Final Report

Tampa Bay Tidal Tributary Habitat Initiative Project

Final Report and Management Recommendations
Submitted to the Pinellas County Environmental Fund by the Tidal Tributary Project Team

April 2008

Tampa Bay Tidal Tributary Habitat Initiative Project

Final Report and Management Recommendations
Submitted to the Pinellas County Environmental Fund
by the Tidal Tributary Project Team
April 2008

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

About this Report

The Tampa Bay Tidal Tributary Habitat Initiative is a multi-year, multi-entity research project designed to improve fisheries management in Tampa Bay by establishing the importance of tidal tributaries as estuarine habitat. Results of the research revealed the equally-important role that tidal tributaries play as "food factories" for estuarine-dependent species. In addition, the importance of watershed connectivity with the tidal tributary systems was a driving theme discovered throughout the multi-disciplinary project.

This Summary Report focuses on major research findings and implications for management of these critical habitats within the context of the mosaic of habitats comprising Tampa Bay. "Tidal tributaries" within Tampa Bay describe a variety of system types and include minor tidally influenced streams and creeks that discharge directly to the bay or into larger main-stem rivers, and dredged inlets and ditches with tidal connections to other larger systems. A limited amount of work has focused on the value of minor tidal tributaries, creeks and dredged inlets, collectively referred to in this report as "tidal tributaries" of Tampa Bay to estuarine resources.

The Report is structured around four primary project objectives to address this information gap:

- Assessing importance of minor tidal tributaries to nekton (fish and macroinvertebrates) in Tampa Bay;
- Evaluating effects of habitat parameters (water and sediment quality, watershed condition, and structural habitat) on nekton resources in minor tidal tributaries;
- Determining effects of food and sources of food production on nekton resources in these habitats; and
- Identifying potential impacts of physical, chemical and biological factors on habitat condition and trophic pathways in Tampa Bay tidal tributaries.

Management implications of the research findings and recommended actions, including suggested priority monitoring strategy elements to track and assess tidal tributary condition and effects of implemented management actions, are also outlined. Detailed technical reports of each of the major tasks are included on the attached CD.

Authors of this report are members of the Project Team. The final summary report was edited by Ed Sherwood, Tampa Bay Estuary Program.

This report should be cited as:

Tampa Bay Tidal Tributary Research Team, E.T. Sherwood, editor. 2008. 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.

The Tampa Bay Tidal Tributary Habitat Assessment and Management Project was funded through a grant provided by the National Fish and Wildlife Federation Pinellas County Environmental Fund, with matching funds and in-kind contributions provided by the Environmental Protection Commission of Hillsborough County, FWC Fish and Wildlife Research institute, Manatee County, Pinellas County, University of South Florida College of Marine Science, Tampa Bay Water, and the Tampa Bay Estuary Program. Two external science advisors, Fred Holland (NOAA) and Mark Peterson (University of Southern Mississippi) contributed greatly throughout the course of this study and to the final report.

1. Project Tasks and Team Members

More than 20 scientists participated in the Tampa Bay Tidal Tributary Habitat Initiative. Major Tasks, team members and their affiliations included:

Project Management

Holly Greening, Tampa Bay Estuary Program

Database Management, GIS and Quality Assurance

Greg Blanchard, Manatee County Environmental Protection Division
Kathleen O'Kiefe, FFWC Fish and Wildlife Research Institute

Water and Benthic Quality, Watershed Characterization and Assessment

Ed Sherwood, Environmental Protection Commission of Hillsborough Co. (now with the Tampa Bay Estuary Program)
Gerold Morrison, EPCHC (now with Terra Ceia Consulting, LLC)
Eric Fehrmann, Pinellas Co. Department of Environmental Management
Andy Squires, Pinellas County Department of Environmental Management
Mark Flock, Pinellas County Department of Environmental Management
Greg Blanchard, Manatee County Environmental Protection Division
Bob McConnell, Tampa Bay Water

Fish and Fish Habitat Characterization

Marin Greenwood, FFWC Fish and Wildlife Research Institute
Bob McMichael, FFWC Fish and Wildlife Research Institute
Tim MacDonald, FFWC Fish and Wildlife Research Institute
Ed Matheson, FFWC Fish and Wildlife Research Institute
Frank Courtney, FFWC Fish and Wildlife Research Institute
Justin Krebs, US Geological Survey
Carole McIvor, US Geological Survey

Fish Diet and Food Source (isotopic analyses)

Bob McMichael, FFWC Fish and Wildlife Research Institute
Ernst Peebles, Univ. of South Florida College of Marine Sciences
David Hollander, Univ. of South Florida College of Marine Sciences
Elon Malkin, Univ. of South Florida College of Marine Sciences

Interpretation and Management Strategy

Holly Greening, Tampa Bay Estuary Program
Lindsay Cross, Tampa Bay Estuary Program
Ed Sherwood, Tampa Bay Estuary Program

2. Project Summary

Tidal tributaries within the Tampa Bay estuary encompass a collection of system types that range in complexity of circulation from those with complete estuarine salinity gradients (i.e. completely freshwater head to tidally-influenced mouth) to those entirely subject to the circulation of adjacent tidal waters. However, all these systems exhibit the conceptual overlap of static and dynamic habitats across the estuarine gradient that has been eloquently described by Browder and Moore (1981). Much work has focused on embayments and large riverine habitats within Tampa Bay (Figure 1); however, few studies have focused on minor, low-salinity backwaters within the Tampa Bay estuary. These systems include coastal and riverine creeks with and without direct freshwater input, dredged inlets, and other "backwaters" –collectively termed "tidal tributaries" in this report. A major goal of this study was to describe the relative importance of these minor, tidal tributary areas to Tampa Bay estuarine resources and ecosystem processes.

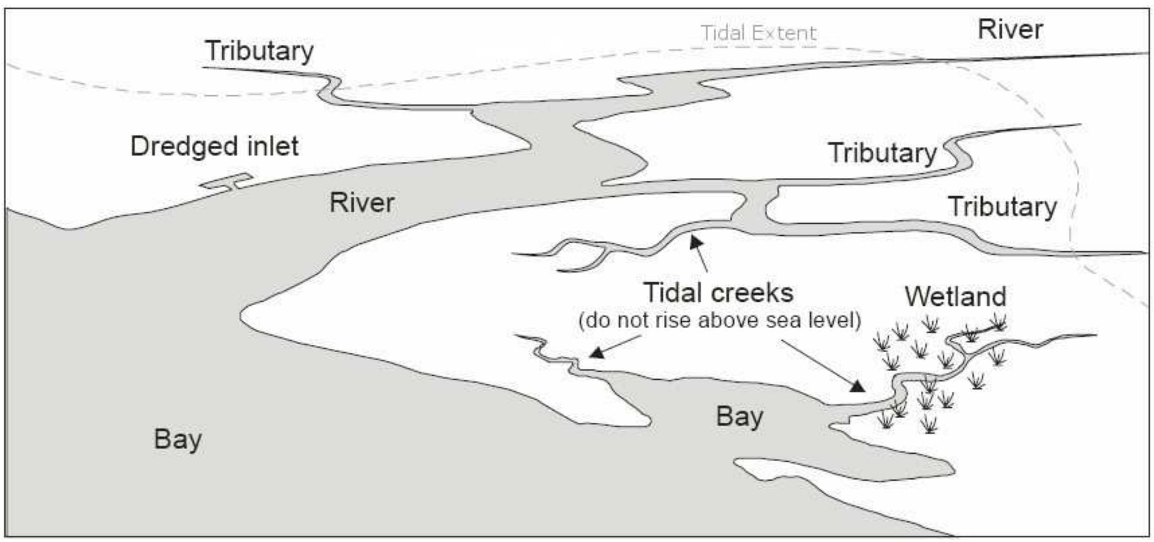


Figure 1: Schematic diagram of various "tidal tributary" systems typically encountered in the Tampa Bay estuary. Well-studied areas in Tampa Bay include bays and rivers.

Results of this two-year study show that tidal tributaries in Tampa Bay are:

- important to estuary-dependent fish populations, and
- provide both habitat and food sources to fish.

These areas provide a location for the production of benthic microalgae (BMA, see Figure 2 scenarios) and trophic intermediates including benthic macroinvertebrates (e.g. amphipods and mysids) that ultimately reach higher trophic levels and influence estuarine juvenile fish production (see Figure 3 scenarios).

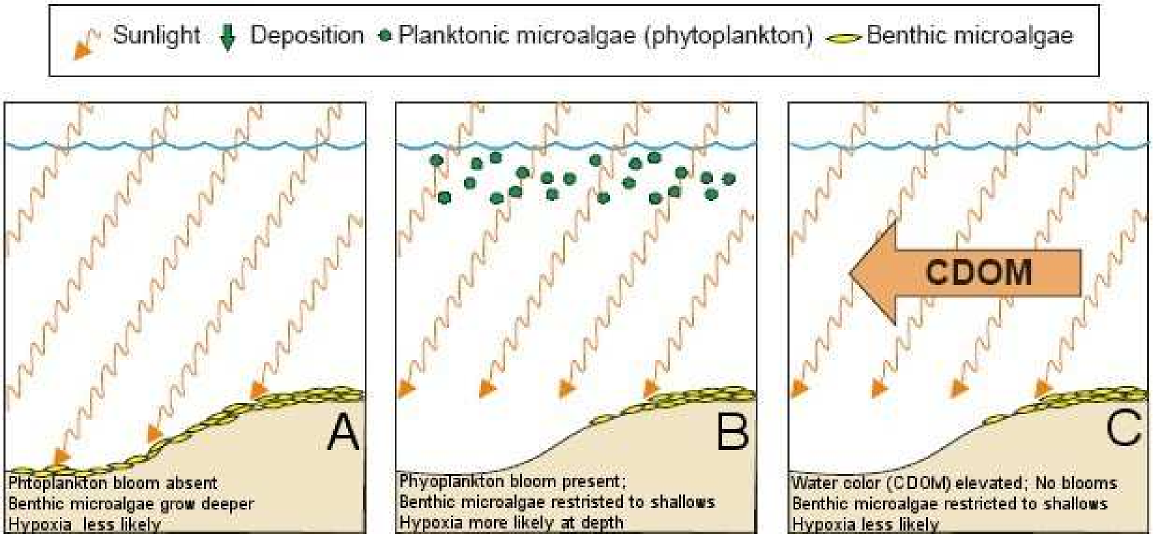


Figure 2: Schematic illustrating three light attenuation and depth scenarios for tidally influenced systems in Tampa Bay.

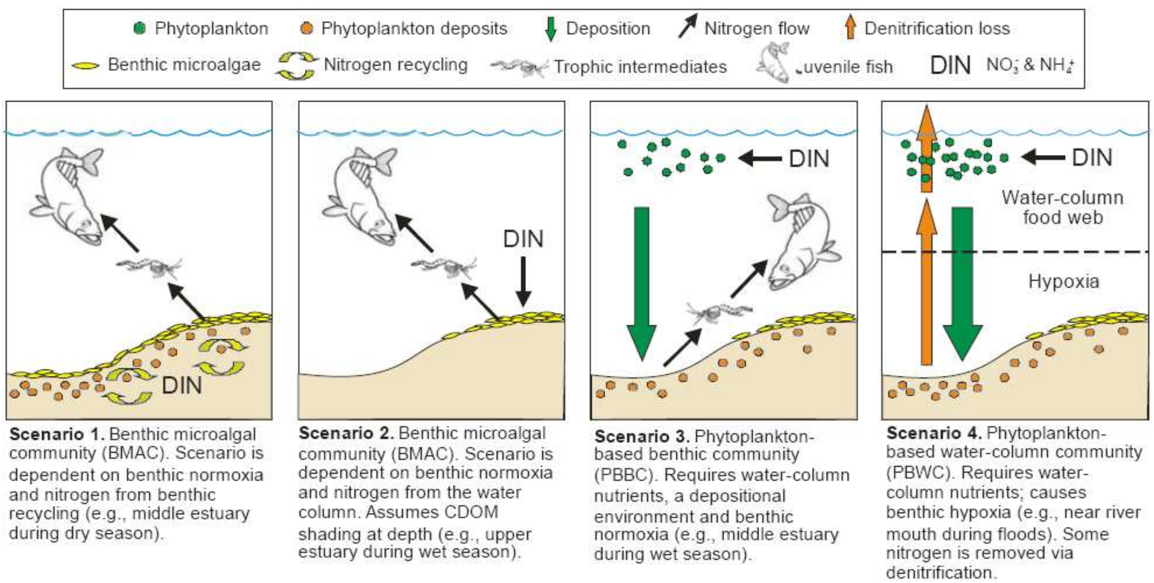


Figure 3: Schematic illustrating four nitrogen pathway scenarios for tidally influenced systems in Tampa Bay.

Many fish species use a continuum of habitat types at different life stages, including tidal creeks, tributaries, adjacent larger tidal rivers, small embayments, open bays, and in some cases, open ocean or gulf waters. Differences in the abiotic and biotic conditions governing fish utilization between the small, tidally-influenced systems were more pronounced than when these systems were compared to the larger waterbodies to which they generally drained. For an important fisheries species, the common snook, low-salinity tidal tributaries and backwater habitats were shown to provide a critically, unique nursery habitat along the "estuarine continuum."

A major driving force of higher trophic processes in Tampa Bay tidal tributaries appears to be the delivery pattern of freshwater inflow to these systems. Inflow from the contributing watersheds can regulate productivity in small tidal tributaries by governing the flux of watershed derived nutrients and constituents that decrease water clarity. Benthic microalgae, which were determined in large part to drive the primary productivity of minor tidal tributaries in Tampa Bay when eutrophication of the water-column is minimal, require adequate light for photosynthesis. Thus, due to their relative shallowness, these systems provide optimal areas for BMA growth when hydrologic and physico-chemical conditions are favorable. Sudden peak inflows or runoff can "flush" out juvenile nekton and sediments, deepen and channelize the systems, and introduce unsuitable water quality conditions within the tributaries, thereby reducing or eliminating BMA production and altering biotic communities (Figure 4).

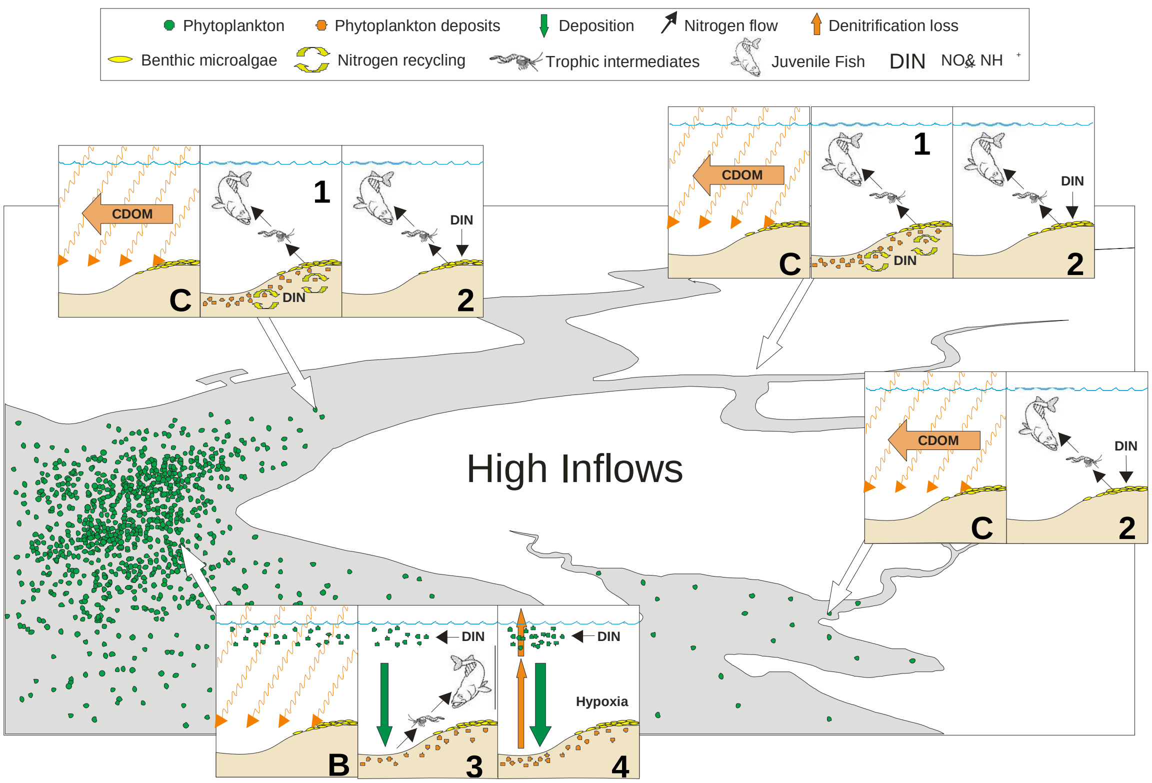


Figure 4: Estuarine processes within and adjacent to tidal tributary systems under high flow conditions. Light attenuation (A, B, C) and nitrogen pathway (1, 2, 3, 4) scenarios are indicated at various locations along the "estuarine continuum."

Similarly, low or no freshwater flow can result in high concentrations of water column algae and hypoxic conditions (low or no dissolved oxygen) due to prolonged residence times in the tidal tributaries, which in turn can also reduce the production of BMA, causing a cascading effect to benthic trophic intermediates and ultimately fishery resources (Figure 5). In terms of sustained ecological production, results of this study suggest that Tampa Bay tidal tributaries with minimally-altered, natural flow regimes exhibit the greatest estuarine value to fisheries resources through sustained BMA production and nitrogen cycling.

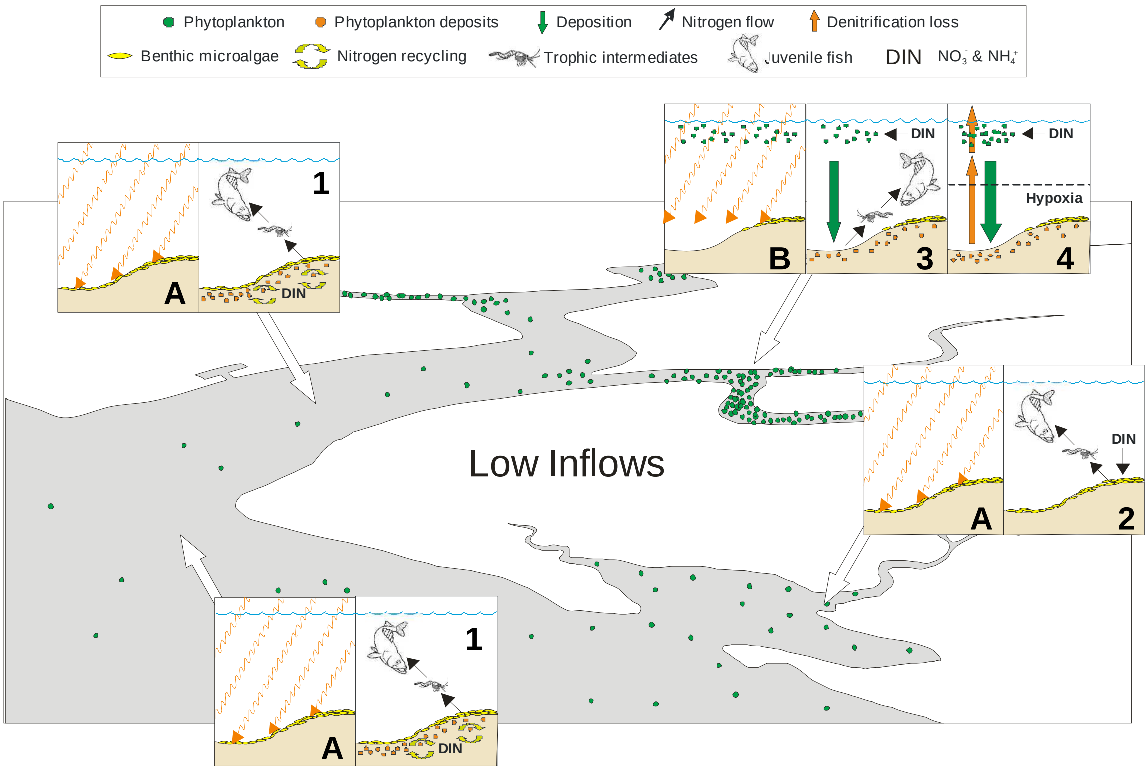


Figure 5: Estuarine processes within and adjacent to tidal tributary systems under low flow conditions. Light attenuation (A, B, C) and nitrogen pathway (1, 2, 3, 4) scenarios are indicated at various locations along the "estuarine continuum."

Furthermore, undeveloped watersheds, and the natural riparian vegetation associated with them, provide a buffer that controls water flow rates to tidal tributaries, retaining rainfall in wetlands and watershed soils during the wet season (thus reducing "flashiness") and gradually releasing water as sustained baseflow to these tidally-influenced systems during the dry season. In developed watersheds with greater amounts of impervious surfaces, rainfall is not as effectively retained in the watershed but can run off quickly and at higher volumes, causing rapid, "flashy" increases in flow and reducing the amount of water retained in the headwaters of a tidal tributary watershed. Results of this study found an apparent link between degraded water and benthic quality conditions in tidal tributaries with higher levels of landscape development along their banks, suggesting that the degree of landscape alteration can have an impact on in-situ abiotic conditions.

Recommended management actions from the Tampa Bay Tidal Tributary Habitat Initiative are focused on the following:

- Maintaining connectivity between open bay waters, tidal rivers and smaller, tidal tributaries to allow fish movement, water flow and nutrient flux. Fish require a mosaic of habitats throughout their life cycle, and management should be based on a system-wide scale. This concept is important in terms of the landscape's connectivity to the surface waters, as well as for processes internal to the hydrologic landscape that promote desirable conditions within the tributaries for nekton.

- Reducing "flashiness" of water flow to tidal tributaries, to promote natural hydrologic regimes and foster productivity of BMA and trophic intermediates. Maintaining and restoring natural wetlands, marshes and riparian corridors in tidal tributary watersheds, as well as considering additional methods of water retention and gradual release throughout their basins, are primary recommendations.

- Tracking condition of nursery functions and physical parameters in Tampa Bay tidal tributaries by monitoring freshwater inflow, watershed development, water quality indicators and nekton habitat use. This recommendation would allow for broader based studies and cataloging of minor tidal tributary systems whose functions are not yet defined.

- Improving public education and stewardship of tidal tributaries by promoting an Adopt-a-Creek program. Tidal tributaries are habitually overlooked in management scenarios and promoting their importance as sentinel habitats in the public perception can lead to an improved management response.

3. Major Technical Findings

3.1. Water and Habitat Quality

- Dissolved oxygen and salinity conditions within most of the tributaries were adequate to support a variety of estuarine biota for much of the sampling period; however, instances of hypoxia and supersaturated oxygen conditions were observed in more altered systems, particularly those tributaries draining to the Alafia River.

- Small tidal tributaries generally had higher nutrient concentrations than adjacent larger tidal rivers and nearshore bay waters to which they drained, but levels of sediment contaminants were generally lower within the tributaries.

- Isotopic results indicate that benthic microalgae (BMA) provide the basis of food webs in small tidal tributaries and that there were seasonal shifts in the production of BMA versus the overlying water-column within the majority of the small tidal tributaries during 2006.

- Sediment organic material is dominated by vascular plant material, but BMA recycle ammonium much more quickly and is the major source of ammonia within the tidal tributary systems. Nitrogen, the limiting nutrient within the studied systems, appeared to follow this trophic pathway within tidal tributaries: from sedimentary ammonia internally recycled from phytoplankton production in the fall to BMA production in the spring to benthic intermediates to fish.

- Tidal tributaries provided BMA a low-energy environment with organic accumulation for sustained production.

3.2. Benthos and Nekton Use of Tidal Tributaries

- A tributary's proximity to the bay was more important than season or whether a fish was collected in a small tributary or an adjacent larger waterbody in describing nekton diet and community structure.

- Most nekton species use both minor tidal tributaries and larger adjacent waterbodies, so both are important for management of estuary-dependent resources.

- For fish, the system-scale (i.e., the bay, river, minor tributaries and backwater systems) is the appropriate management scale for essential fish habitat. Both tidal tributaries and larger adjacent waterbodies are needed to support the suite of species living in estuarine areas.

- Minor tidal tributaries appear to be critical as "food factories" (especially with BMA-based sources) as well as the more traditional habitat nursery areas for fish. These areas may also provide "keystone prey species" (amphipod and mysid species) not as readily available in mainstem rivers and nearshore bay areas.

- Differences in fish diet were very small between tributaries and adjacent habitats, much smaller than differences between seasons or different tributaries. Diets reflected location of feeding in relation to geographic and physico-chemical features of the environment. Fish feeding in the upstream, low-salinity tributaries tended to have diets composed of prey typical of more freshwater habitats (e.g., insects).

- Isotopic signatures from fish guts can indicate the degree of residency of the fish. Diets of fish collected in smaller tributaries upstream are based on watershed sources of nitrogen, while diets of fish collected in larger tributaries downstream are based on nitrogen originating in Tampa Bay. Resident fish obtained their food biomass (primarily BMA) from small tidal tributaries.

- Common snook abundance was between 100% to 3600% higher in small tributaries than in adjacent larger rivers or nearshore bay waters. This was the most economically important species of nekton that consistently showed this pattern.

3.3. Watershed Connectivity to Tidal Tributaries

- Location of the systems both on a micro-(i.e. along a riverine or embayment gradient) and on a macro-(i.e. within the Tampa Bay estuary) geographic scale influenced the overarching abiotic and biotic conditions in tidal tributaries.

