

SARASOTA BAY Numeric Nutrient Criteria: Tidal Creeks

Letter Memorandum

Prepared for:



Protecting Our Water Heritage

Sarasota Bay Estuary Program

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17 March 2011

EXECUTIVE SUMMARY

Tidal creeks are relatively small coastal tributaries (<1-20 km in length) that lie at the transition zone between terrestrial uplands, freshwater streams and the open estuary and serve as a link between terrestrial and estuarine systems. Despite their close connection to these systems, tidal creeks play a unique and integral role in the ecological function of coastal estuaries as:

- a source of high primary and secondary production,
- a site of nutrient cycling,
- a source of food for small-bodied fishes and crustaceans, as well as a foraging area for larger piscivorous fishes, wading birds, snakes and alligators, and
- nursery habitat for juvenile fishes and crustaceans of economic value, including the common snook (*Centropomus undecimalis*).

Tidal creeks possess water quality characteristics that differ from freshwater systems and from the open estuary. As a result of their direct connection and close proximity to watershed sources of nutrient inputs and their smaller volumes and shallower depths relative to the open estuary, tidal creeks have relatively high nutrient and chlorophyll concentrations and low dissolved oxygen (DO) levels compared to downstream waterbodies. DO levels from 2-4 mg/L are commonly observed in tidal creeks in the southeastern United States, including creeks from undeveloped watersheds. Higher nutrient concentrations and lower DO levels in tidal creeks relative to the greater estuary may be required to support the higher levels of primary and secondary production in these systems. Nutrient inputs from the surrounding watershed supply much of the fuel that drives primary production in tidal creeks, in the form of benthic microalgal communities and phytoplankton. The algal stocks, in turn, support upper trophic levels and drive secondary production by benthic macroinvertebrates, fishes and decapod crustaceans.

Despite possessing water-quality conditions that would otherwise be considered impaired in freshwater and estuarine systems, tidal creeks have been shown to support higher densities of many species of small-bodied fishes compared to the adjacent estuary and tidal rivers. Many of these species have acquired physiological and behavioral adaptations, including aquatic surface respiration (ASR) and air-gulping, which allow them to persist under the low-DO conditions that often occur in tidal creeks and to take advantage of the forage- and refuge value of these systems.

In the Sarasota Bay estuary, there are approximately thirteen tidal creeks that are terminal tributaries to the bay or to smaller embayments within the bay. Most tidal creeks in Sarasota Bay are relatively small (<10 km in length) and narrow (spanning only 25-50 m from bank to bank) in contrast to larger tidal rivers in southwest Florida which typically range from 40-170 km in length and 100-300 m wide on average. Most of Sarasota Bay's tidal creeks have been developed for urban and industrial land uses, with little remaining natural mangrove wetlands. Unlike the open estuary of Sarasota Bay which possesses expansive seagrass beds, tidal creeks are typically devoid of seagrass.

Given the current state of knowledge on tidal creeks, three approaches to develop numeric nutrient criteria in tidal creeks are available. Each of these approaches has previously been considered for development of nutrient criteria for the Sarasota Bay estuary. These include:

- Stressor-response models which examine quantitative relationships between nutrient concentrations and either chlorophyll a or DO concentrations within a specific waterbody of concern (i.e., tidal creek),

- Reference condition methods which use available data for selected “reference” creeks to derive numeric nutrient criteria for creeks, and
- Downstream protective values which are based on the relationship between water quality in the creek and that of the downstream receiving estuary such that the water quality in the tidal creek does not result in water-quality exceedances in the downstream estuary.

The most desirable approach to establish numeric nutrient criteria would be to develop stressor-response models. Stressor-response models require the identification of an indicator variable that can be used to evaluate the condition of the tidal creek. Moreover, stressor-response models require identification of a threshold value above (or below) which the system would no longer fully support its designated use. Due to a current lack of data with which to develop stressor-response models for Sarasota Bay’s tidal creeks, potential interim criteria based on chlorophyll a targets for the downstream estuary from the 2001-2005 reference period could provide preliminary numeric nutrient criteria for tidal creeks.

Numeric nutrient criteria established for tidal creeks must consider the different ecological processes and functions that distinguish them from both the freshwater systems upstream and the open estuary downstream. It is important that the established criteria for tidal creeks also account for the fact that these systems by nature are more variable than their upstream or downstream counterparts. This variability is in part what makes these systems so productive and also so difficult to generalize. Implementation of criteria for tidal creeks should rely heavily on quantifying the uncertainties in both the derivation of the criteria and in the evaluation of potential remediation effort associated with failure of the criteria. Only with careful consideration of these attributes can criteria be developed that will maintain the function of tidal creeks in support of the greater estuarine ecosystem.

1.0 Background

Tidal creeks play an integral role in the ecological function of coastal estuaries. The treatment of tidal creeks in the implementation of the estuarine numeric nutrient criteria is, therefore, a significant issue. A thorough understanding of the ecological elements (e.g., faunal and floral species and communities), processes (e.g., primary productivity, nutrient cycling, secondary production), dynamics of tidal creeks (e.g., temporal fluctuations in dissolved oxygen) and function in exporting energy to estuarine and coastal ecotones is paramount to the establishment of ecologically appropriate nutrient criteria. Numeric nutrient criteria established for tidal creeks must consider the different ecological processes and functions that distinguish them from both the freshwater systems upstream and the open estuary downstream. Only with careful consideration of these attributes can criteria be developed that will maintain the function of tidal creeks in support of the greater estuarine ecosystem. The objective of this task is to:

- Provide a definition of tidal creeks,
- Provide a generalized overview of the ecological function of tidal creeks in relation to the estuary,
- Identify factors to be considered when establishing criteria for tidal creeks, and
- Discuss potential methods for data evaluation directed at establishing nutrient criteria for these systems.

