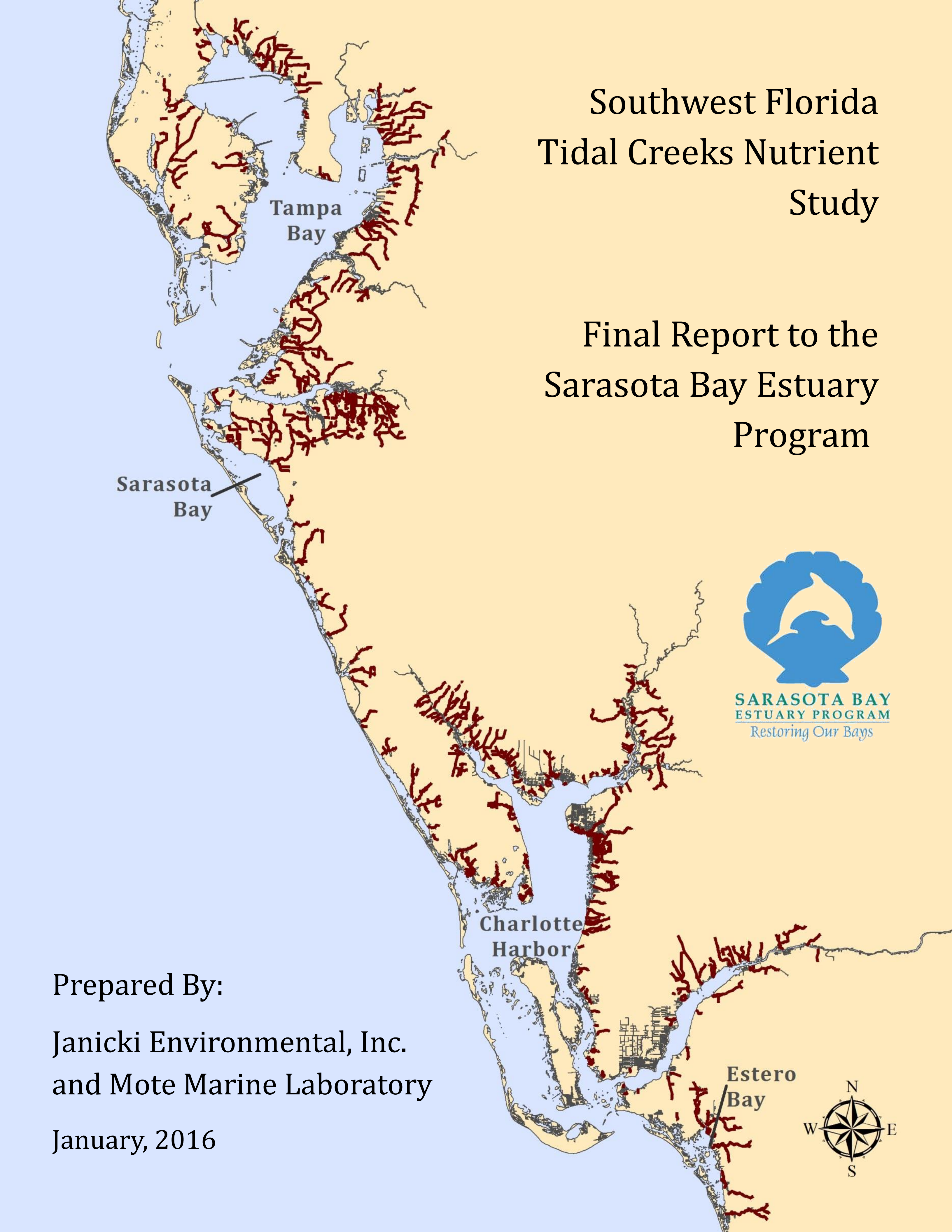
Southwest Florida Tidal Creeks Nutrient Study

Final Report to the Sarasota Bay Estuary Program



SARASOTA BAY
ESTUARY PROGRAM
Restoring Our Bays

Prepared By:

Janicki Environmental, Inc.
and Mote Marine Laboratory

January, 2016

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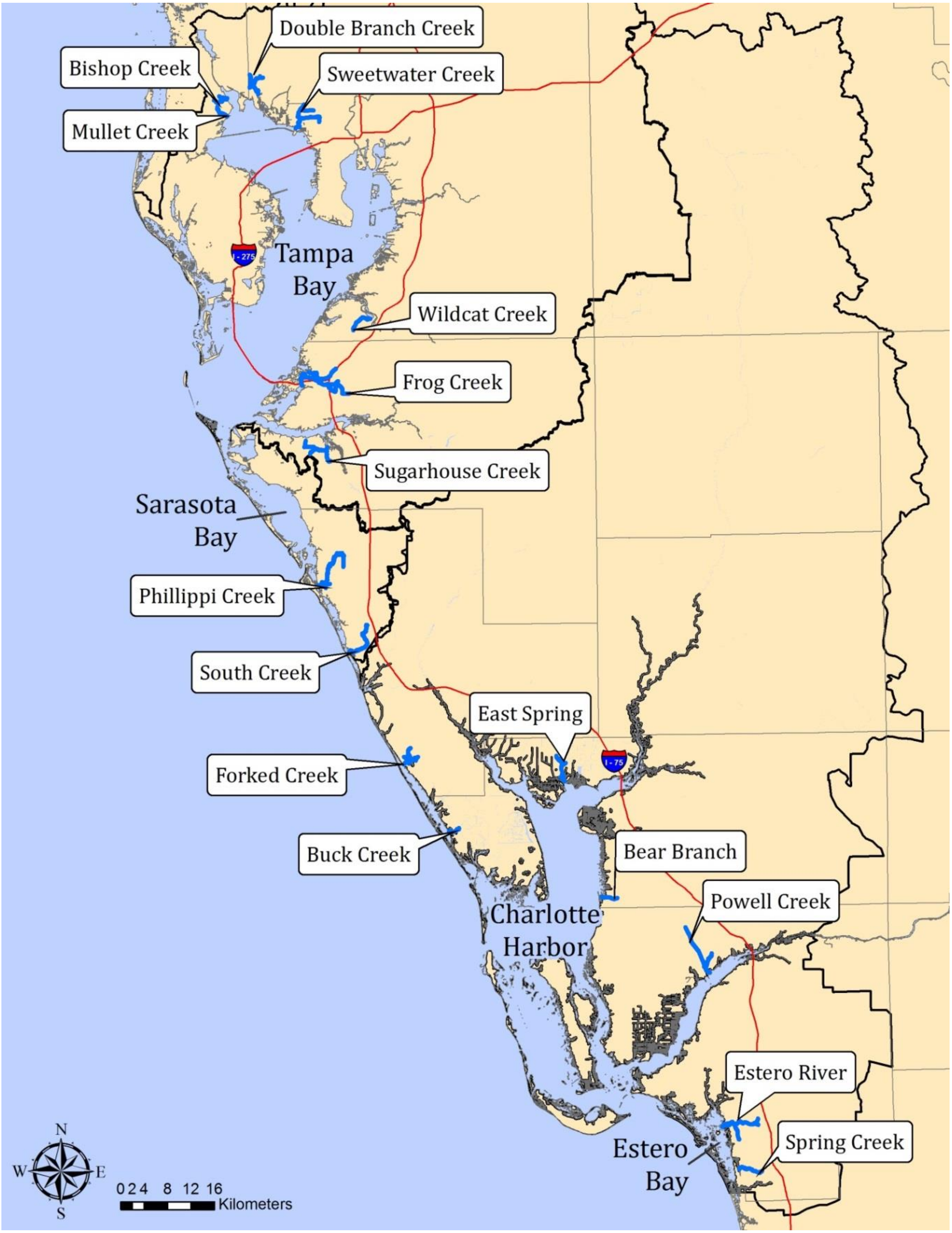
Foreward

The Sarasota Bay Estuary Program (SBEP) was awarded a Wetlands Program Development Grant by the United States Environmental Protection Agency (US EPA Region 4) to conduct a multidisciplinary study of southwest Florida tidal creeks to forward the science relating nutrient inputs, instream processes and biological responses in southwest Florida tidal creeks. Project and grant management was provided by Dr. Jay Leverone, Sarasota Bay Estuary Program with EPA project oversight by Rhonda Evans, United States Environmental Protection Agency. The study was a collaborative effort undertaken by the three southwest Florida Estuary Programs including SBEP, Tampa Bay Estuary Program (TBEP), and Charlotte Harbor National Estuary Program (CHNEP) with in-kind services provided by six counties to assist in the sampling effort. The six counties in southwest Florida include Pinellas, Hillsborough, Manatee, Sarasota, Charlotte, and Lee counties. A contract (Project # 2013SBEP17) was awarded to a team led by Janicki Environmental, Inc. following a competitive bid process. The Janicki Environmental team included Mote Marine Laboratory (P.I. for the water quality laboratory analysis) and the Florida Fish and Wildlife Conservation Commission (P.I. for the fisheries data collection). This report was principally authored by Mike Wessel of Janicki Environmental with contributions to both the report and analysis by Dr. L. Kellie Dixon of Mote Marine Laboratory and edits to content and format by Dr. Jay Leverone, and Ed Sherwood (Tampa Bay Estuary Program). Peer review of the project goals, sampling design and creek selection process was provided by Dr. Alexander Holland, Hollings Marine Laboratory, Retired and Dr. Justin Krebs, AKRF and advice on statistical analysis related to the fish catch by Dr. Bob Muller, Florida Wildlife Research Institute and Dr. Wade Cooper, independent contractor.

All figures that present creek specific results are presented in alphabetical order. While other orders were considered (e.g. geographic) there was no one order that was better suited to report the results than that presented. Please refer to the map (Figure 1) for the location of the creeks within the study area. The map is presented in full page format on the next page for convenience.

The report was written as a mid-level synopsis of the analytical efforts conducted to develop the proposed nutrient management framework in such a way that a variety of readers with varying levels of expertise could conveniently assimilate the information. There is a wealth of information provided in the appendices to this report including: task based reports that provide the background efforts leading up to the data collection effort; current and historical imagery of the sampled creeks; detailed descriptive plots and statistics of the raw data collected during the study, and detailed results from the analytical phase of the project. Those readers interested in details that may not be conveyed in the body of the report should refer to the appendices for additional information. Any questions regarding the report can also be directed to Mike Wessel, Janicki Environmental, Inc. at mwessel@janickienvironmental.com or Dr. Jay Leverone at jay@sarasotabay.org.


Double Branch Creek
Bishop Creek
Sweetwater Creek
Mullet Creek
I-275
Tampa
Bay
Wildcat Creek
Frog Creek
Sugarhouse Creek
Sarasota
Bay
Phillippi Creek
South Creek
East Spring
I-75
Forked Creek
Buck Creek
Bear Branch
Powell Creek
Charlotte
Harbor
Estero River
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Acknowledgements

Janicki Environmental, Inc. would like to thank all the members of the Joint Technical Advisory Committee including individual members of each of the three National Estuary Programs too numerous to mention for their contributions and commitment to the successful completion of this project. Amber Whittle (FWC), Kris Kaufman (SWFWMD), and Gary Comp (STANTEC) served as TAC co-chairs for the joint meetings and are warmly acknowledged for keeping the meetings focused on the meeting goals and objectives during some rather vigorous and vacillating scientific discussions about different aspects of tidal creek ecology. The following participants were directly involved in implementing the study of the 16 tidal creeks sampled for the project and are also warmly acknowledged for their commitment to the protection of southwest Florida tidal creeks:

United States Environmental Protection Agency: Rhonda Evans

Sarasota Bay Estuary Program: Dr. Jay Leverone, and Mark Alderson

Tampa Bay Estuary Program: Ed Sherwood

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Hillsborough County: Tom Ash, Chris Pratt, and Brett Ursin

Manatee County: Rob Brown, Greg Blanchard, and Kerry Harkinson

Sarasota County: John Ryan, Jon Perry, and Kathy Meaux

Charlotte County: Roger Debruler, and Phillip Brouse

Lee County: Keith Kibbey, and Susan Fite

Mote Marine Laboratory: Dr. Kellie Dixon, Dr. Ken Leber, Dr. Nathan Brennan, Camia Charniga, and Dr. Ari Nissanka

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Janicki Environmental: Dr. Tony Janicki, Susan Janicki, Steve West, and Christina Schoonard

University of South Florida Water Institute: David Eilers

Peer Review: Dr. Alexander Holland (Retired) and Dr. Justin Krebs (AKRF)

Ian symbols used in Figures 3 and 41 were provided courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

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Executive Summary

The Sarasota Bay Estuary Program (SBEP) was awarded a Wetlands Program Development Grant by the United States Environmental Protection Agency (EPA) in February, 2013 to conduct a multidisciplinary study of southwest Florida tidal creeks. The goals of the Wetlands Program Development Grant are to conduct projects that promote the coordination and acceleration of research relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution in wetlands. The purpose of this study was to inform the development of management level nutrient water quality targets favorable for the biological integrity of southwest Florida tidal creeks and identify thresholds protective against impairment. The project included a one-year, bimonthly (i.e. every other month) sampling effort in 16 southwest Florida tidal creeks focusing on evaluating the relationship between water column nutrient concentrations and response endpoints including: dissolved oxygen; water column chlorophyll; sediment chlorophyll, and fish community structure. These data were combined with laboratory and field water quality samples, and existing remote sensing and *in situ* data describing landscape level effects at varying spatial scales for analysis of both near field and far field effects of watershed stressors on tidal creek biological integrity.

The principal findings of the study are listed in the bullet points below.

- Southwest Florida tidal creeks are critical habitats for estuarine dependent fish of high economic and ecological value.
- The sampled creeks well represented the range of expected conditions in the larger population of 306 tidal creeks defined as the southwest Florida tidal creek population.
- Rainfall was generally normal to above normal for the months sampled.
- Tidal creeks were characterized by water quality conditions typical of wetland environments with the potential for low dissolved oxygen and elevated chlorophyll concentrations without observed adverse effects to the fish communities utilizing these habitats.
- The current FDEP dissolved oxygen standard for estuaries was an unreliable indicator of biological impairment for southwest Florida tidal creeks as measured in this study in that many creeks that failed the DO standard were found to have biologically healthy and diverse fish communities.

- Those creeks with low fish species diversity did not correlate with higher nutrient concentrations, in fact creeks with the highest diversity tended to have higher nutrient concentrations though nitrite-nitrate concentrations did tend to be elevated in these creeks.
- The relationship between DO and fish probability of occurrence is likely to involve a more complex interaction between dynamic water quality and instream habitat conditions, coupled with seasonally dependent recruitment processes for individual estuarine dependent fish species.
- There was not an observed relationship between water column chlorophyll and dissolved oxygen concentrations that could be used to establish a chlorophyll threshold concentration indicative of adverse effects to biological integrity.
- The annual geometric averages for all creeks were below 20 ug/l though in some individual samples chlorophyll a concentrations measured over 100 ug/l. indicating sporadic, site-specific and transient bloom conditions.
- Creeks exhibiting chlorophyll bloom conditions (i.e. East Spring, Phillippi, Spring, and Sugarhouse were not necessarily the creeks with the highest geometric average total nutrient concentrations indicating mediating factors influence the probability of bloom conditions in these creeks including shading, residence times, and estuarine mixing.
- Nutrient concentrations in the tidal portion of the creeks were influenced by both landscape level anthropogenic stressors as well as riparian buffer characteristics including the potential for nutrient addition from wetland vegetation and instream processes related to the decomposition of organic matter.
- Nutrient concentrations did not follow conservative mixing principles along the salinity gradient suggesting that a dilution curve approach would not be appropriate for establishing tidal creek targets and thresholds.
- There were not observed adverse effects to the creek biological integrity directly attributable to the nutrient concentrations observed in the study, even in creeks with annual geometric average nutrient concentrations approaching their respective freshwater standards.
- Attempts to develop stressor–response based targets and thresholds using nutrient concentrations as an explanatory parameter were confounded by influences due to the physical characteristics of the creek and the habitat associated with the creek shorelines.

Currently, the narrative standard is the only guidance for evaluating tidal creek biological integrity. Compliance with the narrative criteria is based on State DO and chlorophyll threshold values alone, not nutrients. Nutrient impairment is inferred from exceedence of the DO or chlorophyll thresholds. This study has demonstrated the potential for those thresholds to be ineffective yardsticks in evaluating the biological integrity of tidal creeks. Indeed, it is likely that application of existing narrative criteria to southwest Florida tidal creeks would result in the misclassification of many of these wetland environments as impaired when, in fact, they are biologically healthy and productive systems. However, this is not to say that all the creeks sampled during this study were biologically healthy, only that biological integrity could not be directly or indirectly attributed to nutrient concentration threshold values. Instead, a weight of evidence suggested that a reference-based approach could be used as part of a larger management framework to develop nutrient targets and thresholds for tidal creeks under a specific set of condtions to guard against degredation of individual creeks. The reference-based method was developed using the freshwater nutrient criteria as a reference point from which to develop the proposed targets and thresholds. The reasoning for selecting the freshwater criteria as the reference point was based on the weight of evidence described above and in detail throughout the body of this report as well as a lack of evidence to suggest that the estuarine taxa inhabitating the tidal creeks were any more sensitve to nutrients than the taxa inhabitating the freshwater streams that serve as soucewater for many of these creeks. Therefore, a management framework was established that includes: nutrient target concentrations that protect individual creek types within the larger population of creeks; caution levels that are indicative of creeks trending towards a nutrient condition that are above their individual assimilative capacity; a management action level that identifies a potential degredation point as an impetus to develop a site-specific management actions, and thresholds which represent the need for regulatory actions to confirm impairment and identify remediative actions for the creek watershed.

The recommended nutrient management framework provides a protective strategy aimed at minimizing the potential for these creeks to become eutrophic or dystrophic, while also reducing the probability that a tidal creek will be falsely designated as impaired due to naturally occurring water quality conditions. The framework is more robust than the current state regulatory mechanism in that it: is based on nutrient concentrations (not just DO and chlorophyll); provides stewardship benchmarks for individual creeks; provides local governments the tools to evaluate tidal creek water quality data in a systematic manner relative to the population of creeks, and provides recommendations to further the science related to site-specific management criteria for southwest Florida tidal creeks. The proposed nutrient management framework is intended to serve as a more effective and informative approach to manage the effects of nutrients on the biological integrity of these systems. The framework is intended to serve as both a mechanism for evaluating data relative to the need for regulatory action, and to identify stewardship actions that, if properly pursued, are likely to preclude the need for any regulatory actions. The caution levels recommended in this report serve as a site-specific early warning system that an individual creek may be trending towards a eutrophic condition and identify where management actions should begin to identify the most effective means for avoiding a threshold exceedence. In this way, the management framework can preclude expending unwarranted effort and cost due to being evaluated by unreliable standards and provide reasonable assurance that the tidal creek wetlands are being subjected to a rigorous evaluation to determine their compliance with the criteria established to protect their designated use. The recommendations of this report are based on locally derived data directly applicable to the entire population of southwest Florida tidal creeks and include important considerations relating to estuarine mixing in the tidal creek environment.

The proposed nutrient management framework fits well within the existing state and federal water quality standards and is not counter to any regulatory mechanism currently in place. While the report suggests that alternative formulations of the current DO and chlorophyll standards should be considered for southwest Florida tidal creeks, it also provides an additional level of information by defining specific nutrient targets and thresholds that can be used to put the current DO and chlorophyll evaluation results into the context of nutrient conditions indicative of the biological integrity of the population of southwest Florida tidal creeks it is intended to represent. In this way, the proposed management framework serves as a more comprehensive evaluation strategy than the current pass/fail approach used to evaluate these creeks.

The concept of a management strategy for southwest Florida tidal creeks was first promoted by the Tampa Bay Regional Planning Council in 1987. Since that time a number of very important but disparate studies have been conducted on different aspects of tidal creek integrity, but there has yet to be a unified management framework developed to provide management oversight and guidance as well as accelerate the science toward the proper ecosystem-based management of these critical ecotones in a systematic way. The management framework provided in this document is intended to fulfill that long term goal by providing nutrient targets and thresholds as part of an ecosystem-based management approach. The local governments of Southwest Florida are in a unique position to capitalize on the contributions of the three contiguous National Estuary Programs that have Comprehensive Conservation and Management Plans with specific actions addressing the stewardship of tidal creeks. This management framework will allow for the three Estuary Programs, and the six counties within their geographic boundaries to work cooperatively to achieve the common goals of the Estuary Programs, the local governments, and state and federal regulators to protect these vital ecotones that contribute greatly to the ecological productivity and resilience of their respective coastal estuaries.

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Appendix B. Comparison of current and historical imagery for the 16 tidal creeks selected for data collection during this study.

Appendix C. Task 7 Report: Detailed descriptive statistics and plots for all data collected during the study.

Appendix D. Descriptive plots of the relationship between fish diversity metrics and dissolved oxygen using long term fisheries data collected in Tampa Bay tidal rivers. Data courtesy of the Florida Fish and Wildlife Conservation Commission's Fisheries Independent Monitoring program.

Appendix E. Odds ratio estimates based on results of logistic regression analysis of fish species specific probability of occurrence as a function of dissolved oxygen using long term fisheries data collected in Tampa Bay tidal rivers. Data courtesy of the Florida Fish and Wildlife Conservation Commission's Fisheries Independent Monitoring program.

Appendix F. Dilution curve analysis results for all relevant water quality parameters collected as part of the study.

Acronyms and Abbreviations

ANOSIM – Multivariate Analysis of Similarity
BMAC - Benthic Microalgae Chlorophyll Content (mg/sqm)
CDOM - Colored dissolved organic matter
CHLA – Water Column Chlorophyll a Corrected for Pheophytin (µg/l)
CHLA_Ratio – Ratio of CHLA/BMAC
CHNEP - Charlotte Harbor National Estuary Program
CPUE - Catch Per Unit Effort
CWA - Clean Water Act
DO - Dissolved Oxygen (mg/l)
DO% - Dissolved Oxygen (percent saturation)
EPA - United States Environmental Protection Agency
F.A.C. - Florida Administrative Code
FDEP - Florida Department of Environmental Protection
FIM - Fisheries Independent Monitoring Program
FWRI - Florida Wildlife Research Institute
H2O_UAL - Hydrologic Unit Area Load
IWR - Impaired Waters Rule
mg/l - Milligrams per Liter
NH3 – Ammonia (mg/l)
NNC - Numeric Nutrient Criteria
NO23 - Nitrite-nitrate as N (mg/l)
OPO4 - Orthophosphate (mg/l)
OrgP - Organic Phosphorus (mg/l)
PCA – Principal Components Analysis
PSU - Practical Salinity Units
SBEP - Sarasota Bay Estuary Program
SWFWMD - Southwest Florida Water Management District
TBEP - Tampa Bay Estuary Program
TKN - Total Kjeldahl Nitrogen (mg/l)
TMDL - Total Maximum Daily Load
TN - Total Nitrogen (mg/l)
TP - Total Phosphorus (mg/l)
TTHI - Tidal Tributaries Habitat Initiative
µg/l - Micrograms per Liter
umhos/cm - micromhos
WBID - Water Body Identifier
#/100 m2 - Number per 100 square meters
%sat - Percent Saturation

Chapter 1. Background

The Sarasota Bay Estuary Program (SBEP) was awarded a Wetlands Program Development Grant by the United States Environmental Protection Agency (EPA) in February 2013 to conduct a multidisciplinary study of southwest Florida tidal creeks. The goals of the Wetlands Program Development Grant are to conduct projects that promote the coordination and acceleration of research relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution in wetlands. This study was a collaborative effort undertaken by the three southwest Florida Estuary Programs including SBEP, Tampa Bay Estuary Program (TBEP), and Charlotte Harbor National Estuary Program (CHNEP) with in-kind services provided by six counties to assist in the sampling effort. The six counties in the study area include Pinellas, Hillsborough, Manatee, Sarasota, Charlotte, and Lee counties.

The purpose of the study was to inform the development of management level nutrient water quality targets protective of the biological integrity of these vulnerable estuarine resources and identify thresholds protective against impairment. A multi-disciplinary study was designed and data were collected as part of a one-year, bimonthly sampling effort (i.e 6 sampling events) in 16 southwest Florida tidal creeks (Figure 1) focusing on the relationship between water column nutrient concentrations and response endpoints indicative of tidal creek integrity including: dissolved oxygen (DO); water

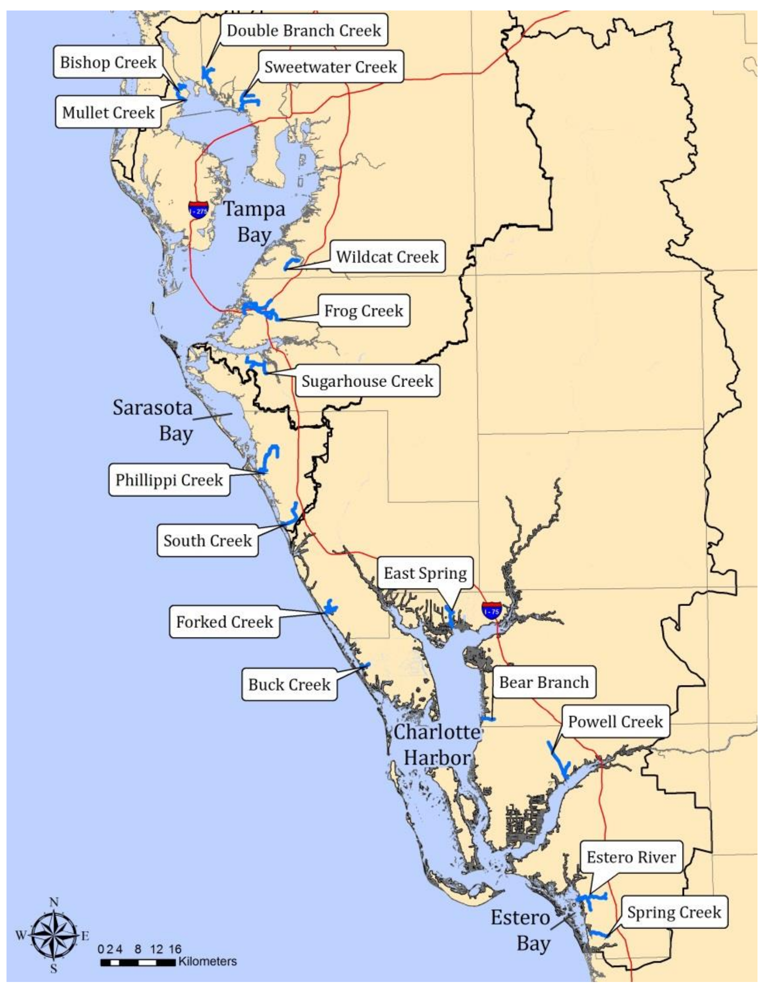


Figure 1. Sixteen tidal creeks sampled between November 2013 and September 2014. (see forward for full page version).

column chlorophyll; sediment chlorophyll, and fisheries collections. These data were combined with laboratory and field water quality samples, and existing remote sensing and *in situ* data describing landscape level effects at varying spatial scales for analysis of both near field and far field effects of watershed stressors on tidal creek biological integrity.

Physical alterations to tidal creeks systems are commonplace in southwest Florida as the historical need to drain lands for agriculture and development resulted in ditching and draining much of the surrounding watersheds. Historical wastewater nutrient loadings to the estuaries increased with development through the 1960s and 1970's until the advancement of wastewater treatment systems and centralized wastewater processing facilities which have since dramatically reduced these impacts in southwest Florida. In some cases salinity barriers were constructed to restrict salt water intrusion into irrigation and drinking water supplies and some remnant structures remain. Watershed development has encroached on natural emergent wetlands, hardened creek shorelines, and increased stormwater runoff. Together, these alterations to the natural landscape have the potential to dramatically alter the biological integrity of pre-impacted tidal creek systems, affect their ecological function, and alter their potential assimilative capacity. While the potential impacts to tidal creek biological integrity are many, the focus of this study was to identify the effects of nutrients on creek integrity within the context of these potential cumulative impacts to southwest Florida tidal creeks.

Prior to conducting the sampling effort, several tasks were completed for this project including: creating a definition of a tidal creek; identifying the population of tidal creeks within the study area; organizing and synthesizing existing information pertinent to the study; developing a creek classification scheme to distribute the sampling effort across the range of creeks in the population; selecting the final 16 creeks for sampling; developing a sampling design, and creating an EPA approved Quality Assurance Project Plan. The results of these efforts were presented in a task based report for this project (Janicki Environmental et. al., 2013) which was approved in September of 2013 and is provided as Appendix A for convenience. A brief description of the sampling design as it relates to interpreting the results provided in this report is provided in the following paragraphs.

The principal objectives of the sampling design were to:

1. characterize the nutrient conditions of the contributing source water (i.e., fresh water) to the tidal portion of the creeks;

2. relate nutrient conditions in contributing source water to nutrient conditions in the tidal portion of the creek;

3. relate nutrient conditions in the contributing source water and in the estuarine portion of the creek to indicators of biological integrity, and

4. provide data that can be used to develop a nutrient management framework that includes protective targets and thresholds indicative of nutrient impairment for these systems.

