Pinellas County and the Southwest Florida Water Management District

2013

Bishop and Mullet Creek Tidal Tributary Project Report

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Executive Summary

This report describes the results of a fourteen month study initiated by Pinellas County and the Southwest Florida Water Management District to characterize variability in nutrient concentrations and water quality responses and evaluate the ecological integrity of the estuarine portions of two Pinellas County tidal creeks: Mullet and Bishop Creeks. At the time the study was initiated, the estuarine portion of these creeks had been deemed impaired by the Florida Department of Environmental Protection based on exceedances of dissolved oxygen and chlorophyll concentrations and the United States Environmental Protection Agency had proposed a Total Maximum Daily Load to reduce nutrient delivery to the estuarine portions of both creeks. Pinellas County challenged the contention that the criteria applied to determine impairment of these creeks were appropriate and recommended that tidal creeks such as Mullet and Bishop Creeks should have distinct criteria that reflect their unique function within the larger estuary. This contention was supported by letters from the three southwest Florida National Estuary Programs that spoke to the distinctions between tidal creeks, relative to their contributing watersheds and the receiving estuary. In these documents, southwest Florida tidal creeks were characterized as having highly variable water quality that is dependent on watershed inputs, geomorphology, tidal amplitude, riparian vegetation, and the degree to which tidal creek ecology is affected by watershed development and physical alteration to the creek itself. The latter is an extremely important consideration in Florida where these low gradient systems have been historically altered by shoreline hardening and flood protection efforts.

The objectives of this study were to characterize variability in water quality within the estuarine portion of these creeks and assess relationships between watershed inputs, estuarine water quality and the ecological health of these systems. The design included a routine monthly water quality and fish sampling and a series of special studies design to investigate aspects of the ecological function of these creeks that contribute to ecosystem health. These special studies included the seasonal collection of benthic macroinvertebrates; seasonal estimates of the chlorophyll a content in the sediments as an estimate of benthic micro algae chlorophyll biomass, a nutrient source evaluation using stable isotope analysis, development of a Surface Water Management Model (SWMM) to estimate nutrient loadings to the creeks and a synoptic mangrove health assessment.

Results of water quality sampling suggested that while dissolved oxygen concentrations were routinely less than the current or newly proposed standards, there was no evidence that nutrient conditions or chlorophyll a concentrations were causative factors resulting in reduced

dissolved oxygen concentrations. The chlorophyll a data collected as part of this study suggest that these creeks would be in compliance with established state chlorophyll a standards. The current development of nutrient standards for tidal creeks is in flux. The Federal Register notice from the latest EPA proposed rule for Estuaries (EPA 2012b) states that the "EPA reviewed the available scientific information and has determined that there are insufficient data and research at this time to develop separate numeric nutrient criteria specifically for tidal creeks." As a result, EPA has proposed two potential approaches that rely on established criteria for adjacent freshwater and estuarine waterbodies along with the mean (presumed to be long-term average) salinity of the creek. This approach is generally described as a "dilution model" method with the expectation that inputs from upstream waters will follow a linear decay in concentration as a function of mixing with estuarine waters as defined by salinity. This study was specifically designed to address that question among others and evidence from this study suggests that this assumption would not be valid for several parameters of interest; notably total nitrogen. Organic nitrogen concentrations actually tended to higher in the downstream sections of the Bishop Creek indicating potential of nitrogen contributions from the heavily mangrove and salt marsh fringe associated with the mouths of this creek. In Mullet Creek, organic nitrogen concentrations were consistent among strata with no discernible dilution as a function of salinity. This has important implications for regulatory inference because organic nitrogen is the dominant form of nitrogen contributing to the observed total nitrogen values in these creeks. The implicit assumption in the dilution model method is that the substance of interest is conservative; however, in the case of these creeks the data suggest nutrient addition is not directly related to watershed inputs or anthropogenic activities. In other words, natural wetland features in these creeks may be acting as a source of nitrogen to the creeks.

The synoptic mangrove health survey conducted as part of this study indicated that the mangrove forests in these creeks are functioning as natural, undisturbed systems. Little anoxia was present in the sediments suggesting little denitrification is taking place within these creeks as well. A nutrient isotope survey also conducted as part of this study suggests that there are several sources of nitrogen, both anthropogenic and non-anthropogenic, taken up by the biota utilizing these creeks likely due to the contribution of freshwater from stormwater ponds to the estuarine portions of these creeks. The SWMM model results suggested that approximately 0.25 tons of nitrogen and 0.06 tons of phosphorus were delivered to the creeks over the study period.

The fish catch associated with the water quality samples contained a number of estuarine dependent species of recreational and commercial importance including Red Drum (*Sciaenops ocellatus*), Spot (*Leiostomus xanthurus*), Snook (*Centropomus undecimalis*), Pink Shrimp (*Farfantepenaeus Duorarum*), and mullet (*Mugil cephalus*). The presence of these taxa

indicates that the creek is supporting recruitment of important estuarine dependent species of economic value; a recognized important role of tidal creek ecosystems. The fact that catch densities were low may be attributable to the extensive wetland features in the downstream reaches that allow fish to avoid capture by the small seines used in this study.

Seasonal sampling for benthic macro-invertebrates and benthic microalgae suggested that these samples were similar to that reported in other Tampa Bay tidal tributaries though there was dramatic sample to sample variation in benthic chlorophyll estimates, even for samples taken in very close proximity on the same sample date. This suggests that this metric may require a revised sampling method that collects a larger sample of the area or by compositing samples taken across the creek channel. Benthic invertebrate species collected during seasonal sampling represented expected euryhaline organisms tolerant of a wide range of estuarine conditions and were similar in community structure to other tidal tributaries in Tampa Bay. Sediments collected in association with the benthic macroinvertebrate sampling were principally sand with little organic content observed in any sample.

In summary, this study has provided a weight of evidence that suggests that the ecological function of the estuarine portions of these creeks is not currently impaired by ambient water quality conditions. There are no indications that either Mullet or Bishop Creek are suffering a degree of anthropogenic impact that would result in adverse effects to their designated use. In fact, these creeks appear to represent some of the more natural tidal creeks in Tampa Bay with little shoreline modification, healthy natural wetland features including extensive mangrove forests, expansive canopy cover and evidence that these creeks are being utilized as nursery areas by several fish and invertebrate species of recreational and commercial importance.

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A. Background

Bishop and Mullet Creeks are two of more than 100 small tidal tributaries to Tampa Bay (Sherwood et. al 2008). Both Bishop and Mullet Creeks are located in Pinellas County with estuarine portions within the city limits of Safety Harbor, Florida (Figure 1). The creeks both discharge to Old Tampa Bay, north of the Courtney Campbell Causeway. The estuarine portion of these creeks has been deemed impaired by the Florida Department of Environmental Protection based on dissolved oxygen (DO) and nutrient concentrations. The United States Environmental Protection Agency (EPA) has proposed a Total Maximum Daily Load (TMDL) for the estuarine portions of both creeks (EPA, 2009). Pinellas County has challenged the contention that these systems are impaired and instead contends that tidal creeks serve a unique function within the larger estuarine system of Tampa Bay and therefore should have distinct criteria. In 2011, Pinellas County, in a cooperative agreement with the Southwest Florida Water Management District (SWFWMD), initiated this study to better understand variability in nutrient concentrations and loads within the estuarine portion of these creeks and identify ecological responses to that variability in an effort to develop a more comprehensive management strategy for tidal creeks to Tampa Bay.

Figure 1. Location of Bishop and Mullet Creeks

A.1 Bishop Creek

The drainage basin for Bishop Creek is highly urbanized and several storm water retention ponds are located adjacent to this creek system; however, only one stormwater retention pond, located north of Wateredge Court and on the south side of downstream portion of the creek, is located within the project's study area (Figure 2). In Figure 2, the FDEP waterbody identifiers (WBIDS) that delineate the estuarine WBIDs from their freshwater contributing basins are overlain.

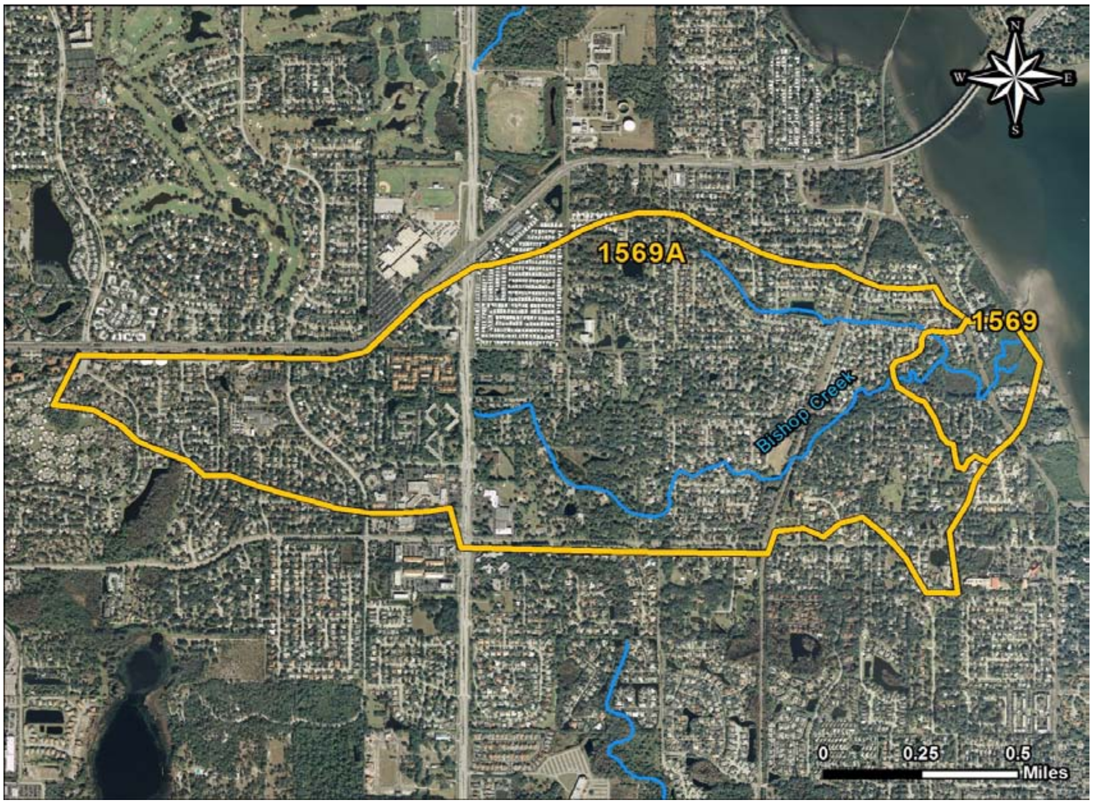


Figure 2. Aerial of Bishop Creek with FDEP WBID boundary (yellow) & stream channel (blue)

Bishop Creek has two branches (Figure 3) which converge approximately at the tidal head. The south branch of Bishop Creek extends west to North McMullen Booth Road, and the north branch of Bishop Creek extends approximately 1.24 kilometers to North Bay Hills Road. Additionally, a stormwater pond is located approximately 0.5 kilometers upstream of the convergence in the north branch.

Figure 3. Convergence of north and south branches of Bishop Creek

During the initial site visits, stormwater outfall locations were identified, a descriptive characterization of shoreline vegetation was conducted, and the entire length of the stream centerline within the study area was captured for use in developing a sampling list framework (Figure 4). Additionally, a SWFWMD Florida Land Use Cover and Forms Classification System (FLUCFCS) map was generated for 100 meters adjacent to the creek's centerline, and this data is provided below in Figure 4 and Table 1.

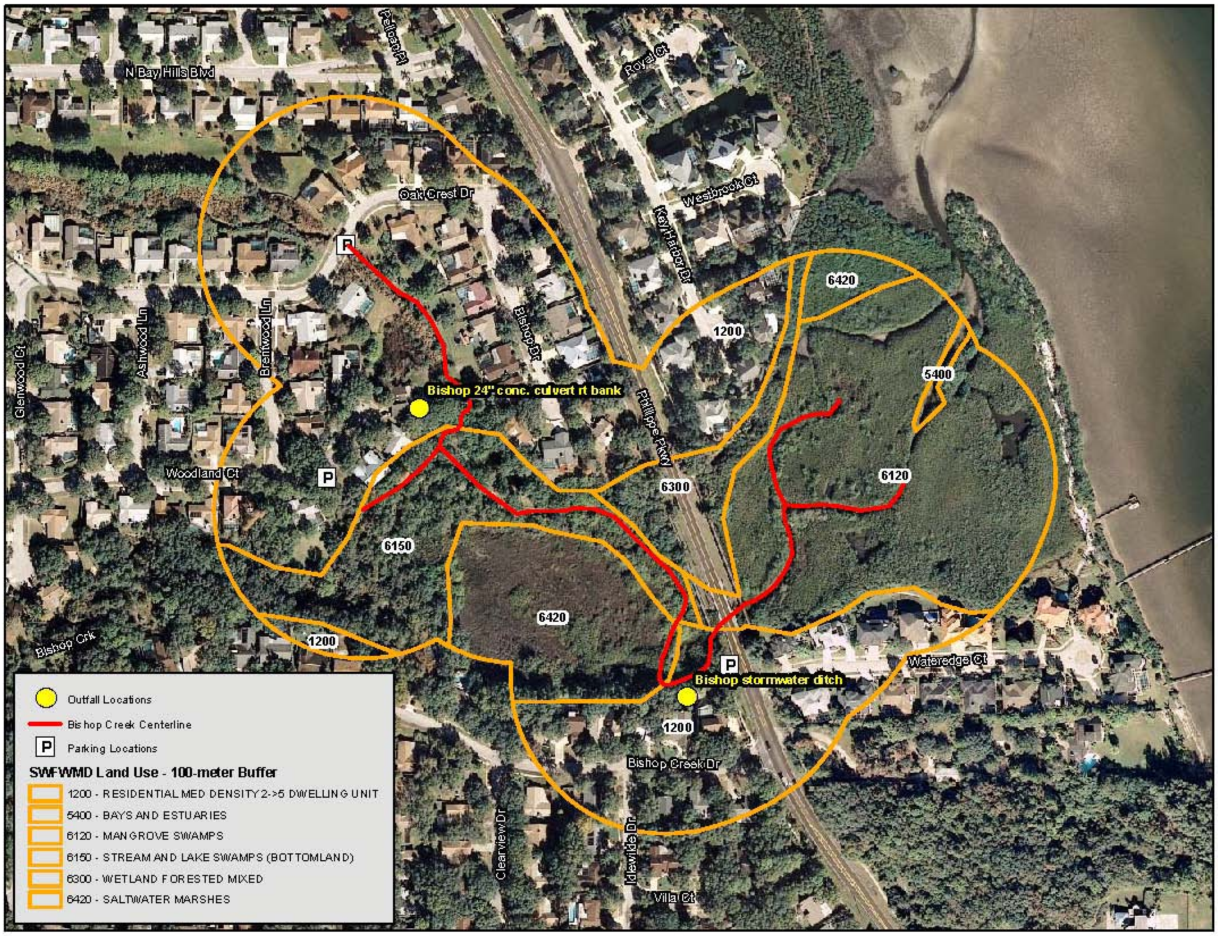


Figure 4. Bishop Creek SWFWMD 2010 FLUCFCS, Centerline, and Outfall Locations

FLUCFCS	Type	Acreage
1200	RESIDENTIAL MED DENSITY 2->5 DWELLING UNIT	0.28
1200	RESIDENTIAL MED DENSITY 2->5 DWELLING UNIT	6.17
1200	RESIDENTIAL MED DENSITY 2->5 DWELLING UNIT	16.96
5400	BAYS AND ESTUARIES	0.16
6120	MANGROVE SWAMPS	9.28
6150	STREAM AND LAKE SWAMPS (BOTTOMLAND)	4.44
6300	WETLAND FORESTED MIXED	1.80
6420	SALTWATER MARSHES	3.55
6420	SALTWATER MARSHES	0.53
	Total	**43.19**

Table 1. Bishop Creek FLUCCS data for 100-meters adjacent to creek centerline

There are a number of residential homes and some light industrial and commercial properties that border the upstream portions of this creek. Despite urbanization of Bishop Creek's drainage basin, the creeks maintain many natural qualities. Site visits during the course of this study concluded that the creek contains a predominately natural shoreline, with the exception of several outfall pipes and occasional retaining walls along the north branch of the creek. The downstream portions of the creek consisted of a relatively flat landform, with the banks dominated with white (*Laguncularia racemosa*) and black (*Avicennia germinans*) mangroves, and scattered red mangroves (*Rhizophora mangle*). Starting just west of Philippe Parkway the mangrove community transitions into a more incised channel that is dominated by a canopy of live oak (*Quercus virginiana*), cabbage palm (*Sabal palmetto*), and a sparse understory of leather ferns (*Acrostichum danaeifolium*) and Brazilian pepper (*Schinus terebinthifolia*). With the exception of scattered Brazilian pepper in the downstream portion (i.e. stratum 1) of the creek, Florida Exotic Pest Plant Council (FLEPPC) Category I and II invasive species were primarily isolated to the upper reaches and predominately freshwater areas (i.e. stratum 3) of the study area. A complete list of invasive species observed is provided in Table 2 below.

Table 2. Bishop Creek Invasive Vegetation List

Scientific Name	Common Name	FLEPPC Category*	Stratum Observed
Alternanthera philoxeroides	alligator weed	II	3
Colocasia esculenta	wild taro	I	3
Dioscorea bulbifera	air potato	I	3
Nephrolepis cordifolia	tuberous sword fern	I	3
Panicum repens	torpedo grass	I	3
Ruellia simplex	Britton's wild petunia	I	3
Schinus terebinthifolia	Brazilian pepper	I	ALL
Sphagneticola trilobata	creeping oxeye	II	3

* Per Florida Exotic Pest Plant Council 2011 Invasive Plant List

A.2 Mullet Creek

The drainage basin for Mullet Creek is also highly urbanized and several storm water retention ponds are located adjacent to this creek system; however, only one stormwater retention pond, located east of Palm Avenue North and on the west side of the upstream portion of the creek, is located within the project's study area (Figure 5). In Figure 5, the FDEP WBIDS that delineate the estuarine WBIDs from their freshwater contributing basins are overlain. Mullet Creek is unbranched throughout the study area, which is primarily tidally influenced, but splits further upstream in the freshwater portions of the creek.

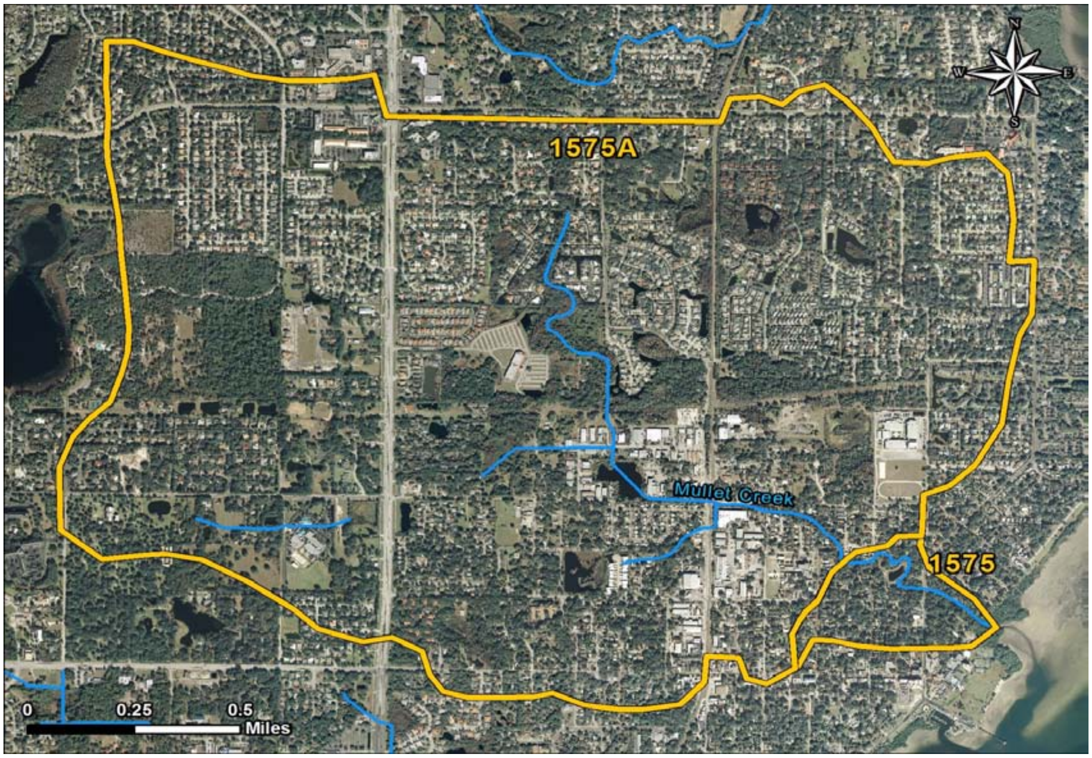


Figure 5. Aerial view of Mullet Creek with FDEP WBID boundary (yellow) and stream channel (blue)

During the initial site visits, stormwater outfall locations were identified, a descriptive characterization of shoreline vegetation was conducted, and the entire length of the stream centerline within the study area was captured for use in developing a sampling list framework (Figure 6). Additionally, a SWFWMD FLUCFCS map was generated for 100 meters adjacent to the creek's centerline, and this data is provided below in Figure 6 and Table 3.

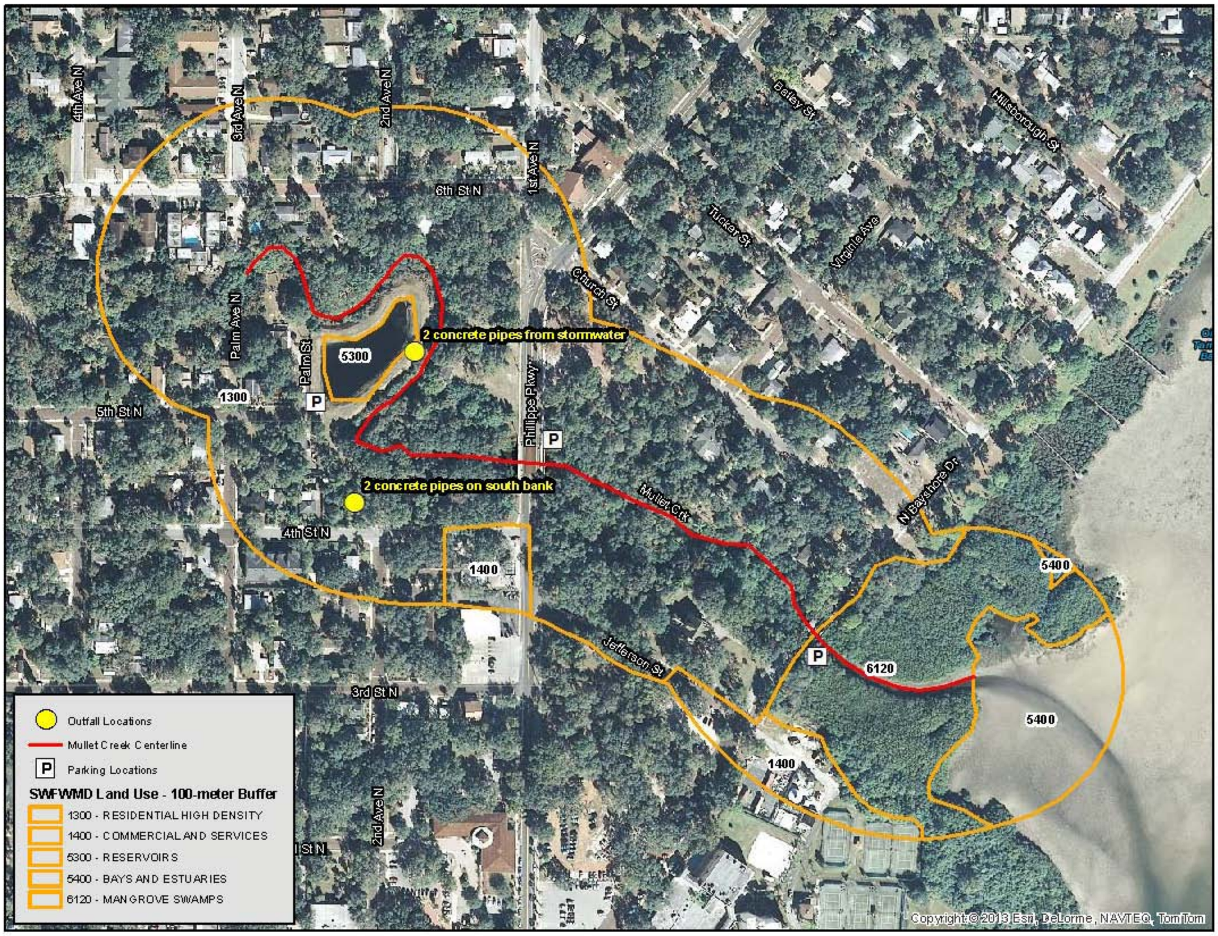


Figure 6. Mullet Creek SWFWMD 2010 FLUCFCS, Centerline, and Outfall Locations

FLUCFCS	Type	Acreage
1300	RESIDENTIAL HIGH DENSITY	30.64
1400	COMMERCIAL AND SERVICES	1.38
1400	COMMERCIAL AND SERVICES	0.79
5300	RESERVOIRS	0.58
5400	BAYS AND ESTUARIES	3.05
5400	BAYS AND ESTUARIES	0.08
6120	MANGROVE SWAMPS	5.20
	Total	**41.71**

Table 3. Bishop Creek FLUCCS data for 100-meters adjacent to creek centerline

There are a number of residential homes and some light industrial and commercial properties that border the upstream portions of this creek. Mullet Creek is densely vegetated and heavily shaded throughout. Similarly, to Bishop Creek, the downstream portions of Mullet Creek consisted of a relatively flat landform, with the banks dominated with white and black mangroves, with scattered red mangroves throughout. The mangrove become more sparse and transition more into a more incised channel, dominated by a canopy of live oak and Brazilian pepper, with an understory of saw palmetto and leather ferns starting at approximately 25 meters west of North Bayshore Drive. With the exception of scattered Brazilian pepper in the downstream portion (i.e. stratum 1) of the creek, FLEPPC Category I and II invasive species were primarily isolated to the upper reaches and predominately freshwater areas (i.e. stratum 3) of the study area. A complete list of invasive species observed is provided in Table 4 below.

Table 4. Mullet Creek Invasive Vegetation List

Scientific Name	Common Name	FLEPPC Category*	Stratum Observed
Alternanthera philoxeroides	alligator weed	II	3
Colocasia esculenta	wild taro	I	3
Dioscorea bulbifera	air potato	I	2,3
Hydrilla verticillata	hydrilla	I	3
Ludwigia peruviana	Mexican primrose willow	I	3
Nephrolepis cordifolia	tuberous sword fern	I	3
Panicum repens	torpedo grass	I	3
Ricinus communis	castor bean	II	3
Ruellia simplex	Britton's wild petunia	I	3
Schinus terebinthifolia	Brazilian pepper	I	ALL
Sphagneticola trilobata	creeping oxeye	II	3

* Per Florida Exotic Pest Plant Council 2011 Invasive Plant List

A.3 Historical Information

For the purposes of the study it was helpful to understand how Bishop and Mullet Creeks may have changed over time. To this end, historical aerial photography from the 1950's was obtained from the USGS Tampa Bay study website:
http://dl.cr.usgs.gov/tampa/prod_search_tampa.aspx

From the historical photography it appears the creeks are currently in much the same general location as historically with no major physical alterations to this portion of the system (Figures 7 and 8). The one exception is the north branch of Bishop Creek which apparently lost quite a bit

of sinuosity since the 1950s. In these photographs, the current creek centerlines were overlaid on the historic photography. One noticeable feature is the substantial sedimentation that historically and currently appears in the photography at the mouths of these creeks. There have been substantial efforts within both creeks regarding flood control based on past public works projects as evidenced by a list of projects that the city of Safety Harbor provided for this study (Table 5).

Figure 7. Current centerline of Bishop Creek overlaid on georeferenced historical aerial photography circa 1950

Figure 8. Current centerline of Mullet Creek overlaid on georeferenced historical aerial photography circa 1950

Table 5. Safety Harbor project list for Bishop and Mullet Creek		
Year	**Creek**	**Project Description**
1994	Mullet Creek	Channel “SWIM” pond. Was signed off from SWFWMD about 2 years ago.
1995	Bishop Creek	Channel A & B (Erosion control and bank stabilization) Approx Lat. 28.01, Lon. -82.69
1995	Mullet Creek	Channel A & B (Bank stabilization) Fernery Lane and Elm Street
1999	Mullet Creek	4th Street Outfall Modification SWFWMD 43018094.000/CT128314. Signed off by SWFWMD July 7, 2004 as mitigation success.
2001	Bishop Creek	Attenuation Pond (Flood control and water quality) Approx. Lat. 28.01, Lon.-82.70 . SWFWMD Permit #4402260.0000.....This is treated monthly for invasive plant species by Armstrong Environmental.
2006	Bishop Creek	Harbor Woods (Bank stabilization and water quality). SWFWMD#44030348.000/CT#192810.... This is treated monthly for invasive plant species by Armstrong Environmental.
2007	Bishop Creek	Rainbow Farms (Bank stabilization and water quality). SWFWMD #44010666.01.... This is treated monthly for invasive plant species by Armstrong Environmental.
2010	Mullet Creek	(bank stabilization and water quality). Approx. Lat.27.99, Lon.-82.70. The project is complete but we are having Armstrong Environmental treat for invasive plants and we are still working with the ACOE to get this signed off from them.
2011	Mullet Creek	South Bayshore Boulevard surface water improvements. Date of construction to begin August 2011. Obtained a FDEP 319 grant and SWFWMD grant for this project. This project will have baffle boxes that remove nutrients and solids before discharging into Tampa Bay as South Bayshore runs parallel with Bay.

A.4 Existing Data

Several important datasets exist that provide information on past and recent water quality and flow information in these creeks. Pinellas County has been monitoring water quality in these creeks since 1991 and flow gages have been established since 2006. To develop expectations for magnitude and variability in water quality and flow conditions, descriptive plots and analysis were conducted using available data from Pinellas County. These data were summarized in the design document located in Appendix A.

B. Study Objectives

Tidal creeks are dynamic systems that are defined by the interaction of marine or estuarine waters and freshwater inflows. While this simplistic description defines a tidal creek, the productivity within tidal creeks relies on a delicate balance of freshwater and nutrient inputs, physical forcing functions, and complex interactions among processes in the tidal mixing zone of the creek. The goal of this study was to gather scientific information that could be used to better understand the relationships among these factors and how they interact to control ecological function of the estuarine portions of these systems. The specific objectives were to:

- evaluate variability in water quality within the estuarine portion of these creeks;
- investigate how physical alterations, including variation in hydrology, affect the assimilation of nutrients both in the water column and by the benthos;
- evaluate sources of nutrients using stable isotope analysis, and
- test metrics that may be used to evaluate tidal creek health and function in support of establishing criteria for other tidal creeks

The principal study elements under consideration are:

- water quality,
- fishes,
- benthic microalgae,
- sediment chemistry,
- nutrient isotope analysis,
- benthic macroinvertebrates,
- vegetation, and
- hydrology,

Within each of these study elements, sampling designs and sampling protocols were established to maximize information gained toward developing metrics that can be successfully used as part of a tidal creeks management strategy in southwest Florida. The study consisted of both routine monthly monitoring events for water quality and fish community composition as well as a suite of special studies designed to address specific questions regarding the process and function of these creeks. The details of each of the study elements are described in more detail below.

C. Study Design and Methods

This study was a combination of a spatially intensive routine water quality monitoring and a series of special studies that will be used to characterize ecological function of the creeks. In order to coordinate these different elements of the design into an efficient and effective study, there were many considerations. An initial survey was used to define the spatial extent of the study area within each creek and characterize the physical conditions effecting sampling logistics. Once the sampling elements were defined, the spatial extent was established, and logistical considerations accounted for, a sampling list framework was developed. A brief characterization of historical aerial photography of the creeks was provided to establish context to current physical conditions relative to the past. Existing data were assessed and used to summarize the expected values and variability in nutrient concentrations within the system. Finally, expected analytical techniques were identified to be employed during the analytical phase of the project. A design document for this project was developed (Janicki Environmental 2011) which was subjected to independent peer review prior to initiation of the study. This design document is provided in Appendix A and is summarized in detail below.

C.1 Sampling Elements

This section provides a synopsis of the sampling elements for this study. Detailed information on the design for each element is provided within the individual subsection of the design section. A synopsis of the sampling elements for this study is described below:

- *Water Quality:* The primary sampling element for this project is water quality. Sampling consisted of a spatially intensive monthly water quality sampling effort. Grab samples were collected for lab analysis and physical data was collected including temperature, salinity, conductivity, pH, dissolved oxygen, turbidity and stream velocity the time of sampling.

- *Fish Sampling:* A 9.1 meter raft seine was used to collect juvenile and small adult fishes within the creek concurrent with the routine water quality collections.

- *Benthic Algae (BMAc):* The chlorophyll content of the top 1 cm of the creek bed was sampled using a 10ml syringe inserted into the top layer of sediment with the creek's bed. This effort was conducted seasonally and concurrently with the fish sampling.

- *Nutrient Isotope*: Nutrient isotopes were collected from a variety of flora and fauna in September 2011 and May 2012 to estimate the nutrient sources and dominant

pathways of nutrients within the creeks. Collection methods for isotope analysis varied depending on the sample types and are described in more detail below.

- *Benthic Macroinvertbrates:* Twelve samples were allotted for this special study with 6 sites in each creek randomly selected from the sampling list framework described above.

- *Mangrove survey*: A special study was conducted to evaluate the health of the mangrove forests occupying the mouths of both tidal creeks in an effort to define a baseline condition of these forests and identify potential methods to develop an index that can be used to assess the contribution to ecological function of mangroves to tidal creeks in southwest Florida.

- *Canopy coverage estimations*: Canopy coverage was calculated both qualitatively and quantitatively by using a densitometer to serve as supplemental information and to assist in identifying any correlations between canopy coverage and various water quality parameters.

- *Stream morphology:* Water depths and stream velocity were taken at each sampling location. Additionally, representative cross section profiles were collected throughout each creek. This information was used to help define the stream morphology and SWMM model.

- *SWMM Model:* A SWMM model was constructed to estimate the nutrient loading and water velocity along the length of both creeks.

A field data sheet was designed to capture pertinent information at each sample location during the study (**Table 6**). The field sheet includes information on site characteristics, and physical habitat including canopy and stream velocity. A Microsoft Excel database was used to transfer data from this field sheet into electronic format.

Table 6. Field Data Sheet for Bishop/Mullet Creek Study

Creek	Date	Time	Strata	Sample Number	Storm Event?	Picture ID

Location	
Latitude	Longitude

Site Characteristics					
Shore type	Inundated?	Overhanging?	Shaded?	Bank	Bottom Depth

Environmental Parameters							
YSI							
	Temp	pH	Salinity	Cond.	DO	Turbidity	Stream Velocity
Surface							
Bottom							

	Sampled?	Notes
Water Quality		
BMAc		
Fish		
Isotope		

Isotope Collection	Sample Number	Latitude	Longitude

C.2 Definition of Study Area

The sampling domain for each creek was defined by three strata of approximately equal length with strata boundaries and upstream limit defined by natural breaks in vegetation and/or geomorphology, with a focus on the tidally influenced portion of the creeks, as determined during the initial survey. The study area is approximately 0.66 kilometers in Bishop Creek and 0.72 kilometers in Mullet Creek (Figure 9). A centerline for each creek was constructed by traversing the creek bed with a GPS unit and recording location throughout the area. The centerline was then divided into equally distance points at 10 meter intervals. Each point within each stratum then represents a potential sampling site within each stratum that had an equivalent probability of being selected each month. Pinellas County maintains fixed water quality stations and flow stations in both creeks (12-04 and 13-5 in Figure 9). Site 12-2 in Bishop Creek is also an active fixed station site though flow is not measured at that site. There are also historical fixed stations in the estuarine portion of both creeks (12-1 and 13-1 in Figure 9). To increase the temporal sampling frequency at active Pinellas County stations and to increase the ability to characterize the water quality of the contributing upstream reaches, several fixed station sites were also established both within and outside the estuarine portion of the study area. The fixed stations are represented by green triangles in Figure 9. The blue rectangles in Figure 9 indicate current Pinellas County fixed station sites that also have a rated staff gage where flows are also measured.

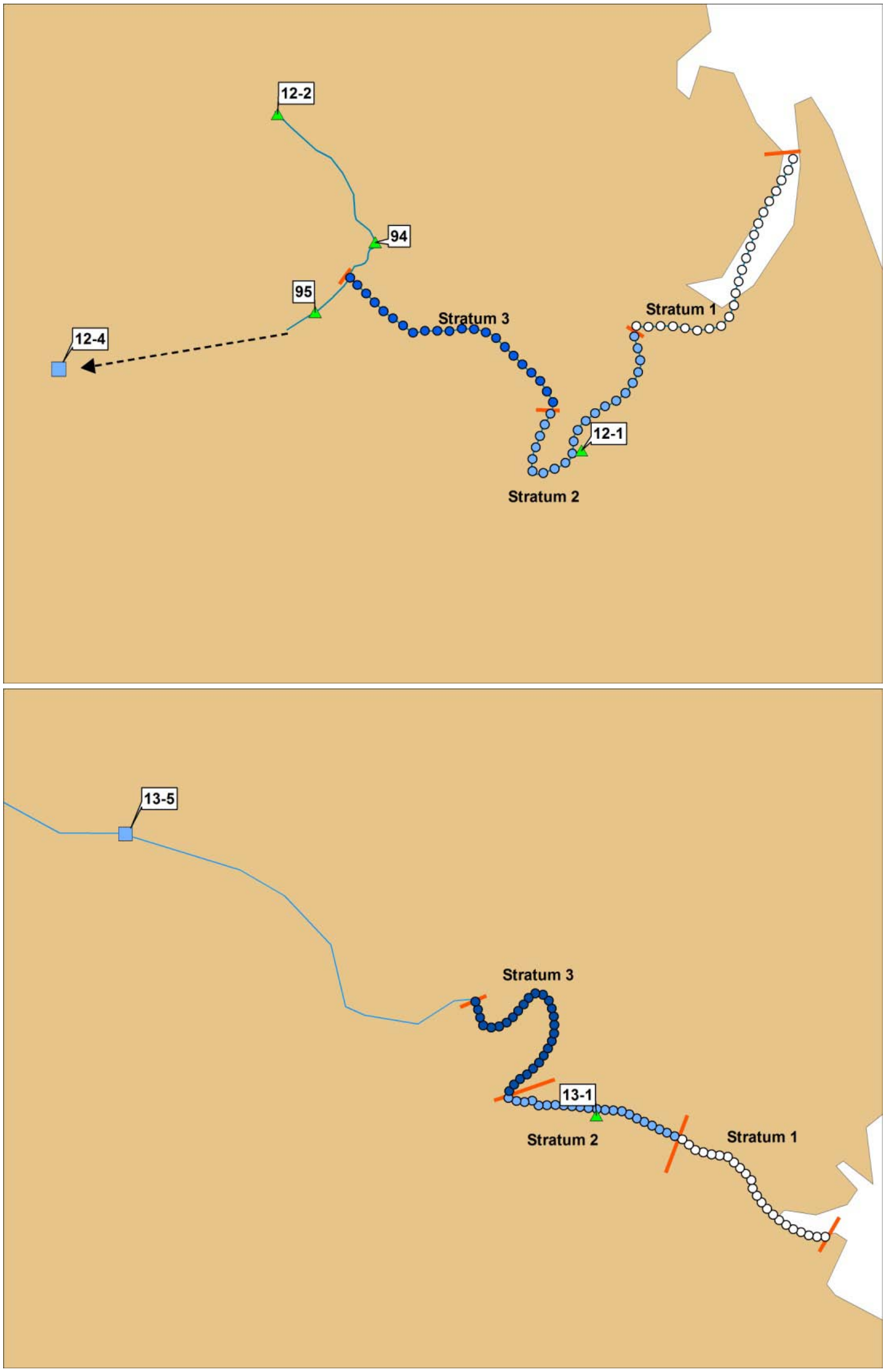


Figure 9. Sampling domain for Bishop Creek (top) and Mullet Creek (bottom). Fixed station locations are the green triangles, squares are fixed stations and flow locations, and circles are potential sampling points for the probabilistic design.

C.3 Design Specifications

The sampling design for this study was built to capitalize on existing monitoring efforts to the extent practical and provide information not only to meet the objectives of this study but also to help optimize future sampling efforts in tidal tributaries to Tampa Bay. In the paragraphs below, the design specifics for each sampling element is described in detail.

C.3.1 Water Quality

The objective of the routine water quality monitoring program was to characterize the spatial variability in water quality throughout the creek and estimate attenuation and sources of nutrients within the system. The creeks were divided into 3 sampling strata and a creek center point file has been generated with points at 10 meter intervals. Each month, 2 sampling points were generated using a random sample generator for each stratum. Therefore, the probabilistic portion of this design is called a stratified random design. In addition, water quality samples were collected at 2 fixed station locations on Mullet Creek and 4 fixed station locations on Bishop Creek. Therefore, a total of 8 water quality samples were collected on Mullet Creek and 10 water quality samples were collected on Bishop Creek each month. The locations of the fixed stations along with the population of potential random sites are shown in Figure 9 above The actual sampling field maps for each creek and month are located in Appendix B.

The decision to use a combination of probabilistic and fixed station design is two-fold:

- First, the objective of the probabilistic design is to get an unbiased estimate of within and across stratum variability within each creek and to be able to generalize information collected at discrete sampling points to the entire domain of the study area. A probabilistic design will minimize potential biases in generalizing water quality data to make inferences regarding the creek.

- Second, the objective of the fixed station component of this design will enhance the existing data by increasing the temporal sampling frequency at Pinellas County's current sampling location. Currently, 8 samples per year are collected at a single station in Mullet Creek and a single station in Bishop Creek. Additionally, the old fixed station site in each creek that was located at the Philippe Parkway Bridge was be sampled at each event. In this way it may be possible to develop a relationship between the old and new stations that have never been concurrently sampled. This may allow for a relationship to be developed to estimate water quality conditions at the upstream station during the historic time period when collection were being taken at Philippe Parkway (i.e., 1992-2002).

In Bishop Creek an additional two samples were taken on a monthly basis since there are two branches of this creek that contribute to the estuarine portion. Since one branch is fed by a storm water retention pond and the other may be fed by a spring, the design allowed for the estimation of the differences in nutrient concentration and loadings from each contributing branch of Bishop Creek. As was observed in the water quality plots of the existing data, there may be substantial differences in TP and NOx concentrations between the north and south branch of Bishop Creek.

Each sampling event began by collecting a water quality sample at the upstream fixed station location that is currently being sampled by Pinellas County. The sampling then began at the most downstream sample point for the month and proceeds upstream so as not to disturb the sample site by treading the stream channel. At each site a field data sheet was filled out to record location, environmental and physical chemistry parameters. A multi-parameter sonde (i.e. YSI 556, Hobria U52, or In Situ Troll 8500) was rented from U.S. Environmental Rental Corporation, which calibrated the sonde prior to every sampling event, to collect the following in-situ parameters:

- Temperature (˚C)
- Dissolved Oxygen (mg/l and % saturation)
- Turbidity (NTU)
- pH
- Conductivity (ms/cm and ms/cm^2)
- Salinity (ppt)

All water samples were collected in accordance with FDEP surface water sampling standard operation procedures (Series FS 2000 and FT 1100, 1200, 1300, 1400, 1500, and 1600) and analyzed by a National Environmental Laboratory Accreditation Conference (NELAC) certified laboratory, Southern Analytical Laboratories, Inc. (TNI00571). Water samples were analyzed for the following parameters:

- Ammonia (EPA 350.1 No Distillation)
- Total Kjeldahl and Organic Nitrogen (EPA 351.2)
- Nitrate-Nitrite (EPA 353.2 (Nitrate-Nitrite (N))
- Total phosphorus (SM 4500-P E)
- Orthophosphate (SM18 4500-P E (Orthophosphate))
- Chlorophyll-a (corrected and uncorrected), Pheophytin, b, and c (SM18 10200 H)
- Color (SM18 2120 B)
- Turbidity (SM18 2130 B)
- Total suspended solids (SM18 2540 D)

- Biological oxygen demand (SM18 5210 B)
- Total Organic Carbon (SM18 5310 B)

Stream velocity was also recorded at each location using a Global Water Flow Probe Hand-held Flowmeter in accordance with FDEP SOP series FT1800.

C.3.2 Fish Sampling

The objective of the fish sampling was to collect fisheries information concurrent with water quality and physical chemistry information to assess fish community composition as a function of water quality. A 9.1 meter raft seine was used to collect fisheries information in these creeks. The 9.1-m raft seine is a small mesh center-bag seine designed to sample small fish in shallow backwater (<1.0 m) habitats. The net forms a vertical “wall” in the water, with the top supported at the surface by floats and the bottom held on the substrate by lead weights. The “bag”, positioned at the center of the net, is an enlarged area of mesh that serves to enclose or box the fish and prevent escapement. The seine was pulled by hand using PVC poles attached to the ends of the net. When the net is pulled through the water the fish cannot swim over, under, or through the net, so they follow the wall of netting which leads them to the bag. When the bag is closed off, the fish are trapped.

The gear deployment methodologies followed those used by previous studies in tidal creeks as described in Sherwood et. al. (2008). Fish sampling was conducted at the same random sites selected each month for water quality; however only one sample was conducted in the most upstream stratum (M3 and B3). Therefore, a total of 5 fish samples were conducted in each creek.

For each sample, all species were enumerated and a sub sample of 10 individuals was selected at random for length frequency measurements. The specifics for measurements of various taxa are described in Figure 10. A randomly selected bank identifier (left or right) was used to determine which bank of the creek to sample at each location.

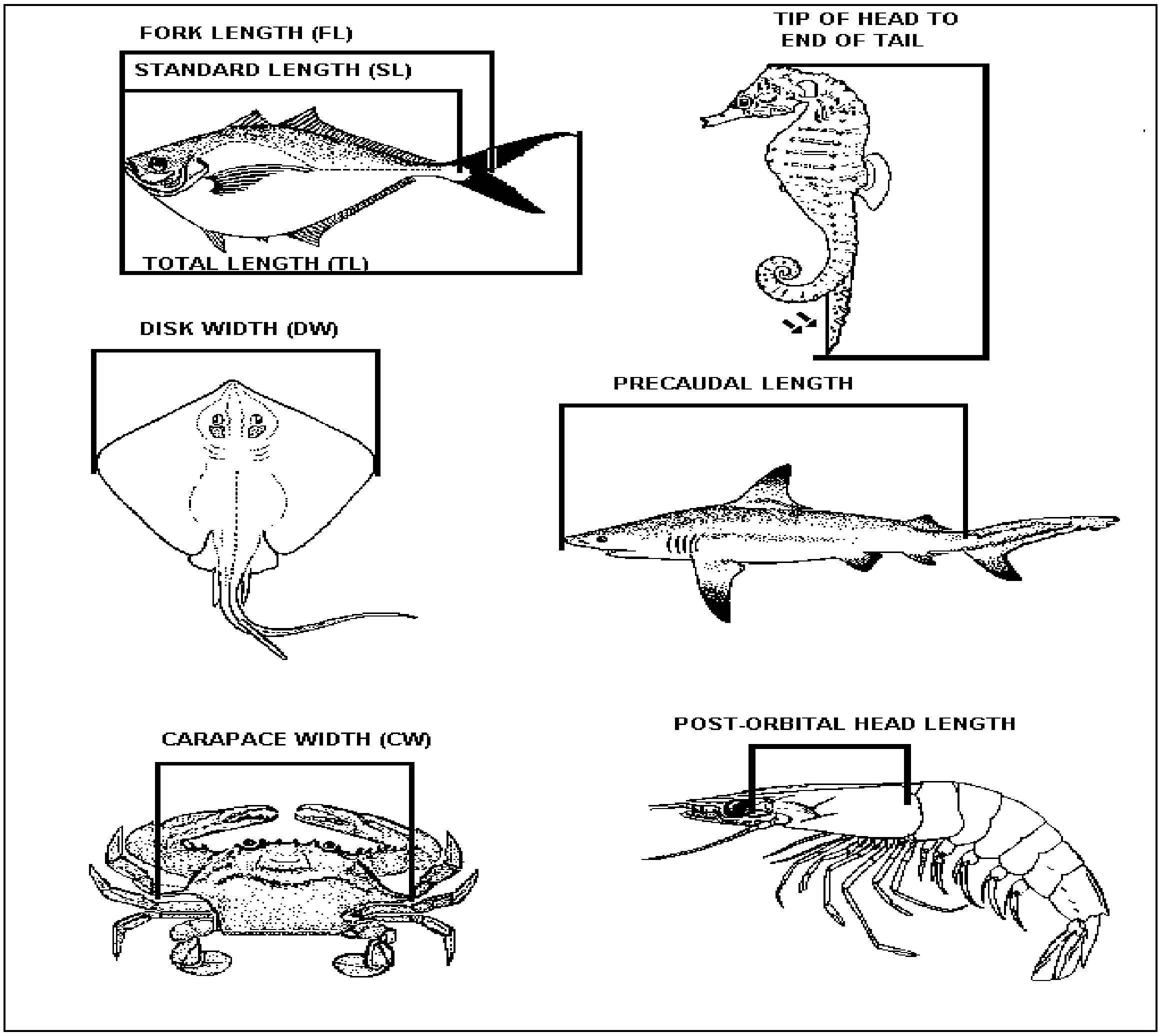


Figure 10. Measurement specifications for various collections from raft seine (taken from Sherwood et. al. 2008).

C.3.3 Benthic Microalgae Chlorophyll Concentration (BMAc)

The objective of collecting information on benthic chlorophyll content was to assess the relationship between water quality, fish community and benthic chlorophyll a concentration. Concurrent with the fish collections, the chlorophyll content of the top 1 cm of the creek bed was sampled using a 10ml syringe. The sample was collected directly from the creek bed. This effort was seasonal with a total of 40 samples collected over the course of the study. Five samples were collected from each creek (Figures 11 and 12) in the months of September, October, April and May to capture wet season and dry season benthic chlorophyll a concentrations in the sediments on seasonal scales. Benthic microalgae community samples were processed by Terra Environmental, Inc. using the spectrophotometric method of Whitney and Darley (1979), which is designed to yield accurate chlorophyll a concentrations in samples

with high quantities of chlorophyll a degradation products. Laboratory protocols are provided in Appendix A.