1.1 Definition of a Tidal Creek

Located at the transition zone between terrestrial uplands and the open estuary, tidal tributaries deliver freshwater and nutrients from the surrounding watershed to the estuary. Tidal tributaries can be classified based on size, with larger tidal rivers often a prominent feature in the estuarine landscape. Smaller tidal tributaries (herein referred to as “tidal creeks”) include natural and manmade creeks, residential canals and navigational channels, and ditches created for stormwater drainage or mosquito control. The geomorphological and physicochemical features of the tidal creeks distinguish them from the non-tidal, freshwater tributaries, springs, and lacustrine systems that are found elsewhere in the watershed and determine zonation patterns for the flora and fauna that inhabit these systems. Tidal creeks may reach well upstream of the mouth and may be distinguished on the basis of elevation; tidal creeks extending above sea-level are often greater in length and drain larger watershed areas than creeks restricted to elevations below sea-level. Those tidal creeks draining only intertidal areas are likely dominated by tidal fluctuations and are less influenced by stormwater runoff than creeks originating above sea-level which often have well-developed freshwater reaches and are more sensitive to stormwater inputs. The differences in physiographic and water quality attributes observed along the gradient from headwater streams to larger rivers are the result of processes related to the flow of water and have been termed the “River Continuum Concept” by Vannote et al. (1980). This concept is based on the idea that first-order tributaries are more strongly linked to terrestrial processes and inputs and, as a result, are inherently different from downstream reaches. Flow-related changes to the geomorphology of the tributary (e.g., stream width, bank slope, channel depth) along the river continuum translate to differences in the composition of floral and faunal communities, trophic structure and ecological processes. There is evidence that this concept can be applied to coastal systems, as well, from freshwater tributaries to tidal tributaries to the estuary (Greathouse and Pringle, 2006).

1.2 Hydrological and Water Quality Processes in Tidal Creeks

Tidal creeks are expected to possess water quality characteristics that differ from freshwater systems and from the open estuary; this should be a key consideration when developing numeric nutrient criteria for transitional systems like tidal creeks. As a result of their direct connection and close proximity to watershed sources of nutrient inputs and their smaller volumes relative to the open estuary, tidal creeks have relatively high nutrient and chlorophyll concentrations and low dissolved oxygen (DO) levels compared to downstream waterbodies (Holland et al., 2004; Sherwood, 2008) where nutrient loads are rapidly diluted by the greater water volumes. Flushing time in unmodified tidal creeks is relatively rapid (Buzzelli et al., 2007), but retention time and concentration of nutrient inputs from the watershed increases in developed watersheds as the hydrology is impaired by sediment deposition, water-control structures, etc. Tidal creeks with extended flushing times or high nutrient inputs, in particular, have the potential to become hypoxic as nutrients are metabolized by the system and oxygen is consumed. For this reason, it is necessary that land use considerations be included when developing water-quality criteria for these systems. Even then, the complexity of the landscape, extent of directly connected impervious areas and the spatial arrangement of land use types within the watershed may limit the ability to use the same criteria for different tidal creeks.

DO levels and biochemical oxygen demand in tidal creeks are tightly coupled to nutrient inputs via algal biomass which responds quickly to increased nutrients, often consuming oxygen in the process (Mallin et al., 2004). A graphical interpretation of the linkages among factors influencing dissolved oxygen levels is provided in Figure 1. Linkages among these factors are consistent across aquatic systems, though the nature of the relationships varies as a result of multiple factors. The relative importance of allochthonous carbon (i.e., detritus from vascular plants, such as mangrove leaf litter, saltmarsh grasses, terrestrial vegetation) versus autochthonous carbon (i.e., phytoplankton and benthic algae produced within the system) has a large influence on the rate of nutrient cycling and fluctuations in DO in tidal creeks. In the open estuary, autochthonous carbon is more important to nutrient, chlorophyll and DO dynamics, but in the transitional waters of the tidal creeks, the contribution of allochthonous inputs may be more important. For any system, including tidal creeks, it is necessary to have sufficient knowledge to relate these factors to the DO response prior to establishing appropriate carbon-supply rates commensurate with desired DO conditions. Typically, information on freshwater inflows, nutrient supplies, the associated autochthonous carbon response (i.e., via phytoplankton), and the biotic integrity of the system are more readily available than the supply rate of allochthonous organic carbon, re-aeration rates, and sediment oxygen demand that influence DO concentrations. Uncertainties related to the effects of these less-defined impacts act as confounding factors in the development of relationships between nutrients, phytoplankton responses, and DO.

Low DO is not uncommon in tidal creeks in the southeastern US, particularly during the warmer spring and summer months and at night when primary producers switch from oxygen production to oxygen consumption (MacPherson et al., 2007). Several tidal creeks from watersheds with varying land use characteristics in North Carolina all experienced low DO (2.0-4.0 mg/L) during the warmer, wetter months between May and September, in contrast to cooler, drier months when considerably higher (4.0-8.0 mg/L) DO levels were observed (MacPherson, et al., 2007). Groundwater inflows, common in coastal areas where the surficial aquifer is in close contact with surface waters, can also be a significant driver of DO conditions in tidal creeks and may need to be accounted for when developing water-quality relationships. As anoxic groundwater infiltrates the tidal creek, greater oxygen demand results (MacPherson, et al., 2007).