- Land use and watershed metrics within 100-m corridors along the tidal tributaries studied were more closely associated with tidal tributary abiotic conditions than watershed metrics encompassing the tidal tributaries' full drainage catchment.

- Landscape development intensity along the tributaries' immediate corridors was more closely associated with in-situ water and sediment quality conditions than with the tributaries' biotic resources (i.e., benthos and nekton).

- Landscape development within the watersheds and corridors of the tidal tributaries studied did not adequately represent end-member systems (i.e.

minimally and highly altered systems) and may explain the lack of more significant association with the biotic resources of the creek systems.

- Watershed physical characteristics and tidal tributary position along the estuarine continuum appear to have influence on tidal tributary biota largely through changes in tributary ‘flashiness’ (or inflow variability) and salinity conditions within the systems.

- Methods need to be developed to quantify the stream morphology of low hydraulic gradient tidal tributaries.

4. Project Introduction

Tidal creeks have a major influence on the productivity and diversity of natural resources in many estuarine systems (Holland et al. 2004). Based on preliminary work in Tampa Bay, minor, tidally-influenced systems which include coastal and riverine creeks with and without direct freshwater input, dredged inlets, and other "backwaters" -- collectively termed "tidal tributaries" in this report -- appear to be subject to a range of anthropogenic impacts and are important nursery habitat for many species of fishery value. However, not enough is known of the conditions within these minor systems or the faunal communities that utilize these areas to develop an effective management strategy. In December 2003, the Tampa Bay Estuary Program's Technical Advisory Committee identified assessing the importance of tidal tributaries as the top-ranked research need (of 54) in reaching Tampa Bay's Comprehensive Conservation Management Plan goals. As a result, TBEP's Policy Board approved the development of restoration and protection goals for tidal tributaries as a management priority.

The recognition of tidal tributaries as potentially important habitats is justified as many are small and have limited watersheds which are easily altered by human land development. Studies from other areas in the Southeast U.S. describe tidal creeks as "sentinel" habitats in that their relatively small scale often supersedes their important estuarine values and functions (Holland et al. 2004). The Florida Fish and Wildlife Conservation Commission lists the status of Florida's coastal tidal streams as 'poor and declining' (Gordon et al. 2005). A 1986 study of thirty representative tidal tributaries around Tampa Bay suggested that 60% were natural or restorable (TBPRC 1986), indicating that these important habitats are not beyond salvation in this area and still provide important function to estuarine processes. Yet until recently, very little formal study of the ecology of Tampa Bay tidal tributaries has taken place.

Initial studies by researchers from the US Geological Survey have noted the importance of tidal tributaries and associated habitats for many highly-valued, estuarine species including blue crab, common snook, and red drum (Krebs et al. 2007; Yeager et al. 2007). In addition, work initiated in Sarasota County on coastal creek systems has focused on rapidly cataloging the relative health of these habitats using a host of physical and biological metrics (Estevez 2007). In our current study, we aimed to advance the science of "tidal tributaries" in Tampa Bay by comparing their ecology with surrounding areas such as open-bay and river shorelines and describing links to watershed processes that may have an effect on their overall ecosystem value and current condition in comparison to other more studied systems in the Bay.

More than 300 named and un-named creeks and tributaries have been identified in the Tampa Bay watershed, including more than 150 which are tidally-influenced. Tidal tributaries occur in all areas of the bay (Figure 6) and include urban, residential, agricultural, mosquito ditches, and relatively unaltered drainage areas that occur at or below sea level.

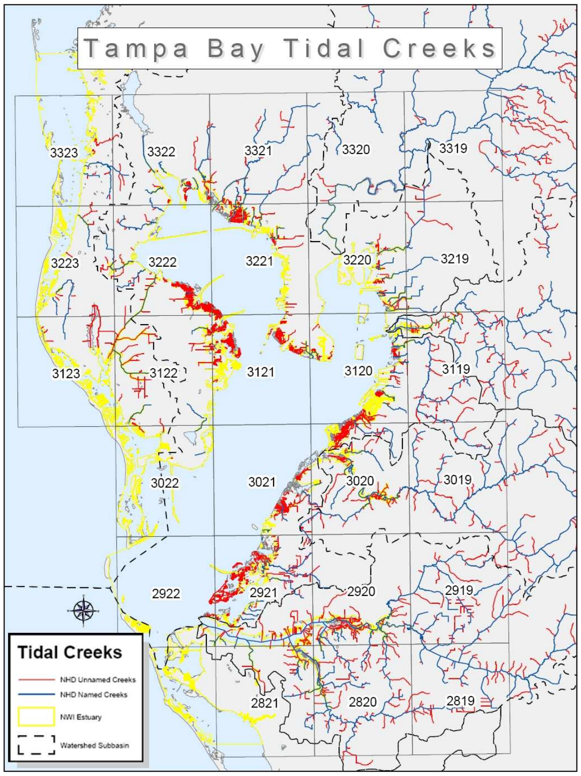


Figure 6: Named and unnamed tributaries and creeks in the Tampa Bay watershed, (Source: K. O'Kiefe, FWC FWRI 2006).

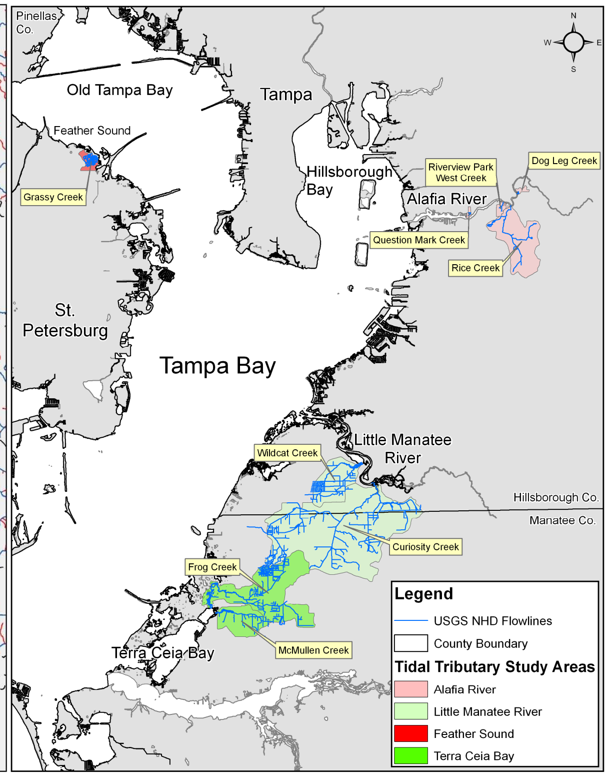


Figure 7: Overview map showing the tidal tributary locations studied within Tampa Bay. "Green" areas were selected a priori as less altered systems, while "red" areas were selected as altered.

The objectives of the Tampa Bay Tidal Tributary Habitat Initiative were to improve protection and management of these minor, tidally-influenced systems in the Tampa Bay estuary by:

1) characterizing the fisheries resources of Tampa Bay tidal tributaries,
2) determining effects of various habitat parameters (e.g., watershed condition, water quality, structural habitat, etc.) on fisheries resources in tidal tributaries,
3) developing measurable goals, management recommendations, and a Tidal Tributary Management Strategy based on study results, and
4) communicating results to managers and the public to support informed decision-making regarding preservation or restoration of tidal tributary habitats.

Assessment of minor, tidally-influenced systems and their adjacent river/bay habitats was conducted in altered and unaltered watersheds in Pinellas, Manatee and Hillsborough counties (Figure 7). We hypothesized that tidal tributaries are critical habitats within the Tampa Bay ecosystem and aimed to assess the extent of their importance in relation to adjacent riverine and bay habitats which have been studied in greater detail in the past. As a further working hypothesis, we postulated that water and sediment quality and biological resources in tidal tributary systems whose watersheds have been modified by human activities will be degraded relative to those in tidal tributaries with less altered watersheds.

Results of this project were used to develop recommended measurable natural resource restoration and protection targets for minor, tidally-influenced systems. We anticipated that targets for water and sediment quality, habitat structure, freshwater inflow, and tidal exchange would be important considerations. Recommendations for elements of a monitoring program for Tampa Bay tidal tributaries were developed based upon the project results, with the objective of tracking recommended restoration and protection targets in the future through additional monitoring programs. Elements of a proposed Tidal Tributary Management Strategy include potential restoration objectives, focused monitoring of tidal tributary restoration projects, and an enhanced assessment of other tidal tributary systems in Tampa Bay to determine the effectiveness of these strategies and progress towards the established targets throughout the Tampa Bay estuary.

5. Project Methodologies

5.1. Tidal Tributary Site Selection and Classifications

Sample areas were chosen such that tidal tributary watersheds with more or less alteration (based on the consensus of the Tidal Tributary Project Team) were represented (Table 1). Reconnaissance of the four selected watersheds was conducted in order to assess the habitat conditions (e.g., water depth, inundation of shoreline vegetation, substrate type) in the sampling areas. Several tidally-influenced systems were selected for study in each watershed based upon this initial reconnaissance. Sites within each of the four watersheds include at least one minor "inside" tributary and a downstream contiguous "outside" sample area (larger river or estuary embayment). A number of the areas investigated did not have names associated with them, so the Tidal Tributary Working Group provided the systems with names as indicated by quotes in Table 1. Aerial photographs of all sampled areas and their adjacent watersheds are shown in Figures 8 – 10 and general descriptions of each tributary follow.

Table 1: Classification and sampling effort for tidal tributary systems sampled during the Tampa Bay Tributary Habitat Initiative.

Major Watershed	Tributary	Tidal System Type	Water Quality Samples	Benthic Samples	Nekton Samples	Isotopic Samples
Alafia River (a priori more altered)	"Dog Leg Creek"	Dredged Inlet	12	2	48	.
	"Question Mark Creek"	Dredged Inlet	12	3	48	36
	Rice Creek	Minor Tributary	16	4	48	26
	"Riverview Park West Creek"	Dredged Inlet	12	3	48	38
	Mainstem Alafia River	Major River	160	18	168	.
Little Manatee River (a priori less altered)	Curiosity Creek	Minor Tributary	28	6	120	71
	Wildcat Creek	Minor Tributary	28	6	120	121
	Other Monitored Tributaries	Minor Tributary	7	.	.	.
	Mainstem Little Manatee River	Major River	12	12	144	.
Feather Sound (a priori more altered)	Grassy Creek	Tidal Creek	23	12	96	92
	Other Monitored Tributaries	Tidal Creek	10	.	.	.
	Adjacent Old Tampa Bay	Embayment	137	14	52	.
Terra Ceia Bay (a priori less altered)	Frog Creek	Minor Tributary	24	6	217	84
	McMullen Creek	Minor Tributary	12	6	82	83
	Adjacent Terra Ceia Bay	Embayment	12	11	102	.

- "Dog Leg Creek" is an approximately 300 m creek-like, dredged inlet that enters the Alafia River at about river kilometer 11 (Figure 8, bottom right).
- "Question Mark Creek" is an approximately 400 m creek-like, dredged inlet that enters the Alafia River at about river kilometer 5 (Figure 8, top left).
- Rice Creek, with its approximately 300 m tidally-influenced sampling area, was the only available named creek on the Alafia River. It had a larger,

more defined watershed than the other sampled tributaries on the Alafia River and entered at approximately river kilometer 9 (Figure 8, bottom left).

- "Riverview Park West Creek" is an approximately 250 m creek-like, dredged inlet that enters the Alafia River at about river kilometer 9 (Figure 8, top right).
- Curiosity Creek, with its approximately 1 km tidally-influenced sampling area, is a relatively unaltered creek draining to the Little Manatee River at approximately river kilometer 12 (Figure 9, top).
- Wildcat Creek, with its approximately 1 km tidally-influenced sampling area, is a relatively unaltered creek draining to Hayes Bayou in the Little Manatee River at approximately river kilometer 8 (Figure 9, bottom).
- Grassy Creek, with its approximately 1 km tidally-influenced sampling area, was considered a relatively altered tributary draining directly to Old Tampa Bay (Feather Sound area specifically) because of extensive mosquito ditching and location of a golf course within its watershed (Figure 10, left).
- Frog Creek, with its approximately 3 km tidally-influenced sampling area, was considered a relatively unaltered tributary draining directly to Tampa Bay (via Terra Ceia Bay) (Figure 10, top right).
- McMullen Creek, with its approximately 1.5 km tidally-influenced sampling area, was also considered a relatively unaltered tributary draining directly to Tampa Bay (via Terra Ceia Bay) (Figure 10, bottom right).

5.2. Project Components

Following initial site evaluation, various methods for gear deployment and retrieval were tested for sampling nekton (fishes and decapod crustaceans) in these compact areas prior to the initiation of the project. A multi-disciplinary sampling regime began during January 2006 to assess the water, sediment, benthos, and fisheries resources within select tidal tributaries of Tampa Bay and the resulting flow of nitrogen sources, identified in this study as the limiting nutrient in these systems, from their watersheds to the fish utilizing these tidal tributary systems. Sampling was conducted on a monthly basis for in-situ water quality parameters and fish utilization of the tributaries, while sediments, benthos, and isotopic analyses were conducted during dry- (nominally March-May) and wet- (nominally August-October) season sampling events. Total sample sizes for analyses from each project discipline are noted in Table 1. Watershed assessments were developed from existing GIS resources, while shoreline habitat characterizations were produced during the time nekton surveys were conducted. Detailed sampling procedures are outlined in the quality assurance project plan (Blanchard 2006) and the attached technical reports for each of the project disciplines. Parameters investigated for each of the project disciplines included the following:

Water Quality

- In-situ physical parameters (depth, water-column temperature, dissolved oxygen, salinity, conductivity, pH and secchi depth)
- Color
- Turbidity
- Total suspended solids (TSS)
- Chlorophyll-a
- Total kjeldahl nitrogen (TKN)
- Dissolved ammonia nitrogen
- Dissolved nitrate + nitrite nitrogen
- Dissolved orthophosphate
- Total phosphorus
- Reactive silica
- Fecal coliforms & Enterococci

Sediment Quality

- Silt-Clay Percentage
- Metals
- Poly-aromatic hydrocarbons (PAHs)
- Poly-chlorinated biphenyls (PCBs)
- Pesticides

Biological Communities

- Benthic macrofauna
- Juvenile and Adult Nekton (fish and decapod crustaceans)

Isotopic Analyses

- δN^{15} and δC^{13} derived from fish tissues, phytoplankton, benthic microalgae, mangroves, emergent vegetation, upland trees, sedimentary organic matter, and sedimentary pore water

Watershed Condition

- % Impervious surfaces (100-m corridor and basin level)
- Landscape Development Intensity Index (100-m corridor and basin level)

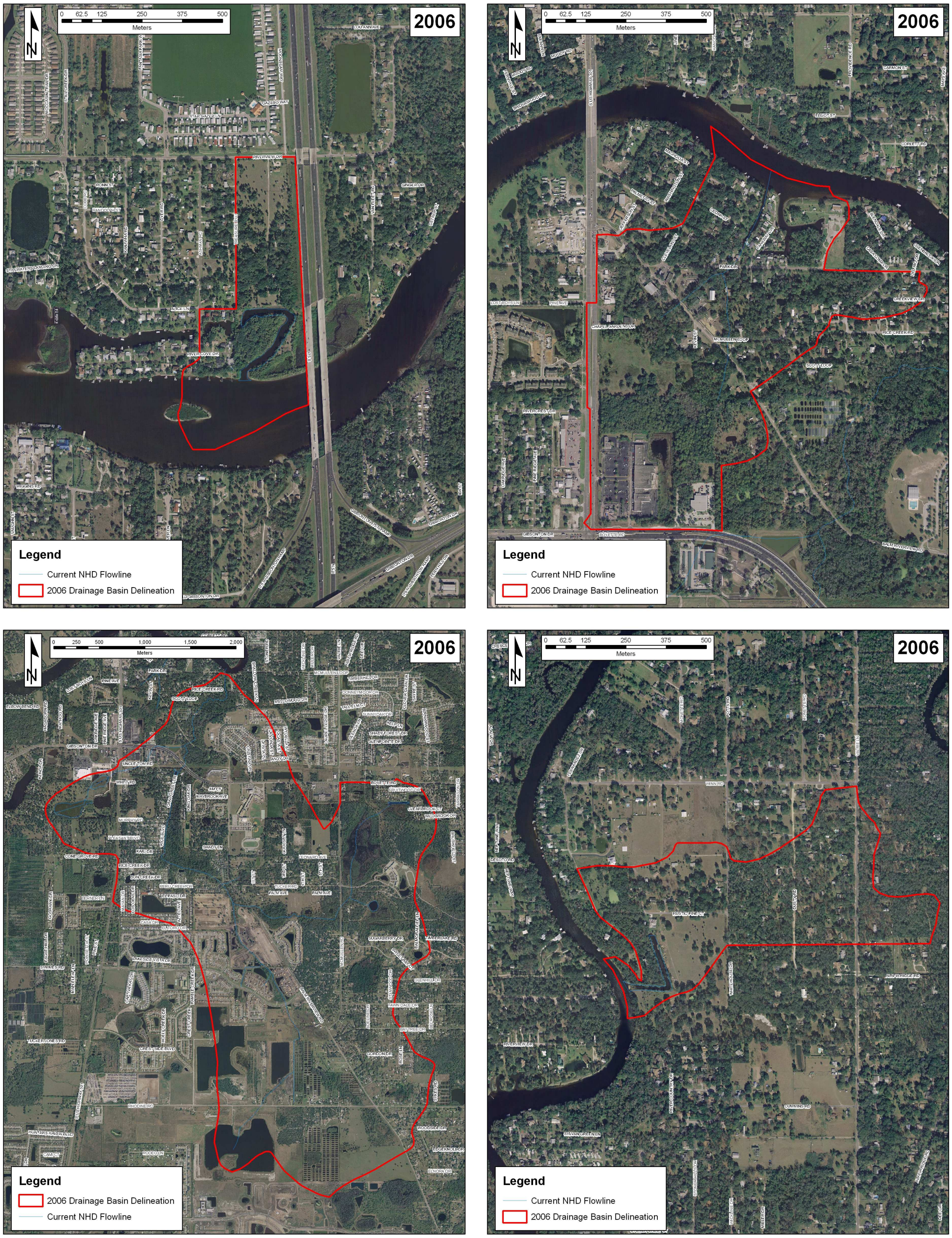
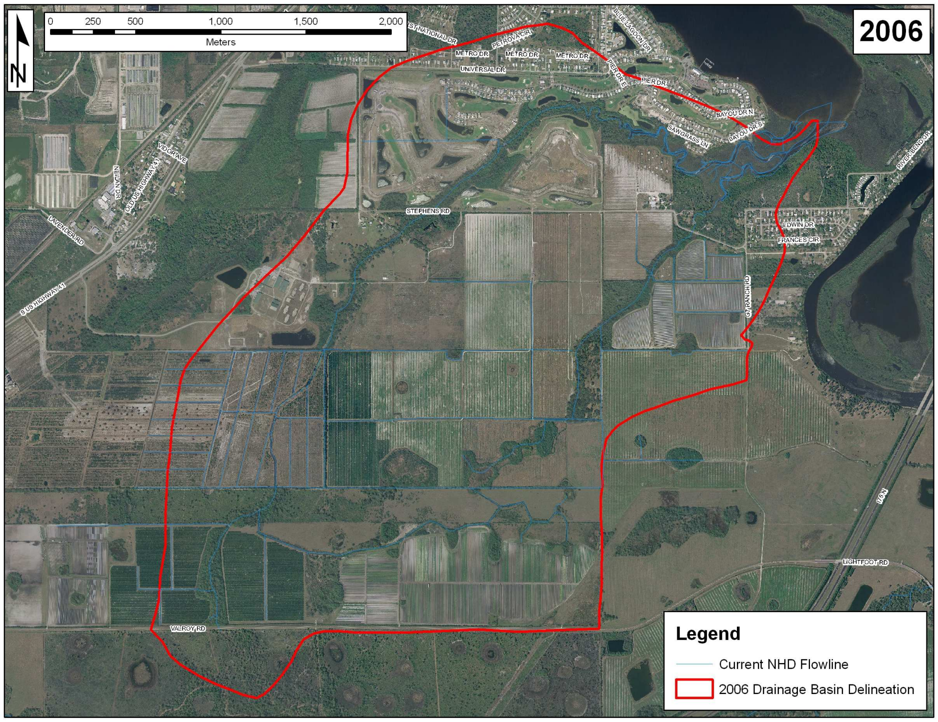


Figure 8: Tidal tributaries draining to the Alafia River. Top Left=”Question Mark Creek”; Top right=”Riverview Park West Creek”; Bottom Left=Rice Creek; Bottom Right=”Dog Leg Creek.”



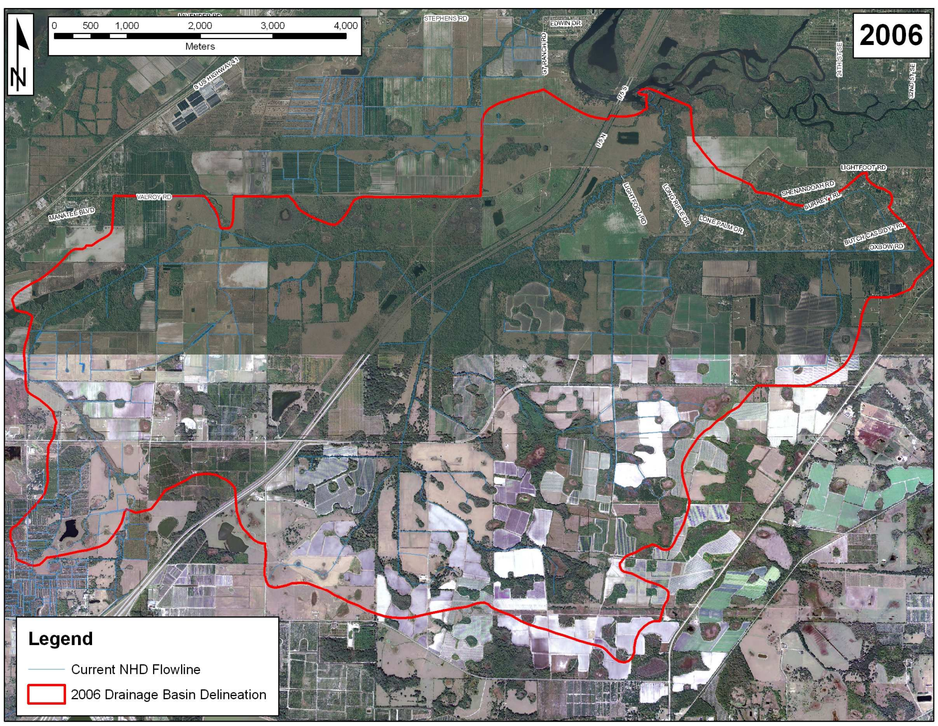


Figure 9: Tidal tributaries draining to the Little Manatee River. Top=Wildcat Creek; Bottom=Curiosity Creek.

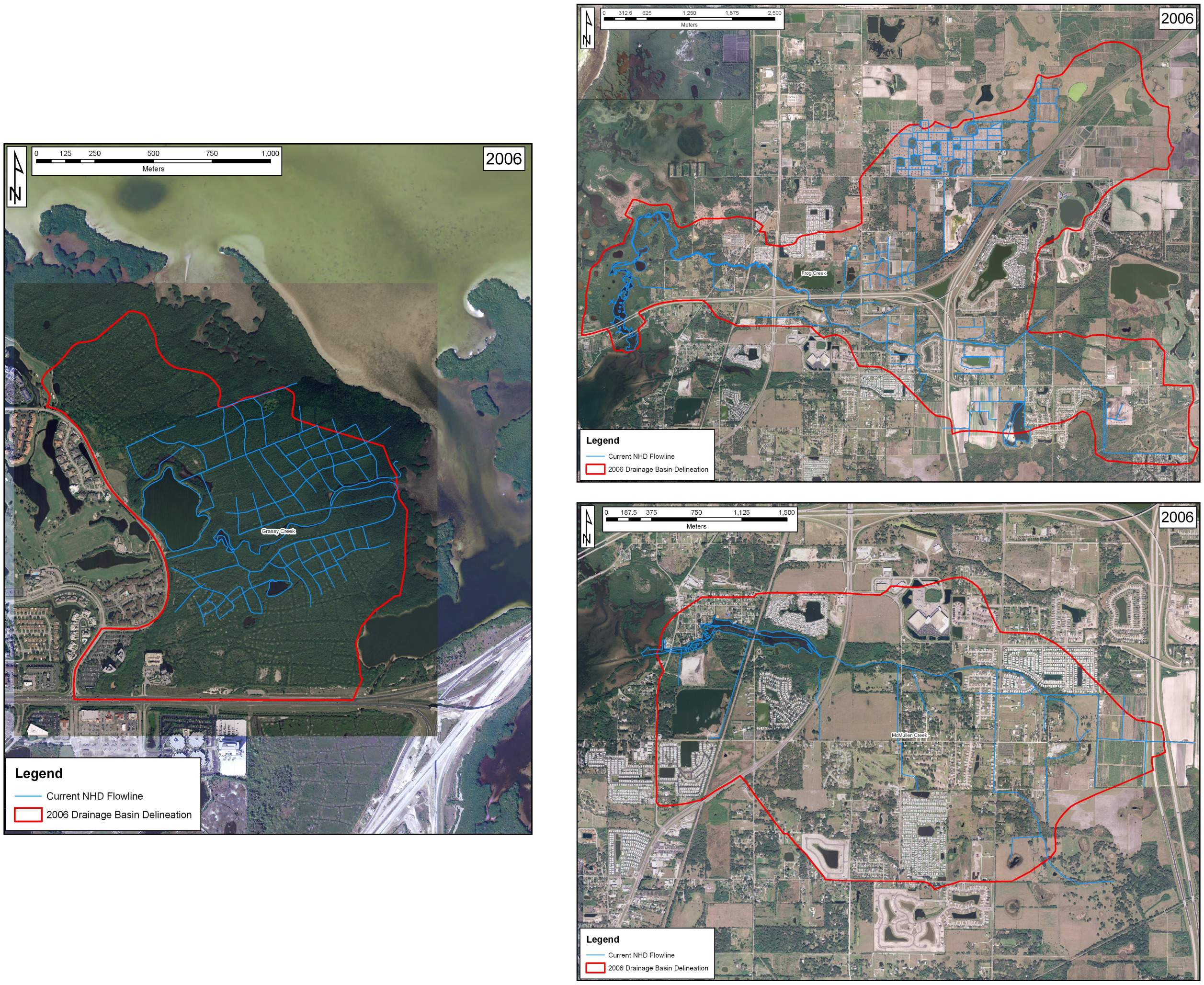


Figure 10: Tidal tributaries draining to Feather Sound (Left=Grassy Creek) and Terra Ceia Bay (Top Right=Frog Creek; Bottom Right=McMullen Creek).