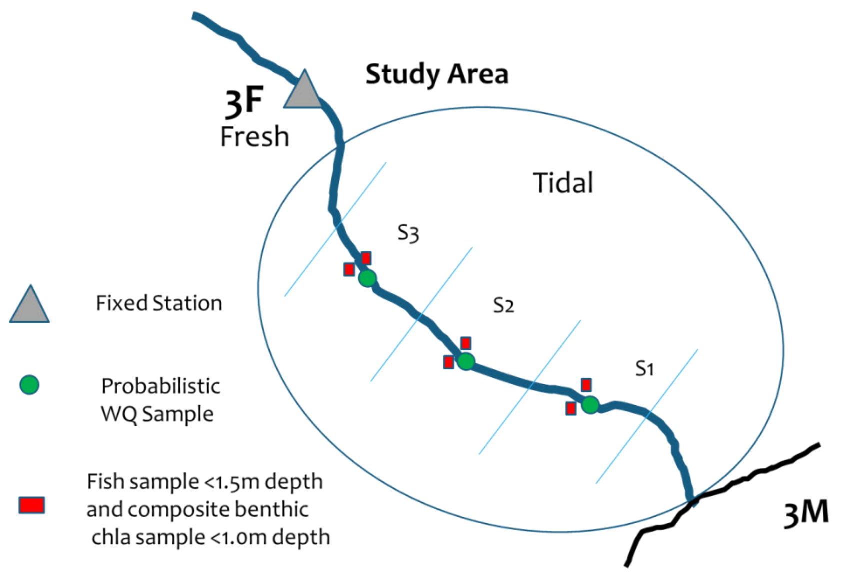


Figure 2. General depiction of the sampling design components for additional sampling of tidal creeks associated with this project.

The sampling design included a combination of a fixed station location located above the tidal head to characterize the contributing source water quality and probability based sampling using stratified random site selection in the tidal portion of the creek (Figure 2). The objectives described above were derived as a way to test the concepts expressed in the conceptual watershed and ecological models developed for this project as described in Janicki Environmental et. al., 2013. The data collected as part of the sampling effort of the study included information on instream water quality, fish communities, and sediment chlorophyll as measured by benthic microalgae chlorophyll content (BMAC). A single water quality sample and two biological samples were collected at each of the probabilistically selected sites. Sampling events were conducted every other month between November 2013 and September 2014 and all 16 creeks were sampled in the same week of the month with the exception of the first sampling event when two creeks were sampled the following week. Detailed descriptions of these creeks are provided in Appendix A and a comparison of recent and historical aerial imagery of these creeks is provided in Appendix B.

Fish were chosen as a principal biological endpoint of interest for several important reasons. Multiple studies, including this one, have documented the importance of tidal creeks in southwest Florida to estuarine dependent fish stocks study such as Snook, Red Drum, and Sheepshead (Clark 1987, Clark 1991, Krebs et. al., 2007; Yeager et. al., 2007, Greenwood et. al., 2008; TTHI, 2008; Sherwood, 2010; MacDonald et. al., 2010; Malkin et. al., 2010, Barbour and Adams, 2012). The larger economic values of the ecosystem services that tidal creeks provide are related to producing robust fish stocks for recreational pursuits (Hindsley and Morgan, 2014. Tidal creeks are key ecological attributes for the success of the fish stocks within the larger estuary. In estuarine waters, fish represent a higher integration of the food web than studying benthic invertebrate populations which are often used in establishing biological response endpoints for water quality criteria in freshwater. The EPA has provided guidance that ecological feedback mechanisms involving higher trophic levels can be a positive tool in nutrient management (EPA, 2001). The EPA goes on to suggest that attempting to understand the nutrient over-enrichment problem in estuaries and coastal ecosystems primarily from a bottom-up perspective provides a limited perspective. Lastly, fish were used as the biological response endpoint for establishing the Florida's revised DO criteria for the estuaries into which these creeks discharge. For these reasons we adopt the premise that the primary ecosystem function of the tidal creeks is to export energy in the form of carbon and nutrients from the terrestrial landscape through the food web and towards the coastal shelf via trophic transfer pathways. That is, to export nutrients as biomass.

The conceptual model describing the trophic pathway for nutrient export is portrayed in Figure 3. This conceptual model has been considered as a working hypothesis around which a great deal of resources has been committed in support of establishing minimum flows and levels for southwest Florida tidal rivers (Flannery et al., 2002; Peebles, 2003;TTHI, 2008) and in evaluating the effects of surface water withdrawals and other hydrologic alterations on indicators of biological integrity such as phytoplankton, benthic invertebrates and fishes (Janicki Environmental 2009, Wessel and Janicki, 2010). In this regard, this study also builds on considerable other work in tidal creeks to identify parameters affecting the recruitment and success of estuarine dependent fishes in southwest Florida tidal creeks (Peebles 2002; Krebs et. al. 2007; Greenwood et. al 2008; TTHI 2008, Malkin et. al. 2010; Sherwood 2010; Wessel 2011) including tidal creeks throughout the Gulf south and southeast Atlantic States (Mallin et al., 2004; Holland et al., 2004; Sanger et al., 2008; Sanger et al., 2011). Other conceptual models including a stressor-response model, watershed management model, and ecological model used to guide the project development are provided in Appendix A (Janicki Environmental et. al., 2013).

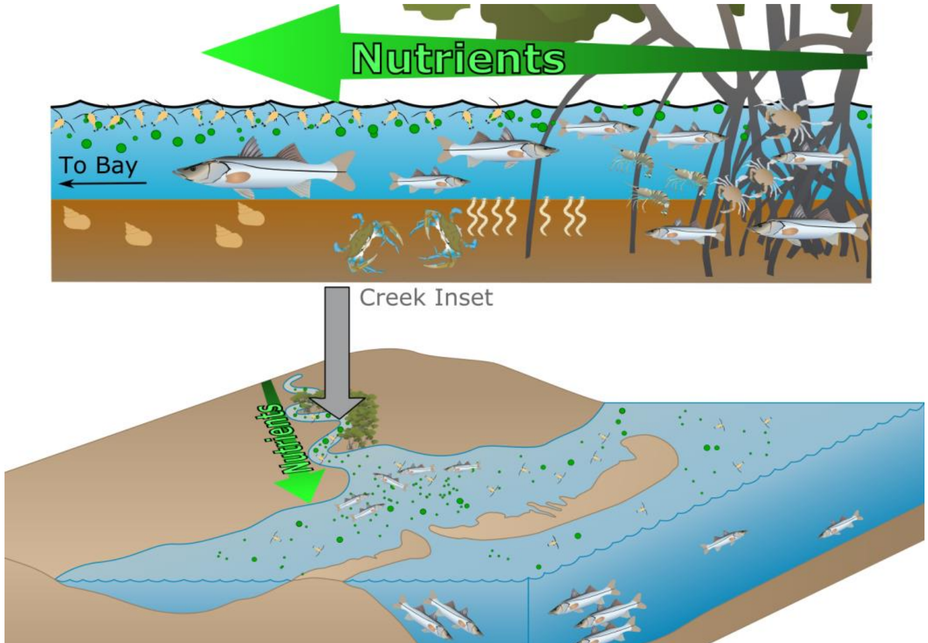


Figure 3. Conceptual model depicting the principal ecosystem function of tidal creeks in exporting nutrients and carbon to the larger estuary and coastal shelf through trophic pathways (Figure adapted from Lewis et al., 1985 and Peebles, 2002).

Chapter 2. Principal Findings

This study confirmed that southwest Florida tidal creeks serve as critical nursery areas for important estuarine sportfish including the Common Snook (aka Snook; *Centropomus undecimalis*), a species of considerable economic value in southwest Florida. Impressively, Snook was the ninth most abundant species collected (Table 1). Six other recreationally important species (in bold text) were found in the top 25 most numerically dominant species collected including the Red Drum (*Sciaenops ocellatus*), Blue Crab (*Callinectes sapidus*), Pink Shrimp (*Farfantepenaeus duorarum*), Striped mullet (*Mugil cephalus*), and Sheepshead (*Archosargus probatocephalus*) in addition to a host of species that serve as prey items for estuarine dependent sportfish. Detailed catch statistics for all species captured are provided in Appendix C.

Table 1. Dominant fish and macro invertebrate taxa collected in the 16 southwest Florida tidal creeks between Nov. 2013 and Sep. 2014.

Scientific Name	Common Name	Total Number
Anchoa mitchilli	Bay Anchovy	15,097
Eucinostomus spp.	Mojarra's < 40mm	11,242
Palaemonetes pugio	Grass Shrimp	2,837
Menidia spp.	Silversides	2,555
Lucania parva	Rainwater Killifish	2,086
Eucinostomus harengulus	Tidewater Mojarra	1,921
Gambusia holbrooki	Eastern Mosquitofish	1,125
Diapterus auratus	Irish Pompano	982
Centropomus undecimalis	**Common Snook**	**775**
Eugerres plumieri	Striped Mojarra	593
Trinectes maculatus	Hogchoker	561
Poecilia latipinna	Sailfin Molly	454
Lagodon rhomboides	Pinfish	412
Microgobius gulosus	Clown Goby	287
Sciaenops ocellatus	**Red Drum**	**271**
Leiostomus xanthurus	**Spot**	**262**
Brevoortia spp.	Menhaden	243
Clupeidae spp.	Unidentified Clupeids	204
Callinectes sapidus	**Blue Crab**	**191**
Oreochromis/Sarotherodon spp.	Tilapia	174
Gobiosoma spp.	Small gobies <20mm	147
Gobiosoma bosc	Naked Goby	141
Fundulus grandis	Gulf Killifish	101
Lophogobius cyprinoides	Crested Goby	85
Farfantepenaeus duorarum	**Pink Shrimp**	**84**
Mugil cephalus	**Striped Mullet**	**81**
Archosargus probatocephalus	**Sheepshead**	**74**

Snook were collected at a significantly higher density (#/100m^2) than other studies by the FWRI FIM program in larger rivers systems of Tampa Bay over the same time period using similar nets with identical mesh size. Six individual creeks including Buck, Frog, South, Sugarhouse, Sweetwater, and Wildcat Creeks, had significantly higher Snook CPUE compared to any of the larger river systems (Figure 4a). When combining all the creeks where Snook were observed (i.e. all creeks but East Spring and Powell), the overall density was also higher than any of the larger rivers (Figure 4b). These findings emphasize the role of southwest Florida tidal creeks as critical Snook nursery areas.

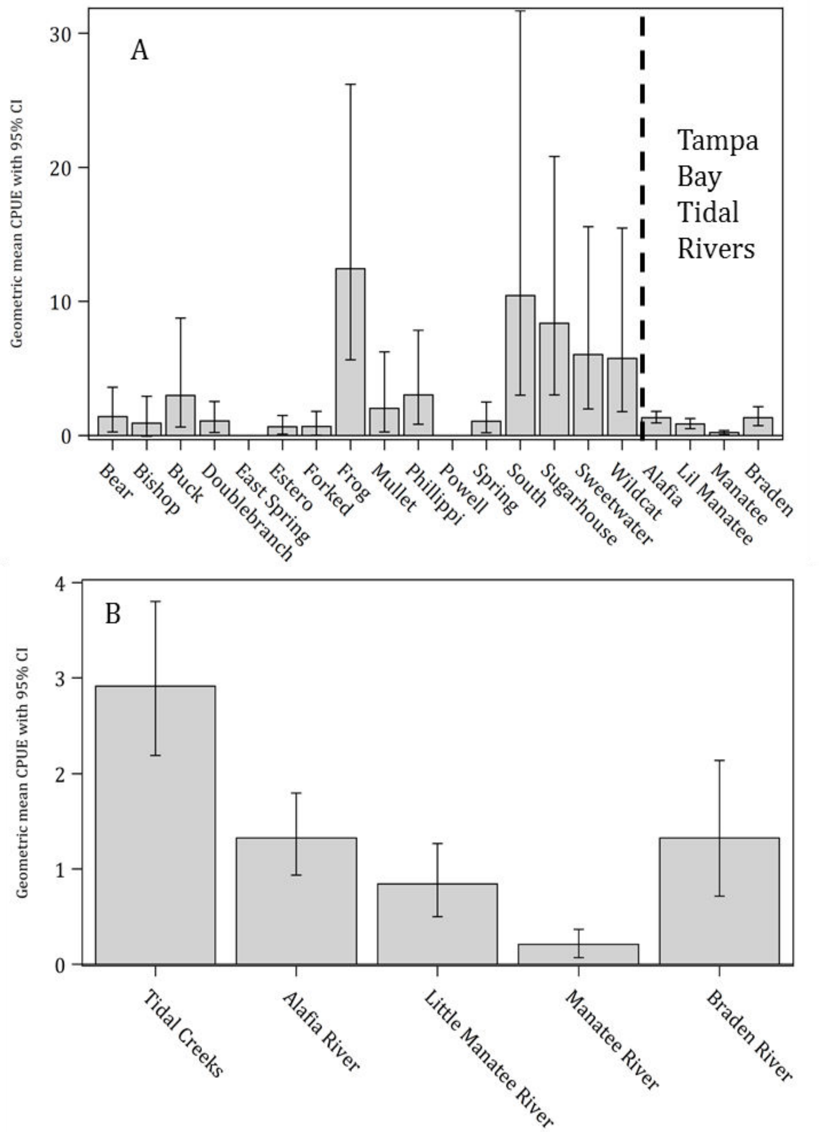


Figure 4. Geometric average Snook catch per unit effort (#/100 m^2) in all 16 creeks compared to Snook catch in the 4 highest recruiting Tampa Bay Tidal Rivers in Tampa Bay (top) and the combined tidal creek catch data compared to the same 4 rivers (bottom). East Spring and Powell were removed from the creek data and the low catch tidal rivers (Lower Hillsborough and Tampa Bypass Canal) were not included in this analysis.

The length frequency distribution of Snook captured in this study included both young of the year and age 1 Snook which are underrepresented in data currently being utilized for Snook stock assessments (Dr. Bob Muller, personal communication). The study documented differential length-frequency patterns for species such as Snook among the different creeks sampled (Figure 5) and used analysis of length frequency distributions and biomass estimates to support characterization of the relative biological integrity of the sampled creeks. The presence of multiple life stages of a particular estuarine dependent species in the catch within a tidal creek is one metric proposed to be indicative of a healthy, well balanced population of fish in accordance with FDEP's definition of the "Designated Use" for these systems which is discussed in greater detail in the next chapter of this report.

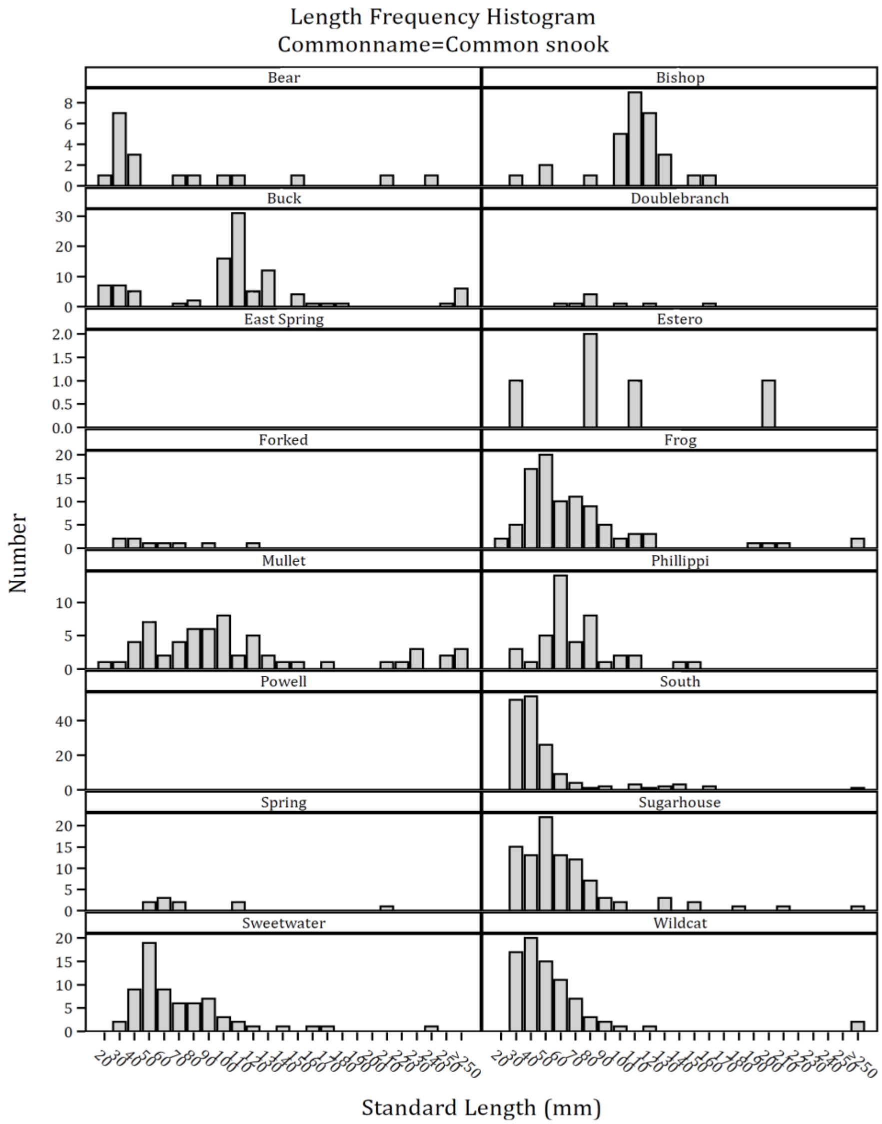


Figure 5. Length frequency distribution for Common Snook (*Centropomus undecimalis*) by creek. Note Y axis scale varies to emphasize within creek length distribution rather than differences among creeks in the number collected.

Fish species diversity metrics including: Shannon Weiner Diversity (H'); Margalef's Species Richness (D); Pielou's Evenness (J'); the number of taxa, and the total number of individuals captured (Zar, 1984) were calculated to investigate the relationship between nutrients and these indices. Invasive fish species were removed from the database prior to calculating the diversity metrics so that increased diversity corresponded to "better" condition. These indices were used as a metric for evaluating the relative biological integrity of these systems. For example, boxplots of the distribution of Shannon Wiener Diversity index and total catch per unit effort (natural log transformed) are provided in Figure 6. Creeks with the highest median diversity included Phillippi, Wildcat, Frog, and Sugarhouse Creeks. These same creeks also had the highest geometric average nutrient concentrations. Creeks with the lowest diversity included Buck, Powell, Spring and Bear Creeks but these creeks were also lower in nutrient concentration. The ranked geometric average nutrient, chlorophyll *a* and dissolved oxygen concentrations are provided in (Table 2). In this table, lower ranks indicate lower concentrations for nutrients and chlorophyll and higher concentrations for DO and benthic chlorophyll concentrations. That is, the rankings are scaled such that lower numbers are considered better conditions. For example, Wildcat, Phillippi, Sugarhouse and Frog Creeks ranked in the bottom quartile when considering the average ranks of the three nitrogen species, TP

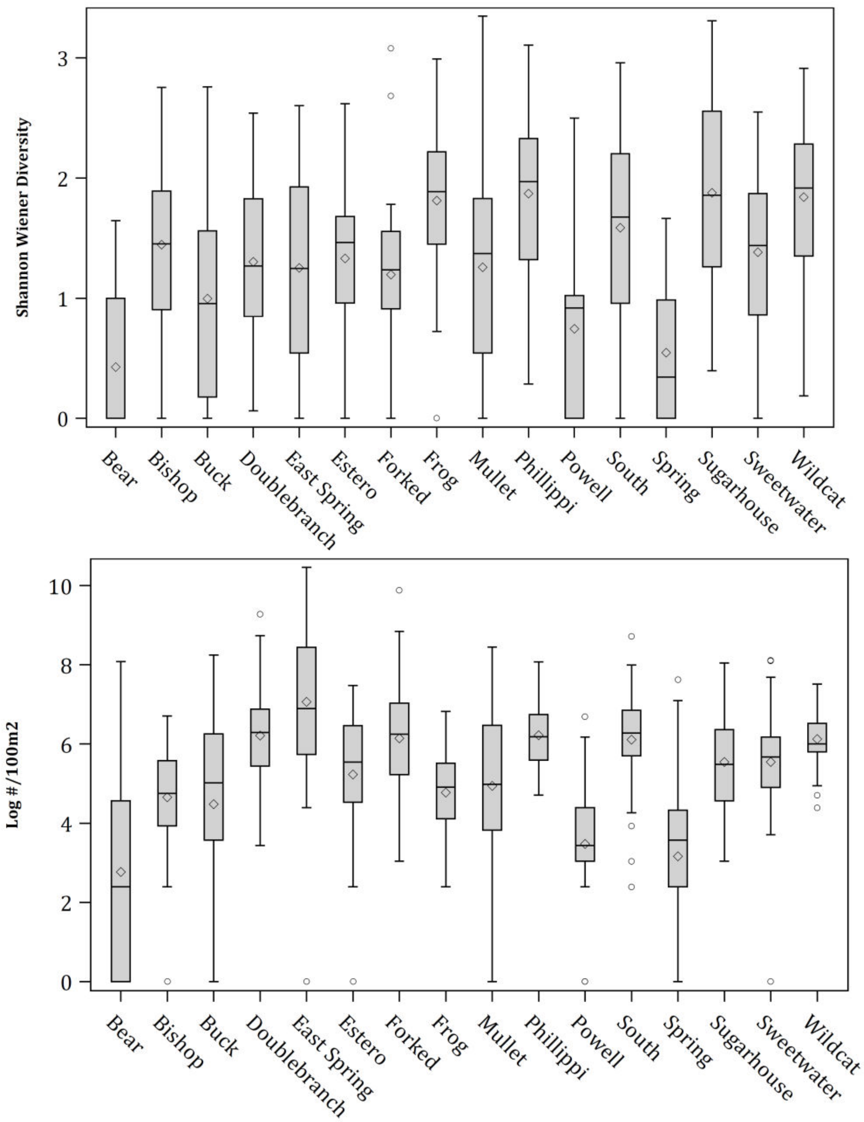


Figure 6. Distribution of Shannon Wiener Diversity (top) and Catch Per Unit Effort for the 16 creeks.

and chlorophyll indicating higher nutrient concentrations typically associated with poorer water quality. These creeks tended to have the highest median diversity metrics. These findings support the contention that these creeks have not yet reached a level of eutrophication indicative of an impaired condition for their designated use with respect to fish. However, there were indications that some of the more labile forms of nutrients were in excess in creeks with the highest total nutrient concentrations. For example, Nitrite-Nitrate (NO23) was, on average, over 15% of the measured TN concentration in Estero, Frog, and Sugarhouse Creeks.

Table 2. Creek ranks for geometric average nutrient, chlorophyll a, and dissolved oxygen concentrations collected in the tidal portion of the creeks. The "Average" is the average of all nutrients and chlorophyll for each creek, not dissolved oxygen which is only shown for additional information.

Creek	Ranks Based on Geometric Average Values						
	Nitrite-Nitrate (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Chlorophyll *a* corrected (µg/l)	Average Rank of left columns	DO % saturation
Bishop	10	2	2	10	1	5	12
East Spring	1	4	1	8	11	5	16
Sweetwater	13	3	3	6	2	5.4	9
Mullet	6	5	5	9	3	5.6	4
Bear	4	8	8	5	8	6.6	1
Forked	2	6	4	12	10	6.8	15
Estero	14	1	6	1	15	7.4	7
South	7	7	7	11	6	7.6	6
Powell	9	9	9	7	5	7.8	3
Buck	5	12	11	4	14	9.2	5
Doublebranch	11	15	14	3	4	9.4	13
Spring	8	13	13	2	16	10.4	2
Phillippi	12	11	10	14	7	10.8	11
Wildcat	3	14	12	13	12	10.8	14
Sugarhouse	15	10	15	15	13	13.6	10
Frog	16	16	16	16	9	14.6	8

Observed water quality conditions in these tidal creeks support the premise posited in recommendations submitted by the SBEP to FDEP (Janicki Environmental, Inc., 2011) that tidal creeks need independent water quality criteria relative to either their freshwater contributing or downstream receiving waters. The majority of the sampled creeks displayed characteristics of healthy and productive systems for the propagation of fish (the

FDEP designated use for these creeks) despite observed dissolved oxygen and chlorophyll concentrations that would likely result in the creeks being placed on the FDEP's "Verified List", a list of WBIDs verified as having impaired water quality. The observed water quality conditions were more reflective of typical wetland environments with the potential for low dissolved oxygen concentrations without deleterious effects. For example, the DO threshold exceedence rates for the tidal portions of the creeks are provided in Figure 7a and suggest that many of the creeks would fail the existing estuarine DO standard. This was true for creeks with the lowest diversity metrics but also for creeks with the highest diversity metrics and included creeks that caught the highest number and biomass of Snook. This was also true for creeks within the most undeveloped watersheds of those sampled. This result is why we refer to the current DO standard as an unreliable indicator for evaluating tidal creek biological integrity. A similar finding was observed for chlorophyll *a* concentrations where half of the creeks exceeded the current annual geometric average threshold for impairment for estuaries of 11 µg/l (Figure 7b).

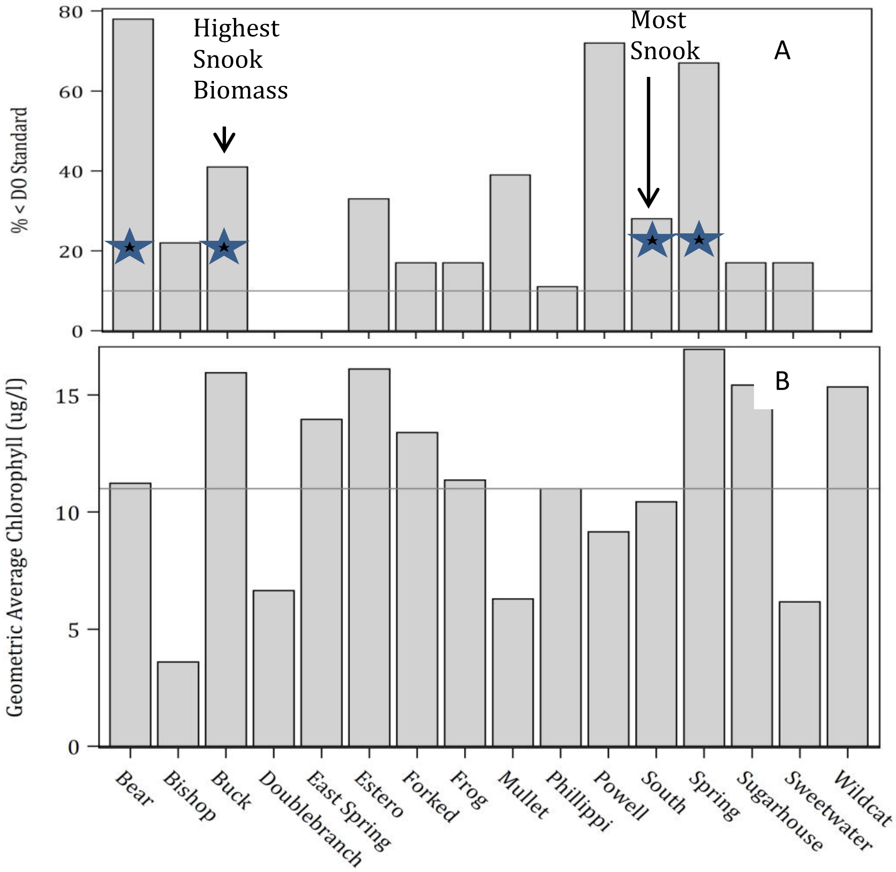


Figure 7. Exceedence frequency of FDEP estuarine dissolved oxygen standard of 42% saturation (top) and chlorophyll standard (11 ug/l: bottom). Horizontal line indicates allowable limits. ★=Creeks with most undeveloped watersheds.

An important outcome of this study has been the acknowledgement that tidal creeks exhibit characteristics of wetland environments. In fact, we recommend referring to tidal creeks as "tidal creek wetlands" to reflect their principal ecological function and emphasize their role within the larger estuary. We recommend this terminology be used in future public information literature to characterize the related primary ecosystem services that tidal creeks provide to the larger estuary with respect to contributing habitat, refuge, sediment control, diversity and resilience to the larger estuarine systems in which they reside. Many of these creeks contained or were adjacent to large areas of fringing mangrove communities sometimes referred to as either “forests” or “swamps” though we recommend the term wetlands be used to describe these communities. As stated in FDEP’s DO criteria technical support document (FDEP 2013a):

[….*because drainage from natural wetlands, swamps, marshes, and mangrove forests typically contain high Colored Dissolved Organic Matter (CDOM) and elevated natural nutrient levels (especially, nitrogen), it is important to not erroneously identify nutrients as the pollutant responsible for low DO levels when the low DO is actually the result of natural conditions. Listing these waters as impaired may result in valuable resources to be erroneously expended in an attempt to rectify a natural condition. Conversely, when natural conditions limit available assimilative capacity (e.g., for oxygen demanding substances), it is important to limit anthropogenic inputs (by means of permits or TMDLs) into the systems to prevent impairment].*

The results of this study suggest that if DO concentrations, or concentrations expressed as percent saturation, are to be used as a relevant water quality standard for tidal creek wetlands, an alternative formulation of the standard is required. The current FDEP estuarine criteria are based on experimental laboratory studies including some fish species that do not occur in southwest Florida tidal creeks. The application of the estuarine DO criteria would result in false declaration of impairment for some systems that were found to be biologically healthy using fish catch data as a biological response endpoint. This study has investigated several lines of evidence in an effort to derive alternative criteria but has not explicitly recommended alternative DO criteria strictly for southwest Florida tidal creeks. More studies are required to derive site-specific alternative criteria for DO in southwest Florida tidal creek wetlands. The study does make several recommendations with respect to developing DO criteria more applicable to southwest Florida tidal creek wetlands based on a suite of analyses described in Chapter 4 of this report including the need to consider a statistic other than the 10th percentile.