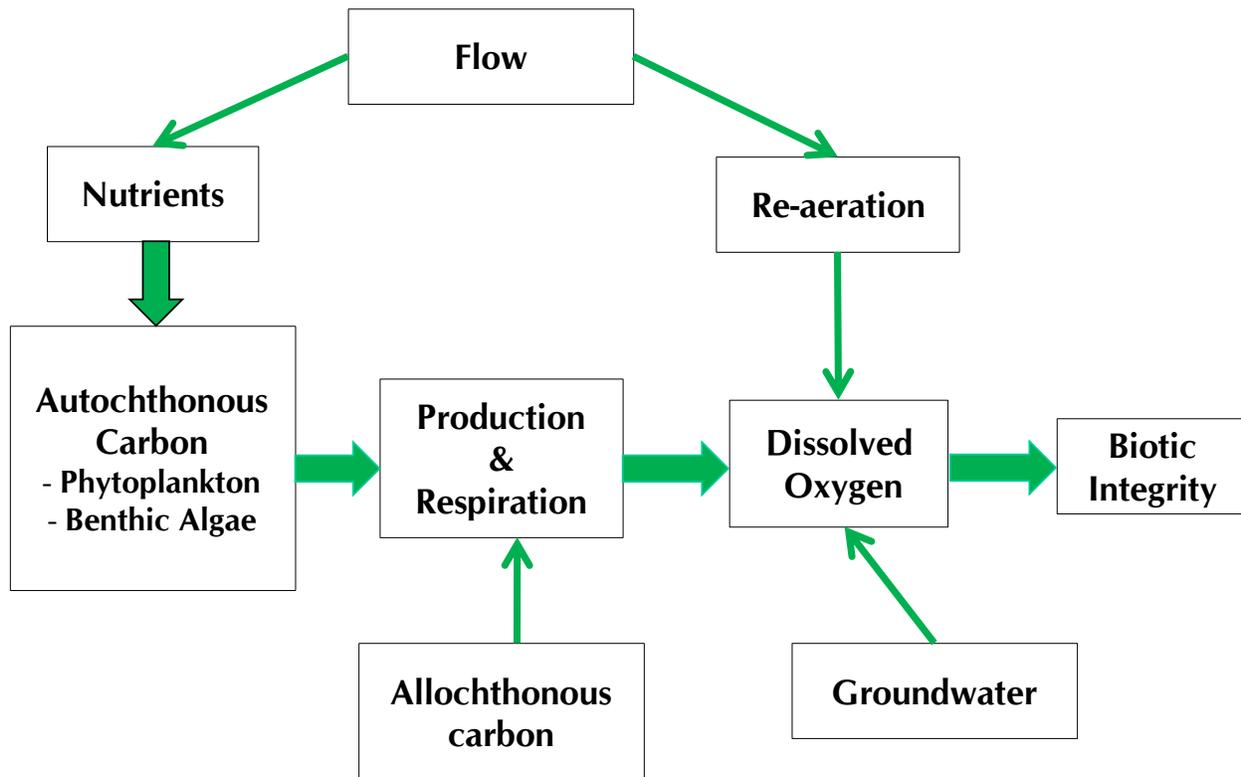


Figure 1. Conceptual diagram depicting the relationships among water-quality parameters and physical factors that influence the biotic integrity of aquatic systems. Large arrows identify the key relationships that can be used to develop numeric nutrient criteria for estuaries and tidal creeks.

1.3 Value of Tidal Creeks as Habitat for Estuarine Benthos and Nekton

Though the ecological role of tidal creeks in the coastal ecosystem is not yet fully understood, their value as a source of primary and secondary production and their contribution as habitat for juveniles of many species of marine, estuarine and freshwater fishes and crustaceans is becoming clear (Mallin and Lewitus, 2004; Holland et al., 2004; Krebs et al., 2007; Greenwood et al., 2008a; Sherwood et al., 2008). Nutrient inputs from the surrounding watershed supply much of the fuel that drives primary production in tidal creeks, in the form of benthic microalgal communities and phytoplankton. The algal stocks, in turn, support small-bodied fishes such as killifishes, sailfin mollies, and mosquitofish that reside permanently in the shallow waters of the tidal creeks (Nordlie, 2000) as well as schooling species like silversides and anchovies that feed on planktonic blooms.

The gently sloping banks of unmodified tidal creeks allow large expanses of intertidal habitat to be inundated by rising tides and provide access to resident fishes which use the intertidal areas adjacent to tidal creeks for spawning, feeding, and refuge from predators. These conditions allow many of the populations of resident fishes and crustaceans to reach densities that exceed those observed in the open estuary (Tukey and DeHaven 2006; Sherwood 2008; Stevens et al. 2010a) and provide an abundant food source which is consumed by upper trophic levels including large-bodied fishes, wading birds, mangrove-saltmarsh snakes, alligators, and raccoons that forage in tidal creeks. In addition to resident taxa, relatively high abundances of juvenile transient fishes and blue crabs are found in tidal creeks (Krebs et al. 2007; Yeager et al. 2007; Greenwood et al. 2008a,b; Brame 2010) compared to adjacent habitats, suggesting that tidal creeks serve as nursery habitat for some estuarine and coastal marine species during their early life history.

Tidal creeks along the mid-Atlantic coast of the U.S. support a large number of nekton species. At least 100 taxa have been identified in tidal creeks from New Jersey to Georgia many of which also occur in Florida's tidal creeks. Schooling species, including Atlantic silversides (*Menidia menidia*), bay anchovy (*Anchoa mitchilli*) and several species of herring and shad, mullet (*Mugil* spp.), *Fundulus* killifishes and palaemonid grass shrimp are the numerically dominant taxa in many of these systems, with penaeid and crangonid (sand) shrimp, spot (*Leiostomus xanthurus*), summer flounder (*Paralichthys dentatus*) and blue crab (*Callinectes sapidus*) among the dominant economic taxa (Cain and Dean. 1976; Hackney et al., 1976; Rozas and Hackney, 1984; Rountree and Able, 1992; Holland et al., 2004).