6. Project Results

6.1. Water and Habitat Quality

6.1.1. Water Quality Was Distinct Among Tidal Tributaries & Between Receiving Waterbodies

Physical water quality parameters (i.e. temperature, salinity, and dissolved oxygen) varied among the tidal tributaries investigated and between the tributaries and the larger waterbodies to which they drained. Influence of tide on water quality was most pronounced in Grassy Creek (discharging to Feather Sound) and Question Mark Creek (discharging to the lower Alafia River) where overall salinities were typically greater than the other tributary systems; however, due to the relative shallowness of the majority of tributaries studied (~1 m or less), very little water column stratification existed within the majority of the tributaries. Water column stratification can have a negative effect on dissolved oxygen concentrations in tidally-influenced systems – this has become particularly apparent in major rivers draining to Tampa Bay that are exacerbated by nutrient enrichment of their contributing drainage basins and ultimately resulting in depressed bottom dissolved oxygen concentrations (see Figure 11 mainstem Alafia River).

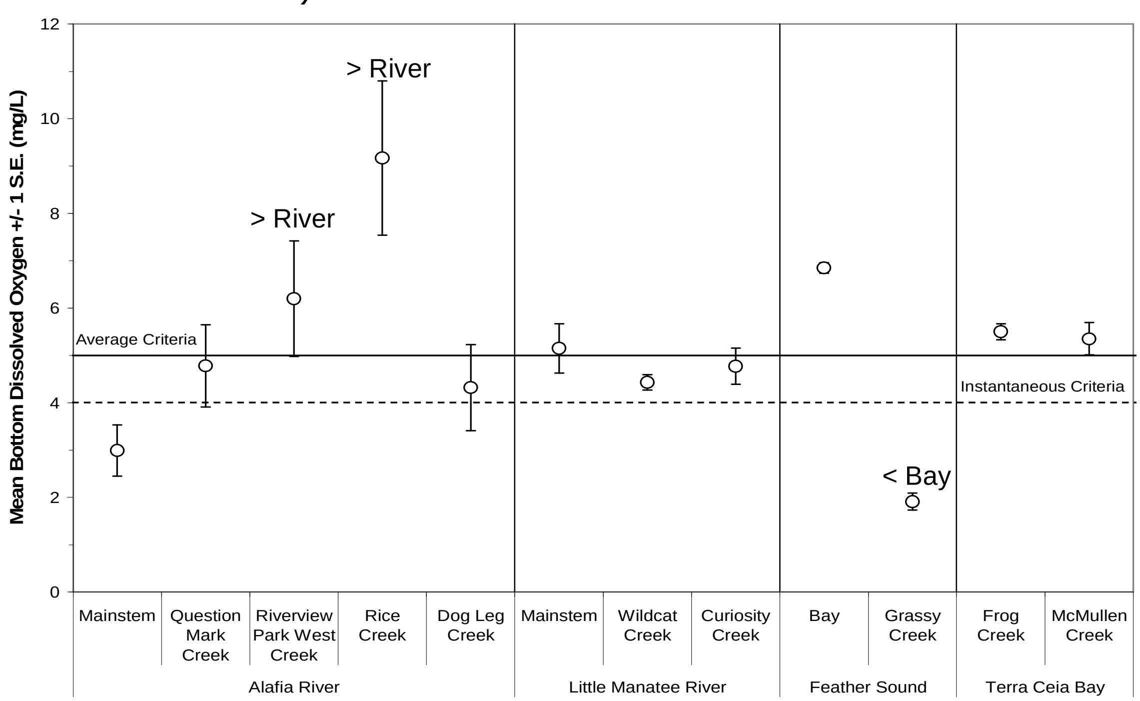


Figure 11: Mean bottom dissolved oxygen concentrations within the tidal tributaries and adjacent larger waterbodies during 2006. Reference lines indicate Florida marine criteria for dissolved oxygen. Significant differences ($P < 0.05$) in dissolved oxygen concentrations between individual tidal tributaries and the areas to which they drain are designated above the respective points.

With the exception of Grassy Creek which generally had low overall dissolved oxygen levels throughout its water column (Figure 11), the other tidal tributaries studied during 2006 typically did not have low dissolved oxygen concentrations in their bottom water column relative to the surface layer. However, the tributaries draining to the Alafia River did show signs of significant algae blooms (chlorophyll-a concentrations in excess of 100 ug/L) and supersaturated oxygen conditions in their surface layers throughout much of the 2006 sampling period. Annual average chlorophyll-a concentrations of the four tributaries draining to the Alafia River and the main stem Alafia River itself exceeded state estuarine (11 ug/L) and freshwater stream (20 ug/L) chlorophyll-a guidelines (Figure 12). The two tributaries draining to the Little Manatee River exceeded the state estuarine chlorophyll-a guideline as well. Tributaries draining to Feather Sound and Terra Ceia Bay did not exceed either the estuarine or freshwater standards.

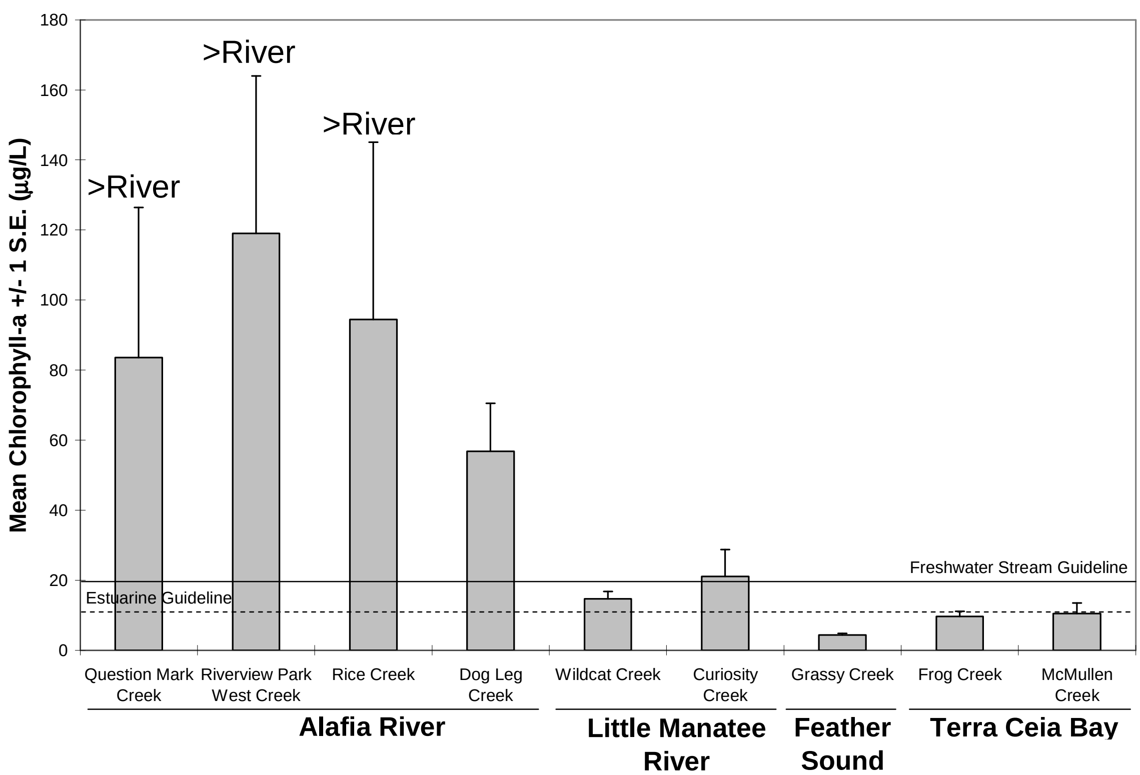


Figure 12: Mean chlorophyll-a concentrations within the tidal tributaries during 2006. Reference lines indicate Florida state guidelines used to determine nutrient impairment in freshwater and estuarine systems. Significant differences ($P < 0.05$) in chlorophyll-a concentrations between individual tidal tributaries and the Alafia River are noted.

Of the four tidal tributary watersheds investigated, the selected tributaries draining to the Alafia River likewise had the "poorest" water quality conditions in terms of nutrient enrichment. Concentrations of nitrogen and phosphorus within the Alafia River tributaries tended to be greater than in the main-stem river as well as greater than the other tidal tributary systems studied that drained to the Little Manatee River, Feather Sound, and Terra Ceia Bay (Figure 13). In all the systems monitored, molar ratios for total and inorganic nutrient constituents (i.e., dissolved inorganic nitrogen:soluble reactive phosphorus) were below Redfield's ratio of 16:1, indicating that nitrogen was the limiting nutrient to primary production in these systems. The influence of enriched nutrient conditions in the Alafia River tidal tributaries was apparent when viewed in the context of observed phytoplankton blooms throughout this estuarine system during 2006.

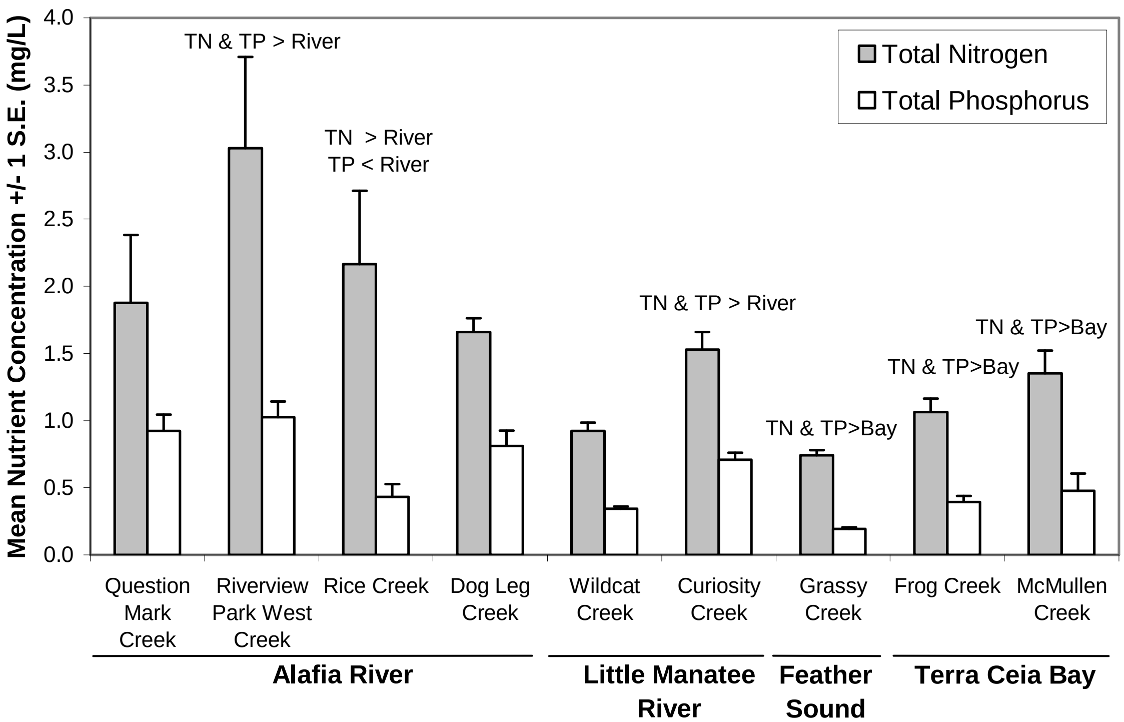


Figure 13: Mean nutrient concentrations within the tidal tributaries during 2006. Significant differences ($P < 0.05$) in total nitrogen (TN) and total phosphorus (TP) concentrations between the tidal tributaries and the areas to which they drained are designated above the respective bars.

6.1.2. Sediment Quality in Tidal Tributaries Better Than in Receiving Waters

A limited number of sediment samples were collected in the tidal tributaries during the spring, dry season and the fall, wet season during 2006 to assess sediment composition and contamination. Those tidal tributaries classified as dredged inlets and that drained to the Alafia River tended to have muddier sediments than tidal tributaries which drained to the other watersheds. Overall sediment contamination levels in the tidal tributaries were generally lower than baseline levels from the larger rivers or embayments to which they drained. However, the one notable exception was "Riverview Park West Creek" in the Alafia River watershed which had relatively high contaminant levels for most heavy metals, poly-aromatic hydrocarbons (PAHs) and DDT (Table 2). Several contaminants were identified as exceeding their threshold effects level (TEL; benthic biota effects may occur) and one parameter (a PAH) exceeded its probable effects level (PEL; benthic biota effects are likely) (MacDonald 1994).

Table 2: Number of individual sediment contaminant threshold effects level exceedances observed in the tidal tributary systems during 2006 for major contaminant types. * indicates 1 probable effects level exceedance for a PAH in the "Riverview Park West Creek."

Major Watershed	Tributary	Tidal System Type	# of Samples	# of Sediment Threshold Effects Level Exceedances			
				Metals	PCBs	PAHs	Pesticides
Alafia River (a priori more altered)	"Dog Leg Creek"	Dredged Inlet	2	2	.	6	.
	"Question Mark Creek"	Dredged Inlet	4	6	.	17	.
	Rice Creek	Minor Tributary	4	2	.	3	.
	"Riverview Park West Creek"	Dredged Inlet	3	13	.	36*	6
Little Manatee River (a priori less altered)	Curiosity Creek	Minor Tributary	8	4	.	.	.
	Wildcat Creek	Minor Tributary	7	3	.	.	.
Feather Sound (a priori more altered)	Grassy Creek	Tidal Creek	14	7	.	1	.
Terra Ceia Bay (a priori less altered)	Frog Creek	Minor Tributary	6	5	.	.	.
	McMullen Creek	Minor Tributary	7	7	.	1	.

6.2. Benthos & Nekton Community Use of Tidal Tributaries

6.2.1. Benthic Community Was Seasonally Variable

Benthic biota sampling within the tidal tributaries was conducted during two seasonal sampling events in the spring, dry season and the fall, wet season using petite ponar ($0.023m^2$) and Young grab ($0.04m^2$) samplers. Although relatively few samples were collected in each tributary, a seasonal pattern in benthic species composition and abundance was observed. This pattern reflected the recruitment of crustacean taxa during the spring season and presumed freshwater inflow to the tributaries or adjacent waterbodies which influenced salinity conditions in the tributaries during the fall. Crustacean taxa dominated the collections during the spring sampling event in all areas monitored including in the adjacent waterbodies to which the creeks generally drained (Figure 14), while insect taxa composition became more pronounced during the fall event in the riverine tributaries when salinities were substantially lower in the creeks. Polychaetes were generally more abundant in the tributaries draining to the embayments.

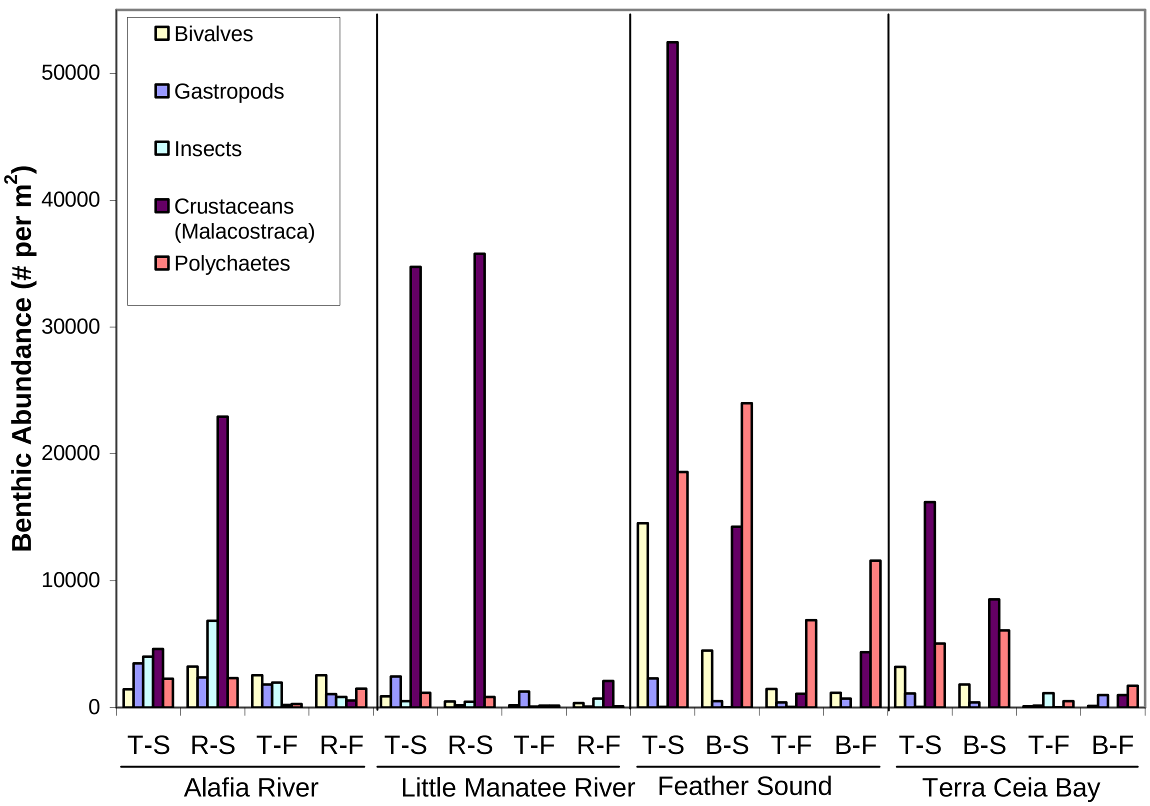


Figure 14: Abundance of major benthic taxa in the tidal tributaries (T) relative to the riverine (R) or embayments (B) to which they drained during spring (S) and fall (F) 2006.

6.2.2. *Estuarine Trophic Intermediates Dominant in the Spring*

Several trophic intermediates were represented in the benthos and may be important to the nekton resources found within the tidal tributaries. Amphipod and mysid crustaceans were found in particularly higher abundance within the tidal tributaries during the spring, dry season sampling event (Figures 15). Amphipods and mysids are important prey items of fish and the seasonal shift in their abundance may reflect a combination of factors including their life history (i.e. seasonal recruitment), changes in tributary water quality associated with inflow, and/or the availability of benthic microalgal communities within the tidal tributaries. Proportional abundance of insect taxa (particularly *Polypedilum* spp.) indicative of enriched nutrient conditions was greater for the tributaries draining to the Alafia and Little Manatee Rivers and Terra Ceia Bay with these areas also having a general increase in their relative abundance during the fall sampling event (Figure 14) when freshwater inflows were presumed to be greater based upon low salinity conditions within the study areas.

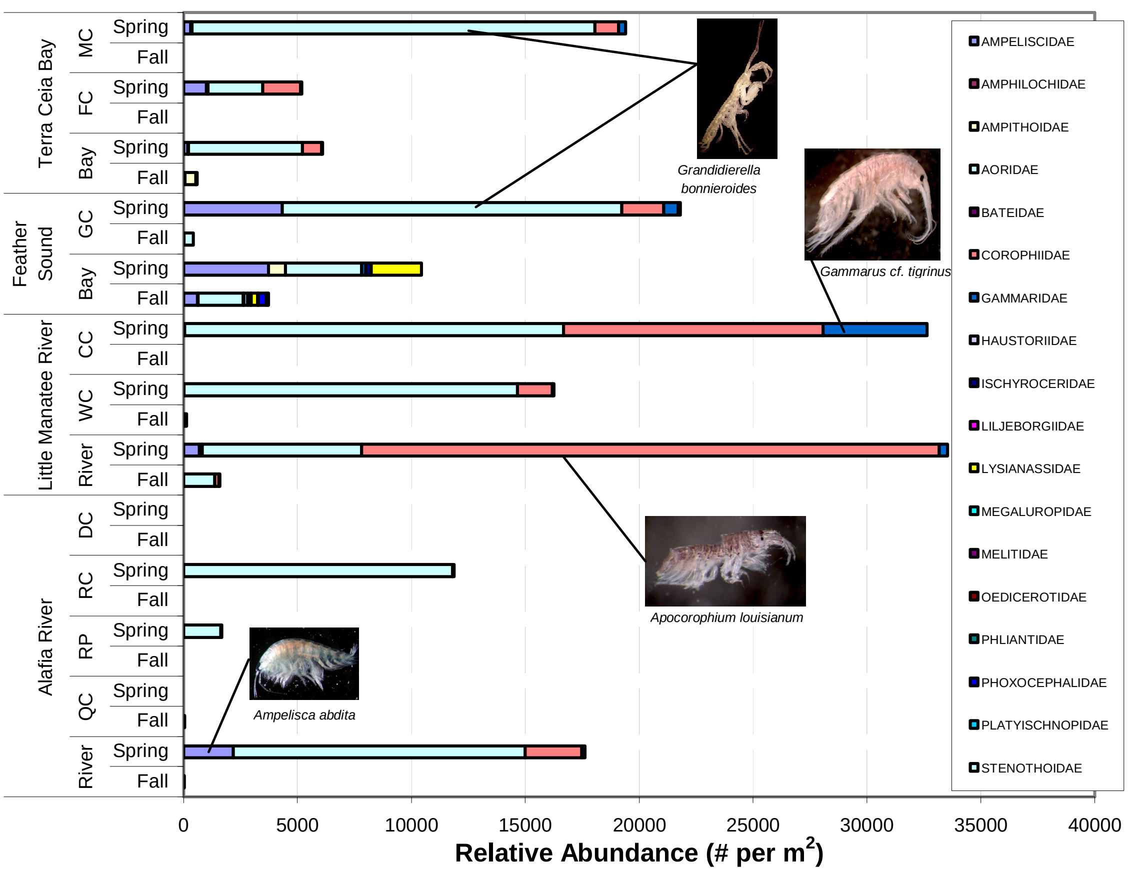


Figure 15: Example of seasonal amphipod abundance in the tidal tributaries during 2006.

6.2.3. Overall Nekton Community Dominated by Resident Species

Monthly nekton sampling within the tributaries during 2006 utilized 9.1-m (30-ft) seines with 3.2-mm (1/8-inch) mesh. In total, 1,293 samples from within and adjacent to the nine tidal tributary systems were collected. Within the tributaries, 73 species of nekton totaling 112,559 individuals were collected from 827 sample sites. The catch within the tributaries was dominated by resident species (found in tidal tributaries throughout their lives), with some transient species (found in tidal tributaries for only part of their lives) also present in relatively high numbers. The five most abundant species (daggerblade grass shrimp, rainwater killifish, bay anchovy, menidia silversides, and eastern mosquitofish) formed over 80% of the total catch (Table 3). The five most abundant species were collected in all tributaries, except bay anchovy (absent in Grassy Creek), but the proportions differed between creeks, as did the identities of many of the remaining abundant species in each creek (Figure 16).

Table 3: The 25 most abundant fish and invertebrate species collected from 827 9.1-m seine samples in nine Tampa Bay tidal creeks. R=resident species (found in tidal creeks throughout their lives), T=transient species (found in tidal creeks for only part of their lives), REC=species targeted by recreational fishers, COM=species targeted by commercial fishers. Main predators are birds (B), fishes (F), or marine mammals (M).