Probably the most important scientific finding of this study was the observation that nutrient addition was common in the tidal portion of the creeks. A focal point of the study was to evaluate the nutrient concentrations in the tidal portion of the creek as a function of the source water concentrations and tidal mixing (i.e. salinity) and the study design was constructed specifically to investigate this aspect of nutrient dynamics. Specifically, EPA/FDEP considered establishing downstream protection values for tidal creeks based on a dilution (or mixing) curve methodology (EPA 2012a). The approach is depicted in Figure 8. where the estuarine standard and the freshwater standard would be used to resolve the tidal creeks standard assuming a linear decay in concentration with salinity. The sampling design allowed us to estimate the expected decay in nutrient concentrations along the estuarine gradient within the creeks based on dilution using the empirical data collected during the study. AS described in more detail in section 4.4, we calculated the expected concentration of nutrients in the tidal portion of the creek as a function of the source water concentration and the proportion of salinity relative to full strength seawater (i.e., 35‰) as a boundary condition. The expected nutrient concentration is:

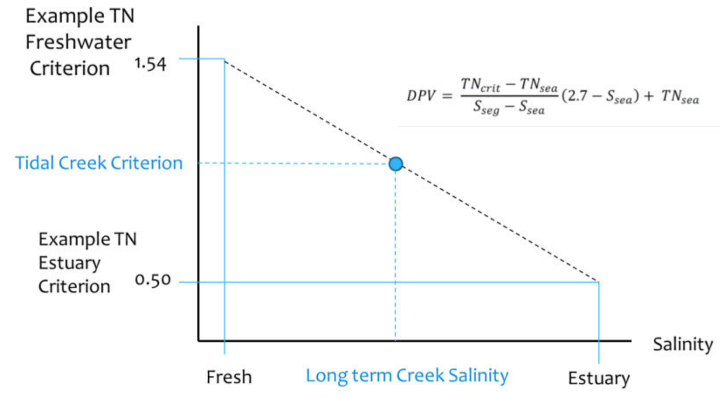


Figure 8. EPA considered dilution curve method for assigning nutrient standards for tidal creeks.

$$En_c = n_f * (1 - (Sal_c / 35))$$

where:

En_c = Expected nutrient concentration at site c in tidal creek

n_f = Nutrient concentration at source water site

Sal_c = Salinity at site c in tidal creek

The equation allows for the computation of an expected nutrient concentration at any sample location within the creek and a comparison of the expected concentration to the observed concentration as the sample location. The results suggest that the tidal portions of these creeks can serve as a supply of nitrogen during some portions of the year and may also serve as nutrient sinks under some conditions rejecting the notion of a linear decay along the salinity gradient. For example, the results of the mixing curve analysis for organic nitrogen in Bishop Creek is provided in Figure 9. For each sample date, the observed concentrations are plotted along with that expected based on dilution (solid line). The upstream stratum was always freshwater as indicated by the line touching the open circle in the plot. However, for sample locations downstream in the tidal portion of the creek, the nutrient concentrations tended to be higher than expected based on dilution, especially in May, July and September.

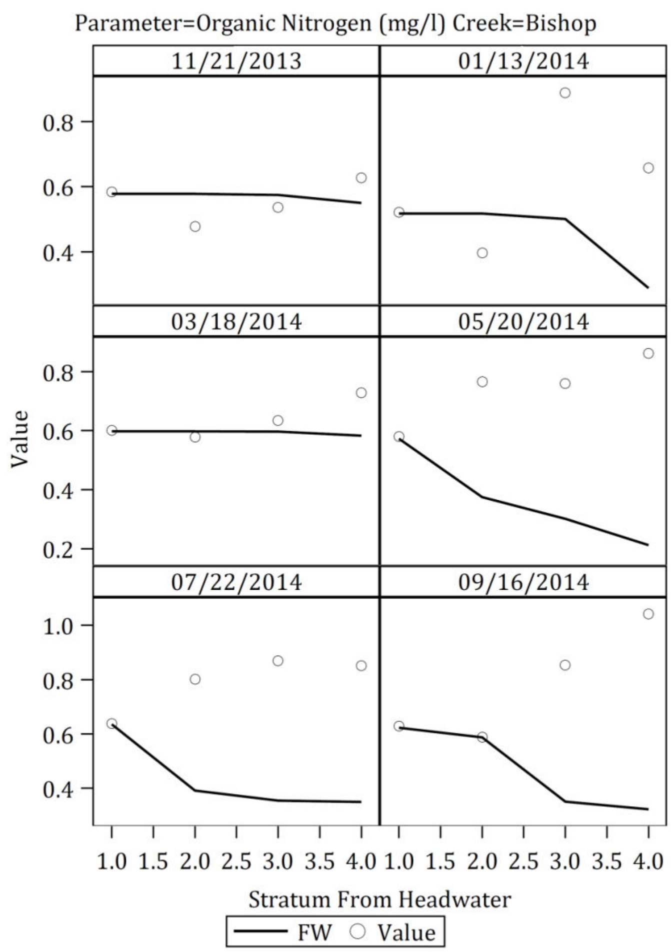


Figure 9. Mixing curve results for organic nitrogen (left) in Bishop Creek. Open circle represents the observed concentration in each stratum (stratum 1 =source water). Line (FW) represents expected concentration based on fresh water concentration and observed salinity.

The ability to relate the nutrient concentrations within the creeks to a particular source, either anthropogenic or natural, was outside the scope of this study but we provide evidence to support that some of the nitrogen in the tidal portion of the creeks may be derived from natural sources including nutrient outwelling from fringing mangrove communities near the mouths of the creeks. Natural wetland vegetation within the creek floodplain and decomposition of organic material within the creek channel have been shown to contribute nutrients to tidal creeks in other studies (e.g., Wolanski, 2007; Smith et al., 2012; Gleeson et. al, 2013). This is an important consideration when developing nutrient criteria for these systems since many of these creeks contained or were adjacent to large areas of fringing mangrove communities. Of course, anthropogenic influences within the tidal portion of the creeks can also contribute to nutrient addition and it is important to try and partition these potential sources when evaluating need for nutrient reductions to the systems. It was beyond the scope of this study to attribute the source of nutrients observed in these creeks; however, consideration of both potential natural and anthropogenic influences is warranted in assigning management actions aimed at reducing nutrient loadings to these systems given the findings of this study. For southwest Florida tidal creeks wetlands, more work is needed in this regard and comparisons of creeks with and without wetlands would be worthwhile provided other factors affecting nutrient concentrations could be controlled.

Together, the results summarized above provide important empirical evidence to inform future management decisions related to the protection of southwest Florida tidal creeks. The details of the analyses leading to the results described above are provided in Chapter 4. First, the next chapter of this report summarizes the results of the data collected in this study within the context of other locally derived data in the coastal watershed and the current state nutrient standards for Florida freshwater streams.

Chapter 3. Creek Nutrient Data and Florida's Numeric Nutrient Criteria

The FDEP recently implemented numeric interpretations of their narrative standard for lakes, springs, freshwater streams, estuaries, and coastal waters (FDEP 2013b). The narrative standard is stated under Rule 62-302.530(47)(b), F.A.C.: "*In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna*." Each water body also has a "Designated Use" in Florida statue. For Class III waters, including all southwest Florida tidal creeks, that designated use is defined as "*recreation and propagation and maintenance of a healthy, well-balanced population of fish and wildlife*" (Rule 62-302.400, F.A.C.). The FDEP relied on a hierarchical approach to guide the establishment of numeric interpretations of the narrative standard (Figure 10). The hierarchy emphasized the use of site-specific criteria where numeric values were in place to guide the protection and restoration of those water bodies (Hierarchy 1). For those waters without established site-specific criteria or pollutant reduction goals, the FDEP utilized stressor-response approaches (Hierarchy 2) to develop criteria (lakes and springs), used a reference-based approach combined with biological confirmation as a third tier approach (Hierarchy 3) for Florida freshwater streams, and relied on narrative language (Hierarchy 4) to protect designated uses for ditches, wetland, canals, and tidal creeks. Implicitly, the hierarchical structure of this approach represents a statement about the confidence of the knowledge underlying the relationships between nutrient enrichment and biological responses in each of these systems. Importantly, tidal creeks currently fall into the lowest hierarchical classification, reflecting the general lack of knowledge of these systems in Florida from which to derive meaningful nutrient criteria.

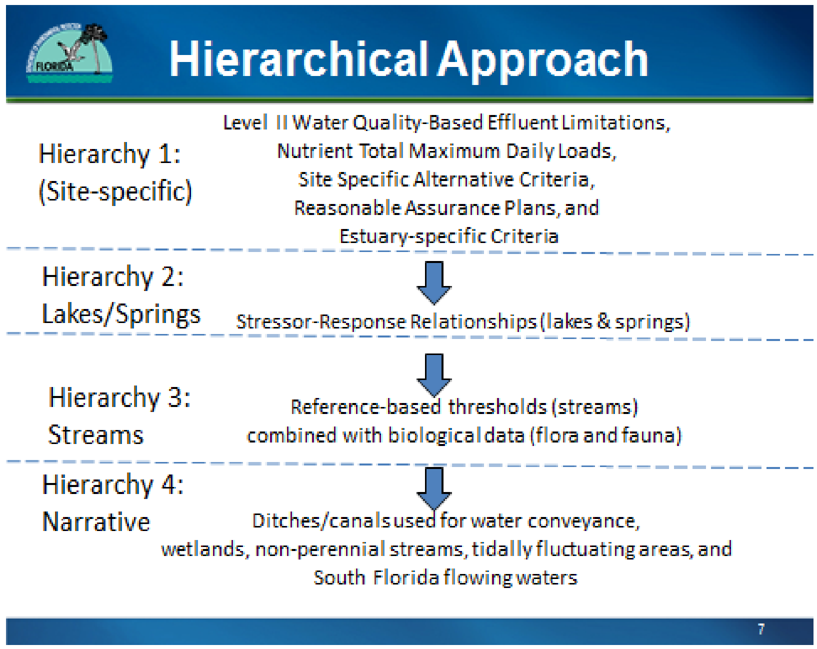
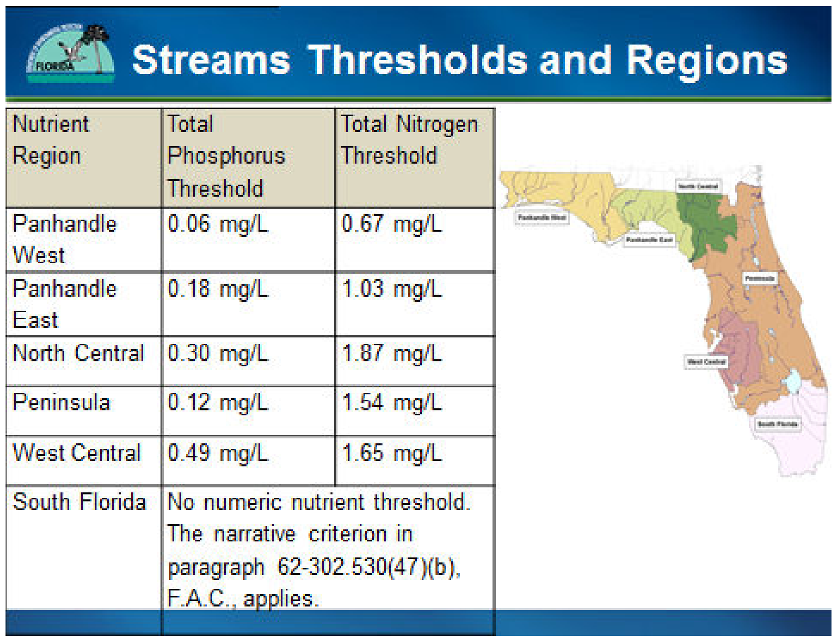


Figure 10. FDEP's Hierarchical approach to establishing numeric nutrient criteria in Florida (Source: Joyner 2015 presentation).

The purpose of this study was to provide additional information that could be used to build on the empirical data collected in southwest Florida tidal creeks in support of establishing more biologically relevant criteria to use in a protective management framework. It is emphasized again here that southwest Florida tidal creek wetlands are currently regulated under this narrative criteria and that the aim of this study is to support more quantitative interpretations of the narrative criteria applicable to protecting the biological integrity of these important natural resources.

The current Florida freshwater streams thresholds, based on a reference-system approach, are provided in Figure 11. The listed values are expressed as annual geometric averages. The estuarine criteria are site-specific throughout the southwest Florida study area between Tampa Bay and Estero Bay and are often expressed as nutrient loads. Therefore, it is most instructive to look to the freshwater standard in reference to the tidal creek conditions since it the freshwater standard represents the standard for the water entering the tidal portion of the creeks.



Nutrient Region	Total Phosphorus Threshold	Total Nitrogen Threshold
Panhandle West	0.06 mg/L	0.67 mg/L
Panhandle East	0.18 mg/L	1.03 mg/L
North Central	0.30 mg/L	1.87 mg/L
Peninsula	0.12 mg/L	1.54 mg/L
West Central	0.49 mg/L	1.65 mg/L
South Florida	No numeric nutrient threshold. The narrative criterion in paragraph 62-302.530(47)(b), F.A.C., applies.	

Figure 11. FDEP Numeric Nutrient Criteria for freshwater streams. (Source: Joyner 2015 presentation).

In Figure 12, the geometric average concentrations of total nitrogen collected in the tidal portions of the creek are plotted in milligrams per liter (mg/l) alongside the contributing upstream concentrations, and alongside our best estimate of the receiving estuarine concentrations from data collected outside of the study during the same time period (though collected on different dates). The plot is oriented by increasing source water "fresh" concentration (magenta filled circles). The open bay estuary concentrations are shown as green squares and the tidal concentrations are shown as blue triangles in the figure. The horizontal bars represent the range of values between the lowest and highest of the three data types. The vertical lines represent the Freshwater Streams thresholds of 1.54 mg/l for the Peninsula and 1.65 mg/l for the West Central regions.

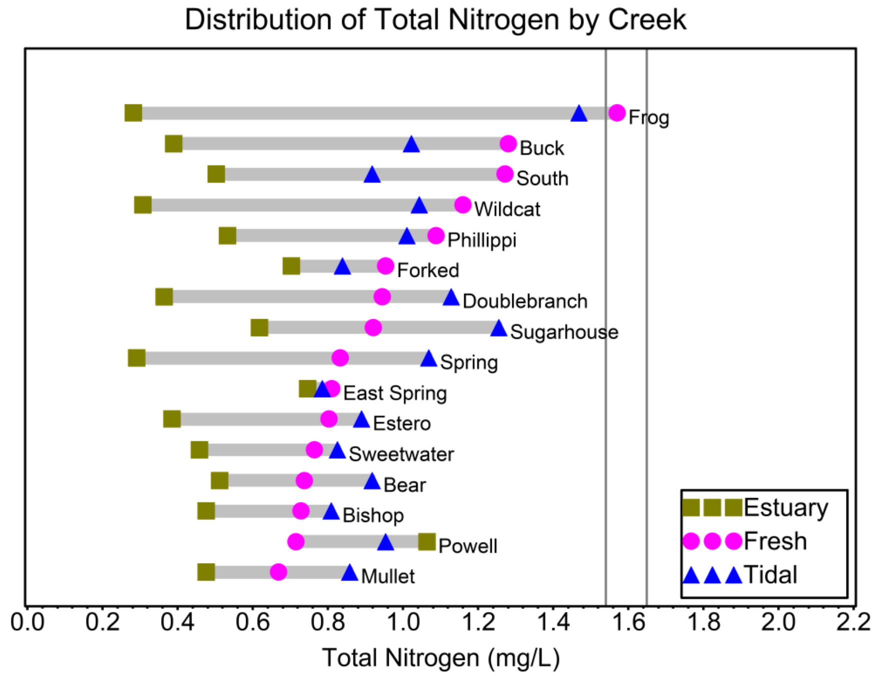


Figure 12. Concurrent annual geometric average total nitrogen (mg/l) concentrations for the source water sites (magenta filled circles), tidal segments (blue triangles), and in the adjacent estuaries (green squares). Vertical lines represent the current regional freshwater nutrient standards.

The "fresh" and "tidal" geometric averages in the figure were derived from data collected during this study and confirm a principal finding of the study that nutrient addition occurs in the tidal portion of many of these creeks. At lower contributing source water concentrations, the tidal concentrations tended to be greater than the source water concentrations. As the source water concentrations increased, the source water concentrations tended to be higher than the tidal concentration. The tidal concentrations in eight of the creeks including: Sugarhouse, Doublebranch, Spring, Bear, Estero, Mullet, Sweetwater, and Bishop were greater than either their representative estuary or freshwater concentrations. The estuarine data used in these plots provide important context in consideration of not only the effect of source water to tidal creek condition, but also the effect of estuarine water mixing within the creek during tidal exchange. For example, in one case (Powell Creek, a tributary to the Caloosahatchee River) the estuarine concentration was higher than either the tidal or source water concentrations. Frog Creek had the highest geometric average freshwater concentrations but because Frog Creek is in the West Central region, its result was below the freshwater standard. The objective of these plots was simply to put the information we collected in the context of other water quality data collected over similar time periods and the plots do not account for uncertainty in the estimate of the geometric average (i.e. no statistical tests were conducted on these data). It should be noted that while the freshwater stations were always located upstream of the "tidal" sites, the upstream station was not always freshwater. Forked Creek is an example where we could not identify an accessible freshwater location to identify the source water and so the site was located as far upstream as possible.

The freshwater total phosphorus (TP) criteria are also regionally dependent but the magnitude of the difference between the Peninsula region and the West Central region, which contains phosphorus rich sediment bed concentrations, are dramatically different. Therefore, the geographic location of the creeks is important in interpreting the results. Wildcat and Frog Creeks had the highest average source water TP concentrations but had different responses within the tidal segment with Frog Creek estuarine TP averages higher than its source water while in Wildcat Creek, the TP concentrations were much lower than its source water (Figure 13). Again, at lower TP concentrations, the tidal segments seemed to have greater concentrations than the source water concentrations while at higher source water concentrations (i.e. above 0.20 mg/l), the source water was generally greater than the tidal segment with the noted exceptions of Frog and Sugarhouse Creeks.

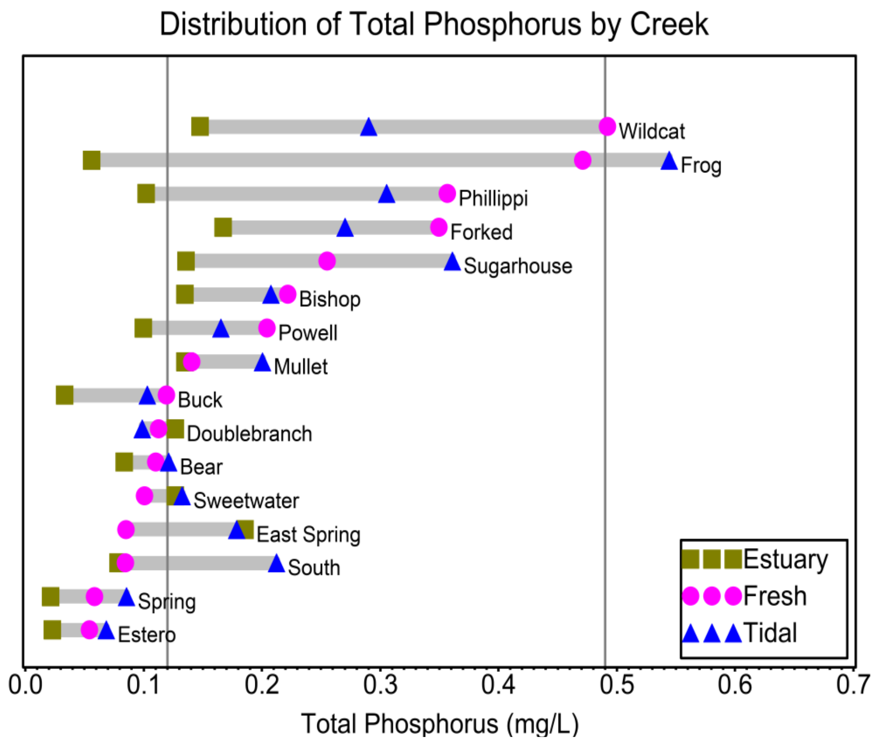


Figure 13. Concurrent annual geometric average total phosphorus (mg/l) concentrations for the source water sites (magenta filled circles), tidal segments (blue triangles), and in the adjacent estuaries (green squares). Vertical lines represent the current regional freshwater nutrient standards.

The results for chlorophyll *a* (µg/l) are provided in Figure 14. In this figure the vertical reference lines represent the geometric average thresholds of 11 µg/l for estuaries and 20 µg/l for freshwater bodies. For all but two creeks, samples from the tidal portion were greater than their freshwater concentrations and in a few cases (i.e. creeks in Old Tampa

Bay), the open estuary concentrations were as high or higher than the creek concentrations. For over 50% of the creeks, the geometric average chlorophyll concentrations were in between the respective estuarine and freshwater criteria. It is important to note that there are site-specific alternative chlorophyll *a* criteria for the estuarine portions of many of these water bodies and that those site-specific values supersede the more general water quality criteria (i.e.11 µg/l) used for reference in these plots. Again, no statistical tests for differences were conducted on these data.

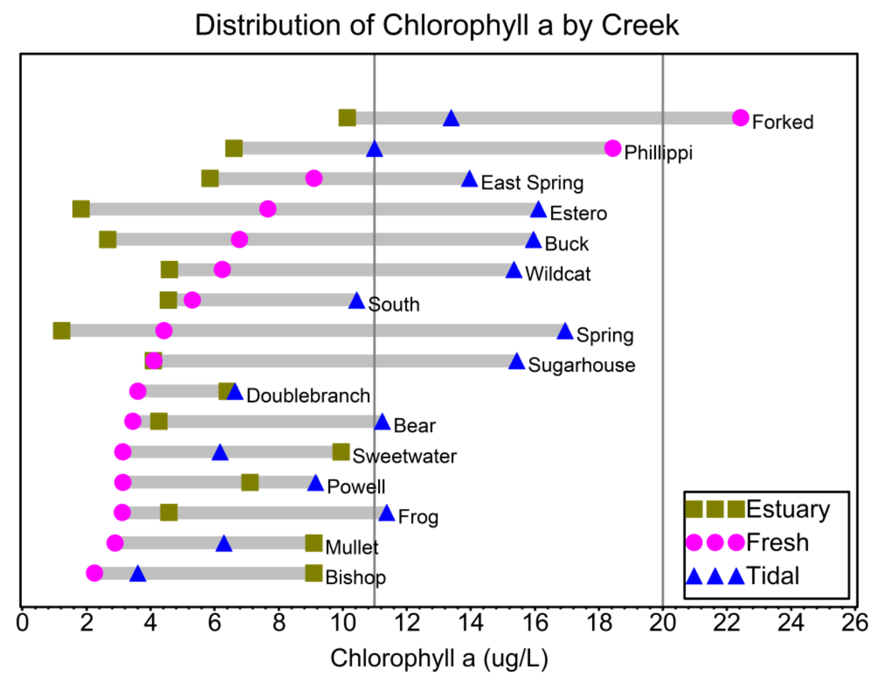


Figure 14. Concurrent annual geometric average chlorophyll a (ug/l) concentrations for the source water sites (pink dots, tidal segments (blue triangles), and in the adjacent estuaries (green squares).

Because the study was constrained to sampling only 16 of the over 300 creeks identified in the study area, there was concern that the sampled creeks may not be representative of the larger population of creek water quality conditions. To address this concern the most recent FDEP dataset containing water quality data use for assessment of impaired waters (IWR Run 49, July 2014) was used to subset all water quality data collected in tributaries to the three estuaries, either 3F indicating a "Freshwater" water body (WBID) of 3M indicating a "Marine" WBID. Note that no open bay estuarine water quality data were included in this comparison

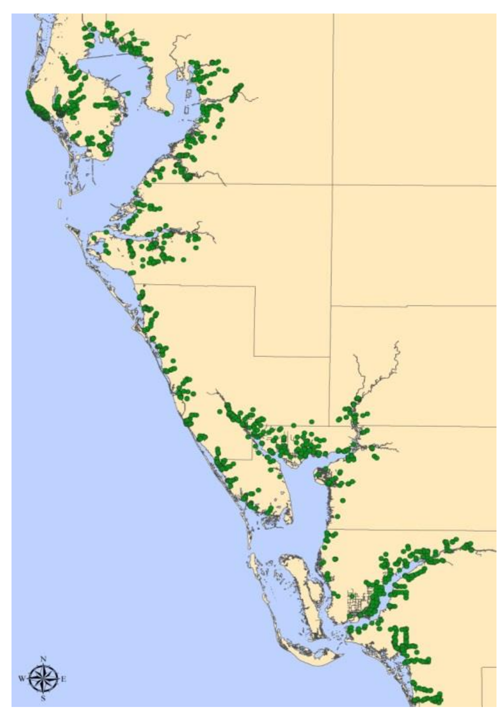


Figure 15. Distribution of water quality samples within the study area taken from FDEP's IWR run 49 dataset in southwest Florida.

(Figure 15). These data were then subset for total nitrogen data collected after 2004 and annual geometric averages were calculated for each WBID. Six observations within a year were required to calculate a geometric average. The distributions of these annual averages were then compared to the distribution of geometric averages of the 16 sampled creeks. The source water stations were compared to the 3F IWR distributions while the tidal data were compared to the 3M distributions.

Figure 16 displays the freshwater results for TN. In this figure, the green broken line with filled circles represents the cumulative distribution of geometric averages for creeks sampled in this tidal creeks survey while the blue solid line represents the cumulative distribution of annual geometric averages of all data available in the IWR dataset between 2005 and 2014. The results are remarkable with respect to the similarities in the cumulative distribution curves which only deviate at the most upper extremes of the distribution.

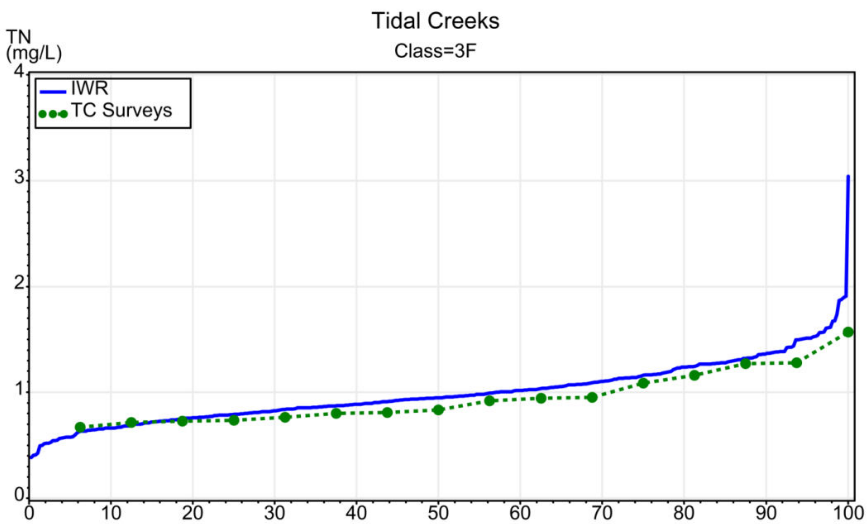


Figure 16. Cumulative distributions of annual geometric average total nitrogen concentrations calculated from the source water sites in this study (green broken line) and IWR dataset between 2005 and 2014 for coastal freshwater stream WBIDs (solid blue line).

Similar results were observed for the TN concentrations in the tidal segment comparisons where differences at the 95th percentile of the distribution were only ca. 0.30 mg/l and greater differences only exist at the extreme tail of the distribution (Figure 17). These results suggest that our study has captured the range of conditions expected for the population of creeks about which we hope to infer management level nutrient targets and thresholds and therefore inferences from this study would be relevant to managing the larger population of tidal creeks in southwest Florida.