In temperate New Jersey estuaries, greater nekton densities have been documented for saltmarsh tidal creeks compared to adjacent seagrass and macroalgae habitats demonstrating the importance of tidal creeks as habitat for fish and crustaceans and suggesting relatively high secondary production of small-bodied forage fishes in tidal creeks compared to adjacent habitats (Sogard and Able, 1991). The value of tidal creeks in terms of their aquatic-life support function is exemplified by higher growth rates and lower mortality of some juvenile fishes relative to downstream habitats in North Carolina (Ross 2001).

Macrobenthic invertebrates are an important component of the faunal community in tidal creeks, particularly as a food source for higher trophic levels. In South Carolina, 97 macroinvertebrate taxa were collected from tidal creeks, though nearly half of these were rarely collected (Lerberg et al., 2000). Annelid worms, specifically oligochaetes and polychaetes were the dominant taxa with nine species representing 90% of the community in terms of abundance, though nemertean worms were also more abundant than most taxa. In Tampa Bay tidal creeks, at least 44 taxa have been documented (Sherwood et al., 2007) with annelid worms, amphipods and mysid crustaceans among the dominant macrobenthos. The latter two taxa may be particularly important as a trophic intermediate between primary production and upper-level consumers (Sherwood, 2008).

In terms of habitat value for macrobenthos, tidal creeks in South Carolina have relatively low Shannon diversity (1.6-3.0) compared to adjacent estuarine habitats (1.9-4.0, Chesapeake Bay; Lerberg et al., 2000). The range of macrobenthic diversity in Tampa Bay tidal creeks (1.5-3.0) was very similar to that observed for creeks in South Carolina for many of the tidal creeks, but very low diversity (0.5-1.0) was observed for several Tampa Bay creeks (Sherwood et al. 2007). Compared to the adjacent estuary, median diversity in Tampa Bay tidal creeks was generally lower (<2.0 vs. approximately 2.5; Karlen et al., 2008).

1.4 Southwest Florida Tidal Creeks

Tidal creeks in Florida are known to support a diverse fish community by providing habitat for numerous species and by maintaining high abundances of forage fish. Approximately 150 taxa of fishes and decapods crustaceans have been collected from almost 80 tidal creeks from Cedar Key to Naples (Adams, 2005; Krebs et al., 2007; Greenwood et al., 2008a,b; Stevens et al., 2008; Stevens et al., 2010a,b). Among these taxa are at least twenty-four species of economic value including spot, mullet, red drum, penaeid shrimp, blue crabs (Yeager et al., 2006) and common snook, many of which use tidal creeks as a nursery during their juvenile stage. In comparison, approximately 200 taxa were collected from the Tampa Bay estuary (including the tidal rivers) during 2008 fisheries-monitoring efforts (FWC, 2008). Similar species numbers were recorded for the Charlotte Harbor and Cedar Key estuaries (FWC, 2008).

Relative to adjacent bay and tidal river habitats, equivalent or higher fish densities have been documented in tidal creeks from Cedar Key to Charlotte Harbor (Tukey and DeHaven, 2006; Krebs et al., 2007; Greenwood et al., 2008a; Stevens et al., 2010a,b). One species in particular, common snook, were observed as juveniles in tidal creeks at densities 2-36 times greater than shoreline habitat just outside the mouth of the creeks in Tampa Bay (Greenwood et al., 2008a) and 6.5 times greater in tidal tributaries of the Caloosahatchee River compared to the mainstem river (Stevens et al., 2010a). Fish densities in Gulf coast tidal creeks typically range from several hundred to several thousand fish/100 m² (Adams, 2005; Tuckey and DeHaven, 2006; Krebs et al., 2007; Greenwood et al., 2008a, b; Dixon and Adams, 2010) though fish densities in some of these study creeks were <100 fish/100 m². Some of the most diverse fish assemblages in Tampa Bay tidal creeks were observed to have densities of 1,000-2,000 fish/100 m² and >30 taxa (Krebs, unpubl. ms). In comparison, average nekton densities from adjacent estuarine habitats, including tidal rivers, seagrass and mangrove shorelines, are typically <1,000 fish/100 m² (Tuckey and DeHaven, 2006), but have been shown to reach 2,500 fish/100 m² just outside the mouth of Tampa Bay tidal creeks (Greenwood et al., 2008a).

1.5 Dissolved Oxygen and Tidal Creek Fishes

Dissolved oxygen levels in tidal creeks are often lower than those observed in the receiving waters. For example, a study by Stevens et al. (2010a) reported average DO levels for the Caloosahatchee River to range from 7.0-7.9 mg/L in contrast to smaller tidal creeks which ranged from 6.4-6.8 mg/L and were 1.3 mg/L less than DO levels in the first 30 km of the mainstem river. Despite lower DO levels in the tidal creeks, total fish densities did not differ between the tidal creeks and mainstem Caloosahatchee River and were, in fact, slightly greater in the tidal creeks (mean 502 vs. 554 fish/100 m²). Species-level differences in abundance between river and creeks were observed, with higher densities of many resident taxa in the tidal creeks. As has been documented in several previous studies (Greenwood et al., 2008; Sherwood et al., 2008; Brame, 2010), higher densities of juvenile common snook were observed in tidal creeks, reinforcing the idea that tidal creeks serve as a nursery for this economically important species. The species composition of the fish assemblage was distinctly different between tidal creeks and adjacent areas, as well. Of the 33 taxa collected during the Stevens et al. (2010a) study, nearly half (n = 14 taxa) were collected in greater abundance in the tidal creeks, while only 9 taxa were collected in greater abundance in the mainstem river. The remaining taxa were equally abundant in both habitats.