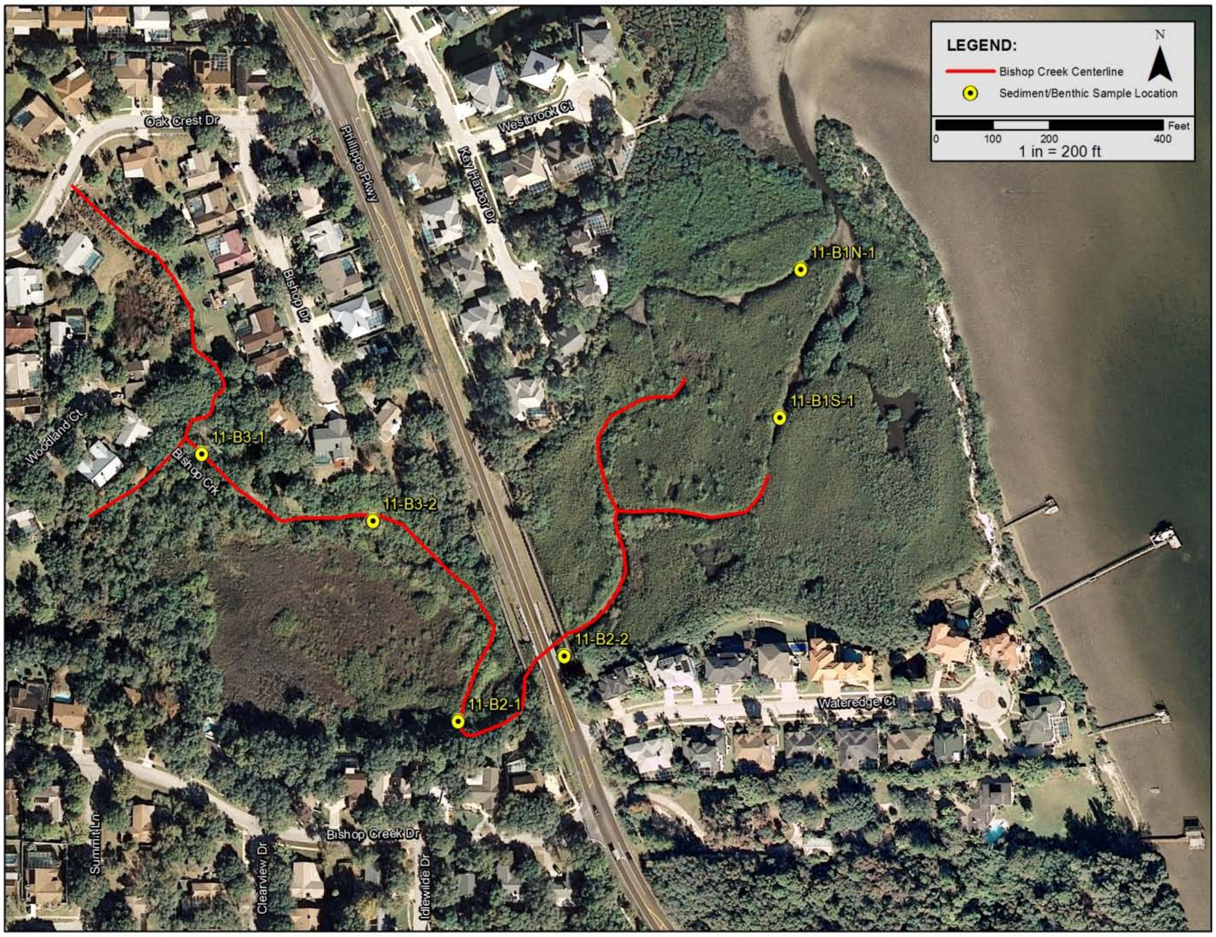


Figure 11. Bishop Creek Sediment and Benthic Sampling Locations

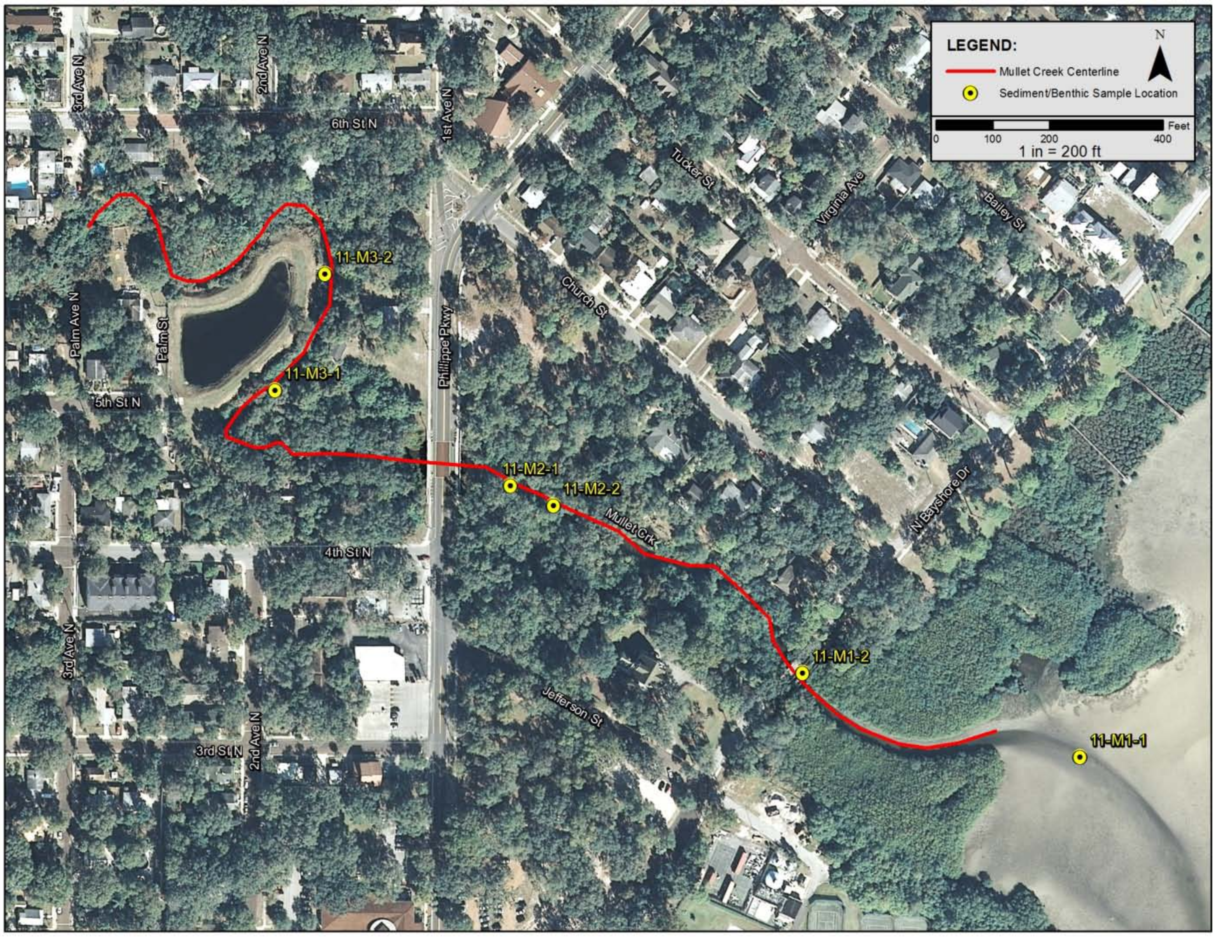


Figure 12.Bishop Creek Sediment and Benthic Sampling Locations

C.3.4 Stable Isotope Collections

Stable isotope analysis provides information on nutrient sources to the creeks and dominant nutrient production pathways within the system. The objective of this collection was to assess the dominant sources of nutrients on a seasonal scale by collection of a variety of flora and fauna inhabiting the creeks. Collections were made during the wet season (September) and dry season (May) to evaluate seasonal differences in nitrogen utilization. Samples will include:

- Emergent vegetation
- Mollusks
- Crustaceans
- Fishes

All samples were placed on ice and frozen upon return to the lab. All of the collected benthic microalgae (BMA), leaf tissues from vascular plants, and animal tissues were dried at 55°C for

48 hours. For fishes and shrimps, only muscle tissue was used when possible. For some very small animals, bone, chitin or internal organs were present in the samples. Dried tissues were powdered and stored in a dessicator prior to isotopic analysis. $\delta^{15}N$ and $\delta^{13}C$ values were measured using a Carlo Erba 2500 Series I elemental analyzer equipped with a zero-nitrogen blank auto-analyzer that was coupled to a Finnigan Mat Delta Plus XL stable-isotope mass spectrometer. Samples were run using spinach leaves (NIST 1570a) as an internal reference for BMA and plants, and bovine liver (NIST 1577b) was used as an internal reference for animals. Carbon and nitrogen isotope values are reported in conventional per mil notation (‰) relative to Pee Dee belemnite limestone and nitrogen gas in air. Specific protocols for sample collection and processing are provided in Appendix A.

C.3.5 Dry Season Macroinvertebrate Survey

Pinellas County designated Mullet and Bishop Creeks for a special study data collection for benthic macroinvertebrates as part of the Tampa Bay Estuary Program's Benthic Monitoring and Assessment Program. Samples were collected according to established EMAP methods (Pinellas County, 2011).

Twelve samples were allotted for this special study with 6 sites in each creek randomly selected from the sampling list framework described above. Sample collections were conducted in both Bishop and Mullet Creek in September 2011. Thirteen samples were collected, 12 originals and 1 duplicate. The 2011 samples were collected by Pinellas County staff.

The objective of this component of the study was to replicate the benthic macroinvertebrate collections performed for the special study in 2011 during the dry season. To that end, the sites sampled during the special study described above were initially set to be revisited during the dry season to characterize the benthic macroinvertebrate community prior to the onset of the wet season. This study was intended to provide additional information on the seasonal variability of the benthic macroinvertebrate communities within the creeks to correlate with the benthic chlorophyll estimates, fish collections and isotope analysis. The second sampling event took place in December of 2012. Twelve samples were collected (no duplicate) at the same sites as the 2011 samples. The 2012 samples were collected by project scientists.

Hillsborough County EPC processed 13 of the 2011 samples, and six of the 2012 samples for taxonomic identification and sediment composition. Terra Environmental process six of the 2012 samples for taxonomic identification, and Eckerd College processed those same six samples for sediment composition.

C.3.6 Mangrove Health Index

A synoptic survey was designed to assess the health of the mangrove forests in the estuarine portion of the study area. There are extensive areas of mangrove forests near the mouths of these tributaries and these forests represent a major component of the tidal creek ecology providing habitat for fishes and birds, a sink for sediments and nutrients and a source of benthic productivity from leaf litter creating a more complex food web. This survey was designed to assess the current health of these mangroves by characterizing plant condition, sediment chemistry, and mangrove root biology as feasible to define an index representing mangrove forest health.

Sampling was conducted by Dr. Jeaninne Lessman of Eckerd College in June 5-9, 2012 along both Mullet Creek and Bishop Creek from the downstream to upstream at grid locations 3, 8, 13, 18, and 23 (Table 7 and Figures 13 and 14). Both sides of the creek were sampled at each sample point (i.e., for each sample at each site within each grid at each sample position, each of the two samples were on opposite sides of the creek). Salinity, pH, and hydrogen sulfide were sampled at the creek edge (underneath the mangrove canopy overhang) as well as at 5 meters interior of the creek's edge. The oxidation-reduction potential (redox potential) was measured only in the interior positions, as the edge positions were too deep for sampling. It should be noted that there was regular and heavy rain during the sampling period, though samples were not collected during a rain event.

Table 7. Mangrove Sampling Locations

Grid	Longitude	Latitude
Bishop-3	-82.68551277	28.02020368
Bishop-8	-82.68573539	28.01980011
Bishop-13	-82.68588794	28.0193712
Bishop-18	-82.68620297	28.01909634
Bishop-23	-82.68670737	28.01912723
Mullet-3	-82.68563006	27.99271224
Mullet-8	-82.68606662	27.9929342
Mullet-13	-82.68633251	27.99330445
Mullet-18	-82.686719	27.99356769
Mullet-23	-82.68717354	27.99373737

Figure 13. Bishop Creek Mangrove Health Index Sampling Locations

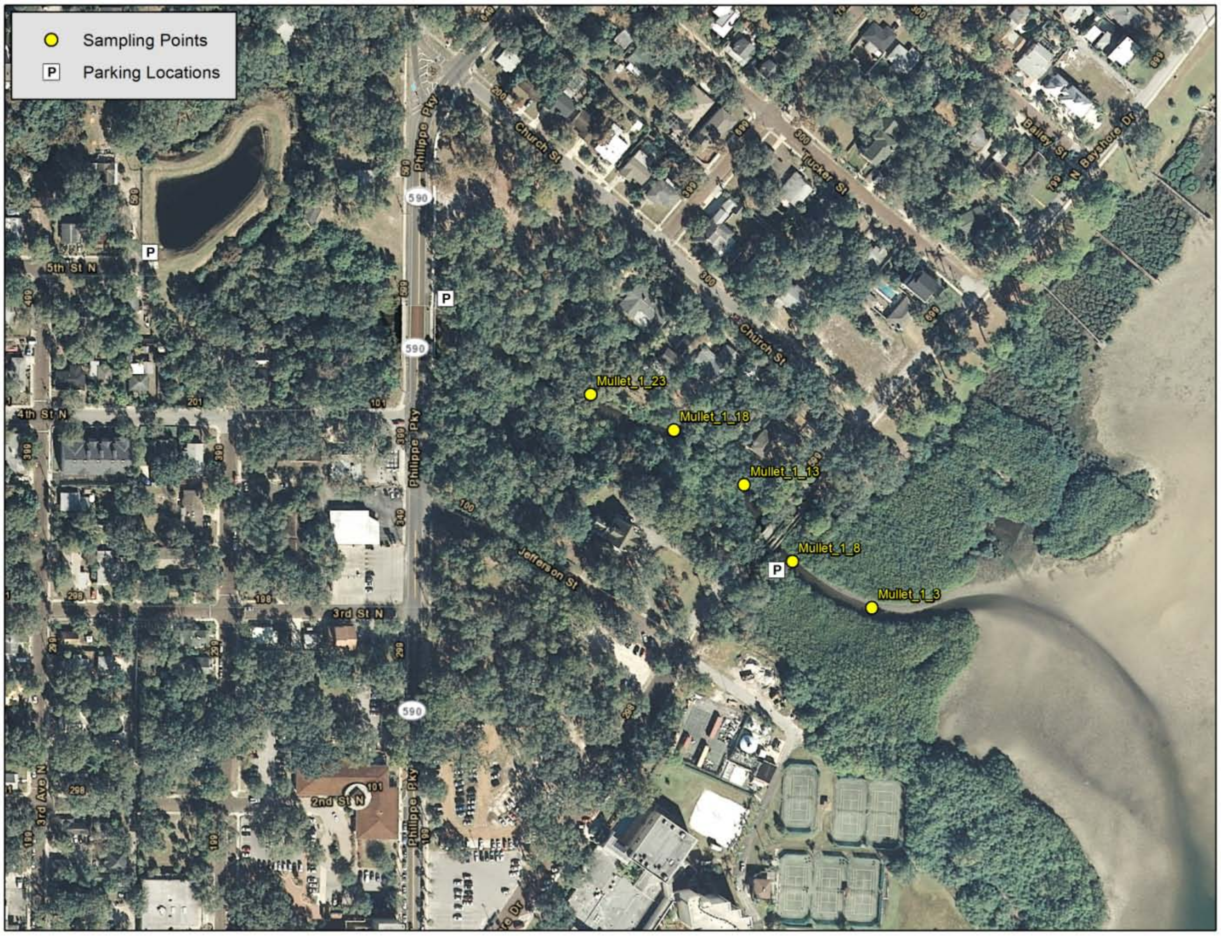


Figure 14. Mullet Creek, Mangrove Health Index Sampling Locations

Soil interstitial water was withdrawn from a depth of 10 cm into a 30 ml syringe using a perforated, rigid steel tube covered with nylon hosiery and cheesecloth to filter particulate material (McKee et al. 1988). The first 10 ml withdrawn was discarded to eliminate water contaminated by air in the tube and disturbed sediment resulting from tube insertion. Salinity was measured with a refractometer. An Altex Model 3560 digital meter and electrode were used to measure pH. Hydrogen sulfide (mM) was determined using the method of McKee et al. (1988) (Lazar Model IS-146 sulfide electrode).

Soil redox potentials (Eh) (mV) at 10-cm depths were measured in triplicate subsample with brightened platinum electrodes. The potential of a standard calomel reference electrode (+244 mV) was added to the millivolt (mV) reading to obtain Eh.

Statistical analyses were completed with SAS (2008). All dependent variables were tested for normality and homogeneity (Shapiro-Wilk test and Bartlett test, respectively) and found to be valid. An ANOVA was conducted on each dependent variable. When main effects were significant at $p<0.05$, Tukey's multiple comparisons were performed. No significant interactions of the main effects were found. Means of each dependent variable for each site, grid, position, and their different interactions were calculated, as well as for all sample data at each site.

C.3.7 Canopy Coverage Estimations

The methods used for estimating canopy coverage included both qualitative and quantitative methods. Qualitative methods included observer estimates of the percent of shading observed at the sample location which was recorded on the field sampling sheet. Quantitative estimates were calculated using a spherical crown densiometer with 24 0.25 inch squares. Upon the initiation of the study, a FDEP standard operating procedure was not currently available; therefore, the use of the densiometer was modeled after the method utilized by the State of California to measure canopy coverage over streams for benthic sampling programs (Eric Burress, personal communication and Appendix C). The California method uses modifications different from the usual open field canopy measurement strategies, utilizing a wedge-shaped area to estimate canopy coverage upstream, downstream, right bank, and left bank (Strickler, 1959).

The densiometer is modified by placing black tape in a V-shape, covering all the 0.25 inch squares, except for 17. At each site, the researcher takes a densiometer reading at 0.3 meters above the water surface, to avoid errors from varying water depths, and to include low-hanging vegetation which would be missed if the researcher was standing up fully.

The densiometer was leveled and held away from the person's body so the head was outside the grid. If any canopy overlies any of the 17 intersection points within the taped V, that point was counted as having cover. This process was repeated in each of the four directions (e.g. upstream, downstream, left bank, and right bank).

For post-processing, the four directional readings were added up, multiplied by 1.5, followed by the removal of a 1% correction percentage to account for canopy overlap and the recounting of points (Strickler, 1959).

D. Results and Discussion

The following sections detail the sampling and modeling results. The supporting data, including but not limited to, field data sheets, excel files of data summaries, and the Microsoft Excel database of sampling results, are located on a CD located in Appendix D.

D.1 Water Quality

A total of 8 water quality samples were collected on Mullet Creek and 10 water quality samples were collected on Bishop Creek each month between September 2011 through October 2012, for a total of 112 samples on Mullet Creek and 140 samples on Bishop Creek. This section provides a comprehensive review of data collected within the context of evaluating water quality conditions in the estuarine WBIDs of Mullet and Bishop Creeks. The section begins with a review of the environmental characteristics during the study period including flow data collected by Pinellas County upstream of the study area, salinity characteristics measured in situ associated with both the fixed station and probabilistic sampling in the three most downstream strata, and colored dissolved organic matter (CDOM) reported as color reported in cobalt platinum units. Biologically associated constituents including chlorophyll a (ug/l), pheophytin, biochemical oxygen demand, dissolved oxygen, total organic carbon, total suspended solids, and turbidity are then discussed. Finally, the nutrient constituents including nitrogen and phosphorus species are discussed. The results are then reported within the context of larger efforts by state and federal agencies to establish management level targets and thresholds for water quality that support full aquatic life uses for species expected to utilize southwest Florida tidal creeks.

The Wilcoxon rank sum test was used to compare the distribution of analytes between creeks and the Kruskal Wallis test was used to compare differences among strata within a creek (Zar 1984). These are nonparametric tests that do not rely on the distributional assumptions typical of parametric statistical tests and are commonly used for water quality data that are not typically normally distributed. For this section the term “strata” or “stratum” refers to both the strata used for the probabilistic sampling component as well as the individual fixed station locations. The most upstream and downstream sampling locations are denoted by the Label “Upstream” and “Downstream”, respectively to aid the reader in orienting the results spatially within the system. In Bishop Creek, the two stations (94 and 95) located just upstream of the north and south branch are grouped for plotting purposes (denoted as “Branch”) but the water quality in these branches are compared in later sections to determine if there are differential contributions of nutrients from these two branches of Bishop Creek.

D.1.1 Flow

Daily flow data have been reported in Bishop and Mullet Creek since August and October of 2006, respectively. A timeseries of flows for each creek is provided in Figure 15. The study period is denoted by the vertical gray reference line in the plots in September of 2011. Flows were not abnormal during the study period despite the passage of tropical storm Debby in June of 2012. Cumulative distribution plots of the flow data for each creek and water year demonstrate that the distribution of flows during the study period was typical in Mullet Creek but lacked the higher percentile flows in Bishop Creek observed during other years in the period of record (Figure 16). It should be noted that the flow gage in Bishop Creek is located in the southern branch of the creek and therefore does not capture the total flow to the estuarine portion of Bishop Creek. However, the flow gage is representative as a relative estimate of inter annual differences in flow.

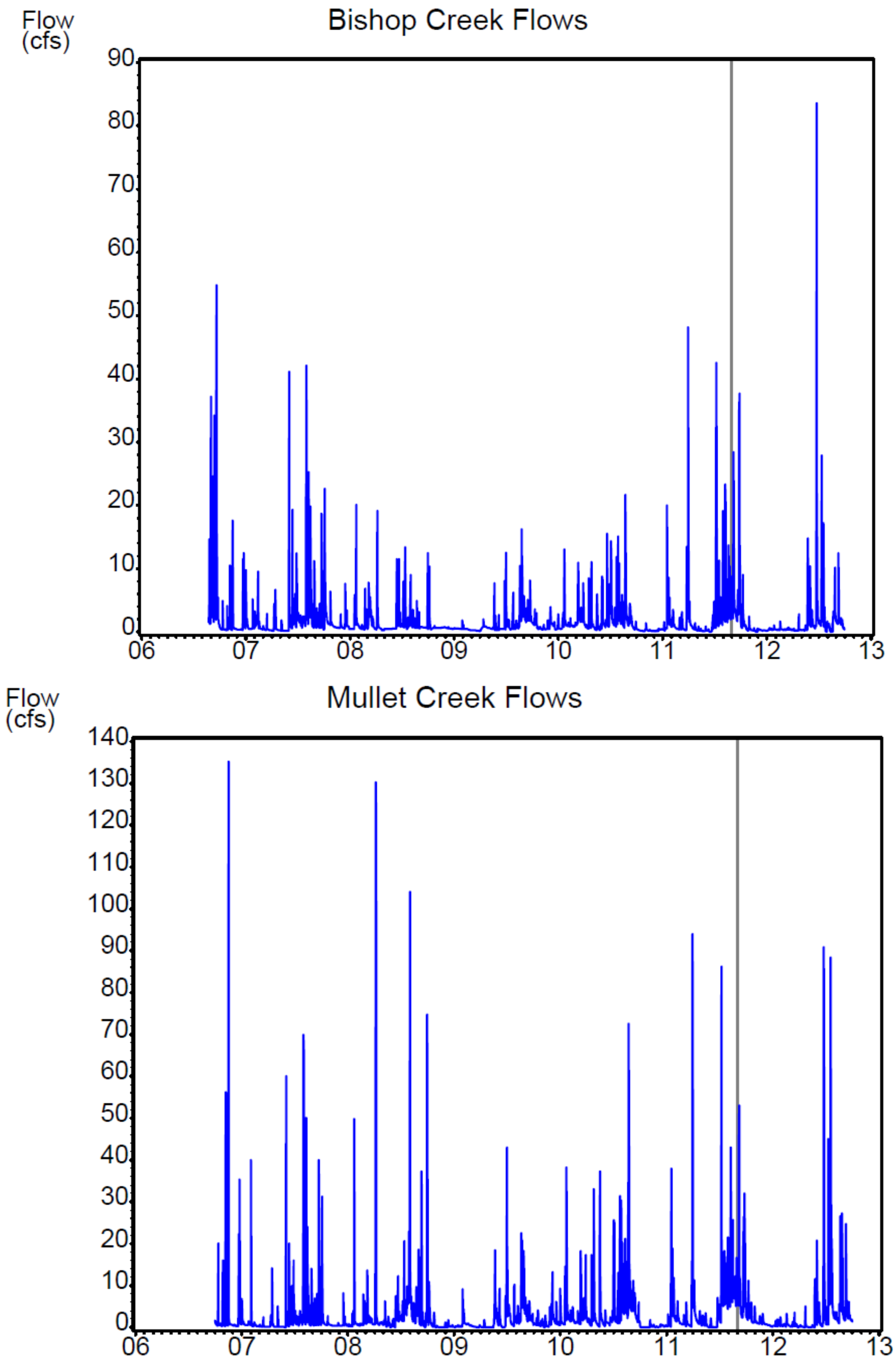


Figure 15.Timeseries of flows in Bishop (top) and Mullet (bottom) creeks.

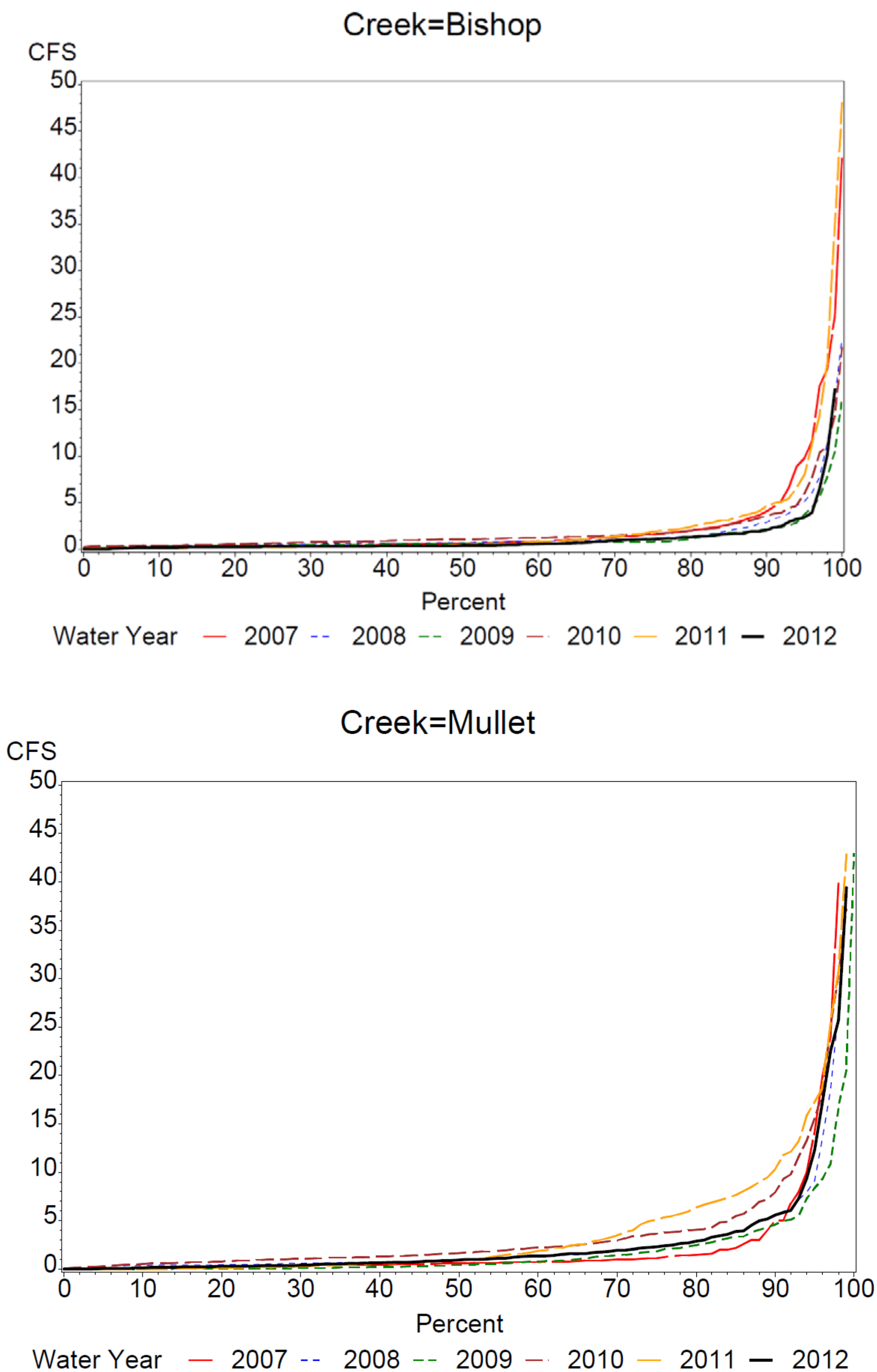


Figure 16. Cumulative distribution plots by water year for Bishop and Mullet Creeks. The study period water year is the black solid line in the figures.

D.1.2 Salinity

In both creeks, the water depths were typically shallow enough at the time of sampling that only a single mid water salinity reading was recorded. Descriptive statistics for salinity measurements at each fixed station and in each stratum of the random sampling component are provided in Table 8. The distribution of salinity values was significantly different among strata within both creeks but not different between creeks. Salinities appeared more normally distributed in Mullet Creek where mean and median stratum specific values were very similar in the lower strata while Bishop Creek salinity appeared more susceptible to salinity intrusion but had lower stratum specific median values in the lower strata than Mullet Creek. Salinity had a predictable pattern both spatially within the creek and temporally throughout the sampling period. The longitudinal pattern of salinity is represented by the stratum specific box and whisker plots of Figure 17. The stratum specific timeseries plots (Figure 18) depict the higher salinities throughout the creek during the dry season which began in late February of 2012 and lasted through May 2012.

Table 8. Descriptive statistics for the analyte Salinity in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Salinity	Bishop	1	28	12.199	10.970	8.300	68.000	8.971
	Mullet	1	28	11.856	11.050	9.315	78.600	6.267
	Bishop	2	28	8.057	3.220	8.369	103.900	3.850
	Mullet	2	28	10.350	10.305	8.868	85.700	4.103
	Bishop	3	28	4.371	0.490	6.557	150.000	1.058
	Mullet	3	28	6.488	3.975	7.359	113.400	2.243
	Bishop	Fixed 91	13	9.352	3.200	9.753	104.300	4.115
	Mullet	Fixed 91	15	11.908	11.470	9.015	75.700	5.416
	Bishop	Fixed 92	14	0.648	0.3	0.783	120.8	0.403
	Mullet	Fixed 95	14	0.629	0.205	1.612	256.100	0.267
	Bishop	Fixed 94	13	1.330	0.430	2.113	158.900	0.618
	Bishop	Fixed 95	13	1.227	0.310	3.138	255.800	0.439

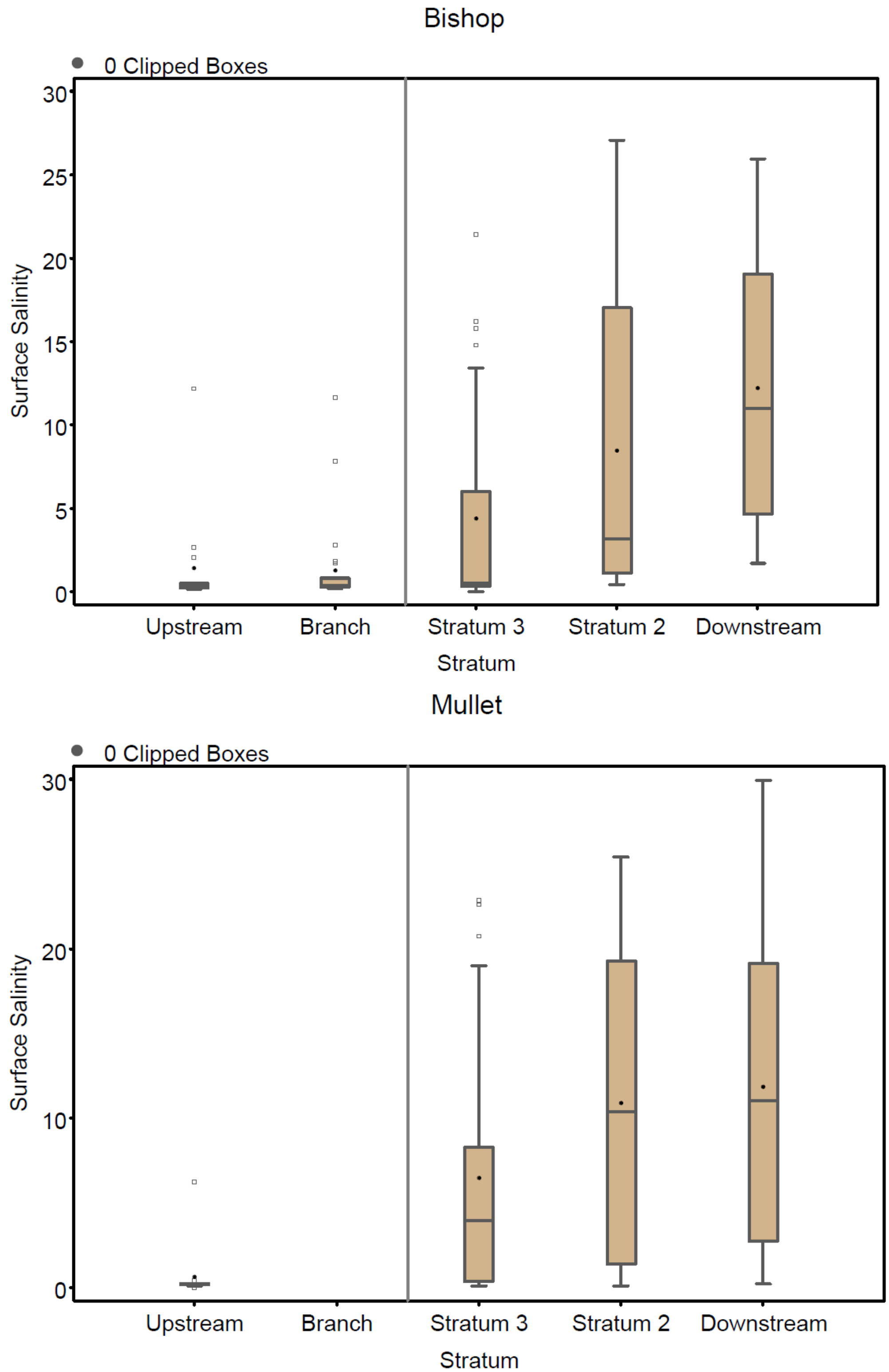


Figure 17. Box and whisker plots for salinity in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.

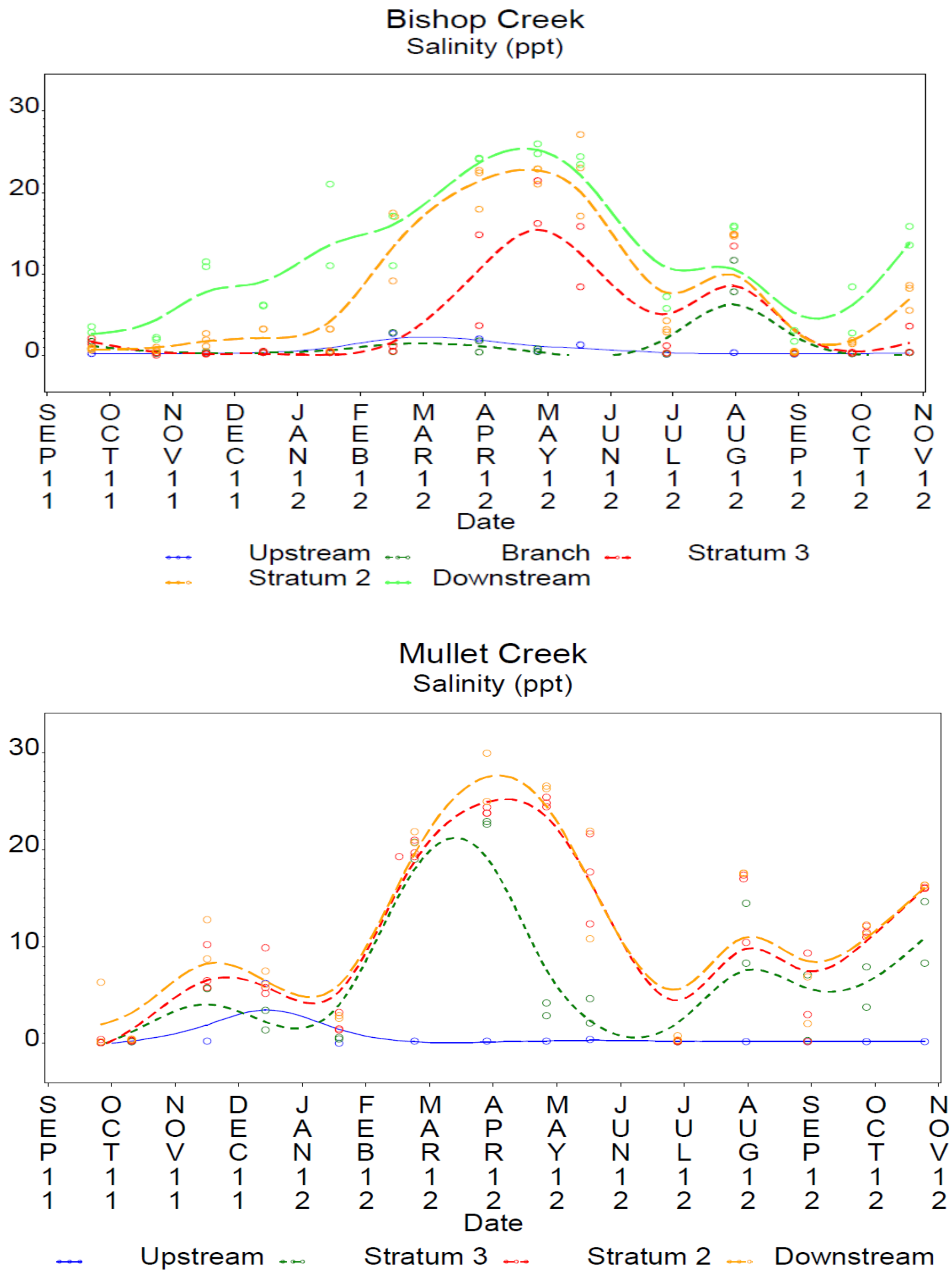


Figure 18. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.3 Color

Color measurements are indicative of the concentration of colored dissolved organic matter in the water column and color is typically the primary attenuator of light through the water column. Mullet Creek color values tended to be higher than Bishop Creek color values in all strata (Table 9). There were no significant differences either among strata within a creek or between creeks (Figure 19). All strata responded in remarkably similar fashion throughout the time period of the study with increasing values during the wet season and reduced values in the dry season indicating that color acts as a conservative substance (Figures 20).

Table 9. Descriptive statistics for the analyte Color in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Color	Bishop	1	28	46.429	30.000	31.823	68.500	37.228
MDL = 5 (PCU)	Mullet	1	28	56.429	37.500	43.819	77.700	41.444
	Bishop	2	28	45.357	37.500	24.718	54.500	39.437
	Mullet	2	28	58.214	37.500	41.816	71.800	45.653
	Bishop	3	28	47.143	45.000	18.729	39.700	43.630
	Mullet	3	28	63.036	55.000	37.573	59.600	52.620
	Bishop	91	12	46.250	45.000	22.373	48.400	41.018
	Mullet	91	15	59.333	40.000	43.296	73.000	46.568
	Bishop	92	14	46.071	35.000	26.252	57.000	40.579
	Mullet	95	14	69.643	65.000	37.079	53.200	60.898
	Bishop	94	14	45.357	40.000	22.486	49.600	40.990
	Bishop	95	14	47.143	42.500	19.779	42.000	43.689

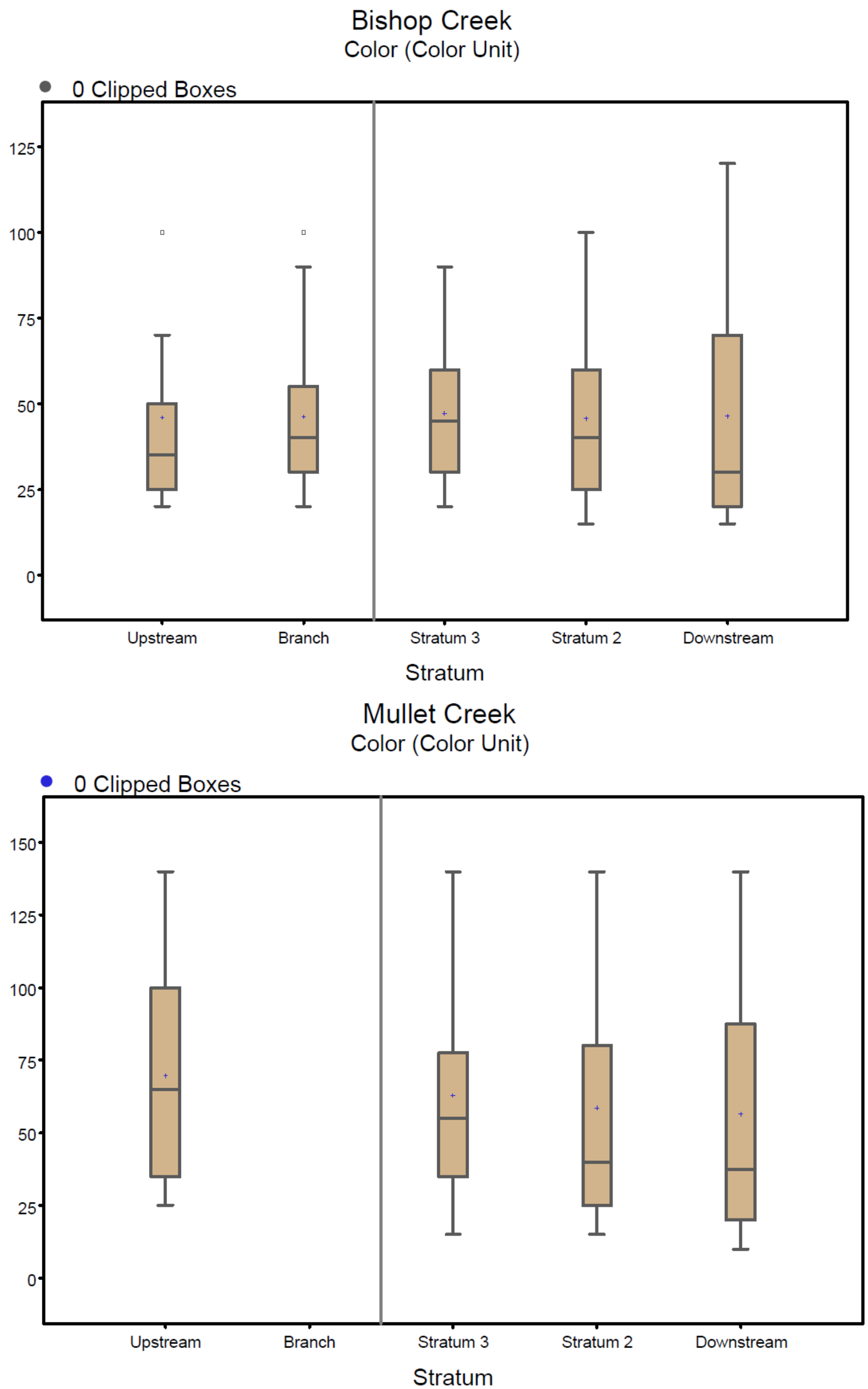


Figure 19. Box and whisker plots for Color in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.

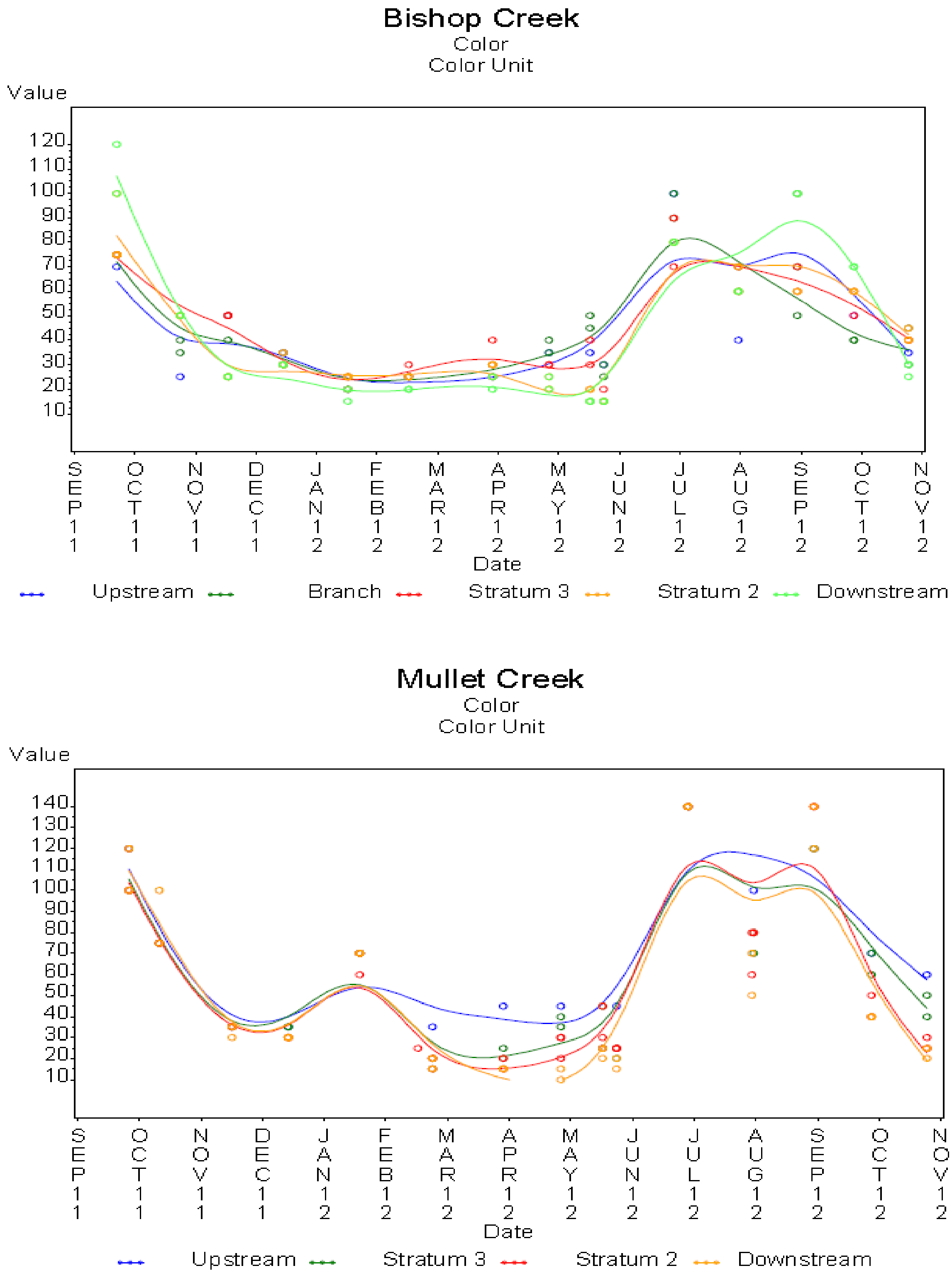


Figure 20. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.4 Chlorophyll a Corrected

Chlorophyll a (Chl a) is used as an index of the concentration of phytoplankton in the water column. The FDEP has currently adopted an annual average concentration of 11 ug/l of chlorophyll as a water quality standard indicative of impairment when exceeded. While the values reported in Table 10 are calculated over the entire study period which in the case of chlorophyll includes from November 2011 through October 2012, the arithmetic mean values are below 11 ug/l at all strata (Table 10; Figure 21). There were no significant differences either among strata within a creek or between creeks. Interestingly, some of the highest values reported were in December of 2011 in both creeks. There were some initial lab issues regarding the analysis of chlorophyll in September and October of 2011 which were removed from the analysis. It may be that these issues carried into December of 2011 as well. Otherwise, the highest chlorophyll values were observed in late July in Bishop Creek and Late September in Mullet Creek (Figure 22) indicating potential for differential nutrient loading or response dynamic in the two creeks. This is further evaluated in the next section of this report.