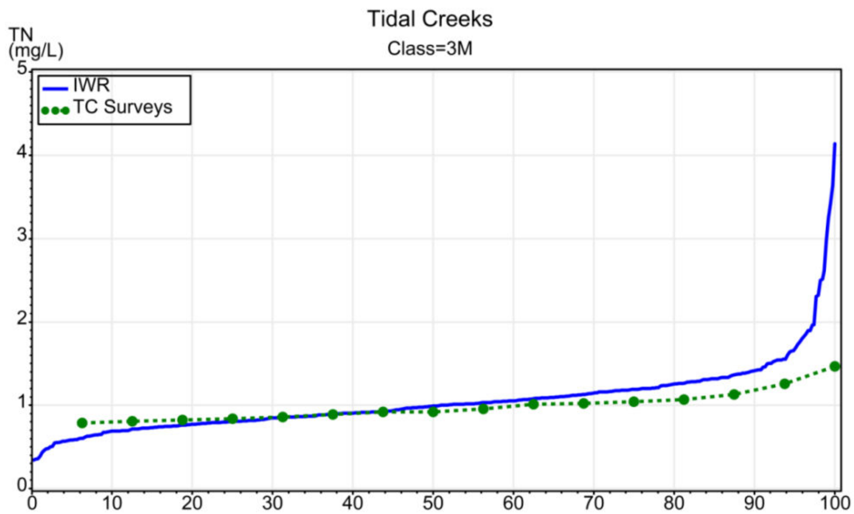


Figure 17. Cumulative distributions of annual geometric average total nitrogen concentrations calculated from the "tidal" sites in this study (green broken line) and IWR dataset between 2005 and 2014 for coastal "marine" WBIDs not in open bay waters (solid blue line).

The results of this study, described in the context of the current state regulatory nutrient framework, have provided a weight of evidence to inform management level targets and thresholds for nitrogen and phosphorus concentrations for southwest Florida tidal creeks aimed at providing proper stewardship of these critical estuarine resources. Ultimately, the proposed targets and thresholds recommended in this report were developed using a reference-based approach. While several statistically significant stressor-response relationships were discovered in the analytical phase of this project, the lack of a unifying relationship that could serve as a predictive equation for all creeks in the population resulted in the final recommendation of the reference-based approach described in Chapter 5. The analysis did provide a wealth of information that served to inform the identification of management level targets and thresholds as well as future efforts required to develop more predictive models for future use. A detailed description of the analysis attempting to identify stressor-response relationships is provided in the next chapter (Chapter 4) of this report followed by a description of the reference-based approach ultimately used to derive the management criteria proposed in Chapter 5. Those readers uninterested in the results of the more detailed analysis relating to attempts to develop a stressor-response relationship may proceed directly to Chapter 5.

Chapter 4. Analysis In Pursuit of a Stressor-Response Relationship

As described in Chapter 3, both stressor-response and reference-based approaches have been used to establish numeric interpretations of the narrative criteria for nutrients in Florida waters. This study investigated several independent lines of evidence to support science based numeric interpretations of the narrative standard for southwest Florida tidal creeks. The lines of evidence included bivariate regression relationships between water quality parameters, exploring the effects of interactions between water quality, nutrients and landscape level habitat metrics, testing hypotheses related to theoretical mixing of nutrients in estuarine waters, and investigating multivariate response metrics intended to evaluate the effects of nutrients on water quality and fish community structure. In the following sub-sections, these independent lines of evidence are summarized.

4.1 Bivariate Relationships

Bivariate regression relationships between water quality parameters were evaluated in an attempt to identify unifying relationships that could be used to develop a stressor-response model applicable to identify protective nutrient thresholds for tidal creeks. The statistical model chosen to assess bivariate water quality relationship was a hierarchical linear mixed effects model. This model was chosen to account for the potential correlation that existed from taking multiple samples within the same creek on the same date (i.e., correlation among strata within date) (Clark 2007). The model allows for statistical inference to account for correlated errors as specified by the error covariance (R) matrix. Compound symmetry was selected to define the R matrix of the model. A creek term was also included as a random effect to allow the inference to be generalized to the entire population of creeks in southwest Florida. The model as specified is:

$$Y_{ijk} = a + a_{oi} + B_1 * X_j + B_2 * X_k + e_{ijk}$$

Where:

a=grand intercept

a_{oi}=Creek specific intercept specified as a random effect

X_j = Temperature covariate

X_k = Independent predictor such as nutrients

B = regression coefficients (i.e. slopes)

e_{ijk} = error term comprised of two components: a random normal error component and an error term expressing the correlation among observations collected in the same creek on the same date

The model was implemented using the GLIMMIX procedure in SAS 9.4 (SAS Institute, 2014). Temperature was included as a covariate in the model to account for the seasonal effects in the relationship between the water quality parameters being tested and parameters were natural log transformed prior to analysis. Dissolved oxygen was expressed as percent saturation in all analyses to conform to FDEP revised rule on DO (FDEP, 2013a). The regression analysis was conducted to test various aspects of the conceptual stressor-response model used to guide the establishment of state water quality standards (Figure 18). The model assumes that increased nutrient concentrations increase chlorophyll concentrations which in turn reduce DO and ultimately result in adverse effects to fish and benthos.

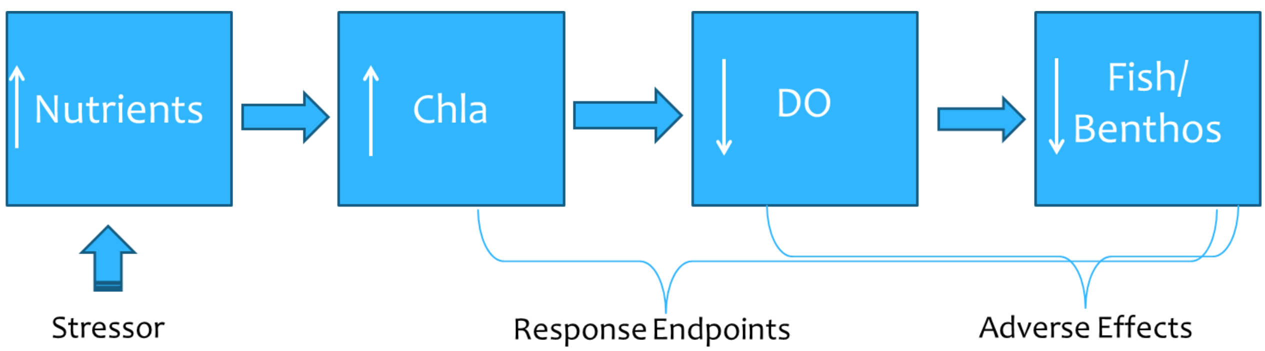


Figure 18. General stressor-response relationship used in a nutrient management framework.

Statistically significant relationships were observed between both total nitrogen and total phosphorus and chlorophyll a concentrations though considerable variability remained unexplained in this relationship (Figure 19a and 19b). Dissolved oxygen was significantly related to total nitrogen concentrations (Figure 19c). There was a marginally significant positive relationship (P=0.11) between benthic chlorophyll concentrations and total nitrogen (Figure 19d). Temperature was a significant covariate affecting many of these relationships; in particular the relationship between nitrogen and dissolved oxygen measured as percent saturation. This is an important finding indicating that, in addition to the effects of water temperature on the physical ability of water to hold oxygen molecules, other processes are at work that reduce dissolved oxygen in the water column as a function of temperature. These other processes are explored in more detail later in this report.

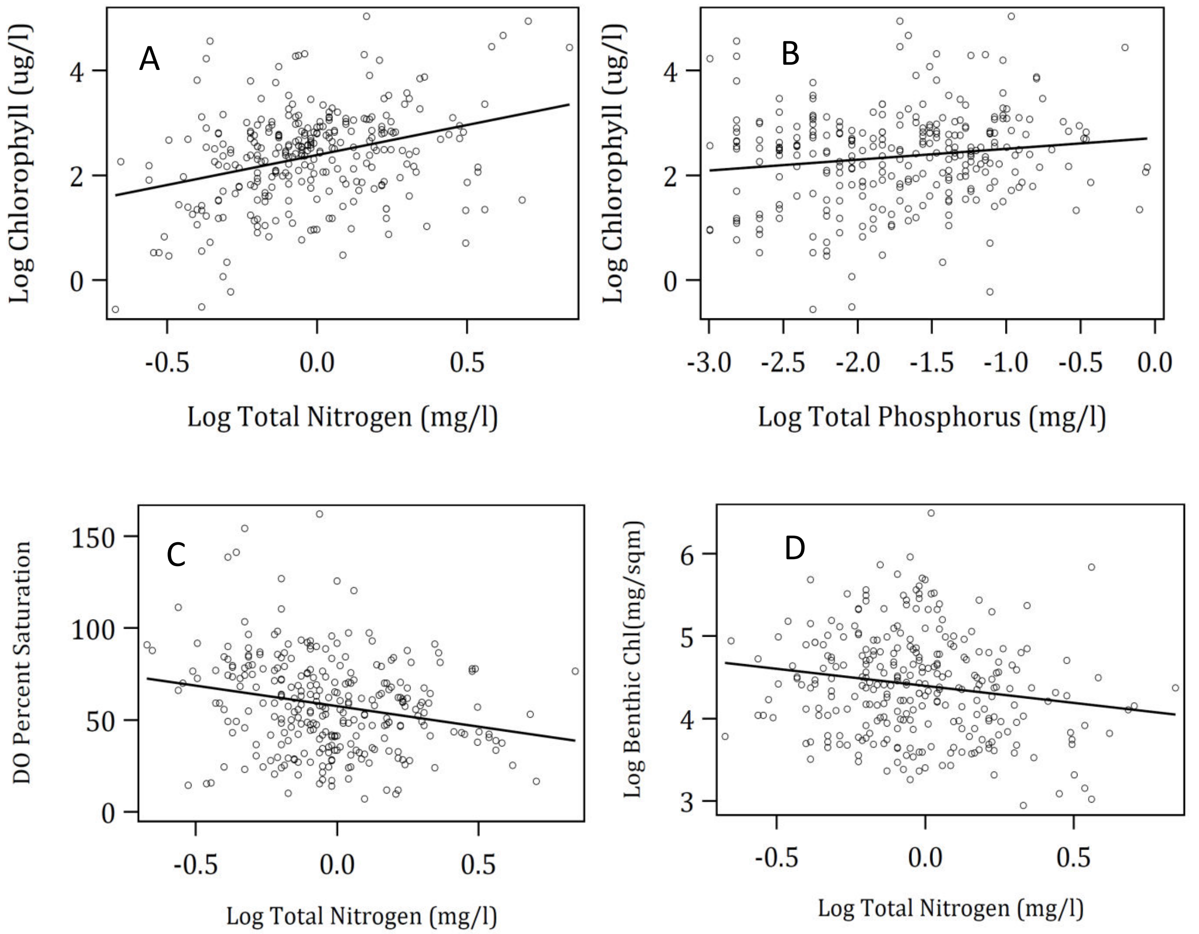


Figure 19. GLIMMIX model results for statistically significant bivariate regressions between water quality parameters including a temperature covariate term.

However, other analyses rejected the assumptions of the conceptual model described above. There was no evidence to suggest that increased chlorophyll concentrations resulted in depressed dissolved oxygen conditions (Figure 20a). Other related bivariate relationships explored included testing the relationship between benthic chlorophyll production and water column phytoplankton production. The TTHI (2008) study in Tampa Bay tidal creeks suggested benthic production can be limited by shading due to increased water column production. Our results did not support the assertion that increased water column production results in decreased benthic chlorophyll production in the creeks sampled. The relationship was marginally significant and positive (p=0.11: Figure 20b) indicating that benthic and water column production weakly covary in a positive manner. This was supported by calculating creek geometric averages for water column and benthic chlorophyll and regressing those parameters which also resulted in a weak but statistically significant positive relationship (R^2=0.37: P=0.012). This result suggests that water column production was generally not limiting to benthic primary production in these systems based on observed measurements.

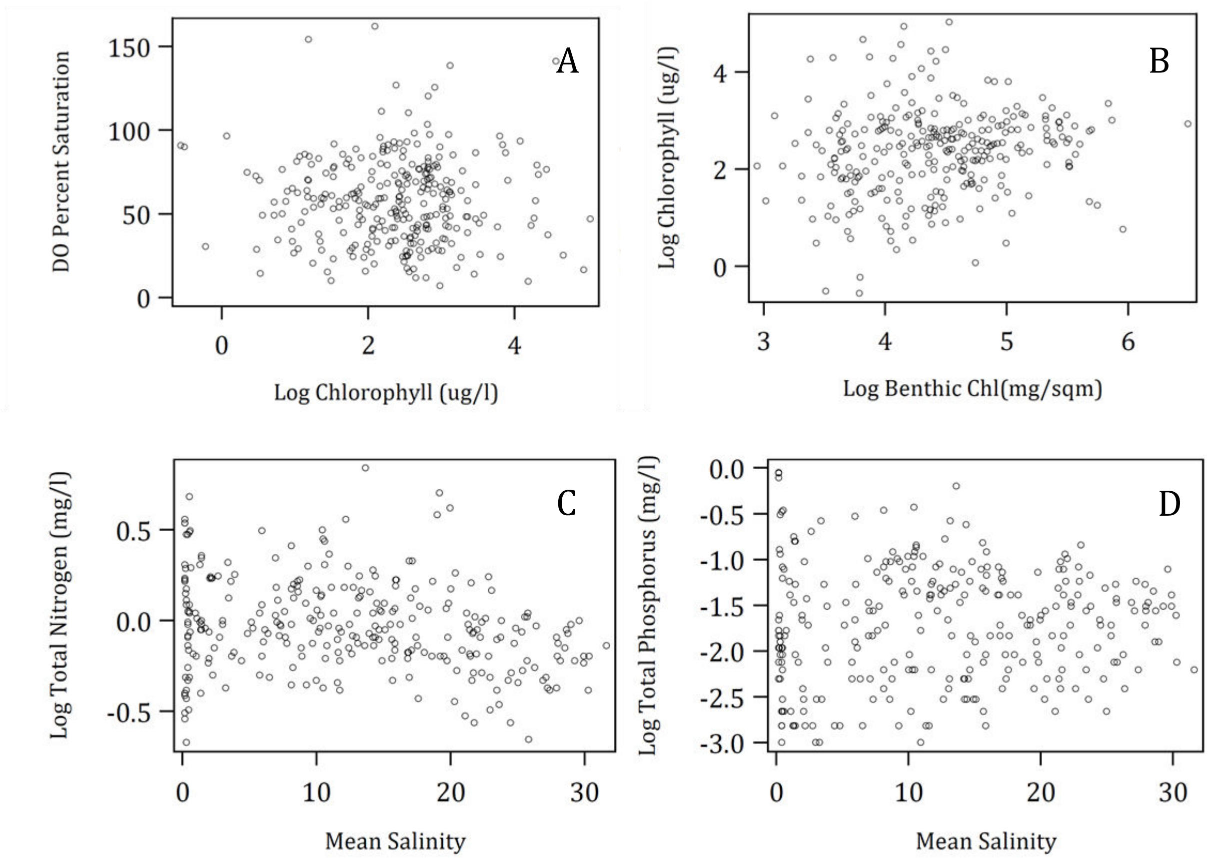


Figure 20. Bivariate relationships that did not conform to the *a priori* conceptual models.

Further, there was no observed relationship between salinity and total nitrogen or total phosphorus, rejecting the conceptual model that the concentration of nutrients follows conservative dilution properties along the tidal creek continuum (Figure 20c and d). Detailed descriptive plots of creek specific bivariate relationships among water quality parameters are provided in Appendix C.

Results of the regression analysis indicated that there was a lack of a single unifying relationship that could be used to define a threshold of impairment for all these systems. Therefore, it is also unlikely that there is a single criterion value that is optimal as a protective threshold for all creeks. Instead, the results suggest that tidal creeks are highly variable environments and that underlying stressor-response relationships are likely to be conditional based on creek specific attributes related to either their instream processes or their landscape attributes, or both. These higher level interactions were explored by developing and evaluating a host of landscape metrics calculated at different spatial scales. To investigate the relationship between water quality response indicators was analyzed as a function of:

- other water quality parameters,
- instream processes,
- riparian buffer vegetation types,
- land use intensity within the buffer and at the "creekshed" level, and
- estimates of the underlying geomorphology and nutrient loadings at the watershed scale.

The following subsection describes the results of using decision tree analysis to identify conditional relationships between water quality responses and creek specific attributes.

4.2 Habitat Interactions

Decision Trees are a class of methods used for data mining and predictive analysis (Rokach and Maimon 2008). Statistically based decision trees have been successfully used to assist in the development of numeric nutrient criteria for lakes in Michigan (Soranno et al., 2008). Conditional inference trees (Hothorn et al., 2006) and ensemble models such as RandomForest (Brieman 2001) are types of decision trees used to identify a set of classifiers that maximize the difference in the response distribution using binary splits of the data. We conducted decision tree analysis using the R software language (R Core Development Team 2012) and specifically using the PARTY (Hothorn et al., 2006) and RandomForest (Brieman 2001) packages in R. These packages recursively partition the response variable into binary splits ("nodes") based on statistical relationships among a host of predictors. The partitioning process iteratively searches for a point in the predictor variable that maximizes the difference in the distribution between two groups of response data. The point in the stressor variable at which the p value is minimized, after adjustment for multiple comparisons, is assigned as the breakpoint defining the split of the response variable into 2 groups. Once the first split is made, the process continues the subsequent nodes conditional on the first split. Hence, the term "conditional inference" or "conditional probability analysis" that has been popularized recently by the EPA as a potential approach for establishing numeric nutrient criteria. This class of decision tree is applicable to all kinds of regression problems, including nominal, ordinal, numeric, censored as well as multivariate response variables and arbitrary measurement scales of the covariates (Rokach and Maimon 2008).

The objective of the analysis was to identify the most influential predictor variables that discriminate the response endpoint under evaluation. An advantage of the conditional inference tree approach is that the routine identifies thresholds indicative of potential nonlinear changes in the response distribution instead of assuming a linear relationship among parameters. Decision tress will also identify a specific threshold value for each significant predictor that corresponds to the change in the response distribution conditional on the previous split. A disadvantage of conditional inference trees is that they are among a group of "weak classifiers" indicating that the results from a single run of the model may not result in a model that serves well as a predictive tool. The random forest implementation of the conditional inference tree is an attempt to overcome this issue by using bootstrap aggregation of 1000's of model runs based on random subsets of the data. An advantage of this approach is its ability to identify the most influential variables that have increased robustness in generalizing to new data. However, the disadvantage of this approach is that the model results are not directly attributable to specific threshold values of the predictor that maximizes the difference between two groups. We used both techniques as exploratory methods to identify conditional relationships among a host of parameters (Table 3) that might inform more formal statistical analysis on stressor-response relationships based on a certain subset of environmental conditions.

Table 3. List of parameters tested using Decision Tree approach.	
Instream Biological Responses	**50m Buffer Attributes**
Water Column Chlorophyll	Landscape Development Index
Benthic Chlorophyll	% Urban
Ratio of Water Column/Benthic Chlorophyll	% Natural
Fish	%Agriculture
Instream Attributes	%Golf Course
USF Bathymetry	USF Canopy Cover Estimates
USF Bottom Hardness	Number of Floral species
USF- # Observed Outfalls	% Exotic Floral Species
Water Quality	**Watershed Attributes**
Dissolved Oxygen (DO)	Nutrient and Hydrologic Loads
Salinity	Hydric Soil Types
Temperature	Elevation
Water Column Chlorophyll Concentration	Landscape Development Index
Turbidity	Impervious Area
Total Nitrogen (TN)	Stormwater Treatment
Ammonia (NH3)	Road Density
Nitrite and Nitrate (NO2+NO3)	Distance to Nearest Pass
Conductivity	Bed Sediment Phosphorus
Total Kjeldahl Nitrogen (TKN)	
Orthophosphate (OPO4)	
Total Phosphorus (TP)	
Colored Dissolved Organic Matter (CDOM)	

An example of a conditional inference tree result using DO saturation as the response variable is provided in Figure 21. The first split of the data occurred based on hydrologic unit area loads. Two creeks with the highest hydrologic loads relative to their watershed size (Bear and Powell Creeks) had the lowest distribution of dissolved oxygen; significantly lower than the remainder of the data. After partitioning these data (far right boxplot in Figure 21) from the remainder of the distribution, the next split occurred based on TN concentrations. Samples that had TN concentrations greater than 0.74 mg/l had a significantly lower average DO than collections with TN concentrations less than 0.74 mg/l.. The final split of the data (Node 4) occurred based on a creek salinity classification metric developed from other analyses. Mesohaline creeks had a lower distribution of DO than the other three types of creeks. Statistical stopping rules prevented further splitting of the DO data though using bottom DO saturation instead of water column average resulted in a further split of the mesohaline creeks based on TN concentrations greater than 0.83 mg/l and then again based on the proportion of natural vegetation (mangroves and marshes) within the 50 meter buffer (100 meter corridor) of the creek (Figure 22).

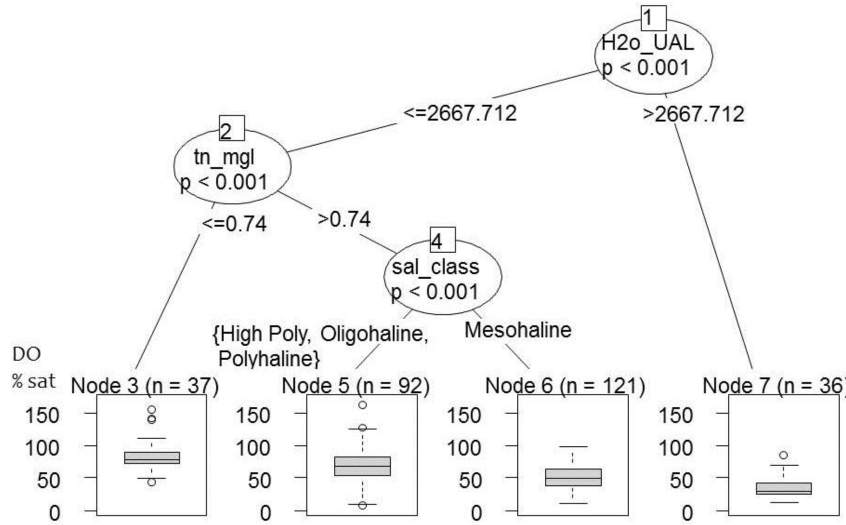


Figure 21. Conditional Inference tree identifying significant predictors and threshold values for creek attributes that are determinant in separating the distribution of water column dissolved oxygen percent saturation (boxplots) into statistically significant separate groups. H2o_UAL = unit area hydrologic load tn_mgl = total nitrogen (mg/l).

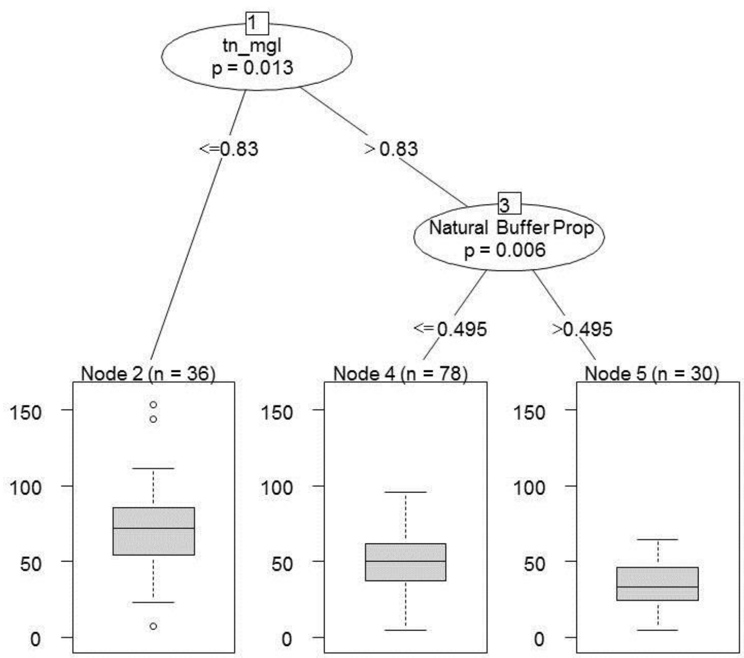


Figure 22. Conditional Inference tree identifying significant predictors and threshold values for creek attributes that are determinant in separating the distribution of bottom dissolved oxygen percent saturation (boxplots) in mesohaline creeks into statistically significant separate groups.

The Random Forest implementation of the decision tree approach was used to identify and summarize which attributes are most influential in segregating the response distribution. The results are informative for identifying parameters that are most deterministic in segregating the response data into distinct groups. For water column average DO (%sat), the most influential attributes were colored dissolved organic matter (CDOM 345), TN, Orthophosphate (OPO4 mg/l), hydrologic unit area loads (H2O_UAL), the proportion of natural vegetation in the creek buffer, and salinity class (Figure 23). These six parameters explained ca. 42% of the total variation in water column dissolved oxygen saturation. Similar analyses were conducted for chlorophyll a, total nitrogen, total phosphorus, benthic chlorophyll, and the ratio of water column and benthic chlorophyll. The results of the random forest analyses for those response endpoints tested are provided in (Table 4). For water column chlorophyll, the most influential parameters included total kjeldahl nitrogen, ammonia, and TN, as well as organic phosphorus, turbidity, and the proportion of natural buffer area in the creek. Total nitrogen was correlated with TP (and sub species OPO4 and OrgP), CDOM, turbidity as well as the proportion of agriculture in the buffer area, acreage of golf course in the watershed, the natural buffer proportion and the number of outfalls in the surveyed portion of the creeks. Total phosphorus was correlated with TN and TKN as well as by the proportion of agriculture in the buffer area, acreage of golf course in the watershed, the natural buffer proportion and the number of outfalls in the surveyed portion of the creeks and had the highest overall proportion of variance explained of any of the response variables evaluated. Benthic chlorophyll was only weakly explained by salinity, OPO4, CDOM, Natural Buffer proportion, creek length, TP and NH3. Finally, the most influential parameters defining differences in the chlorophyll ratio metric included TN and its sub species TKN, NH3, and NO23 as well as turbidity, natural buffer proportion, OPO4, TP and CDOM.

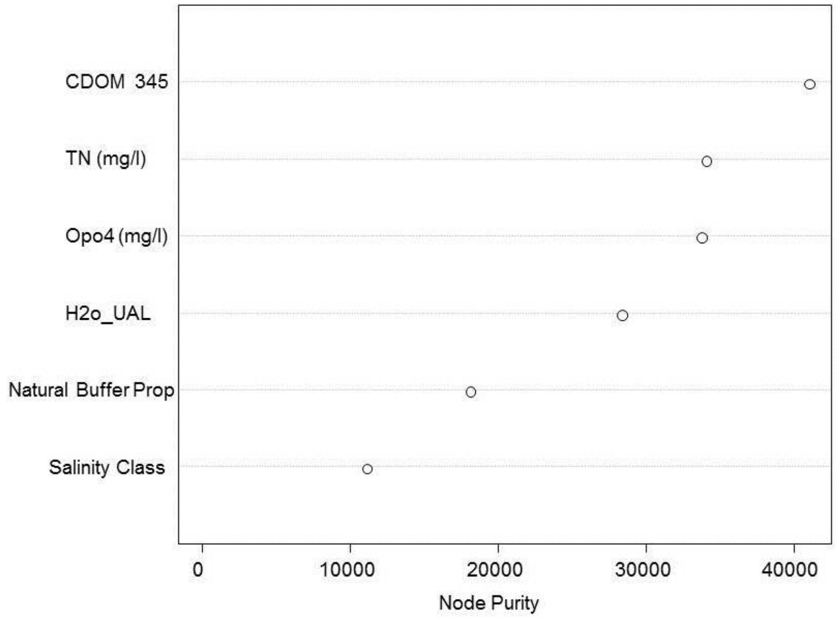


Figure 23. Most influential parameters affecting water column average dissolved oxygen percent saturation based on implementation of Random Forest routine.

Table 4. Results of random forest bootstrap implementation of conditional inference tree. Analysis related the response variable to a set of water quality and habitat metrics in the sampled creeks.		
Response Variable	Predictor	Percent of Variance explained
Water column average (DO % sat)	CDOM 345, TN , OPO4, H2O_UAL, natural buffer proportion, salinity class	42.03%
Water Column Chlorophyll	TKN, TN, NH3, OrgP, Turbidity, natural buffer proportion	46.84%
Total Nitrogen	Creek Length, TP, CDOM, Turbidity, OPO4, OrgP, proportion of agriculture in the buffer, acreage of golf course in the watershed, natural buffer proportion, and the number of outfalls in the surveyed portion of the creek	69.97%
Total Phosphorus	Creek Length, TN, Proportion of agriculture in the buffer, TKN, acreage of golf course in the watershed, natural buffer proportion, and the number of outfalls in the surveyed portion of the creek	84.24%
Benthic Chlorophyll (BMAC)	Salinity, OPO4, CDOM, natural buffer proportion, creek length, TP, and Nh3	20.27%
Chlorophyll Ratio	TKN, TN, Nh3, NO23, turbidity, natural buffer proportion, OPO4, TP, and CDOM	34.05%

Combined, the conditional inference tree analyses suggest that water quality responses in southwest Florida tidal creeks are subject to both natural and anthropogenic influences including nutrient inputs, hydrologic conditions and instream processes related to the influence of the buffer area of the creeks. Agricultural land use types were found to be associated with increased TN and TP concentrations (e.g., Frog and Sugarhouse). Few creeks had any agricultural activity in the watershed and in creeks with agricultural activity there could be other factors in these watersheds that may also contribute to elevated TN and TP concentrations. This should be further investigated. The number of outfalls observed in the surveyed portion of the creeks was also influential segregating the nutrient response data indicating non-point source pollution also affects the distribution of nutrient response in the creeks. Other factors such and the landscape development intensity index were not deterministic in segregating either the nutrient, chlorophyll or DO responses in these creeks though the natural buffer proportion consistently appeared as an influential parameter affecting these distributions. Creeks with a high proportion of natural vegetation in the buffer were associated with lower bottom DO % saturation values which is an important finding supporting the contention that mangrove dominated creeks should be considered wetland environments and evaluated as such in the regulatory context. Chlorophyll concentrations were primarily related to nitrogen inputs, though organic phosphorus was also a correlative factor. Landscape level factors were less influential in identifying thresholds in the water column chlorophyll distributions and the overall percent explained by the model was lower than for the nutrient endpoints. Benthic chlorophyll was only weakly related to the landscape metrics and overall there was a large degree of unexplained variability in the benthic chlorophyll data. Overall, these results suggest that, based on the scale at which we evaluated them, near field effects including instream water quality and riparian buffer attributes were more closely related to water quality responses than landscape level effects. Evaluation of water quality responses to landscape level attributes are more likely to express themselves over longer time scales such as annual geometric averages but this evaluation would require additional data in these tidal creeks.