Seasonally, fish abundances in Tampa Bay tidal creeks are highest near the end of the summer months when water temperatures are highest and dissolved oxygen levels are lowest. The trend is reversed during the cooler winter months when dissolved oxygen levels are highest and fish densities are lowest (Adams, 2005; Greenwood et al., 2008b). Although no relationship was found between land use and the community structure of macrobenthos in Tampa Bay tidal creeks (Sherwood et al., 2007), there was a clear pattern for tidal creek benthos in coastal South Carolina where pollution-tolerant taxa dominated the assemblage in urban watersheds (Lerberg et al., 2000). Lack of a relationship in Tampa Bay tidal creeks may have been related to very low rainfalls (i.e., low connectivity) during the study year and less runoff from the watershed.

Nekton species that commonly occur in tidal creeks have adapted to the physiologically stressful conditions of these systems. The often low DO conditions in tidal creeks have been suggested to provide a physiological refuge from predation for small fishes and crustaceans. For example, juvenile snook have been shown to have a much greater tolerance to low DO levels than adult snook, which has been proposed as a way to segregate smaller from larger individuals and reduce

cannibalism (Peterson and Gilmore, 1991). Atlantic tarpon and Mayan cichlids are also able to persist at low DO levels by gulping air and storing it until oxygen is absorbed into the bloodstream (Geiger et al., 2000; Schofield et al., 2009). Similar physiological and behavioral adaptations have been observed for highly abundant prey species such as the poeciliid, cyprinodontid and fundulid fishes which include sailfin mollies, gulf killifish, and sheepshead minnows, all of which are capable of aquatic surface respiration (Nordlie, 2006), an adaptation that allows these species to utilize dissolved oxygen at the air-water interface when DO levels are otherwise low in the tidal creek. Abundances of palaemonid grass shrimp and juvenile striped mullet, also very common prey for many species including juvenile snook and tarpon, were negatively correlated with DO, with the highest abundances observed between 3-6 mg/L and very low abundances at DO >6 mg/L (Greenwood et al. 2008a).

2.0 Establishing a Foundation for the Development of Numeric Nutrient Criteria in Sarasota Bay Tidal Creeks

The following sections provide a summary of information that should serve as the foundation for developing meaningful and relevant numeric nutrient criteria that will preserve the ecological function and habitat value of Sarasota Bay tidal creeks. Further summary of recent and historical studies on the ecology of tidal creeks in the Tampa Bay/Sarasota Bay area is provided by Estevez et al. (2010), Krebs et al. (2010), MacDonald et al. (2010) and Sherwood (2010).

2.1 Sarasota Bay Tidal Creeks

The Sarasota Bay estuary is a series of coastal embayments including Palma Sola Bay, Sarasota Bay, Roberts Bay, Little Sarasota Bay and Blackburn Bay. The estuary is enclosed by several barrier islands from Anna Maria Island at the north to Siesta Key and Venice Inlet at the south. The watershed within the Sarasota Bay Estuary Program encompasses 407 km². There are approximately ten tidal creeks that are terminal tributaries to Sarasota Bay or to smaller embayments within the bay (Figure 2). From north to south are: Bowlees Creek, Whitaker Bayou, Hudson Bayou, Phillippi Creek, Matheny Creek, Elligraw Bayou, Clower Creek, Catfish Creek, North Creek and South Creek. Most of the tidal creeks in the Sarasota Bay watershed range in size from 2-8 km and drain relatively small areas (<20 km²), but Bowlees and Phillippi Creeks are the exception running nearly 16 and 18 km in length along the main channel and draining much larger areas (24 km² and 145 km², respectively). South Creek also drains a relatively large area (51 km²). Unlike the Tampa Bay estuary to the north, there are no large tidal rivers that drain to the Sarasota Bay estuary. However, Sarasota Bay tidal creeks are similar in scale to those found in Tampa Bay and also differ substantially in scale from larger tidal rivers. These differences in scale have consequences for the channel geomorphology of Sarasota Bay's tidal creeks and result in disparate hydrological and physicochemical characteristics compared to larger tidal rivers such as those found in the Tampa Bay estuary. Some of the larger tidal creeks in Sarasota Bay extend far enough into the watershed that they have freshwater reaches and lower order, freshwater tributaries that feed into them (e.g., Phillippi Creek, Bowlees Creek). Tidal creeks also differ from freshwater tributaries of the same size primarily due to their connection to the estuary. Small freshwater tributaries do not experience the semidiurnal tides which cause the daily and even hourly fluctuations in water level, flow direction, salinity, water temperature and dissolved oxygen (DO) often recorded in tidal creeks (Buzzelli et al., 2007). Delineation of estuarine and freshwater tributaries to Tampa Bay is provided in Figure 3.

Unmodified tidal creeks are characterized by sinuous, meandering channels with average water depths <1.0 m, while those creeks modified for drainage, mosquito control, or navigation often have straightened channels with steeper, more uniform banks than unmodified creeks. Tidal creeks altered for navigation are typically deeper than other creeks (>2.0 m in depth) and often have hardened shorelines that have been cleared of vegetation. Most tidal creeks in Tampa Bay are relatively narrow, spanning only 25-50 m from bank to bank, in contrast to the tidal rivers which are 100-300 m wide on average, although some of the larger tidal creeks reach 100 m or more in width near the mouth. The bathymetry of tidal creeks consists of alternating areas of deep, erosional and shallow, depositional bottom, unless the creek has been channelized, in which case, it is often uniformly deep.