Common name	Scientific name	Number collected	Cate-gory	Known Predators	Fisheries
Daggerblade grass shrimp	*Palaemonetes pugio*	40,620	R	B, F	-
Rainwater killifish	*Lucania parva*	16,373	R	B, F	-
Bay anchovy	*Anchoa mitchilli*	14,744	T	B, F	-
Menidia silversides	*Menidia* spp.	11,812	R	B, F	-
Eastern mosquitofish	*Gambusia holbrooki*	10,297	R	B, F	-
Sailfin molly	*Poecilia latipinna*	4,355	R	B, F	-
Striped mullet	*Mugil cephalus*	2,735	T	B, F, M	COM/REC
Hogchoker	*Trinectes maculatus*	1,871	T	B, F	-
Sheepshead minnow	*Cyprinodon variegatus*	1,791	R	B, F	-
Clown goby	*Microgobius gulosus*	1,702	R	B, F	-
Eucinostomus mojarras	*Eucinostomus* spp.	724	T	B, F	-
Brackish grass shrimp	*Palaemonetes intermedius*	715	R	B, F	-
Gulf killifish	*Fundulus grandis*	699	R	B, F	-
Goldspotted killifish	*Floridichthys carpio*	518	R	B, F	-
Naked goby	*Gobiosoma bosc*	428	R	B, F	-
Seminole killifish	*Fundulus seminolis*	355	R	B, F	-
Tidewater mojarra	*Eucinostomus harengulus*	234	T	B, F	-
Common snook	*Centropomus undecimalis*	225	T	B, F	REC
Bluefin killifish	*Lucania goodei*	211	R	B, F	-
Spot	*Leiostomus xanthurus*	202	T	B, F, M	REC
Least killifish	*Heterandria formosa*	199	R	B, F	-
Coastal shiner	*Notropis petersoni*	193	R	B, F	-
Blue crab	*Callinectes sapidus*	185	T	B, F	COM/REC
Diamond killifish	*Adinia xenica*	143	R	B, F	-
Marsh killifish	*Fundulus confluentus*	141	R	B, F	-

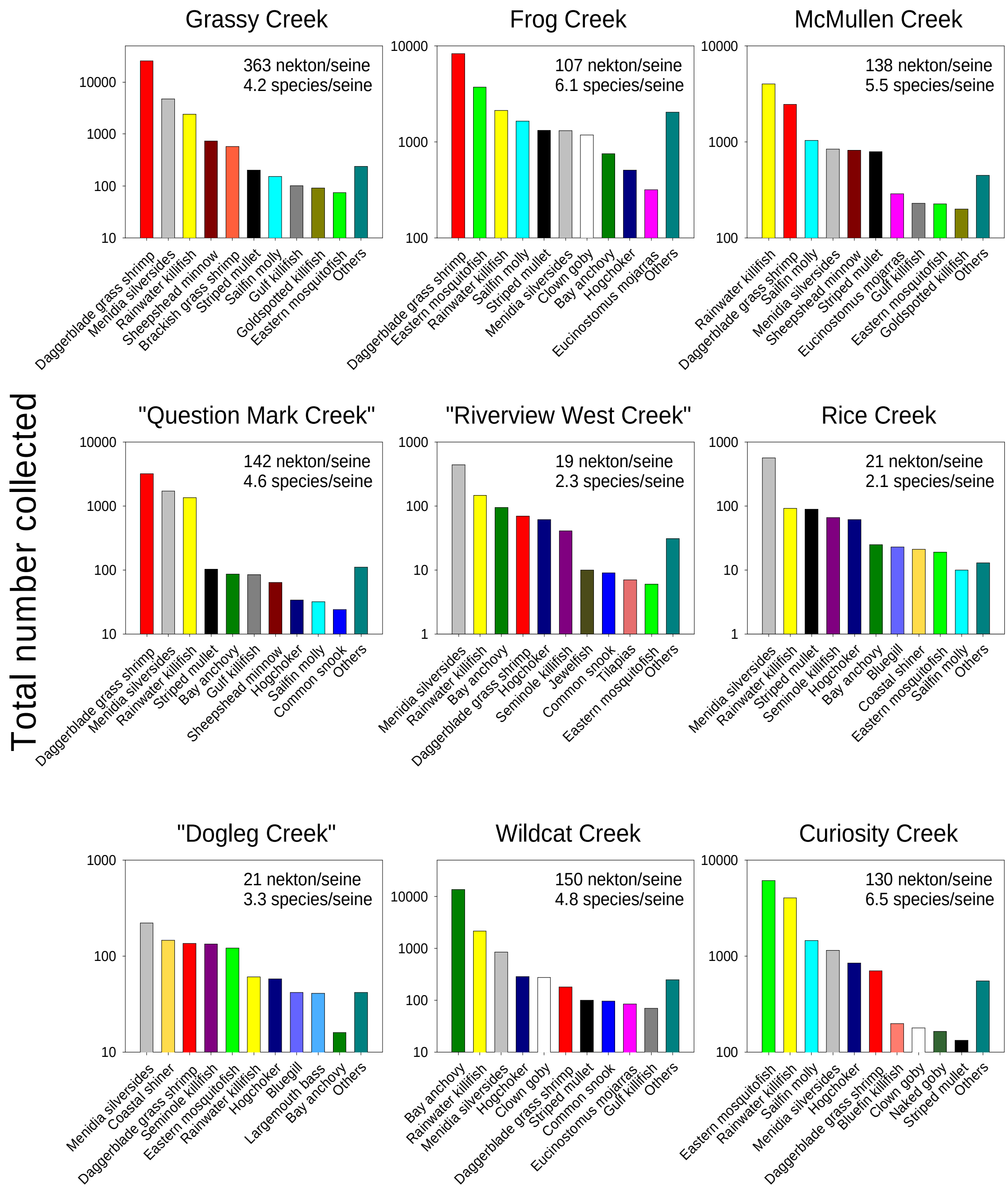


Figure 16: Total numbers of fish and macroinvertebrates (nekton) collected within the nine study creeks, January–December 2006. The ten most abundant species in each creek are listed individually, with the remainder summed.

6.2.4. Nekton Tributary Use vs. Adjacent "Outside" Areas

Nekton communities collected within the tidal tributaries were significantly different from the communities found outside these systems. The degree of difference depended on the tributary considered and for most tributaries, the communities inside overlapped the communities outside the tributaries to a great extent (Table 4). Differences in nekton community structure from comparing inside versus outside the tributaries were generally less than the temporal difference in nekton community across months (Table 4). Nekton communities within the Little Manatee River tidal tributaries (i.e., Wildcat Creek and Curiosity Creek), which reflected more unaltered tributary systems, were the most different from the adjacent riverine habitats to which they drained. It should be noted that the shorelines of these tributaries were composed of vegetation that was different from the vegetation in the adjacent Little Manatee River. Patterns in average species richness also varied by individual tidal tributary. Frog and Curiosity creeks tended to have greater species richness than in their outside areas, while Grassy, Rice, and Wildcat Creeks tended to have greater species richness outside. The remaining creeks did not show any differences compared to the outside areas sampled.

Table 4: Differences in nekton community structure between tidal tributaries and adjacent habitats. Results are R values from two-way crossed Analysis of Similarities ($P \leq 0.002$ for all). Higher R values indicate greater differences.

Major Watershed	Tributary	Tidal System Type	Inside vs. Ouside	Month
Alafia River (a priori more altered)	"Dog Leg Creek"	Dredged Inlet	0.231	0.484
	"Question Mark Creek"	Dredged Inlet	0.207	0.528
	Rice Creek	Minor Tributary	0.32	0.417
	"Riverview Park West Creek"	Dredged Inlet	0.21	0.409
Little Manatee River (a priori less altered)	Curiosity Creek	Minor Tributary	0.434	0.396
	Wildcat Creek	Minor Tributary	0.6	0.48
Feather Sound (a priori more altered)	Grassy Creek	Tidal Creek	.	.
Terra Ceia Bay (a priori less altered)	Frog Creek	Minor Tributary	0.186	0.406
	McMullen Creek	Minor Tributary	0.186	0.494

When combined, the average abundance of all species found in the tributaries was significantly less than the waterbodies to which they drained, but this pattern was not true when individual tributaries were examined separately (Figure 17). There was no significant difference in abundance between inside and outside for "Question Mark Creek" in the Alafia River watershed or Curiosity Creek in the Little Manatee River watershed. Abundance inside Grassy Creek was greater than outside in the Feather Sound area of Old Tampa Bay. Greater abundances of all nekton species occurred outside Frog Creek, McMullen Creek, "Riverview Park West Creek", "Rice Creek", "Dog Leg Creek", and Wildcat Creek.

Removing the most dominant species, grass shrimp, from the analyses altered some of the results for individual creeks, but the overall pattern of greater abundance in the larger waterbodies to which the tributaries drained remained consistent.

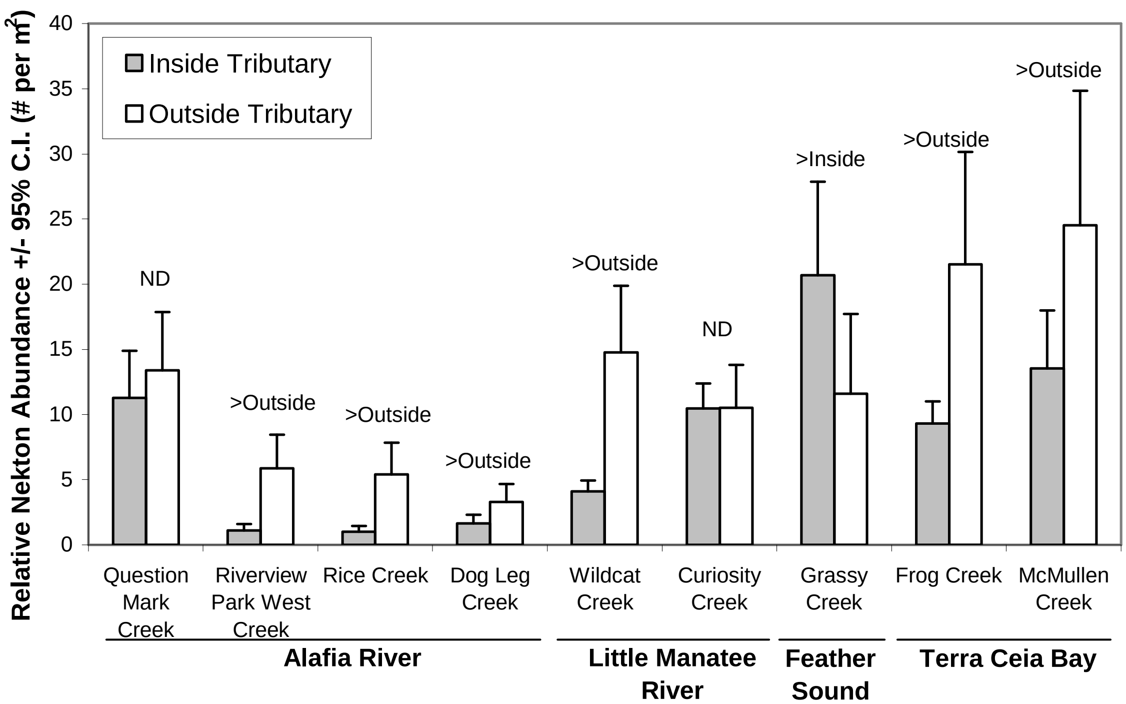


Figure 17: Differences in nekton relative abundance (number per m^2) among individual tidal tributaries when compared to the adjacent waterbodies to which they drained. ND=no difference.

When considered individually, average abundance for the majority of species was not different inside the tributaries compared to the larger rivers or embayments to which they drained. For those species which exhibited differences in abundance between the two areas, the majority were significantly more abundant outside the tributaries than inside. However, there were a few notable exceptions. When data from all the tidal tributary systems were considered, significantly more common snook, eastern mosquitofish, and sailfin molly were captured within the tributaries than outside. Irrespective of these patterns in abundance, tidal tributaries provided habitat to commercially and recreationally important species that are also common along bay shorelines and river main stems, including striped mullet, blue crab, spot, and red drum.

6.2.5. Nekton Community Use Among Tidal Tributaries Varied

Differences in nekton community structure within the tributaries were associated with physical and chemical characteristics of the creeks, such as pH, salinity and temperature. As a result, community structure differences were pronounced even among tributaries draining to the same larger waterbody (e.g., tributaries draining to the Alafia River or Little Manatee Rivers) (Table 5). Daggerblade grass shrimp largely accounted for the differences in community structure between tributaries: they were most abundant in tributaries with higher salinities, typically those that were closer to Tampa Bay proper.

Table 5: Differences in nekton community structure between tidal tributaries (February–December 2006). Results are R values from two-way crossed Analysis of Similarities (ANOSIM; $P \leq 0.03$ for all). Global R = 0.473 (general tributary differences) and 0.405 (month).

	Grassy Creek	Frog Creek	McMullen Creek	"Question Mark Creek"	"Riverview Park West Creek"	Rice Creek	"Dogleg Creek"	Wildcat Creek
Frog Creek	0.283	—	—	—	—	—	—	—
McMullen Creek	0.383	0.154	—	—	—	—	—	—
"Question Mark Creek"	0.351	0.238	0.348	—	—	—	—	—
"Riverview Park West Creek"	0.556	0.525	0.559	0.497	—	—	—	—
Rice Creek	0.665	0.604	0.681	0.751	0.124 (P = 0.026)	—	—	—
"Dogleg Creek"	0.644	0.433	0.627	0.714	0.321	0.29	—	—
Wildcat Creek	0.675	0.443	0.649	0.474	0.472	0.588	0.639	—
Curiosity Creek	0.75	0.396	0.746	0.75	0.704	0.756	0.779	0.539

Overall nekton sampling results did not clearly demonstrate the importance of shoreline vegetation or substrate within the tidal tributaries, however there were exceptions. For instance, daggerblade grass shrimp (an important prey item for fishes and some wading birds) were most abundant in areas with oysters along the shore or substrate. Likewise, there was little evidence that differences in watershed development could account for the differences in nekton community among the tributaries studied (although the level of landscape development was generally quite low, it was correlated with some of the physico-chemical variables, and may not have reached a threshold above which ecological effects manifested to the biota of the systems). Further study of additional end-member systems is needed to truly investigate the effect of watershed development on the nekton community.

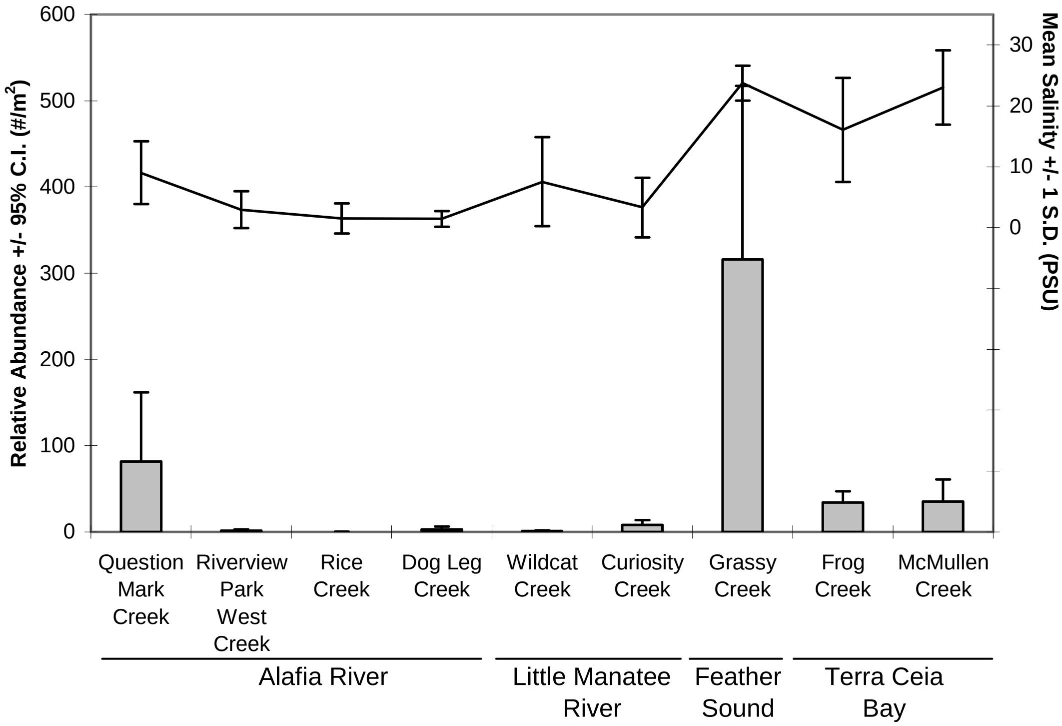


Figure 18: Comparison of nekton relative abundance (number per m^2) across individual tidal tributaries in relation to the mean salinity of the tributaries.

The average abundance of all species combined was greatest in Grassy Creek and least in "Riverview Park West Creek", Rice Creek, and "Dog Leg Creek" (Figure 18). Grass shrimp were largely responsible for the patterns of abundance shown among the tributaries and when they were excluded, average abundance was found to be greatest in Curiosity Creek. Average species richness was greatest in Frog Creek and Curiosity Creek and least in Rice Creek and "Riverview Park West Creek."

Average abundance of all species combined and average species richness in each tributary was not significantly related to landscape metrics (i.e. landscape development intensity and impervious surfaces) or in-situ water quality in the tributaries (i.e., temperature, salinity, pH, dissolved oxygen, or water depth). However, select individual species abundance patterns were observed to be associated with water quality conditions. For example, hogchoker increased in abundance as salinity decreased and grass shrimp abundance decreased as salinity decreased. There also appeared to be evidence that some species moved between tidal creeks and adjacent habitats as creek flows changed. Juvenile common snook abundance inside Wildcat Creek increased (compared to outside the creek) as salinity increased (i.e., flow decreased); snook may have been moving in response to changing physical and chemical conditions, or perhaps because they were following prey up the tributary.

6.2.6. Tidal Tributaries Provide Critical Snook Habitat

Tidal tributaries provided a critical nursery habitat for juvenile common snook. Common snook was the only species that was consistently collected in greater abundance inside the creeks than outside (although none were found in Grassy Creek or Rice Creek). Based on the results of our study, there is 95% confidence that the average abundance per unit area of juvenile common snook within tidal tributaries was between 2 and 36 times more than in adjacent habitats to which the tributaries drained (along the main river channel or the shorelines of Tampa Bay) (Figure 19).

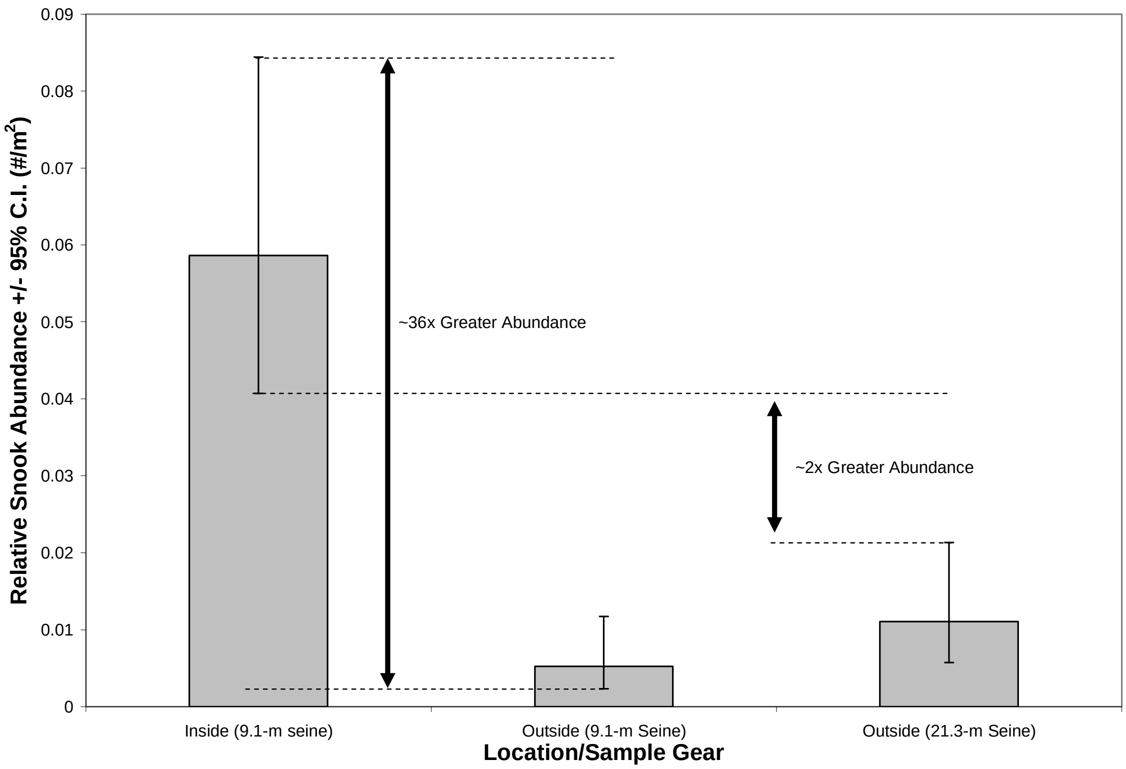


Figure 19: Difference in snook abundance (number per m^2) inside all creeks combined compared to the adjacent outside areas sampled.

Ancillary project results also suggest that other "backwater" habitat types are important within the context of larger river and bay systems. The average abundance of juvenile common snook was greatest in Hayes Bayou, a small embayment within the Little Manatee River (Figure 20). The patterns of juvenile common snook abundance between tributaries were not clearly related to physical, chemical, or watershed development: average snook abundance was high in both Wildcat Creek (a relatively undeveloped creek lined by salt marsh) and in "Question Mark Creek" (a dredged inlet with a mixture of native and exotic shoreline vegetation)—this implies that the species has a general preference for "backwater" habitats. Other factors may be important in determining the distribution patterns observed, e.g., the location of snook spawning grounds (locations within Tampa Bay and its adjacent passes) and the resulting supply of larvae to the tidal tributary nurseries may depend on their proximity to major spawning sites and predominant bay currents. Common snook require a mosaic of different habitat types during their lives (Figure 21; Lewis et al., 1985), so it is essential that the full range of these habitats are protected in order to minimize cohabitation of different life stages (otherwise, larger common snook may eat smaller common snook). Preserving, restoring, and creating juvenile habitat is likely to be at least as effective as traditional fishery management methods (size limits, bag limits) in increasing the size of the common snook population (Lewis and Robison 1996).

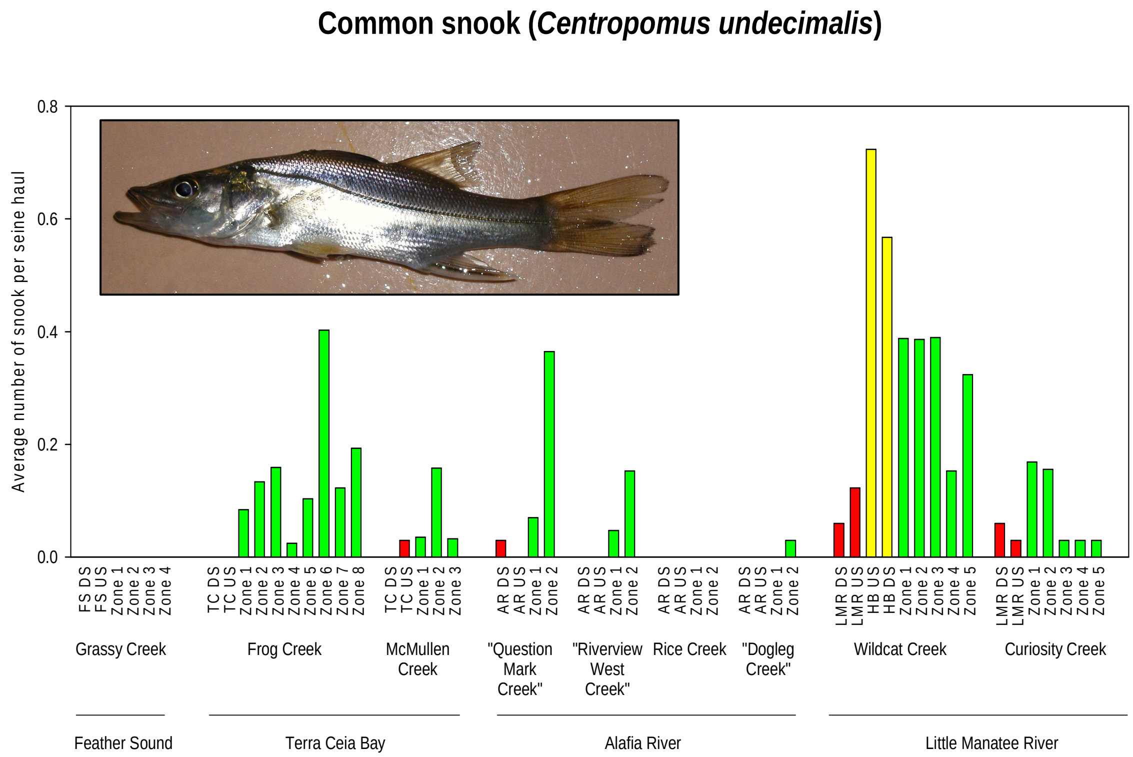


Figure 20: Average abundance (geometric mean) of common snook in the study area's zones. Green represents zones within the tidal creeks, red represents zones outside the creeks, and yellow represents zones in the Hayes Bayou (HB) backwater area. US and DS indicate zones that were upstream and downstream of the creek's mouths, with initials indicating the watershed (FS = Feather Sound, etc.).