Table 10. Descriptive statistics for the analyte Chlorophyll a Corrected in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Chlorophyll a, Corrected	Bishop	1	22	8.227	6.100	6.065	73.700	6.828
MDL =0.5 mg/M^3	Mullet	1	24	8.783	4.800	10.776	122.700	5.076
	Bishop	2	22	7.403	4.900	7.660	103.500	5.138
	Mullet	2	24	8.358	5.550	11.814	141.300	4.510
	Bishop	3	22	7.239	4.250	7.815	108.000	4.445
	Mullet	3	24	5.163	4.650	3.788	73.400	3.833
	Bishop	91	9	6.454	6.500	4.553	70.500	4.921
	Mullet	91	13	9.754	5.200	15.292	156.800	4.812
	Bishop	92	11	8.900	5.300	8.485	95.300	5.708
	Mullet	95	12	5.125	4.000	3.629	70.800	3.754
	Bishop	94	11	4.891	2.800	3.941	80.600	3.628
	Bishop	95	11	4.960	3.800	5.708	115.100	2.803

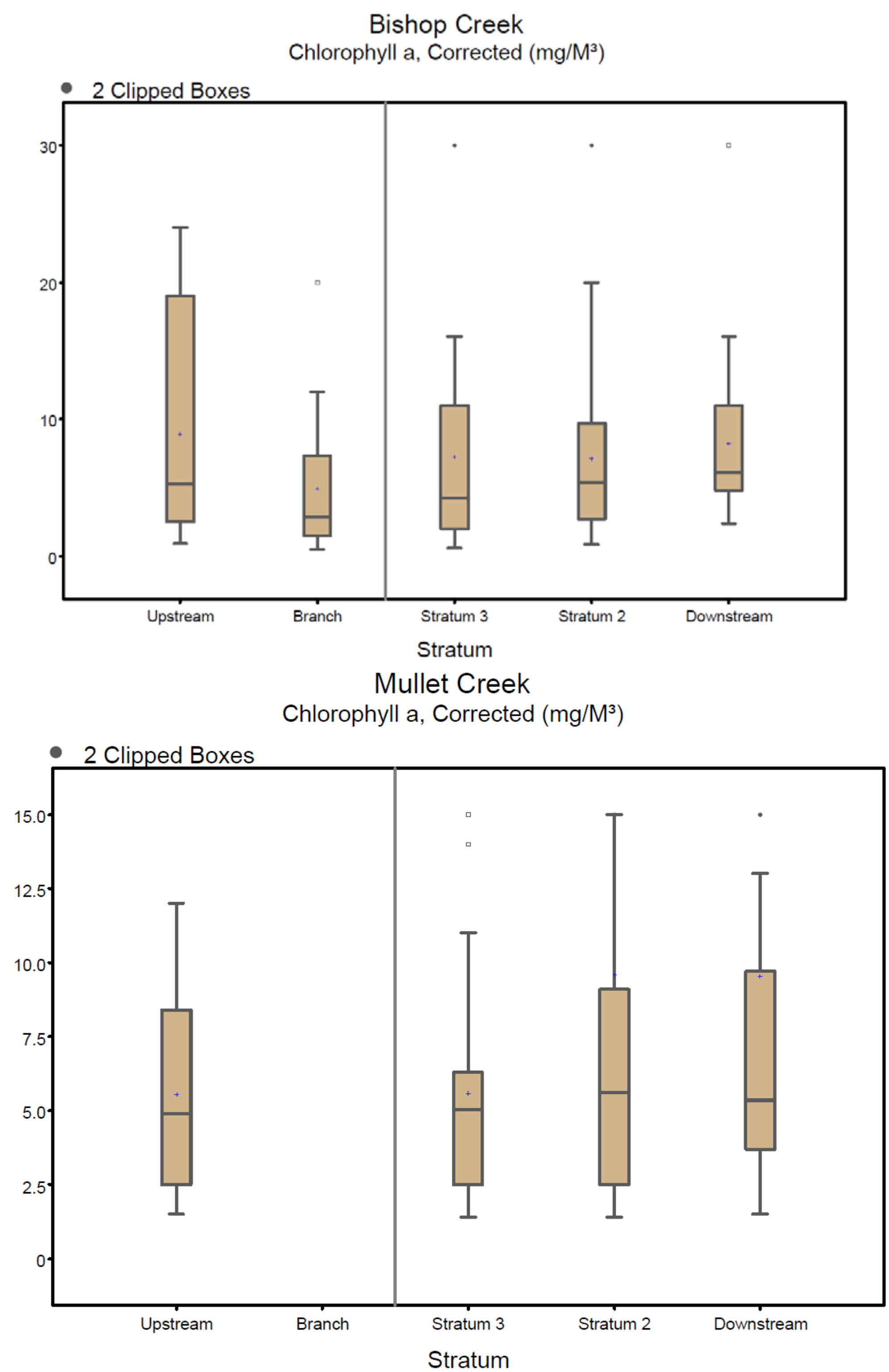
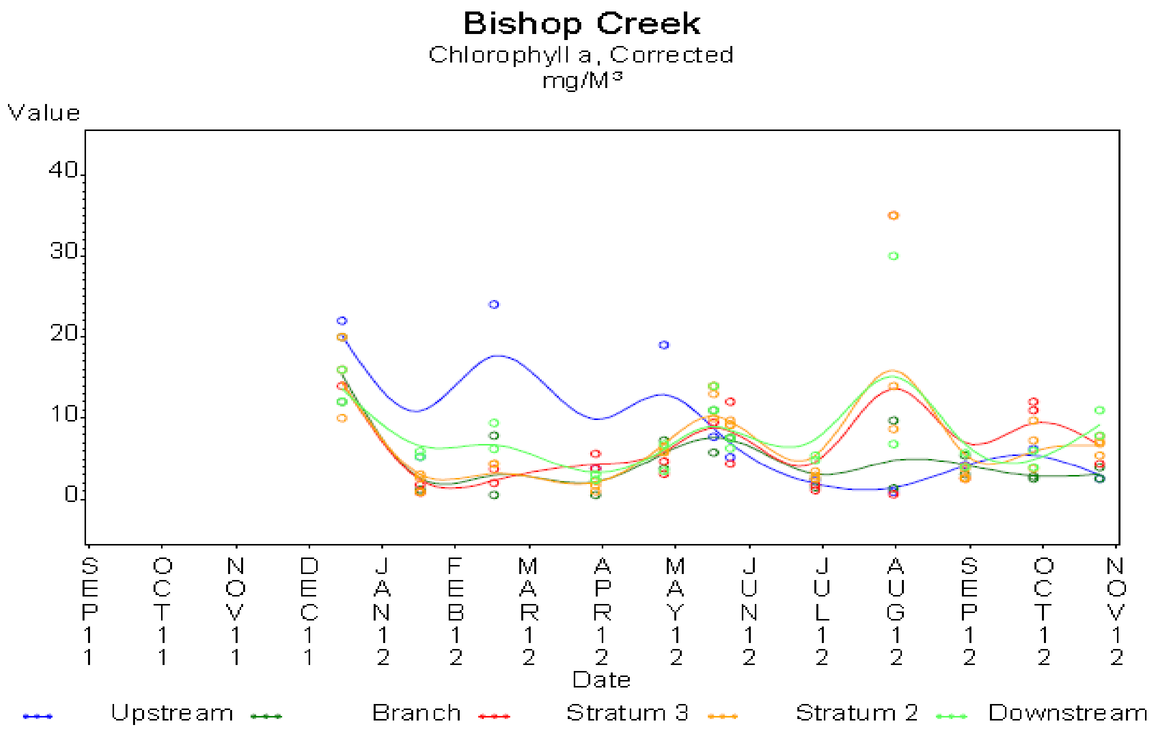


Figure 21. Box and whisker plots for Chlorophyll a, Corrected in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



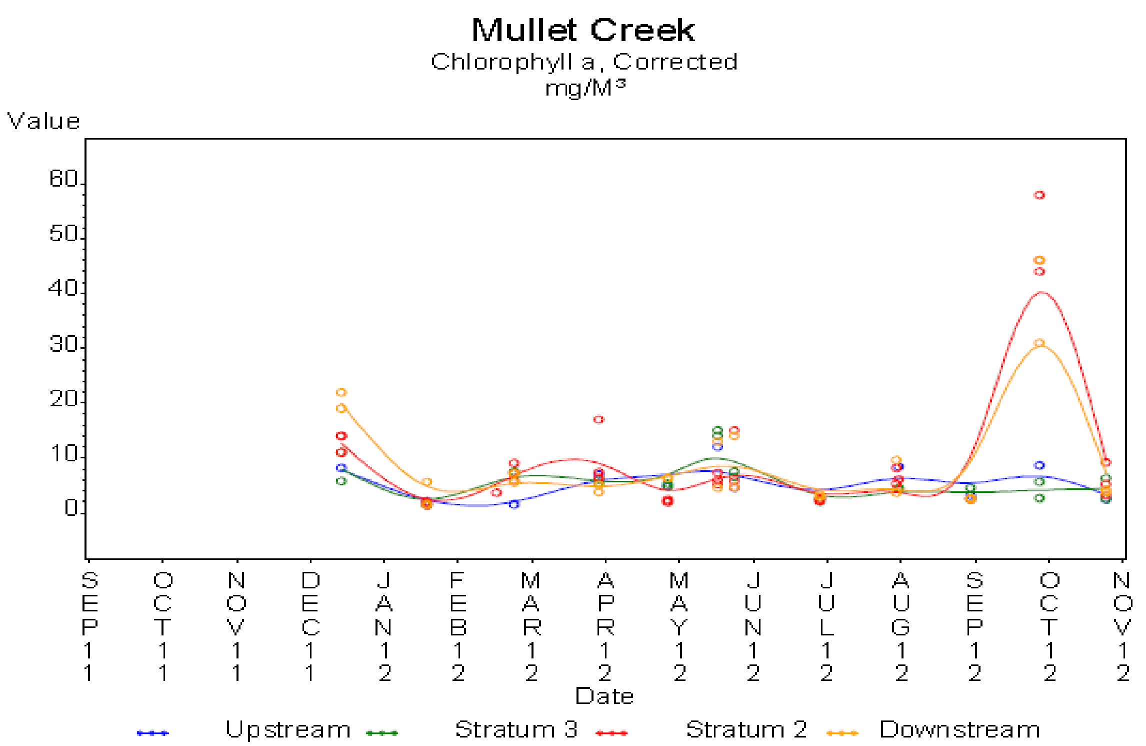


Figure 22. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.5 Pheophytin:

Pheophytin is a natural degradation product of chlorophyll and is used to correct chlorophyll values to estimate the concentration of living phytoplankton in the water column at the time of sampling. The values are provided in Table 11 are for reference only and have no regulatory implications. However, they may serve as an indicator of areas or times of high phytoplankton production observed in Figures (23 and 24). There were no significant differences among strata within a creek; however, Bishop Creek had significantly higher pheophytin concentrations than Mullet Creek.

Table 11. Descriptive statistics for the analyte Pheophytin in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Pheophytin a	Bishop	1	24	3.795	3.000	2.324	61.200	3.071
MDL =0.5 mg/M^3	Mullet	1	22	3.725	2.550	3.422	91.800	2.893
	Bishop	2	24	5.037	3.650	3.835	76.100	3.703
	Mullet	2	22	3.232	2.800	1.776	54.900	2.836
	Bishop	3	24	5.039	3.700	4.461	88.500	3.305
	Mullet	3	22	2.760	2.300	2.092	75.800	2.009
	Bishop	91	10	6.680	4.450	5.810	87.000	4.723
	Mullet	91	12	3.467	3.050	2.340	67.500	2.890
	Bishop	92	12	4.367	2.800	4.986	114.200	2.854
	Mullet	95	11	3.833	2.500	3.310	86.400	2.637
	Bishop	94	12	3.006	2.300	2.545	84.700	2.197
	Bishop	95	12	2.124	2.400	1.362	64.100	1.667

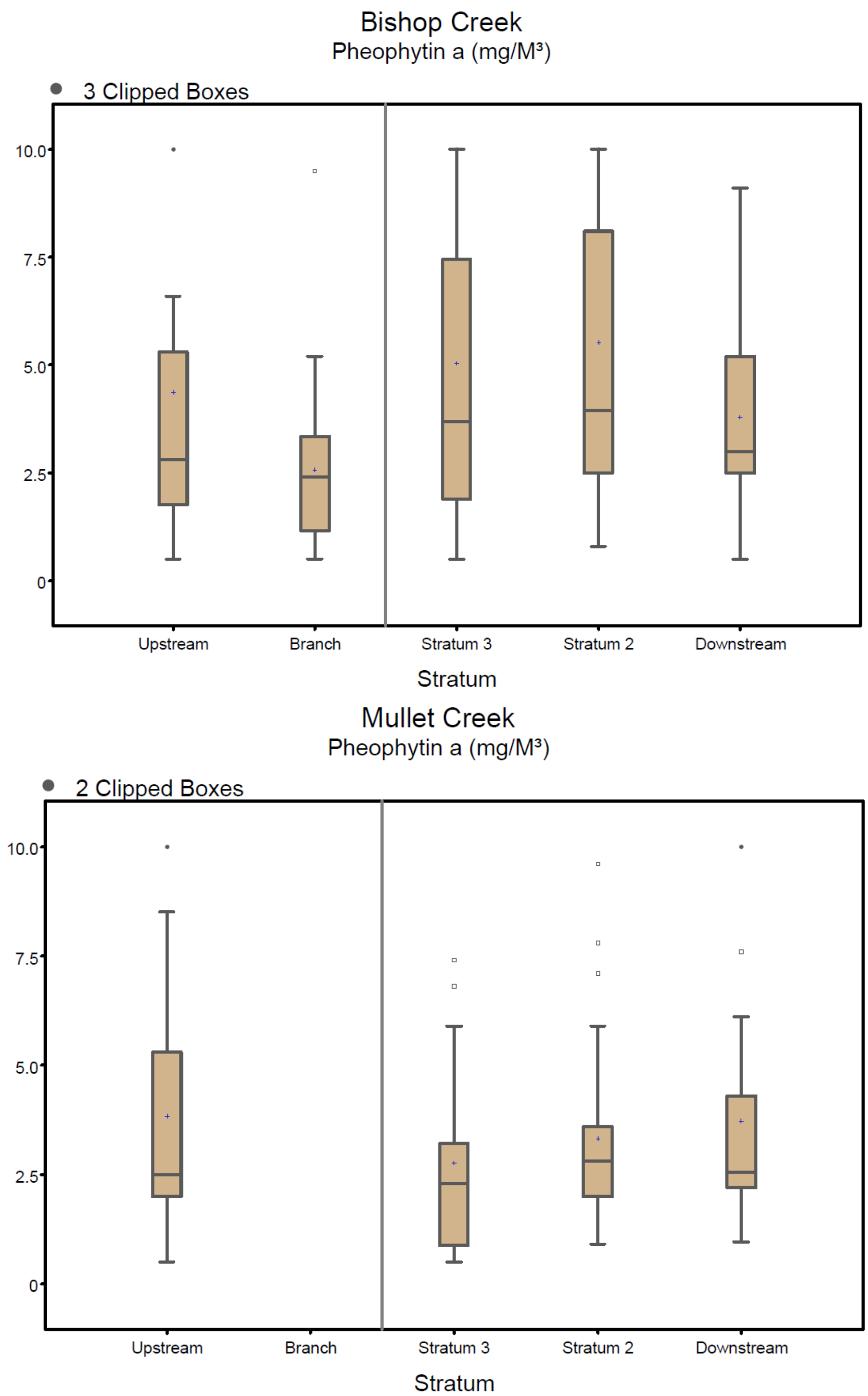
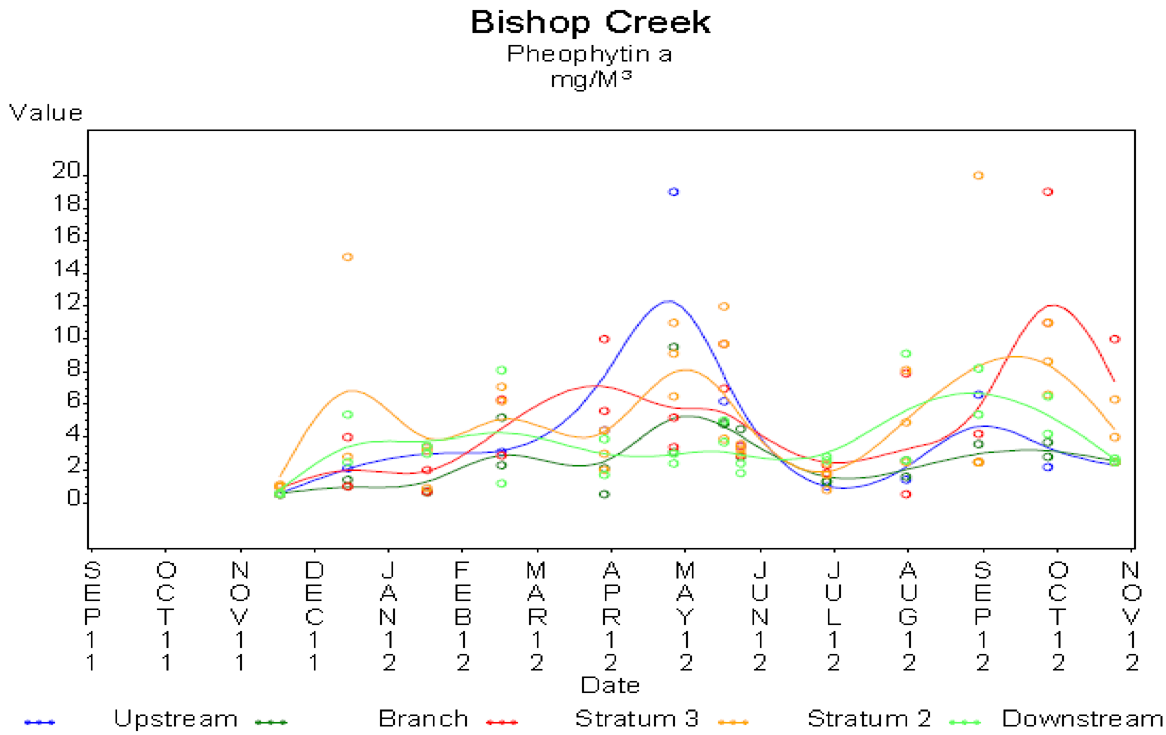


Figure 23. Box and whisker plots for Pheophytin a in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



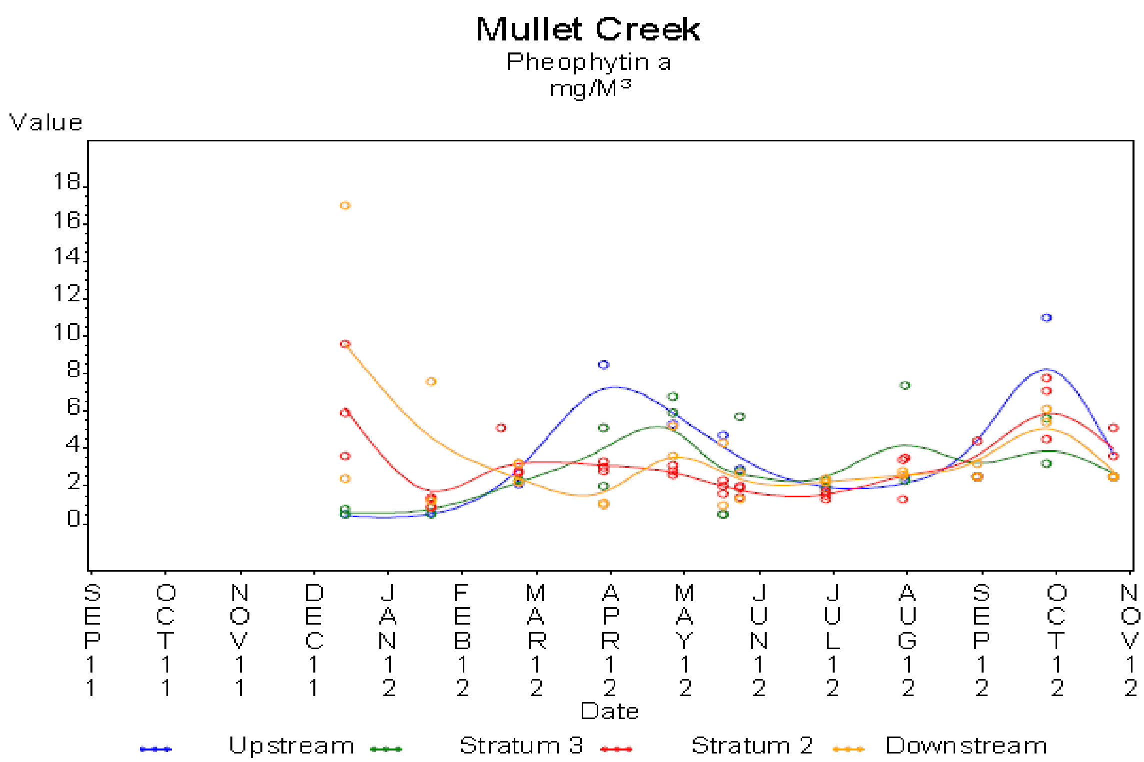


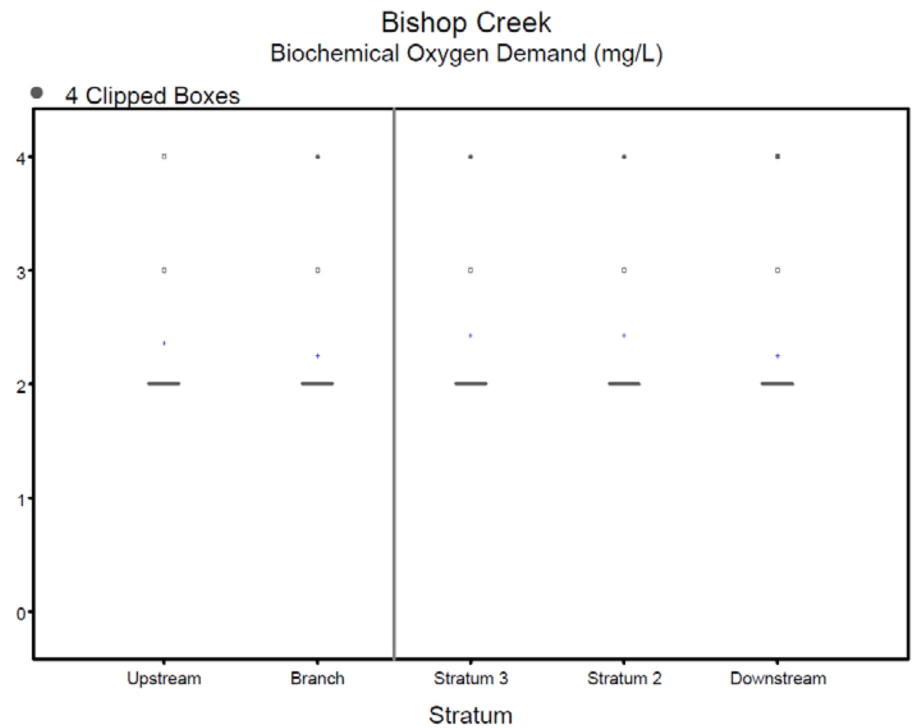
Figure 24. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.6 Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. It is typically most useful to assess the efficiency of wastewater treatment but is also applied by EPA and FDEP in the estimation of Total Maximum Daily Loads (TMDLs) for waterbodies including tidal creeks. BOD samples were very near the detection limit of 2 mg/l in all samples (Table 12) and there was little longitudinal or temporal variation across the study period (Figures 25 and 26). There were no significant differences either among strata within a creek or between creeks.

Table 12. Descriptive statistics for the analyte Biochemical Oxygen Demand in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Biochemical Oxygen Demand	Bishop	1	28	2.250	2.000	0.701	31.100	2.181
MDL =2 mg/l	Mullet	1	28	2.607	2.000	1.474	56.500	2.376
	Bishop	2	28	2.464	2.000	1.453	58.900	2.262
	Mullet	2	28	2.250	2.000	0.701	31.100	2.181
	Bishop	3	28	2.429	2.000	1.069	44.000	2.292
	Mullet	3	28	2.036	2.000	0.189	9.300	2.029
	Bishop	91	12	2.333	2.000	0.888	38.000	2.233
	Mullet	91	15	2.267	2.000	0.799	35.200	2.184
	Bishop	92	14	2.357	2.000	0.745	31.600	2.273
	Mullet	95	14	2.143	2.000	0.363	16.900	2.119
	Bishop	94	14	2.357	2.000	0.842	35.700	2.263
	Bishop	95	14	2.143	2.000	0.363	16.900	2.119



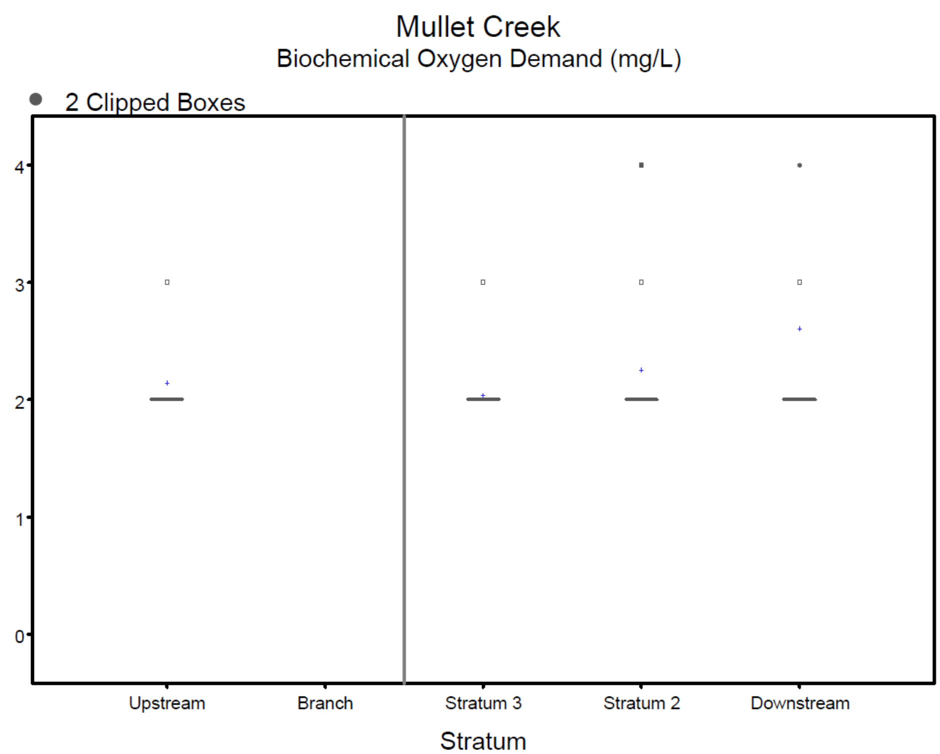
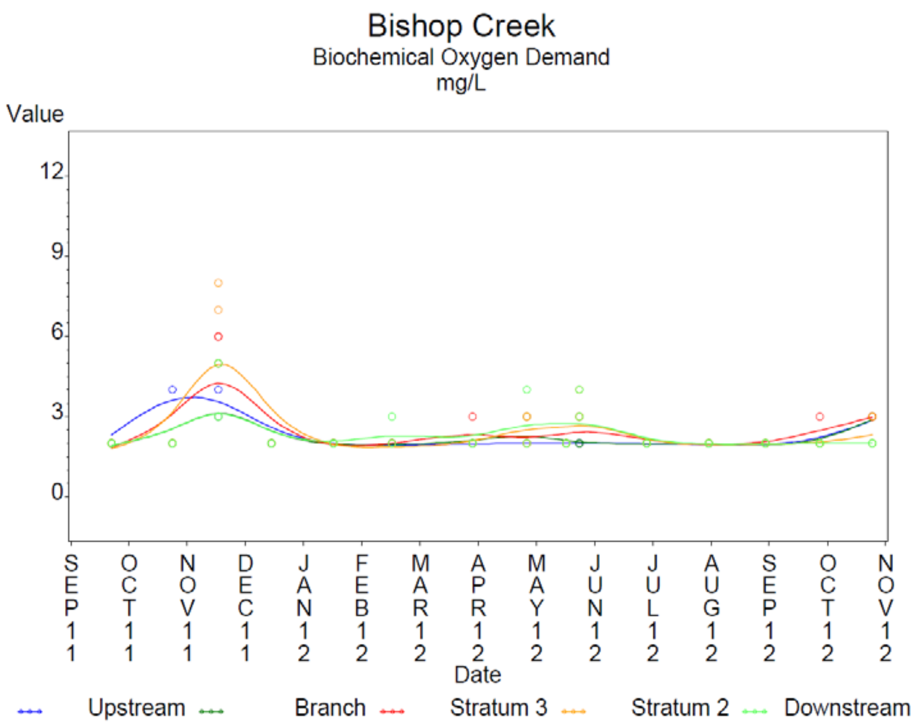


Figure 25. Box and whisker plots for Biochemical Oxygen Demand in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



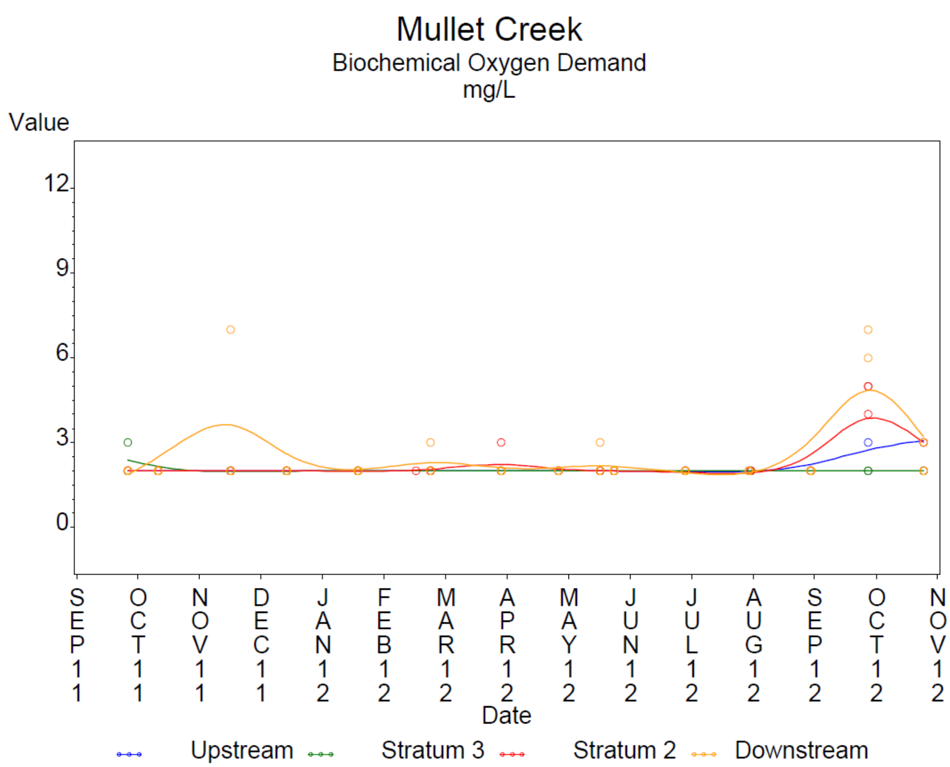


Figure 26. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.7 Dissolved Oxygen:

Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in the water and available for consumption by aquatic animals. The EPA and FDEP use dissolved oxygen as a response indicator of nutrient pollution. Previously, the FDEP assumed that if greater than 10% of measured DO values collected in a year were below 4 mg/l the system was impaired. The FDEP has since revised that criterion and intends to express the criterion values as percent saturation with 42.0% being the threshold value for estuarine water bodies. Despite average concentrations near or above 5 mg/l in all strata (Table 13) both Bishop and Mullet Creek would likely fail either the existing or the proposed criteria with respect to DO based on data collected as part of this study with exceedance rates between 30% and 40% for both metrics. There were no significant differences among strata within either creek but Bishop Creek had significantly higher DO concentrations and percent saturation than Mullet Creek over the study period (Figure 27 -30). Timeseries plots indicate dynamic DO patterns that may or may not be related to phytoplankton production which is explored in later sections.

Table 13. Descriptive statistics for the analyte Dissolved Oxygen (DO) concentration (mg/l) and percent saturation in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
DO (mg/l)	Bishop	1	25	6.044	5.540	3.277	54.200	5.273
	Mullet	1	28	5.134	4.645	2.418	47.100	4.477
	Bishop	2	26	6.392	5.285	3.866	60.500	5.398
	Mullet	2	28	4.784	4.385	2.314	48.400	3.932
	Bishop	3	26	7.476	7.130	4.659	62.300	6.143
	Mullet	3	28	4.874	4.355	2.269	46.600	4.380
	Bishop	91	13	6.311	5.510	3.757	59.500	5.363
	Mullet	91	15	4.270	4.150	1.793	42.000	3.849
	Bishop	92	12	7.317	6.880	3.937	53.800	6.462
	Mullet	95	13	6.121	5.700	2.271	37.100	5.721
	Bishop	94	12	7.859	7.220	3.855	49.100	7.126
	Bishop	95	12	8.622	8.350	3.565	41.300	7.948
DO (%)	Bishop	1	22	79.714	65.050	47.467	59.500	70.321
	Mullet	1	22	66.723	61.650	27.898	41.800	60.060
	Bishop	2	22	79.095	70.250	54.340	68.700	66.998
	Mullet	2	22	58.351	52.650	25.241	43.300	49.212
	Bishop	3	22	93.673	84.550	68.769	73.400	75.619
	Mullet	3	22	58.200	52.850	22.385	38.500	53.990
	Bishop	91	10	77.800	64.950	58.412	75.100	64.041
	Mullet	91	12	52.517	52.350	18.523	35.300	48.928
	Bishop	92	11	83.409	79.700	45.489	54.500	73.599
	Mullet	95	11	99.855	66.300	94.266	94.400	80.657
	Bishop	94	10	101.820	90.900	54.445	53.500	92.976
	Bishop	95	10	107.419	93.800	49.811	46.400	100.568

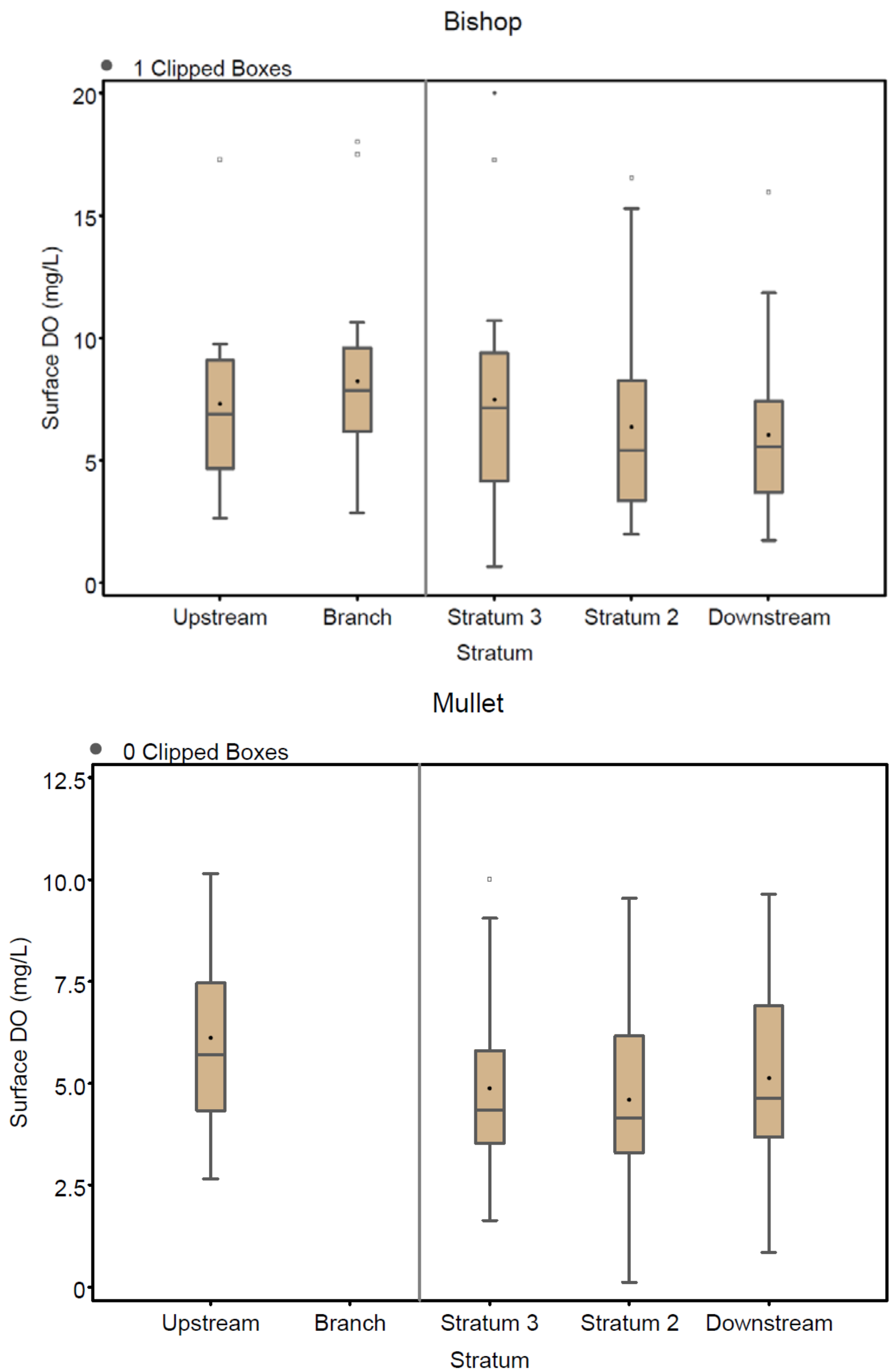
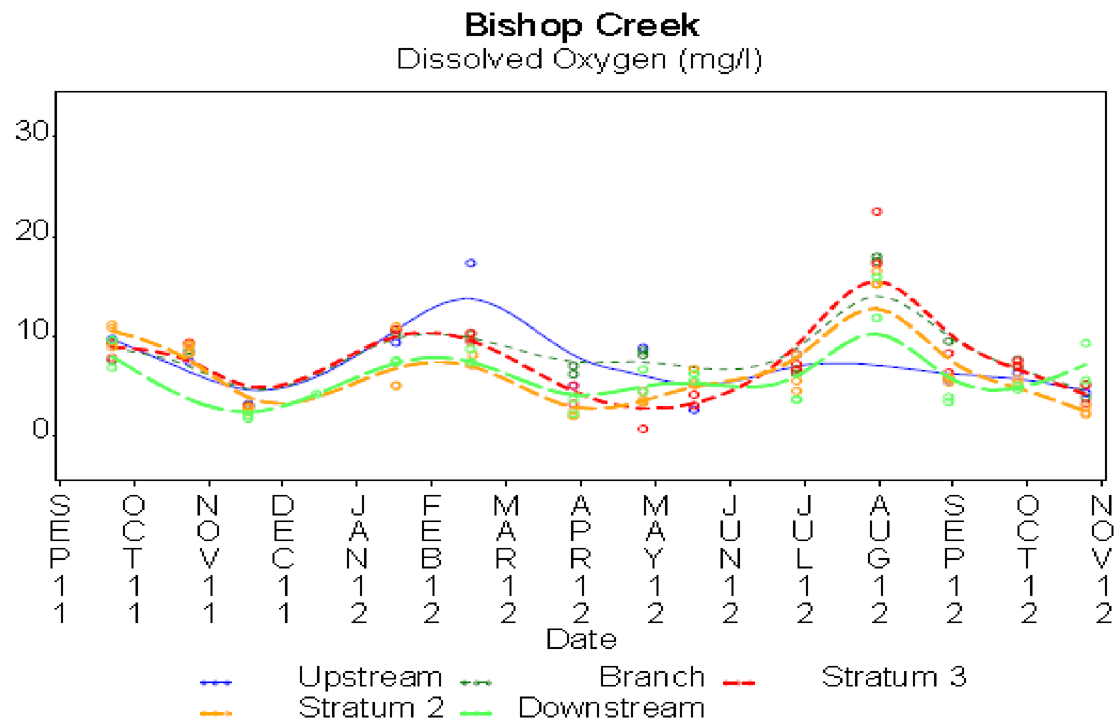


Figure 27. Box and whisker plots for Surface Dissolved Oxygen in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



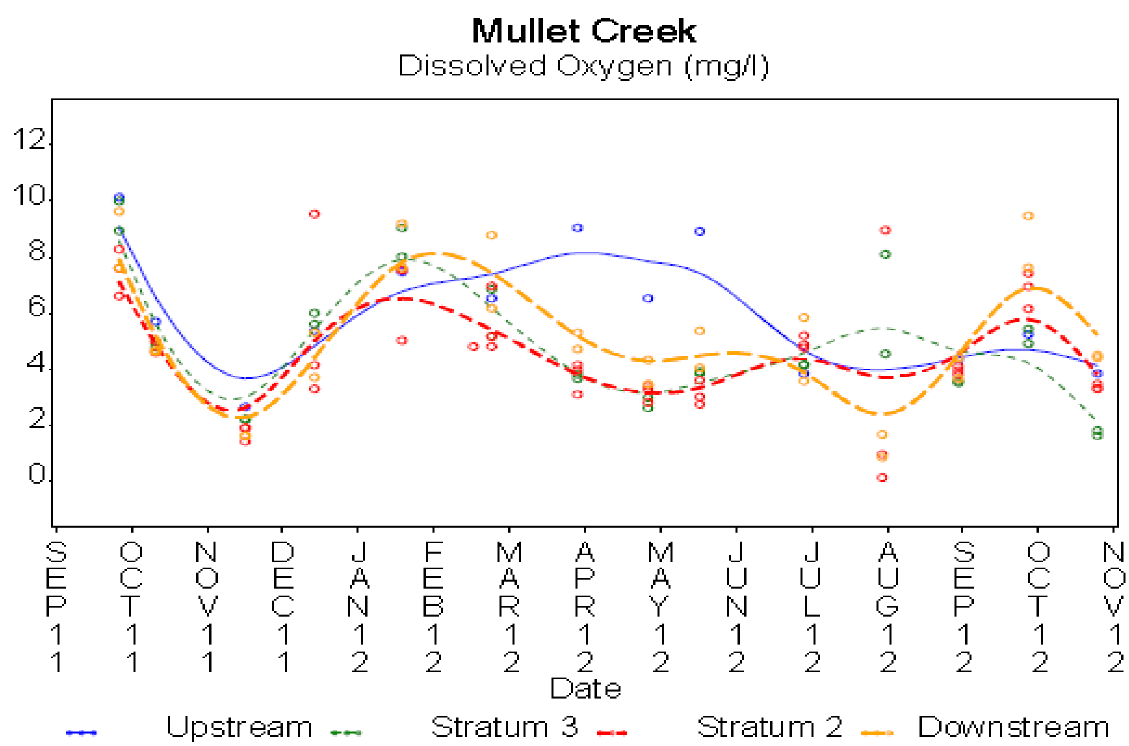
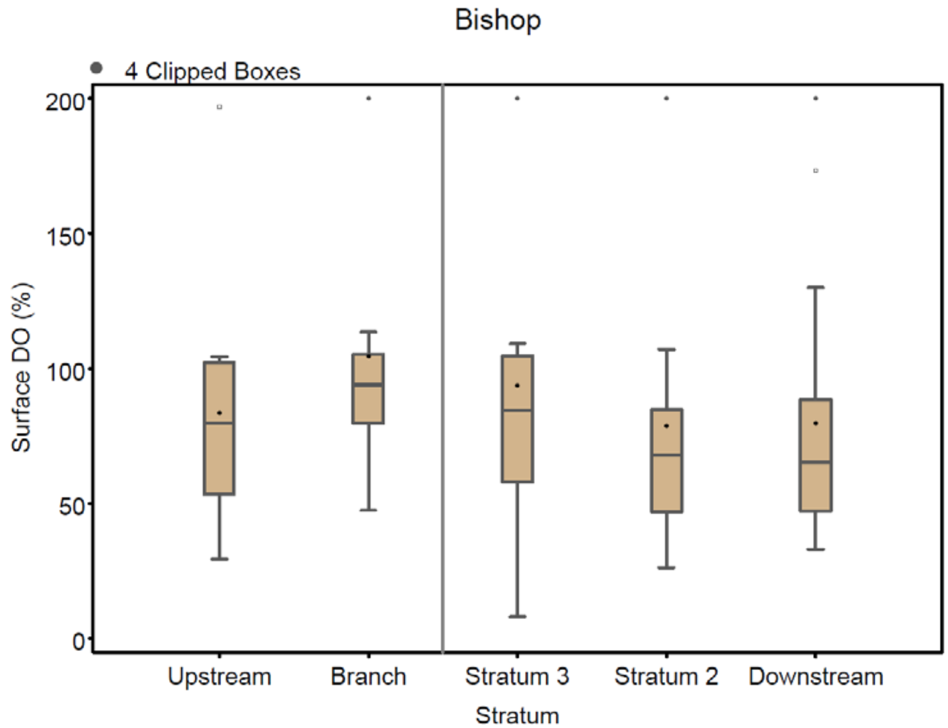


Figure 28. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).



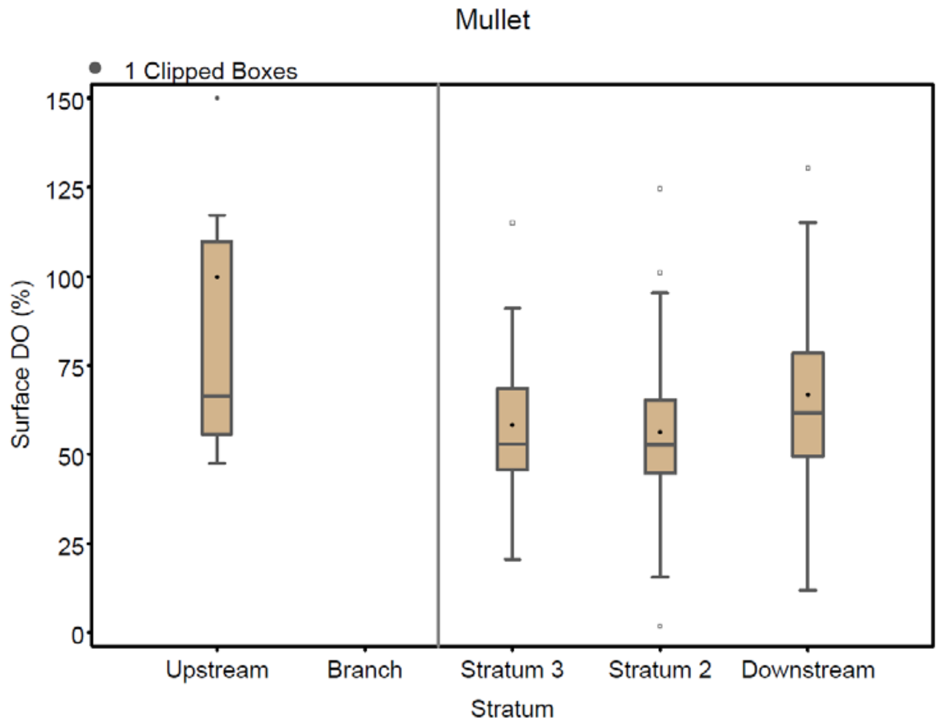
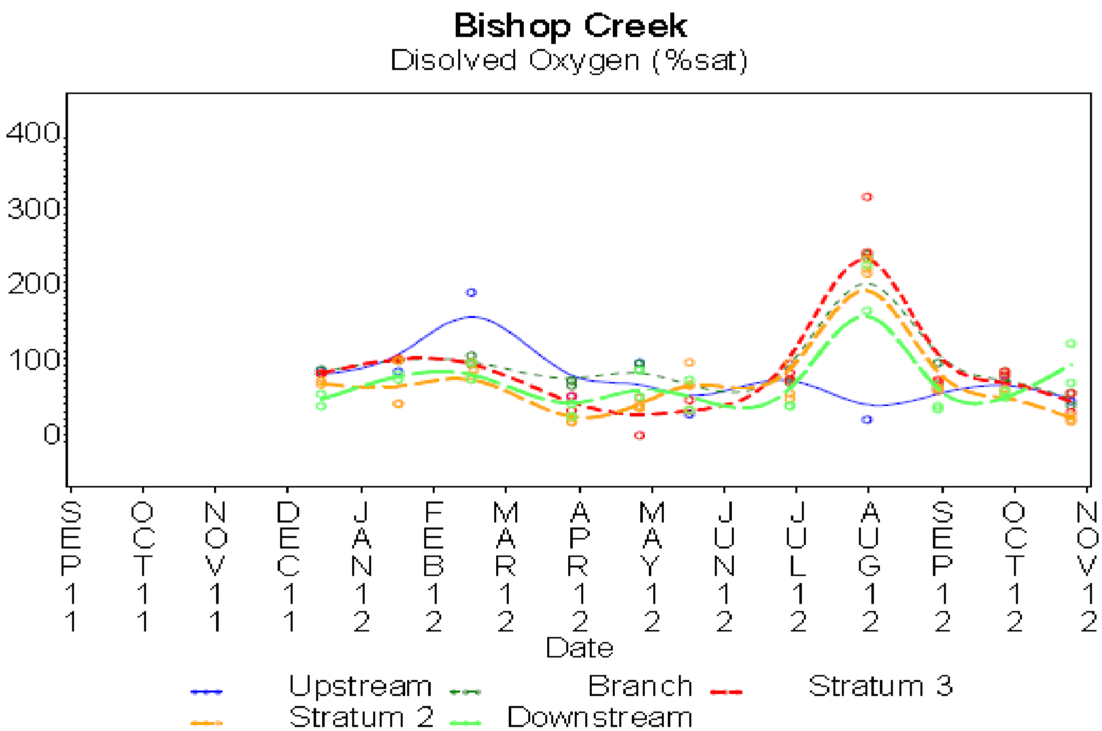


Figure 29. Box and whisker plots for Surface Dissolved Oxygen (%) in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



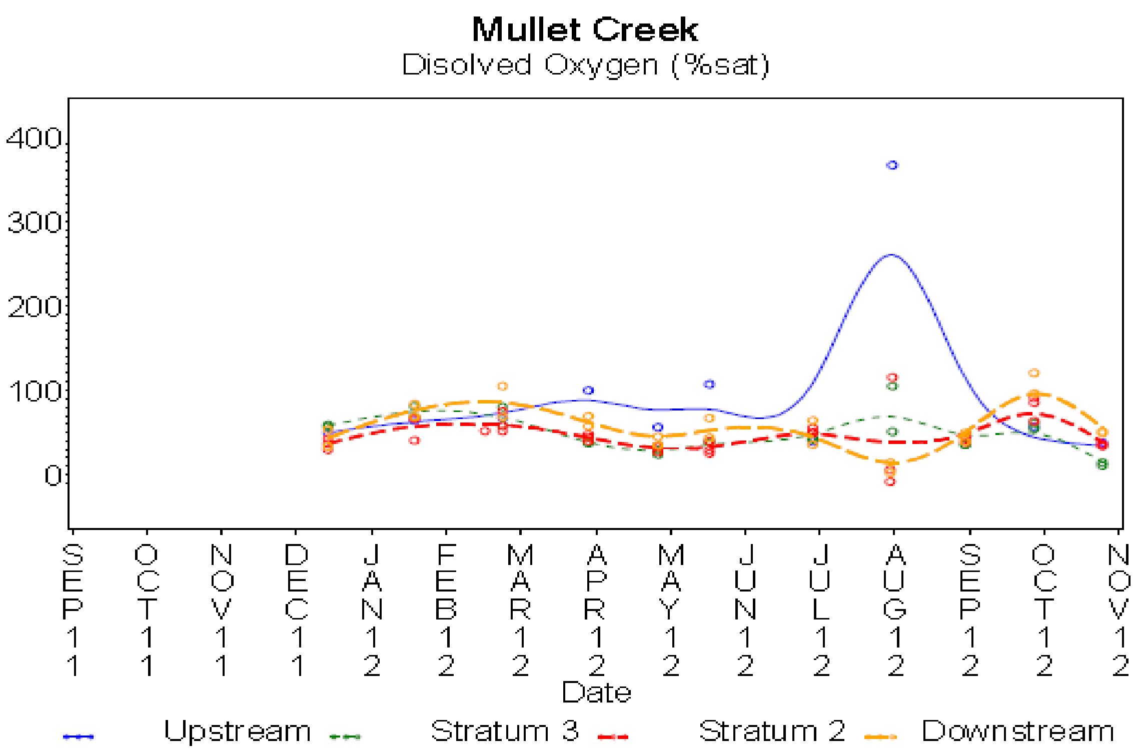


Figure 30. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.8 Total Organic Carbon

Total Organic Carbon (TOC) is derived primarily from decaying vegetation and bacterial growth and is an important measure used in drinking water standards. Total Organic Carbon is an important measure used in water quality modeling but is typically not used as a regulatory surface water quality standard in Florida. The TOC concentrations collected during the study period were typically around 10 mg/l with a very small coefficient of variation (Table 14) indicating little variation in concentration over the study period. There were no significant differences either among strata within creeks or between creeks (Figure 31). Timeseries plots (Figure 32) indicate that dry season concentrations tended to be lower than wet season concentrations which were expected given that the wet season correlates with growing season for riparian vegetation and emergent wetland plants in these creeks.