4.3 Dissolved Oxygen as an Indicator of Adverse Effects

The FDEP did an excellent job of summarizing the science and management issues related to DO effects on biological integrity and the issues associated with using the measure as an indicator of adverse effects in their revised DO criteria document (FDEP 2013a). However, as stated earlier, the data collected as part of this study suggested that the DO criteria as specified in Florida Administrative Code (F.A.C.) were not a reliable indicator of adverse effects in southwest Florida tidal creeks. That is, the conceptual model used by FDEP suggests that increased nutrient loadings result in lower DO concentrations, which in turn result in adverse effects to fish and wildlife was not supported. In FDEP's technical support document, the authors go to great lengths to describe the role of wetlands in depressing DO concentrations and recommending biological confirmation prior to establishing total maximum daily loads based on DO exceedence analysis. The following excerpts from FDEP 2013a summarize that sentiment.

> *Natural estuaries especially subject to low DO include those receiving significant drainage from wetlands or marshes, those in areas surrounded by mangrove forests or tidal marshes, or those estuaries where salinity stratification occurs (Hendrickson et al. 2003)……*
>
> *….When estuaries are minimally disturbed by humans and are characterized by a healthy, well balanced aquatic community, it is critical that natural low DO not be misinterpreted as a response solely to anthropogenically derived nutrients or oxygen demanding substances.*

The revised FDEP DO standards for estuaries were based on experimental laboratory (LC50) experiments (FDEP 2013a). The LC50 denotes the DO concentration where 50% of test organisms expire within a certain period of time (e.g., 1 hour). Recruitment curves were developed to translate the LC50 information based on acute and chronic toxicity values for the four most sensitive Florida species. The four most sensitive species in this case were: *Morone saxatilis*, (striped bass), *Chasmodes bosquianus* (striped blenny), *Dyspanopeus sayi* (Say mud crab), and *Octopus burryi* (Burry's octopus). The final recruitment curve based on these species is provided in Figure 24 copied from FDEP 2013a.

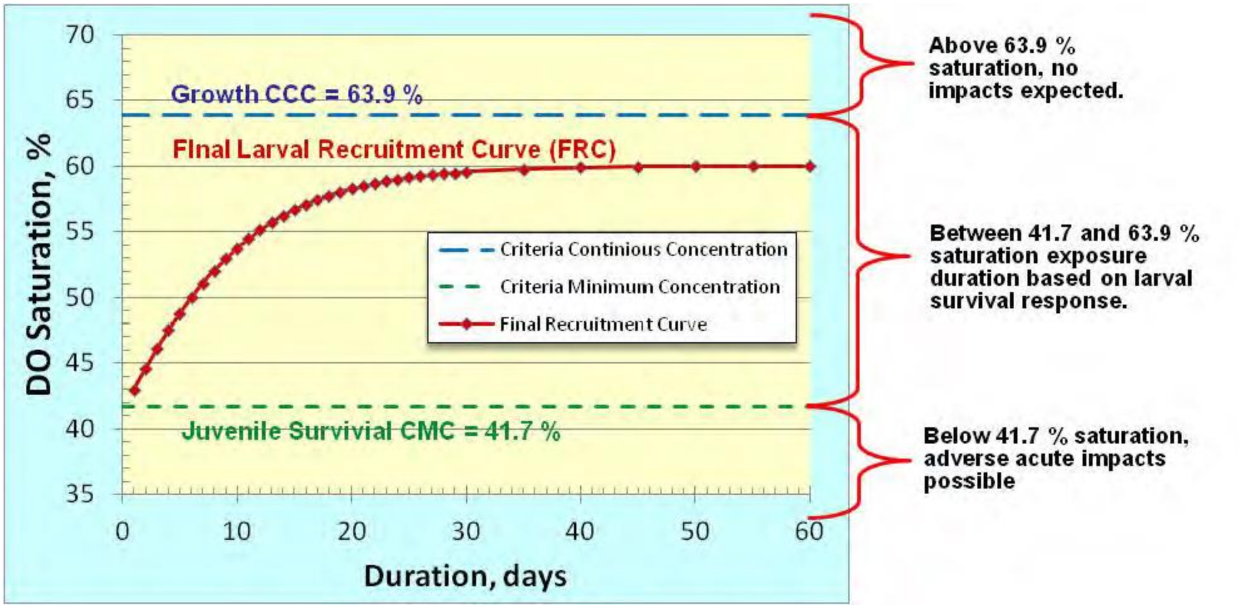


Figure 24. FDEP final recruitment curve used to establish revised marine DO standards (FDEP 2013a).

The final proposed criteria for Class II and III marine waters are expressed as:

- The daily average shall not be below 42% saturation more than 10% of the time
- The weekly and monthly averages of 51% and 56% respectively.

The state accounts for areas that transition between salt and freshwaters, e.g. tidal creeks, depending on the conductivity/salinity at the time the DO was measured. For example, if the DO of waterbody measured within a transitional zone as defined by FDEP, and that water's conductivity is below 4,580 umhos/cm or 2.7 PSU, than the applicable freshwater is applied. Conversely, the marine standard is applied if the conductivity exceeds that threshold. However, none of the four most sensitive species used to develop the final recruitment curve for the marine standard were found in the tidal creeks we sampled and these species are not typically found in any of the southwest Florida open estuary systems sampled by the FIM program. In addition, the fisheries data we collected in the sampled tidal creeks suggest that, despite DO conditions not meeting the current standards, many of these creeks were healthy and productive systems providing nursery and refugia for important fish species such as Snook. Therefore, alternative analyses were pursued to identify potential alternative DO criteria for southwest Florida creeks.

Data on acute DO toxicity (i.e., LC50) provided in Appendix E of FDEP 2013a were subset for species observed in the sampled tidal creeks and used to evaluate potential alternative

DO criteria for tidal creeks under the assumption that the acute threshold values are indicative of conditions that these species would avoid. These species include: *Anchoa mitchilli; Farfantepenaeus duorarum; Gobiosoma bosc; Lagodon rhomboides; Leiostomus xanthurus; Palaemonetes pugio; Sciaenops ocellatus* and *Palaemonetes vulgaris.* Because estuarine dependent species have temporally specific utilization patterns in tidal creek, the concentration based LC50 acute values were converted to percent saturation values based on the average temperature and salinity of each creek for the month sampled and a weighted average of all species was then calculated based on the probability of occurrence for each species each month. The results are presented in Figure 25 with spline smoothing curves used to display the creek specific response. Because the LC50 experiments are concentration based, the required percent saturation necessary to maintain a specific percent saturation changes as a function of temperature and salinity. Using the highest percent saturation of any month (i.e., July) two potential alternative criteria would be ca. 23% using Forked Creek which was the most sensitive of all creek curves, or ca. 20% if the average of all creeks for the most sensitive month were used. If only considering the most sensitive species, (*Anchoa mitchilli*), using the LC50 value of 2.1 mg/l, the results are displayed in Figure 26 and indicate that potential values would be ca. 31% if using the most sensitive creek, and ca. 27% using the average of all creeks. Using the 31% value and the 10% criterion would resolve the exceedence rate for 6 additional creeks; however, even the most lenient of these criteria (i.e. 20%) would result in exceedences for the three creeks with the most undeveloped watersheds in our study (Table 5). The combined results of these analyses to derive potential alternative site-specific DO criteria suggest that while it

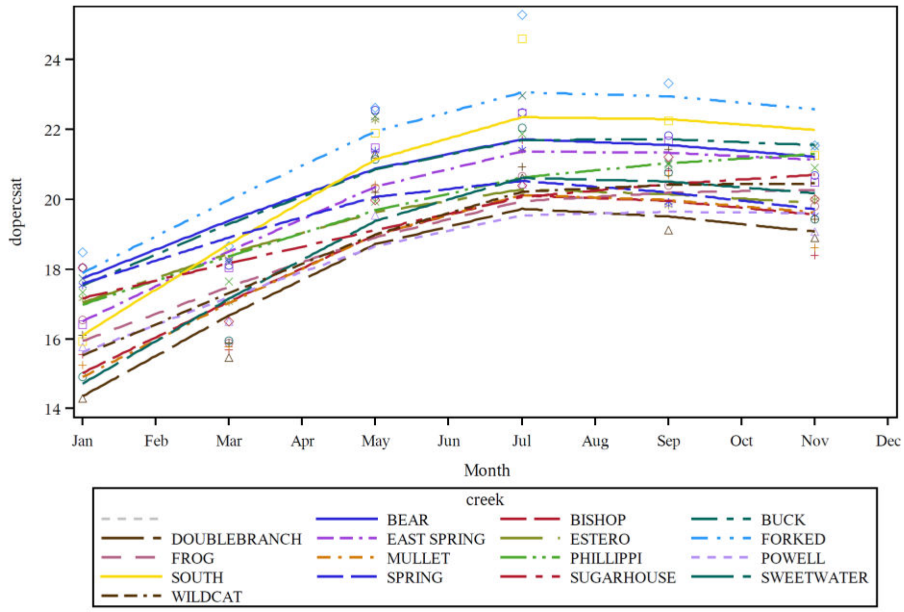


Figure 25. Results of alternative analysis to derive a site-specific DO standard for southwest Florida tidal creeks using LC50 values for several species observed during the study that were listed in FDEP 2013a Appendix E.

is possible to derive locally specific alternative standards for tidal creeks, if compliance with those criteria is forced to rely on the 10% exceedence rate, alternative standards would not ameliorate the issues associated with compliance with the current standards. Therefore, it is recommended that alternative distributional cutpoints for identifying exceedence rate thresholds be considered that are not associated with the tails of the DO distribution.

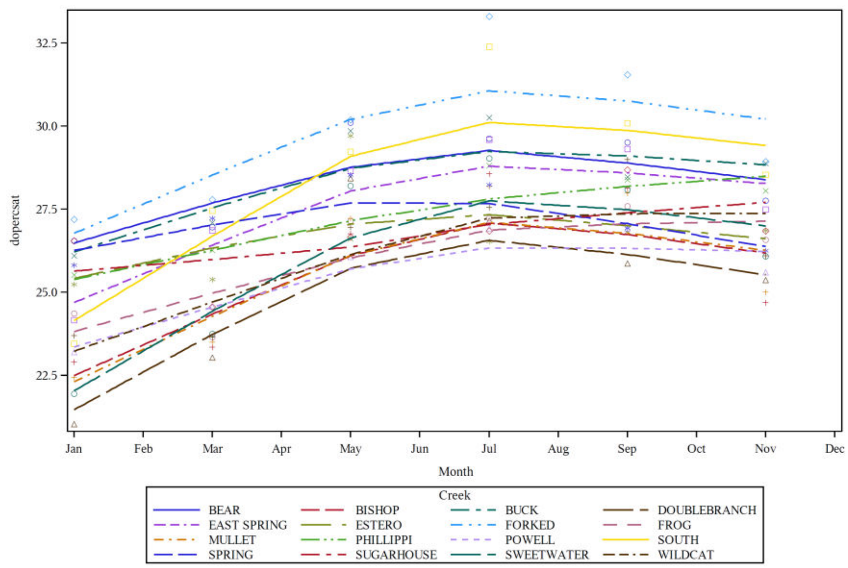


Figure 26. Results of alternative analysis to derive a site specific DO standard for southwest Florida tidal creeks using the LC50 value of 2.1 mg/l for *Anchoa Mitchilli*.

Table 5. Distributional statistics for water column average DO percent saturation with the 10th percentile highlighted indicating the values relative to that used to evaluate compliance with current DO standards in estuaries. * indicates creeks with most undeveloped watersheds.

Creek	p10	p25	p90	p100
Bear *	14.0	25.4	115.0	119.0
Bishop	28.5	52.0	92.0	155.0
Buck *	16.3	30.0	104.0	153.0
Doublebranch	57.5	59.8	95.0	97.7
East Spring	57.0	67.8	93.8	104.1
Estero	34.2	40.9	97.0	142.0
Forked	42.0	55.0	126.3	162.8
Frog	40.3	42.5	78.0	93.0
Mullet	24.0	32.3	64.3	80.0
Phillippi	41.6	49.2	89.0	111.9
Powell	24.8	28.0	52.5	84.5
South *	17.5	48.4	87.3	100.0
Spring *	21.5	27.5	84.0	93.0
Sugarhouse	40.0	46.0	79.5	83.0
Sweetwater	36.1	49.0	101.0	120.0
Wildcat	39.0	53.4	91.8	93.8

As an additional line of evidence in relating DO to fish communities we evaluated long term fisheries monitoring data collected by the Florida Fish and Wildlife Conservation Commission's Fisheries Independent Monitoring (FIM) program which has been collecting fish and *in situ* field chemistry data (including DO) in larger tidal rivers in Tampa Bay for over 15 years. For example, in Figure 27 Margalef's species richness index was plotted as a function of binned DO percent saturation midpoints for boat set seines collected in the larger Tampa Bay tidal rivers. The boat set seine is a similar gear type to the raft seines used to sample tidal creek shorelines. A horizontal line is provided in this panel of plots at a value 2.5 as a reference point. While data collected using the trawl gear used to sample bottom waters in the channel of these systems was more responsive to DO, there was little evidence to suggest that any of the diversity metrics calculated for the boat set seine gear in this long term database were adversely impacted by low DO conditions for data collected. Plots for both gear types and all diversity metrics are provided in Appendix D. While no nutrient data were associated with these fish collections, the data were also sufficient to evaluate the probability of occurrence of several individual fish species collected in this study as a

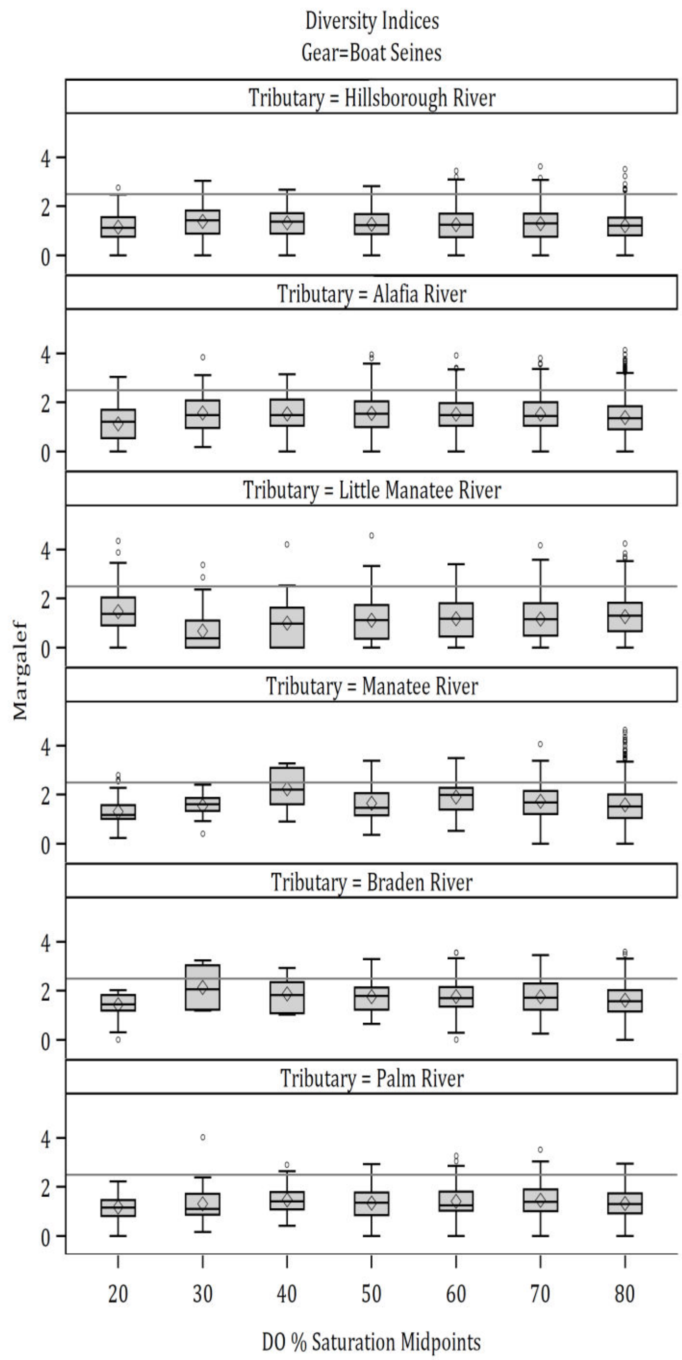


Figure 27. Distribution of Margalef's species richness by DO percent saturation category in larger Tampa Bay tidal rivers. Data were collected independent of this study and were provided upon request.

function of DO concentrations (and DO % saturation). To identify a potential threshold indicative of an adverse effect, we investigated the relationship between DO and fish probability of occurrence in this long term database.

Individual species response to DO in the long term FIM database was evaluated using logistic regression (Proc Logistic: SAS Institute, 2014) for the species used in the acute toxicity experiments described above as well as for Snook. Logistic regression estimates the probability of occurrence of a specific binary response (e.g., the presence of a particular fish taxon) as a function of either categorical or continuous predictors. We evaluated these relationships using DO as both a continuous and categorical explanatory variable in separate analysis. For the categorical analysis, DO categories were derived by binning DO concentrations in 1 mg/l increments between 2 and 8 mg/l rounded to the nearest integer value. Similarly, we binned DO % saturation values in 10 % increments between 20 and 80% saturation. Any values above the maximum category were included in the maximum category and any values below the minimum (i.e. 25%) were included in the minimum category. The lowest category was used as the reference group for each analysis such that the odds of occurrence were evaluated relative to the lowest category (i.e. the odds ratio). For each fish taxa, months were eliminated from the analysis if no fish were ever captured in that month and river. Additionally, a seasonal term was added to the model in an attempt to account for seasonal differences in the probability of occurrence. The seasonal levels were defined as Summer (April – September) and Winter (October – March) with summer used as the reference group for the comparison.

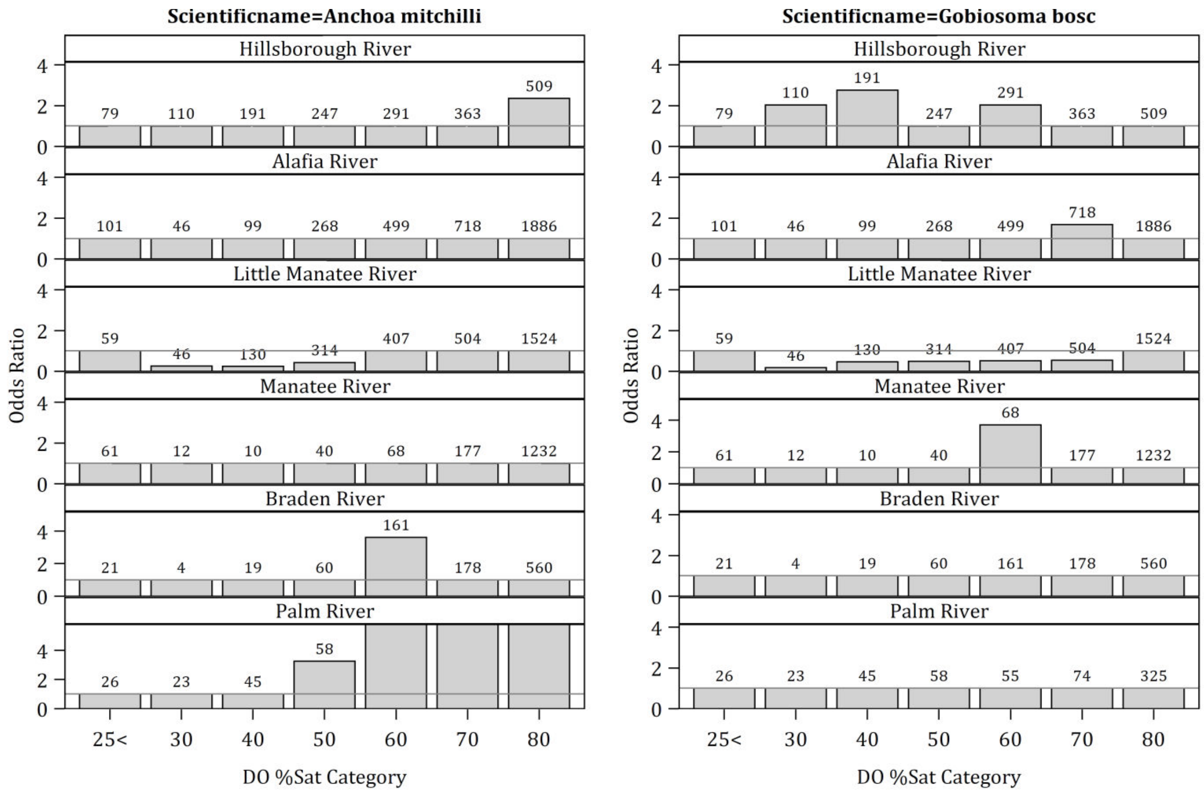


Figure 28. Results of logistic regression predicting the probability of occurrence of Bay Anchovy (left) and Naked Goby (right) based on DO percent saturation categories in Tampa Bay tidal rivers.

The results of the logistic regression analysis are summarized using bar graphs of the odds ratio estimates relative to the reference group (i.e. samples collected when DO %sat was less than 25%).In the bar graphs, values of 1 represent equal (non-significant) likelihood relative to the reference group. Values less than one indicate that the likelihood of capture significantly decreased relative to the reference group, while values greater than one indicate that the likelihood of occurrence increase relative to the reference group. It is important to note that the odds ratio is asymmetric around the value of 1 so bars below 1 appear to be smaller differences but are not necessarily. The numbers plotted above each bar represent the number of observations for each group. Figure 28 displays the results for *Anchoa Mitchilli* and *Gobiosoma Bosc*, two commonly collected species that occur year round in Tampa Bay Rivers. The results were highly system dependent for these two species (and for all other species tested) with no effect in some rivers, protective effects in others and antagonistic effects of low DO in other systems. For example, in the Little Manatee River which is the most natural river system of all of the rivers evaluated, both Bay Anchovy and the Naked Goby responded negatively to increased DO category relative to the reference group, while in other systems there were no significant effects. In the case of Bay Anchovy in the Palm River (a highly physically altered system), a significant increase in probability of occurrence as a function of DO above 45% relative to the reference category was observed. For Snook, there were indications that increased DO values would increase the probability of capture relative to a DO saturation value of 25% in some rivers (e.g., Alafia River results in Figure 29a) but in other rivers there was not a statistically significant effect. For Red Drum in the Alafia River, the likelihood of capture was significantly reduced at DO values above 25% (Figure 29b) while for most other rivers there was not a significant relationship. Plots for other species evaluated are provided in Appendix E. Together, these results suggest that while DO was significantly related to the probability of occurrence in some cases, there was no unified response to DO in these systems. Rather, the response was conditional and likely mediated by other factors such as the relationship between static habitat factors and dynamic water quality attributes as described by Browder and Moore 1981.

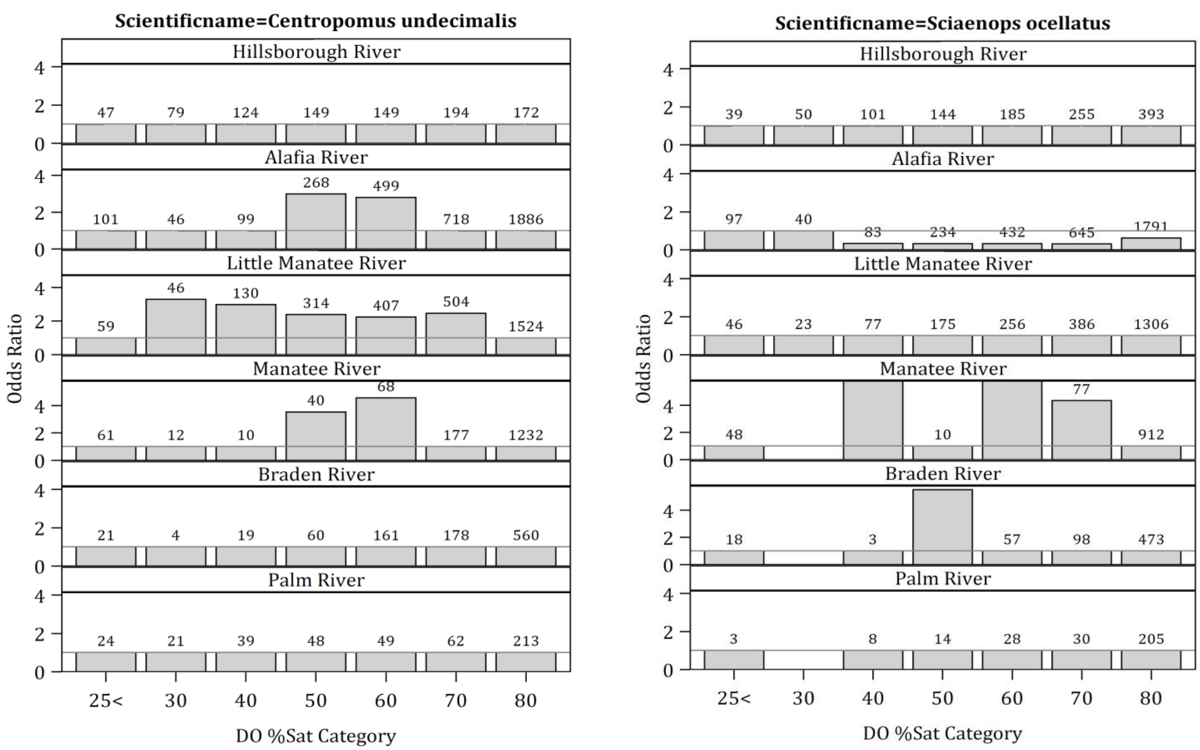


Figure 29. Results of logistic regression predicting the probability of occurrence of Common Snook (left and Red Drum (right) based on DO percent saturation categories in Tampa Bay Tidal Rivers.

In summary, we suggest that the experimental evidence used to develop Florida's marine DO standards should be observable in the empirical data in order to be appropriate for the systems to which they are applied. The combined results of the analysis of DO and fish response suggest limited and inconsistent evidence that, in evaluating observational data, DO is an reliable indicator of adverse effects for fish communities in southwest Florida tidal creeks. While the seining method may not capture the deepest portion of the creek, it does sample the entire water column (unlike trawl gear) and is the most effective method to sample fish communities in tidal creeks. Therefore, while the DO standards may be satisfactory for open bay estuarine environments, the estuarine criterion is not recommended as a mechanism for evaluating adverse effects in southwest Florida tidal creeks without biological confirmation. We recommend that alternative formulations of the DO standard be considered if DO is to be used as a water quality standard for southwest Florida tidal creeks. The alternative formulations should in particular include a statistic representative of something other than the tail of the DO distribution (i.e., the 10^{th} percentile). Additional studies are likely required to derive alternative standards for DO in southwest Florida tidal creeks but the results presented within should provide additional insights useful towards that effort.

4.4 Nutrients as a Conservative Substance

One of the most significant findings of this study was that the nutrient concentrations in the tidal portions of these creeks were generally higher than expected based on dilution of the source water by mixing with estuarine waters and in some cases could be in excess of the source water concentrations. This finding is counter to the EPA/FDEP considered method for establishing downstream protection values for tidal creeks based on the dilution curve method (EPA 2012) and provides insights into the potential instream processes that may contribute to this result. The sampling design for this study was constructed, in part, to specifically test whether nutrients acted as conservative substances in tidal creeks. By collecting water quality samples at the upstream source water station and in the downstream tidal portions of the creek on the same date (generally within a four hour window) the observed source water concentration was assumed to be representative of the expected influence of the source water on tidal creek concentrations. Using a modification of the freshwater fraction equation (Sheldon and Alber, 2006), we calculated the expected concentration of nutrients in the tidal portion of the creek as a function of the source water concentration and the proportion of salinity relative to full strength seawater (i.e., 35‰) as a boundary condition. The expected nutrient concentration is:

$$En_c = n_f * (1 - (Sal_c / 35))$$

where:

En_c = Expected nutrient concentration at site c in tidal creek

n_f = Nutrient concentration at source water site

Sal_c = Salinity at site c in tidal creek

The equation allows for the computation of an expected nutrient concentration at any sample location within the creek and comparison of the expected concentration to the observed concentration as the sample location. This comparison was used to identify the behavior of nutrients in the tidal portions in the creek over various temporal and spatial scales. For example, the results of the mixing curve analysis for organic nitrogen in Mullet Creek is provided in Figure 30a. For each sample date, the observed concentrations are plotted along with that expected based on dilution (solid line). The upstream stratum was always freshwater as indicated by the line touching the open circle in the plot. However, for sample locations downstream in the tidal portion of the creek the nutrient concentrations tended to be higher than expected based on dilution, especially in May, July and September. Notice also that in March the entire tidal portion of the creek was freshwater as indicted by the mixing curve line being completely flat throughout the study area. Results for colored dissolved organic matter (CDOM) for Mullet Creek are presented in Figure 30b. CDOM is expected to generally be a more conservative substance in tidal creeks though wetland vegetation in the tidal portion of the creeks can contribute CDOM to the system.