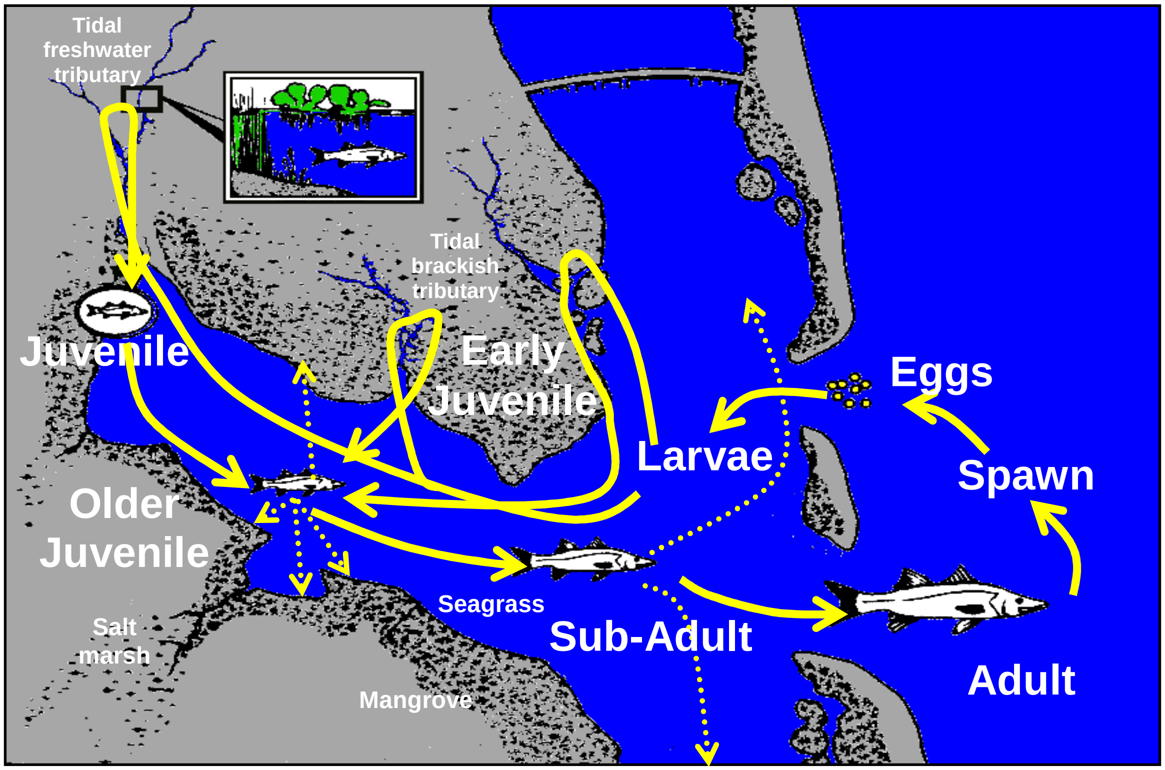


Figure 21: The life cycle of the common snook (adapted from Lewis et al., 1985). 1) Eggs are spawned at the estuary mouth and ocean passes; 2) Larvae move into brackish and freshwater tidal tributaries to grow into early juveniles (up to 1-year old); 3) Early juveniles grow older and bigger and move to estuarine shorelines; 4) Older juveniles and sub-adults occupy a variety of estuarine habitats, particularly mangrove shorelines; 5) Adults move towards the estuary mouth and passes to spawn.

6.2.7. Exotic Fish Species Were Generally Quite Common in Tidal Tributaries

Future management of these areas should consider the impacts that exotic species may have on native populations of nekton, particularly as previously highlighted by the importance of tidal tributary habitats to the common snook. A number of exotic nekton species were found within the tidal tributaries. Small tilapias were the most abundant exotic species collected, followed by pike killifish, which were the most frequently collected exotic species (nearly 3.5% of all samples). Five exotic species were collected in the most developed creek, "Riverview Park West Creek."

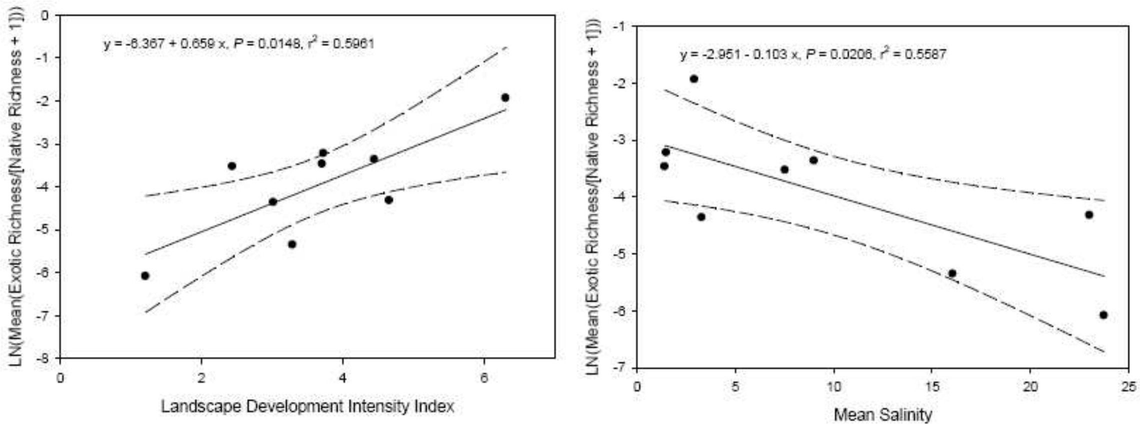


Figure 22: Relationship of exotic:native nekton species richness to landscape development intensity and mean salinity conditions in the tidal tributaries.

The ratio of average abundance and species richness of exotic species to native species increased as the amount of watershed development increased. However, this ratio also increased in relation to decreasing average salinity, so it is not conclusive that watershed development increases the prevalence of exotic fish because most Tampa Bay exotic species are typically freshwater species (Figure 22). Pike killifish, a predator of small fish, was very abundant in Wildcat Creek, the most important common snook nursery in our study, but we did not find any juvenile snook remains in the stomachs of pike killifish from this area.

6.3. Sources of Tidal Tributary Production

6.3.1. Food Source for Nekton is Microalgae in Tidal Tributaries

Stable isotopes are useful tools for identifying plant types that form the foundation of the food web. Isotope ratios, reported in per mil values (‰), change predictably as ingested material passes along the food web. The isotope ratios of the plant source are recorded within successive organisms at higher levels in the food web. This allows us to trace the isotopes recorded in fish tissues back to the plant material at the foundation of the food web. If a fish is positioned two steps above plants in the food web, its isotope ratios will be higher than the plants by 6‰ for nitrogen and 2‰ for carbon. The stable isotope data collected as part of this project indicate benthic microalgae ultimately support fish biomass during both wet and dry seasons (Figure 23). The isotope ratios measured from fish tissues within the tidal tributaries most closely matched the ratios found in benthic microalgae (BMA) and phytoplankton (POM). In contrast, vascular plant detritus derived from upland plants, emergent

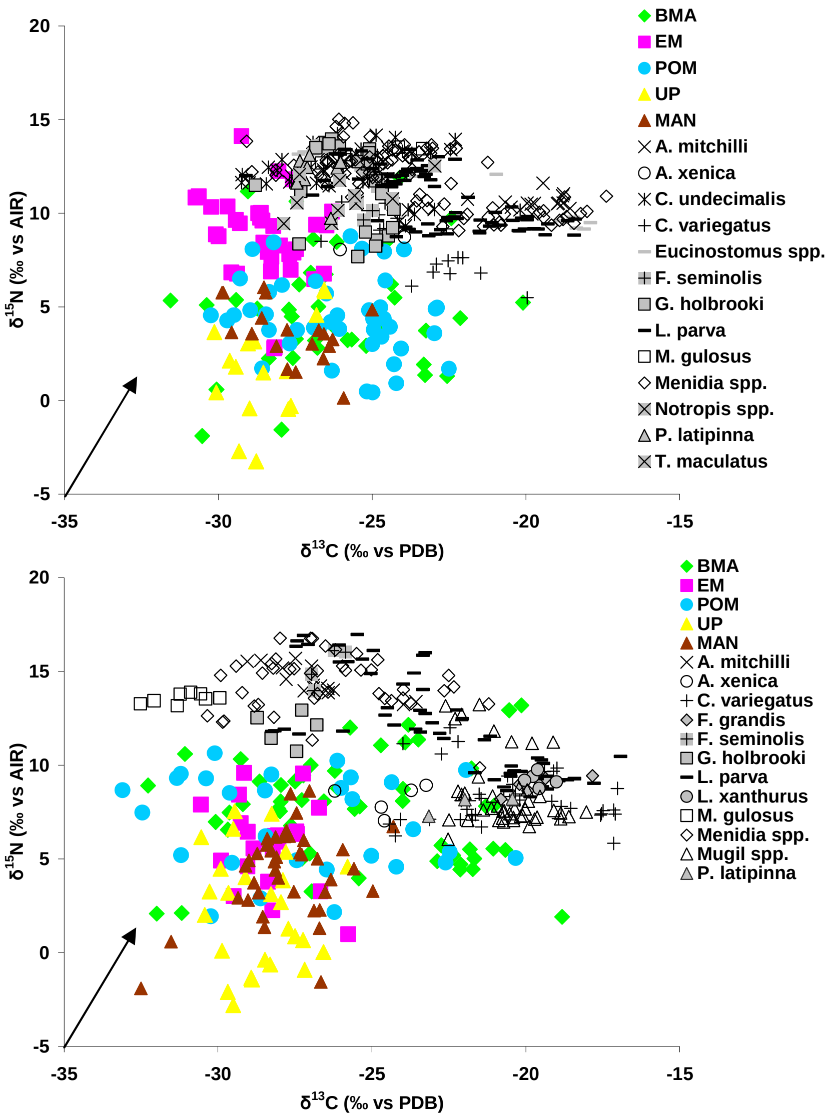


Figure 23: δ13C vs. δ15N plots for the wet season (top) and dry season (bottom). Data from all systems are included. Arrows at lower left provide a reference 6:2 isotopic shift that would be associated with an offset of 2 trophic levels. Primary producers include benthic microalgae (BMA), phytoplankton (POM), emergent vegetation (EM), upland plants (UP), and mangroves (MAN).

vegetation, and mangroves are not likely important in supporting fish biomass because these plants had narrow ranges of carbon and wide ranges of nitrogen isotope values.

6.3.2. Benthic Microalgae are Connected to Sediment Nutrients in the Dry Season

Benthic microalgae (BMA) are closely tied to sedimentary ammonium during the dry season. Both phytoplankton (POM) and BMA have an isotopic connection to the ammonium in sediment pore water (Figure 24), but this relationship is stronger in BMA. This observation suggests BMA are either intercepting the recycled ammonium moving out of the sediments or are continuously contributing to the sedimentary ammonium pool. It is also likely that in areas with low BMA cover, ammonium is moving out of the sediments to support phytoplankton during the dry season. This dry-season microalgal recycling phenomenon is essential for maintaining fish biomass during the dry season. In this pathway, nitrogen flows from sedimentary ammonium to BMA to fish. The nitrogen in the dry-season sedimentary ammonium likely originates from the decomposition of phytoplankton deposits that were created during the wet season. In areas where extensive phytoplankton deposits do not occur, BMA may obtain nutrients from the water column directly.

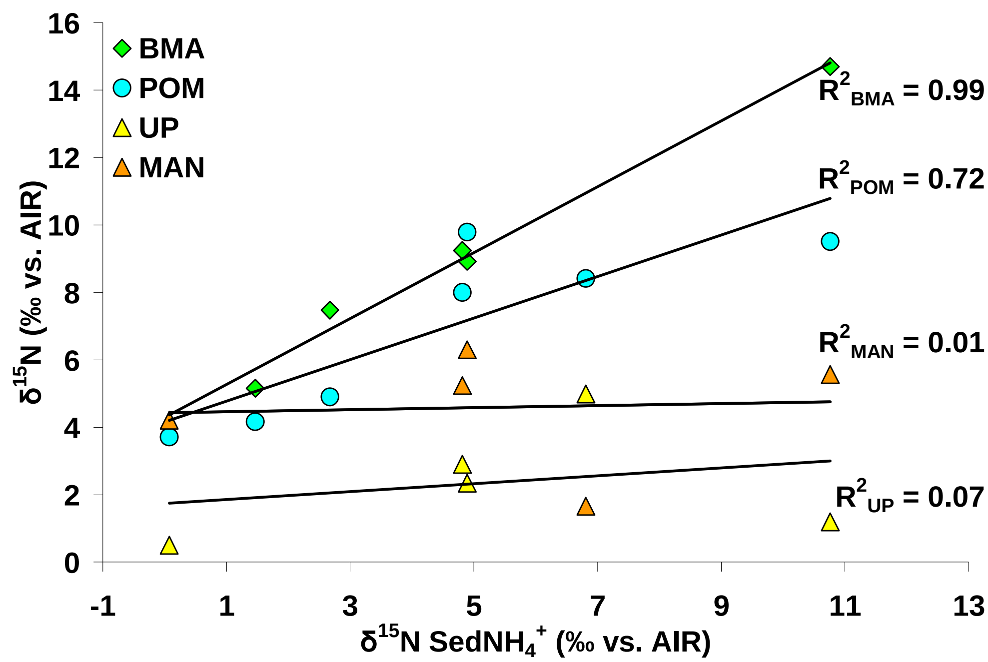


Figure 24: Plot of site-averaged δ15N values of benthic microalgae (BMA), particulate organic matter (POM), mangroves (MAN), and upland plants (UP) against δ15N values of sedimentary pore water ammonium ($SedNH_4^+$).

6.3.3. Fish Isotopes Track Land Use

Land use was a principal control on fish nitrogen isotope values. An isotope mixing model based on relative percent land use of pastureland and cropland, residential development, and golf courses was successfully used to predict the isotopic composition of mullet (*Mugil* spp.). Because of the Alafia River's overwhelming influence on data from Rice Creek, "Dog Leg Creek", "Question Mark Creek", and "Riverview Park West Creek", these locations were not included in the model. The pattern in the top panel of Figure 25 suggests that fish stable isotopes reflect differences in land use. Hypothetically, as cattle country becomes converted into residential areas, the nitrogen isotopes should change accordingly. The strong connection between land use and isotopes is also apparent in nekton other than mullet.

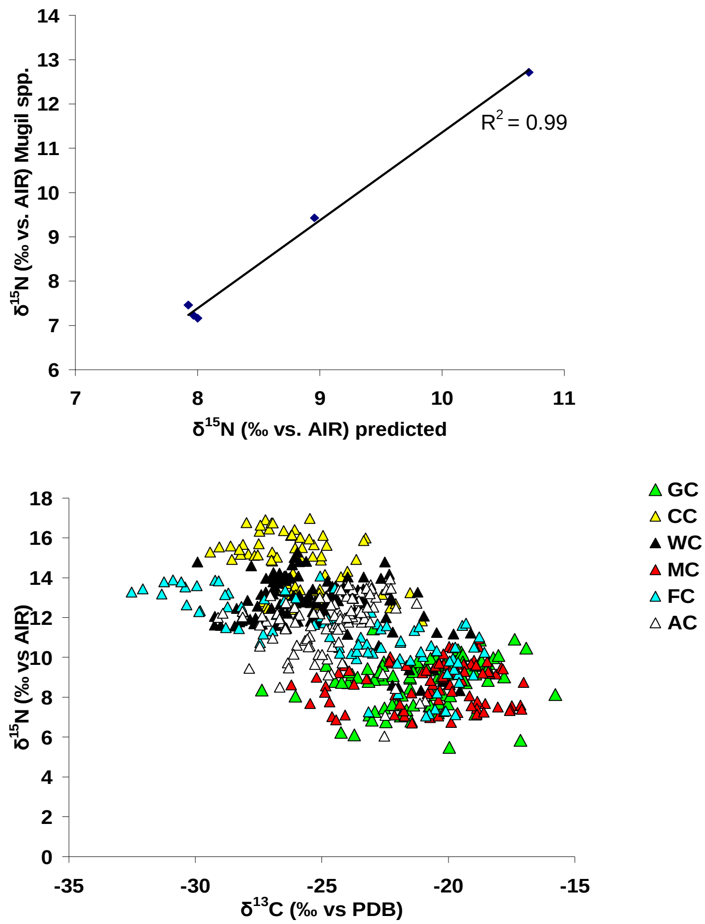


Figure 25: Results of isotopic land use model (top). All fish isotope data are combined and color coded by system. Systems include Grassy Creek (GC), Curiosity Creek (CC), Wildcat Creek (WC), McMullen Creek (MC), Frog Creek (FC) and all Alafia tributaries combined (AC) (bottom).

The particular tidal tributary sampled was the principal distinguishing factor for fish isotope patterns (bottom of Figure 25). The unique land uses found within each area's drainage basin heavily influenced the isotopic distribution of the fish found within the tidal tributaries. In terms of making isotopic distinctions among individual fish, site (i.e. tributary) was the most influential distinguishing factor, followed by season (wet vs. dry), and then whether the fish were collected inside or immediately outside the creek or tributary.

6.4. Watershed Influences Were Observed

6.4.1. Landscape Connectivity: Land Surfaces to Surface Waters

Land use conditions within the select tidal tributary systems investigated in this project have undergone various alterations since the early 1900s. Historically (circa 1940 – present), changes in land use within these relatively small watersheds have been pronounced as evidenced from comparisons of decadal aerial photography. Three watersheds (Rice, Curiosity, and Frog Creeks) were selected for analysis of long-term land use changes using photometric interpretation of aerials. An interesting transition in regional agricultural practices was observed from the 1940s to the 1970s in these watersheds. Agricultural land uses changed from open range to row crops to a mix of row crop and small improved pastures during more recent times. A general increase in tree coverage was noted during the last agricultural conversion even for improved pastures. This was also observed in the Rice Creek watershed when the landscape of older subdivisions developed mature tree canopies (Figure 26). Agriculture remains a significant factor in the Curiosity and Frog Creek watersheds, while Rice Creek's watershed appears to have become the most urbanized of the three tributaries investigated over the period from about 1940 – 2006 based upon photometric analysis.

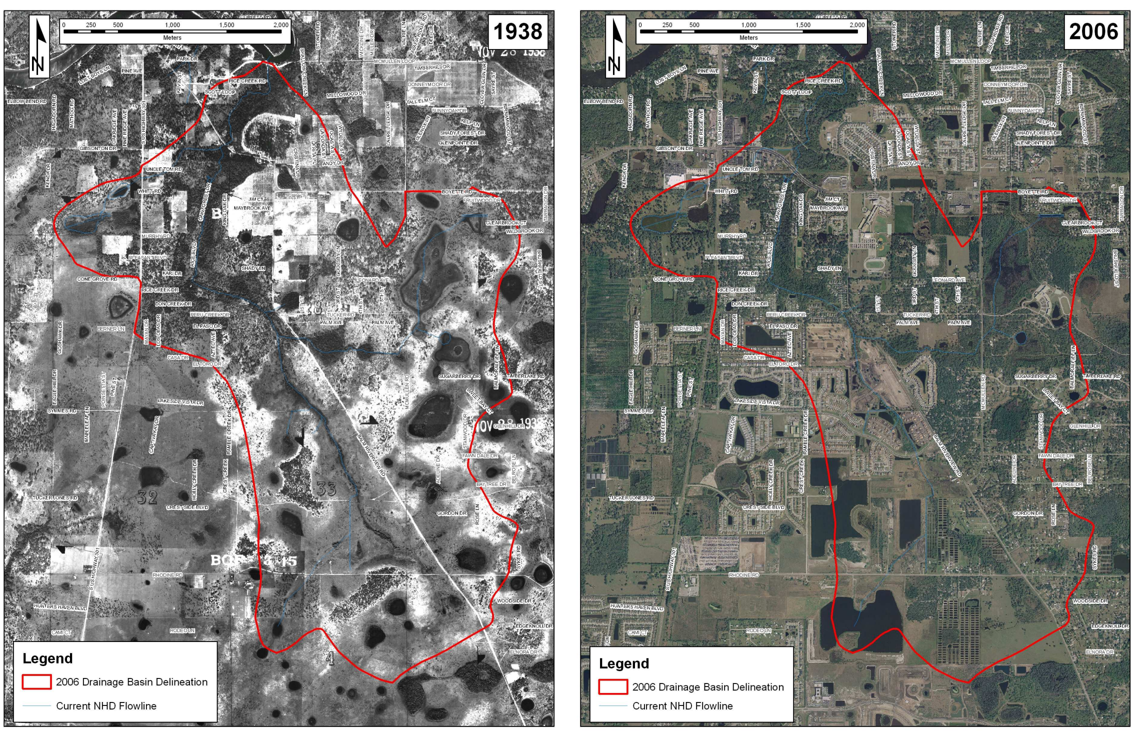


Figure 26: Example aerial photography of the Rice Creek watershed in 1938 (left) and in 2006 (right).

Over a more recent period (1990 – 2004), slight increases in the intensity of human land use (e.g. conversion of natural land to row crop) along corridors surrounding each tidal tributary and within their larger drainage basins (Figure 27) have generally been observed.

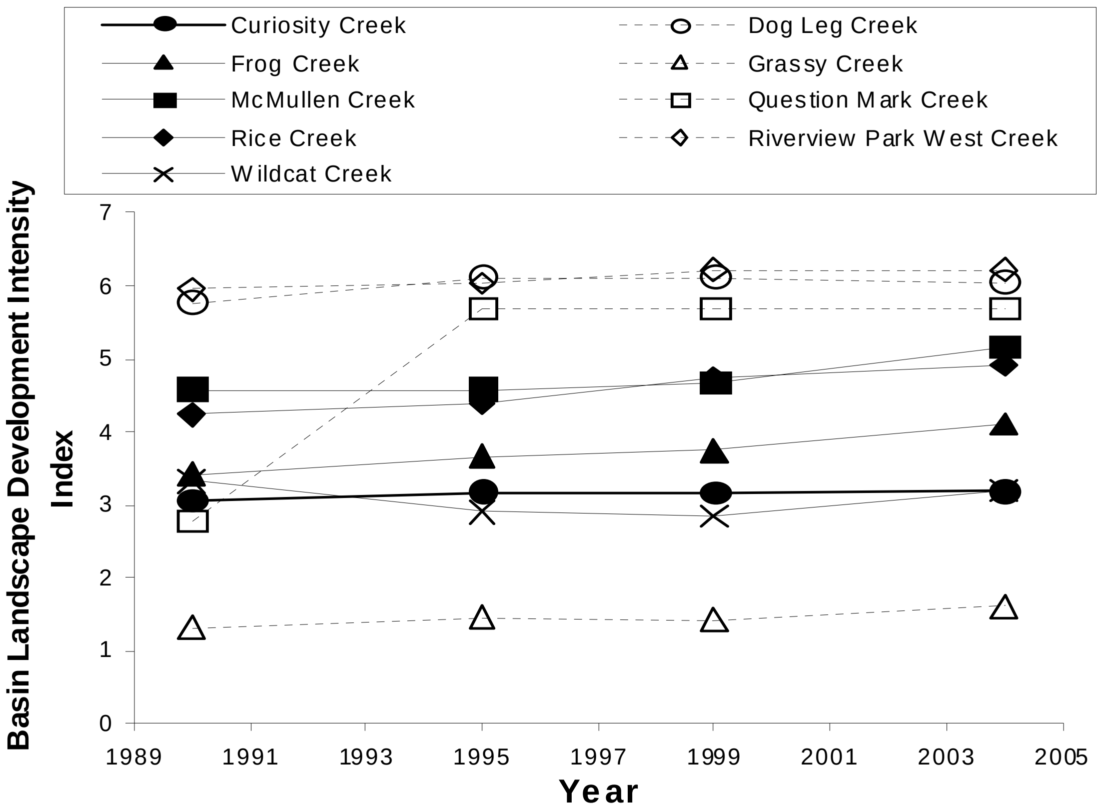


Figure 27: Historical landscape development intensity (LDI) in the entire basin areas of the 9 tidal tributaries studied from 1990 - 2004**.**

From a landscape perspective, the connection of the tributary corridors and larger drainage basins to in-stream conditions was a primary objective of this study and the most recent GIS information was used to link with abiotic and biotic observations taken within the tidal tributaries. In addition, the current degree of natural vs. hardened shoreline habitats within the tidal tributaries was investigated during the course of nekton sampling in an attempt to relate nekton distribution to in-situ habitats. Observations from nekton sampling indicated that hardened shorelines tended to be most prevalent within the Alafia River systems where landscape-level land use alterations were also most prevalent as determined from the available GIS information (Figure 28).

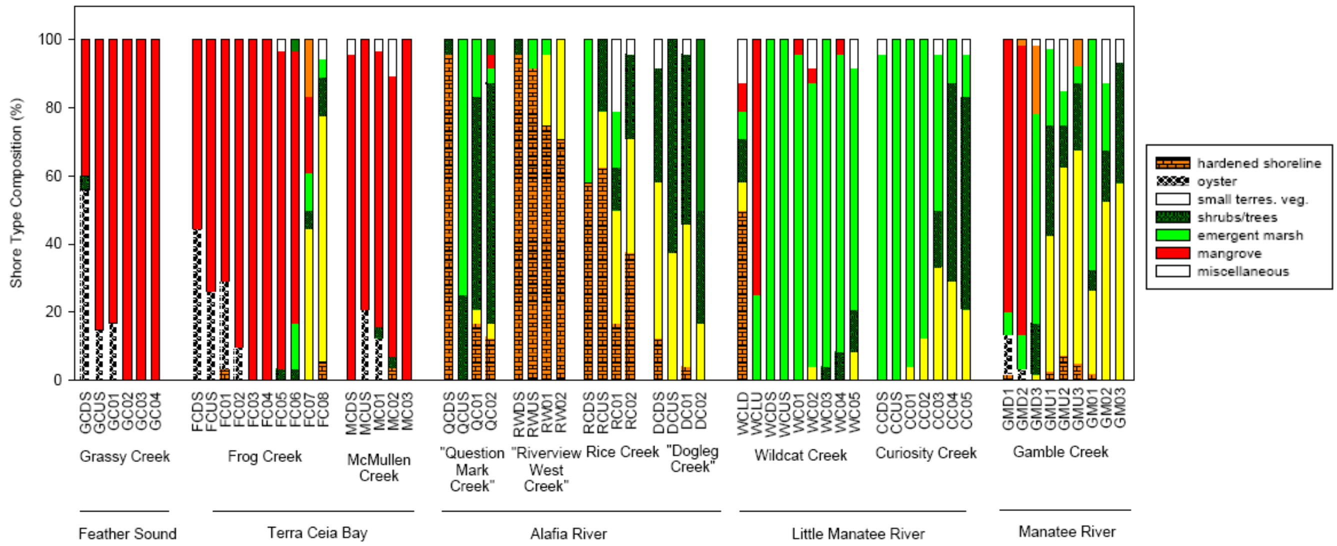


Figure 28: Generalized dominant shoreline types encountered during nekton sampling in each of the tidal tributaries sampled.