Table 14. Descriptive statistics for the analyte Total Organic Carbon in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Total Organic Carbon	Bishop	1	28	11.411	12.000	3.335	29.200	10.937
MDL =0.5 mg/L	Mullet	1	28	12.046	11.500	3.864	32.100	11.445
	Bishop	2	28	11.971	12.000	3.909	32.700	11.400
	Mullet	2	28	12.707	13.000	4.341	34.200	12.018
	Bishop	3	28	11.064	12.000	2.986	27.000	10.627
	Mullet	3	28	13.204	14.000	3.882	29.400	12.653
	Bishop	91	12	11.225	12.000	2.728	24.300	10.901
	Mullet	91	15	12.513	12.000	4.399	35.200	11.831
	Bishop	92	14	11.229	11.500	2.980	26.500	10.858
	Mullet	95	14	14.186	14.000	2.934	20.700	13.905
	Bishop	94	14	10.693	11.500	2.622	24.500	10.370
	Bishop	95	14	10.836	12.000	3.265	30.100	10.304

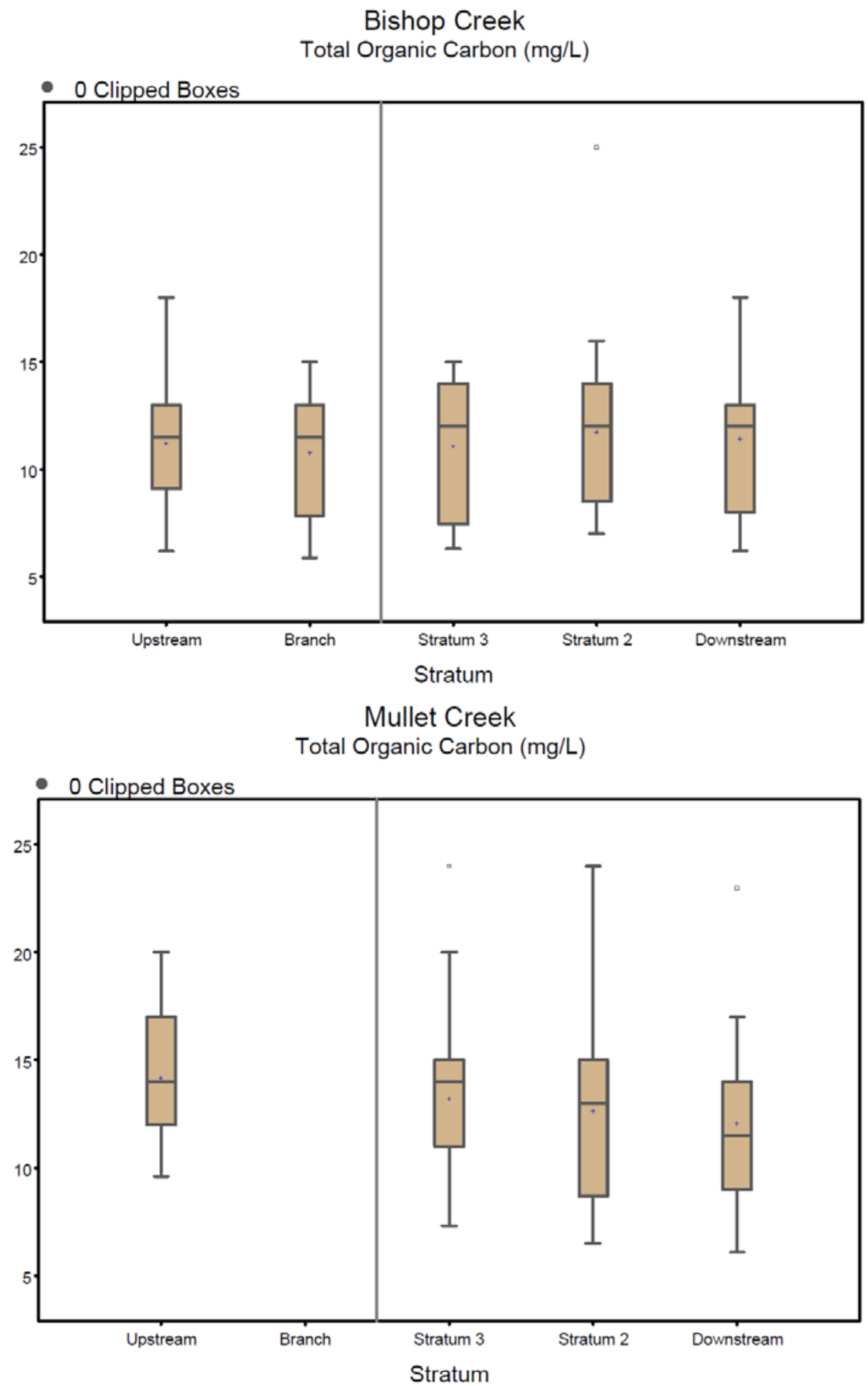
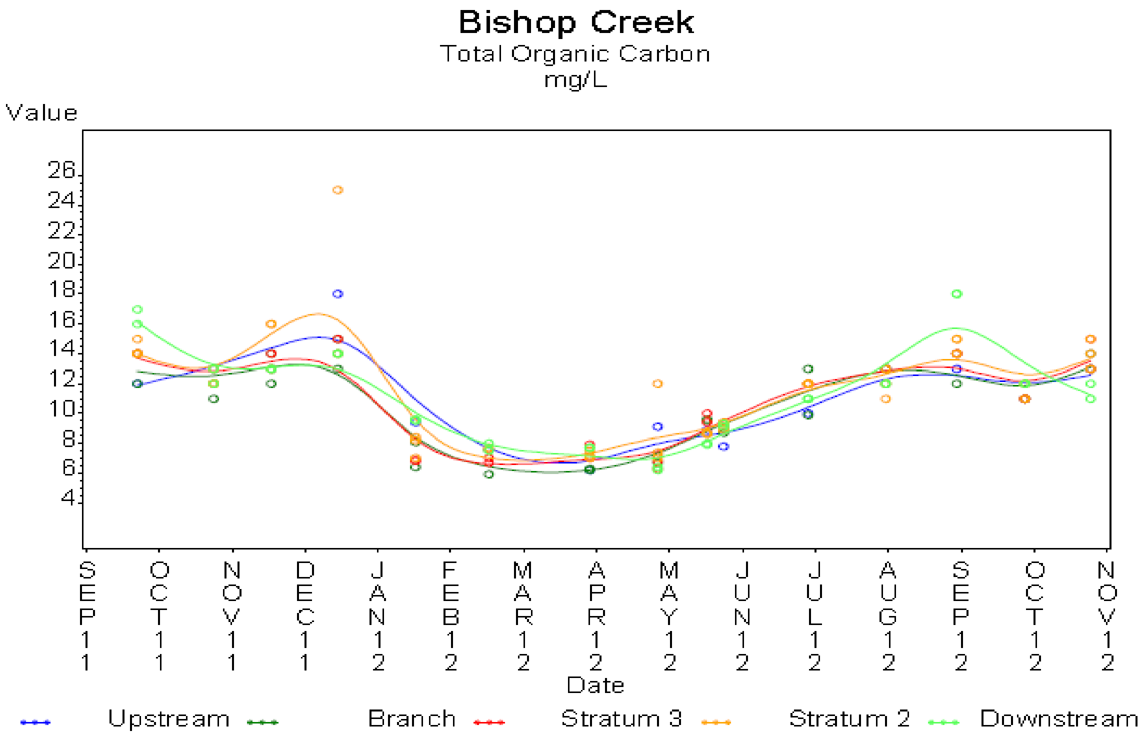


Figure 31. Box and whisker plots for Total Organic Carbon in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5^{th} and 95^{th} percentile values.



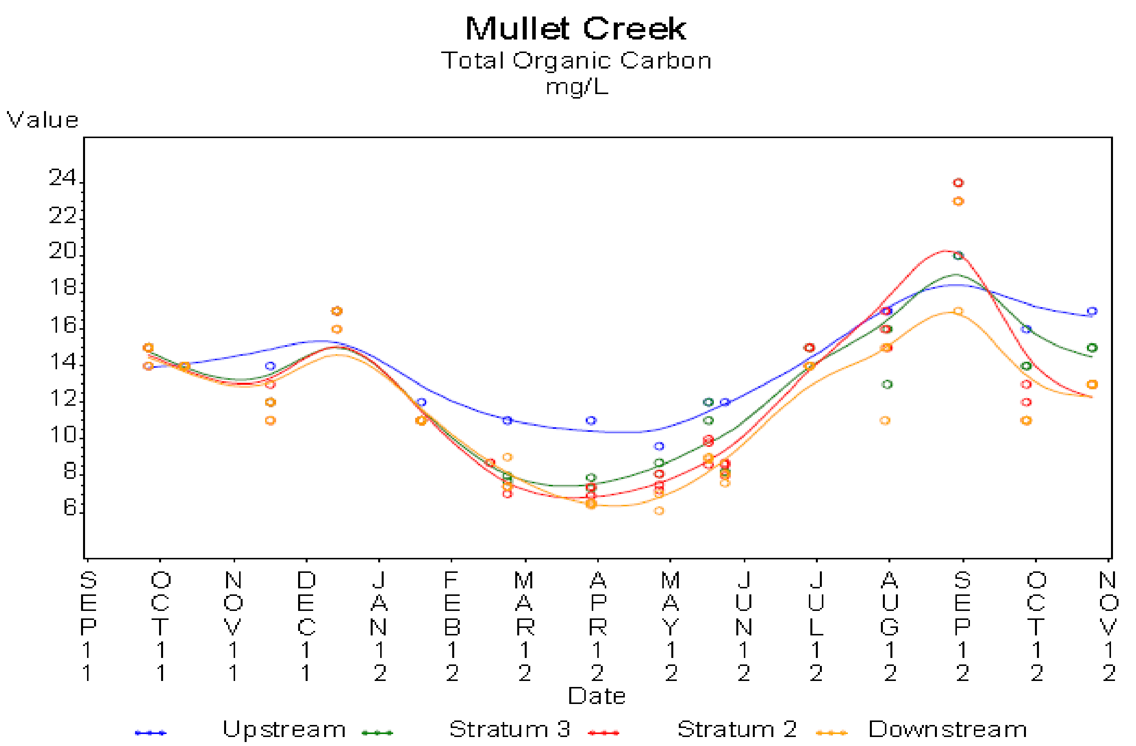


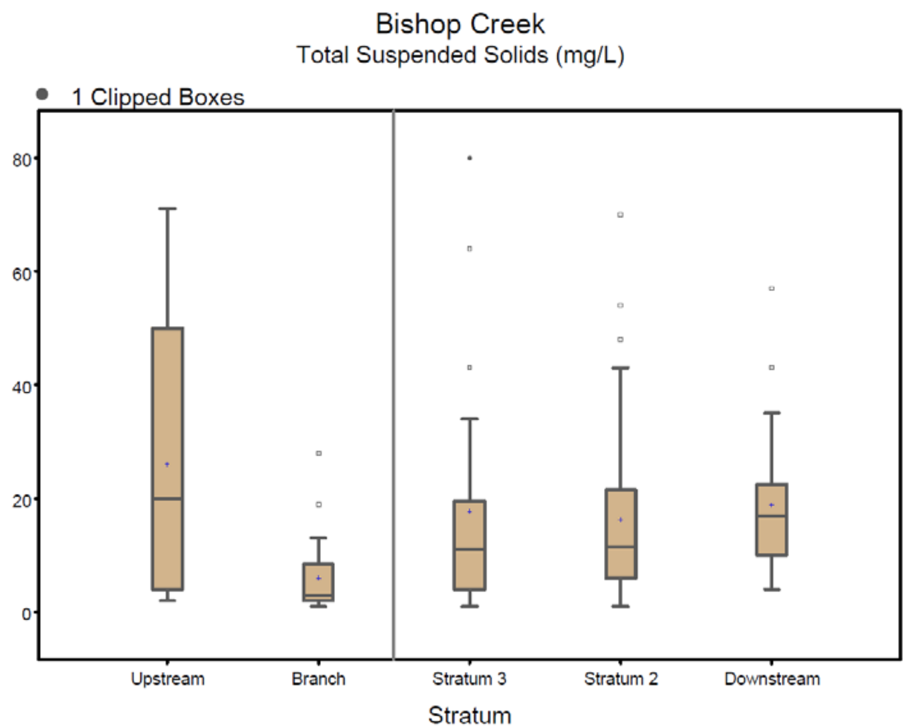
Figure 32. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.9 Total Suspended Solids

Total suspended solids (TSS) is a measure of the dry-weight of particles in a sample trapped by a filter and can be of organic or inorganic origin. High TSS can reduce the amount of light passing through the water, effecting water column and benthic photosynthesis. Descriptive statistics for TSS are provided in Table 15. There were significant differences between creeks with higher TSS in Bishop Creek. Bishop Creek also had significantly different TSS distributions across strata due principally to the higher values observed at the most upstream station on the north branch of Bishop Creek (Figure 33). Interestingly, TSS concentrations tended to be lower during the wet season than in the dry season (Figure 34).

Table 15. Descriptive statistics for the analyte Total Suspended Solids in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Total Suspended Solids	Bishop	1	28	18.821	17.000	11.776	62.600	15.727
MDL =1 mg/L	Mullet	1	28	10.286	5.500	11.816	114.900	6.795
	Bishop	2	28	13.036	9.500	10.627	81.500	8.852
	Mullet	2	28	6.964	4.000	5.872	84.300	4.791
	Bishop	3	28	17.750	11.000	24.119	135.900	8.944
	Mullet	3	28	8.286	4.500	10.205	123.200	4.581
	Bishop	91	12	23.833	15.500	21.595	90.600	16.514
	Mullet	91	15	10.600	10.000	8.667	81.800	6.853
	Bishop	92	14	26.000	20.000	24.061	92.500	14.621
	Mullet	95	14	9.143	4.500	9.281	101.500	5.876
	Bishop	94	14	6.786	3.000	7.954	117.200	4.137
	Bishop	95	14	5.214	4.000	4.509	86.500	3.437



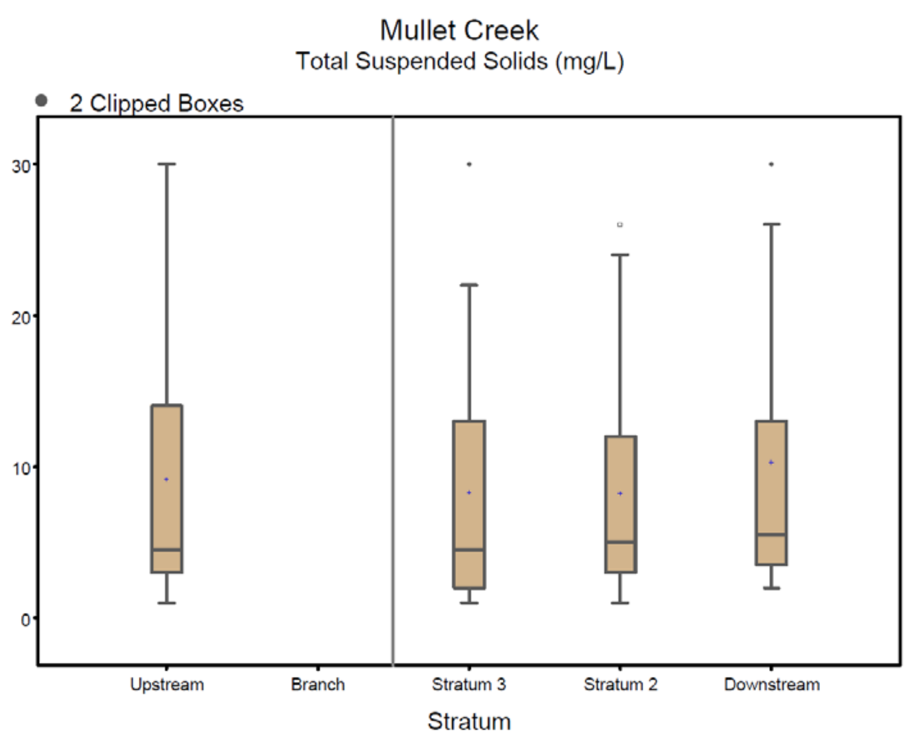


Figure 33. Box and whisker plots for Total Suspended Solids in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.

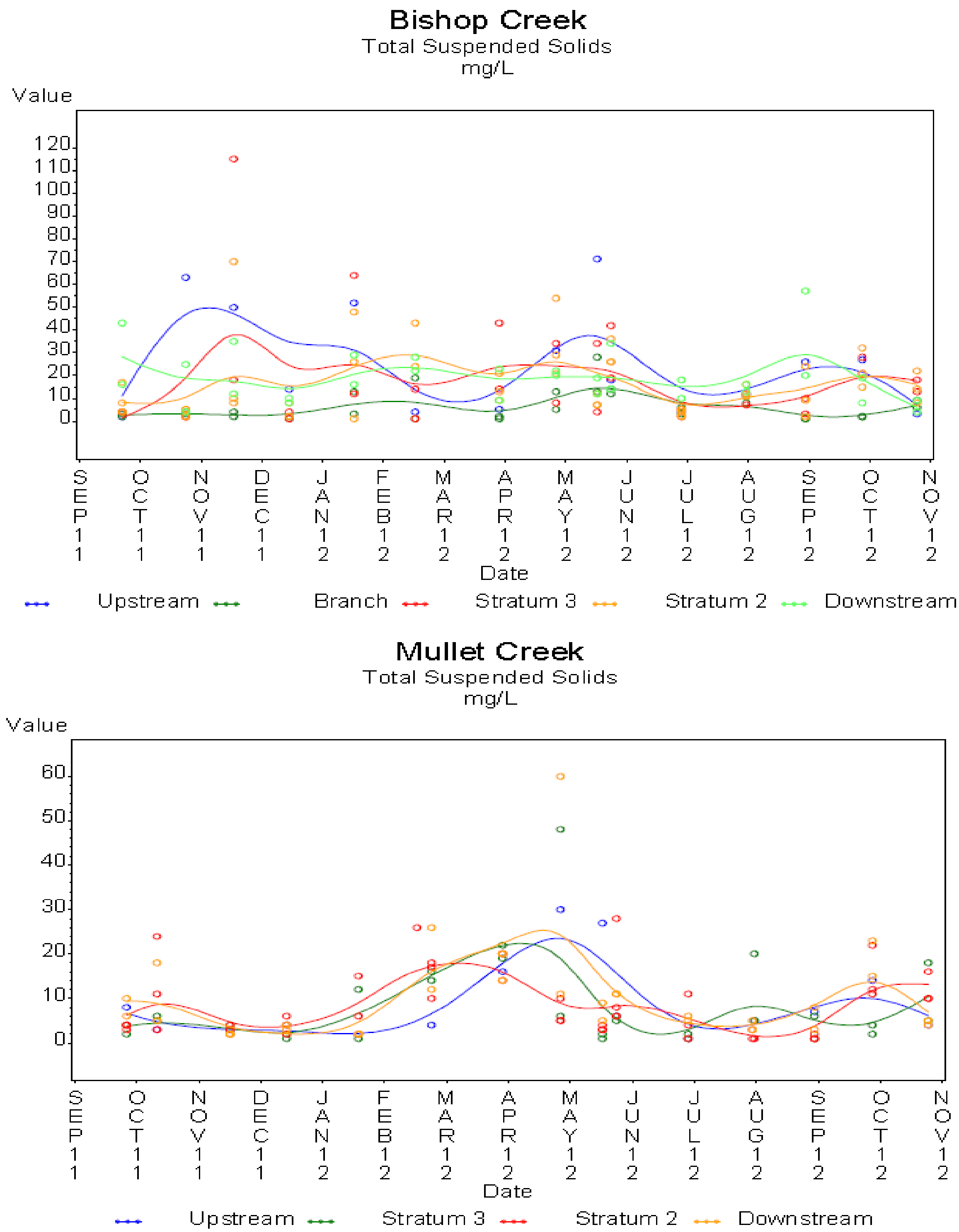


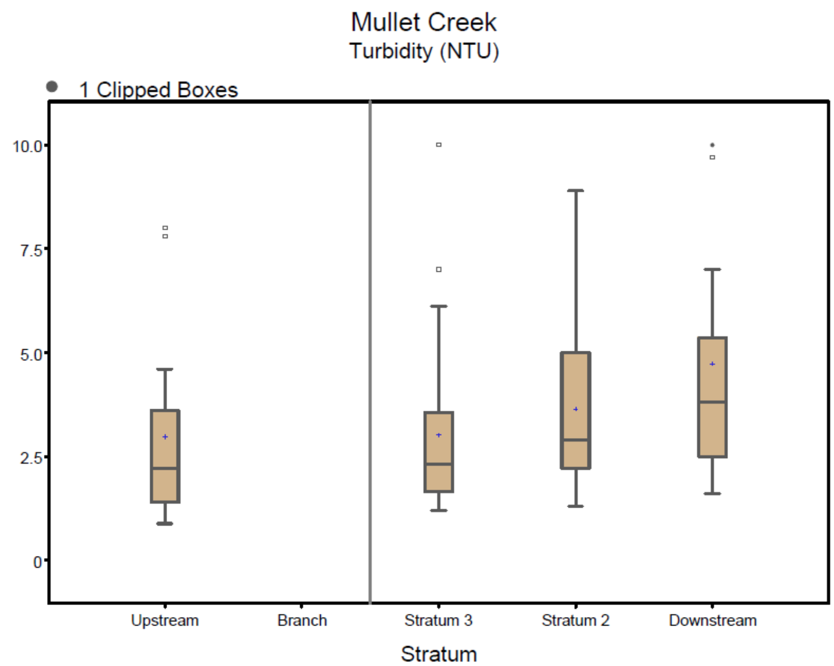
Figure 34. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.10 Turbidity

Turbidity measures the cloudiness or haziness of the water sample and is therefore also a measure of water clarity, similar to TSS. However, turbidity is measured by passing light through the sample and evaluating the amount of that light scattered by the particles. Turbidity was measured in situ at the time of sampling as well as in the lab. The values reported here are based on laboratory data. Descriptive statistics for turbidity are provided in Table 16. There were significant differences in turbidity values between creeks with Bishop Creek significantly higher than Mullet Creek, principally due again to the most upstream fixed station in Bishop Creek. Bishop Creek also had significant differences among strata within the creek (Figure 35). Examination of timeseries plots (Figure 36) suggest that the highest turbidity values tended to occur in the Fall of 2012 in Bishop Creek, but were more consistent throughout the year in Mullet Creek (Figure 36).

Table 16. Descriptive statistics for the analyte Turbidity in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Turbidity	Bishop	1	28	7.257	7.000	3.306	45.600	6.757
	Mullet	1	28	4.725	3.800	4.045	85.600	3.910
	Bishop	2	28	6.479	5.400	4.502	69.500	5.292
	Mullet	2	28	3.504	2.850	1.828	52.200	3.118
	Bishop	3	28	5.475	3.250	6.690	122.200	3.737
	Mullet	3	28	3.018	2.300	2.064	68.400	2.546
	Bishop	91	12	8.333	5.750	5.775	69.300	6.667
	Mullet	91	15	3.887	3.300	1.998	51.400	3.407
	Bishop	92	14	6.393	4.650	4.569	71.500	5.414
	Mullet	95	14	3.657	3.200	1.288	35.200	3.475
	Bishop	94	14	4.608	2.100	9.096	197.400	2.410
	Bishop	95	14	2.963	2.200	2.307	77.900	2.366



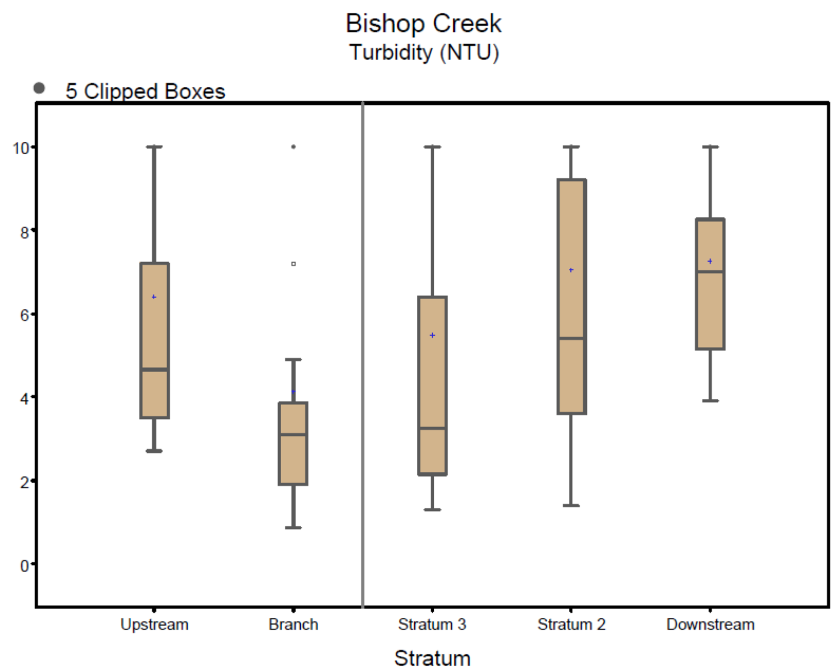
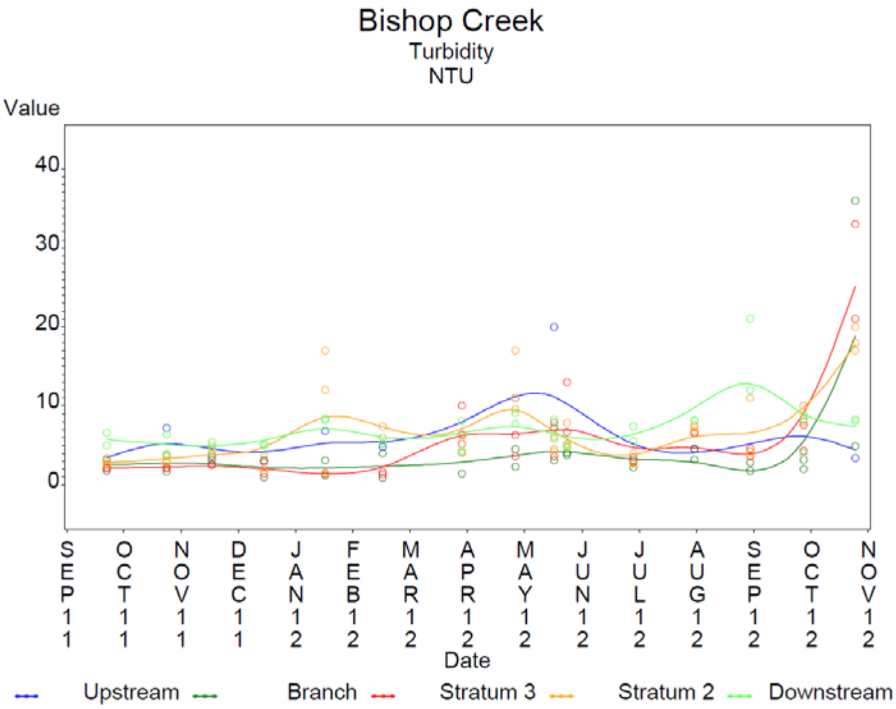


Figure 35. Box and whisker plots for Surface Turbidity in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



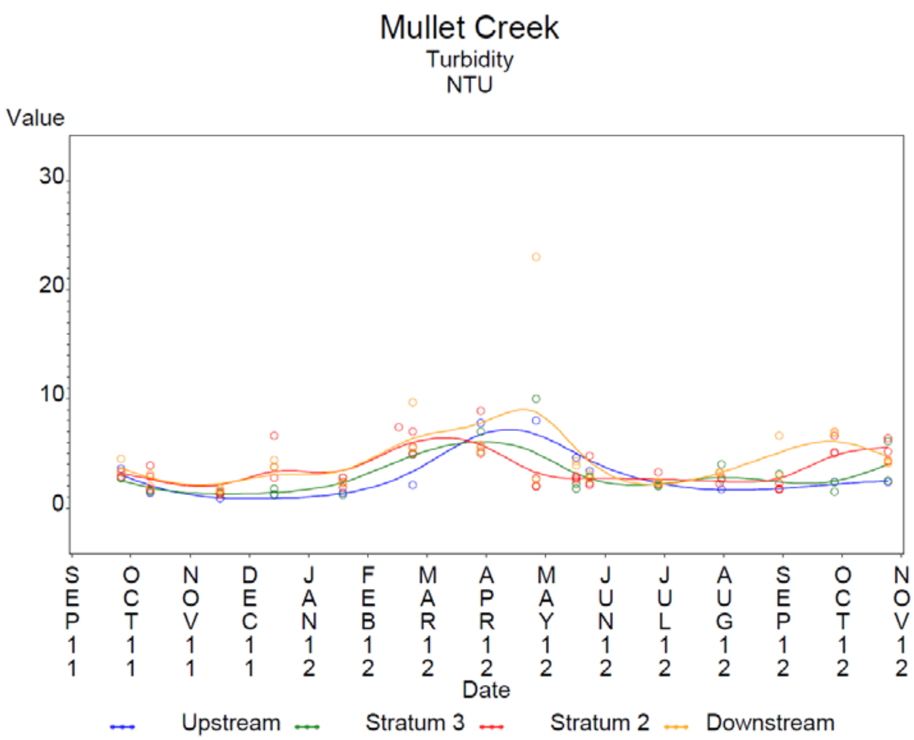


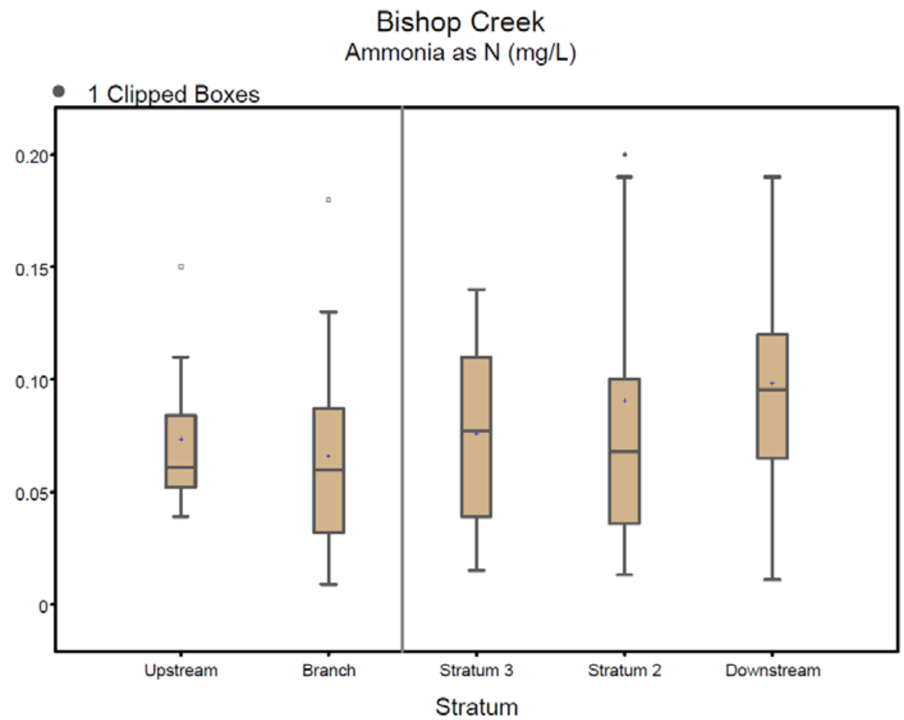
Figure 36. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.11 Ammonia

Ammonia is an inorganic component of total nitrogen that, along with nitrate and nitrite, and organic nitrogen together forms total nitrogen. Ammonia is readily taken up by plant material and is excreted by animals. Descriptive statistics for ammonia are provided in Table 17. There were no significant differences in ammonia between creeks though in Mullet Creek among strata differences were significant. This is principally due to lower values in the upstream fixed station site in Mullet Creek than in the remaining strata sampled using the probabilistic design (Figure 37). Examination of timeseries plots (Figure 38) suggest dynamic differences among strata in both creeks as a function of time indicating that ammonia may be an important indicator of biological processes in these creeks.

Table 17. Descriptive statistics for the analyte Ammonia (NH3) in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	median	Standard Deviation	Coefficient of Variation	Geometric Average
Ammonia as N	Bishop	1	14	0.098	0.096	0.047	47.600	0.084
MDL =0.01 mg/L	Mullet	1	13	0.066	0.062	0.033	50.100	0.055
	Bishop	2	14	0.101	0.068	0.112	110.900	0.064
	Mullet	2	14	0.060	0.065	0.020	33.500	0.055
	Bishop	3	8	0.076	0.077	0.043	56.600	0.062
	Mullet	3	9	0.073	0.073	0.041	56.200	0.058
	Bishop	Fixed 91	11	0.078	0.071	0.050	63.700	0.063
	Mullet	Fixed 91	14	0.066	0.069	0.026	40.000	0.059
	Bishop	Fixed 92	13	0.073	0.061	0.032	43.500	0.068
	Bishop	Fixed 95	13	0.041	0.032	0.029	70.900	0.031
	Bishop	Fixed 94	13	0.091	0.082	0.040	43.600	0.083
	Mullet	Fixed 95	13	0.038	0.043	0.025	66.800	0.030



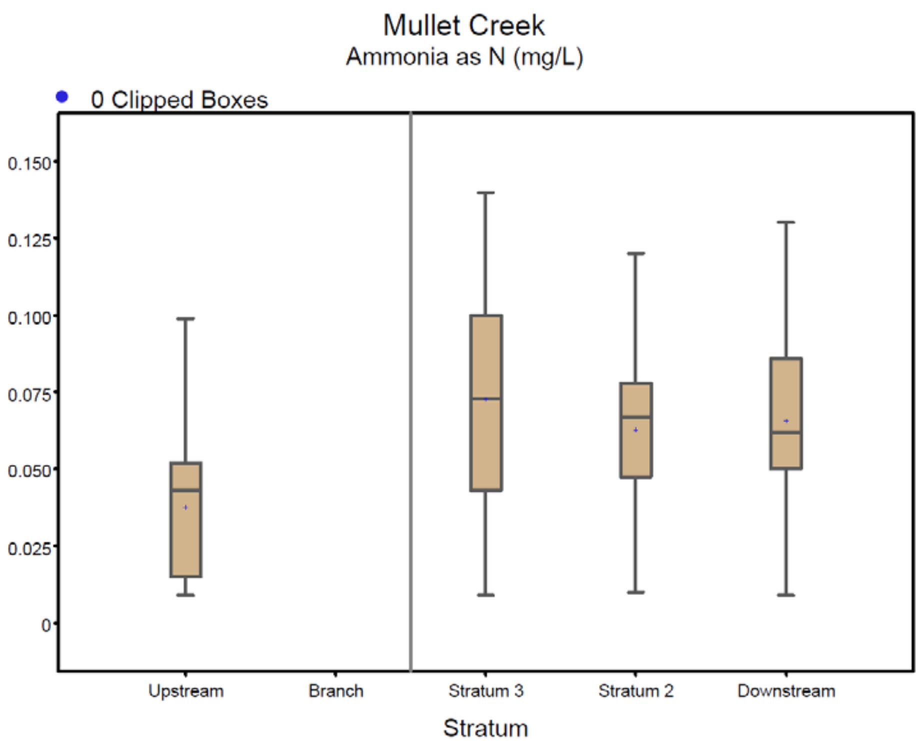
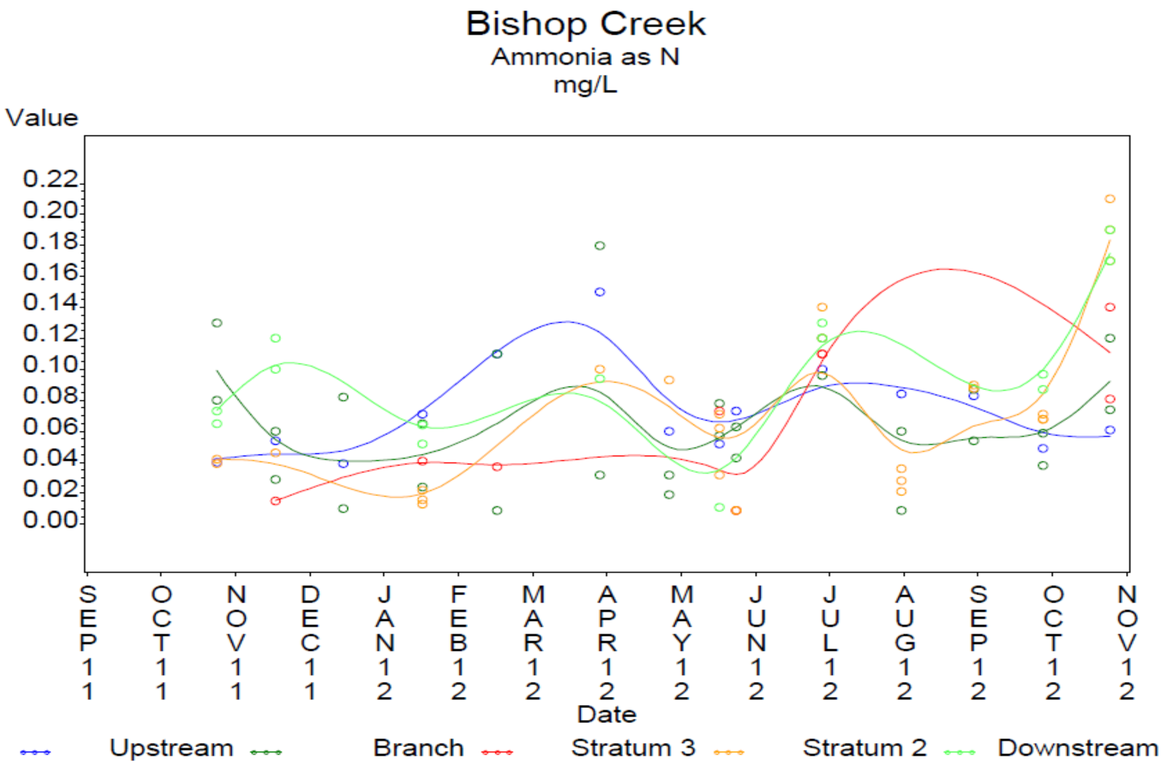


Figure 37. Box and whisker plots for Ammonia in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



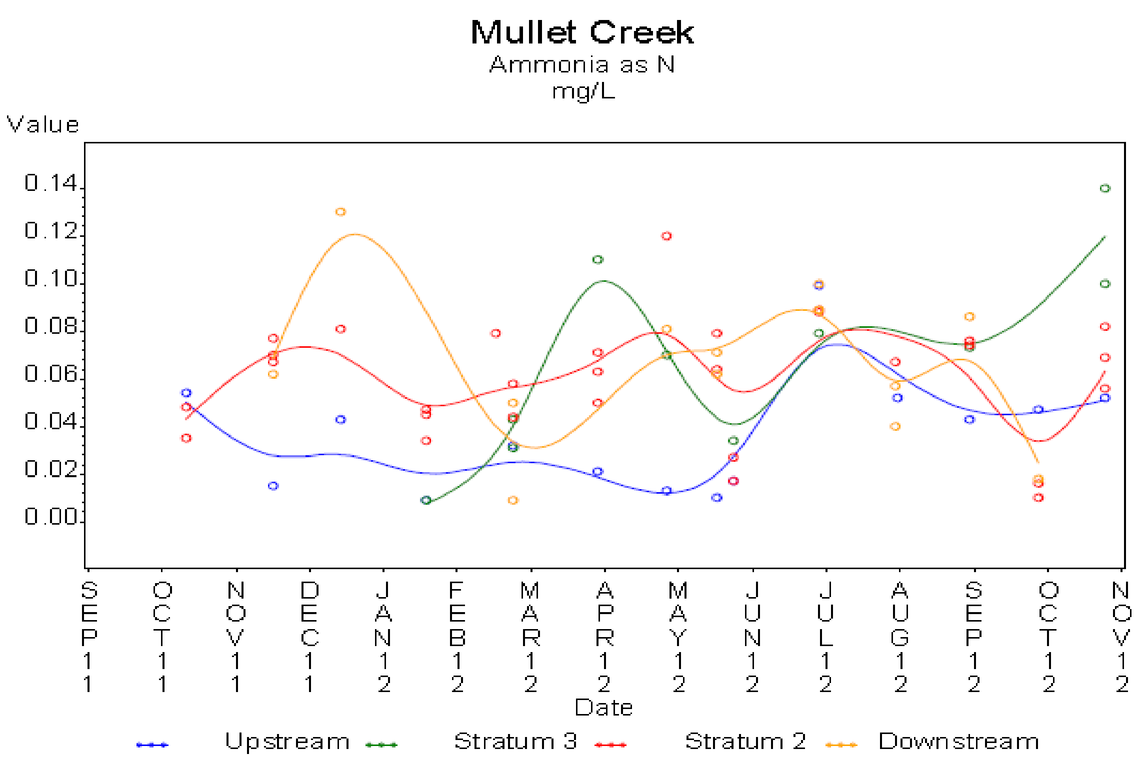


Figure 38. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.12 Nitrate+Nitrite

Nitrate and nitrite (NOx) are inorganic forms of nitrogen that when combined with organic nitrogen and ammonia result in total nitrogen. Inorganic nitrogen is readily taken up by plants and therefore is important in limiting primary production in aquatic systems. Descriptive statistics for NOx are provided in Table 18. There were no significant differences in NOx between creeks though in Bishop Creek among strata differences were significant (Figure 39). This is principally due to lower values in the most downstream strata Bishop Creek though in both creeks the most upstream stations tended to be higher than samples collected downstream. Examination of timeseries plots (Figure 40) suggest a strong relationship with flow as NOx is depleted during the dry season and increases during the wet season.

Table 18. Descriptive statistics for the analyte Nitrate + Nitrite in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Nitrate+ Nitrite (N)	Bishop	1	28	0.062	0.035	0.062	99.000	0.037
MDL =0.01 Mg/L	Mullet	1	28	0.064	0.050	0.063	99.900	0.039
	Bishop	2	28	0.106	0.095	0.083	77.900	0.068
	Mullet	2	28	0.070	0.050	0.069	98.800	0.042
	Bishop	3	28	0.134	0.135	0.109	81.100	0.080
	Mullet	3	28	0.081	0.060	0.069	85.300	0.056
	Bishop	91	12	0.108	0.105	0.083	77.000	0.069
	Mullet	91	15	0.071	0.050	0.070	99.300	0.042
	Bishop	92	14	0.135	0.105	0.089	66.000	0.099
	Mullet	95	14	0.103	0.080	0.084	81.700	0.071
	Bishop	94	14	0.116	0.090	0.091	77.900	0.083
	Bishop	95	14	0.156	0.145	0.113	72.100	0.111

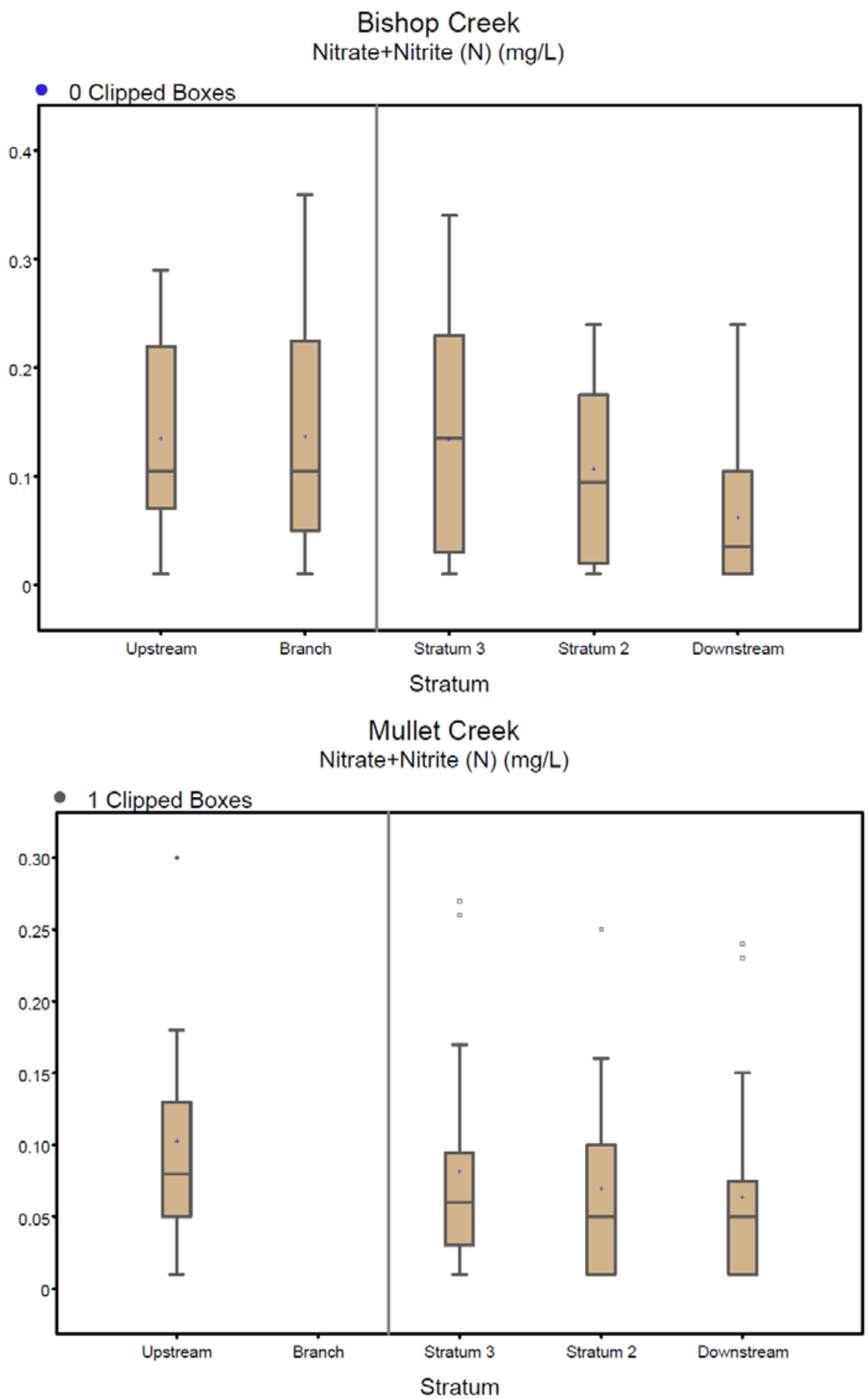
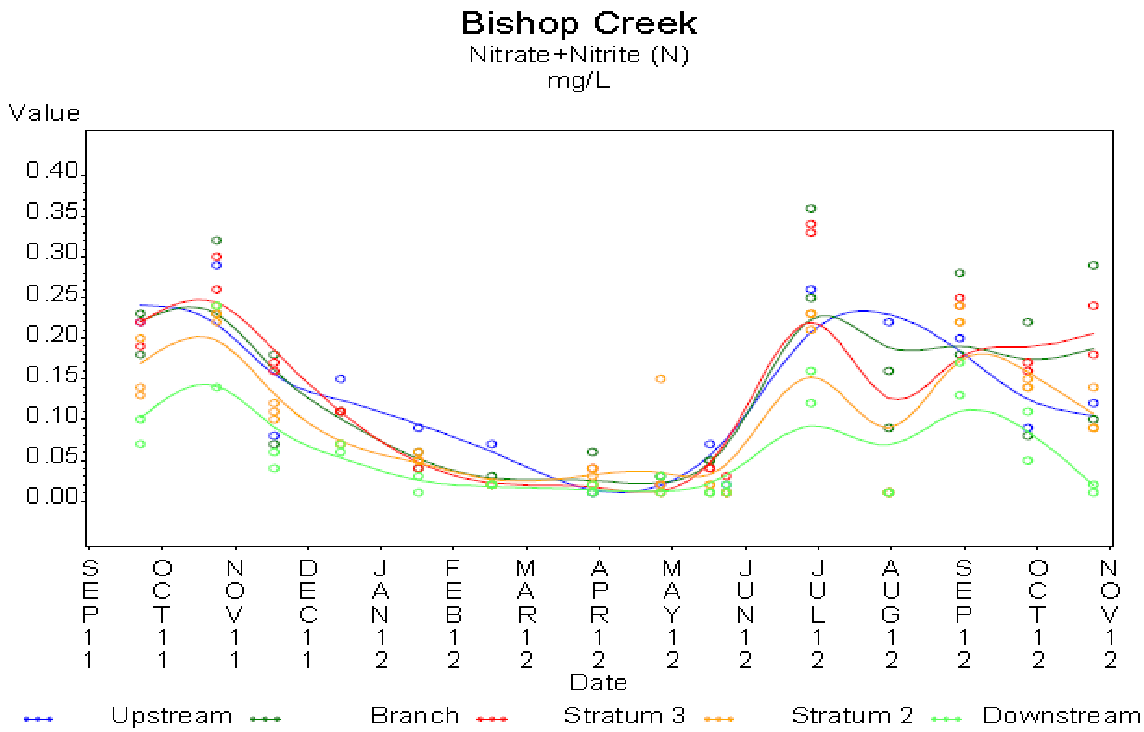


Figure 39. Box and whisker plots for Nitrates and Nitrites in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



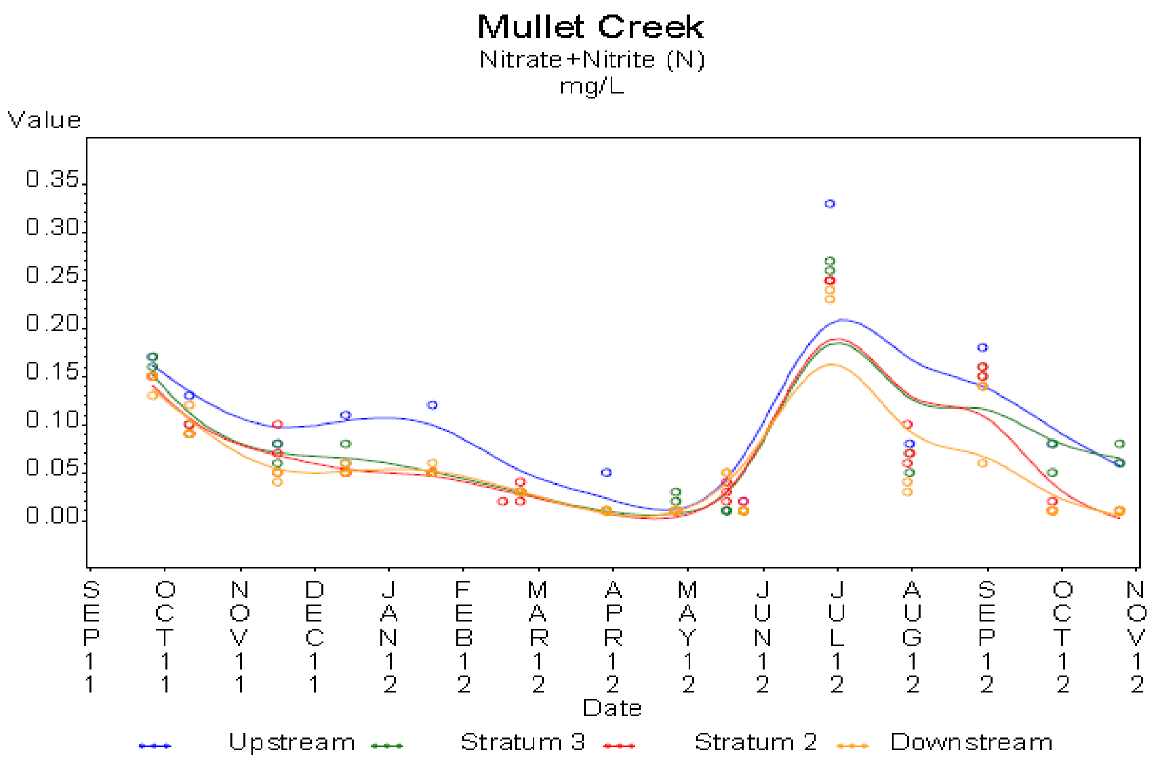


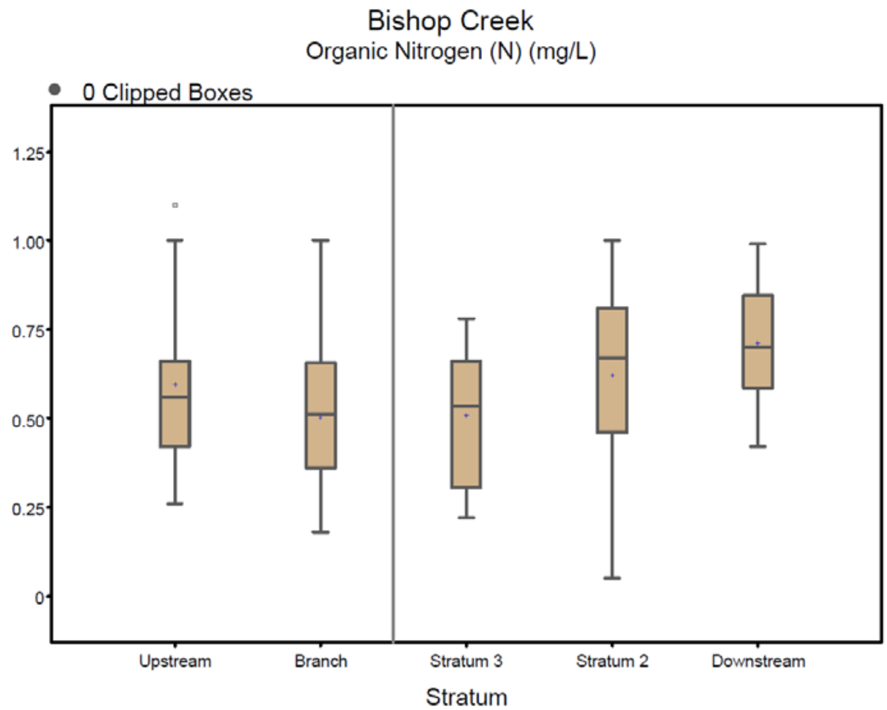
Figure 40. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.13 Organic Nitrogen

Organic nitrogen is a byproduct of living organisms and typically is the largest contributing component to total nitrogen. Descriptive statistics for organic nitrogen are provided in Table 19. There were no significant differences in organic nitrogen between creeks though in Bishop Creek among strata differences were significant (Figure 41). Organic nitrogen concentrations tended to increase in downstream strata in Bishop Creek, while in Mullet Creek concentrations were relatively constant across strata. Examination of timeseries plots (Figure 42) suggest that a similar temporal signal was observed across strata within each creek.