Figure 2. Named tidal creeks within the Sarasota Bay Estuary Program area.

2.1.1 Riparian vegetation

Shoreline vegetation in many of tidal creeks in the SBEP area consists largely of red mangrove (*Rhizophora mangle*) or white mangrove (*Laguncularia racemosa*), especially in the more mesohaline to polyhaline reaches and transitions. Black needlerush (*Juncus roemerianus*) and cordgrass (*Spartina* spp.) are also found along the banks in the higher salinity reaches, but are not nearly as common as mangroves. In the larger tidal tributaries with large watersheds, freshwater-tolerant and upland vegetation such as cattails (*Typha* spp.), leather fern (*Acrostichum danaeifolium*), buttonwood (*Conocarpus erectus*) and oak (*Quercus* spp.) occur as the tributary moves further into the upland areas.



Figure 3. Approximate location of the upstream limit of tidal creeks and rivers as defined by empirical salinity data analysis in the Sarasota Bay Estuary.

2.1.2 Submerged aquatic vegetation

Unlike shallow embayments and open estuarine areas, submerged aquatic vegetation is typically absent from tidal creeks, perhaps due to the proximity to freshwater pulses and the resulting lower salinities found in tidal creeks. Occasionally, ephemeral beds of widgeon grass (*Ruppia maritima*) have been observed in Sarasota Bay's tidal creeks but seagrass beds consisting of turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*) and shoal grass (*Halodule wrightii*) are not typically found in Sarasota Bay tidal creeks.

2.1.3 Dissolved oxygen and fishes

The relationship between fish abundance and species richness with DO has been examined from a number of Sarasota Bay tidal creeks sampled by Mote Marine Laboratory, including Bowlees, Phillippi, Matheny, Catfish, North and South Creeks, as well as Hudson and Whitaker Bayous (Figures 4 and 5; N. Brennan unpubl. data). Both fish abundance and species richness in these tidal creeks appear to be similar across the range of DO levels from <1 to >5 mg/L, although both abundance and richness were comparatively higher between 4-5 mg/L. Fish abundance alone may not be a clear indicator of the DO in tidal creeks, as many taxa from these systems are eurytolerant to low DO and have adapted to persist at these levels. This is often exemplified by high abundances and low richness observed at low dissolved oxygen concentrations. Species richness, and possibly community structure, is probably a more sensitive indicator of the aquatic-life support function of tidal creeks as less tolerant taxa are more likely to occur at higher dissolved oxygen levels, thus increasing species richness. These results emphasize the unique nature of tidal creeks and deserve consideration when the eventual nutrient criteria are proposed.

2.1.4 Phytoplankton as measured by chlorophyll a

There is currently a paucity of data on in-stream chlorophyll a concentrations for Sarasota Bay tidal creeks. Many of the tidal creeks in Sarasota Bay have not been routinely monitored for a long enough time period to allow the use of stressor-response models. Yet, the available information suggests that these creeks are highly productive systems and that benthic algae could be a useful indicator of overall productivity in tidal creeks. While benthic algae are not unique to tidal creeks, their relative contribution to system productivity seems to be greater in tidal creeks than in most other estuarine habitats. Further research is needed to understand in-stream chlorophyll-a concentrations and to establish benthic algae as an indicator to develop tidal creek nutrient criteria.

2.1.5 Nutrients

Tidal creeks are ecologically distinct in many ways: both from the freshwater streams that drain into them and from the downstream estuarine waters to which they drain. Of particular note, the expectations for water quality in tidal creeks differ from both upstream and downstream waters. Specifically, chlorophyll a concentrations (including planktonic and benthic forms) needed to provide full aquatic-life support in tidal creeks are higher than in the upstream or downstream waters. Similarly, the DO concentrations needed to provide full aquatic-life support in tidal creeks are lower than those required in the upstream or downstream waters. As such, the endpoints used to establish numeric nutrient criteria should be unique to these tidal creeks. Therefore, it is recommended that the eventual numeric nutrient criteria for tidal creeks be based on:

- stressor-response relationships between TN, TP and chlorophyll a or DO concentrations,

- chlorophyll a thresholds and DO standards that reflect the unique nature of these systems.

Potential options for developing numeric nutrient criteria, including the stressor-response approach are detailed below.