Two watershed metrics were used to characterize the landscape-level degree of human-induced alteration within the tributaries' watersheds and along the immediate 100-m corridor surrounding each area: 1) percent impervious surfaces and 2) landscape development intensity. Corridors of 100-m were used on the basis of results and suggestions of previous studies in Florida which identified that "the characterization of the lands within a 100-meter buffer around an isolated wetland or forest patch is sufficient to 'capture' the disturbance gradient" of surrounding land uses (Lane 2003; Brown and Vivas 2005). For this study, the 100-m corridor served as the best proxy for correlations of in-stream eutrophication and sediment contamination with the tributaries' surrounding landscape. This does not imply that changes to a watershed outside this corridor do not have effects on in-stream measures of water or sediment quality degradation, but that our ability to detect association with development impacts in the contributing watershed of the studied tributaries was more readily seen with the land uses directly connected to the tributaries.

Impervious surfaces (i.e., pavement, roof tops, and other hard surfaces), which are closely related to the amount of urbanization in a given area, have been used in many studies to link landscape development to water quality degradation and changes in aquatic fauna (Arnold and Gibbons 1996; Holland et al. 2004). Water quality degradation has been shown to occur in South Carolina tidal creeks when impervious surfaces exceed 10% of the basin area and for biological resources when imperviousness exceeds 20% (Holland et al. 2004). Estimates of imperviousness in the basins of the tidal tributaries evaluated in the Tampa Bay study ranged from 1 – 16.5% and along 100-m corridors of the tributaries ranged from 1.2 – 9% (Table 6). Based on these estimates it was expected that some of these tidal tributaries would exhibit some form of water quality degradation and only minor degradation of biological resources. As expected, weak correlations with water, sediment and biological metrics were found for the Tampa Bay systems using impervious surface estimates of the surrounding landscape.

Table 6: Summary of watershed metrics for the tidal tributaries studied.

Major Watershed	Tidal Tributary	Basin Size (ha)	% Impervious Cover (USGS 2001)		Landscape Development Intensity Indices (SWFWMD 2004)	
			Basin (%)	100-m Corridor (%)	Basin (Indices)	100-m Corridor (Indices)
Alafia River	"Dog Leg Creek"	35.5	2.55	2.13	6.04	3.05
	"Question Mark Creek"	23.2	7.04	2.35	5.68	3.96
	Rice Creek	1315.4	9.81	6.9	4.91	3.72
	"Riverview Park West Creek"	68.2	16.57	6.93	6.22	6.43
	Average	**360.6**	**9.0**	**4.6**	**5.7**	**4.3**
Little Manatee River	Curiosity Creek	5725.9	0.9	0.58	3.19	3.01
	Wildcat Creek	926.3	1.89	0.83	3.2	2.48
	Average	**3326.1**	**1.4**	**0.7**	**3.2**	**2.7**
Feather Sound	Grassy Creek	159.9	4.24	1.18	1.62	1.08
Terra Ceia Bay	Frog Creek	2357.2	6.65	3.12	4.11	3.31
	McMullen Creek	757.5	13.89	9.12	5.16	4.79
	Average	**1557.4**	**10.3**	**6.1**	**4.6**	**4.1**

As a further extension of evaluating the degree of watershed landscape development on tidal tributary resources, a relatively new metric was examined for each of the tidal tributary watersheds. Landscape development intensity (LDI; Brown and Vivas 2005), calculated from the individual land uses present in a contributing drainage area, is an index from 1 – 10 that rates the relative intensity of human activities in a watershed from natural to highly impacted. Derivation of the landscape development intensity index is based upon ecological principles developed by Odum (1996), whereby non-renewable energies are estimated as a proxy for human disturbance of a defined drainage basin through emergy use per unit area per time (empower density). These LDI values are based on actual energy consumption data from previous studies performed in Florida. The LDI concept has not been applied outside Florida; however, this does not preclude its use in other areas if sufficient, regionally specific energy consumption data are available to estimate LDI coefficients.

Recent studies by the FDEP indicate that reference, unimpacted freshwater wetland systems that have "healthy" water quality and biological resources typically exhibit LDI values less than 2 (Brown and Reiss 2006). The estimated LDI indices for the majority of tidal tributaries in this study fell slightly above this critical break point (Table 4), and it was expected that water quality and biological resources would show some degree of response along the lowest and highest estimates of LDI for these systems.

In general, Grassy Creek exhibited the least amount of impact from land use alterations attributed to development for both metrics investigated. However, it should be noted that the hydrology of this system has been extensively modified through mosquito ditching. Watershed metrics indicative of land use alterations increased along the tributaries draining to the Little Manatee River followed by those that drained to Terra Ceia Bay and the Alafia River.

Links between increasing watershed landscape development intensity, nutrient enrichment of tributaries, and water-column algal blooms was observed in this study. For the select tidal tributaries studied, there was a significant correlation (Pearson r=0.721, *P*=0.029) between increasing landscape development intensity along the immediate, 100-m corridors of the tributaries and the severity of algal blooms within the tributaries' water column during 2006 (Figure 29). Likewise, the degree of sediment contamination was correlated with landscape development in the tidal tributaries (Pearson r=0.829, *P*=0.006). Correlations were also reflected in a number of individual sediment contaminants including heavy metals, PAHs, total PCBs, and pesticides which generally showed increasing concentrations in more developed tributaries.

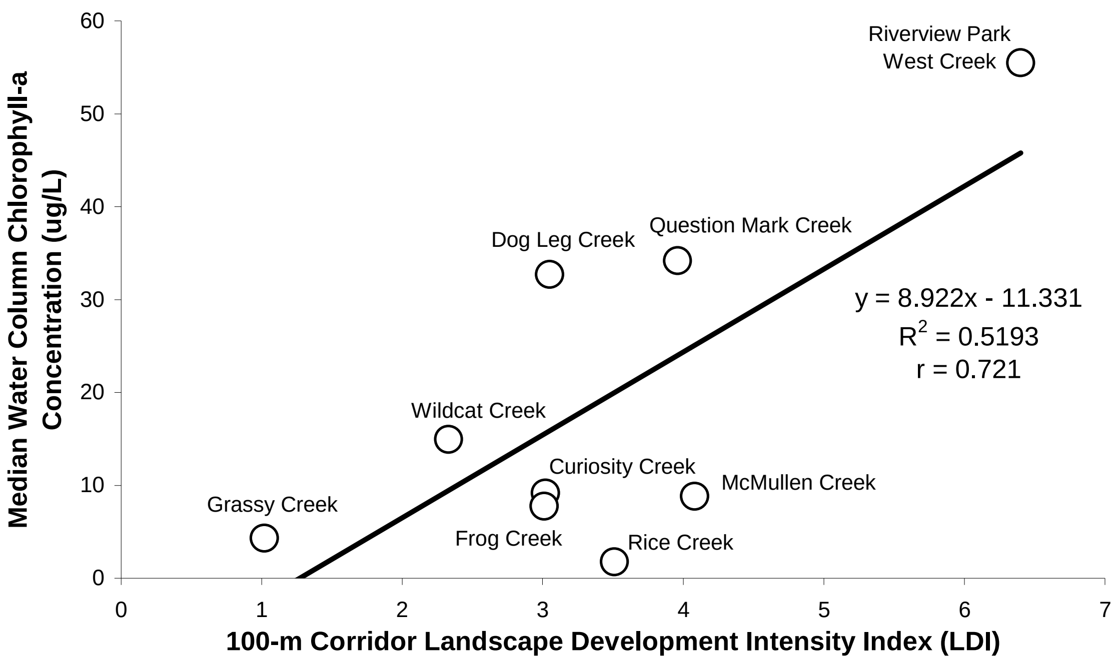


Figure 29: Example relationship of landscape development intensity along the tributaries corridors and median observed chlorophyll-a concentrations in the tidal tributaries during 2006.

Biotic resources in the tidal tributaries did not relate as well with the watershed metrics investigated. Weak or no apparent relationships were observed for select benthic biota and nekton measures within the tidal tributary systems studied. As a process to determine landscape effects on in-situ tributary biotic conditions, selection and monitoring of end-member tidal tributaries within the Tampa Bay estuary according to the land use metrics previously identified should be considered in the future.

6.4.2. Surface Water Connectivity: Bay Waters to Backwaters

Another concept that emerged during the course of this study was the importance of connectivity between separate estuarine systems within the hydrologic landscape to nekton and benthic intermediates. Seasonal distributions of species within the tidal tributaries were influenced by watershed hydrology in that the centers of distribution for benthic microalgal food sources, macroinvertebrate intermediates, and nekton shifted in response to freshwater inflows and ontogenetic patterns. At the trophic base, benthic microalgae (BMA) were identified as an important food source for nekton production within the tributaries and BMA abundance peaked within most of the tidal tributaries during the spring, dry season. During the fall, wet-season a shift to water-column algal production occurred and BMA abundance was reduced during the time when freshwater inflow was presumed to be greatest (salinities were reduced within the tributaries).

Nekton sampling demonstrated that Tampa Bay's tidal tributaries provide very important habitats to a number of resident and transient species. However, other ancillary observations reinforced the importance of these habitats in the context of the "estuarine system." Sampling within some portions of the tidal tributaries was difficult because of low water, and while this was inconvenient for assessments, such conditions were favorable to wading birds as nekton became more concentrated and are more easily captured within these confined areas. As an example, three threatened sandhill cranes were observed in Wildcat Creek during low-water conditions in January 2006. These shallow-water habitats are often not available in adjacent main-stem rivers. Birds have been shown to remove between 8% and 13% of fish production from a creek-like habitat in Florida, with a further 12–20% being exported by piscivorous fishes (Stevens et al. 2007). Tidal tributaries are therefore important intermediate habitats that transfer much of their production across uplands and the open estuary.

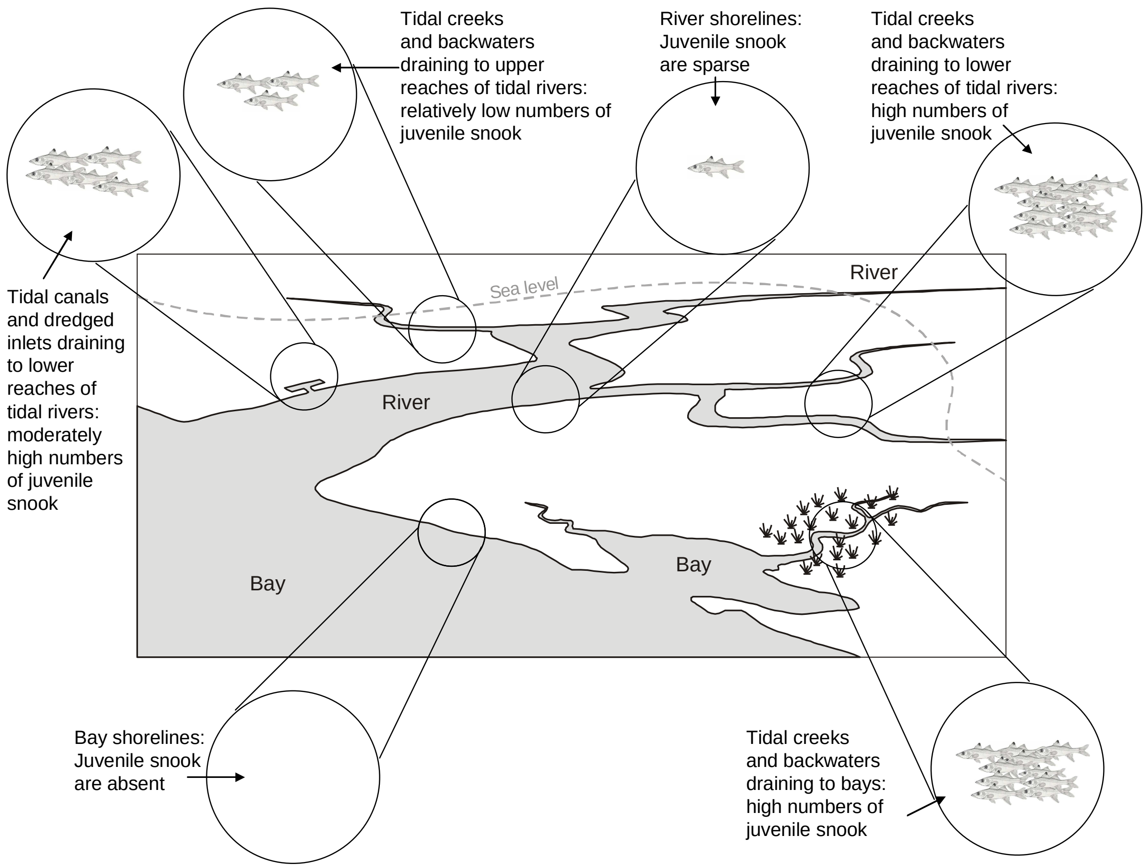


Figure 30: Conceptualization of the relative importance of tidal tributaries and other backwaters as critical juvenile common snook nursery habitat in relation to adjacent rivers and bay shorelines.

The continuum of habitats along differing system types was also highlighted by the juvenile distribution of an economically important fishery species, the common snook (Figure 30). For instance, juvenile common snook abundance inside Wildcat Creek increased (compared to outside the creek) as salinity increased (i.e., flow decreased). Snook may have been moving in response to physical and chemical cues within the tributary, or perhaps because they were following prey. There were clear differences between the nine tidal tributary systems which could be accounted for both on the position of these systems within the larger Tampa Bay estuary as well as where these systems fell along the embayments or rivers to which they drained. Tidal tributaries proved to be an important intermediate habitat in the estuarine continuum in terms of water quality buffering and nekton utilization.

7. Tidal Tributary Management Implications

7.1. Sentinel Habitats for Nekton

Despite their relative size to other estuarine systems in the bay, tidal tributaries represent an important habitat for both transient and resident estuarine species. Changes to their watersheds have the potential to influence the habitat structure and ecosystem processes inherent to these important "backwater" areas. The extent to which nekton occupy tidal tributaries varied as physical, chemical, and biological conditions changed in the tributaries and it is important to consider the dynamic processes occurring over differing tidal tributaries with inherently different static habitats. Fish and invertebrate communities were more disparate across the tidal tributaries studied than between the individual tributaries and the larger areas adjacent to where they drained. It is therefore vital to consider the nature of a tidal tributary's functionality based upon physico-chemical, hydrological, and land use characteristics inherent to the placement of these systems along the "estuarine continuum" and the links of these habitats to adjacent waterbodies.

Some nekton appeared to move into and out of tidal tributaries as freshwater inflow changes, so control of drainage to tributaries should aim to mimic natural hydrological regimes, as much as possible. Tidal tributaries are critical nursery habitats for common snook, with juveniles being up to an order of magnitude more abundant in minor tidally-influenced systems than in adjacent non-backwater habitats. It is imperative that any development within the watershed of these small systems maintain and not fragment adequate hydrological connections to the bay and does not result in habitat fragmentation, otherwise juvenile snook and other species may not be able to access these backwater nurseries. Systematic losses of these tidal tributaries and backwaters may concentrate snook populations into sub-optimal areas, resulting in increased competition and reduced growth/survival. As a result, juvenile snook may be forced to occupy river main stems or bay shorelines where they would be increasingly exposed to larger predators (including older common snook). Therefore, management should focus on the maintenance of habitat mosaics. For instance, while juvenile snook require tidal tributaries as nurseries during the first year of life, they grow, leave these habitats, and begin to occupy adjacent larger river and bay shorelines, which are also very important for their successful recruitment to adult populations. Maintaining a balanced link between these estuarine systems should be a focus for the continued management of the Bay's resources.

7.2. Trophic Transfer of Watershed Resources

Development within the watershed also has the potential to change the processes and quality of resources delivered to tidal tributaries and then transferred to higher trophic levels. Isotopic signatures of a watershed are influenced by land use and this signature is reflected in its primary producers (BMA, water-column algae, and higher plants). The primary producers, in turn, pass the watershed's signature on to the fish that are ultimately dependent on them for biomass. Therefore, the dominant nutrient pools of a watershed are reflected in its biota. For example, nekton analyzed within Curiosity Creek had distinctly heavy $\delta^{15}N$ values. This is indicative of nitrogen sources originating from intensive pastureland cover. Since large-scale residential development has only recently begun within its watershed, Curiosity Creek represents an ideal opportunity to monitor any associated changes to the originating sources of its inherent fish production that may be associated with rapid land development from its contributing watershed.

Monitoring changes to the trophic transfer of watershed resources within this relatively unaltered tidal tributary would provide valuable insight regarding 1) the rate at which new development-associated nitrogen sources enter nekton biomass, and 2) the extent of influence that these new nitrogen sources have on downstream nitrogen pathways. The effects of these nutrient-flow processes, in concert with any anticipated changes to the hydrology of Curiosity Creek's freshwater inflow patterns associated with urbanization of its watershed, would provide additional insight on estuarine processes within these intermediate habitats as it relates to changes in the watershed.

7.3. Inflow Flashiness to Tidal Tributaries

Short-term variations in runoff and base flow result in corresponding variations in flow and stage. Since these inputs may originate anywhere within a watershed, inflow and stage in a receiving tributary varies rapidly and apparently unpredictably. Flash flooding is the extreme expression of this phenomenon, but the same phenomenon occurs at much smaller scales, as is the case for smaller watersheds. The hydrologic literature refers to this as the 'flashiness' characteristic of surface waters. Although there does not appear to be one widely accepted definition of the term, 'flashiness' is used for flow variations on the order of hours to a few days.

A number of physical and ecosystem effects can be regulated by flashiness within tidal tributaries. For instance, biotic communities may be relocated by increased currents out of these minor systems into adjacent, larger waterbodies. Water depths can vary over short temporal periods influencing the range of suitable habitat for BMA colonization by flooding previously dry areas and making previously shallow areas too deep for solar illumination. Increased velocities will, at a point regulated by the tributary's physical channel, scour the bed of accumulated detritus and structure. The channel itself may migrate. Based upon the relative shallowness of Tampa Bay tidal tributaries, sensitivity of flashiness events may be more pronounced during the dry season, when lower volume conditions persist in the tributaries. Additional runoff from the watershed will move bands of suitable habitat farther downstream than the same runoff delivered during the wet season.

Inflow variability was investigated in Frog Creek, the only tidal tributary which had a USGS gaging station associated with its watershed (Figure 31). Inflow during 2006 for this tidal tributary is color-coded by the significance of flow-duration events (TNC 2007). The blue sections of the record indicate local high flow pulses or times when the flow dramatically increased for a very short time. The green sections indicate events where the average flow did not quickly return to its previous value resulting in 'flood' events. Notice that there are distinct wet and dry seasons. As a first approximation, the 'flashiness' of Frog Creek is represented by the number, magnitude, and distribution of the pulsed events over the course of 2006.

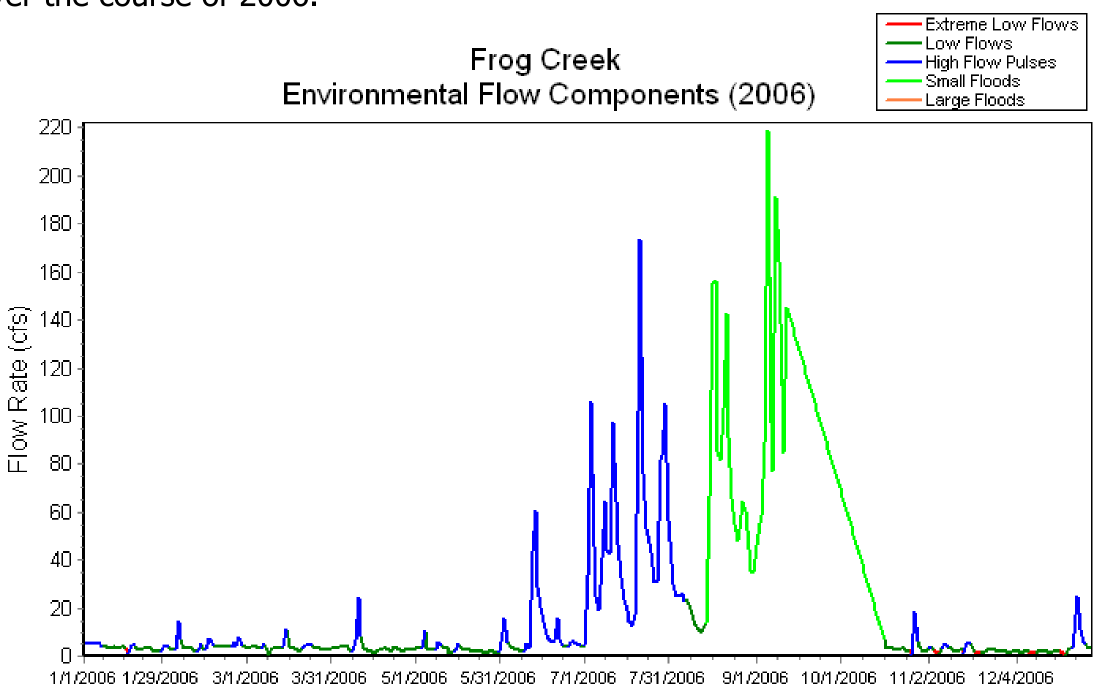


Figure 31: Mean daily flow (cfs) from the Frog Creek gage during calendar 2006. Flow is color-coded by the Environmental Flow Characteristic as described in Indicators of Hydrologic Alteration, Version 7.0.4.0 (TNC 2007).

Many anthropogenic watershed modifications can affect runoff or base flow, and consequently the 'flashiness' of the receiving tributary. As previously mentioned, increased impervious surface area (roofs, roadways, etc.) within a watershed has the potential to change inflow variability. Rainfall that would first percolate to the receiving tributary through the surficial groundwater aquifer over a period of days can instead be routed immediately to the watercourse. Watershed-wide drainage improvements such as ditching and canals also deliver runoff directly to the receiving stream bypassing land surface sheet flow and surficial groundwater aquifer routes.

An investigation of the flow pathways within the Frog Creek watershed visibly highlights channel modifications that might be affecting the observed flashiness of the system (Figure 32). The normal channel has been supplemented by a network of agricultural drainage ditches. Major transportation improvements, housing, and industries have increased the level of impervious surfaces (~6.6% of the basin). Row-crop agriculture has significant irrigation demands, and in absence of tail-water recovery systems, produces significant runoff. Less evident is the degree of physical modification to the channel to increase flow velocities and drainage capacity by channelization. Frog Creek has also been affected by the connection to the Buffalo Canal (Figure 32) which doubles the area draining to tidal tributary.

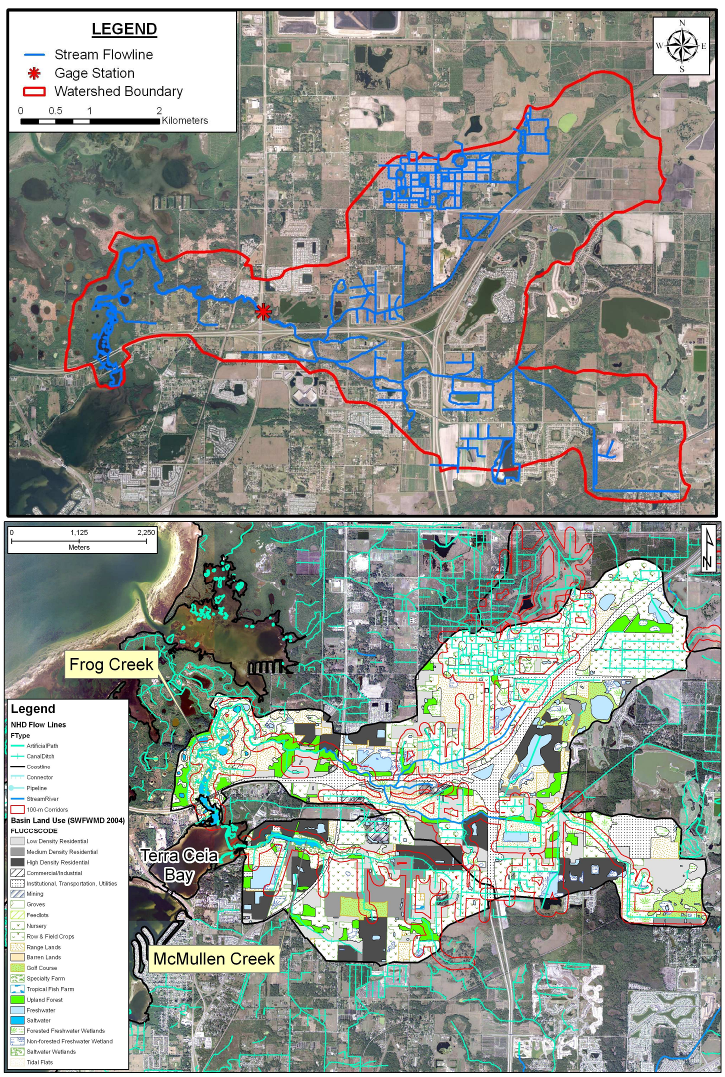


Figure 32: Frog Creek watershed boundary and stream flow pathways (top) and generalized watershed land uses (bottom).