Table 19. Descriptive statistics for the analyte Organic Nitrogen in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Organic Nitrogen (N)	Bishop	1	28	0.711	0.700	0.158	22.300	0.693
MDL =0.05 mg/L	Mullet	1	28	0.726	0.735	0.219	30.200	0.695
	Bishop	2	28	0.608	0.650	0.227	37.400	0.542
	Mullet	2	28	0.668	0.680	0.186	27.900	0.643
	Bishop	3	28	0.507	0.535	0.190	37.500	0.468
	Mullet	3	28	0.673	0.660	0.180	26.700	0.647
	Bishop	91	11	0.653	0.670	0.232	35.500	0.609
	Mullet	91	14	0.787	0.735	0.286	36.300	0.745
	Bishop	92	14	0.594	0.560	0.234	39.400	0.554
	Mullet	95	14	0.738	0.720	0.275	37.200	0.688
	Bishop	94	14	0.546	0.570	0.209	38.300	0.505
	Bishop	95	14	0.457	0.460	0.182	39.700	0.419



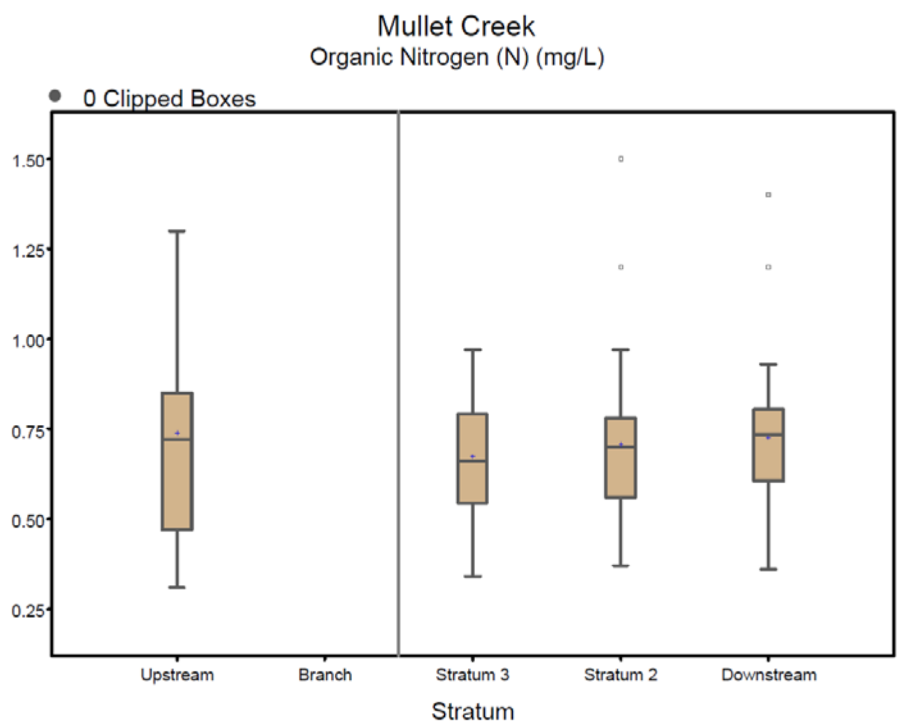
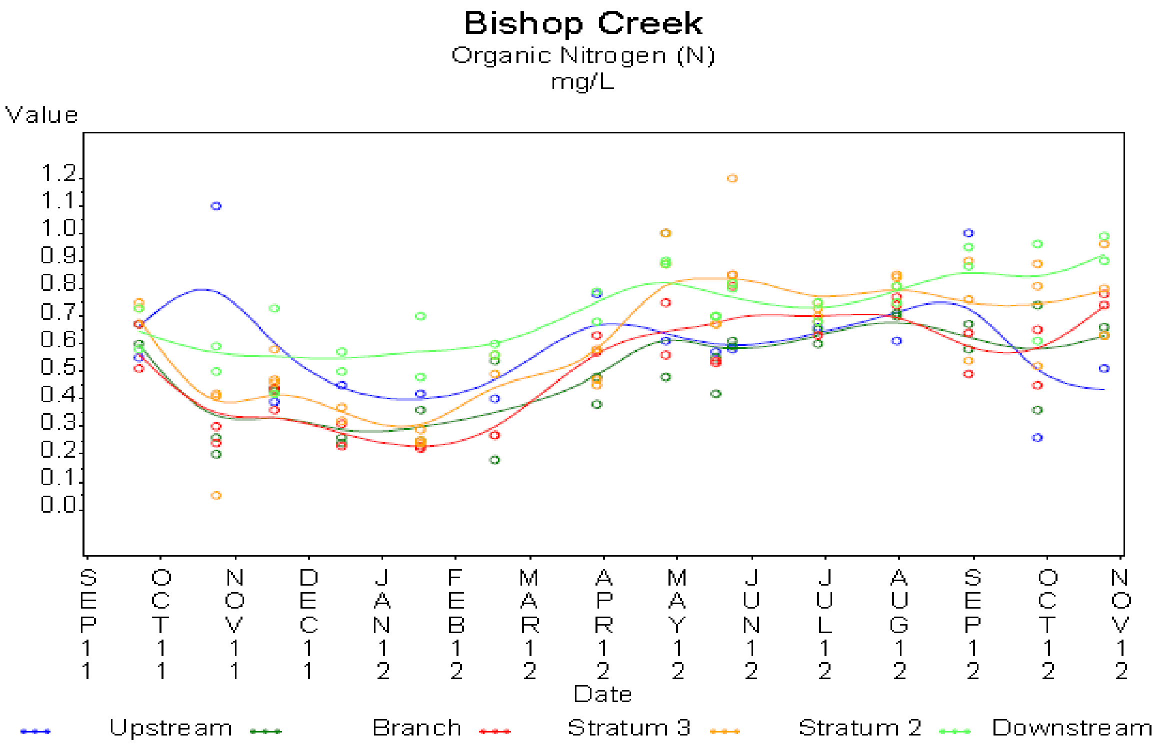


Figure 41. Box and whisker plots for Organic Nitrogen in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



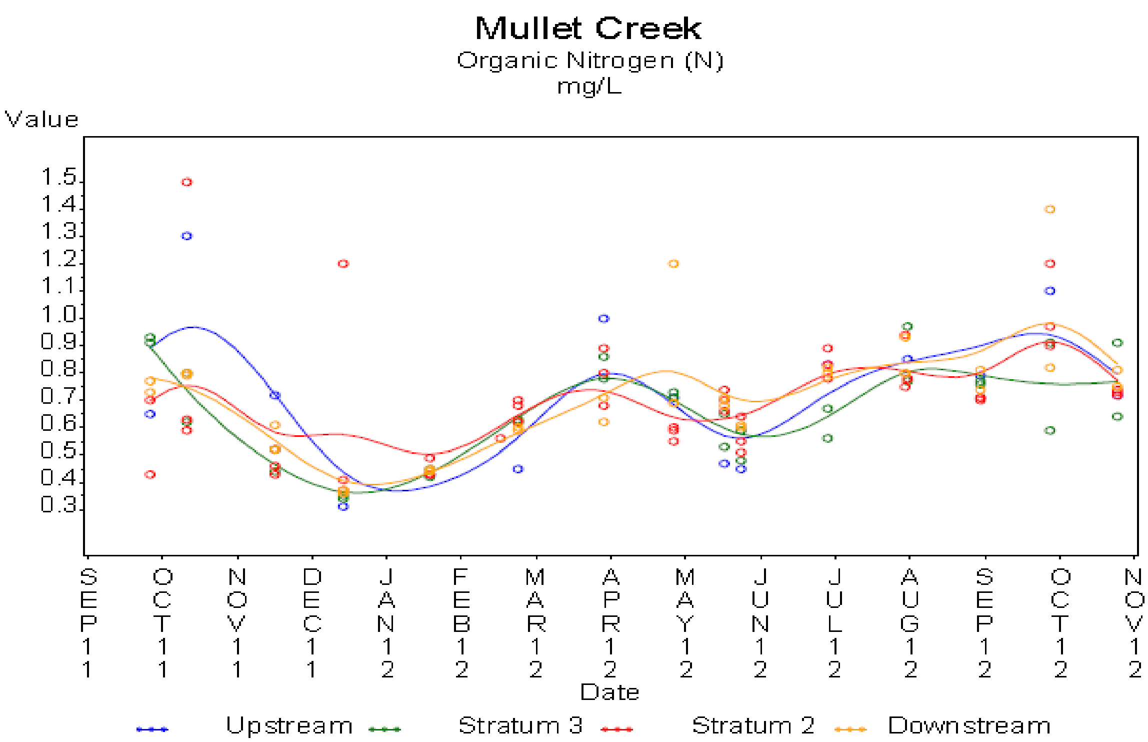


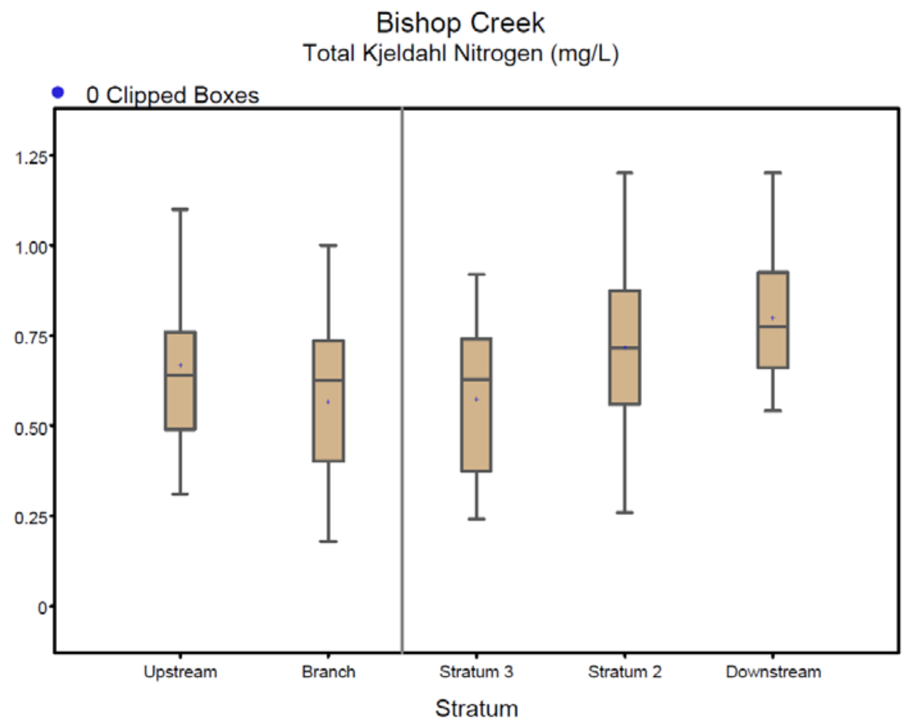
Figure 42. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.14 Total Kjeldahl Nitrogen

Organic nitrogen and ammonia are combined and together described as total kjeldahl nitrogen (TKN). Because ammonia values are so small relative to organic nitrogen, the TKN distributions are largely driven by organic nitrogen. Descriptive statistics for TKN are provided in Table 20. As with organic nitrogen, there were no significant differences in TKN between creeks though in Bishop Creek among strata differences were significant (Figure 43). TKN concentrations tended to increase in downstream strata in Bishop Creek, while in Mullet Creek concentrations were relatively constant across strata. Examination of timeseries plots (Figure 44) suggest that a similar temporal signal was observed across strata within each creek.

Table 20. Descriptive statistics for the analyte Total Kjeldahl Nitrogen in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Total Kjeldahl Nitrogen	Bishop	1	28	0.798	0.775	0.179	22.400	0.779
MDL =0.05 mg/L	Mullet	1	28	0.791	0.800	0.212	26.800	0.765
	Bishop	2	28	0.715	0.735	0.232	32.400	0.673
	Mullet	2	28	0.733	0.745	0.174	23.800	0.713
	Bishop	3	28	0.573	0.630	0.211	36.800	0.529
	Mullet	3	28	0.740	0.770	0.194	26.200	0.714
	Bishop	91	12	0.722	0.675	0.264	36.600	0.672
	Mullet	91	15	0.853	0.800	0.284	33.300	0.815
	Bishop	92	14	0.667	0.640	0.237	35.500	0.630
	Mullet	95	14	0.779	0.755	0.294	37.700	0.727
	Bishop	94	14	0.635	0.680	0.193	30.300	0.605
	Bishop	95	14	0.498	0.480	0.198	39.900	0.456



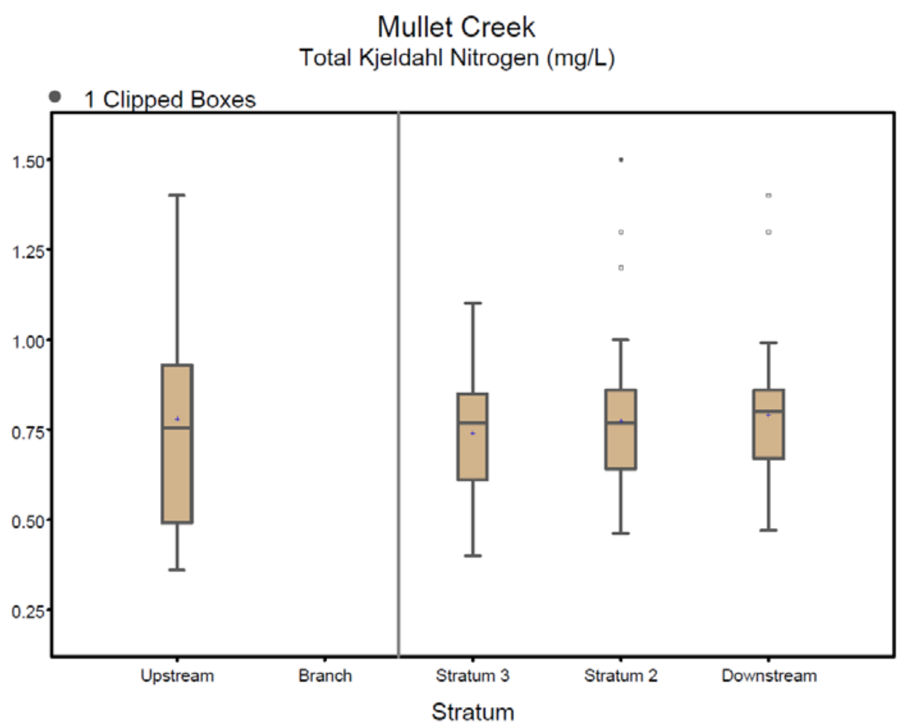
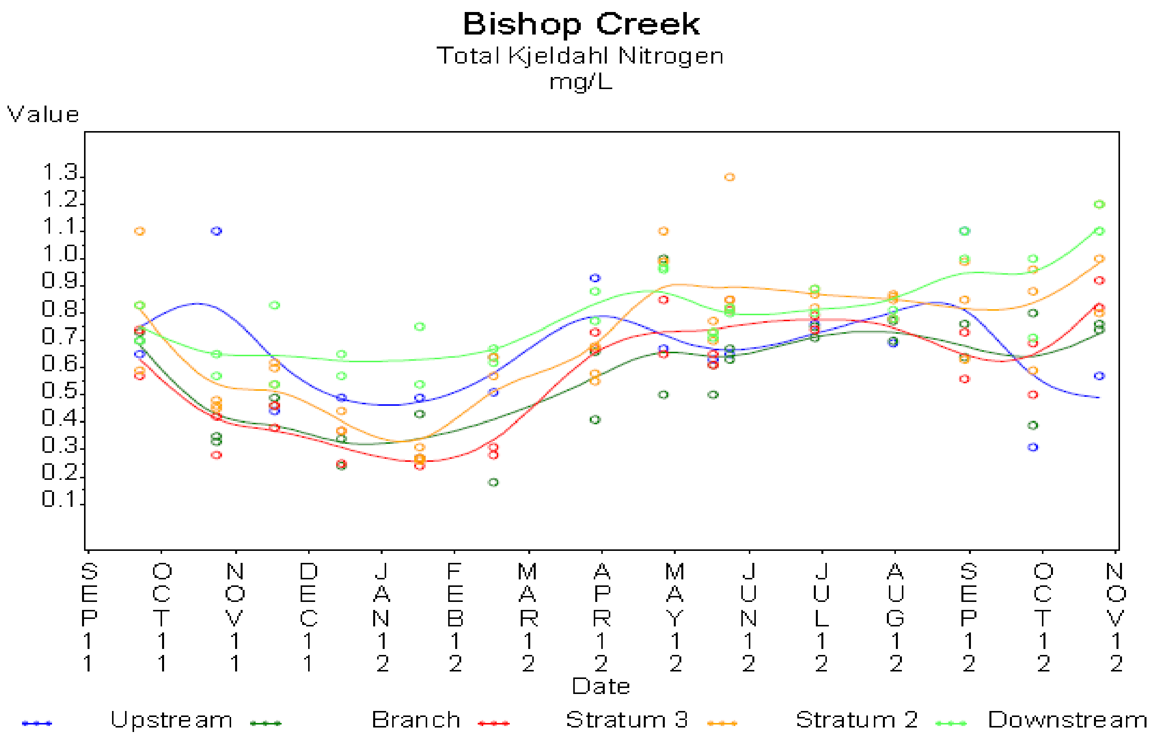


Figure 43. Box and whisker plots for Total Kjeldahl Nitrogen in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



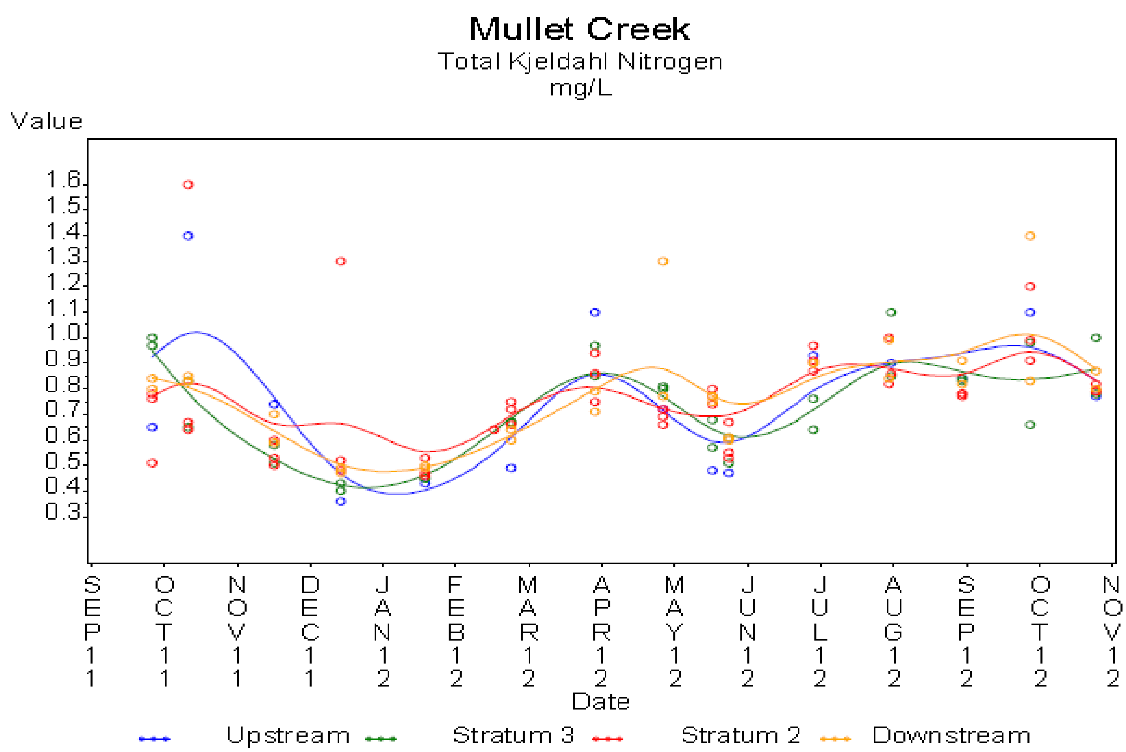


Figure 44. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.15 Total Nitrogen

Total nitrogen (TN) is the sum of all forms of nitrogen as discussed above. Total nitrogen is an analyte currently being targeted for development as a Florida water quality standard in the form of a numeric nutrient criterion; however, the criterion values for Florida tidal creeks have yet to be established. Descriptive statistics for TN are provided in Table 21. There were no significant differences in TN between creeks or among strata within creeks (Figure 45). Examination of timeseries plots (Figure 46) suggest that TN concentrations were lower in winter and increased with increasing temperatures and with the onset of the wet season. The temporal pattern was remarkably consistent among strata within each creek.

Table 21. Descriptive statistics for the analyte Total nitrogen in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Total Nitrogen	Bishop	1	28	0.860	0.805	0.188	21.9	0.840
MDL = 0.05 mg/l	Mullet	1	28	0.855	0.83	0.222	26	0.828
	Bishop	2	28	0.821	0.82	0.259	31.5	0.777
	Mullet	2	28	0.802	0.76	0.194	24.1	0.781
	Bishop	3	28	0.707	0.7	0.248	35	0.658
	Mullet	3	28	0.822	0.835	0.214	26	0.793
	Bishop	91	12	0.83	0.745	0.272	32.8	0.784
	Mullet	91	15	0.924	0.92	0.299	32.3	0.884
	Bishop	92	14	0.802	0.695	0.288	35.9	0.757
	Bishop	94	14	0.751	0.765	0.195	25.9	0.726
	Bishop	95	14	0.654	0.625	0.278	42.5	0.592
	Mullet	95	14	0.882	0.825	0.322	36.5	0.827

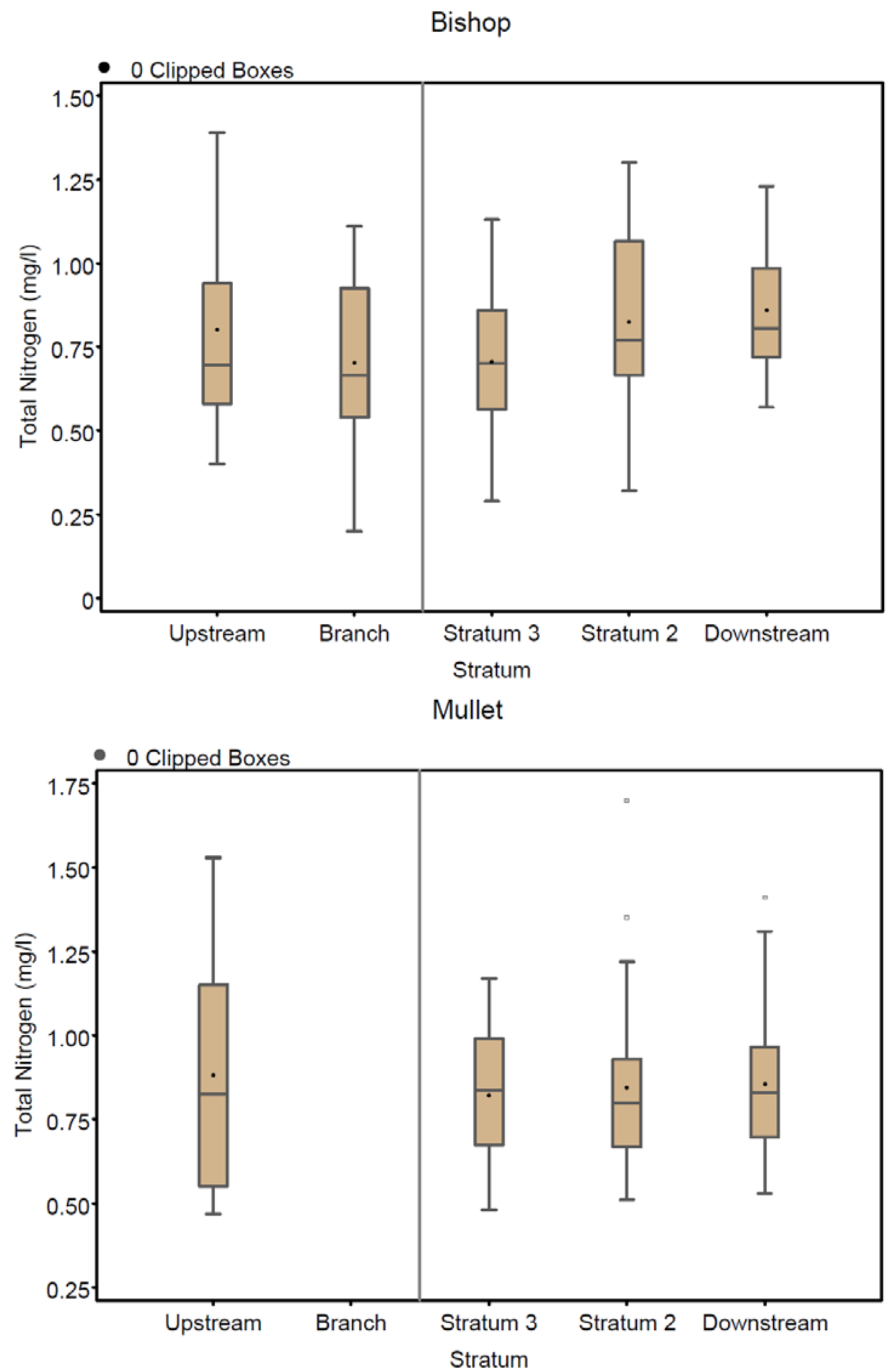
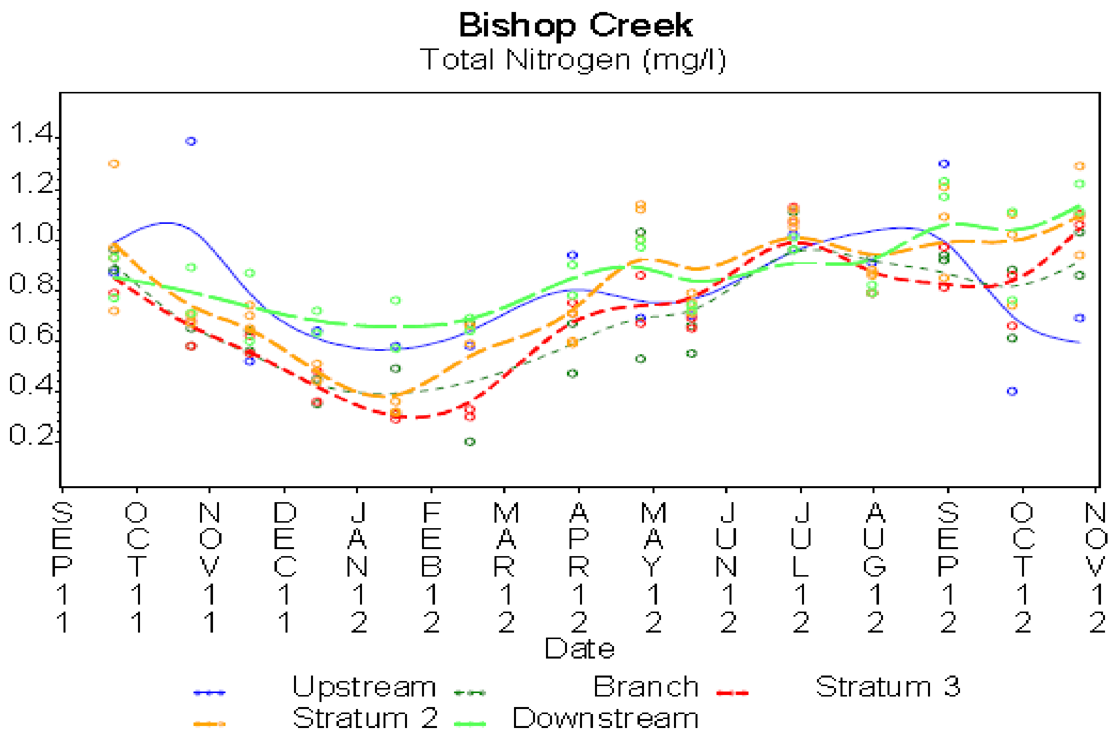


Figure 45. Box and whisker plots for Total Nitrogen in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



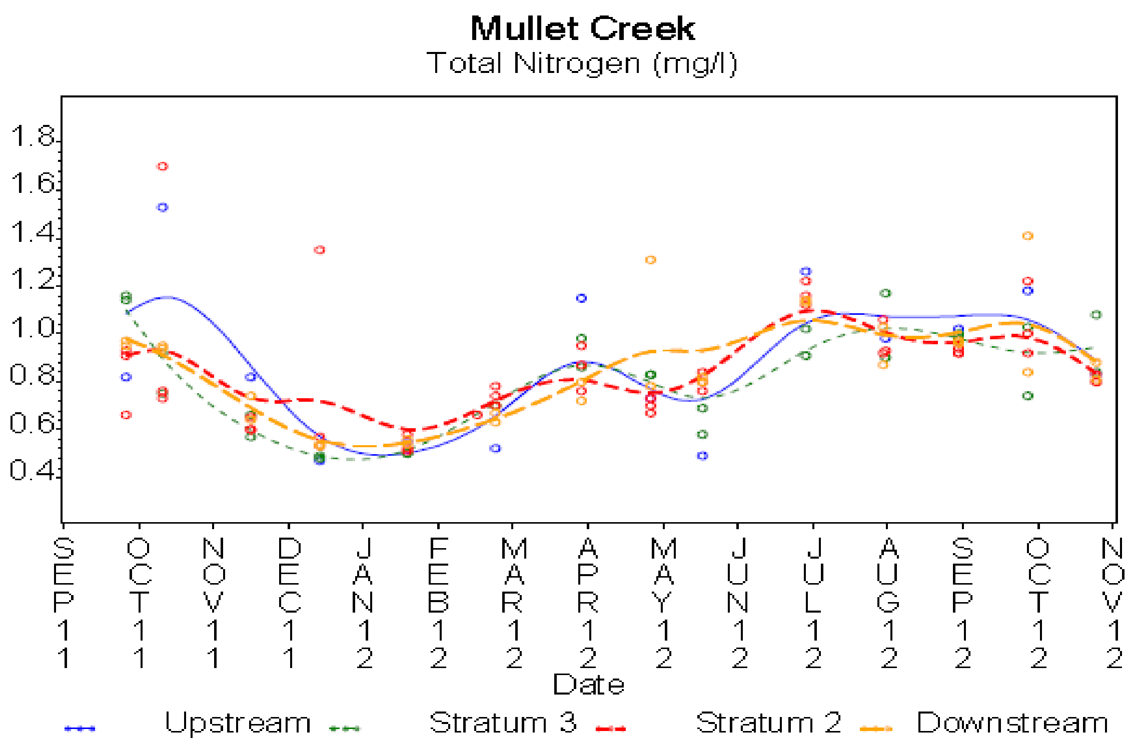


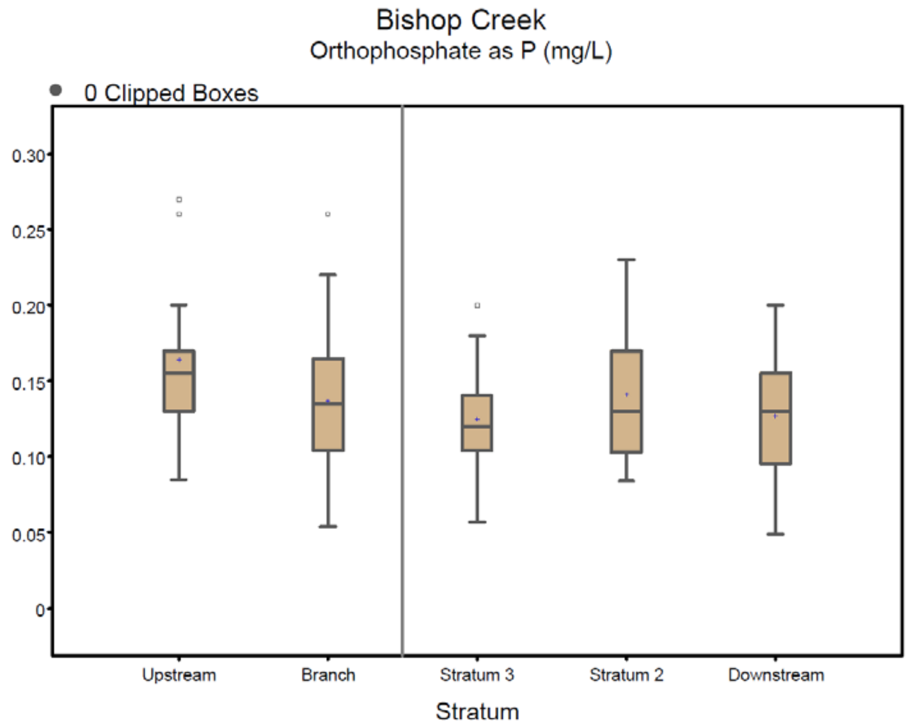
Figure 46. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.16 Orthophosphate

Orthophosphate or reactive phosphorous is the inorganic form of phosphorus and is the form most readily available to plants. While most estuarine waters are thought to be generally nitrogen limited rather than phosphorus limited, phosphorus limitation does occur. Descriptive statistics for orthophosphate are provided in Table 22. There were significant differences in orthophosphate between creeks with Bishop Creek having significantly higher concentrations than Mullet Creek. Significant differences among strata were also observed in Bishop Creek but not in Mullet Creek (Figure 47). Examination of timeseries plots (Figure 48) suggested different temporal dynamics between Bishop and Mullet Creek over the study period. While concentrations were lowest in Mullet Creek in the beginning of the study period, Bishop Creek had relatively high concentrations during that time. While Bishop Creek concentrations decreased with the onset of winter, in Mullet Creek concentrations were consistent and even slightly increased.

Table 22. Descriptive statistics for the analyte Orthophosphate in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Orthophosphate as P	Bishop	1	28	0.127	0.130	0.042	32.800	0.119
MDL =0.01 mg/L	Mullet	1	28	0.105	0.099	0.027	25.800	0.102
	Bishop	2	28	0.139	0.130	0.040	29.100	0.133
	Mullet	2	28	0.111	0.110	0.034	30.500	0.102
	Bishop	3	28	0.125	0.120	0.033	26.600	0.120
	Mullet	3	28	0.116	0.115	0.038	32.600	0.109
	Bishop	91	12	0.146	0.145	0.045	30.900	0.139
	Mullet	91	15	0.114	0.110	0.030	26.700	0.110
	Bishop	92	14	0.164	0.155	0.051	30.900	0.157
	Mullet	95	14	0.095	0.100	0.040	42.300	0.079
	Bishop	94	14	0.159	0.155	0.047	29.500	0.153
	Bishop	95	14	0.114	0.110	0.036	31.700	0.109



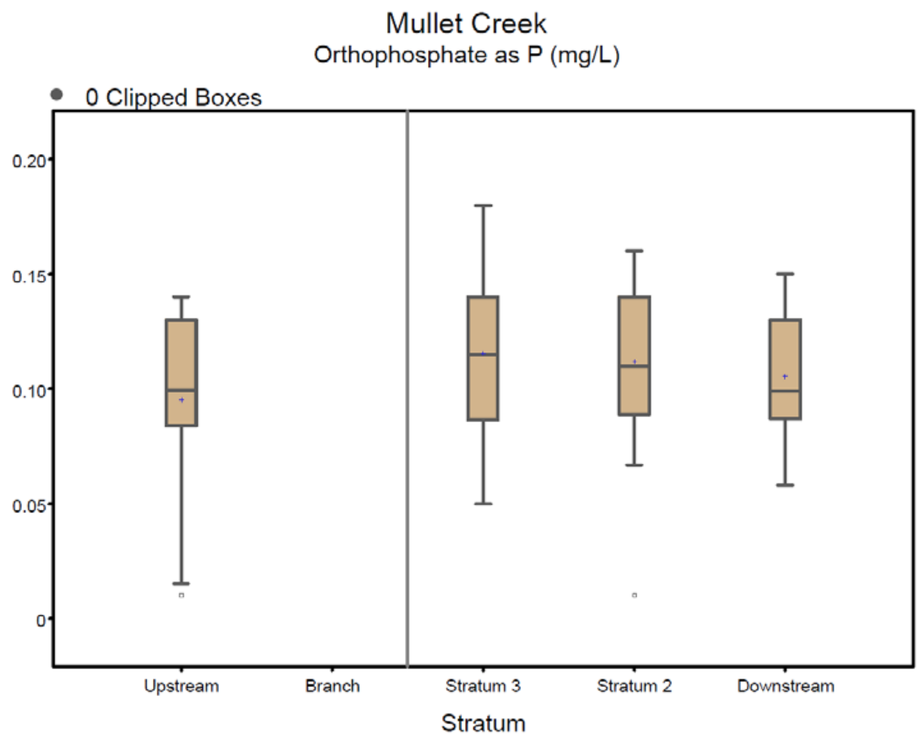
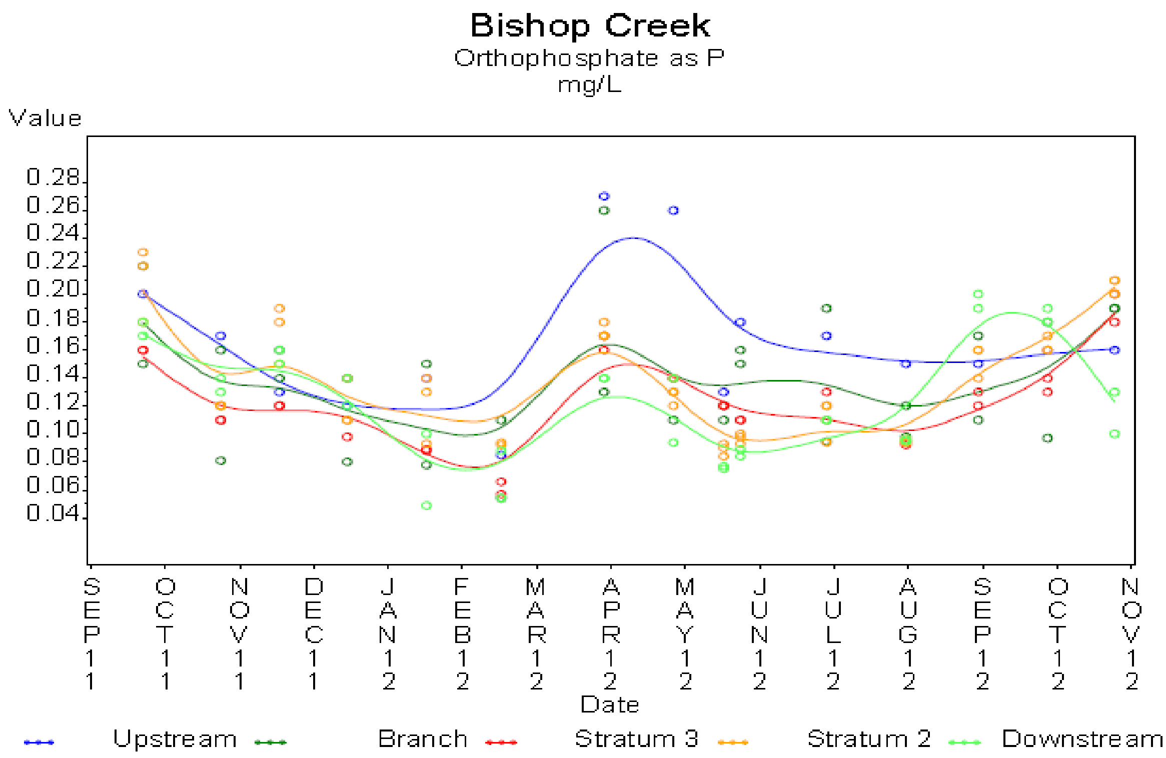


Figure 47. Box and whisker plots for Orthophosphate as P in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.



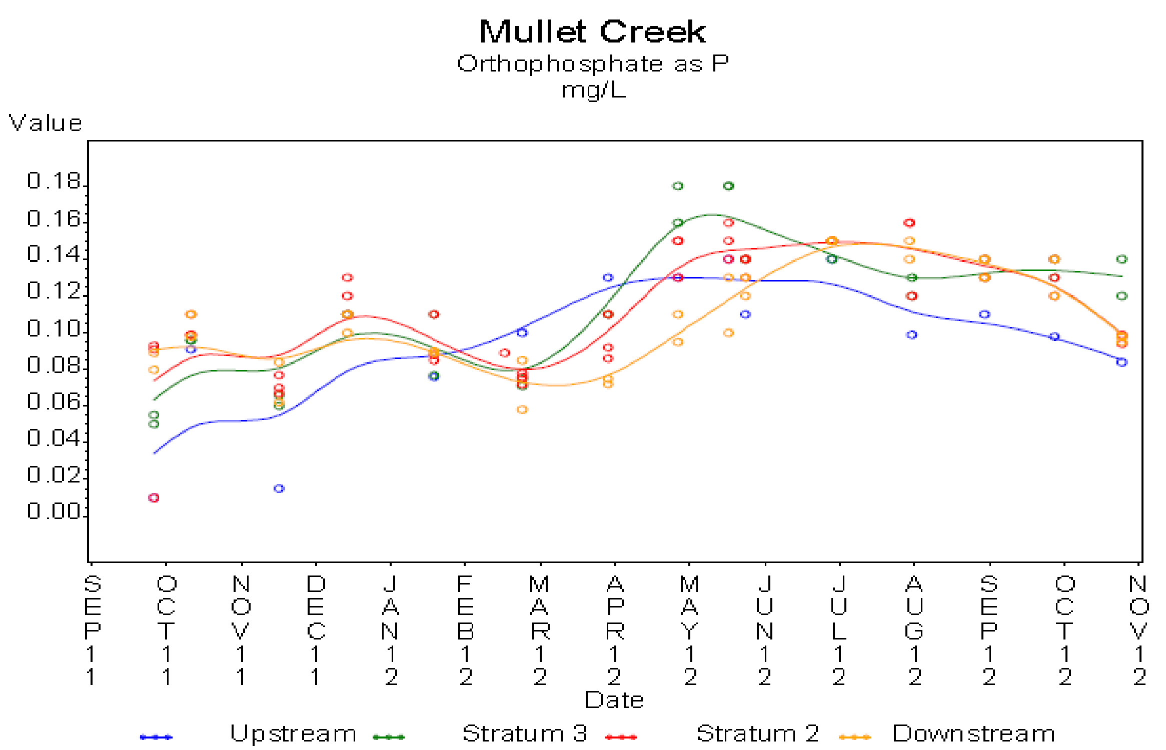


Figure 48. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.17 Total Phosphorus

Total phosphorus (TP) combines organic and inorganic forms of phosphorus and is also a nutrient subject to the development of numeric nutrient criteria for Florida waters. Descriptive statistics for TP are provided in Table 23. There were significant differences in TP between creeks with Bishop Creek having significantly higher concentrations than Mullet Creek. Significant differences among strata were also observed in Bishop Creek where the most upstream station in the north branch of Bishop Creek had dramatically higher TP values than the remaining downstream samples (Figure 49). Among strata distributions of TP in Mullet Creek were not significantly different. Examination of timeseries plots (Figure 50) suggested that temporal dynamics in TP concentrations were more similar both between creeks and among strata within each creek than the orthophosphate plots.

Table 23. Descriptive statistics for the analyte Total Phosphorous in each stratum and fixed station location in Mullet And Bishop Creek.

ANALYTE	Creek	Stratum	Number of observations	Arithmetic Average	Median	Standard Deviation	Coefficient of Variation	Geometric Average
Phosphorous - Total as P	Bishop	1	28	0.199	0.185	0.056	28.400	0.192
MDL = 0.01 mg/L	Mullet	1	28	0.163	0.165	0.040	24.500	0.158
	Bishop	2	28	0.194	0.200	0.047	24.400	0.189
	Mullet	2	28	0.165	0.165	0.038	22.900	0.161
	Bishop	3	28	0.172	0.165	0.040	23.100	0.168
	Mullet	3	28	0.169	0.160	0.056	33.000	0.162
	Bishop	91	12	0.216	0.210	0.067	31.000	0.207
	Mullet	91	15	0.172	0.170	0.037	21.300	0.169
	Bishop	92	14	0.294	0.225	0.167	56.600	0.260
	Mullet	95	14	0.191	0.150	0.099	51.900	0.174
	Bishop	94	14	0.236	0.220	0.073	30.700	0.226
	Bishop	95	14	0.147	0.140	0.040	27.600	0.142

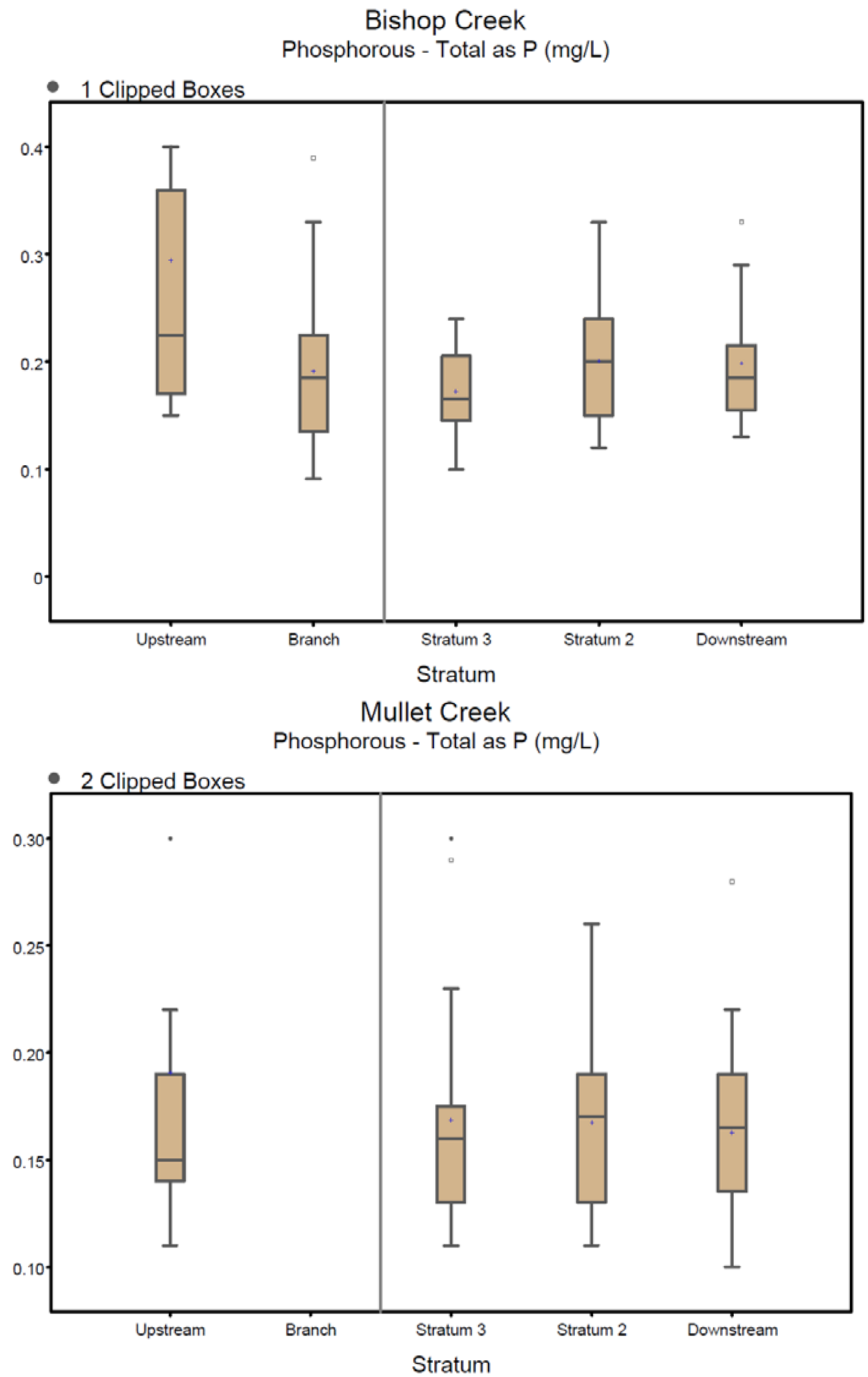


Figure 49. Box and whisker plots for Phosphorous in Bishop Creek (top) and Mullet Creek (bottom). Vertical gray line separates fixed station locations in the freshwater portion of the creek (left) and the 3 random strata to the right of the line. The median value is represented by the horizontal line within the box, the mean is represented by a cross within the box and the whiskers represent the 5th and 95th percentile values.