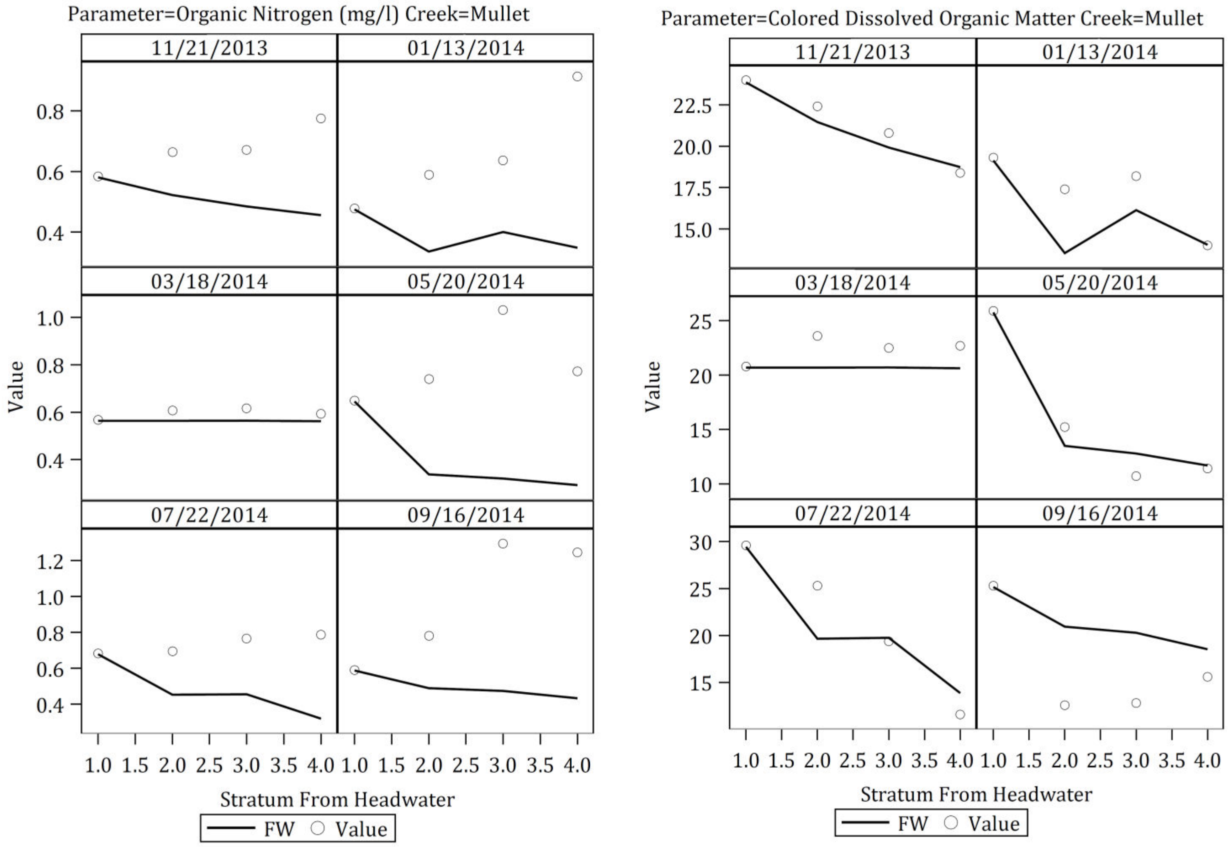


Figure 30. Mixing curve results for organic nitrogen (left) and colored dissolved organic matter (right) in Mullet Creek. Line (FW) represents expected concentration based on fresh water concentration and downstream salinity. Open circle represents the observed concentration within the tidal portion of the creek.

The results suggest that CDOM acted in a more conservative manner for most sampling events though in January higher than expected concentrations were observed and lower than expected concentrations were observed in September. This analysis was conducted for all creeks and all nutrient parameters including: organic nitrogen, organic phosphorus, CDOM, nitrate-nitrite, orthophosphate, total nitrogen, total phosphorus, and ammonia. The results suggested addition in the estuarine portion of the creek. For example, the differences between the observed and expected nutrient concentrations (both total nitrogen and total phosphorus) were mostly positive in all creeks with the exception of TP in Wildcat and Powell Creeks (Figure 31). Plots of the results for all relevant parameters are provided in Appendix F.

The sources of the nutrients in the estuarine portion of the creek may be either from natural or anthropogenic sources. Potential explanations worthy of further investigation include:

- Stormwater runoff that can contribute nutrients to the tidal portions of the systems. The nutrients in stormwater may be derived from multiple sources; however, it seems reasonable to assume that stormwater will only increase the concentrations delivered to the tidal portions the creek are substantially higher than the concentration of stormwater runoff from the contributing source water.

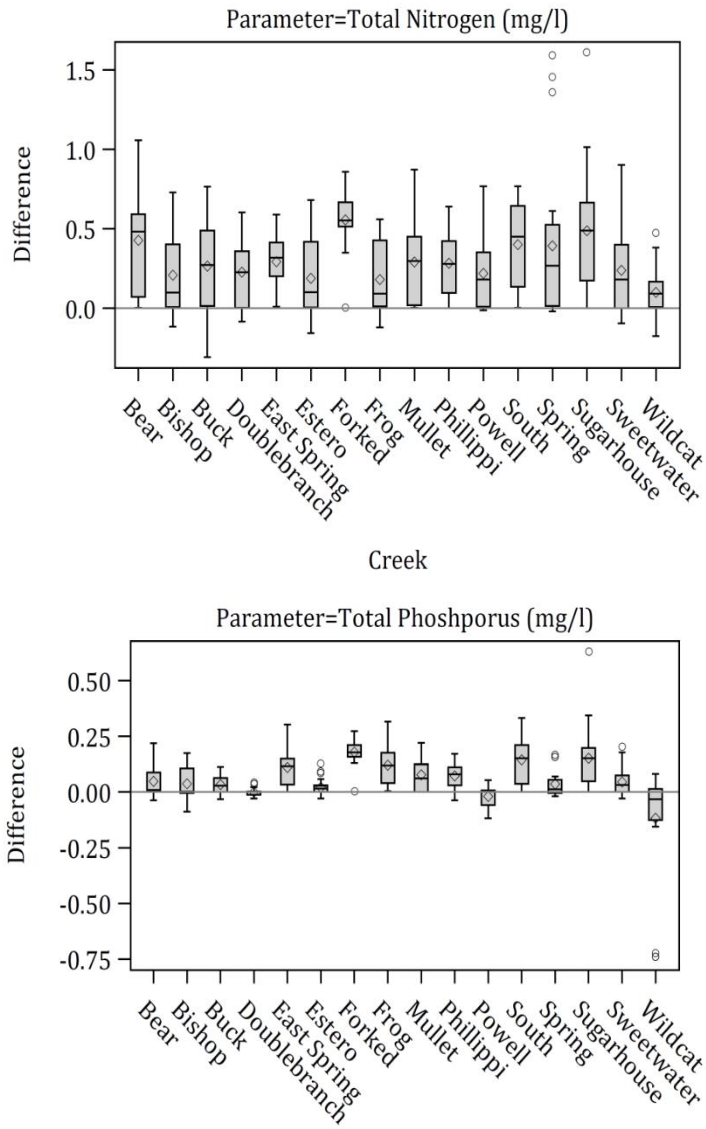


Figure 31. Distribution of differences between observed and expected concentrations of total nitrogen (top) and total phosphorus (bottom) for the 16 tidal creeks sampled in southwest Florida.

- The contribution of septic tank effluent to the tidal portion of the creeks. The relative contribution remains unknown though it is thought that the majority of these creek watersheds have been converted to central sewer systems and septic effluent is not generally believed to be the cause of the differences observed across all these creeks.

- Decomposition of organic material in both particulate and dissolved forms that settle into the tidal portion of the creek can release nutrients back into the tidal portions of the creeks.

- Natural wetland vegetation in the tidal portion of the creek can contribute nutrients to the system through sequestration and subsequent outwelling of organic material within the creek (Wolanski 2007).

While the exact source of nutrient contribution remains unknown, these findings represent an important contribution to the understanding of tidal creek processes that should be considered in establishing regulatory nutrient thresholds for these systems. This is further discussed in Chapter 8.

4.5 Fish Communities and Nutrients

The analysis of fish data described above concentrated on describing the effects of dissolved oxygen on the probability of occurrence for a host of fish species collected both in this tidal creeks study as well as in long term datasets collected in larger tidal rivers within the study area. The results suggested that the dissolved oxygen concentrations (or percent saturation) as currently specified were an unreliable indicator of the potential adverse effects on fish probability of occurrence in these systems. The analysis described in this section reports on the relationship of nutrients as a direct effect on individual fish species, species diversity, and fish community structure. Exotic (i.e., non-native) species were removed from the dataset prior to analysis. The Fish species diversity metrics evaluated included: Shannon Weiner Diversity (H'); Margalef's Species Richness (D); Pielou's Evenness (J'); the number of taxa, and the total number of individuals captured (Zar, 1984). Creek based ranks for these indices are provided in Table 6. Bear, Spring, and Powell Creeks had the lowest median diversity measures of the creeks sampled and while their DO concentrations were low, their nutrient concentrations were not elevated compared to some of the more productive creeks (e.g., Frog, Phillippi, Sugarhouse, and Wildcat).

Table 6. Creek ranks for median fish diversity statistics from data collected in the estuarine portion of the creeks. Higher Ranks equals lower Diversity statistics indicating potentially lower biological diversity or integrity.

Creek	Ranks Based on Median Values					
	Margalef's Species Richness	Pielou's Evenness	Shannon Weiner Diversity	Number of Individuals	Number of Species	Average Rank
Phillippi	3	5	1	5	1	3
Sugarhouse	1	2	4	9	3	3.8
Wildcat	5	4	2	6	3	4
South	4	9	5	3	1	4.4
Frog	2	1	3	12	6	4.8
Doublebranch	8	12	10	2	6	7.6
East Spring	10	13	11	1	3	7.6
Bishop	6	3	7	13	10	7.8
Sweetwater	7	8	8	7	9	7.8
Estero	9	7	6	8	10	8
Forked	11	14	12	4	6	9.4
Mullet	12	6	9	11	10	9.6
Buck	14	11	13	10	13	12.2
Powell	13	10	14	15	14	13.2
Spring	15	15	15	14	14	14.6
Bear	16	16	16	16	16	16

To examine the relationship between nutrients and the species diversity metrics, plots were constructed using the tidal creek nutrient geometric averages (i.e., TN and TP). The plots were oriented such that the creeks were arranged in increasing order of nutrient concentration. The median diversity metric for the creeks was then overlaid on the plots. The results suggested that creeks with the highest nutrient concentrations also tended to have the highest fish species diversity and supported multiple life history stages of Snook. Total Phosphorus concentrations were somewhat positively correlated with increases in the median number of species captured, Shannon Weiner Diversity, Pielou's Evenness, and Margalef's Species Richness (**Error! Reference source not found.**) and was not negatively ssociated with any species diversity metric. The same species diversity metrics were not either positively or negatively correlated with TN concentrations though the highest median values of Margalef' and Pielou's were observed at the highest TN concentrations. Only in the case of the median total number of individuals of all species captured was there any indication of a negative response to increasing nutrients and that was due to a single sampling event with abnormally large catch in East Spring Creek. However, it is important not to misconstrue these findings to suggest that increased nutrients necessarily result in increased fish production. This is not the inference suggested from this analysis. Rather, the results suggest that the nutrient concentrations observed in these creeks does not appear to be at levels that have resulted in adverse effects. There were indications that the more labile forms of nitrogen (nitrite, nitrate, and ammonia) were in excess the creeks with the highest overall nutrient concentrations.

These results support the conceptual model described by EPA in their technical guidance manual for developing nutrient criteria for estuaries (Figure 32: EPA 2001). This figure describes increased fisheries yield as a function of increased nutrient loading to the estuary to a point where over-enrichment can result in dystrophic conditions and a loss of fisheries production. That TP was more strongly correlated with increasing species diversity metrics was an interesting finding. The estuarine portions of these systems are thought to be principally nitrogen limited and the lines of evidence pursued with respect to factors influencing water column chlorophyll above support this contention. However, riparian wetland vegetation such as mangroves and marshes, as well as other vascular plants that provide habitat for fish species may be promoted by the elevated levels of phosphorus in these systems. This sets up a complex dynamic when attempting to evaluate the potential adverse effects of nutrients on the system since the habitat provide mediating

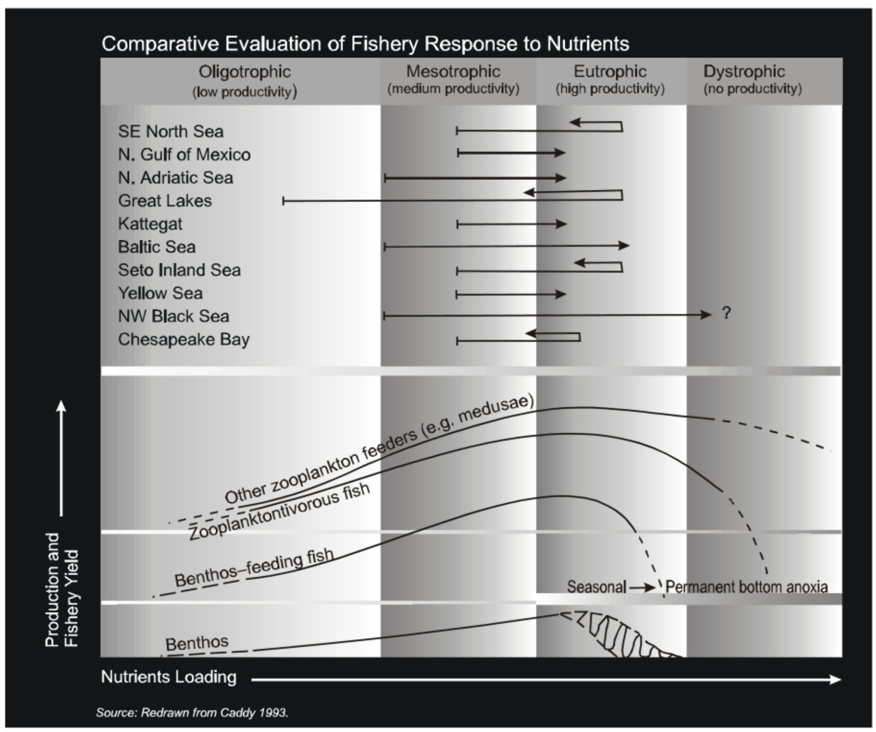


Figure 32. Comparative evaluation of fishery response to nutrients. Each generic curve in the lower half of the figure represents the reaction of a species guild to increasing nutrient supplies. Source: EPA 2001

effect of elevated nutrients. That is, the increased habitat availability may offset some of the potential deleterious effects of nutrients for estuarine dependent fishes.

Multivariate analyses were conducted using Primer V6 (Clark and Gorley, 2006), a multivariate analysis package commonly used to evaluate fish communities in southwest Florida (Krebs et. al. ,2007, Greenwood et. al., 2008, TTHI, 2008, Sherwood, 2010, MacDonald et al., 2010). The Primer software package analytical tools include; Hierarchical agglomerative clustering (CLUSTER),Similarity Percentage Analysis (SIMPROF), rank correlation methods (e.g. BioEnv), and Analysis of Similarity (ANOSIM), a non-parametric test analogous to analysis of variance (Clark 1993). Prior to analysis, the fish catch data were forth root transformed and a Bray-Curtis similarity resemblance was generated for the 36 most abundant taxa. Likewise, water quality data were normalized and a resemblance matrix calculated based Euclidean distance (Clark and Gorley 2006). The R value (which ranges between 0 and 1) was reported for all statistically significant findings. The objective of the multivariate analysis was to identify factors affecting the multivariate distribution of fish community structure, including both habitat and water quality.

The results of multivariate analysis suggested that there were significant differences in both water quality and fish species composition among creeks based on the SIMPROF test (Figure 33). The first group (a) included Frog and Sugarhouse Creeks which were more similar to one another in terms of water quality than to any other creek. As stated earlier, these creeks tended to have the highest nutrient concentrations and also the highest species diversity of any creeks sampled. A second group of creeks including Doublebranch and Wildcat Creeks were the lower salinity creeks in Hillsborough County but water quality factors contributing most to the differences between these groups were OPO4, TP, NO23, NH3 and TN which together contributed to 67% of the total difference between groups. All of these parameters were higher in magnitude on average in Frog and Sugarhouse relative to Doublebranch and Wildcat. Otherwise, the creeks grouped seemingly based on geographic location with the exception of Phillippi Creek in Sarasota County which grouped most closely with three creeks in Old Tampa Bay, and Bear Creek which was most similar in terms of water quality to South Creek.

The Fish SIMPROF test also resulted in significant differences among creeks with Frog and Sugarhouse again grouping more similar to one another than to other creeks; however, fish species composition in these creeks was not statistically different from a larger group of creeks represented by all counties in the study area. Mullet and Bishop Creeks were most similar to one another in fish species composition and grouped with two other groups all located in Old Tampa Bay. Bear, Powell, and Spring Creeks formed the last group which was most dissimilar to the remaining creeks. This group had the lowest overall diversity measures and the fish species most representative of this group were the Eastern mosquitofish (*Gambusia affinis),* small Mojarra's (*Eucinostomus spp*.) and Silversides (*Menidia spp*.) and well as Tilapia.

The BioEnv procedure was used to correlate the fish community structure with water quality. For this analysis the field chemistry data (e.g. DO , salinity, etc.) were separated from the nutrients and chlorophyll data. The nutrient matrix (which including nutrients, water column chlorophyll, benthic chlorophyll, and sediment quality) was not statistically correlated with fish community structure indicating that these parameters were not deterministic in separating fish community structure (P=0.14). The field chemistry data were more directly related to differences in fish species composition but the relationship was weak (Rho=0.19: P=0.01) on the individual sample scale and potentially confounded by seasonal differences in fish community structure that correlated with changes in water quality parameters including temperature, salinity, and dissolved oxygen concentrations.

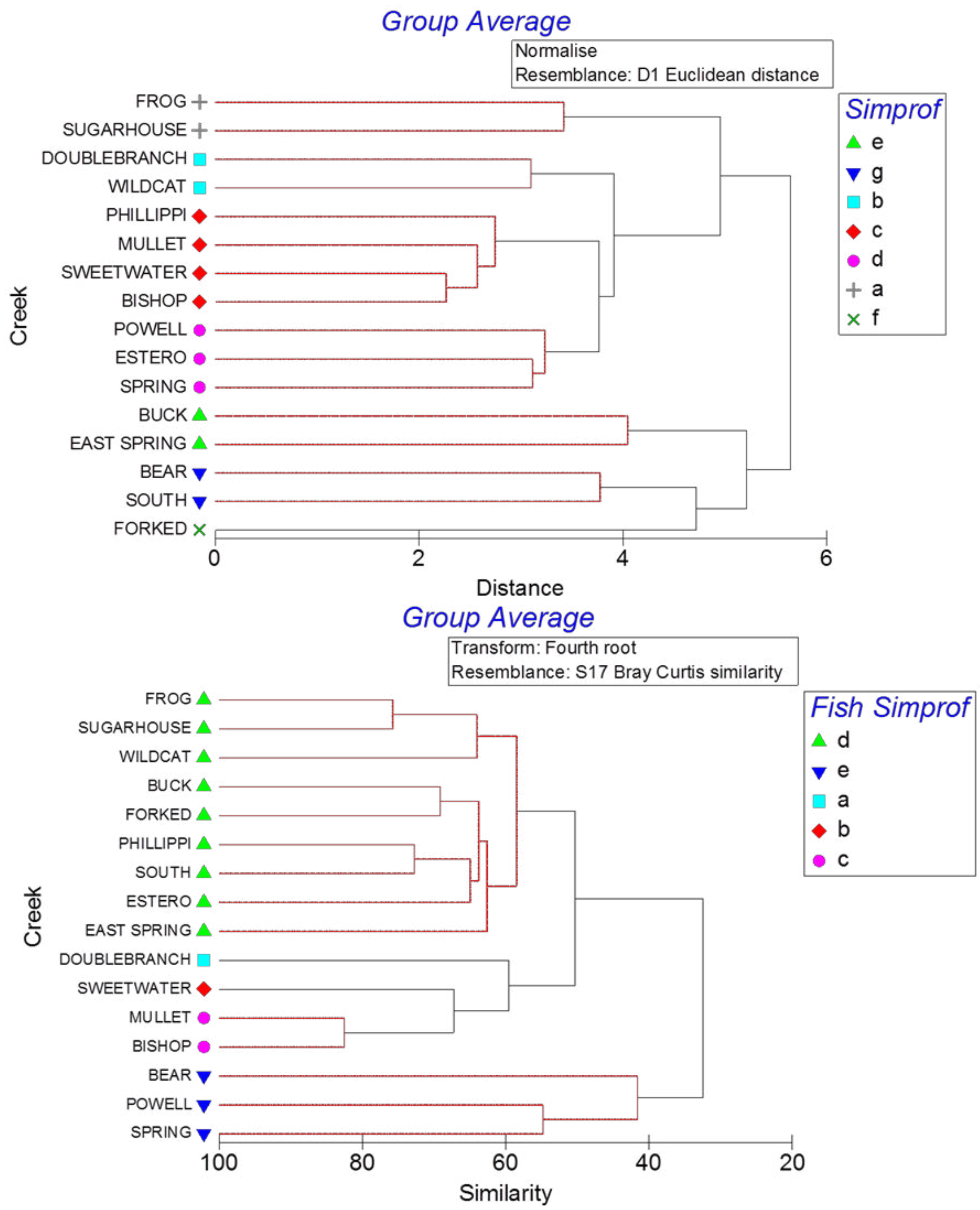


Figure 33. Results of hierarchical cluster analysis for creek average water quality (top) and fish community structure (bottom).

On the annual time scale (i.e. averaging the water quality and fish composition data by creek across all samples), the nutrient data were also not correlated with changes in fish composition but the field chemistry data were more indicative of differences in fish composition with average temperature and DO differences significantly correlated with fish community structure.

The combined results of the fish community analysis suggested that neither the species diversity indices nor the multivariate fish community structure were negatively affected by increasing nutrient concentrations at the concentrations we observed during our study. While there were significant differences in community structure among the creeks sampled, the differences were more related to geographic location within the estuary and were only weakly correlated with salinity and DO. These results indicate the highly conditional nature of fish community response to changes in environmental condition and its resilience in coping with the highly variable environments of tidal creeks. As described by Browder and Moore (1981), the response of fish communities to changes in environmental condition depends on the overlap of static and dynamic habitat attributes and the choice between staying in a preferential habitat and dealing with changes in environmental condition (e.g., changing salinity), or leaving the static habitat to occupy preferential dynamic environmental gradients. These results infer that static habitats may be more important in determining species occupancy in tidal creeks given the widely varying and rapidly changing environmental condition of those creeks.

Chapter 5. Analytical Summary and the Reference-Based Approach

The following sections summarize the analysis of Chapter 4 and provide the basis for the reference-based approach used to derive the nutrient management framework proposed for southwest Florida tidal creeks.

5.1 Analytical Summary

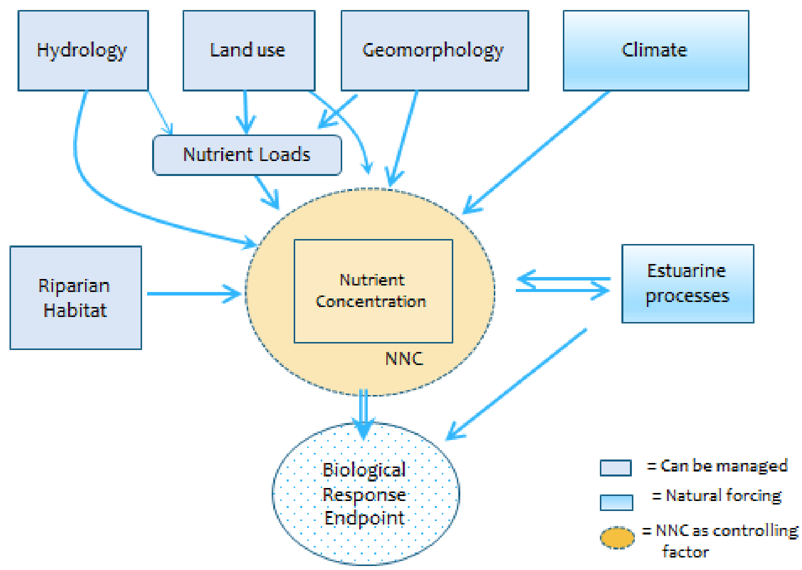


Figure 34. Conceptual watershed management model for southwest Florida tidal creeks.

The lines of evidence we pursued to develop a stressor-response based approach to establish nutrient targets and thresholds for southwest Florida tidal creeks provided valuable insights into tidal creek processes and the principal contributing factors that influence the interactions among landscape level stressors, instream processes and biological responses in these systems. It is important to remember that nutrients are only one type of stressor that can impact tidal creek condition. As described by the conceptual watershed management model developed for this project (Figure 34), hydrologic alterations, riparian habitat and estuarine processes can also influence fish community structure independent of anthropogenic nutrient inputs. Much of southwest Florida has been hydrologically altered for coastal development and quantifying those effects were outside the scope of this project. The data collected in this study suggest a weight of evidence that protective criteria can be developed as part of a larger management framework for tidal creeks that provides both targets that serve as numeric interpretations of a stewardship goal for the desired condition of tidal creeks and threshold values that define the protective limits above which the likelihood of adverse effects on tidal creek productivity increases. The principal outcomes of the analysis suggested that:

- The tidal creeks sampled during this study have not yet reached a dystrophic level due to nutrient over-enrichment though there were significant differences in the fish catch among the creeks.

- There was no single unifying relationship that described the effects of nutrients on biological integrity for all these creeks.

- Nutrient concentrations along the salinity gradient did not follow conservative mixing principles in such a way that a dilution curve approach could be used to establish creek criteria.

- Nutrient concentrations in the tidal portion of the creeks were a function of landscape level anthropogenic stressors as well as riparian buffer habitats including potential nutrient addition from wetland vegetation, allochthonous material, and instream processes related to the decomposition of organic matter, with considerable interaction among these attributes.

- There was no observed relationship between water column chlorophyll and dissolved oxygen concentrations in these creeks that could be used to define a chlorophyll threshold concentration indicative of adverse effects.

- The current FDEP DO standard for estuaries was an unreliable indicator of biological integrity of southwest Florida tidal creeks as measured in this study.

- An alternative formulation of the DO criterion is possible but should be constructed around something other than the tail of the distribution (i.e. the 10^{th} percentile).

- The relationship between DO and fish probability of occurrence is likely to involve a more complex interaction between dynamic water quality conditions and instream habitat conditions, coupled with seasonally dependent recruitment processes for individual estuarine dependent fish species.

Given the complexity observed in the biological response to nutrients, including the observed high order interactions among stressors, there was no single unifying relationship that could be identified to develop stressor-response based criteria. Therefore, a reference-based approach was used to identify the recommended nutrient thresholds for southwest Florida tidal creeks. The following paragraphs describe the rationale used to derive the recommended nutrient targets and thresholds and draw parallels to the process used by FDEP/EPA to develop the NNC for Florida freshwater streams.

5.2 The Reference-Based Approach

The FDEP/EPA used the reference-based approach for deriving instream protective TN and TP criteria for Florida freshwater streams (EPA 2010). While modest stressor-response relationships were observed between DO and SCI scores (R^2 ca.0.25) and nutrients and SCI scores, the relationships were insufficient to develop stressor-response based NNC for Florida freshwater streams (EPA 2010). Quantifiable linkages to the conceptual model that nutrients increase phytoplankton/periphyton, that in turn result in lower DO and, consequently, adverse effects on SCI scores were not supported. For this reason the reference-based approach was adopted for establishing Florida's freshwater streams criteria. The approach defined criteria based on the distribution of values from a reference population, defined as "relatively undisturbed stream segments that could serve as examples of the natural biological integrity of a region". For its final rule, EPA explored two reference populations by screening stream sites with nutrients data: (1) the Benchmark Population represented by sites evaluated as least-disturbed by humans and (2) an SCI Population represented by sites with demonstrated biologically healthy conditions. The final TN and TP criteria for each region were based on the Benchmark Population for all regions except the West Central region where the criteria are based on the SCI Population approach detailed in EPA's proposed rule (EPA 2010). These criteria were deemed "inherently protective" because they were based on a highly selective population representing natural conditions and the most sensitive taxa available to derive the standards; therefore, the standards were deemed protective of all designated uses for freshwater streams. Within each region, a single numeric nutrient criterion value represents the standard by which all creeks are evaluated for nutrient impairments.

