zwick, P. D. and M. H. Carr. 2006. Florida 2060: A Population Distribution Scenario for the State of Florida. Gainesville (FL): http://www.1000friendsofflorida.org/wp-content/themes/1000freinds/formpop/download.php?file=pops/florida-2060/2060-executive-summary-Final.pdf Accessed July 15, 2015.