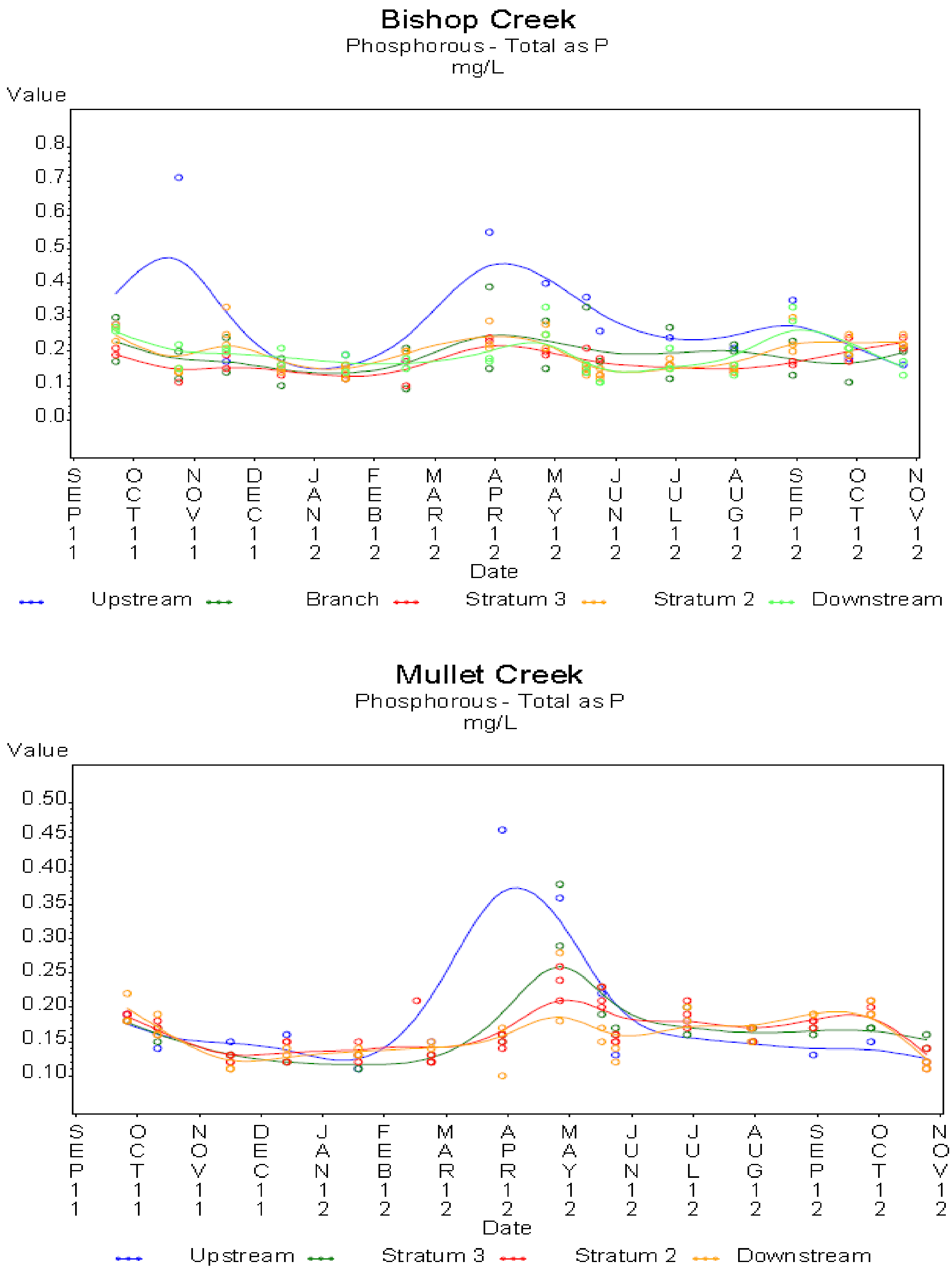


Figure 50. Stratum specific timeseries plots comparing trends among strata for Bishop Creek (top) and Mullet Creek (bottom).

D.1.18 Relevance to Water Quality Standards

Florida water quality standards are currently in a state of flux with EPA and FDEP both proposing new criteria to evaluate compliance with their respective regulatory obligations regarding the Clean Water Act. Third party lawsuits have and will likely continue to play a role in the final outcome of proposed rules to establish numeric criteria for nitrogen and phosphorus in Florida waters. Meanwhile the TMDL process continues and the TMDL's for Mullet and Bishop Creek are currently being subjected to re-evaluation. The FDEP has currently adopted an annual average concentration of 11 ug/l of chlorophyll as a water quality standard indicative of impairment when exceeded. However, the new rules may utilize a federally recognized alternative criterion for Old Tampa Bay of 9.3 ug/l as the standard to evaluate Mullet and Bishop Creek. This depends on the outcome of current legal proceeding at the state level. While the chlorophyll a values reported in Table 10 are calculated over the entire study period as opposed to an annual average which in the case of chlorophyll includes from November 2011 through October 2012, the arithmetic mean values are below 11 ug/l at all strata and below 9.3 in all but one stratum indicating that these creeks would be in compliance with regulatory standards for chlorophyll. The EPA and FDEP use dissolved oxygen as a response indicator of nutrient pollution. Previously, the FDEP assumed that if greater than 10% of measured DO values collected in a year were below 4 mg/l the system was impaired. The FDEP has since revised that criterion and intends to express the criterion values as percent saturation with 41.7% being the threshold value for estuarine water bodies. Despite average concentrations near or above 5 mg/l in all strata (Table 13) both Bishop and Mullet Creek would likely fail either the existing or the proposed criteria with respect to DO based on data collected as part of this study with exceedance rates (i.e. values below the threshold value) between 30% and 40% for both the concentration or percent saturation based thresholds. Numeric nutrient criteria have yet to be established for tidal creeks. The EPA and FDEP have previously accepted nutrient criteria for Old Tampa Bay in the form of hydrological normalized annual nutrient loading limits. How these limits might translate into site specific criteria for tidal creeks is yet to be determined and the Tampa Bay Estuary Program along with other estuary programs in southwest Florida have argued that tidal creeks need distinct criteria from either freshwater or open bay estuaries.

Based on the results of this study there are no indications that either Mullet or Bishop Creek are suffering a degree of anthropogenic impact that would result in adverse effects to their designated use. Despite dissolved oxygen levels that are in exceedance of state water quality standards, results of biological response endpoint monitoring including chlorophyll a values, fish collections, benthic macroinvertebrates, benthic micro algae chlorophyll content, and the health of the mangrove forests suggested that these creeks are ecologically well functioning

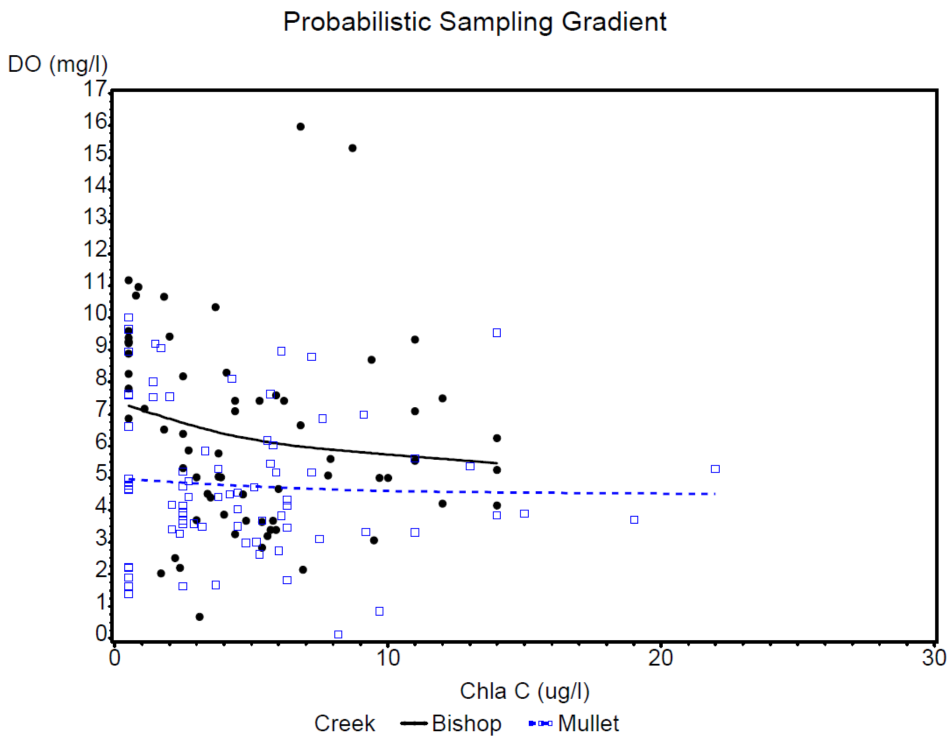
systems. In the following section, stressor response relationships are investigated using bivariate water quality plots to better understand the stressor response relationship among water quality constituents in Mullet and Bishop Creeks and investigate potential threshold values indicative of adverse effects.

D.1.19 Stressor Response Relationships

The conceptual model that serves as the foundation of FDEP's Impaired Waters Rule is that excess nutrient loading and resulting increased concentration of nutrients in receiving waters results in increased primary production and this production results in increased organic material deposits that are decomposed by bacteria, consuming oxygen and reducing dissolved oxygen concentrations within the system. Therefore, key linkages in this conceptual model are the relationships between nutrients and chlorophyll a values, and chlorophyll a concentrations and dissolved oxygen concentrations in the form of both concentration and percent saturation. These relationships were examined in the estuarine portion of the study area using the data collected using the probabilistic design.

The relationship between chlorophyll a concentrations and dissolved oxygen concentration and percent saturation was stable across the range of chlorophyll values (Figure 51). In Mullet Creek, average DO concentrations were somewhat higher at the lowest chlorophyll concentrations but the lowest DO values also occurred at Chl a concentrations below 10 ug/l. In Bishop Creek, some of the lowest DO concentrations occurred at the lowest Chl a concentrations. Dissolved oxygen was not significantly related to TN concentrations in either creek (Figure 52) but was significantly related to TP concentrations in Bishop Creek with increasing TP resulting in decreasing DO in the estuarine segment (Figure 53). However, the same relationship was not observed in Mullet Creek between DO and TP.

Chlorophyll concentrations were highest at intermediate TN and TP concentrations and appeared to decrease at higher concentrations of TN and TP (Figure 54). This non-linear result likely represents seasonal dynamics and residence times that also effect phytoplankton production. Seasonal dynamics did not appear to be a function of the canopy cover at the point of sampling as indicated by the plot of Chl a and the percent canopy cover measured at the time of collection (Figure 55; top). The Chl a concentrations did appear to be effected by stream velocity with a decreasing central tendency in concentrations with increasing stream velocity in both creeks (Figure 55; bottom) though the relationship was not statistically significant. Statistics from linear regression output attempting to develop predictive relationships based on these plots are presented in Table 24. Log transforming the variables did not improve the model fit, indicating that these relationships are more complex than postulated by the EPA and FDEP.



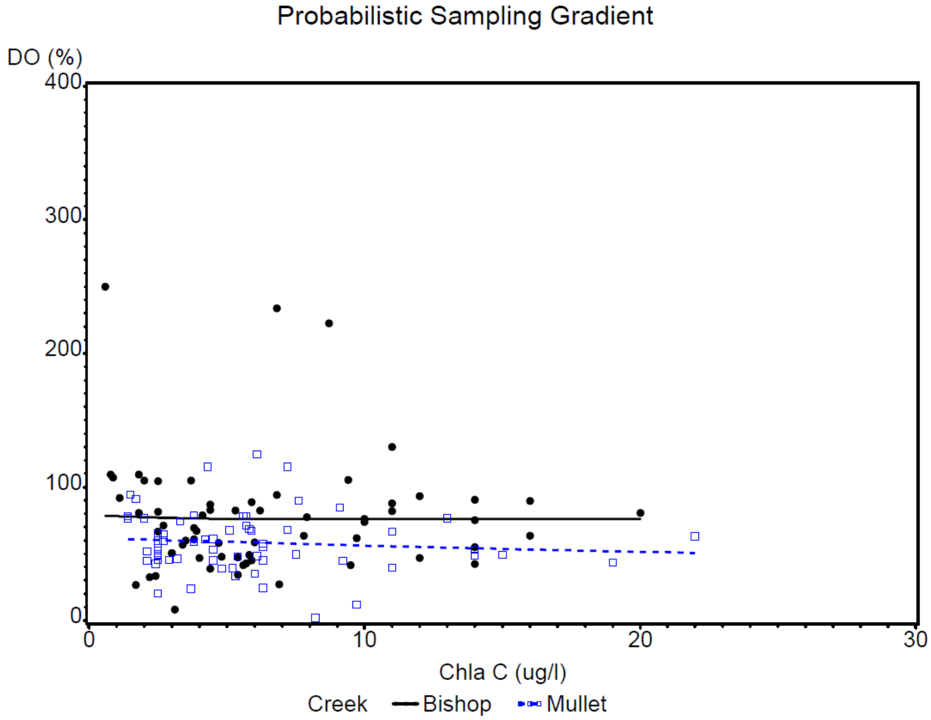
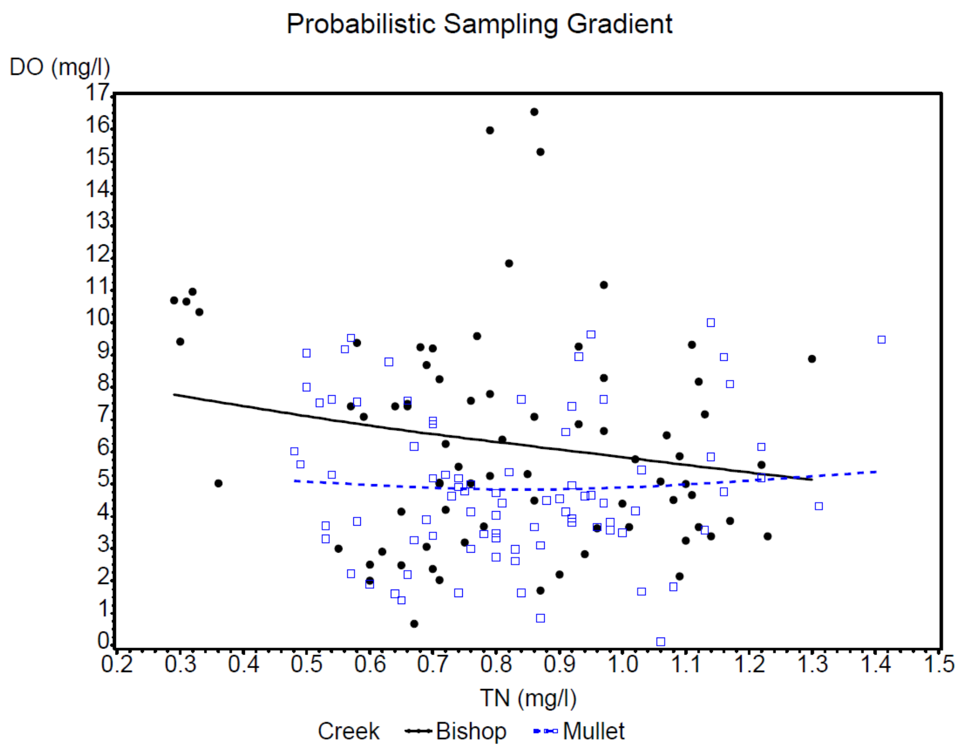


Figure 51. Relationship between chlorophyll a concentrations (Chl a C) and dissolved oxygen concentrations (top) and percent saturation (bottom).



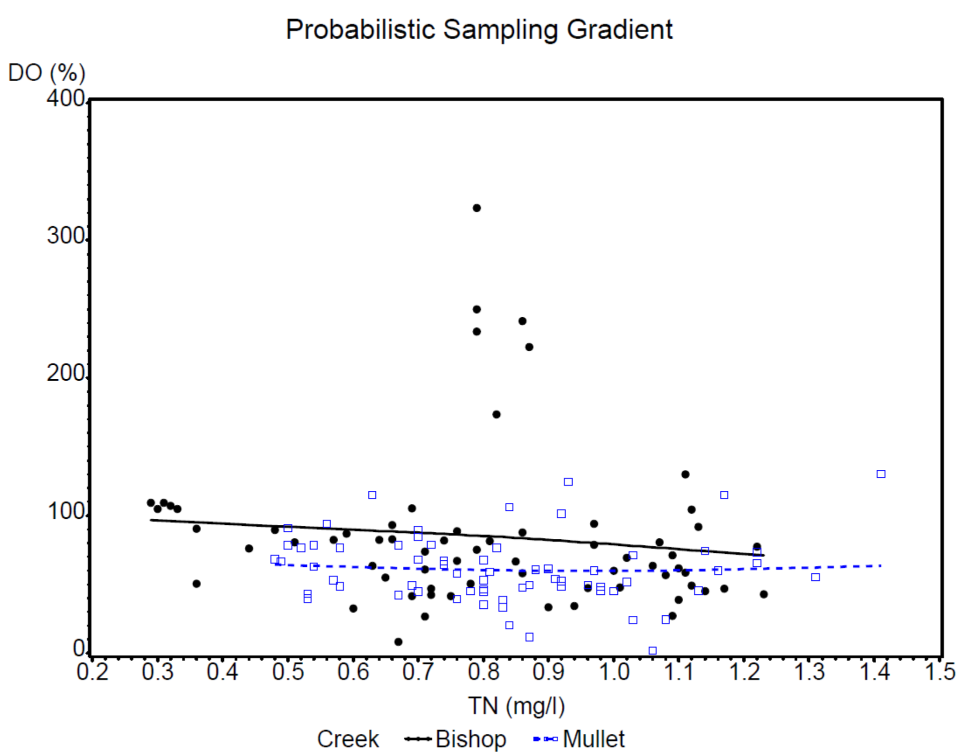
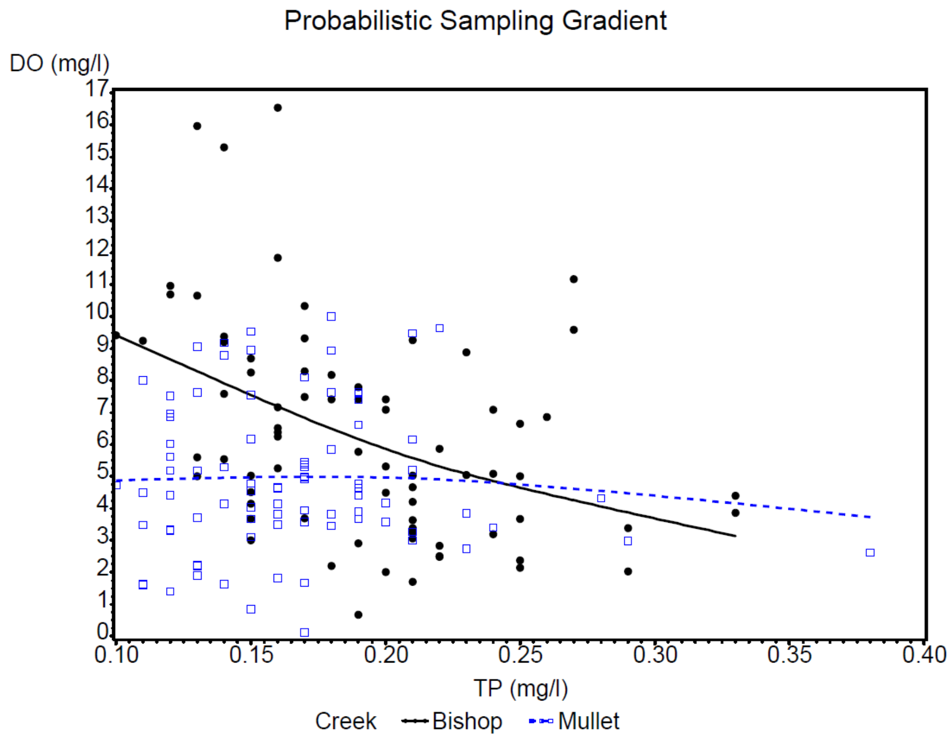


Figure 52. Relationship between total nitrogen concentrations and dissolved oxygen concentrations (top) and percent saturation (bottom).



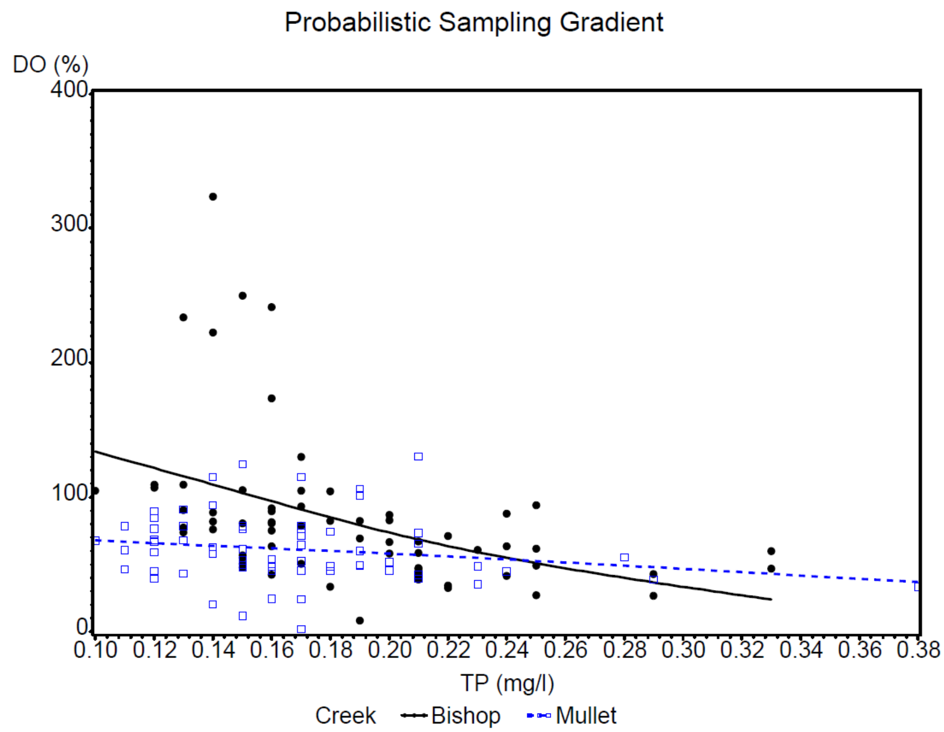


Figure 53. Relationship between total phosphorus concentrations and dissolved oxygen concentrations (top) and percent saturation (bottom).

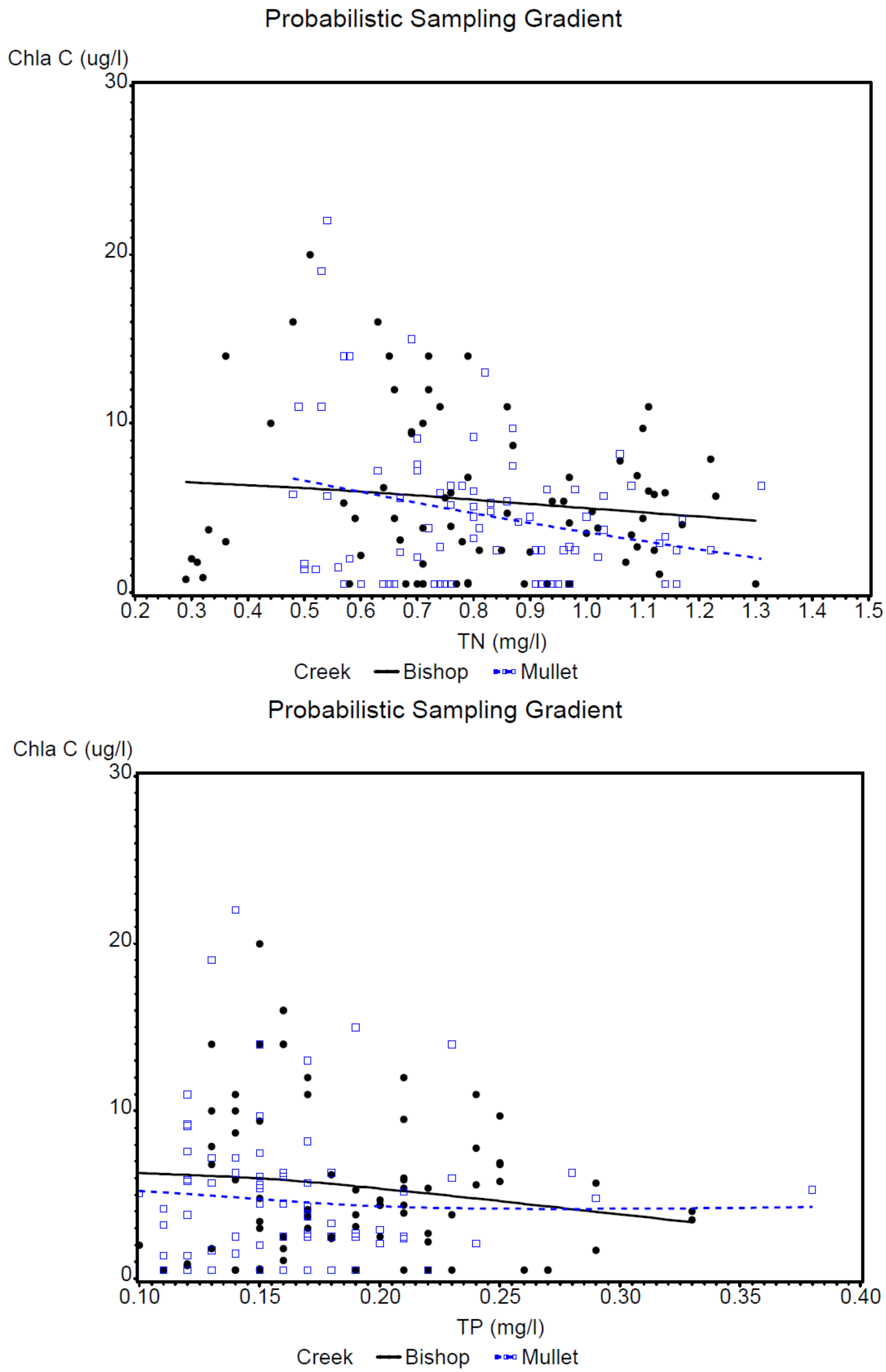
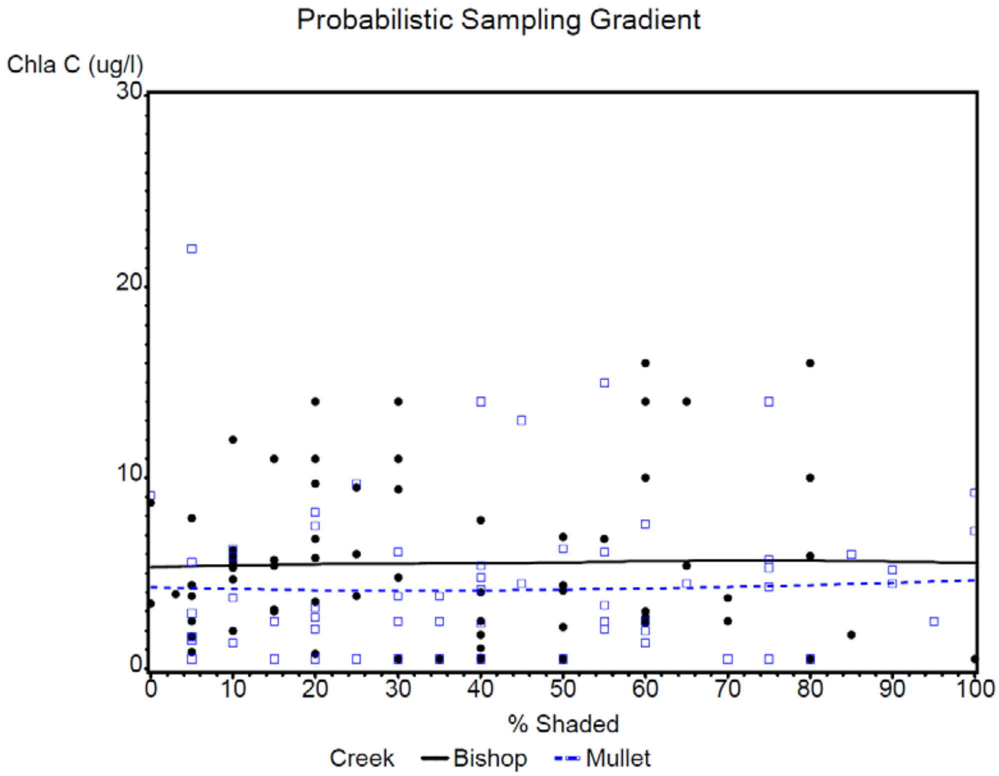


Figure 54. Relationship between chlorophyll a concentrations (Chl a C) and total nitrogen (top) and total phosphorus (bottom) in Mullet and Bishop Creeks.



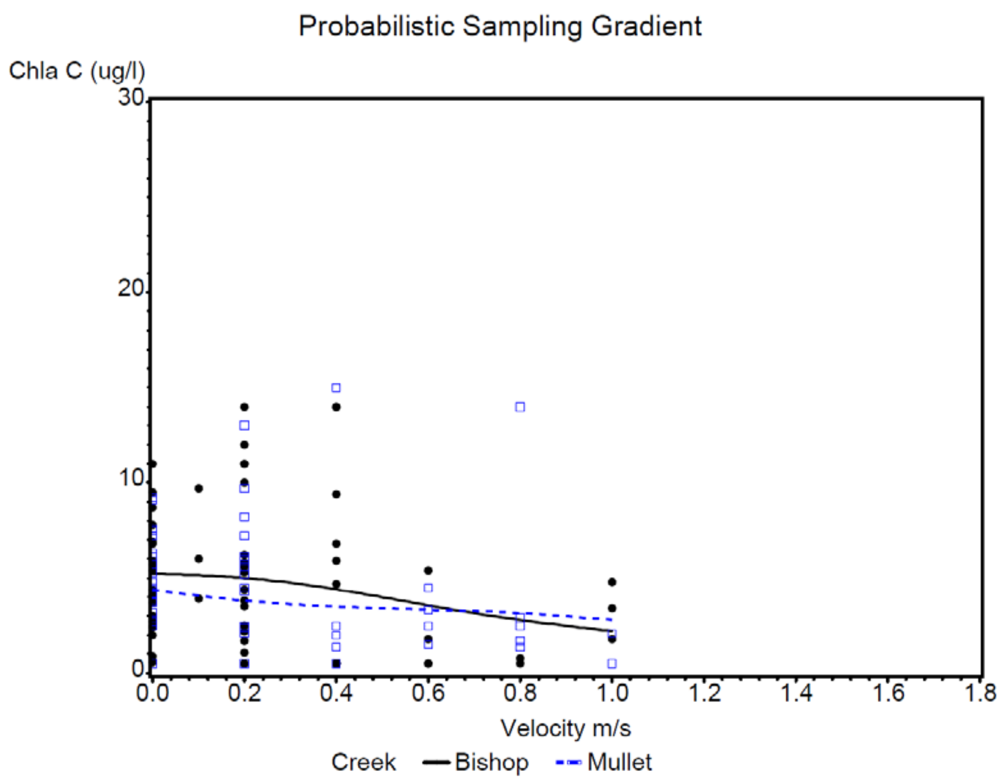


Figure 55. Relationship between chlorophyll a concentrations (Chl a C) and canopy cover (top) and maximum stream velocity at the time of sampling (bottom) in Mullet and Bishop Creeks.

Table 24. Results of linear regression analysis on potential stressor response relationships in Bishop and Mullet creeks.

Dependent Variable	Independent Variable	Bishop		Mullet	
		R^2	alpha<0.05	R^2	alpha<0.05
DO (mg/l)	Chla C (ug/l)	0	No	0	No
DO (%sat)	Chla C (ug/l)	0.02	No	0	No
DO (mg/l)	TN (mg/l)	0.02	No	0	No
DO (%sat)	TN (mg/l)	0	No	0	No
DO (mg/l)	TP (mg/l)	0.05	Yes	0	No
DO (%sat)	TP (mg/l)	0.07	Yes	0	No
Chla C (ug/l)	TN (mg/l)	0.02	No	0	No
Chla C (ug/l)	TP (mg/l)	0	No	0	No
Chla C (ug/l)	Shading (%)	0	No	0	No
Chla C (ug/l)	Velocity (m/s)	0.03	No	0.03	No

D.1.20 Estuarine Mixing and Dilution

EPA has proposed an approach for establishing tidal creek numeric nutrient criteria that relies on criteria for adjacent freshwater and estuarine waterbodies and the mean (presumed to be long-term average) salinity of the creek. This approach is generally described as a “mixing diagram” or “dilution model” with the expectation that inputs from upstream waters will follow a linear decay in concentration as a function of mixing with estuarine waters as defined by salinity. The proposed method was represented by EPA in Figure 56, Cifuentes et al. (1990) and has been generally used as a method of identifying sinks and source of nutrients to tidal tributaries.

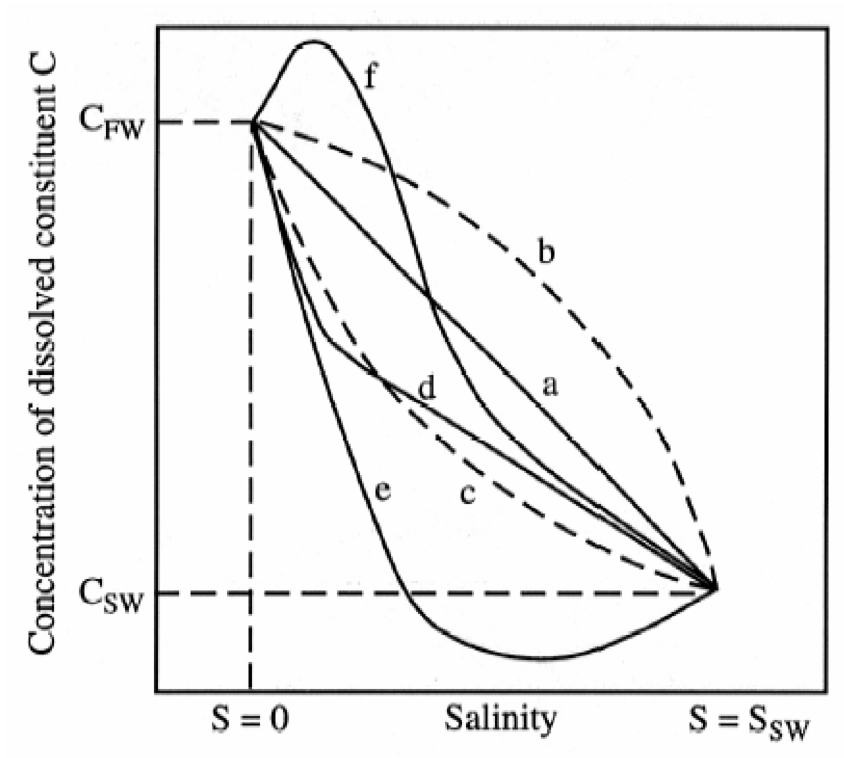


Figure 56. Constituent C has a concentration of C_{FW} in river water (S=O) and of C_{SW} in seawater ($S=S_{SW}$). Line (a) is the conservative mixing line, (b) is addition from the estuary, (c) is removal from the estuary. Curve (d) is removal in the upper estuary only; curve (e) is removal within the estuary that exceeds the riverine input; curve (f) is addition to the upper estuary, followed by removal in the lower estuary (Cifunetes et al., 1990).

Evidence from this study suggests that the dilution model may not characterize the spatialvariability in nutrient concentrations that exists between freshwater inputs and the open bay waters of Old Tampa Bay. TN and TP concentrations were flat across the salinity gradient (Figures 57 and 58) and indications are that there may be significant inputs of organic nitrogen throughout the tidal portion of these creeks as evidenced by flat or even increasing concentrations of organic nitrogen as a function of salinity (Figure 59). These inputs are assumed to be attributed to the large area of emergent vegetation (i.e. mangroves and saltmarsh) near the mouths of these creeks. The synoptic mangrove health survey conducted as part of this study suggested that the mangrove forests are functioning as natural, undisturbed systems. This has important implications for regulatory inference because organic nitrogen is the dominant form of nitrogen contributing to the observed total nitrogen values in these creeks. In the case of these creeks the data suggest nutrient addition that is not directly related to watershed inputs or anthropogenic activities. In other words, natural wetland

features in these creeks may be acting as a source of nitrogen to the creeks. The dominant inorganic form of nitrogen (i.e. NOx) did follow a relatively linear decay as a function of salinity; however, it is unlikely that NOx is a conservative substance in the estuary. More likely is that NOx is readily taken up as it mixes with estuarine waters and the phytoplankton communities in these waters (Figure 60). Total organic carbon however, did exhibit relatively conservative behavior (Figure 61).

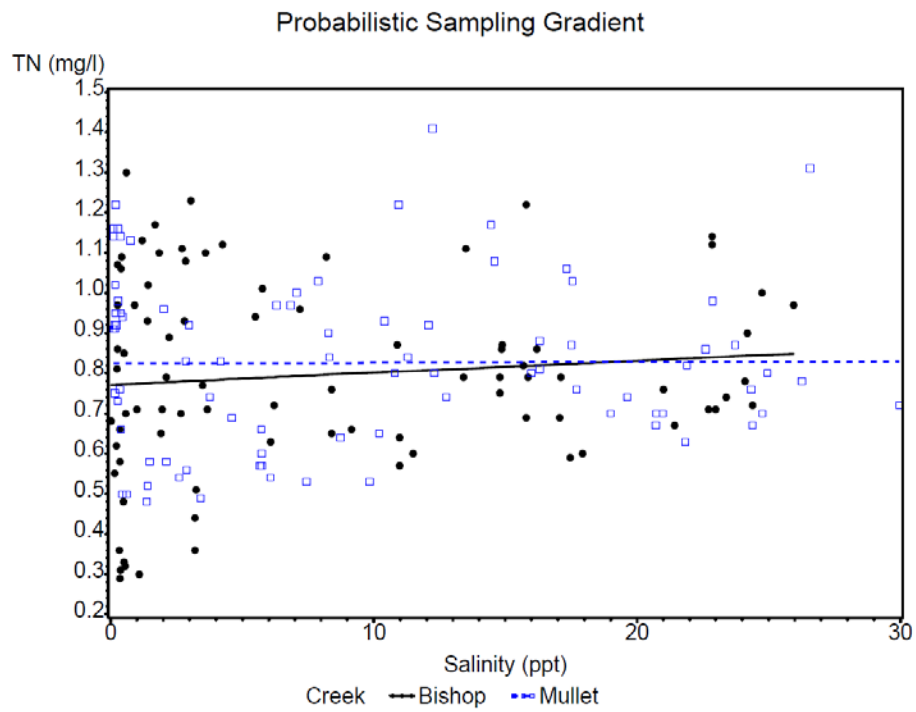


Figure 57. Relationship between total nitrogen and salinity in Mullet and Bishop Creek.

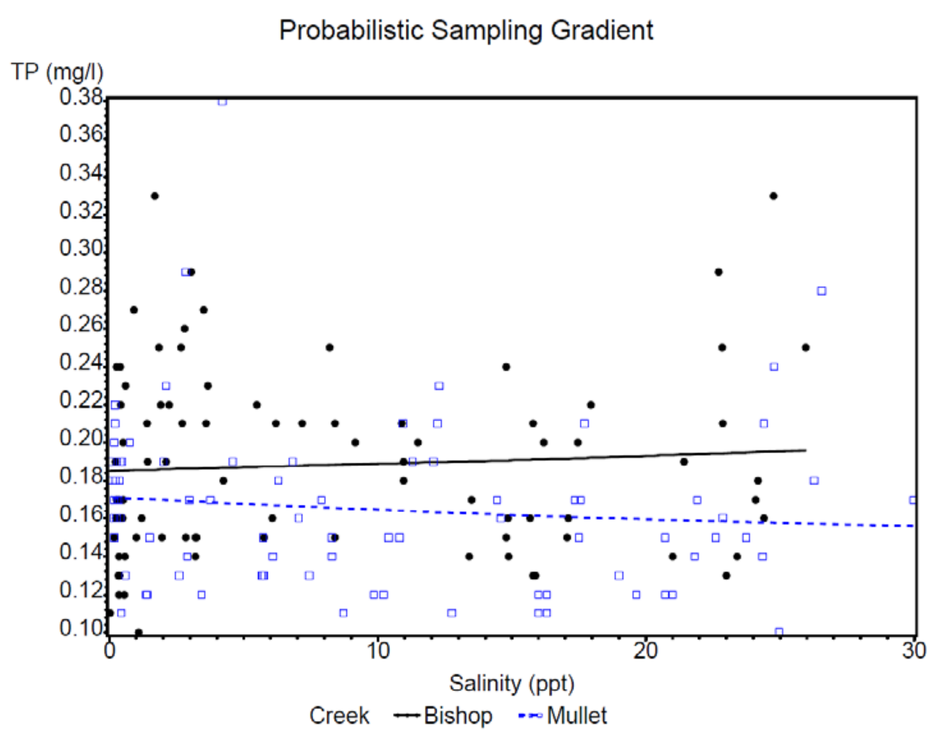


Figure 58. Relationship between total phosphorus and salinity in Mullet and Bishop Creek.

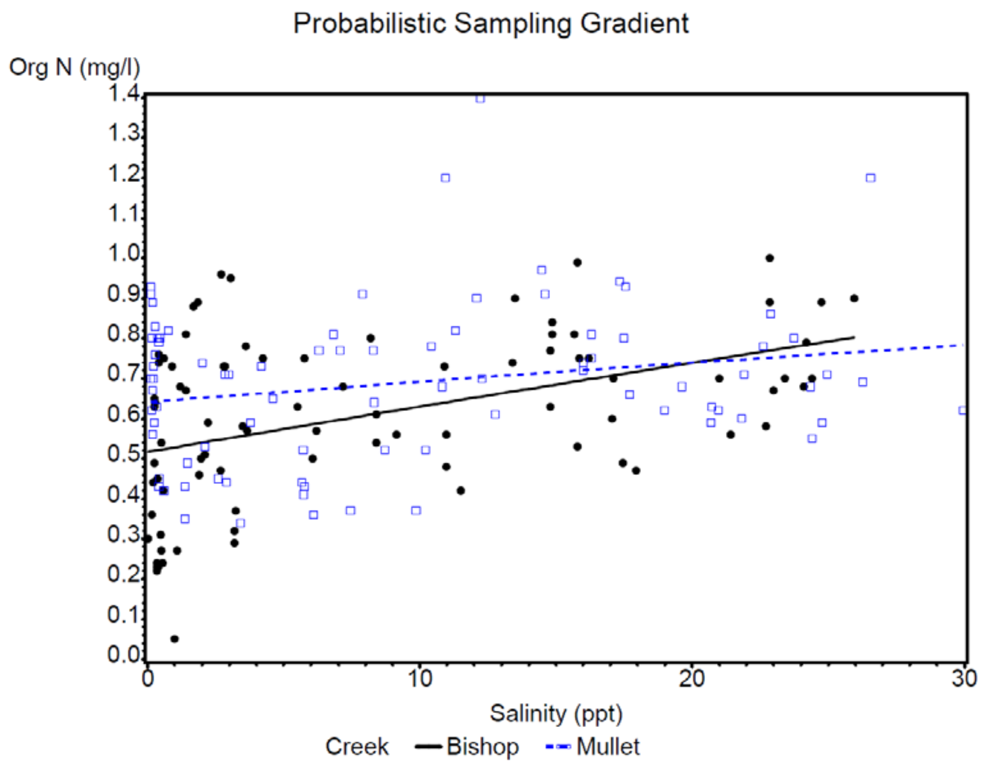


Figure 59. Relationship between organic nitrogen and salinity in Mullet and Bishop Creek.

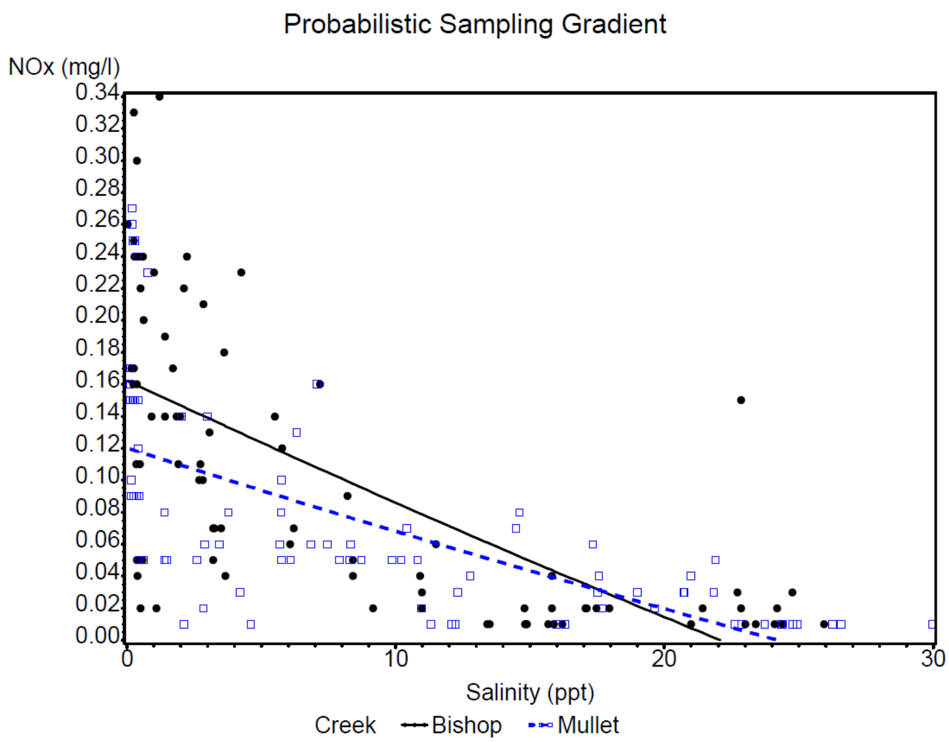


Figure 60. Relationship between Nitrate - Nitrite and salinity in Mullet and Bishop Creek.

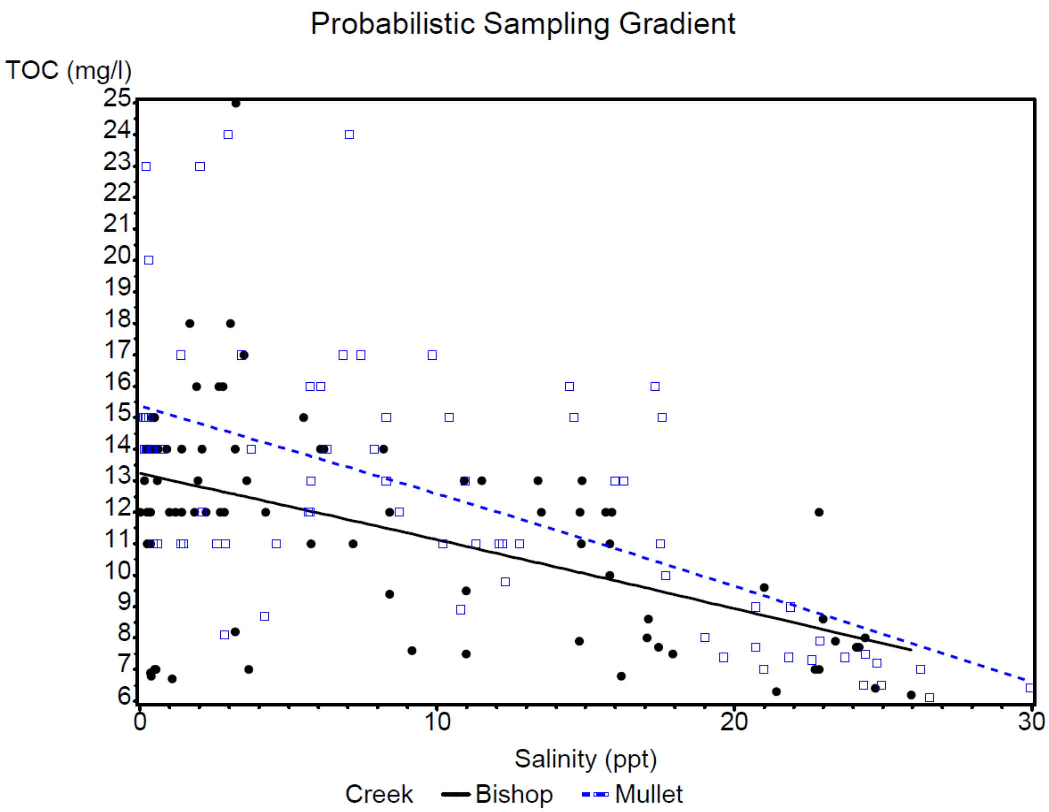


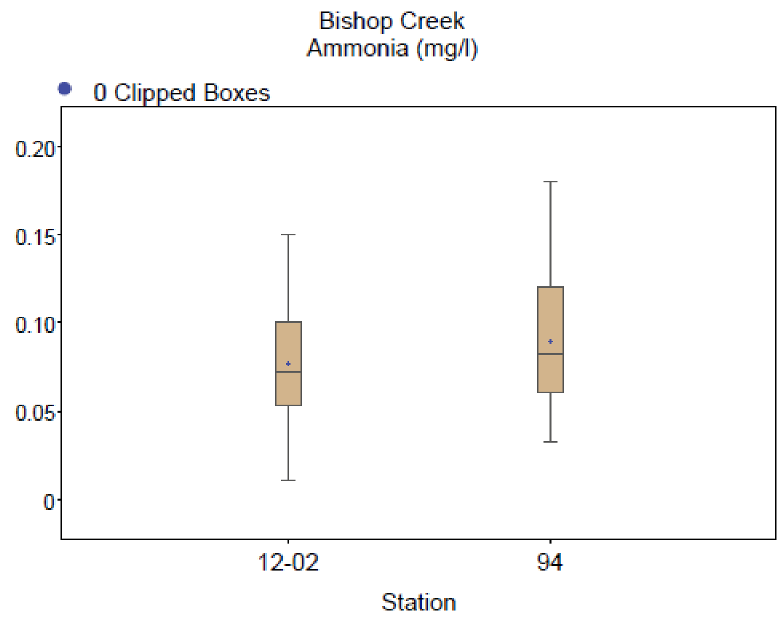
Figure 61. Relationship between total organic carbon and salinity in Mullet and Bishop Creek.