Several measures of flow variability or indicators of environmental impact of flow variability have been developed for non-tidal rivers and freshwater streams (Table 7). Many of these are intended for comparison purposes, and the number in itself has little diagnostic value. The variability indices in Table 7 generally indicate a "moderately flashy" tributary. This is surprising in that the topography of the watershed is so flat that without a careful examination of watershed properties it's hard to envision mechanisms that would generate these values. Channel width, sinuosity (curvature), depth profile, bottom gradient, and bank topography all mediate the effect of flow and stage variations upon biota.

Table 7: Inflow characteristics from Frog Creek gage for calendar 2006.

Category	Parameter	Value	Remarks
Flow Characteristics	Mean Flow	22.87 cfs	
	Maximum Flow	219 cfs	
	Extreme Low Flow	1.64 cfs	10th percentile value
	High Pulse Threshold	24.72 cfs	75th percentile value
Variability Indices	Coefficient of Variability	1.65	
	Fall Rate	-1.348 cfs/day	
	Rise Rate	0.7581 cfs/day	
	R-B Index	0.423	

Collectively, these factors are referred to by the term "stream morphology." Although many tools exist to quantify stream morphology in high gradient or mountain streams, an appropriate, applicable methodology for low gradient tidal tributaries is lacking. An understanding of tidal tributary morphology would allow us to predict any anthropogenic effects to flow variability of a system, suggest mitigation strategies, and improve watershed management. Results of this study identify the need for a robust tidal tributary morphology assessment.

The 'flashiness' concept of a tidal tributary system adds a new linkage between watershed characteristics and tributary environmental impacts. Watershed imperviousness and drainage improvements are acting not only through the volume of water and concentrations of pollutants they deliver to the receiving surface waters, per-se, but also the degree they are changing inflow variability of the hydrographs. Our water quality and benthic assessments showed that every sampled tributary was impacted to a certain degree by anthropogenic pollutant inputs to the tributaries. However, estuarine nekton and benthos were resilient to these perturbations. Explaining the effects of watershed imperviousness and development has been challenging, especially in these relatively undeveloped systems. An oft-cited rule of thumb is significant impacts to biota occur when watershed imperviousness is greater than or equal to 10% (Schueler 1992; Holland et al. 2004). Other studies suggest that the impact of imperviousness is actually on a continuum, and that the 10% threshold resulted from the simplicity of earlier studies. If proven, our paradigm would support the continuum interpretation and provide a linking mechanism which should explain why the ecological effects of watershed imperviousness has been difficult to relate to biota of marginally developed systems.

8. Development of Measurable Targets for Protection and Restoration of Tampa Bay's Tidal Tributaries

The results from this project will form the technical basis for a new pilot Tampa Bay Tidal Tributaries Management Strategy, following an adaptive management process. Previous successful natural resource target-setting processes completed in Tampa Bay include the following steps (Greening and Janicki 2006), and we anticipate using a similar process for the Tidal Tributaries Management Strategy:

1. Set specific, quantifiable natural resources and habitat goals.
2. Determine ecological requirements and appropriate targets necessary to support achievement of goals.
3. Define and implement resource management strategies needed to achieve management targets.
4. Monitor indicators of natural resources goals and ecological targets.
5. Periodically re-evaluate the goals and targets, using monitoring results.

This project provided the basis for Steps 1-4. Defining specific resource management strategies and potential actions needed to achieve targets are included in the Management Strategy, but will ultimately be the responsibility of entities represented within the TBEP (including the Technical Advisory Committee (TAC), and Management and Policy Boards).

Setting quantified seagrass restoration and protection goals and targets was a multi-year effort, and we expect that the Tidal Tributaries Habitat Initiative will also require several years. Results from this project have provided the technical basis, draft monitoring plan elements and a pilot resource management strategy for the future. Implementation of the strategy through partner actions will be an ongoing effort, once goals and targets are adopted. Our long-term objective is to provide the technical basis and tidal tributaries management strategy in time for the scheduled Tampa Bay Estuary Program Habitat Master Plan update.

Based on results from this project, the Tidal Tributary Project Team evaluated seven indicators as potential measurable targets for tidal tributary function as habitat and as the base of the food web in these systems. Measurable targets were identified for two indicators based on conservative application of project results, and we anticipate that these targets will be refined in the future as more information is gathered for other Tampa Bay tidal tributaries. These preliminary targets include:

1. *Presence of common snook in tidal tributaries* as an indicator of habitat connectivity among Tampa Bay open bay waters, riverine habitats, and minor, tidally-influenced systems.

2. *Current State of Florida dissolved oxygen standards* as measurable, protective water quality targets for Tampa Bay tidal tributaries to protect fish and benthic production. DO should not average less than 5 mg/l over a 24-hour period and should never fall below 4 mg/l.

Five other indicators were identified as strong potentials, but requiring additional evaluation in more Tampa Bay tidal tributaries prior to identifying measurable targets:

3. *Ratio of benthic algal production to water column algal production* as a potential indicator of tidal tributary eutrophication.

4. *Sediment characterization* as an indicator of associated land use*.* Landscape development intensity along the 100-m corridors of the tidal tributaries was positively correlated with sediment silt-clay percentage and sediment contaminants which may indicate a tendency for altered systems to become muddier and more prone to the deposition of contaminants over time.

5. *Landscape Development Intensity Index for 100-m stream corridors* as an indicator of potentially degraded water and sediment quality in tidal tributaries.

6. *Exotic species presence or abundance* as an indicator of stressed habitat. Nekton results suggested that exotic species may provide an indicator for tidal tributaries whose watersheds have been altered; however, other confounding physical factors precluded the direct association of exotic species with watershed alteration. Exotic benthic species were also not associated with tidal tributaries whose watersheds were determined to be more altered.

7. *Watershed metrics* as an indicator of benthic biota condition. Although general declines in benthic community metrics were observed for altered watersheds, no statistical links were determined.

8.1. Recommended Measurable Targets

1. *Common Snook as an indicator of habitat connectivity*

The presence of juvenile common snook within tidal tributaries is an indicator of the utility of these habitats as nurseries. In particular, the presence of juvenile common snook in the tidal tributaries studied in considerably greater abundance than in adjacent bay or river habitats is of particular relevance, as the functionality and utility of these tidally-influenced backwaters as fisheries habitat can be assessed. The presence of juvenile common snook may indicate that tidal tributaries have adequate hydrological connections to Tampa Bay and are serving as essential fish habitat.

2. *Dissolved oxygen as an indicator of adequate water quality for nekton production*

Fish and other aquatic organisms rely on adequate quantities of dissolved oxygen (DO) to survive in the water that they inhabit. As DO drops towards critical levels, fish may seek water with higher DO concentrations. Studies from around the world consistently show a great reduction in fish numbers if a habitat becomes *hypoxic* (DO below 2 mg/l). With *anoxia* (complete lack of oxygen), mass mortalities may occur if alternative habitats cannot be reached. There may be impairment of fish growth and reproduction if consistently low (but not necessarily hypoxic) conditions persist over long periods. Therefore we recommend current state DO standards as measurable, protective targets for Tampa Bay tidal tributaries and canals: assuming that, because of their estuarine (brackish) nature, these can be classified as predominantly marine creeks, DO should not average less than 5 mg/l over a 24-hour period and should never fall below 4 mg/l. Maintenance of these standards would classify tidal tributaries and canals as Class III waters, designated to be used for recreation and propagation of healthy, well-balanced populations of fish and wildlife.

8.2. Indicators Requiring Additional Data

3. Ratio of benthic algal production to water column algal production
Seasonal changes in the algal community structure within the tidal tributaries may serve as an important indicator of tributary "health." Pilot analyses of the ratio of benthic microalgal communities, as measured by chlorophyll-a concentrations along the substrate within the tidal tributaries, compared to phytoplankton communities, as measured by chlorophyll-a in the water column, were different for the majority of the tributaries during the dry and wet season sampling events (Figure 33). Shifts to water-column based algal production, whereby benthic:phytoplankton chlorophyll-a ratios approach 1:1 or are less than 1 during the typical dry season may serve as an additional indicator of tributary eutrophication and could potentially have higher level trophic effects. Continued investigation of "natural" cycles in benthic microalgal and phytoplankton communities within Tampa Bay tidal tributaries is recommended.

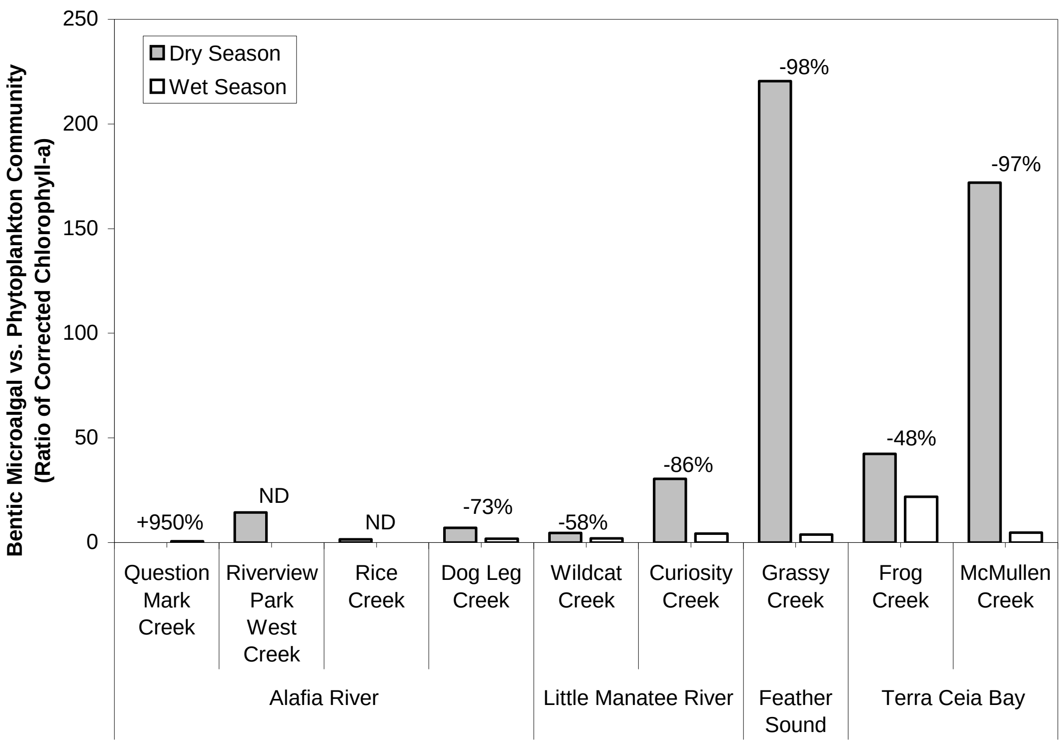


Figure 33: Relative change (%) in seasonal ratios of benthic:phytoplankton algal communities in the tidal tributaries during 2006.

4. Sediment characterization as an indicator of land use
"Healthy" tidal tributaries tended to have sandy sediments and were typically shallow over much of their tidal extent. As development continues in the tidal tributary watersheds, it is anticipated that "flashy" inflow to the system is likely to occur. Pulsed flow events could potentially change the channelization and sediment characteristics of the tributaries over time. Landscape development intensity (LDI) along the 100-m corridors of the tidal tributaries was positively

correlated with sediment silt-clay percentage which may indicate a tendency for altered systems to become muddier over time. Likewise, sediment contamination in the tributaries also increased with increasing LDI which suggests that those tributaries with muddy, depositional bottom areas may be more likely to become contaminant as development increases in their watershed (Figure 34). Consequently, the more altered dredged inlet systems found within the Alafia River tended to have muddier sediments (Figure 35).

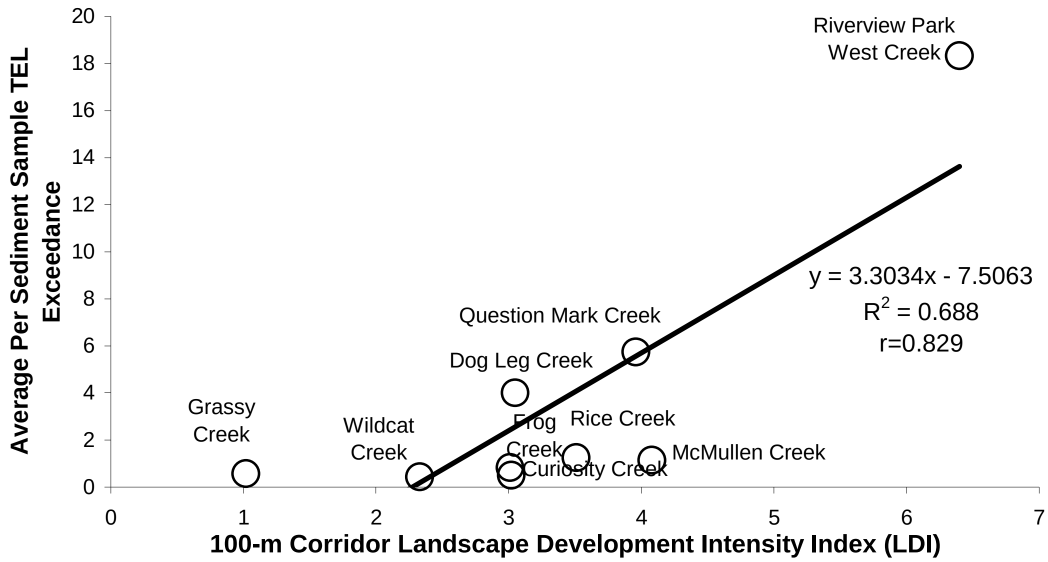


Figure 34: Relationship of 100-m corridor landscape development intensity indices (LDI) and average per sediment sample threshold effects level (TEL) exceedance in the select tidal tributaries during 2006.

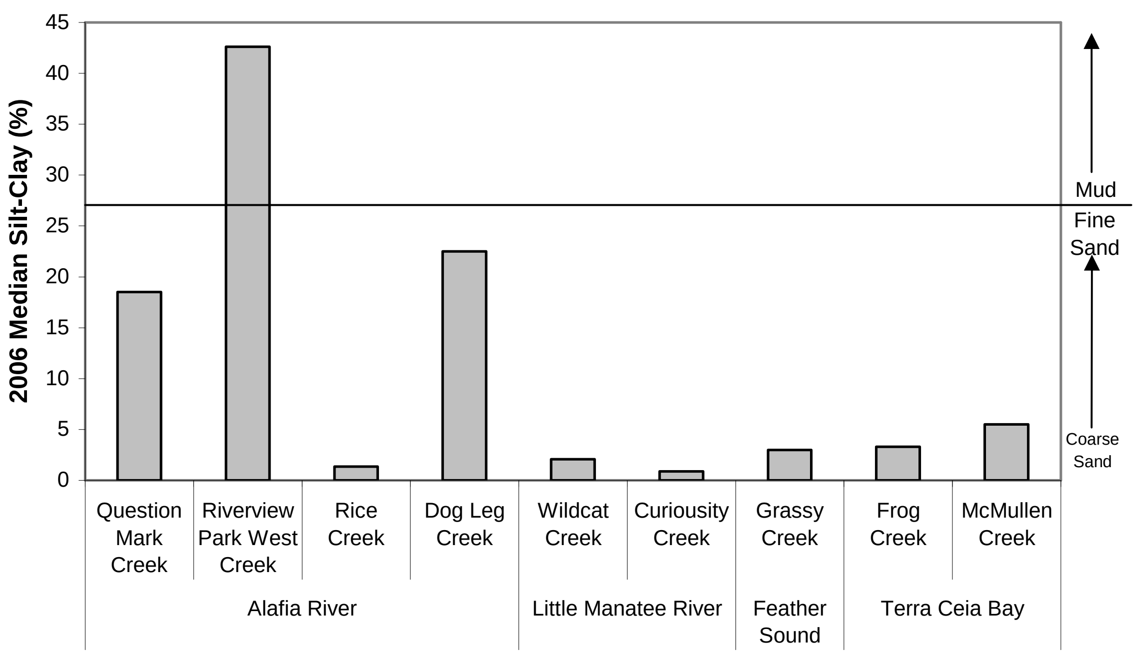


Figure 35: Median silt-clay percentages in sampled tidal tributaries.

5. Landscape Development Intensity Index for 100-m corridor as an indicator of potentially degraded water and sediment quality in tidal tributaries

Two watershed metrics indicative of human-related landscape alteration were investigated as part of the tidal tributary study: percent impervious cover and the landscape development intensity (LDI) index. These metrics were applied at the basin and stream corridor scales and were found to correlate more closely with each other along 100-m corridors of the tidal tributaries rather than at the basin level (Figures 36).

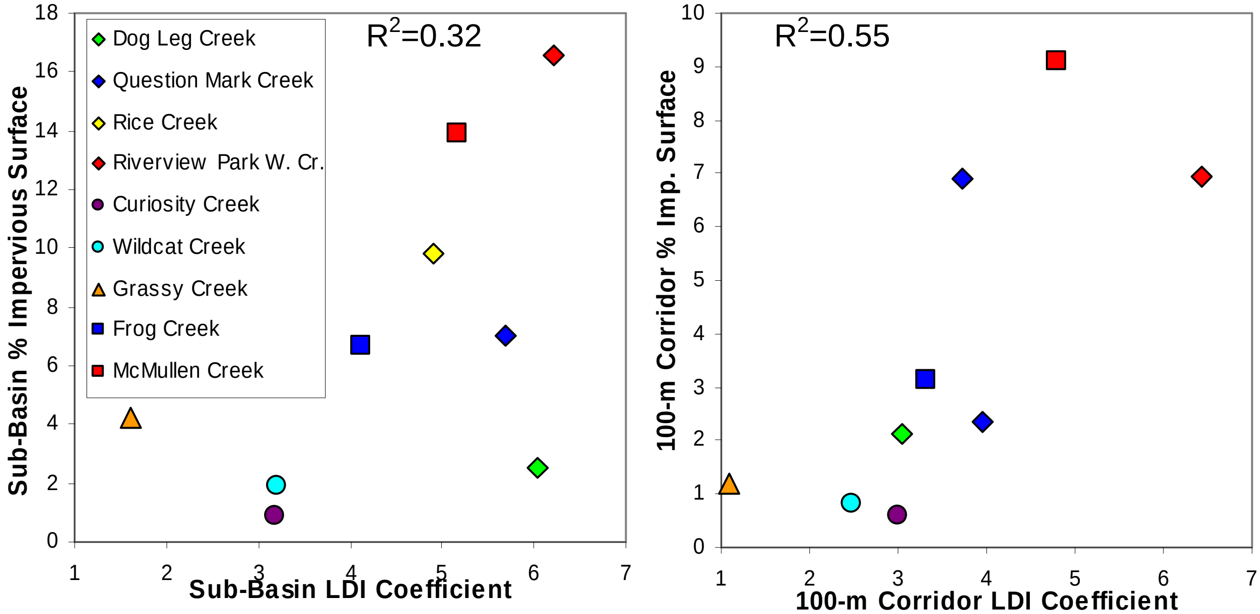


Figure 36: Relationship of watershed metrics at the basin (left) and 100-m corridor (right) scales for the tidal tributaries.

In comparison to other areas in the southeast U.S. and Florida where similar metrics have been evaluated, the majority of tidal tributaries selected for this study were found to have minimally impacted watersheds based upon imperviousness and landscape development intensity. Regardless, significant correlations with water and sediment quality metrics that could potentially indicate degradation within the tributary systems were observed. Landscape development intensity indices along the 100-m corridors showed the best correlations. Positive correlations were detected between stream corridor LDI and a number of water and sediment quality metrics. These included median observed turbidity, water-column dissolved oxygen, total phosphorus and nitrogen, and chlorophyll-a concentrations within the water-column and a host of sediment contaminant concentrations including their associated PEL and ERM quotients, sediment silt-clay percentage, and the number of total sediment contaminant TEL exceedances. Development of a target LDI for Tampa Bay tidal tributaries will require additional corridor assessments, including those with more intensely developed watersheds that represent end-member systems in order to further assess whether these associations are manifested to the biota of systems with extreme LDIs beyond which this study was able to detect.

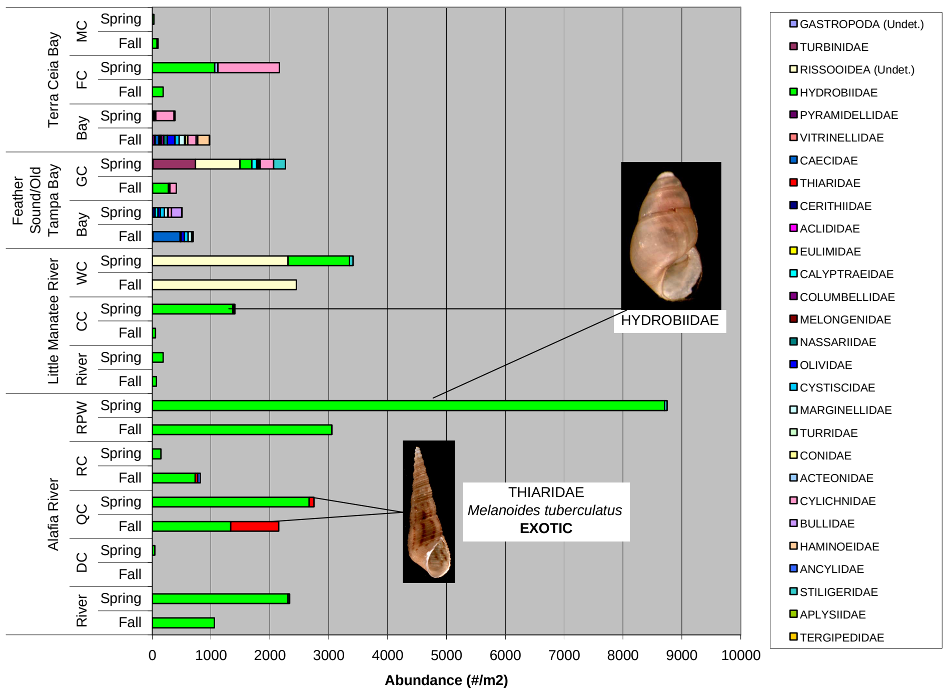
6. Exotic Species as an indicator of stressed habitat

The presence of exotic fish or invertebrate species in high proportions relative to native species may be an indicator of a stressed habitat (e.g., "Riverview Park West Creek"). Exotic species may compete with, or prey upon, native species within tidal tributaries and could potentially serve as a metric to identify a tidal tributary's functional ecologic health. By maintaining the ecological integrity of tidal tributary ecosystems, the influence and invasive capacity of exotic species could potentially be limited.

Our study indicated that both exotic fish and invertebrate species were found within tidal tributaries at a relatively high proportion. For exotic fish species, an association with degraded watershed condition was observed, but this observation was confounded by physical characteristics of the systems studied (e.g. salinity). Continued investigation of the association of exotic fish species in other tidal tributary watersheds in Tampa Bay, particularly those tidal tributaries which represent end-member systems in terms of watershed alteration, may provide further insight on the preliminary observations of this study. However, the confounding influences identified during this study would need to be addressed in subsequent investigations.

The only benthic macrofauna taxa that were identified as invasive species within the tidal tributaries studied were the gastropod *Melanoides tuberculatus* (red-rim melania snail) and the bivalve *Corbicula fluminea* (Asian clam). Both taxa are considered to be mainly freshwater species but *M. tuberculatus* has been reported in mangrove habitats with salinities as high as 30 PSU and *C. fluminea* is commonly found in oligohaline areas (Baker et al. 2004). *Melanoides tuberculatus* was found only in "Question Mark Creek" in the Alafia River system. It was present during both seasons, but was more abundant in the fall (Figure 37 top). *Corbicula fluminea* was found primarily in Rice Creek in the Alafia River system, but was also present in lesser numbers in the Little Manatee River fall samples (Figure 37 bottom). The Asian clam was present during both seasons in Rice Creek but abundances were higher in the fall, probably due to lower salinities.

There was no clear pattern of presence or abundance of exotic invertebrate species in relation to potentially stressed habitats for these tidal tributary systems, as was seen for nekton. Again, as was the case for nekton, continued investigation of exotic benthos distribution in relation to end-member tidal tributary systems within Tampa Bay would need to be tempered against confounding physico-chemical conditions of the systems investigated.