The outcomes of this study with respect to developing a stressor-response based approach to identify numeric threshold values were similar to outcomes of the freshwater streams criteria. While there are no established metrics such as the SCI scores currently applicable to rulemaking for estuarine waters, the weight of evidence suggested that the nutrient concentrations we observed were not directly related to negative impacts on biological integrity in a quantitative manner using either fish species diversity metrics or metrics related to the recruitment and success of Snook. In the same way that there was no single unifying relationship that described the effects of nutrients on biological integrity for all the tidal creeks studied, there is also likely no one nutrient criterion value that will optimize the sustainability and productivity of all southwest Florida tidal creeks. Given the difficulties in identifying a stressor-response relationship that might serve as a unifying explanatory model to establish numeric interpretations of the narrative criteria for tidal creeks, a reference-based approach was used to develop the recommended nutrient targets and thresholds for southwest Florida tidal creeks.

The data collected from this study provided a weight of evidence that protective criteria can be developed as part of a larger management framework for tidal creeks that provides both targets that serve as numeric interpretations of a stewardship goal for the desired condition of tidal creeks and threshold values that define their protective limits. The reference point for developing the proposed targets and thresholds was defined by the the existing FDEP regional nutrient criteria for freshwater streams. The rationale for choosing the freshwater standards as the reference points for the proposed reference-based approach are described in the bullets below:

- There were no observed adverse effects to creek biological integrity directly attributable to nutrient concentrations observed in the study, even in creeks with annual geometric average nutrient concentrations approaching their respective freshwater standards.

- Nutrient concentrations did not follow conservative mixing principles in the tidal portions of the creeks.

- The mixing curve analysis suggested the potential for nutrient addition from fringing mangrove communities and nutrient recycling associated with decomposition of organic matter in the tidal portion in addition to anthropogenic inputs.

- The sampled creeks were deviod of seagrass, a sensitive indicator used in the larger estuary as a response endpoint. We are confident that the majority of tidal creeks in the population do not contain seagrass and qualify the proposed approach would not include that portion of any creek found to contain seagrass.

- The freshwater standards were based on a very specialized reference population and are thought to be “inherently protective” of all stream systems in Florida. There was no evidence to suggest that the estuarine taxa observed in this study were more sensitive to nutrient enrichment than those used to set the freshwater criteria.

The proposed management framework includes: nutrient target concentrations that protect individual creek types within the larger population of creeks; caution levels that are indicative of creeks trending towards a nutrient condition that are above their individual assimilative capacity; a management action level that identifies a potential degredation point as an impetus to develop a site-specific management actions, and thresholds which represent the need for regulatory actions to confirm impairment and identify remediative actions for the creek watershed. The details explaining the development of each of these categories of the management framework are provided in Chapter 6.

Chapter 6. Proposed Targets, Caution Levels, and Thresholds

The weight of evidence collected during this study suggest that the adopted freshwater nutrient criteria can be used as a reference point within a larger managment framework to develop nutrient targets and thresholds for tidal creeks under a specific set of condtions to guard against degredation of individual creeks. The mangement framework includes target levels, caution levels, a preemptive management action levels, and the proposed threshold values established as the NNC. The respective freshwater NNC for freshwater streams are proposed to serve as the nutrient thresholds indicative of the need for regulatory action. The preemptive management action level was derived by applying a margin of safety that descreased the likelihood of an annual geometric average ever exceeding the threshold value. Exceedance of the action level criteria would entail the development of a nutrient management action plan to identify best practices for reducing nutrient concentrations in the tidal creeks to prevent an exceedence of the regulatory threshold (NNC) value. The caution levels are scaled by specific creek attributes that can be assigned to any creek within the population allowing for an early warning system that is creek-specific. Values lower than the caution levels are target values that reflect the desired numeric nutrient concentrations for each individual creek as a stewardship goal. The specific details outlining the process by which the targets and thresholds were developed is defined in the following paragraphs.

The reference based approach utilized the freshwater streams criteria as the reference point from which to identify a distribution of nutrien values protective of southwest Florida tidal creeks. The current NNC rules for Florida freshwater streams specify that no more than 1 in 3 annual geometric average nutrient concentrations may exceed the criteria threshold values. For the West Central region, the total nitrogen criterion is 1.65 mg/l. Therefore, the grand average (i.e., the average of all annual geometric averages) must be less than 1.65 mg/l in order to be protective. In fact, it must be a distribution such that only 33% of the values exceed the NNC. Using Monte Carlo simulation based on the highest observed standard deviation of nutrient concentrations collected during our study, we simulated a distribution of nutrient samples and, assuming six sampling events per year, generated a distribution of annual geometric averages around a range of expected values to identify a grand nutrient geometric average resulting in a 5% probability of exceeding the NNC. For the West Central region, we estimated the expected value would be a distribution with a grand average of 1.46 mg/l (Figure 36). This value was defined as the lower limit of the preemptive management action level. Because the distribution of geometric averages is normally distributed, the grand average and the median value (i.e the 50th percentile) should be very similar. Therefore, if more than 50% of the annual geometric averages are above the caution value, that would indicate that the underlying distribution of creek geometric averages has a higher than 5% chance of being above the NNC. For the West Central region, these values are plotted in reference to the average geometric average total nitrogen concentrations observed during the study (Figure 35). Note that the Frog Creek concentration was directly associated with the upper threshold for the caution level. The caution levels for nitrogen and phosphorus for both FDEP nutrient regions within the study area are provided along with the proposed tidal NNC values in Table 7.

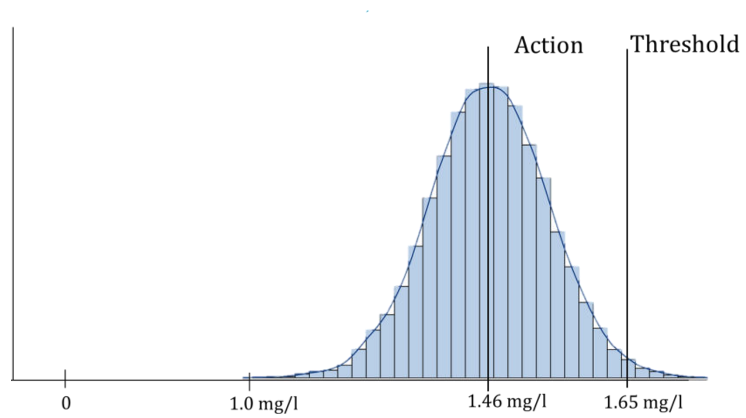


Figure 36. Simulated distribution of annual geometric average nitrogen concentrations associated with the West Central region nitrogen thresholds. Simulation based on highest observed standard deviation and 6 sampling events per year.

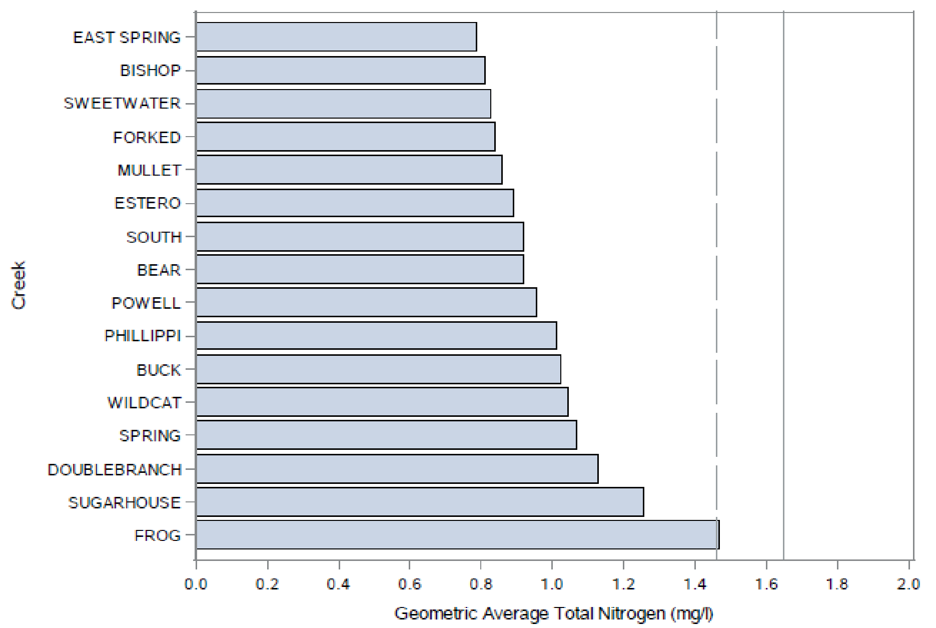


Figure 35. West Central region creeks with geometric average total nitrogen concentrations, proposed lower threshold of the management action level (broken line) and proposed creek NNC threshold value (solid line).

Annual geometric average nutrient concentrations that fall between action levels and the NNC thresholds represent a range under which preliminary management actions should begin to identify effective means of reducing nutrient concentrations in the system. The phosphorus criteria were derived in the same manner as the nitrogen criteria described above except for the Peninsula region where estuarine mixing was likely to contribute to increased TP concentrations in estuaries receiving waters from the West Central Region such as Tampa Bay. Therefore, the freshwater standards were used as both the threshold and caution level criteria for the Peninsula region.

Table 7. Proposed NNC and upper threshold caution levels for southwest Florida tidal creeks.

Nutrient	Region	Threshold Geometric Average	Threshold Exceedence Frequency	Caution Geometric Average	Caution Exceedence Frequency
Total Nitrogen	West Central	1.65 mg/l	No more than 1:3	1.46 mg/l	No more than 2:5
	Peninsula	1.54 mg/l	No more than 1:3	1.36 mg/l	No more than 2:5
Total Phosphorus	West Central	0.49 mg/l	No more than 1:3	0.40 mg/l	No more than 2:5
	Peninsula	0.12 mg/l	No more than 1:3	0.12 mg/l	No more than 2:5

So far, we have proposed threshold values that represent the need for potential regulatory action, and a margin of safety that will serve as an early warning indicator that the system may be trending towards impairment. However, the goals of the collective southwest Florida National Estuary Programs are to provide guidance towards the proper stewardship of these important resources and it was desirable that the management framework include an additional level of protection that was site-specific as a stewardship goal. A single regional standard is considered underwhelming as a stewardship goal. Therefore, an additional layer of protection was included in the management framework by developing caution levels that incorporated site-specific attributes of the creeks. By doing this, the caution levels better reflect the relative potential to assimilate nutrient loads. This was accomplished by deriving a regression equation between the length of each creek and the observed annual geometric average of the creek. While creek length was used as the scaling factor for the caution levels, several other creek attributes reflecting the effects of watershed size including the buffer acreage, the area of natural wetland vegetation within tidal reaches, and the geometric average concentration of colored dissolved organic matter were also correlated with either the geometric average TN or TP concentrations though all the results left a majority of the variation unexplained (Table 8).

Table 8. Robust regression results for bivariate regressions of creek attributes on geometric average total nitrogen and total phosphorus concentrations. Values represent coefficient of determination (R^2) based on robust regression results. ns =nonsignficant result.

Independent Variable	Dependent Variable	
Creek Attribute	Total Nitrogen R^2	Total Phosphorus R^2
Creek Length	0.26	0.28
Buffer Acres	0.34	0.26
Natural Buffer Acres	0.18	ns
CDOM Geometric Average	0.32	ns
Watershed Acres	0.15	ns

The regression relationship using creek length is potrayed in Figure 37. The fact that Frog Creek had the largest estuarine extent, and its geometric average concentration was at the caution level made the decision to scale the caution levels by the size of the creek an intuitive choice. Because creek length is a metric that can be easily calculated for any creek in the population, it is adaptable to the entire population of creeks and is proposed as an effective metric to derive site-specific caution levels as an additional level of protection against degredation until more rigorous relationships can be developed. Once site-specific caution levels were derived, target values were designated as any value below the caution levels.

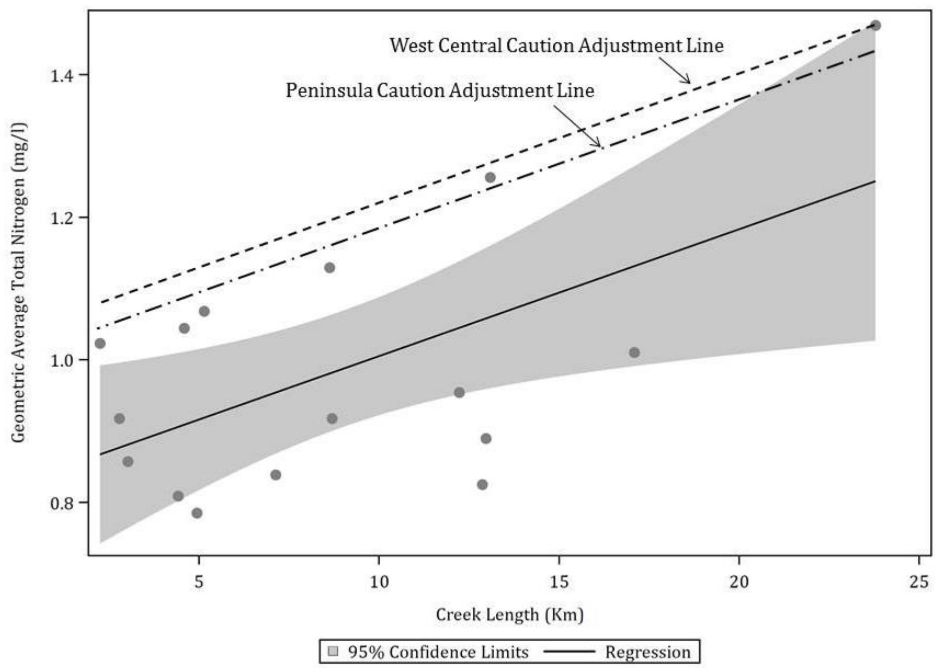
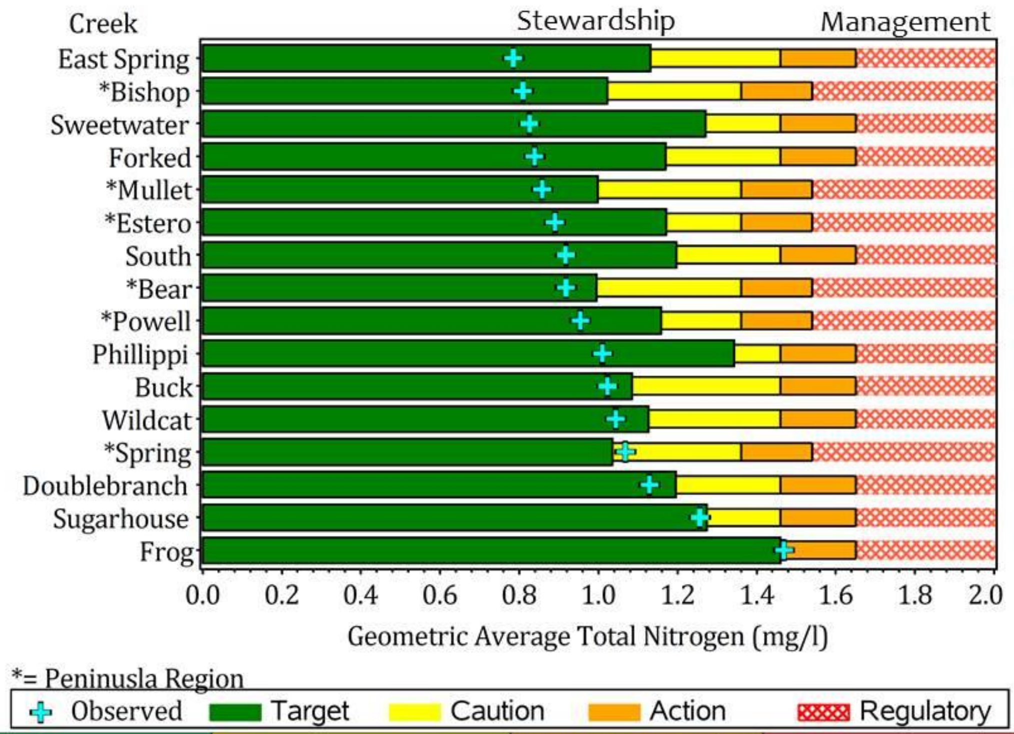


Figure 37. Regression of geometric average TN concentration and creek length used to scale the Tier 2 caution levels. Broken line represents the Tier 1 caution levels adjusted based on creek length.

The full suite of protection thresholds for the 16 sampled southwest Florida tidal creeks is provided in Figure 38 along with the evaluation criteria associated with the management framework. It is important to remember that this framework can be applied to all 306 creeks in the population in southwest Florida. The management strategy associated with this framework is further discussed in the next section.



Target	Caution Level	Management Action Plan	Regulatory (NNC)
Running geometric average	Running geometric average	2:5	1:3

Figure 38. Proposed management framework applied to the 16 sampled creeks with observed geometric average nitrogen concentrations overlaid as a cross in the figure.

Chapter 7. Implementation of the Management Framework

The concept of a management strategy for southwest Florida tidal creeks was first promoted by the Tampa Bay Regional Planning Council in 1987 (Clark 1987). Since that time a number of very important but disparate studies have been conducted on different aspects of tidal creek integrity but there has yet to be a unified management framework developed to provide management oversight and guidance to accelerate the science towards the proper management of these critical ecosystems in a systematic way. The management framework provided in this document is intended to fulfill that long term goal by providing nutrient targets and thresholds as part of an ecosystem-based management approach. The local governments of Southwest Florida are in a unique position to capitalize on the contributions of the three contiguous National Estuary Programs in southwest Florida that have Comprehensive Conservation and Management Plans with identified action plans that address the proper stewardship of tidal creeks. This management framework will allow for the three Estuary Programs, and the six counties within their geographic boundaries to work cooperatively to achieve the common goals of the Estuary Programs, the local governments, and state and federal regulators to protect these vital ecosystems that contribute greatly to the ecological productivity and resilience of the larger coastal estuaries in which they reside.

The Wetland Program Development Grant provided the opportunity to accelerate research to define a more scientific basis for managing tidal creeks in southwest Florida. The goals of this project included accelerating the science, proposed management level targets and thresholds and recommending those targets and thresholds for consideration as numeric interpretations of the narrative criteria for southwest Florida tidal creeks. Currently, the narrative criterion is the only guidance for evaluating tidal creek biological integrity. Compliance with the narrative criterion evaluation is based on state DO and chlorophyll threshold values alone, not nutrients. Nutrient impairment is inferred from exceedence of the DO or chlorophyll thresholds. This study has demonstrated the potential for these thresholds to be ineffective yardsticks in evaluating the biological integrity of these systems. Indeed, it is likely that application of those criteria to southwest Florida tidal creeks would result in the misclassification of many of these wetland environments as impaired when, in fact, they are biologically healthy and productive systems.

The proposed tidal creek nutrient management framework is intended to serve as a more effective and informative approach to manage the effects of nutrients on the biological integrity of these systems. The recommendations provided are based on locally derived data directly applicable to these creeks and include important considerations relating to estuarine mixing in the tidal creek environment. The recommended nutrient management framework provides a protective strategy aimed at minimizing the potential for these creeks to become eutrophic or dystrophic, while also reducing the probability that a tidal creek will be falsely designated as impaired due to naturally occurring water quality conditions. The framework is more robust than the current regulatory framework in that it:

- is based on nutrient concentrations not just DO and chlorophyll;
- provides stewardship benchmarks for individual creeks;
- provides a management framework for local governments to evaluate tidal creek water quality data in a systematic manner relative to the population of creeks in southwest Florida;
- provides recommendations to further the science related to site-specific management criteria for these systems, and
- provides the three National Estuary Programs with a mechanism by which to further the goals of their CCMP.

Importantly, the proposed southwest Florida tidal creek nutrient management framework fits well within the existing state and federal water quality standards and is not counter to any State or Federal regulatory mechanism currently in place. While the report suggests that alternative formulations of the current DO and chlorophyll standards should be considered for southwest Florida tidal creeks, the management framework provides an additional level of information by defining specific nutrient targets and thresholds that can be used to put the DO and chlorophyll evaluation results into the context of nutrient conditions indicative of the biological integrity of the population of southwest Florida tidal creeks it is intended to represent. In this way, the proposed management framework serves as a more comprehensive evaluation strategy than the current pass/fail approach used to evaluate these creeks.

An admittedly overly simplistic view of the regulatory framework associated with the Clean Water Act as it relates to Florida's Impaired Waters Rule (FAC Chapter 62-303) would suggest that the framework is comprised of two principal components: What the number is (i.e., the identified impairment threshold value); and what the number means (i.e., in terms of remediative regulatory action). The first component (evaluating the data in relationship to the threshold) is currently a binary (i.e. pass/ fail) process. Recently, biological confirmation has been added for some waterbodies; namely freshwater streams, to guard against the possible misclassification of healthy systems as impaired. Adding this condition to the regulations explicitly acknowledges that uncertainty exists in assuming nutrients were the sole cause of a threshold exceedence. The second component addresses implications of exceeding the threshold value and is often left to the development of a Basin Management Action Plan including identifying a Total Maximum Daily Load (TMDL) to estimate the assimilative capacity of the waterbody. The management framework proposed herein is intended to serve as both a mechanism for evaluating data relative to the need for regulatory action, and as a stewardship plan that, if properly pursued, is likely to preclude the need for any regulatory actions on creek that are currently achieving their designated use.

The current regionally based nutrient criteria for regulating Florida waterbodies provide an important regulatory mechanism but are underwhelming as a stewardship goal though they are sometimes viewed in that context. Site-specific criteria are more desirable for protecting the biological integrity of individual systems. The proposed management framework is intended to bridge the gap between regionally based regulatory criteria and site-specific stewardship goals. The level of effort related to understanding indicators of tidal creeks in Florida has lagged behind freshwater streams and there is a lot left to learn about the drivers and biological responses in these systems as acknowledged in this report. However, this study has provided a scientific foundation to help bridge that gap as well as a management framework from which to unify efforts towards more rigorous site-specific standards. In particular, the proposed caution levels are intended to serve as site-specific early warning indicators that an individual creek may be trending towards a eutrophic condition and identify where management actions should begin to identify the most effective means for avoiding a threshold exceedence. The management structure also identifies a range of target values that represent creek-specific attributes that are protective of the fish and wildlife populations that define their designated use. In this way, the management framework can preclude expending unwarranted effort or cost due to being evaluated by unreliable standards and provide reasonable assurance that the tidal creek wetlands are being subjected to a rigorous evaluation that determines their compliance with the criteria established to protect their designated use.

From a practical perspective, using the freshwater criterion as a reference point from which to derive tidal creek targets and thresholds was intuitive since it is the source water to the tidal portion of the creek. The majority of routine monitoring programs in southwest Florida that collect water quality samples in creeks that drain to estuaries have fixed water quality monitoring stations located near the freshwater interface, above the tidal head. Our study design included a fixed station located above the tidal head and used the fixed stations to evaluate the relationship between source water nutrient concentrations and nutrient concentrations in the tidal portions of the creek. We found that the nutrient concentrations measured in the source water were not solely diluted by mixing in the tidal portion of the creek but were more related to a complex set of creek specific conditions that include potential contributions from both natural and anthropogenic sources. While this precludes the use of a dilution curve approach to establishing nutrient thresholds based on salinity, it does not obviate the use of source water concentrations to make inferences about downstream water quality. This approach would have great value from an efficiency perspective as a screening tool. The degree to which source water concentrations could serve as a deterministic estimate of the tidal creek concentrations warrants further investigation and requires additional study. The establishment of such a relationship could serve as a valuable tool in a triage approach to identify those tidal creeks that are most likely to have nutrient conditions encroaching on the potential for adverse effects to the tidal portion of the system. We found that the potential for nutrient addition in the tidal portion of the creek as well as other site-specific factors precluded the development of a unified explanatory model to predict creek concentrations from source water concentrations. Further research is required to support such a model. In the meantime, this study has proposed a nutrient management framework that will serve as a protective mechanism for the proper stewardship of these important estuarine systems while future research is conducted to identify more unified explanatory models capturing the highly complex nature of site-specific biological responses to nutrient inputs in these creeks that can be used in a stressor-response approach. Recommendations for future research to address these site-specific factors are described in more detail below. These future efforts include:

- the need for considering the potential for nutrient addition in the tidal portion of the creeks from both anthropogenic and natural sources;
- development and testing of recruitment indices for important estuarine dependent fish species;
- developing additional metrics of biological integrity for tidal creeks;
- the consideration of a nutrient use efficiency metric that is related to trophic transfer and tidal creek production, and
- identifying the effects of physical and hydrologic alterations on the relative potential assimilative capacity of these systems.

These topics are discussed in more detail in the next chapter.

Chapter 8. Future Efforts

This study has made significant contributions to the level of knowledge regarding nutrient dynamics in southwest Florida tidal creeks. Perhaps the most important scientific finding of the study was that nutrient addition was common in the estuarine portion of the creeks. It was beyond the scope of this study to identify the sources of nutrients in the creeks. Malkin et al., 2010 used stable nitrogen isotope analysis of fish tissue collected from southwest Florida tidal creeks to identify sources of nitrogen in some of these systems. Nitrogen inputs from row crops, tree crops, and wetlands were principal determinants of nitrogen in fish muscle tissue with those inputs considered to be exporting more nitrogen to nearby aquatic systems than their relative areas would suggest (Malkin et al., 2010). However, few of the watersheds in our study contained agricultural acreage and Greenwood et al., 2008 found fish isotopic signatures in creeks with more residential land uses presented a seasonally variable mix of influences including septic tanks, fertilizer application, and soil redistribution. Wet season and dry season results differed with more homogenized influences during the wet season when hydrologic connectivity was high and more influence of septic tanks during the dry season though other sources were also considered to contribute. In particular, *in situ* nitrogen recycling and decomposition of organic material were posited as additional potential contributing sources of nutrients. Allen et al. (2013) conducted a series of powerful field experiments in a South Carolina tidal salt marsh dominated creek and found that nekton (i.e., fish and shrimp) can contribute greatly to the concentration of dissolved nutrients in tidal creeks. Tidally controlled patterns of nekton movements and feeding result in retention and reintroduction of nutrients to the upper reaches of the intertidal basins. Allen et al. (2013) conclude that nekton can be important and underappreciated contributors of dissolved nutrients in tidal systems. Nutrient outwelling from mangrove communities can also contribute nutrients to tidal creeks (Wolanski, 2007; Gleeson et al., 2013) and are more likely than salt marsh to be a contributing source of nutrients in the creeks we sampled. Again, sourcing nutrient inputs in these creeks was beyond the scope of this study but the results of other studies summarized above illustrate the complexity in attributing nutrient conditions to particular sources in these systems. More study is needed to identify critical thresholds of anthropogenic nutrient inputs that lead to adverse effects and this study has provided evidence that considering nutrients as a conservative substance in these creeks is overly simplistic and will lead to misclassification of healthy waterbodies as impaired.

Investigating nutrient mixing properties in these systems should be strongly considered in future studies evaluating the link between the incoming source water concentrations and concentrations in the tidal creeks. Nutrient budgets should consider the potential internal loads of the estuarine portions of the systems, where those nutrients were derived and how they contribute to the potential impairment of the designated use of the waterbody.

The need for the unified management framework proposed in this report is in part due to the highly complex interactions observed between watershed stressors, instream processes and biological responses during the study. No single study of such a diverse assemblage of estuarine environments would provide a definitive guide to optimize the stewardship of these important resources. However, the proposed management framework will serve to unify future efforts dedicated towards identifying science-based management outcomes leading to a more efficient and effective accumulation of knowledge towards the effective stewardship of southwest Florida tidal creeks. There is a great deal left to learn regarding the role of nutrients in governing tidal creek function. Disparate studies can sometimes lead to conflicting results. A unified management framework can help guide research leading to more effective science necessary to identify the site-specific attributes of tidal creeks that optimize their productivity within the larger estuary. The management framework we proposed included both stewardship and management components and the strength of future scientific results can affect both of these components of the management process in an adaptive management strategy. For example, the effects of landscape development on the productivity of tidal creeks has been well studies in the southeast United States (Mallin 2004; Holland et al., 2004; Sanger et al., 2008, Sanger et al., 2011; Greenwood et al., 2008; Krebs et al., 2013) but the results have been mixed. Holland et al., found significant negative effects of landscape development intensity on tidal creek integrity in South Carolina tidal creeks while Greenwood et al. (2008) and this study found limited evidence of any adverse impact based on landscape development intensity. Krebs et al., 2013 found some evidence to suggest that urbanization of creek watersheds may increase the energetic reserves of some resident fish species. These seemingly conflicting results can be unified by the fact that both Greenwood et al., 2008; Krebs et al., 2013 and this study suggest that near field effects such as riparian buffer and instream water quality conditions may be more important than more landscape level attributes in determining fish community composition in southwest Florida tidal creeks. The proposed unified management framework provides a vehicle to accelerate the science needed to further these individual hypotheses to inform management decisions and encourage local participation in the stewardship process.