D.1.21 Comparing Water Quality in the North and South Branch of Bishop Creek

The sampling design for this study was constructed to allow for the comparison of water quality between two water quality stations within each branch of Bishop Creek as well as between the two branches of Bishop Creek. As described earlier, on each branch there is an upstream fixed station that is actively sampled by Pinellas County. This study located an additional fixed station on each branch near their convergence. The result of this design was that between September 2011 and October 2012 there were 14 samples collected at stations 94 and 95 near the convergence of the north and south branch, respectively, 14 samples collected monthly at station 12-02 on the North branch as part of this study, and 8 samples collected by Pinellas County at stations 12-02 and 12-04. The objective of this section is to examine potential differences in the contribution of water quality indicators to the estuarine portion of Bishop Creek from each of these branches. Boxplots were generated displaying the distribution of data values and the Wilcoxon Rank Sum test was again used to test for statistically significant differences. It should be noted that samples sizes are relatively small for these comparisons; however, in several cases there were statistically significant differences resulting from this analysis.

When comparing water quality differences between stations within each branch, the majority of significant differences between stations were observed in the south branch. Specifically, Ammonia, Chl a, TP, and TSS were significantly higher in the lower Station (i.e., 95) compared to the upstream fixed station (12-04) sampled by Pinellas County. In the north branch, the only parameter exhibiting a significant difference was TSS which was higher in the upstream station compared to the downstream station. Box plots comparing these distributions are provided in Figures (62 through 65).

When comparing water quality differences between branches of Bishop Creek, there were more significant differences observed. This analysis was performed separately comparing the Pinellas County stations between branches and the special study stations between branches. Ammonia concentrations were higher in the north branch in both the Pinellas County and Special Study comparison (Figure 66). Orthophosphate, TP and TKN concentrations were also higher in the north branch at both the Pinellas County and special study stations (Figures 67-69). Other parameters including DO, Chl a, TN and TSS were significant only when comparing the Pinellas County sites between creeks (Figures 70-73). Dissolved oxygen was higher in the south branch while the other parameters were higher in the north branch.



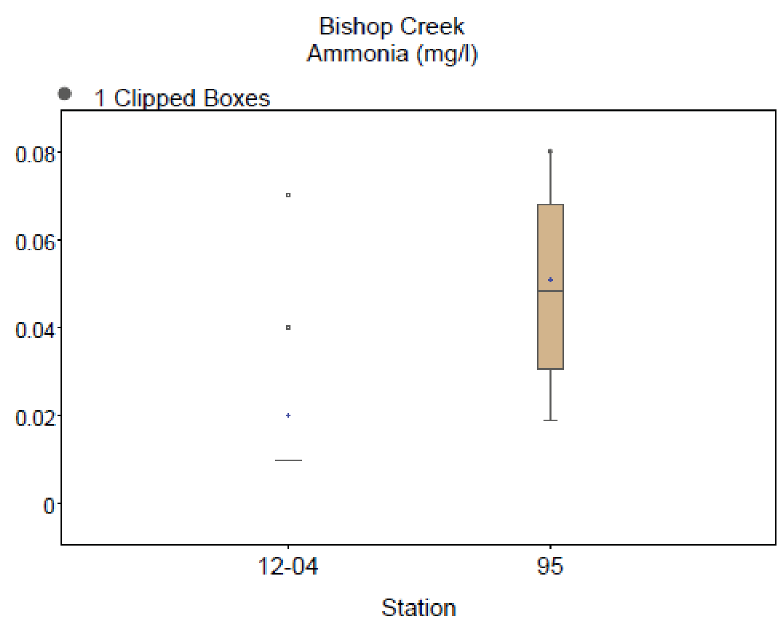
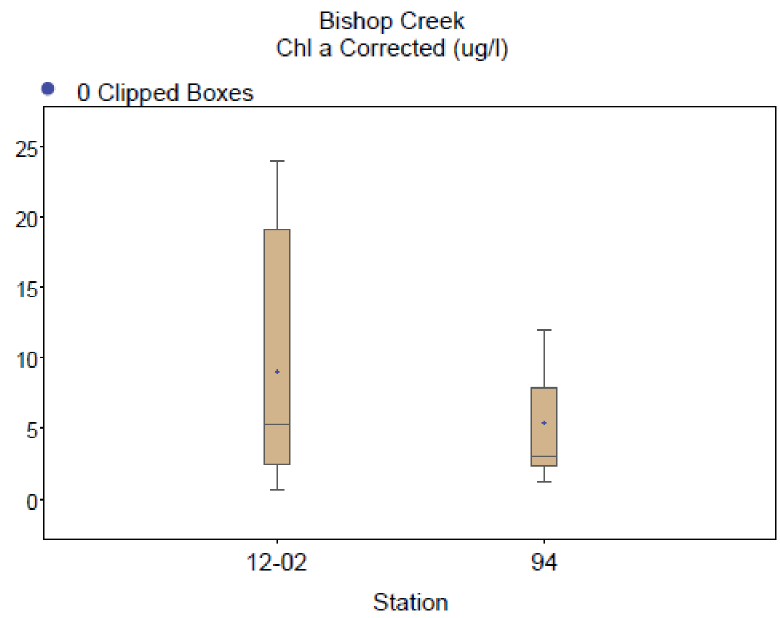


Figure 62. Box plots comparing distribution of Ammonia in the north branch (Top) and south branch (Bottom) of Bishop Creek.



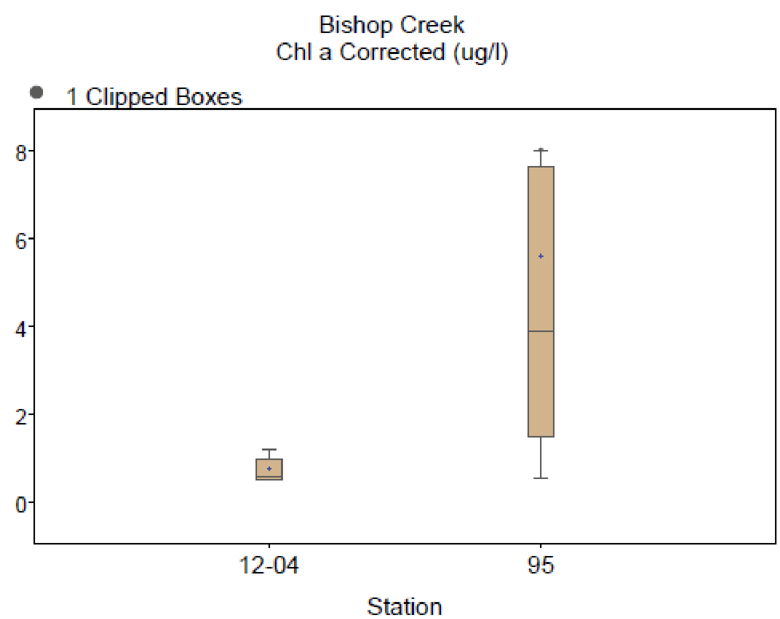
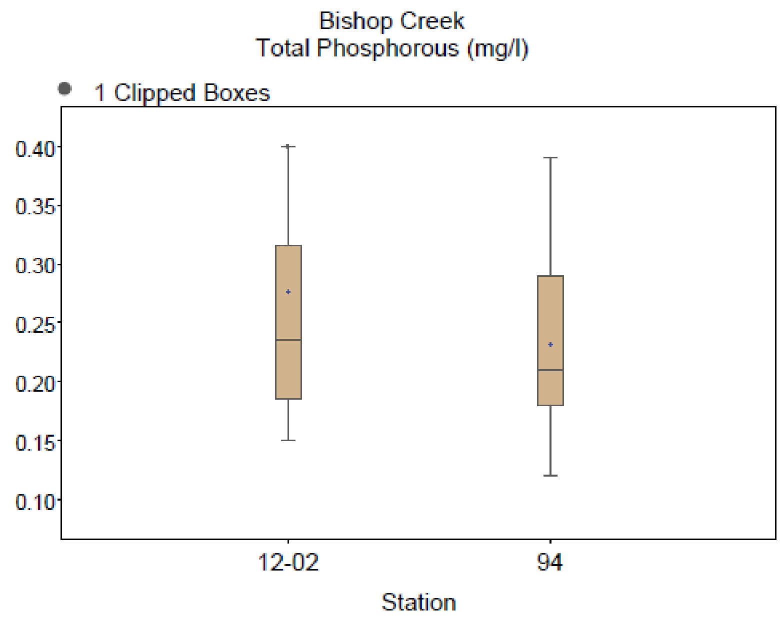


Figure 63. Box plots comparing distribution of chlorophyll a corrected in the north branch (Top) and south branch (Bottom) of Bishop Creek.



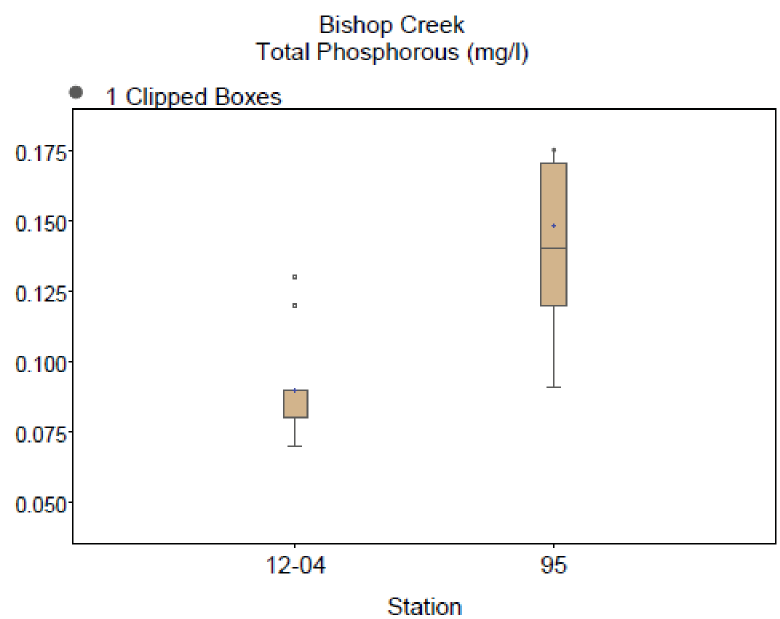
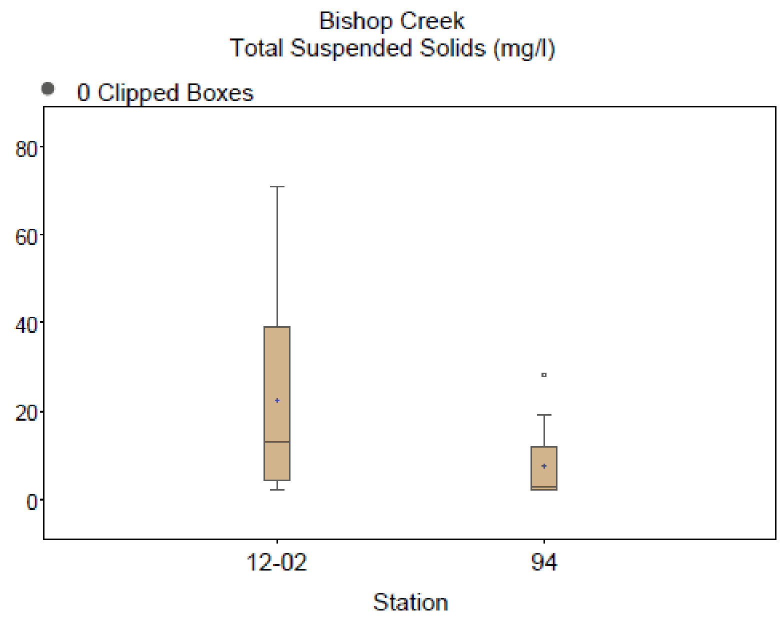


Figure 64. Box plots comparing distribution of total phosphorus in the north branch (Top) and south branch (Bottom) of Bishop Creek.



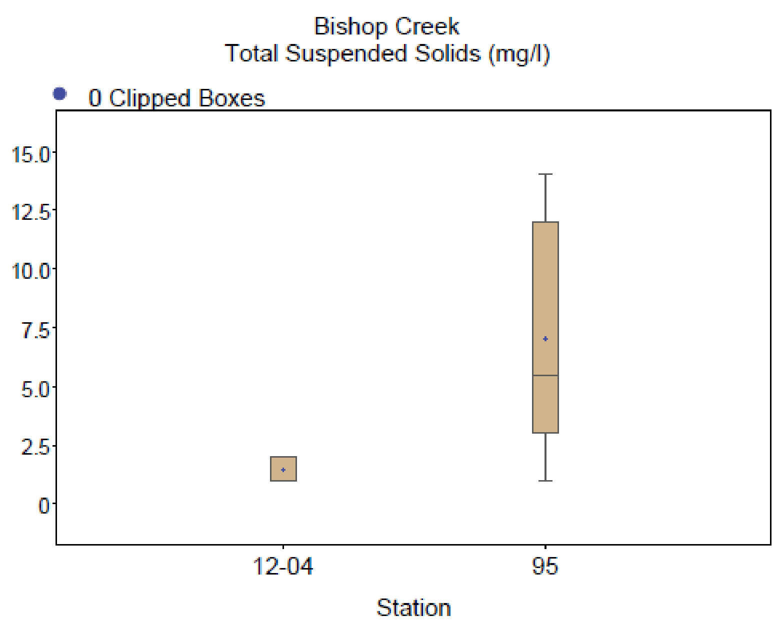
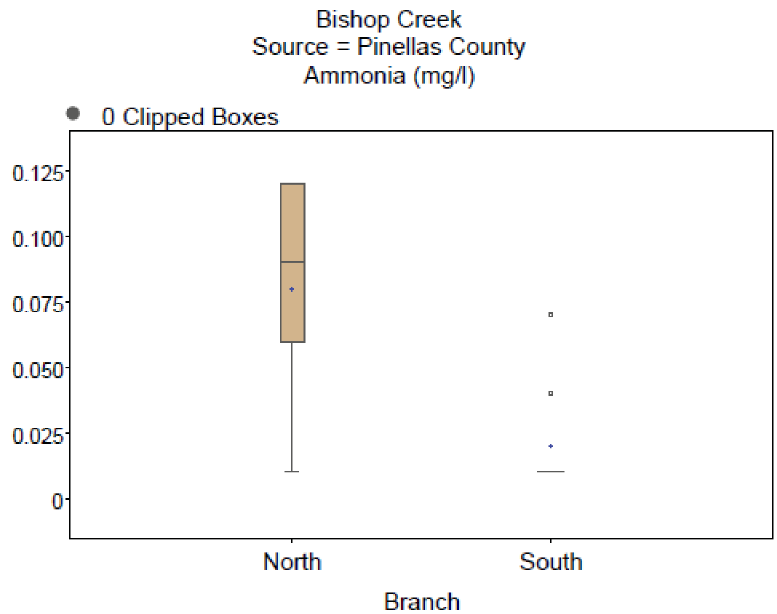


Figure 65. Box plots comparing distribution of total suspended solids in the north branch (Top) and south branch (Bottom) of Bishop Creek.



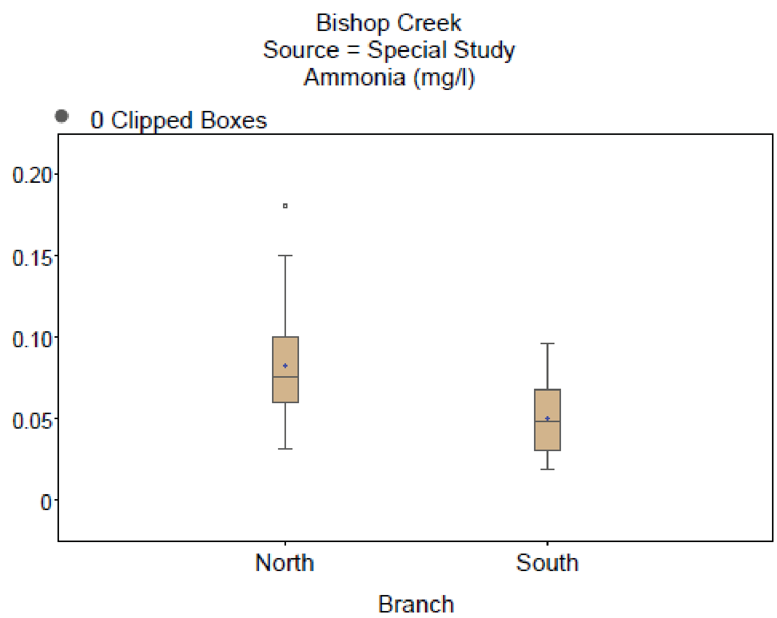
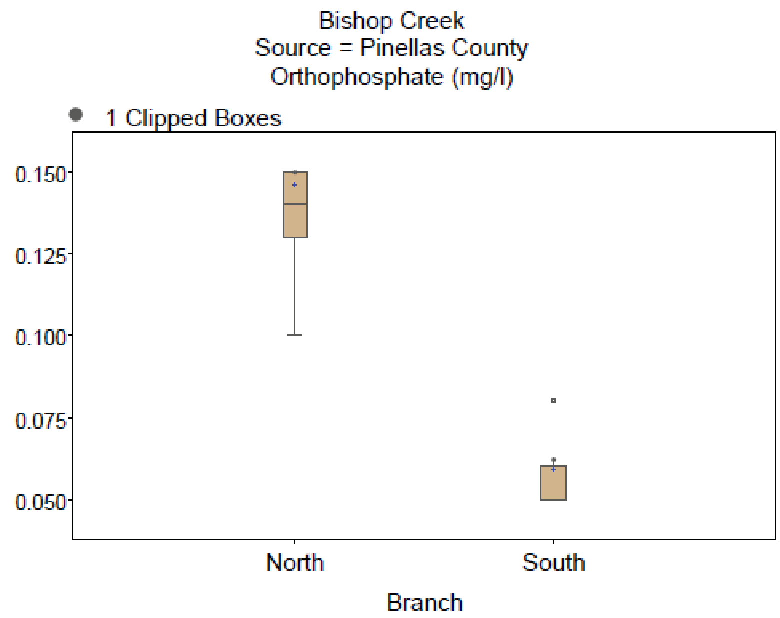


Figure 66. Box plots comparing distribution of Ammonia between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



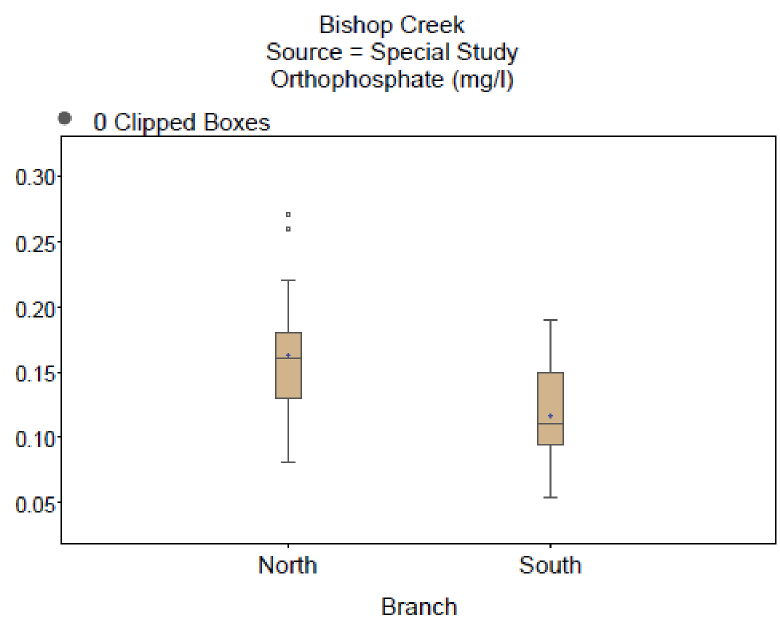
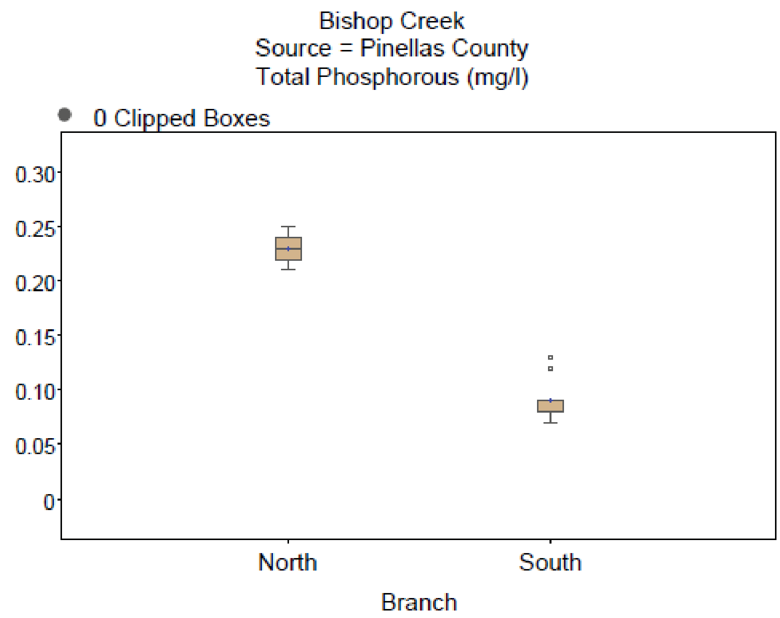


Figure 67. Box plots comparing distribution of orthophosphate between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



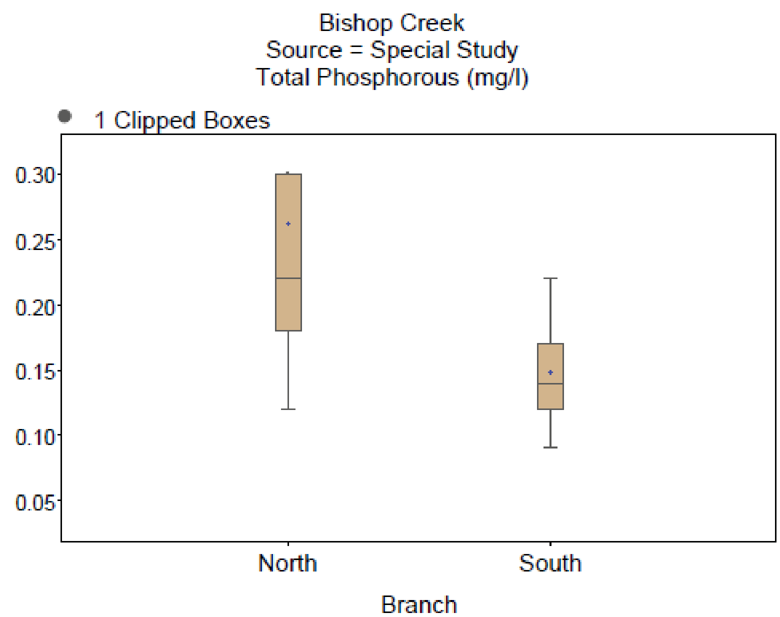
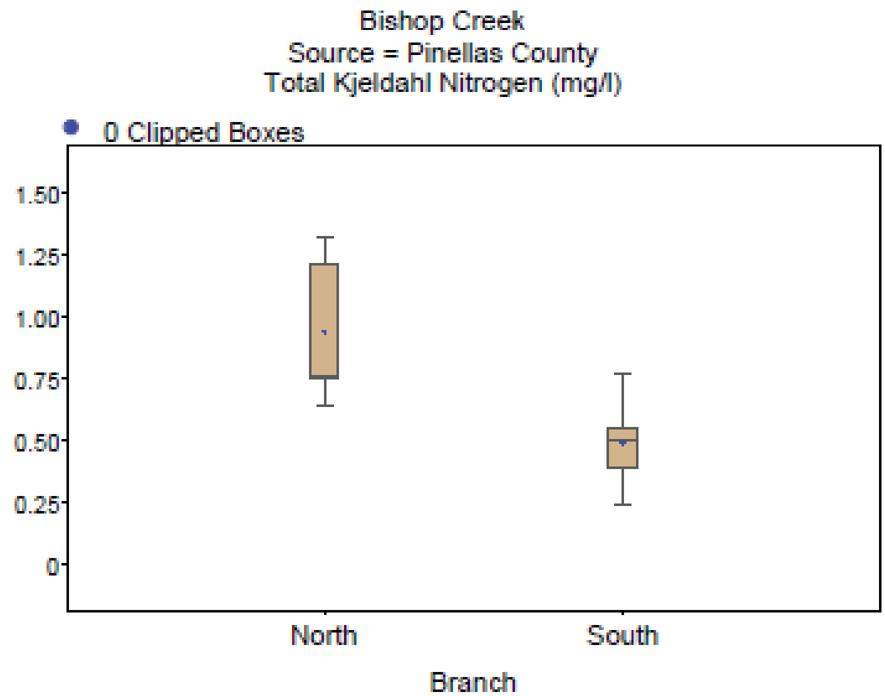


Figure 68. Box plots comparing distribution of total phosphorus between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



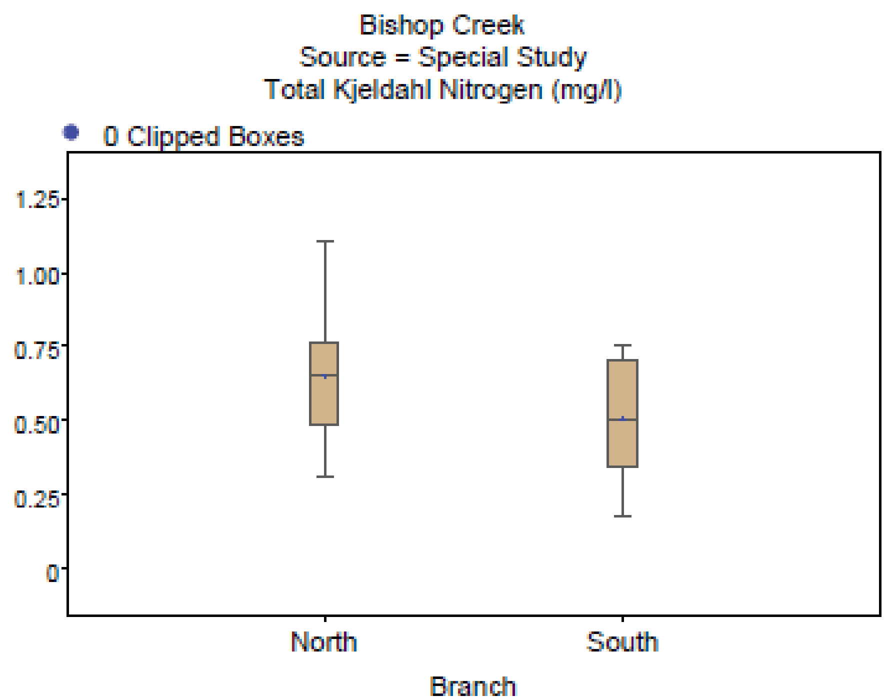
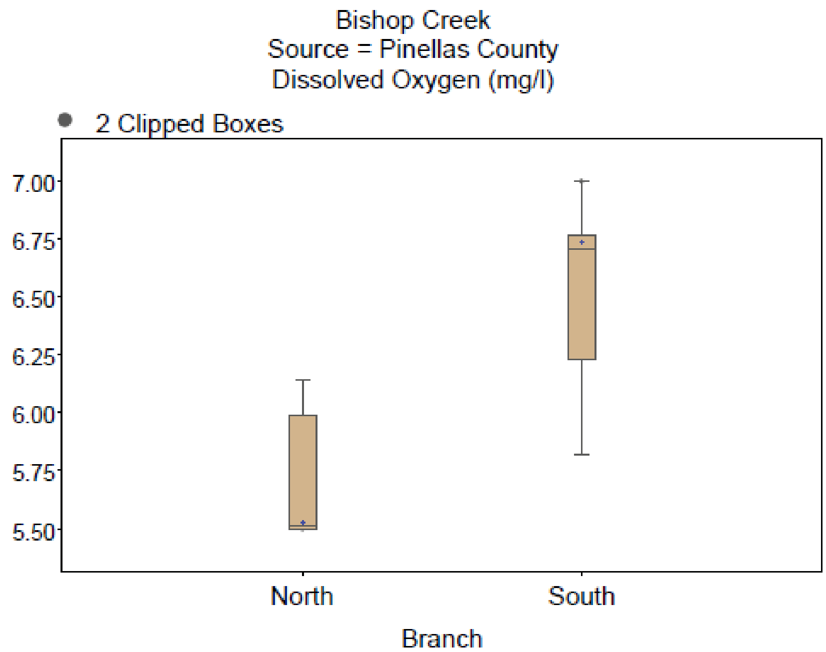


Figure 69. Box plots comparing distribution of total kjeldahl nitrogen between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



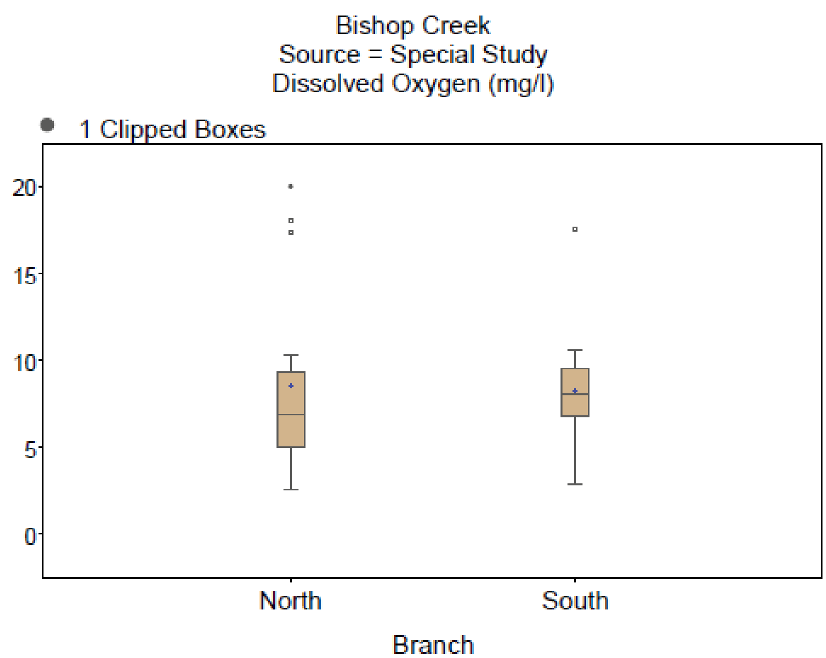
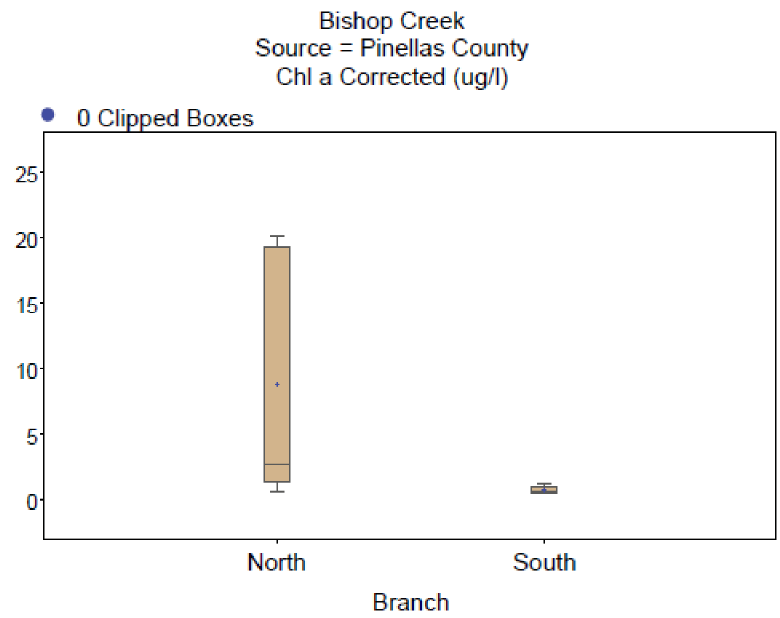


Figure 70. Box plots comparing distribution of dissolved oxygen between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



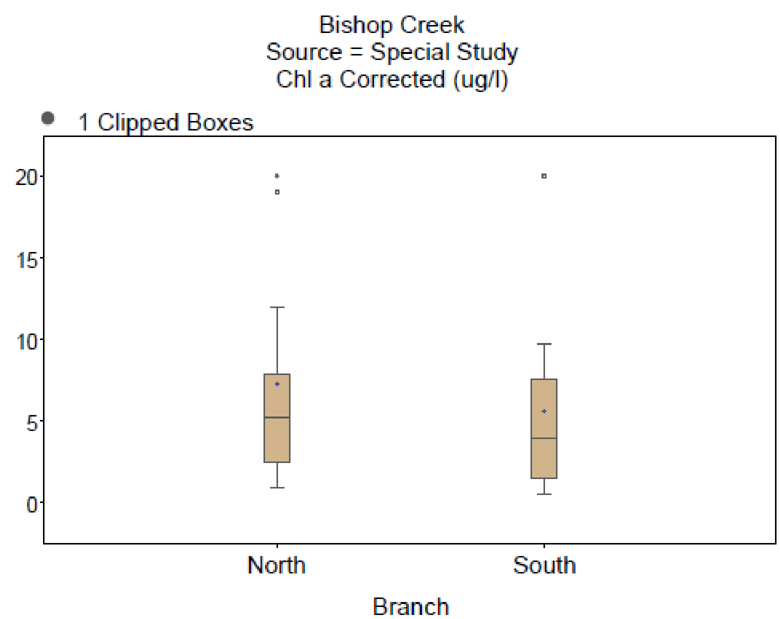
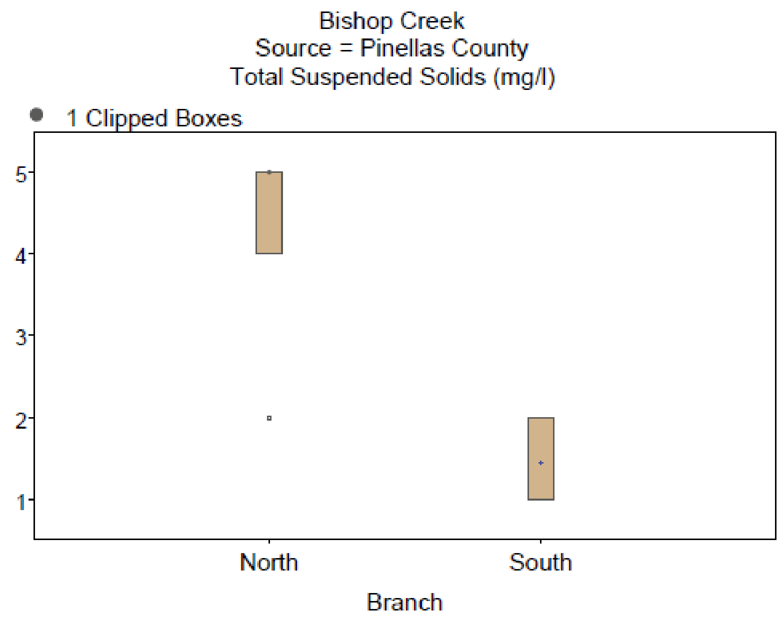


Figure 71. Box plots comparing distribution of chlorophyll a corrected between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



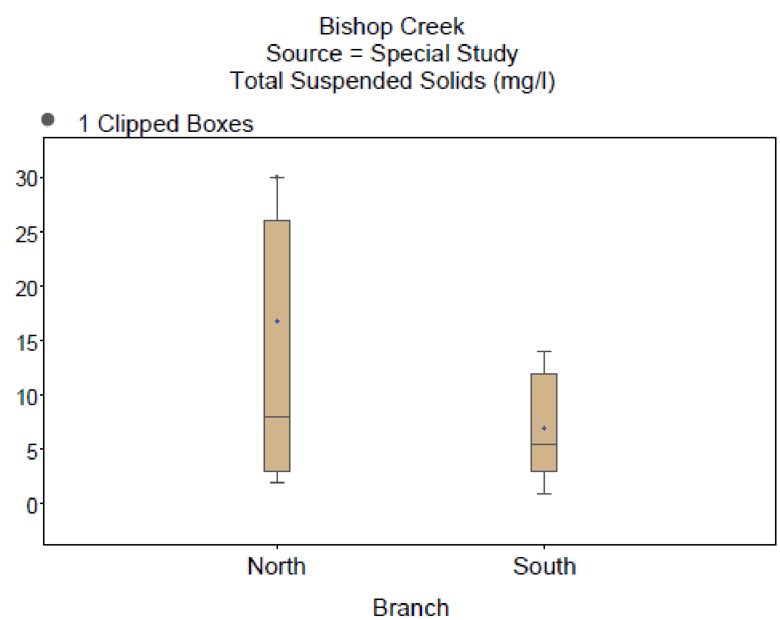
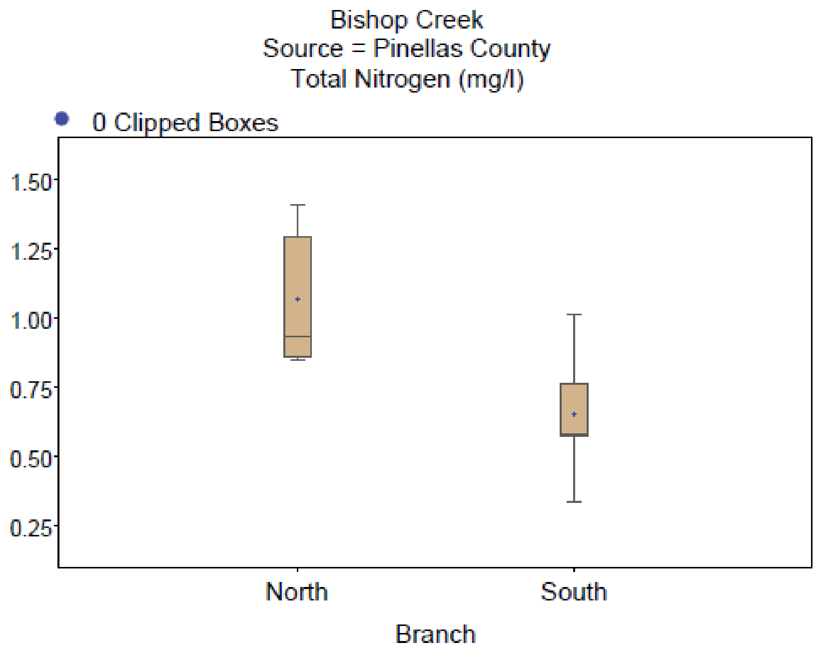


Figure 72. Box plots comparing distribution of total suspended solids between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).



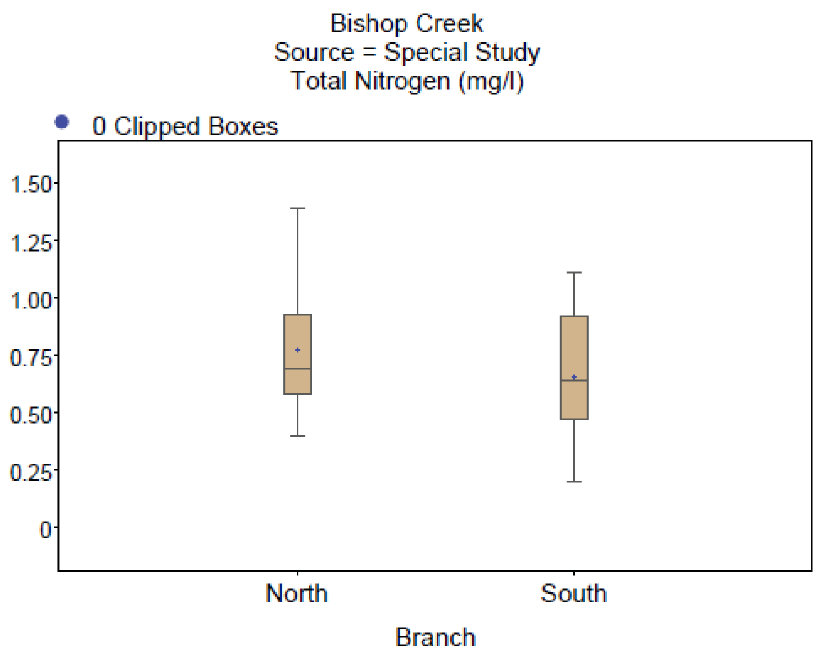


Figure 73. Box plots comparing distribution of total nitrogen between branches of Bishop Creek using the Pinellas County data (Top) and the special study data (bottom).

D.1.22 Summary

Based on the results of this study there are no indications that either Mullet or Bishop Creek are suffering a degree of anthropogenic impact that would result in adverse effects to their designated use. Despite dissolved oxygen levels that are in exceedance of state water quality standards, there is no evidence that excess nutrients of proliferation of phytoplankton or nuisance algae blooms are causative factors in the observed dissolved oxygen concentrations. Tidal creeks are expected to have lower dissolved oxygen concentrations than open bay systems or freshwater streams (Holland et al., 2004; Sherwood, 2008). The relative importance of allochthonous carbon (i.e., detritus from vascular plants, such as mangrove leaf litter, saltmarsh grasses, 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 (Janicki Environmental 2012). In the open estuary, autochthonous carbon is more important, but in the transitional waters of the tidal creeks and bayous, the contribution of allochthonous inputs to nutrient, chlorophyll, and DO dynamics may be more important (Janicki Environmental 2012). The noted increase in organic nitrogen in the most downstream strata evidenced in this study support those conclusions by suggesting that the extensive mangrove forests near the mouths of both of these creeks are contributing organic nitrogen to the systems.

The differential water quality dynamics observed between upstream and downstream stations in the south branch of Bishop Creek warrant further investigation. In particular, orthophosphate and total phosphorus concentrations were much higher at the downstream station established for this study compared to the upstream station monitored by Pinellas County. Possible explanations for this result include the potential for an intervening source between the two stations, or simply that waters from the north branch are mixing with the south branch waters. While this second explanation is possible it is unlikely given that these branches are located near the tidal head. Therefore, an inspection may be warranted in an attempt to identify potential sources in the south branch between these two locations.

The results of this study also suggest that total freshwater replacement time in these creeks may be longer than expected by stream channel morphology alone. The large area of emergent wetlands may hold large volumes of water that is exchanged over tidal cycles between the wetland and the creek channel but not necessarily flushed from the system. The hydrodynamic mechanisms by which this occurs have been described by Mazda et al. (2005) and are presented in Figure 74 below. In our study, the stability in the TN, TP and Chl a concentrations throughout the lower two sampling strata may be a result of this tidal recycling of the mixed fresh and estuarine waters. Since there appears to be little denitrification taking place within

the creek channels, the inorganic forms of these nutrients are likely derived from watershed inputs rather than denitrification. The inorganic forms of these nutrients were observed to be more readily taken with decreasing distance to the mouth of the creeks. However, it should be noted that there was no indication that the inorganic forms of nutrients are currently problematic with respect to designated use within either of these creeks.

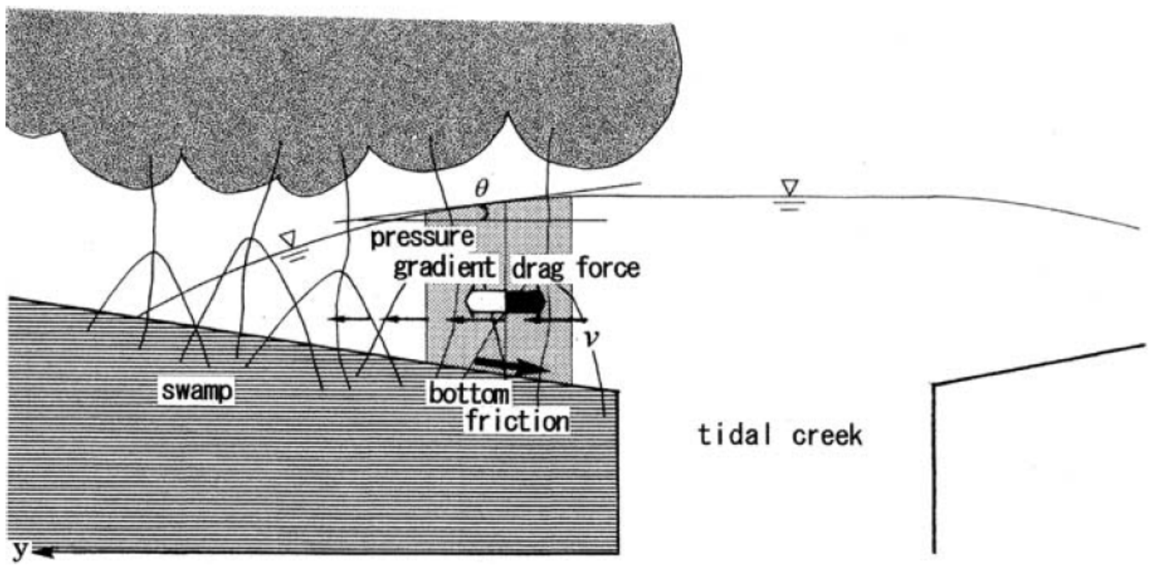


Figure 74. Hydrodynamic interactions between tidal creeks and mangrove forests as described by Figure 2 of Mazda et al. 2005

The stable isotope analysis suggested multiple forms of nitrogen assimilated by the creek biota and this makes sense given the stormwater retention areas feeding both creeks. However, there are also a few direct stormwater outfalls to the creeks. Proper stormwater pond maintenance would therefore seem to be a prudent aspect in ensuring future stewardship of these creeks.

D.2 Fish

Seventy-five (75) seine hauls were collected during the study period between September 2011 and August 2012. Fish sampling was suspended between March and June 2012 due to a necessary reallocation of effort into the water quality monitoring component of the study. In the remaining months, two samples were collected in the lower two strata of each creek and a single sample was performed in the uppermost strata of each creek. Seven of the seventy-five samples contained no fish. Additionally, five samples were not collected due to insufficient water depth in the uppermost stratum of Bishop Creek.

Sample collections were principally represented by resident species including diamond killifish (*Adinia xenica*), mosquitofish (*Gambusia holbrooki*), rainwater killifish (*Lucania parva*), and sailfin molly (*Poecilia latipinna*) which comprised the majority of the fish collected during the study period (Table 25). Resident species are thought to reside in or very near the tributaries throughout their entire life history. Conversely, estuarine dependent species utilize these tidal creeks during only a portion of their life history, typical as juveniles. The substantial number of red drum (*Sciaenops ocellatus*) collected indicates that these creeks are important recruitment areas for juvenile estuarine dependent species of economic importance. A few other notable estuarine dependent species collected included common snook (C*entropomus undecimalis*), pink shrimp (*Farfantepenaeus duorarum*), and Atlantic croaker (*Micropogonius undulates*), a fairly uncommon species in Tampa Bay fish collections.

Table 25. Taxon list and total number of animals collected by creek for fish and selected macroinvertebrates collected as part of the Mullet and Bishop Creek Studies 2011-2012.

Scientific Name	Common Name	Bishop	Mullet	Total
Adinia xenica (RP)	Diamond Killifish	463	0	463
Anchoa mitchilli (RP)	Bay Anchovy	9	252	261
Callinectessapidus (TD)	Blue Crab	7	6	13
Centropomus undecimalis (TC)	Common Snook	3	1	4
Cynoscion nebulosus (TC)	Spotted Seatrout	1	0	1
Cyprinodon variegatus (RP)	Sheepshead Minnow	98	18	116
Eucinostomus harengulus (RP)	Tidewater Mojarra	15	93	108
Farfantepenaeus duorarum (TD)	Pink Shrimp	2	4	6
Fundulus confluentus (RP)	Marsh Killifish	60	71	131
Fundulus grandis (RP)	Gulf Killifish	41	24	65
Fundulus similis (RP)	Longnose Killifish	25	0	25
Gambusia holbrooki (RP)	Mosquitofish	148	557	705
Gobiosoma spp. *(RP)*	Goby	5	39	44
Harengula jaguana (TP)	Scaled Sardine	0	1	1
Leiostomus xanthurus (TC)	Spot	2	36	38
Lepomis macrochirus (RC)	Bluegill	2	1	3
Lucania parva (RP)	Rainwater Killifish	80	365	445
Menidia spp. *(RP)*	Silversides	439	302	741
Micropogonias undulatus (TC)	Atlantic Croaker	3	0	3
Micropterus salmoides (RC)	Large Mouth Bass	4	8	12
Mugil cephalus (TD)	Striped Mullet	3	3	6
Opisthonema oglinum (TP)	Threadfin Herring	0	1	1
Palaemontes pugio (RD)	Daggerblade Grass shrimp	82	687	769
Poecilia latipinna (RP)	Sailfin Molly	309	330	639
Sciaenops ocellatus (TC)	Red Drum	46	210	256
Trinectes maculatus (RD)	Hogchoker	10	37	47

Note: Letter in parentheses following species names indicate: R=resident T=transient P=planktivore (including benthic micro algae) D=detritivore C=Carnivore.

The length frequency statistics for the fish species collected in Mullet and Bishop Creek are provided in Table 26.

Table 26. Length frequency statistics (minimum, median, and maximum standard lengths in millimeters) for fish species collected in Bishop and Mullet Creek

Species Name	Bishop Creek			Mullet Creek		
	minsl	medsl	maxsl	minsl	medsl	maxsl
Adinia xenica	11	22	31	-	-	-
Anchoa mitchilli	21	26	27	23	38	50
Callinectes sapidus	18	67	116	17	51	96
Centropomus undecimalis	36	37	41	31	31	31
Cynoscion nebulosus	60	60	60	-	-	-
Cyprinodon variegatus	16	24	45	20	23.5	40
Eucinostomus harengulus	20	36	51	16	34	72
Fundulus confluentus	16	42	85	29	45	115
Fundulus grandis	21	52	72	44	52	60
Fundulus similis	11	19	28	-	-	-
Gambusia affinis	8	22	42	15	22	34
Gobiosoma bosc	22	32.5	42	14	31	53
Harengula jaguana	-	-	-	31	31	31
Leiostomus xanthurus	67	67	67	27	60	71
Lepomis macrochirus	40	56	72	70	70	70
Lucania parva	14	29	41	14	27	55
Menidia spp.	19	45	72	20	41	62
Micropogonias undulatus	33	35	37	-	-	-
Micropterus salmoides	88	115	163	58	67	96
Mugil cephalus	70	83	90	85	88	94
Opisthonema oglinum	-	-	-	48	48	48
Poecilia latipinna	13	26	60	12	39	65
Sciaenops ocellatus	18	37	68	12	36	93
Trinectes maculatus	14	17.5	70	7	17	59

The lowest total fish catch occurred in the most upstream (lowest salinity) stratum in both creeks (Figure 75). In the lower portion of the creeks, fish catch tended to be higher in the most downstream stratum in Mullet Creek and the middle stratum in Bishop Creek.