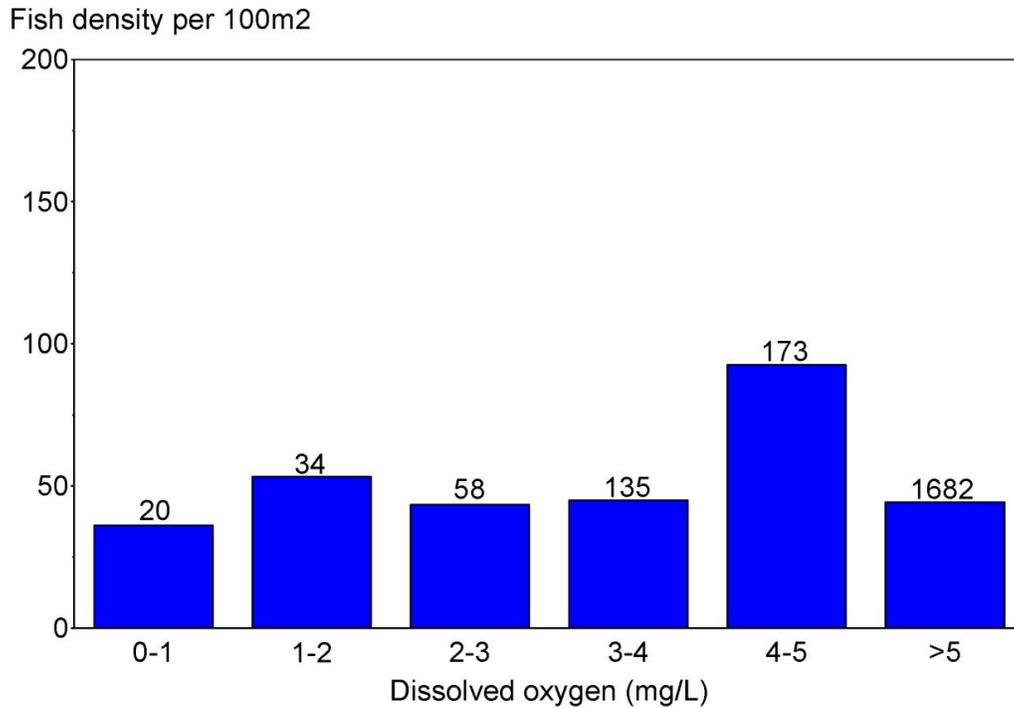


Figure 4. Relationship between mean nekton density and DO in Sarasota Bay tidal creeks. The numbers above each bar is the number of samples.

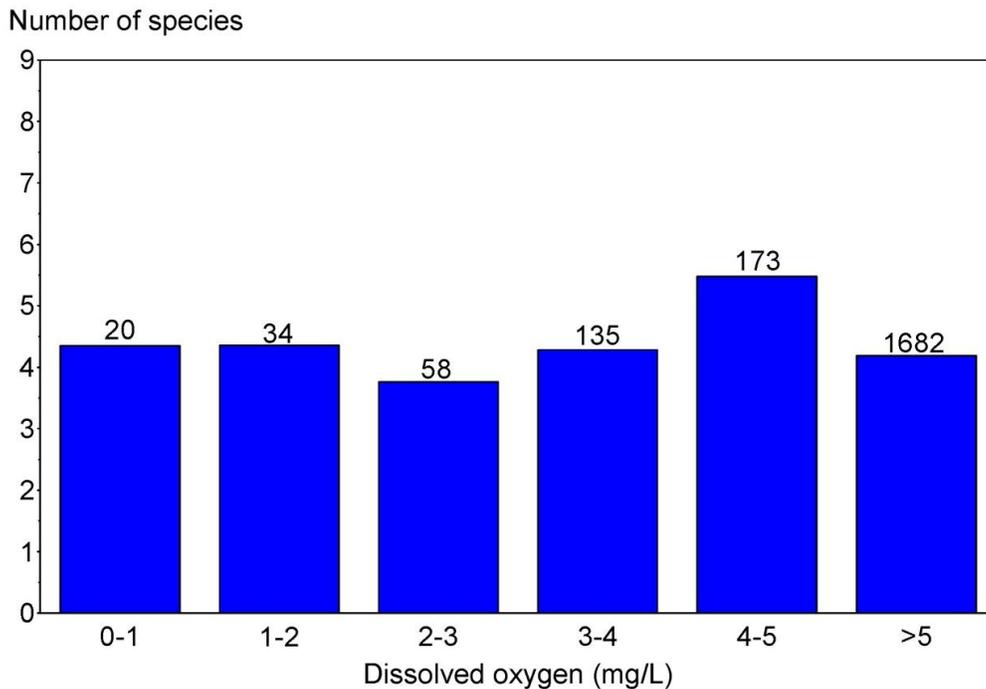


Figure 5. Relationship between mean species richness and DO for nekton in Sarasota Bay tidal creeks. The numbers above each bar is the number of samples.

3.0 Potential Approaches for the Development of Nutrient Criteria for Tidal Creeks

Given the current state of knowledge on tidal creeks, three approaches to develop numeric nutrient criteria in tidal creeks are available. Each of these approaches has previously been considered for development of nutrient criteria for the Sarasota Bay estuary (Janicki Environmental, 2010a and b).

- Stressor-response models – Examining quantitative relationships between nutrient concentrations and either chlorophyll a or DO concentrations within a specific waterbody of concern (i.e., tidal creek);
- Reference condition methods - Using available data for selected “reference” creeks to derive numeric nutrient criteria for creeks;
- Downstream protective values - Based on the relationship between the water quality in the creek and that of the downstream receiving estuary such that the water quality in the tidal creek does not result in water-quality exceedances in the downstream estuary.

3.1 Stressor-Response Method

The stressor-response modeling approach to establish numeric nutrient criteria in tidal creeks relies on the development of a quantitative relationship between known indicators of system health (e.g. chlorophyll a concentrations and DO) and anthropogenic stressor variables (e.g. TN or TP). Using these relationships, the goal is to first identify the threshold response beyond which adverse conditions are observed. Once this threshold value is determined, the relationship between stressors and response can be used to set limits on the magnitude of the stressor variable that is expected to maintain adequate water quality and avoid adverse conditions.

3.2 Reference Condition Method

The reference condition method uses available data for the system of interest to establish numeric nutrient criteria. The process involves the identification of ambient water-quality conditions when the system was meeting full aquatic-life support and establishing the criterion values for stressors and response indicators based on these conditions. Often it is advantageous to establish both target values and threshold values using this approach. Target values are those that represent a desired management endpoint for the system while threshold values are those beyond which the system is likely to exhibit adverse effects.