There are no known long term monitoring efforts of fish and water quality in small tidal creeks in southwest Florida to provide results in the context of inter-annual variation in these metrics; however, in Tampa Bay's larger river systems there are both long term fisheries and water quality data collection programs ongoing. It would be highly beneficial to evaluate data from these larger rivers to provide additional information on inter-annual variability in both water quality and fish recruitment in these larger systems whose tidal portions also seem to currently fall under the narrative criteria. More work is needed to understand the effect of inter-annual variation which is why this report also includes the recommendation for future efforts to forward the science in this regard in a subset of southwest Florida tidal creeks. In particular, we recommend that each county maintain an existing water quality monitoring station in one of their tidal creeks and commit to additional water quality sampling within the tidal portion of the creek using a design scheme similar to that used in this study. This would allow for a better understanding of the inter-annual variability in these creeks and help to better define the relationship between the source water nutrient concentrations and nutrients in the tidal portion of the creeks. Additional fisheries collections in these creeks would be a valuable addition to this effort and considerations are provided in these recommendations for the development of a set of potential fish indices that can provide valuable information with limited effort to enhance our understanding of the relationships described above.

The chlorophyll content of the benthic sediment layer was also investigated as a response endpoint in an effort to capture estimates of production of the benthic microalgae (BMAC). Intuitively, benthic chlorophyll content makes sense as an endpoint because it integrates nutrient conditions over time and serves as a seasonally important source of primary productivity to higher trophic levels in southwest Florida tidal creeks (TTHI 2008). The FDEP also recognizes the importance of sediment periphyton as an indicator of stream condition for Florida freshwater streams and springs. However, our results did not support benthic chlorophyll as a unifying indicator of the relationships between nutrients, benthic chlorophyll concentrations, fish assembles, and the potential for identifying adverse effects though we still feel that this parameter is both an important trophic pathway and a potential indicator of trophic state in these creeks. Based on our study, water column chlorophyll production did not appear to be sufficient to limit availability of the benthic pathway on the scale in which we measured it. Unfortunately, there are no known reliable tools currently available to derive an integrated estimate of the "whole creek" benthic productivity in tidal creeks. Site-specific values were highly variable, contributing to uncertainty in our stressor-response relationships. In addition, site-specific conditions such as canopy cover and water clarity can mediate the relationships between nutrients and sediment primary production. Despite these limitations, future efforts should consider the importance of sediment phytoplankton as a source of trophic transfer and pursue alternative methods to quantify the contribution of benthic primary production to the food web in tidal creeks.

Consideration of the effects of organic matter decomposition as a mediating factor in the relationship between dissolved oxygen and fish community structure also warrants more investigation. This study found that despite using DO expressed as percent saturation, there was still a relationship between temperature and DO indicating biological processes related to decomposition likely play a role in the observed DO conditions in the creek and therefore seasonally variable DO criteria may be warranted. The microbial (or detrital) loop is well known as a significant source of productivity in estuarine systems increasing the complexity and production of the food web but also putting additional demands on DO. This detritus may come from phytoplankton, plant growth and decay, outwelling from wetlands, and rivers (Wolanski, 2007). Conrads et al., (2002) found that salt marsh loadings over tidal cycles contribute significantly to diel variation in dissolved oxygen concentrations. For mangrove dominated tidal creeks such as those in southwest Florida, the contribution of organic rich soils and fine sediments can increase detrital community and are likely to result in similar effects on DO to that described above. Thereby, estimates of the effects of decomposition of organic material on dissolved oxygen are another attribute worthy of future scientific investigation.

While the nutrient concentrations observed during the study did not appear to be deleterious to the biological integrity of these creeks, a host of interrelated factors complicate this interpretation. For example, physical and hydrologic alterations to individual waterways may have a profound influence on tidal creek integrity but this was only partially quantified in this study based on land use characteristics. Land use analysis suggested increased urbanization may actually have negative effects on productivity as measured by chlorophyll concentrations. For example, the percent impervious surface of the watershed, as well as the proportion of urban land use within the creek buffer area were negatively correlated with median chlorophyll concentrations, while the proportion of natural wetland vegetation (i.e. mangroves and marshes) within the buffer area was positively correlated with water column chlorophyll concentrations (Figure 39). Natural wetland vegetation within the buffer area was also correlated with a higher likelihood of exceeding existing state DO criteria for estuaries. This suggests that the underlying conceptual model currently applied using existing state DO and chlorophyll standards to evaluate these creeks under the narrative criterion may need to be reconsidered. This will require more research and sampling, to test the influence of anthropogenic alterations to the physical and hydrologic environment of the creek. Dredging creeks have been shown to result in negative effects on tidal creek biomass (Bilkovic and Roggero (2008); Bilkovic, 2011) and (Christian and Allen (2014) found that shallow wide tidal creeks lead to greater trophic efficiency that deeper creeks. These results support the conceptual models developed during this study (Janicki Environmental, 2013) that nutrients are only one of several important factors contributing to tidal creek integrity.

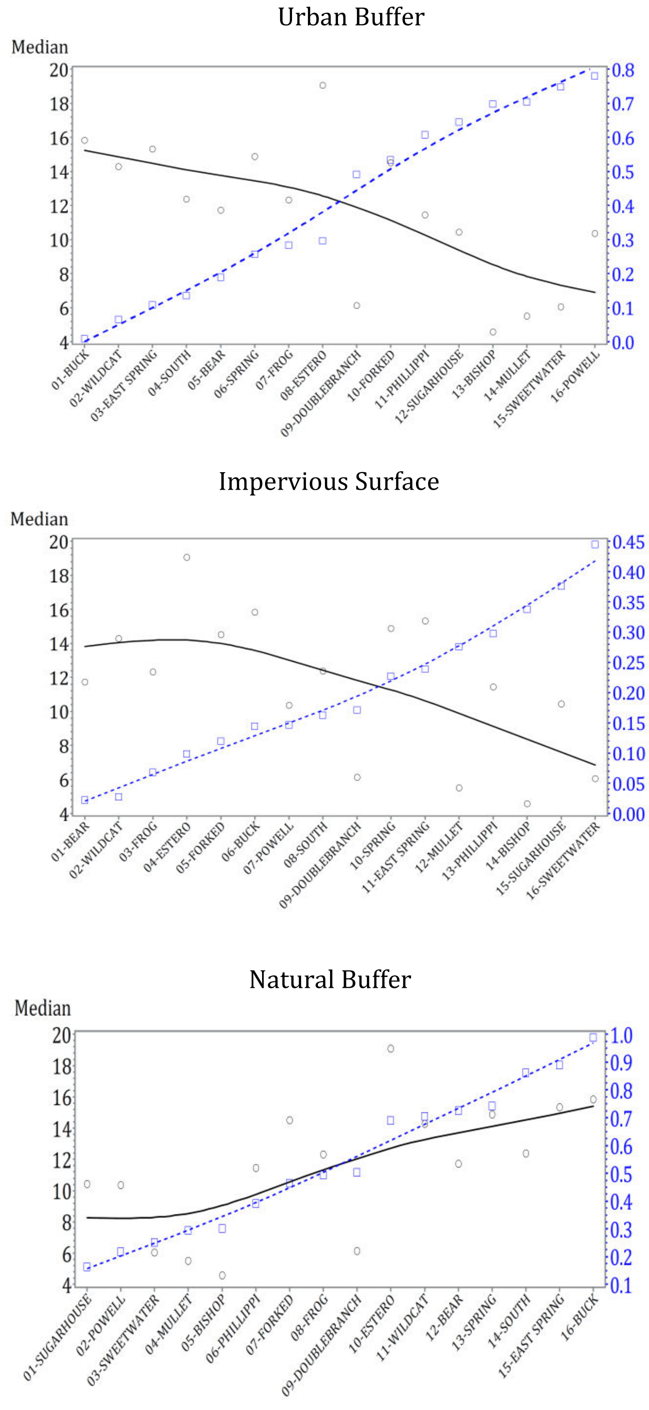


Figure 39. Plots of median water column chlorophyll concentrations (left) as a function of the proportion of urban land use in the buffer area (top), impervious surface (middle), and natural wetland vegetation (bottom). Plots are oriented with increasing watershed metric (x axis).

Trophic efficiency is an important concept that needs more investigation in southwest Florida tidal creeks. Nutrient concentrations measured in this study did not represent dystrophic conditions to tidal creek biological integrity but there was evidence that some creeks were more efficient in converting nutrients to biomass than others. For example, Mullet Creek had the second highest biomass of Snook in our study but only ranked 6th in terms of the total number of Snook (Table 9). Conversely, the most Snook were caught in South Creek but it was not the highest in terms of total biomass. Sugarhouse and Frog Creek had the highest geometric average nutrient concentrations but also had high numbers and high biomass of Snook. This reflects the high level of complexity in evaluating the relationship between nutrients and fish community response. We used length frequency distributions and biomass estimates as potential metrics to evaluate tidal creek condition for fish communities. Lipid storage reserves (Weinstein et al., 2012; Krebs et al., 2013) and length weight ratios (Greenwood et al., 2008) have been used locally as other metrics of fish condition in efforts to differentiate landscape development impacts to these estimates of fish community function with mixed success but the hope is that as more efforts are conducted there will be a convergence of the science needed to use indices such as these to evaluate tidal creek condition in southwest Florida.

Table 9. Snook biomass ranks with associated total number caught, and geometric average TN and TP concentration ranks (larger number=more).

Creek	Biomass	Number	TN	TP
East Spring	1	1	1	8
Powell	1	1	9	7
Forked	3	5	4	12
Doublebranch	4	4	14	3
Estero	5	3	6	1
Spring	6	6	13	2
Phillippi	7	9	10	14
Bear	8	7	8	5
Bishop	9	8	2	10
Sweetwater	10	11	3	6
Sugarhouse	11	14	15	15
South	12	16	7	11
Wildcat	13	12	12	13
Frog	14	13	16	16
Mullet	15	10	5	9
Buck	16	15	11	4

In some instances higher nutrient concentrations were positively correlated with fish species diversity. However, these results are complicated by instream processes such as the flow regime, amount of natural wetland vegetation within the creek, canopy cover, and degree of physical alteration. The degree to which natural habitat features can mask the potential deleterious effects of nutrients in tidal creeks is currently unknown. In theory, more natural habitat features within the estuarine portion of the creeks should increase species diversity, thereby masking the potential negative consequences of nutrient inputs. However, these same natural habitat features (e.g. mangroves) may, at times, limit the effectiveness of gear utilized in sampling, resulting in reduced species abundance and diversity. This is, in part, why we relied on fish length-frequency distributions as a metric of biological integrity. We propose estimates of recruitment and survival of estuarine-dependent fish as an index for identifying healthy creeks. The estuarine dependent species tend to be the more directly related to the recreational or commercial fisheries that drive large economic impacts to southwest Florida. Many of these species recruit as newly hatched juveniles to tidal creeks during certain portions of the year. This would allow for an index period sampling effort to evaluate the recruitment and success of these select taxa as an estimate of creek biological integrity in an ecosystem based management framework. Evaluating creeks in this way is directly tied to the biological communities that represent key ecological attributes for southwest Florida tidal creeks. Over the millennia, fish species have adapted reproductive strategies to maximize their potential for success. Temporal resource partitioning (Ross 1986) is one such mechanism by which these species maximize their probability of success by utilizing the same resource (tidal creeks) over different temporal (seasonal) patterns. An example of this is shown in Figure 40 which displays the recruitment windows for several important fish species in southwest Florida tidal rivers. Tidal creeks that are able to support higher recruitment and survival rates for multiple species throughout the year contribute to the integrity and resilience of the larger estuaries to which they connect. The index would need to be refined to include considerations of the individual species reproductive strategies, inter-annual variation in year class strength, and potential for emigration, but the occurrence of multiple size classes of a particular estuarine dependent species that is identified as a key ecological attribute is in itself an indication that the creek is meeting it's identified designated use.

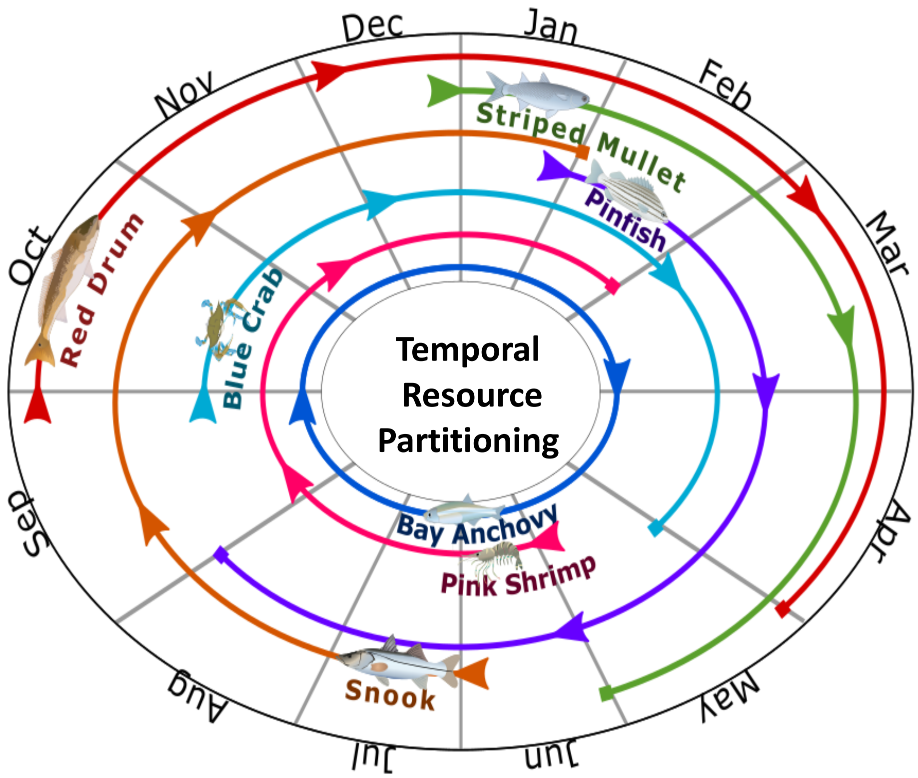


Figure 40. Temporal resource partitioning of estuarine dependent fish taxa utilizing southwest Florida tidal creeks.

Using these concepts, the methodology applied to this study could be used towards the development of a management system that could be generalized to other systems throughout Florida and beyond. For example, Red Drum recruit throughout Florida's Gulf Coast and this species could serve as a valuable indicator in the same manner in which Snook were used in this study. Inter-annual year class strength hinders the reliance on any one species and therefore there is a need to consider multiple species for this type of ecosystem-based management approach within the larger nutrient management framework. Southwest Florida is unique in that the FIM program has a long term monitoring program established in all three estuaries that can be used to provide indices of inter annual recruitment that may be correlated to tidal creek recruitment.

In conclusion, this study made important contributions to the development of a protective nutrient management strategy for southwest Florida tidal creeks. The strategy provides management guidelines and actions to be implemented that minimize the potential for these creeks to become eutrophic or dystrophic, while also minimizing the probability that a tidal creek waterbody will be designated as impaired due to naturally occurring water quality conditions. Natural resource managers and state and federal regulators can easily apply the proposed management strategy as an effective means of evaluating tidal creeks in a systematic manner and report the results within the context of other metrics used to evaluate tidal creek impairments (e.g., DO and Chla). The local governments of Southwest Florida are in a unique position to capitalize on the contributions of the three contiguous National Estuary Programs that have Comprehensive Conservation and Management Plans with specific actions addressing the stewardship of tidal creeks. This management framework will allow for the three Estuary Programs, and the six counties within their geographic boundaries to work cooperatively to achieve the common goals of the Estuary Programs, the local governments, and state and federal regulators to protect these vital ecotones that contribute greatly to the ecological productivity and resilience of their respective coastal estuaries.

Chapter 9. Literature Cited

Allen, D. M., S. A. Luthy, J. A. Garwood, R. F. Young, and R. F. Dame. 2013. Nutrient subsidies from nekton in saltmarsh intertidal creeks. Limnology and Oceanography. 58(3):1048-1060.

Barbour, A. B. and A. J. Adams. 2012. Biologging to examine multiple life stages of an estuarine dependent fish. Marine Ecology Progress Series. V457:241-250.

Bilkovic, D. M. AND M. Roggero. 2008. Effects of coastal development on nearshore estuarine nekton communities. Marine Ecology Progress Series 358:27-39.

Bilkovic D. M. (2011) Response of Tidal Creek Fish Communities to Dredging and Coastal Development Pressures in a Shallow-Water Estuary. *Estuaries and Coasts* 34: 129-147

Breiman, L. (2001), *Random Forests*, Machine Learning 45(1), 5-32.

Brennan, N. P., C. J. Walters, AND K. M. Leber. 2008. Manipulations of Stocking Magnitude: Addressing Density-Dependence in a Juvenile Cohort of Common Snook (*Centropomus undecimalis)*. Reviews in Fisheries Science 16:215-227.

Browder, J. A. and D. Moore. 1981. A new approach to determining quantitative relationship between fishery production and the flow of freshwater to estuaries, p. 409-430. In Cross, R. and D. Williams (eds.). 1981. Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Report FWS/OBS-81/04. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

Christian, R. R. and D. M. Allen 2014. Linking hydrogeomorphology and food webs in intertidal creeks. Estuaries and Coasts 37(S1): S74-S90.

Clark, P. A. 1987. Condition and management of Tampa Bay tidal tributaries. in: Webb, Frederick J., Jr. ed. Proceedings of the Fourteenth Annual Conference on Wetlands Restoration and Creation: May 14-15, 1987. pp. 88-102.

Clark, P. A. 1991. Management directions and needs for Tampa Bay tidal tributaries. in: Treat, S. F. and Clark, P. A. eds. Proceedings, Tampa Bay Area Scientific Information Symposium 2. 1991 February 27-March 1, Tampa, FL. pp. 497-510.

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18:117-143.

Clarke, K. R. and R. N. Gorley. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E Ltd: Plymouth, United Kingdom. 190 p.

Clark, J. S. 2007. Models for Ecological Data: An Introduction. Princeton University Press. Princeton N.J. 08540

Conrads, P. A. E. A. Roehl, and J. B. Cook. 2002. Estimation of tidal creek loading effects in a complex estuary. In Coastal Water Resources, J. R. Lesnik (ed). AWRA 2002. Spring Specialty Conference Proceedings. TPS-02-01 pp307-312.

Environmental Protection Agency (EPA). 2000. Nutrient Criteria Technical Guidance Manual: Rivers and Streams. EPA-822-B-00-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Environmental Protection Agency (EPA). 2001. Nutrient Criteria Technical Guidance Manual: Estuarine and Coastal Marine Waters. Office of Water 4304. EPA-822-B-01-003. October 2001. Washington D.C.

Environmental Protection Agency (EPA). 2010. Technical Support Document for U.S. EPA's Final Rule for Numeric Criteria for Nitrogen/Phosphorus Pollution in Florida's Inland Surface Fresh Waters. November 2010. Washington D.C.

Environmental Protection Agency (EPA). 2012a. Technical Support Document for U.S. EPA's Proposed Rule for Numeric Nutrient Criteria, Volume 1 Estuaries. Office of Water, Washington D.C. November, 2012

Environmental Protection Agency (EPA). 2012b. Water Quality Standards for the State of Florida's Estuaries, Coastal Waters, and South Florida Inland Flowing Waters. In Federal Register, Vol. 77, No. 243, December 19, 2012, Part II.

Florida Department of Environmental Protection (FDEP) 2012. Appendix B: Technical support document for U.S. EPA's proposed rule for Numeric Nutrient Criteria for Florida Estuaries, Coastal Waters, and South Florida flowing waters.

Florida Department of Environmental Protection. 2013a. Technical Support Document: Derivation of dissolved oxygen criteria to protect aquatic life in Florida's fresh and marine waters. DEP-SAS-001/13. Tallahassee, Florida.

Florida Department of Environmental Protection (FDEP) 2013b – Implementation of Florida's numeric nutrient standards. Document submitted to EPA in support of the Department of Environmental Protection's adopted nutrient standards for streams, spring vents, lakes, and selected estuaries. Tallahassee, Florida. April 2013.

Flannery, M. S., E. B. Peebles and R. T. Montgomery. 2002. A percent-of-flow approach for managing reductions of freshwater inflows from unimpounded rivers to southwest Florida estuaries *Estuaries* 25: 1318–1332.

Gleeson, J., I. R. Santos, D. T. Maher, and L. G. Smith. 2013. Groundwater-surface water exchange in a mangrove tidal creek: Evidence from natural geochemical tracers and implications for nutrient budgets. Marine Chemistry. 156. P27.

Greenwood, M. F. D. 2007. Nekton community change along estuarine salinity gradients: can salinity zones be defined? Estuaries and Coasts 30:537-542.

Greenwood, M. F. D., E. Malkin, E. B. Peebles, S. D. Stahl, and F. X. Courtney. 2008. Assessment of the value of small tidal streams, creeks, and backwaters as critical habitats for nekton in the Tampa Bay watershed. Report by the Fish and Wildlife Research Institute to the Florida State Wildlife Grants Program, Project SWG05-015.

Hindsley, P. R. and O. A. Morgan. 2014. The Sarasota Bay Economic Valuation Project: Phase II. Report submitted to the Sarasota Bay Estuary Program.

Holland, A. F., Sanger, D. M., Gawle, C. P., Lerberg, S. B., Santiago, M. S., Riekerk, G. H. M., Zimmerman, L. E., and Scott, G. I. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their wetlands. Journal of Experimental Marine Biology and Ecology. 298, 151-178.

Hothorn T., K. Hornik, and A. Zeileis. 2006. Unbiased recursive partitioning: a conditional inference framework. Journal of Computational and Graphical Statistics. 15:651–674.

Janicki Environmental, Inc. 2009. Examining the relationship between freshwater flows, nutrient loads, chlorophyll a concentrations and the distribution of benthic macro-invertebrates in the lower Alafia River. Report submitted to Tampa Bay Water. Clearwater Florida.

Janicki Environmental, Inc. 2011. Sarasota Bay Numeric Nutrient Criteria: Task 4 -Implementation Issues. Letter Memorandum Prepared for Sarasota Bay Estuary Program. Sarasota, Florida

Janicki Environmental, Inc. 2013 Southwest Florida Tidal Creeks Numeric Nutrient Project: Tasks 1 - 5 Report. Report submitted to the Sarasota Bay Estuary Program.

Joyner, D. 2015. Florida's numeric nutrient criteria and water quality credit trading. Presentation to the Technical Meeting of the Florida section of the American Water Resources Association. March 2015

Krebs, J. M., A. B. Brame, and C. C. McIvor. 2007. Altered mangrove wetlands as habitat for estuarine nekton: are dredged channels and tidal creeks equivalent? Bulletin of Marine Science. 80:839-861.

Krebs, J. M., S. S. Bell, and C. C. McIvor. 2013. Assessing the link between coastal urbanization and quality of the nekton habitat in mangrove tidal tributaries. Estuaries and Coasts. Published online 08 November 2013

Lewis, R. R., R. G. Gilmore, D. W. Crewz, and W. E. Odum. 1985. Mangrove Habitat and Fishery Resources of Florida, p. 281-336. In W. Seaman Jr. (ed.), Estuarine Habitat and Fishery Resources of Florida. Florida Chapter of the American Fisheries Society, Eustis.

MacDonald, T. C., R. E. Matheson, Jr., E. B. Peebles, R. H. McMichael, Jr. and M. F. D. Greenwood. 2010. Tidal Creeks as Nekton Habitat in the Tampa Bay Estuary. In: S.T. Cooper (ed.). Proceedings, Tampa Bay Area Scientific Information Symposium, BASIS 5: 20-23 October 2009. St. Petersburg, FL. pp. 319-330.

Malkin, E., D. Hollander, and E. Peebles. 2010. Using estuarine fish stable nitrogen isotopes to pinpoint land cover nutrient origins. In: S.T. Cooper (ed.). Proceedings, Tampa Bay Area Scientific Information Symposium, BASIS 5: 20-23 October 2009. St. Petersburg, FL. pp. 347-354.National Elevation Dataset. *National Elevation Dataset*. USGS, Aug. 2006. Web. Accessed 09 Apr. 2013.

Mallin, M. A., Parsons, D. C., Johnson, V.L., McIver, M. R. and H. A Covan 2004. Nutrient limitation and algal blooms in urbanizing tidal creeks. Journal of Experimental Marine Biology and Ecology. V298:211-231.

Muller, Robert. Dr. Fisheries Stock Assessment Division. Florida Wildlife Research Institute. St. Petersburg, FL. 33704

Peebles, E. B. 2002. Temporal resolution of biological and physical influences on bay anchovy (*Anchoa mitchilli*) egg abundance near a river-plume frontal zone. *Marine Ecololgy Progress Series* 237:257-269

Peebles, E. B. 2003 Presentation to Tampa Bay Water annual HBMP focus group meeting. Tampa Bay Water. Clearwater, Florida.

R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Rokach, L. and O. Maimon. 2008. Data mining with Decision Trees: Theory and Applications. Series in Machine perception artificial intelligence. Vol 69. World Scientific Publishing Co. Singapore.

Ross, S. T. Resource partitioning in fish assemblages: a review of field studies. Copiea, 9, 352-388

Sanger D, Bergquist D, Blair A, Riekerk G, Wirth E, Webster L, Felber J, Washburn T, DiDonato G, Holland AF (2011). Gulf of Mexico Tidal Creeks Serve as Sentinel Habitats for Assessing the Impact of Coastal Development on Ecosystem Health NOAA Technical Memorandum NOS NCCOS 136 Silver Springs, MD 64.

Sanger D, Blair A, DiDonato G, Washburn T, Jones S, Chapman R, Bergquist D, Riekerk G, Wirth E, Stewart J, White D, Vandiver L, White S, Whitall D (2008) Support for Integrated Ecosystem Assessments of NOAA's National Estuarine Research Reserves System (NERRS), Volume I:. The Impacts of Coastal Development on the Ecology and Human Well-being of Tidal Creek Ecosystems of the US Southeast NOAA Technical Memorandum NOS NCCOS 82 Silver Springs, MD 76.

SAS Institute Inc. 2014. SAS/STAT® 9.4 User's Guide. Cary, NC: SAS Institute Inc.

Sheldon, J. E. and M. Alber 2006. The calculation of estuarine turnover times using freshwater fraction and tidal prism models: a critical evaluation. Estuaries and Coasts. V29(1). 133-146.

Sherwood, E. T. 2010. Results and Management Recommendations from the 2006 Tampa Bay Tidal Tributaries Habitat Initiative. In: S.T. Cooper (ed.). Proceedings, Tampa Bay Area Scientific Information Symposium, BASIS 5: 20-23 October 2009. St. Petersburg, FL. pp. 355-373.

Smith, J., M. A. Burford, A. T. Revill, R. R. Haese, and J. Fortune. 2012. Effect of nutrient loading on biogeochemical processes in tropical tidal creeks. Biogeochemistry. 108:358-380.

Soranno, P. A., K. S. Cheruvelil, R. J. Stevenson, S. L. Rollins, S. W. Holden, S. Heaton, and E. Tong. 2008. A framework for developing ecosystem specific nutrient criteria: Integrating biological thresholds with predictive modeling. Limnol. and Oceanogr. 53:773-787.

TTHI 2008. Tampa Bay Tidal Tributary Research Team, E.T. Sherwood, editor. Tampa Bay Tidal Tributary Habitat Initiative Project: Final Report and Management Recommendations. Tampa Bay Estuary Program Technical Report #02-08. Report to the Pinellas County Environmental Fund. St. Petersburg, FL.

Weinstein, M. P., S. Y. Litvin, and M. G. Frisk 2012. Reversing two centuries of wetland degradation: can science better inform policy and practice. In: *Sustainability Science*. Weinstein and Turner Ed.. Springer, New York.

Wessel, M. R. and A. Janicki. Developing an index of phytoplankton biomass for Tampa Bay's lower Alafia River. In: S.T. Cooper (ed.). Proceedings, Tampa Bay Area Scientific Information Symposium, BASIS 5: 20-23 October 2009. St. Petersburg, FL. pp. 355-373

Wessel, M. R. 2011. Defining the Fish–Flow Relationship in Southwest Florida Tidal Rivers: Building on the Toolbox of Analytical Techniques. Technical report prepared for the Southwest Florida Water Management District Brooksville, Florida. Subjected to independent peer review by Dr. Kenneth Rose, Louisiana State University.

Wolanski, E. *Estuarine Ecohydrology*. Amsterdam: Elsevier, 2007. Print.

Yeager, L. A., J. M. Krebs, A. B. Brame, and C. C. McIvor. 2007. Comparison of juvenile blue crab abundances in three mangrove habitat types in Tampa Bay, Florida USA. Bulletin of Marine Science. 80:555-565.

Zar, H. J. 1984. Biostatistical Analysis. Prentice Hall. Englewood Cliffs, New Jersey. 07632