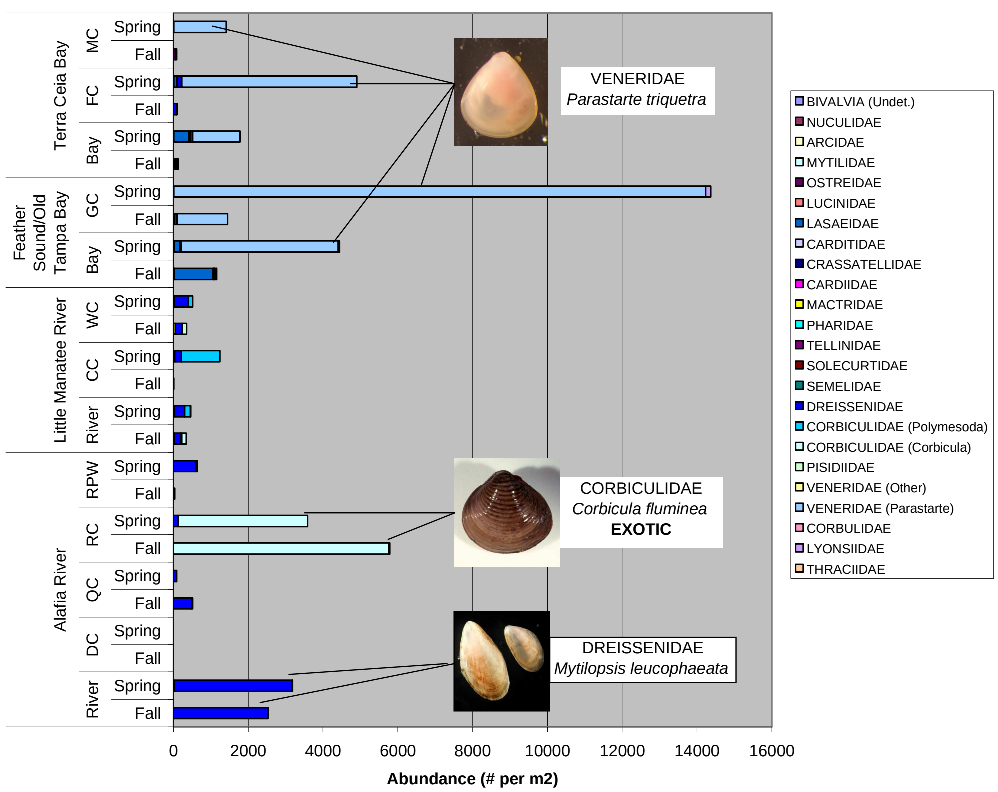
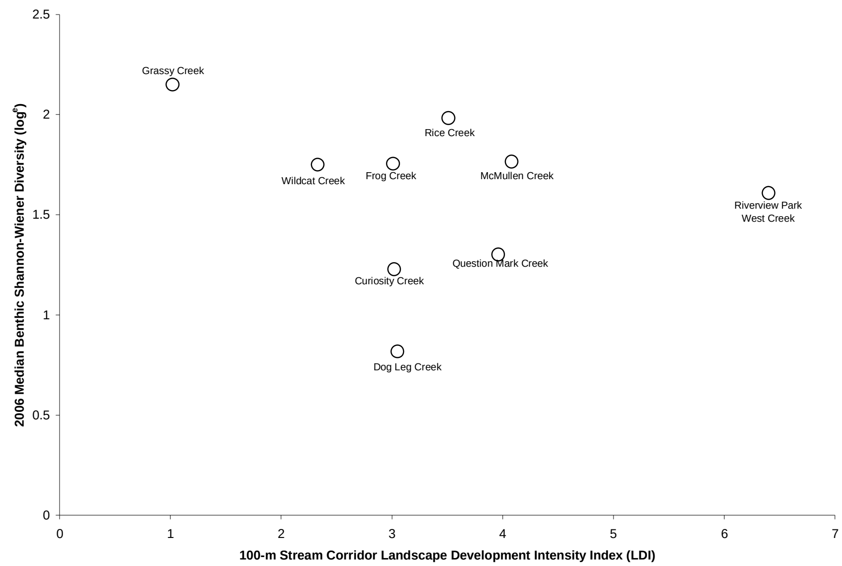


Figure 37: Seasonal gastropod (top) and bivalve (bottom) abundance in the tidal tributaries during 2006 and relative proportion of the invasive exotics *Melanoides tuberculatus* (top) and *Corbicula fluminea* (bottom).

7. Watershed metrics as an indicator of benthic biota condition

Weak or no apparent links of the watershed metrics with select benthic biota measures were observed for the systems (Figure 36). This may have been a result of the lack of selection of tributaries with a greater degree of watershed alterations, as indicated by the imperviousness and landscape development intensity metrics. Therefore we recommend study of additional tidal tributaries to assess whether association of metrics indicative of watershed alteration are manifested to measures of benthic biota "health."



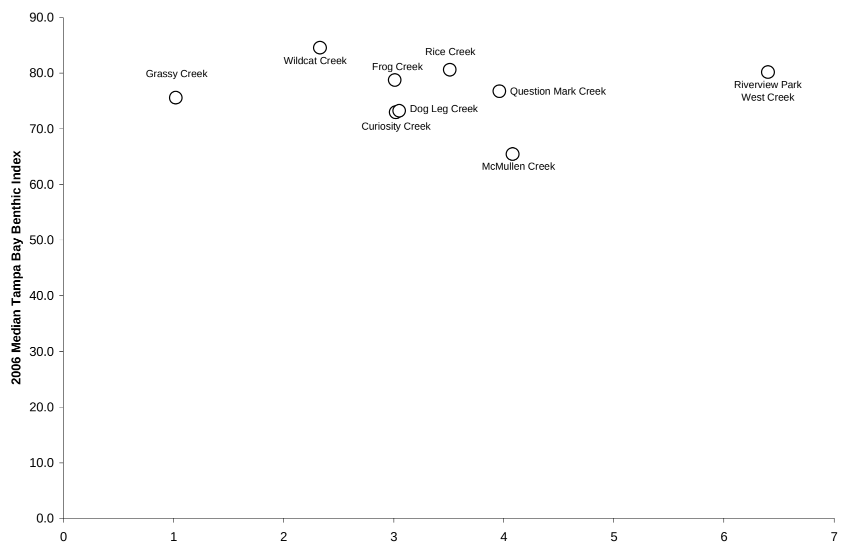


Figure 38: Relationship of 100-m corridor landscape development intensity indices (LDI) derived from 2004 SWFWMD land use/land cover information and median observed Shannon-Wiener benthic diversity (H′ as $\log_e$) (top) and the Tampa Bay Benthic Index (bottom) in the select tidal tributaries during 2006.

9. Recommended Future Monitoring Strategy Elements for Tampa Bay Tidal Tributaries

Ideally, future monitoring activities for Tampa Bay tidal tributaries should be coordinated among partners to maximize funding resources. Comprehensive monitoring strategies to develop multi-parameter metrics for biologic integrity or health of Tampa Bay tidal tributaries would be preferable and in accordance with similar studies performed in Florida (Estevez 2007). The following recommendations have been made by the Project Team for future Tampa Bay tidal tributary monitoring based upon sampling experiences and results from this project.

9.1. Fish and Fish Habitat Monitoring Strategy

- Based on the results of the nekton study, development of a long-term tidal tributary nekton monitoring program, following the protocols of the Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute's Fisheries-Independent Monitoring Program is recommended to further characterize the varying systems found within the Tampa Bay estuary.

- A tidal tributary nekton monitoring program would consist of a set number of monthly 9.1-m seine samples from a selected group of representative tidal tributaries around the Tampa Bay watershed, in particular those susceptible to watershed alteration (e.g., Wildcat Creek and Curiosity Creek) and those with perceivably greater watershed alteration than those that were studied for this project (e.g., Delaney Creek).

- Depending on funding availability, the sampling could be year-round, or else limited to the main recruitment season for common snook (and by extension, red drum) to determine tidal tributary ecological function.

- A monitoring program for nekton would allow managers to track environmental quality in Tampa Bay tidal tributaries and would also yield additional benefits, including improved stock assessments for common snook and provision of data for ancillary studies (e.g., determining the nursery habitat of adult snook by examining the chemical composition of otolith [ear bone] cores and linking this to the chemical composition evident in juvenile snook otoliths from tidal tributaries).

- Estimated funding requirements, based on the collection and processing of 40, 9.1-m seine samples per month from August to December, would be approximately $20,000 per year (2007 estimate).

9.2. Tidal Tributary Flow Monitoring

- Pilot study results point to the importance of accurate measurement of short-term flow variability to effectively manage local tidal tributaries. Flow variability, or flashiness, could not be directly estimated from other watershed characteristics, so direct flow measurements are needed to describe the "flashiness" of a tidal tributary system.

- Few of Tampa Bay's tidal tributaries are gaged in their polyhaline or mesohaline reaches. Conventional float-style gages do not distinguish flow direction and tidal adjustments to measured flows from a float-type gage are crude estimates and difficult to calibrate.

- Side-looking Acoustic Doppler Velocimeters (ADV) with pressure transducers are now available and several have been deployed and tested within other tidal tributaries in the region. ADV equipment simultaneously measures flow, flow direction, and stage. ADV gage station management is similar to a conventional gage station and could be used for tidal tributary systems.

- Installation of one ADV gage station in the lower reaches of a tidal tributary whose watershed is undergoing rapid development may be sufficient to document changes to inflow variability. Opportunistic placement of a particular gage station may also be sufficient to simultaneously characterize several closely-spaced second-order tidal tributaries.

- Input from a hydrologist/engineer should be considered in determining existing stormwater structures or any other discharges that could impact direct flow measurements, and therefore estimates of flashiness, in the tidally-influenced portions of a tributary.

9.3. Water and Sediment Quality Monitoring

- Nutrient cycling in the tidal tributaries appeared to follow seasonal cycles whereby assimilation during the dry season tended to be dominated by benthic microalgae (BMA) and during the wet season by phytoplankton. Quarterly sampling within tidal tributaries would allow for detection of seasonal shifts in algae production as related to freshwater inflow to the system.

- Tidal tributary sampling could be focused in areas where rapid urbanization is anticipated to take place in the near future (e.g. Curiosity Creek) in order to detect any anticipated changes to the nutrient cycling processes of the tributary over time.

- Quarterly sampling could be focused at fixed locations along a tidal tributary or randomized along the tidal gradient as long as adequate access to the tributaries was possible. Anticipated per sample costs for water quality and BMAC analyses would be $310 (2006 estimate). Ten, quarterly samples (40) would cost approximately $12,400 annually for collection and processing.

- Sediment contamination within the tidal tributaries closely followed depositional characteristics of the systems. For the most part, the tidal tributaries studied had sandy sediments and only those tributaries with deeper channels and subsequently muddier sediments showed signs of sediment contamination. Periodic (5-year synopsis) sediment contamination sampling is recommended for tidal tributaries where rapid watershed alteration is anticipated to take place and affect the "flashiness" of tributary systems in order to assess the degree of contamination attributable to changes in sediment deposition rates. Anticipated per sample costs for lab processing of sediment chemistry samples would be $291 (2006 estimate). A baseline characterization of the sediments of an individual tributary would involve at least 3 samples along the tributary's salinity gradient with focused sampling in muddier, depositional areas.

- Benthic communities within the tidal tributaries followed a pronounced seasonal cycle. Continued monitoring of benthos would be useful in describing the distribution and abundance of important trophic intermediates available to the nekton resources found within the tidal tributaries during peak seasonal recruitment windows. Detecting changes to this cycle could be useful in describing impacts to tidal tributary systems. Anticipated per sample costs for collection and processing of benthic biota in the tidal tributaries over two seasonal index periods (nominally the spring, dry and fall, wet season) would be $450 (2006 estimate). Twenty, dry/wet season samples (40) would cost approximately $18,000 annually for collection and processing.

10. Action Plan Elements

Developing specific action plan elements stemming from results of the Tidal Tributary Habitat Initiative is focused on integration with the Tampa Bay Estuary Program's existing Comprehensive Conservation and Management Plan (CCMP). The CCMP was first adopted in 1996 and has been updated in 2006 to include eight broad action plan elements. In December 2003, the Tampa Bay Estuary Program's Technical Advisory Committee identified assessing the importance of tidal tributaries as the top-ranked research need (of 54) in reaching Tampa Bay's CCMP goals. As a result, TBEP's Policy Board approved the development of restoration and protection goals for tidal tributaries as a management priority. Consequently, the Tampa Bay Tidal Tributary Habitat Initiative was incorporated into Action Plan FW-6 (Preserve the Diversity and Abundance of Bay Wildlife) of the CCMP during the 2006 update.

Four preliminary management actions have been developed as a result of the research conducted during the Tampa Bay Tidal Tributary Habitat Assessment Project and include:

- Maintaining connectivity between open bay waters, tidal rivers and smaller, tidal tributaries to allow fish movement, water flow and nutrient flux. Fish require a mosaic of habitats throughout their life cycle, and management should be based on a system-wide scale. This concept is important in terms of the landscape's connectivity to the surface waters, as well as for processes internal to the hydrologic landscape that promote desirable conditions within the tributaries for biotic resources.

- Reducing "flashiness" of water flow to tidal tributaries, to promote natural hydrologic regimes and foster productivity of BMA and trophic intermediates. Maintaining and restoring natural wetlands, marshes and riparian corridors in tidal tributary watersheds, as well as considering additional methods of water retention and gradual release throughout their basins, are primary recommendations.

- Tracking condition of nursery functions and physical parameters in Tampa Bay tidal tributaries by monitoring freshwater inflow, watershed development, water quality indicators and nekton habitat use. This recommendation would allow for broader based studies and cataloging of minor tidal tributary systems whose functions are not yet defined.

- Improving public education and stewardship of tidal tributaries by promoting an Adopt-a-Creek program. Tidal tributaries are habitually overlooked in management scenarios and promoting their importance as sentinel habitats in the public perception can lead to an improved management response.

The TBEP will work with partners to further refine these preliminary actions and determine the relevance of these actions in other Tampa Bay tidal tributary watersheds. A major effort will need to be made to catalog the existing habitat and fisheries value of tidal tributaries throughout the Tampa Bay area as recommended from future monitoring strategy elements previously described in this report. This information will further guide development of action plan elements for Tampa Bay tidal tributaries. The Tidal Tributary Project Team anticipates that final adoption and implementation of the four preliminary management actions described above will require additional participation and input from TBEP partners. Preliminary action plan elements developed from this project requiring additional partner input follow.

ELEMENT 1: Maintain connectivity of the estuarine continuum

ACTION: Protect important estuarine processes from being fragmented across the watershed by encouraging greater protection of minor, tidally-influenced tributaries

STATUS: Ongoing. Action to support research, management, education and restoration opportunities to protect abiotic and biotic processes inherent to the mosaic of habitats that are hydrologically linked across the Tampa Bay estuary's watershed.

BACKGROUND:

Recent restoration activities have focused on providing a mosaic of habitat types within a given project to maximize the benefits to fish and wildlife. This concept appears important along a system-wide scale, as well. Cumulative functional losses of transitional habitat types, such as tidal tributaries, may impair estuarine processes. It is important to rehabilitate existing fragmented habitats along the "estuarine continuum" and promote their sustained connection to the Tampa Bay estuary, so that larger receiving waterbodies do not become overly burdened and exhausted.

The importance of "backwater" tidal tributary areas and their interconnection with adjacent bay and riverine waters was exemplified by juvenile common snook abundance, an economically important fisheries species.

STRATEGY:

STEP 1 Identify critical tidally-influenced habitats either currently fragmented or that may become fragmented in the future.

Responsible Parties: Local governments, TBEP
Timeline: Ongoing

STEP 2 Include the restoration and protection of tidal tributaries in the 2007 Tampa Bay Habitat Masterplan.

Responsible Parties: TBEP
Timeline: 2008

ELEMENT 2: Protect the natural hydrologic regime of tidal surface waters

ACTION: Assess impacts of inflow "flashiness" to tidal tributary systems throughout the Tampa Bay watershed and provide recommendations for restoration of the watersheds hydrology.

STATUS: New action to support research, management and education

BACKGROUND:

In as much as minor, tidally-influenced tributaries have been neglected in terms of monitoring relative to larger riverine and embayments in Tampa Bay, so too have they been neglected in terms of maintaining appropriate inflow necessary to preserve their ecological functions. The ecological effects of freshwater inflows to the major rivers of Tampa Bay have been largely addressed through the enactment of state legislation to define "minimum flows" for these larger systems; however, minor tidal tributaries have not been granted the same level of protection. Many times these minor systems act as coastal arterials to the larger waterbodies, such as the major rivers, where cumulative freshwater inflow is collected. Sustaining the natural hydrology and preserving the ecological functions served as part of the delivery of freshwater inflow of these minor systems will only promote a healthier linkage to the Tampa Bay estuary as a whole. Preliminary results from the Tidal Tributary Habitat Initiative Project suggested that inflow "flashiness" to tidal tributaries in Tampa Bay needs further investigation, particularly in relation to its negative effects on downstream ecological processes.

STRATEGY:

STEP 1 Maintain or restore permeability of altered drainage areas surrounding tidal surface waters.

Responsible Parties: Local governments, SWFWMD
Timeline: Ongoing

STEP 2 Develop protective land use codes in tidal tributary watersheds, particularly for the 100-m corridors surrounding a tributary.

Responsible Parties: Local governments
Timeline: TBD

STEP 3 Develop guidelines for habitat restoration of altered tidal tributaries to decrease flashiness, maintain shallow water depths, and increase watershed permeability.

Responsible Parties: TBD
Timeline: TBD

STEP 4 Encourage incentives for homeowners who plant trees or other native, drought-tolerant flora instead of grass (tax breaks?) to promote greater retention of water in coastal catchments and thereby decrease flashiness to tidally-influenced areas.

Responsible Parties: TBD
Timeline: TBD

STEP 5 Restore mosquito ditches to more natural tidal tributary morphology by re-establishing sheet flow and natural tidal flushing and creating transitional buffering habitats to uplands.

Responsible Parties: TBD
Timeline:

STEP 6 Restore natural inflow variability in Frog Creek.

Responsible Parties: Manatee County
Timeline: TBD

ELEMENT 3: Monitor the status of tidal tributary habitats

ACTION: Continue monitoring the abiotic and biotic conditions of tidal tributary systems throughout the Tampa Bay watershed in order to catalog the variety of functions these small systems provide to the overall estuary.

STATUS: Ongoing. Action to support continued research and management of tidal tributary systems.

BACKGROUND:

Results from the Tampa Bay Tidal Tributary Habitat Initiative Project highlighted the individual uniqueness of tidal tributaries found within the Tampa Bay estuary. Four broad watershed areas were investigated in this study, and results from water, sediment, and nekton sampling determined that the 9 tidal tributary systems studied varied to great extent over these 4 broad areas and also within each watershed. Because these 9 systems represented only a fraction of the total number of minor, tidally-influenced systems in Tampa Bay (>150), continued monitoring of other systems is recommended. External reviewers of this project as well as the Project Team have concluded that focused monitoring in other Tampa Bay tidal tributaries whose watersheds represent end-member systems may strengthen some of the associations of monitoring data with watershed alteration metrics.

STRATEGY:

STEP 1 Implement future monitoring strategies identified through the Tampa Bay Tidal Tributary Management Plan.

Responsible Parties: TBD
Timeline: TBD

STEP 2 Catalog imperviousness, landscape development intensity, and other relevant watershed metrics for other tidal tributary systems in Tampa Bay to focus monitoring towards end-member systems.

Responsible Parties: TBD
Timeline: TBD

ELEMENT 4: Establish a tidal tributary awareness campaign

ACTION: Evaluate the initiation of an Adopt-a-Creek public education and action program, modeled after the successful Adopt-a-Pond and Stream-Watch county-sponsored programs.

STATUS: New action to promote public awareness and volunteer monitoring of tidal tributary habitats in the Tampa Bay watershed.

BACKGROUND:

Potential negative ecological effects of non-point source stormwater pollution to surface waters of the bay are expected as regional growth and land use alterations continue within the drainage basins of coastal areas. An important component for protecting tidal tributaries in the face of watershed development will be education and advocacy of new land owners adjacent to these resources. Modeled after similar county programs, an Adopt-A-Creek education campaign would help land owners maintain or improve water quality, wildlife habitat, and natural corridors along tidal tributaries that are or are anticipated to be developed. This program would encourage residents to monitor the status of adjacent tidal tributaries and provide incentives for maintaining adequate ecological integrity from their land to the adjacent tidally-influenced systems. Successful implementation of the campaign could be facilitated through the web-based, Tampa Bay Estuary Atlas by allowing communication and distribution of awareness campaign materials to the public and other interested stakeholders.

STRATEGY:

STEP 1 Focus on education and stewardship programs for residential land owners adjacent to tidal tributary systems.

Responsible Parties: TBD
Timeline: TBD

STEP 2 Initiate a pilot program in the Curiosity Creek watershed where land uses are anticipated to transition to rural development.

Responsible Parties: TBD
Timeline: TBD

STEP 3 Develop on-line materials and information about the Adopt-A-Creek program for inclusion into the Tampa Bay Estuary Atlas.

Responsible Parties: TBD
Timeline: TBD

11. References

Arnold, C.L. and C.J. Gibbons. 1996. Impervious surface coverage. *J. Am. Plan. Assoc*. 62 (2), 243–258.

Baker, P., Baker S.M., Fajans, J. 2004. Nonindigenous marine species in the greater Tampa Bay ecosystem. Tampa Bay Estuary Program Tech. Pub. # 02-04.

Blanchard, G. 2006. Tampa Bay Tidal Tributaries Habitat Assessment: Quality Assurance Project Plan. V 3.1, April 2006. Plan Submitted to the Pinellas County Environmental Fund.

Browder, J.A. and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of fresh water to estuaries, p. 403-430. *In* R. Cross and D. Williams (eds.), Proc. Nat. Symp. On Freshwater Inflow to Estuaries. Vol. 1 FWS/OBS-81/04. US Fish and Wildlife Service, Washington, D.C.

Brown, M.T. and M.B. Vivas. 2005. Landscape development intensity index. *Environmental Monitoring and Assessment* 101:289-309.

Brown, M.T. and K.C. Reiss. 2006. Proposed Breakpoint of LDI < 2.0 for Determining Minimally Affected Reference Conditions for Water Bodies. Center for Environmental Policy, Department of Environmental Engineering Sciences, University of Florida. Technical Report Submitted to the Florida Department of Environmental Protection.

Estevez, E. 2007. Sarasota Tidal Creek Condition Index for Coastal Streams in Sarasota County, Florida. Mote Marine Laboratory Technical Report Number 11331. Final 2006 Report Submitted to Sarasota County Water Resources.

Gordon, D., D. Shaw, L. Geselbracht, E. Contreras, and R. Torres. 2005. Threats and Actions for Florida's Comprehensive Wildlife Conservation Strategy. The Nature Conservancy, Gainesville, FL. Final Report submitted to the Florida Fish and Wildlife Conservation Commission.

Greening, H. and A. Janicki. 2006. Toward reversal of eutrophic conditions in a subtropical estuary: water quality and seagrass response to nitrogen loading reductions in Tampa Bay, Florida, USA. *Environmental Management* Vol. 38, No. 2, pp. 163-178.

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. *J.Exp. Mar. Biol. Ecol.* 298, 151-178.

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.

Lane, C.R.. 2003. Development of Biological Indicators of Wetland Condition for Isolated Depressional Herbaceous Wetlands in Florida. Ph.D. Dissertation, Department of Environmental Engineering Sciences, University of Florida, Gainesville.

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.

Lewis, R. R., III and D. Robison. 1996. Setting Priorities for Tampa Bay Habitat Protection and Restoration: Restoring the Balance. Tampa Bay National Estuary Program Technical Publication #09-95. Tampa Bay National Estuary Program, St. Petersburg, Florida.

MacDonald, D.D. 1994. Approach to the assessment of sediment quality in Florida coastal waters. Volume 1 – Development and evaluation of sediment quality assessment guidelines. Prepared for the Florida Department of Environmental Protection. 126pp.

Odum, H.T. 1996. Environmental Accounting: Emergy and environmental decision making. John Wiley and Sons. New York. 370p.

Odum, W. E., C. C. McIvor, and T. J. Smith, III. 1982. The Ecology of the Mangroves of South Florida: A Community Profile. Fish and Wildlife Service Office of Biological Services Report FWS/OBS-81/24. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

Schueler, T.R. 1992. Mitigating the Adverse Impacts of Urbanization on Streams: A Comprehensive Strategy for Local Government. *In* P. Kimble and T. Schueler, (eds.), Watershed Restoration Sourcebook. Publication #92701 of the Metropolitan Washington Council of Governments.

Stevens, P. W., C. L. Montague, and K. J. Sulak. 2007. Fate of fish production in a seasonally flooded saltmarsh. *Marine Ecology Progress Series* 327, 267-277.

TBRPC (Tampa Bay Regional Planning Council). 1986. Ecological Assessment, Classification and Management of Tampa Bay Tidal Creeks. Tampa Bay Regional Planning Council, St Petersburg.

TNC (The Nature Conservancy). 2007. Indicators of Hydrologic Alteration, v. 7.0.4.0.
http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html

Yeager, L. A., J. M. Krebs, C. C. McIvor, and A. B. Brame. 2007. Juvenile blue crab abundances in natural and man-made tidal channels in mangrove habitat, Tampa Bay, Florida (USA). *Bulletin of Marine Science* 80, 555-565.

APPENDICES (on DVD)

A. Tampa Bay Tidal Tributaries Habitat Initiative: Quality Assurance Project Plan - includes Monitoring and GIS Databases

B. Tampa Bay Tidal Tributary Final Report: Water Quality, Sediment Chemistry, Benthic Macrofauna, and Watershed Characterization

C. Tampa Bay Tidal Tributaries Habitat Initiative: Fish and Fish Habitat Technical Report (including fish diet analyses)

D. Stable Isotope Analysis of Tampa Bay Tidal Tributary and Tidal Creek Ecosystems (fish food sources)

E. External Reviewers/TBEP TAC Comments and Project Team Responses