3.3 Downstream Protective Value Method

The goal of the downstream protection method would be to use the estuarine nutrient criteria as a target to establish criteria for the tidal creek that is protective of downstream water quality. For example, relationships between total nitrogen concentration in the tidal creek compared to that in the adjacent bay segment could be used to determine how increases or decreases in nitrogen in the tidal creek might be related to nitrogen concentrations in the bay segment, and to identify the nitrogen concentration in the tidal creek that would be commensurate with the downstream estuarine nitrogen criterion. Using this approach is less desirable, however, as it is not based on ecological function and may result in nutrient criteria for the tidal creek that are insufficient to maintain the biological integrity of these waterbodies, including the high levels of primary production that are characteristic of these systems.

4.0 Recommendations

Although there has been limited ecological study of Sarasota Bay's tidal creeks, work from Tampa Bay's tidal creeks has revealed compelling evidence that these systems represent unique ecotones within the greater estuary. Tidal creeks play an integral role in the ecological function of coastal estuaries as sites of high primary and secondary production, nursery and refuge habitat for several species of economically important fish and decapods crustaceans, and foraging areas for large-bodied fishes, wading birds, and other piscivorous species. Higher nutrient concentrations in tidal creeks relative to the greater estuary may be required to support the higher levels of primary and secondary production in these systems.

Analysis of fish collections in tidal creeks suggests that fishes inhabiting tidal creeks appear to be very tolerant to the typical DO conditions found in these systems. Both fish abundance and species richness data indicate that fish communities are relatively invariant to DO levels between 2-10 mg/L, although mean fish density and species richness are comparatively higher between 4-5 mg/L. Species richness of fish and decapods crustaceans may be a more sensitive indicator of the aquatic-life support function of tidal creeks; however, these need further quantification to eliminate the possibility that seasonal recruitment patterns of estuarine-dependent fishes are not correlated with seasonal variation in dissolved oxygen concentrations due to temperature.

This report has provided a foundation from which further research can be conducted to establish scientifically sound and ecologically meaningful numeric nutrient criteria for Sarasota Bay tidal creeks. Future research into developing criteria for these systems should recognize that:

- Tidal creeks represent a unique habitat within the estuary, one that serves a different ecological function than both freshwater tributaries, tidal rivers and downstream estuarine environments
- Tidal creeks as generally highly colored systems with reduced water clarity and generally are devoid of seagrass
- Tidal creek productivity (measured as chlorophyll a concentration) is linked to benthic algal production rather than production by water-column phytoplankton
- Dissolved oxygen concentrations are routinely below the current state standard of 4 mg/l for marine waters and evidence from analysis of fish collections suggests that DO does not appear to limit fish abundance or richness until DO concentrations reach levels < 2 mg/l
- There is currently a paucity of empirical data from which to establish stressor-response relationships or reference condition approaches for Sarasota Bay tidal creeks

The most desirable approach to establish numeric nutrient criteria would be to develop stressor-response models. Stressor-response models require the identification of an indicator variable that can be used to evaluate the condition of the tidal creek. Moreover, stressor-response models require identification of a threshold value above (or below) which the system would no longer fully support its designated use.

Based on current available data it will be difficult to select a reference condition for many of Sarasota Bay's tidal creeks due to the paucity of empirical data in these systems. Much of the available data were generated from short duration studies that were intended as investigational and

to serve as baseline information. More effort is needed to identify a representative period of time when the systems were fully supporting aquatic uses to confidently establish reference condition criteria.

As potential interim criteria, estuarine criteria similar to those recommended for Tampa Bay tidal creeks could serve to provide a mechanism for establishing preliminary numeric nutrient criteria for tidal creeks. For example, the Sarasota Bay Estuary Program's chlorophyll a thresholds are based, in part, on conditions during the reference period from 2001-2005 in Sarasota Bay. Conceivably, data collected in creeks during this same time period of time in Sarasota Bay could be used to establish criteria under the assumption that if the bay was meeting its designated uses, then conditions in the tidal creeks were supportive of the estuary. This would at least provide a starting point from which more meaningful criteria could be established.

It is important that the established criteria for tidal creeks also account for the fact that these systems by nature are more variable than their upstream or downstream counterparts. This variability is in part what makes these systems so productive and also so difficult to generalize. The timing and volume of freshwater inflows are physical drivers that exert a great deal of control on tidal creeks. Inflows are deterministic of salinity regimes, nutrient delivery, water depths, temperatures and the potential for salinity stratification in these systems. Inflows also may control access to these systems for both small recruit species looking for refuge and for large-bodied predators. Therefore, the quantification of the effects on inflows on these systems will be necessary both to determine appropriate criteria and in the evaluation process.

Implementation of criteria for tidal creeks should rely heavily on quantifying the uncertainties in both the derivation of the criteria and in the evaluation of potential remediation effort associated with failure of the criteria. Only if the criteria are actually relevant to the ecological function of the system will the criteria be meaningful in protecting full aquatic-life uses in these systems. As such, there are many considerations in the implementation process. These considerations are provided in detail in Janicki Environmental (2010c).

It is recommended that the assessment of compliance with the proposed numeric nutrient criteria be performed in a manner similar to that which has been proposed by TBEP for compliance with both the Tampa Bay Reasonable Assurance and TMDL (TBEP, 2009). The goal of the estuarine numeric nutrient criteria is to provide full aquatic-life support within the estuary. The TBEP and SBEP have determined that seagrasses are important indicators of desirable conditions in the bay and has defined the water-quality conditions (i.e., chlorophyll a concentrations) that allow for the maintenance and growth of seagrass beds in the Tampa Bay and Sarasota Bay estuaries. Therefore, TBEP bases its compliance assessment on the comparison of both observed chlorophyll a concentrations and seagrass extent to the goals that have been established.

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