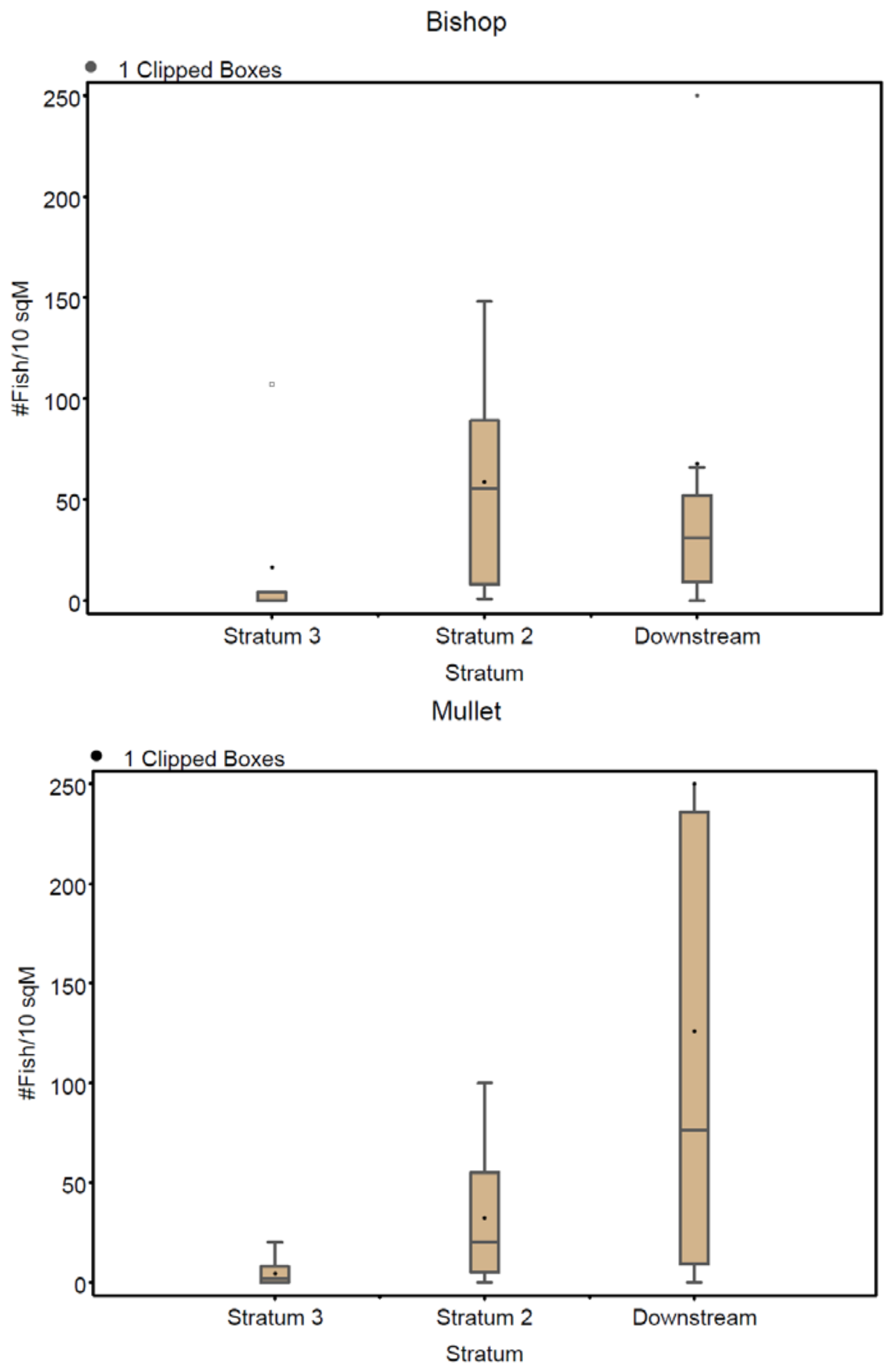


Figure 75. Distribution of total fish catch in each stratum of Bishop and Mullet Creeks.

Interestingly, no species was caught in every month of sampling (Tables 27 and 28) though several species were captured in all strata within each creek (Tables 29 and 30). Species captured in all strata included many of the resident cyprinodont family that is widely known to be euryhaline and capable of withstanding large variation in salinity. Resident species also exhibited some of the highest catch frequencies, occurring in ca. 30%-40% of the samples (Tables 31 and 32). Silversides (*Menidia* spp.) were among the most frequently collected taxa, represented in between 30% and 50% of the total number of samples in each creek though they utilize both tidal creek and adjacent open estuary habitats and are therefore not strictly resident species.

Most of the species of economic value are considered estuarine dependent, spending only a portion of their life history within the system or transiting among multiple estuarine habitats within a year. While resident species were commonly collected and represented the largest proportion of the total catch, transient species were also captured in notable abundance. Red drum in particular is a pulse recruiting species of local economic importance that recruit to Tampa Bay tidal tributaries in October/November and utilize these habitats as nursery and refugia. Red drum was captured in approximately 20% of all samples in Mullet and Bishop Creeks and was present in each month between November and February. Red drum also represented approximately 5% of the total number of individuals collected in the study. They were predominantly captured in the lower portions of both systems where the salinities were higher and the shorelines were dominated by mangrove fringe along the creek bank. Assuming that no differential mortality existed between these creeks and others in Tampa Bay, the fact that red drum occurred in four months of sampling is a good indication that these creeks are functioning as an important nursery area to support juvenile red drum in Tampa Bay.

Notably absent from the catch were *Lagodon rhomboides* (pinfish), recruitment age *Mugil cephalus* (Striped Mullet), *Leiostomus xanthurus* (Spot), and *Cynoscion arenarius* (Sand Seatrout). This is likely an artifact of the gap in fish collections between March and June when these species tend to recruit to Tampa Bay tidal tributaries.

Multivariate Analysis of Similarity (PRIMER V6: Clarke and Gorley 2006), was used to test for significant differences in community structure between Mullet and Bishop Creek. There was not a statistically significant difference between creeks (alpha=0.05). There was also low correlation between community structure and water quality indicators. The Best procedure in PRIMER was used to evaluate rank correlations between multivariate community structure and water quality indicators in stepwise fashion selecting the "best" combination of water quality variables that explained variation in community structure. The four variable combination of water quality indicators most correlated with community structure included stream velocity,

total Kjeldahl nitrogen (TKN), nitrate-nitrite (NOx), and orthophosphate (OPO4); however, the Spearman's Rho value was low (Rho= 0.23) indicating much of the variation in community structure was unexplained by water quality.

In addition to the multivariate analysis, overall catch per unit effort, number of species per haul, and several indices of diversity including Shannon Wiener, Margalef's, Pielou's, and Simpson indices were examined as potential univariate indicators of water quality. Direct stressor response relationships between water quality and these indices were not readily apparent based on analysis of individual samples. There was substantial variability between samples that affected the ability to draw inferences on these responses directly. For example, in Figure 76, Pielou's evenness values based on individual samples were plotted against NOx concentrations and display a decreasing trend in evenness with increasing NOx concentrations, especially in Bishop Creek which had higher values of NOx. However, there is substantial variability in this relationship that would result in weak inference as to the true underlying relationship between the stressor (NOx) and biotic response. Similarly, evenness appeared to decline as a function of increasing turbidity concentrations (Figure 77).

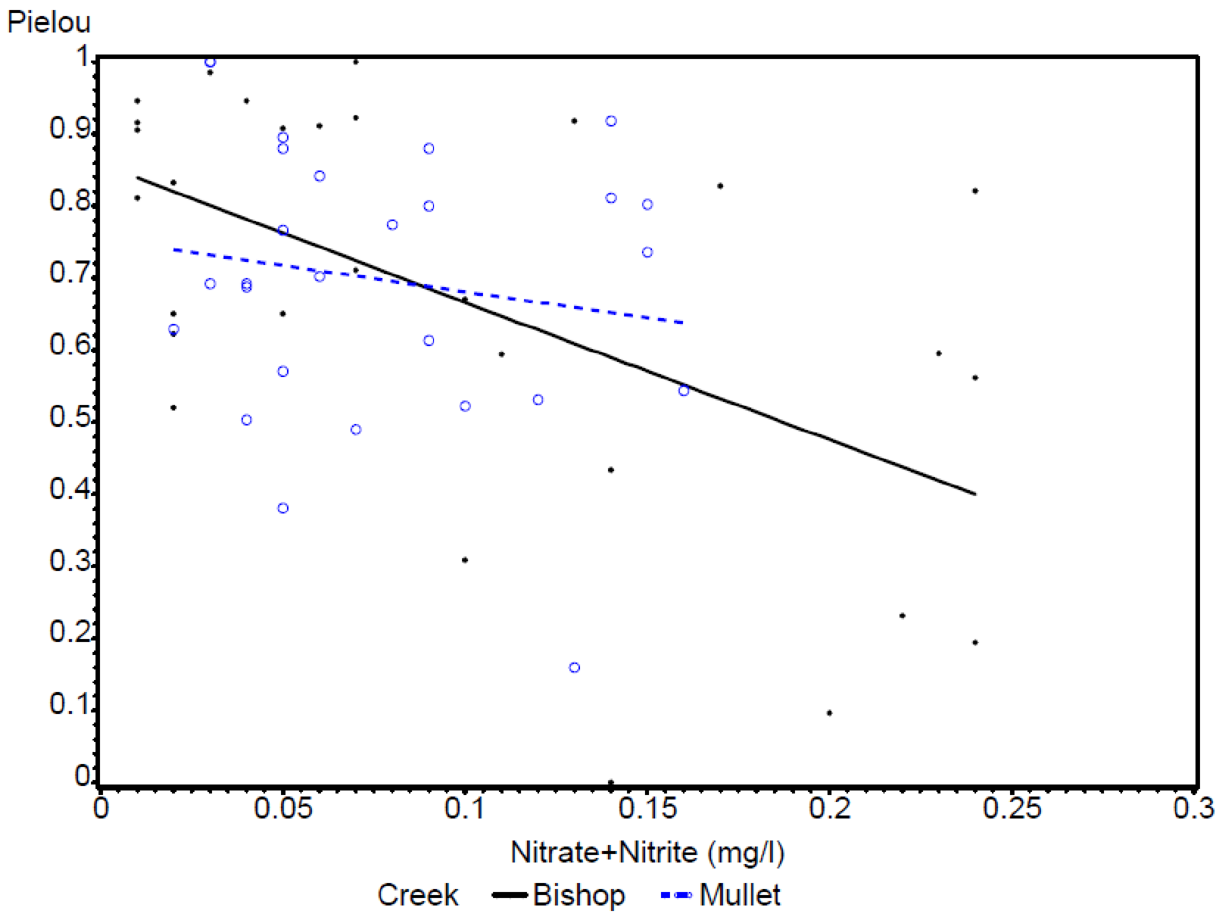


Figure 76. Bivariate plot of Pielou's index values and Nitrate Nitrite concentrations measured coincident with the fish samples. Linear regression slopes are provided to help visualize the underlying trend in the data.

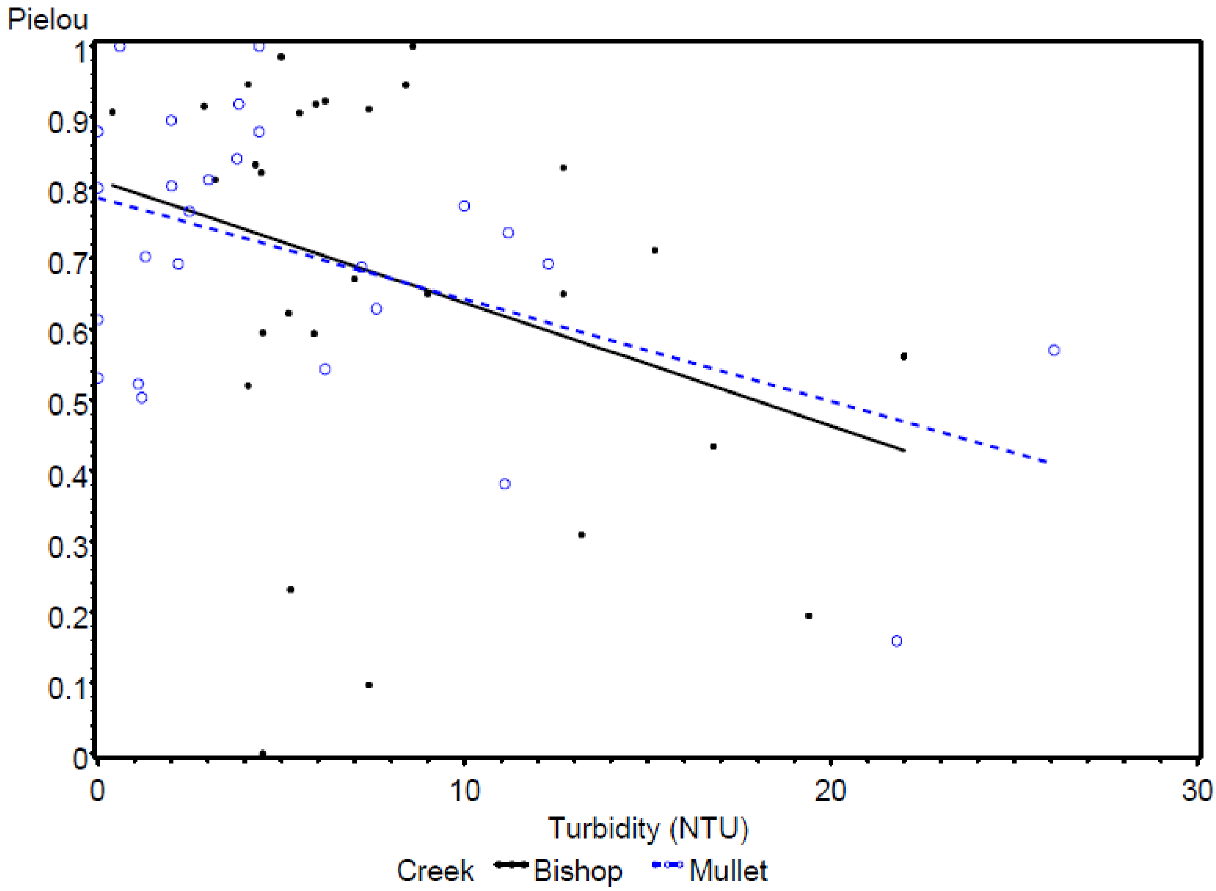


Figure 77. Bivariate plot of Pielou's index values and Turbidity values measured coincident with the fish samples. Linear regression slopes are provided to help visualize the underlying trend in the data

Table 27. Number of individuals captured by month during the study period in Bishop Creek.

Species Name	Sep	Oct	Nov	Dec	Jan	Feb	Mar - Jun	Jul	Aug
Adinia xenica	0	462	0	0	0	1	No Sampling	0	0
Anchoa mitchilli	0	0	0	0	0	0		9	0
Callinectes sapidus	1	1	1	1	0	3		0	0
Centropomus undecimalis	0	0	0	0	0	0		0	3
Cynoscion nebulosus	0	0	0	0	0	0		0	1
Cyprinodon variegatus	9	12	26	36	14	1		0	0
Eucinostomus harengulus	1	6	3	0	0	0		1	4
Farfantepenaeus duorarum	1	1	0	0	0	0		0	0
Fundulus confluentus	5	13	0	22	2	6		0	12
Fundulus grandis	2	2	20	0	11	0		0	6
Fundulus similis	0	25	0	0	0	0		0	0
Gambusia holbrooki	6	77	21	0	2	33		1	8
Gobiosoma spp.	0	0	0	2	2	0		1	0
Leiostomus xanthurus	2	0	0	0	0	0		0	0
Lepomis macrochirus	1	0	0	0	0	0		1	0
Lucania parva	0	9	0	19	6	28		0	18
Menida spp.	113	14	24	0	13	109		9	157
Micropogonias undulatus	0	0	3	0	0	0		0	0
Micropterus salmoides	1	0	0	0	0	0		3	0
Mugil cephalus	0	2	0	0	0	0		0	1
Palaemonetes pugio	0	44	1	0	0	37		0	0
Poecilia latipinna	0	142	117	0	11	14		0	25
Sciaenops ocellatus	0	2	21	9	5	9		0	0
Trinectes maculatus	0	2	4	0	0	2		1	1

Table 28. Number of individuals captured by month during the study period in Mullet Creek.

Species Name	Sep	Oct	Nov	Dec	Jan	Feb	Mar-Jun	Jul	Aug
Anchoa mitchilli	0	0	0	0	0	47	No Sampling	0	205
Callinectes sapidus	0	1	0	5	0	0		0	0
Centropomus undecimalis	0	1	0	0	0	0		0	0
Cyprinodon variegatus	0	0	0	17	0	1		0	0
Eucinostomus harengulus	0	0	21	0	18	8		11	35
Farfantepenaeus duorarum	0	0	1	2	1	0		0	0
Fundulus confluentus	9	24	1	20	0	16		1	0
Fundulus grandis	0	0	1	0	17	6		0	0
Gambusia holbrooki	31	200	1	287	38	0		0	0
Gobiosoma spp.	1	2	19	6	5	3		2	0
Harengula jaguana	0	0	0	0	0	1		0	0
Leiostomus xanthurus	5	24	0	0	0	5		1	0
Lepomis macrochirus	1	0	0	0	0	0		0	0
Lucania parva	0	0	50	116	24	172		3	0
Menida spp.	94	0	16	31	12	76		69	4
Micropterus salmoides	0	1	0	0	0	0		6	1
Mugil cephalus	0	3	0	0	0	0		0	0
Opisthonema oglinum	0	0	0	0	0	1		0	0
Palaemonetes pugio	7	38	67	125	424	26		0	0
Poecilia latipinna	31	223	48	2	2	22		2	0
Sciaenops ocellatus	0	10	116	29	2	53		0	0
Trinectes maculatus	1	2	11	16	4	3		0	0

Table 29. Number of individuals captured by stratum during the study period in Bishop Creek.

Species Name	Stratum 1	Stratum 2	Stratum 3
Adinia xenica	93	370	0
Anchoa mitchilli	6	3	0
Callinectes sapidus	3	2	2
Centropomus undecimalis	0	3	0
Cynoscion nebulosus	0	1	0
Cyprinodon variegatus	16	81	1
Eucinostomus harengulus	6	9	0
Farfantepenaeus duorarum	0	2	0
Fundulus confluentus	21	36	3
Fundulus grandis	17	24	0
Fundulus similis	0	25	0
Gambusia holbrooki	104	4	35
Gobiosoma spp.	2	2	1
Leiostomus xanthurus	0	2	0
Lepomis macrochirus	0	0	2
Lucania parva	19	38	23
Menida spp.	307	103	29
Micropogonias undulatus	0	3	0
Micropterus salmoides	0	0	4
Mugil cephalus	2	1	0
Palaemonetes pugio	27	42	13
Poecilia latipinna	185	119	5
Sciaenops ocellatus	15	31	0
Trinectes maculatus	2	8	0

Table 30. Number of individuals captured by stratum during the study period in Mullet Creek.			
Species Name	**Stratum 1**	**Stratum 2**	**Stratum 3**
Anchoa mitchilli	60	192	0
Callinectes sapidus	1	5	0
Centropomus undecimalis	0	1	0
Cyprinodon variegatus	0	18	0
Eucinostomus harengulus	28	64	1
Farfantepenaeus duorarum	0	4	0
Fundulus confluentus	13	57	1
Fundulus grandis	1	23	0
Gambusia holbrooki	113	185	259
Gobiosoma spp.	13	15	10
Harengula jaguana	0	1	0
Leiostomus xanthurus	5	30	0
Lepomis macrochirus	0	0	1
Lucania parva	102	263	0
Menida spp.	142	152	8
Micropterus salmoides	7	0	1
Mugil cephalus	3	0	0
Opisthonema oglinum	1	0	0
Palaemonetes pugio	157	518	12
Poecilia latipinna	36	293	1
Sciaenops ocellatus	10	199	1
Trinectes maculatus	18	16	3

Table 31. Individual species percent occurrence in each stratum in Bishop Creek.

Species Name	Stratum 1	Stratum 2	Stratum 3	% Occurrence
Adinia xenica	15	21	0	15
Anchoa mitchilli	0	7	0	3
Callinectes sapidus	8	21	14	15
Centropumus undecimalis	15	0	0	6
Cynoscion nebulosus	8	0	0	3
Cyprinodon variegatus	62	29	14	38
Eucinostomus harengulus	23	36	0	24
Farfantepenaeus duorarum	15	0	0	6
Fundulus confluentus	23	57	14	35
Fundulus grandis	38	29	0	26
Fundulus similis	8	0	0	3
Gambusia affinis	0	0	14	3
Gambusia holbrooki	15	43	29	29
Gobiosoma spp.	0	14	14	9
Harengula jaguana	0	0	0	0
Leiostomus xanthurus	15	0	0	6
Lepomis macrochirus	0	0	14	3
Lucania parva	31	36	14	29
Menida spp.	62	57	29	53
Micropogonias undulatus	8	0	0	3
Micropterus salmoides	0	0	14	3
Mugil cephalus	8	7	0	6
Opisthonema oglinum	0	0	0	0
Palaemonetes pugio	23	29	14	24
Poecilia latipinna	31	50	14	35
Sciaenops ocellatus	31	21	0	21
Trinectes maculatus	38	14	0	21

Table 32. Individual species percent occurrence in each stratum in Bishop Creek.				
Species Name	**Stratum 1**	**Stratum 2**	**Stratum 3**	**% Occurrence**
Adinia xenica	0	0	0	0
Anchoa mitchilli	14	21	0	14
Callinectes sapidus	14	7	0	8
Centropumus undecimalis	7	0	0	3
Cynoscion nebulosus	0	0	0	0
Cyprinodon variegatus	7	0	0	3
Eucinostomus harengulus	43	29	0	27
Farfantepenaeus duorarum	21	0	0	8
Fundulus confluentus	36	29	11	27
Fundulus grandis	21	7	0	11
Fundulus similis	0	0	0	0
Gambusia affinis	0	14	0	5
Gambusia holbrooki	29	29	22	27
Gobiosoma spp.	36	29	22	30
Harengula jaguana	7	0	0	3
Leiostomus xanthurus	29	0	0	11
Lepomis macrochirus	0	0	11	3
Lucania parva	43	21	0	24
Menida spp.	50	36	11	35
Micropogonias undulatus	0	0	0	0
Micropterus salmoides	0	21	0	8
Mugil cephalus	0	7	0	3
Opisthonema oglinum	0	7	0	3
Palaemonetes pugio	43	29	33	35
Poecilia latipinna	57	43	11	41
Sciaenops ocellatus	43	21	11	27
Trinectes maculatus	29	36	22	30

D.2.1 Metric Recommendations

One objective of this study was to use the fish data to develop recommendations for metrics that could be used to evaluate the relationship between water quality and ecological integrity of these tidal creeks. Based on the information available as part of this study, several recommendations are made in the following paragraphs.

The scale of inference is of primary importance in considering how the nekton community responds to variation in tidal creek water quality. The types of effects that nutrient pollution has on nekton can be characterized as either acute effects or chronic effects. The FDEP has used dissolved oxygen threshold concentrations as one measure of acute effects on biota in Florida waters. Chronic effects of nutrient pollution might change the dominant forms of primary producers in the tidal creek and thereby alter community structure of tidal creeks relative to those creeks with lesser nutrient inputs. For resident species that occupy the creeks throughout the year and typically reproduce more than once annually, population dynamics are likely controlled by chronic effects to the extent that water quality exerts any control over their population dynamics (predation and interspecies competition are other controlling factors). For transient species (which tend to be secondary consumers), the conditions available at the time of recruitment to the tidal creek are more likely to govern the success of these taxa. These conditions include the suitability of water quality conditions as well as the availability of prey resources forming the base of the food web upon which they depend. The ability to appropriately capture these stressor-response relationships will therefore require careful consideration of the scale on which these factors interact.

Burghart et al. (2013) compared spring fed and surface fed estuaries in southwest Florida and found that benthic feeding taxa that utilize benthic microalgae as a basal resource were strong indicators of oligotrophic spring fed estuaries whereas, plankton feeders were indicators of more nutrient enriched surface water fed systems. They suggested that strong breakpoints exist between these systems which are related to the availability of benthic production. These results support other efforts to identify community level indicators of ecological integrity and eutrophication in southwest Florida tidal tributaries. These metrics tend to integrate samples over either space or time or both to characterize broad scale conditions of system state (i.e., chronic effects).

Beta diversity is another metric being considered by Burghart et al. (2013) to characterize diversity across the ecological gradients. Beta diversity characterizes the change in diversity of species that exists from one environment to another. In the case of tidal tributaries, beta diversity could be used to characterize the change in species along a salinity gradient within the tidal portion of the tributary. Low beta diversity might suggest eutrophication or compromised

ecological integrity relative to systems with greater diversity of species along the salinity gradient.

Wessel (2011) developed a method of evaluating environmental favorability for species common to Tampa Bay's Alafia River and examined the effects of variations in freshwater inflow on favorability for a suite of species including resident taxa and transient recruiting species. The method uses presence and absence data to develop expectations for the utilization of tidal river habitats and accounts for species-specific salinity and physical habitat preferences. This method could be adapted to examine deviations from those expectations as a function of water quality conditions within tidal creeks as another means of identifying compromised ecological integrity due to nutrient pollution.

Whichever method is used to associate nekton ecological integrity with water quality conditions must account for a host of interacting processes that affect their utilization and success in the tidal tributaries. Indices seem to be a logical choice as a biological response metric due to the fact that they integrate information across space or time at time scales relevant to expected changes in nekton community structure. However, indices are not without their drawbacks as their exact definition with respect to ecological integrity can be somewhat ambiguous. For example, Pielou's evenness is affected negatively by large abundances of a particular species. If that species is red drum, there seemingly should be no negative consequence to ecological integrity. Shannon Wiener diversity is the most common diversity index used but was not sensitive to changes in water quality in this study. Aggregating data to the monthly time scale would result in only 8 data points per creek, too few to draw inferences from. However, these data serve as an important contribution to a larger dataset being gathered throughout southwest Florida tidal tributaries which together will provide a robust set of information from which to identify targets and thresholds that can be used to guide management decisions on regulating nutrient delivery to southwest Florida tidal creeks.

D.3 Benthic Microalgae

Benthic microalgae community (BMAc) biomass is an essential component of the productivity pathways and food webs in tidal tributary systems (Malkin, 2010; TBTTRT, 2008). Benthic microalgae production is driven by photosynthesis so shallow tidal tributary systems are ideal for their growth, especially where hydrologic characteristics are favorable. Flashy or sudden peak systems which alter the morphology of the tidal system can adversely affect BMAC biomass. As described in the design document (Appendix A), BMAC richness is indicated by corrected chlorophyll-a concentrations in the top 1-cm of sediment. The BMAC sampling results for Bishop and Mullet Creek are presented in Table 33 below.

Bishop Creek	Max	6112.8
	Min	3.0
	Median (µg/L)	606.9
	Median (fall)	953.8
	Median (winter)	346.8
Mullet Creek	Max	6199.5
	Min	3.0
	Median (µg/L)	476.9
	Median (fall)	585.3
	Median (winter)	433.5

Table 34. BMAC results for Bishop and Mullet Creeks

Due to the way the samples are processed, there were some results with negative values. Per EPC's recommendations, those values were assigned the maximum detection limit (MDL) of 3.0 µg/L. The maximum readings for both systems were similar in value and both were recorded for samples taken on the same day (10/12/11). According to EPC, these high readings may indeed be accurate readings, or they may be simple data outliers. There was no indication in the field of any site conditions which would account for these high readings. The test for the BMAC samples is spectro-photometric, which measures the absorbance at a specific wavelength. In preparing the samples, effects of other compounds are minimized but not eliminated, and abnormal results may just be outliers due to interferences.

The literature (TBTTRT, 2008) indicates seasonal variances in BMAC values, between fall/wet season and spring/dry season, samples. The BMAC samples in this study were only split between late wet season and dry season. In the previous tidal tributary work in Tampa Bay (TBTTRT, 2008), the fall/wet season BMAC values were reduced, however in this study median values in both creeks were higher in late fall than those in the dry season. A reason for this may be that the wet season samples were taken much later/closer to the dry season, than those in the previous study. There are not enough data to fully investigate this discrepancy in seasonality.

The median values in both creeks overall were in line with values obtained during previous tidal tributary studies (Sherwood et al, 2007; TBTTRT, 2008), indicating that Bishop and Mullet Creek are functioning similar to the tidal creeks in those studies in regards to benthic microalgae production. However, making a definitive statement regarding the health of the Bishop and

Mullet systems with regards to benthic microalgal production is difficult because of the limited dataset.

The BMAC values were highly variable spatially within both Bishop and Mullet Creek as evidence in (Figure 78 and 79, respectively). This is a novel method being pursued to link tidal creek production to basal resources. Results of this study suggest that compositing multiple samples taken across the channel at the same site should be considered in future efforts to estimate benthic chlorophyll production in tidal creeks to reduce the sample to sample variability evident in data collected from this special study.

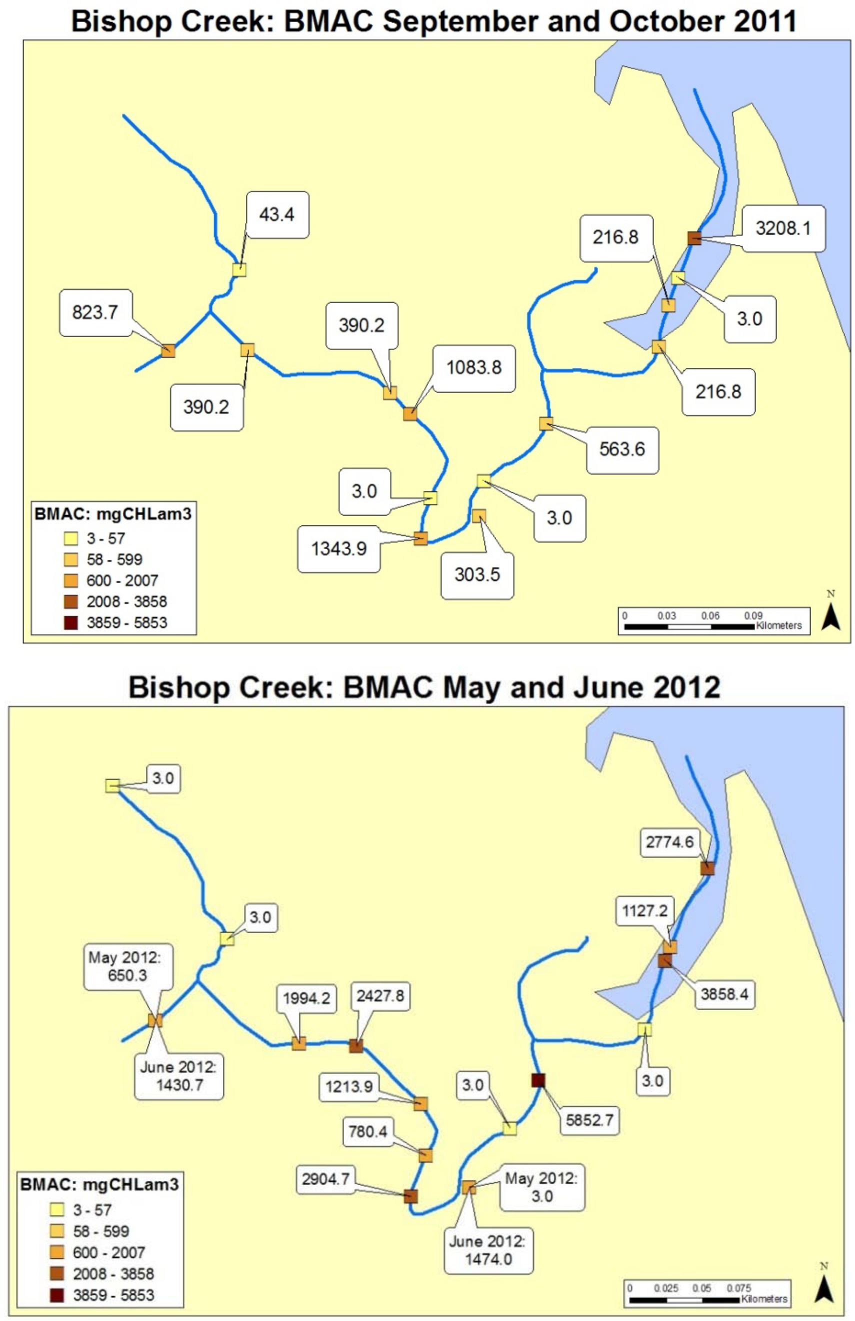
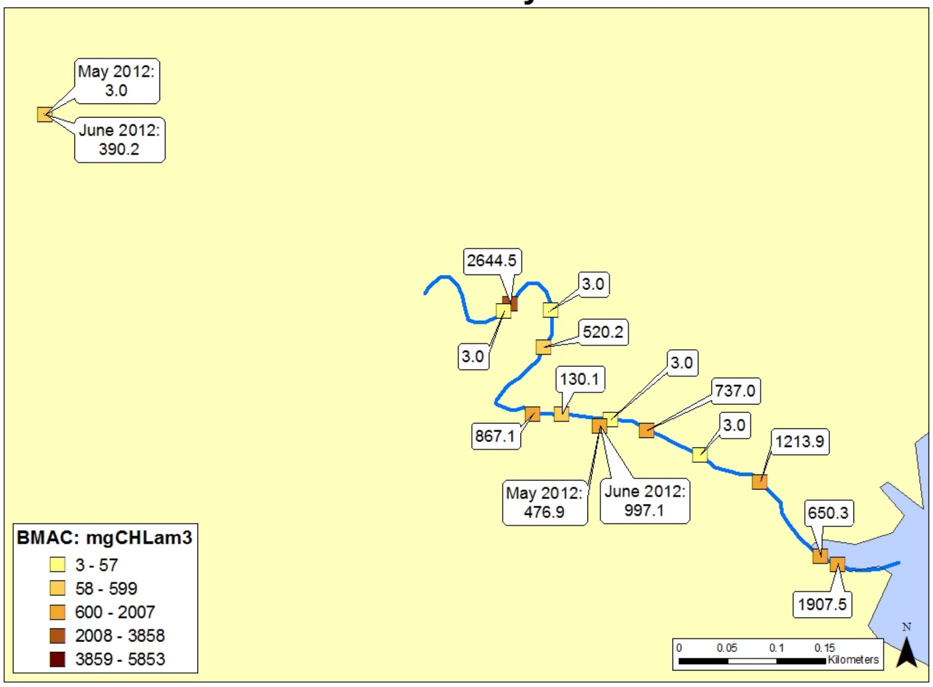


Figure 78. Results of Fall 2011 and Spring 2012 BMAc sampling in Bishop Creek

Mullet Creek: BMAC May and June 2012



Mullet Creek: BMAC September and October 2011

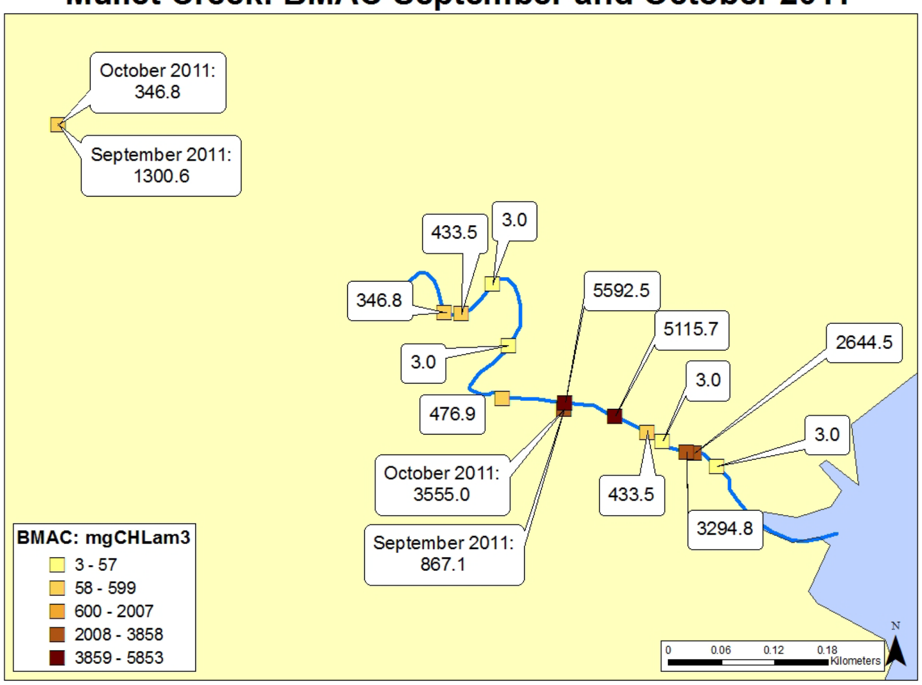


Figure 79. Results of Fall 2011 and Spring 2012 BMAc sampling in Mullet Creek

D.4 Isotope Analysis

There were no apparent differences in vascular-plant $\delta^{15}N$ between Bishop and Mullet Creeks (Figure 80, top panel). The range of $\delta^{15}N$ observed in vascular plants was large, having low values that correspond to inputs from inorganic (Haber-Bosch) fertilizer or atmospheric N2 fixation by cyanobacteria, and high values that are indicative of nitrogen from sewage or animal waste (i.e. the sources of fixed nitrogen to the creeks were mixed). There were no high chl a values (i.e. >30 ug/l) present in the water sampling results, implying that the low values weren't associated with the presence of cyanobacteria. Consumer isotopes were more tightly grouped than vascular plant isotopes (Figure 80, bottom panel). The lowest δ15N value for a consumer came from a fiddler crab (*Uca* sp.) (1.5‰), which is a detritivore and primary consumer of BMA that might also ingest nitrogen-fixing cyanobacteria (Currin et al., 1995). The highest $\delta^{15}N$ values occurred in planktivorous fish such as the leatherjack (*Oligoplites saurus*), (11.5‰) and larger (>100 mm SL) piscivores such as largemouth bass (*Micropterus salmoides*), (11.1‰).

As with nitrogen, values for $\delta^{13}C$ were not different between the two creeks. In general, carbon isotopic values were low, which is indicative of quiescent, low-energy environments where CO^2 evolving from decomposing organic matter is more likely to be recycled into new photosynthesis, doubling the photosynthetic fractionation effect and producing highly negative $\delta^{13}C$ values (Figure 81). The lone high $\delta^{13}C$ value was from torpedo grass (*Panicum repens*), a C4 plant (C4 photosynthesis results in less negative fractionation than C3 photosynthesis). The absence of elevated $\delta^{13}C$ in consumers indicates minimal biomass input from C4 plants to consumers in the two creeks.

There were no collections of BMA representing the dry season, and too few dry-season vascular plant collections to allow for statistical comparison. Therefore, the only seasonal comparison that was made involved consumers (Figure 81). There was no apparent seasonal difference in consumer isotopes.

Trophic fractionation is variable, but typically results in differences of 2.3-3.4‰ per trophic step for $\delta^{15}N$ and 1.0-2.3‰ per trophic step for $\delta^{13}C$ (DeNiro and Epstein, 1978; 1981; Peterson and Fry, 1987; Pinnegar and Polunin, 1999; Sweeting, 2007; Caut et al., 2009). Mean consumer $\delta^{15}N$ (8.1‰) was offset from vascular plants (4.8‰) by 3.3‰, or only 1.0-1.4 trophic steps (Figure 82). Consumer offset from BMA $\delta^{15}N$ (3.3‰) was 4.8‰, which translates to a more reasonable 1.4-2.1 trophic steps. In terms of $\delta^{13}C$, the mean consumer value (-24.9‰) was offset from that of vascular plants (-30.5‰) by 5.6‰, which translates to 2.0-5.6 trophic steps. The offset from mean BMA (-28.6‰) was 3.7‰, which translates to a more reasonable 1.6-3.7 trophic steps. These results suggest the consumers in the two creeks were more reliant on benthic microalgae as a basal resource than vascular plants.

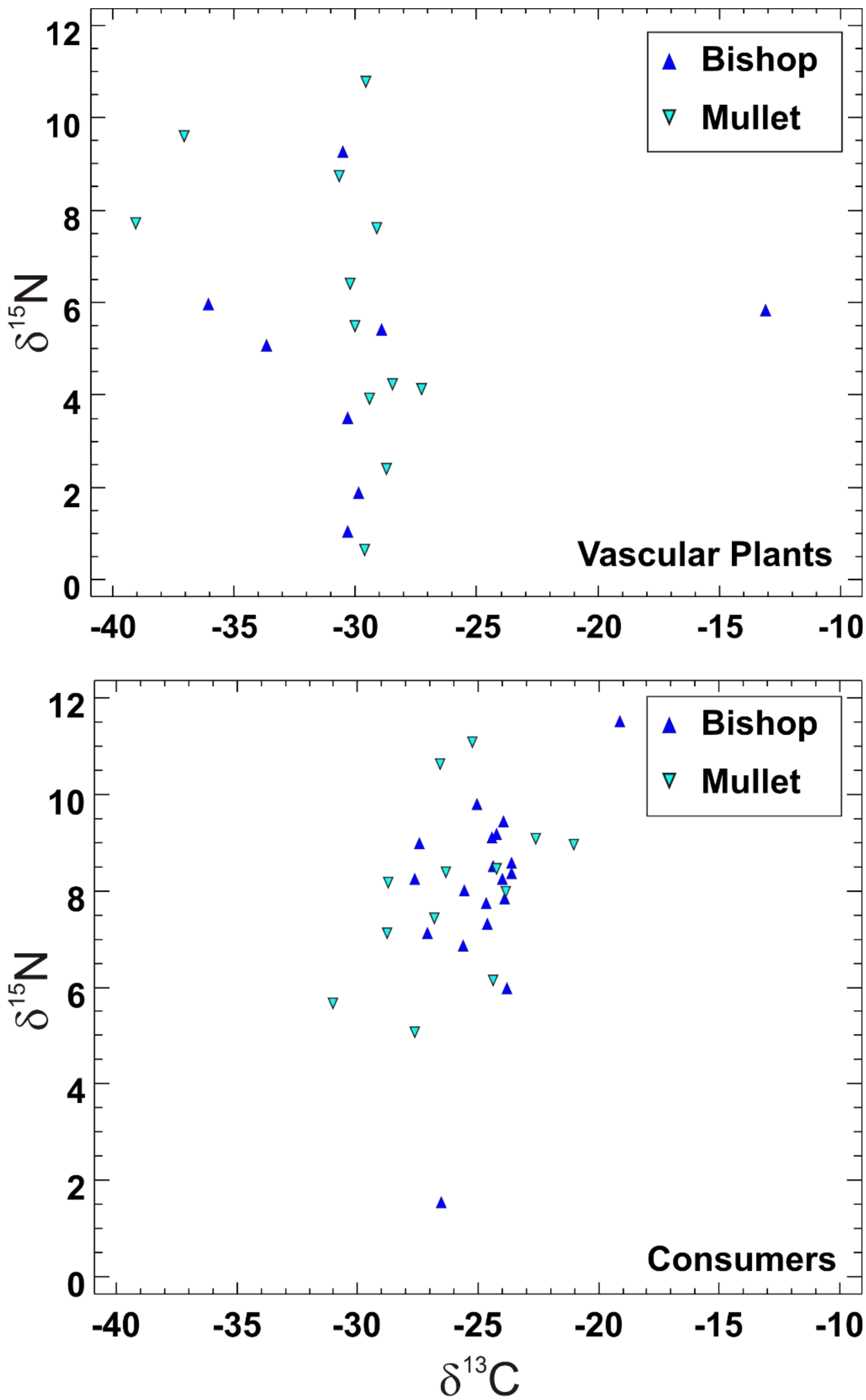


Figure 80. Stable-isotope values for vascular plants and fish/crustaceans (consumers) in Bishop and Mullet Creeks. Each point represents the creek-specific mean for individual species.

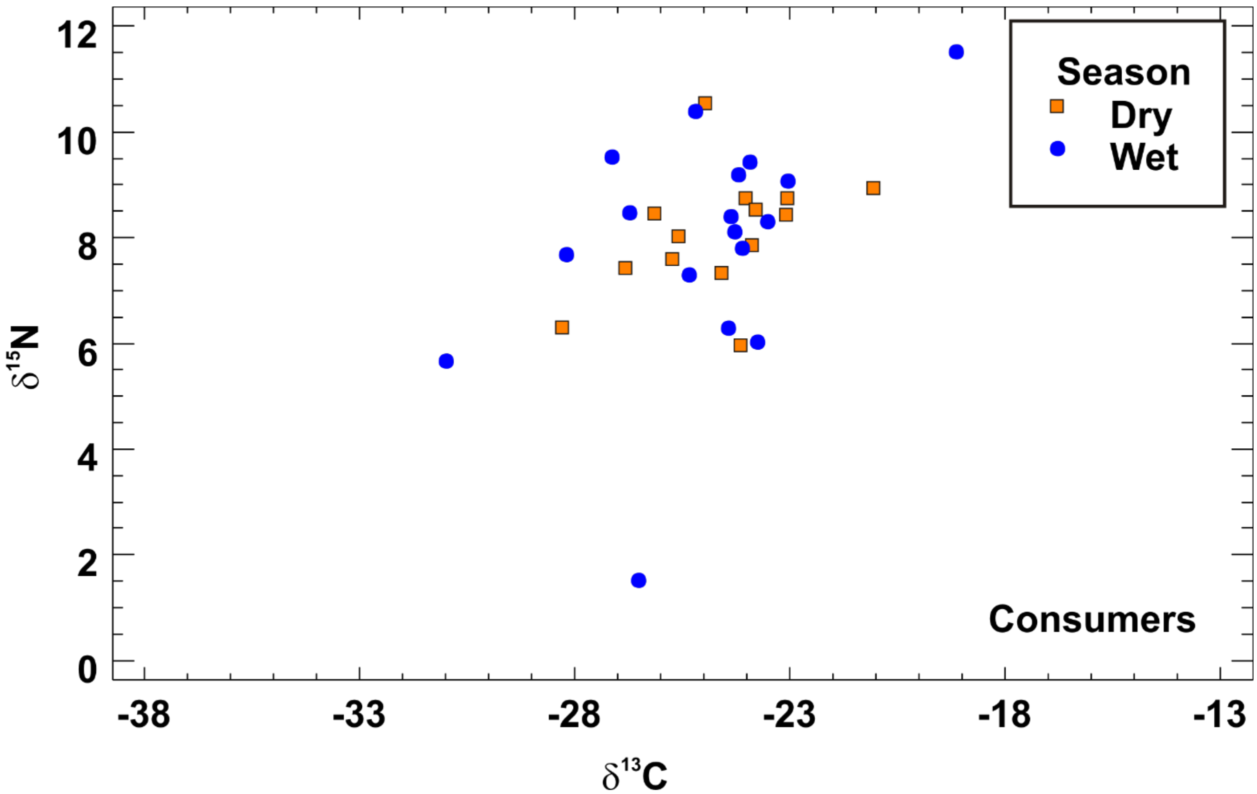


Figure 81. Mean isotopic values of consumers by season, with Bishop and Mullet Creeks plotted together. Each point represents species-specific averages.

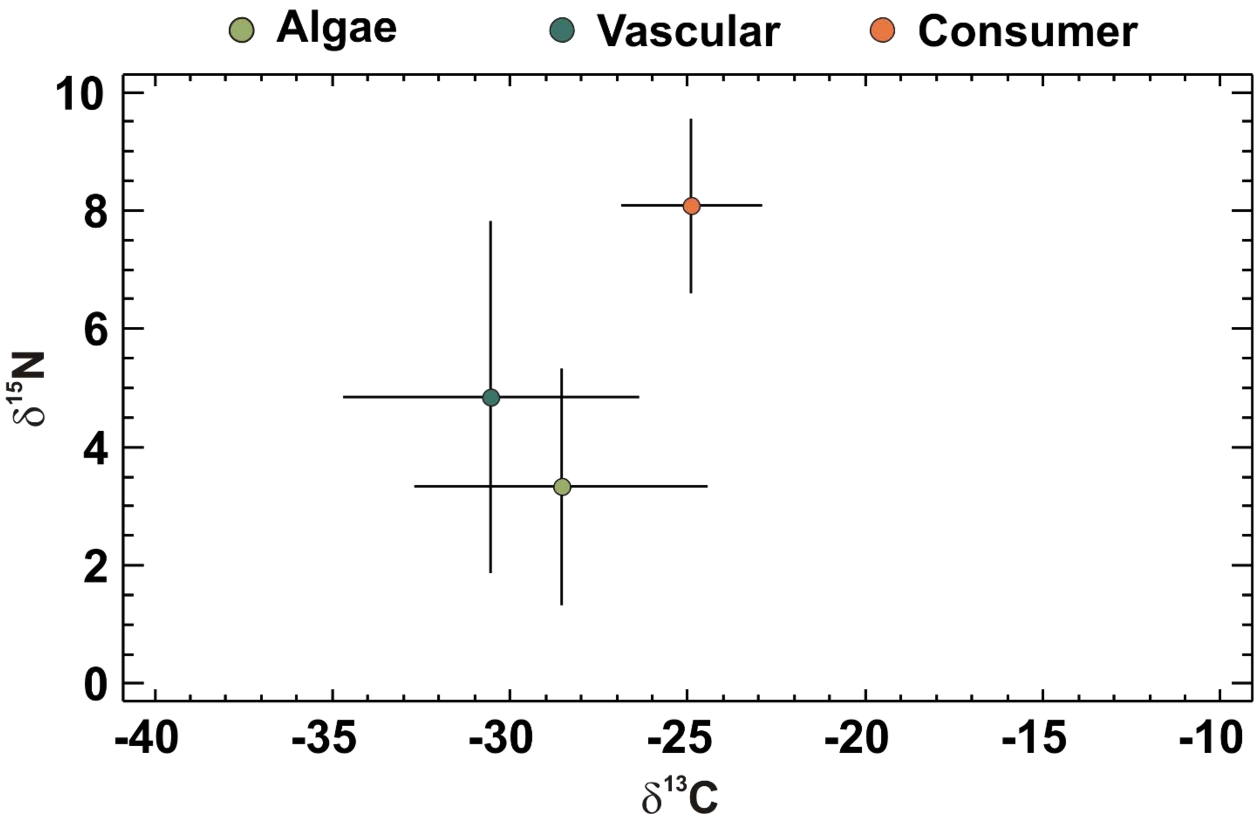


Figure 82. Stable isotope values for benthic microalgae (algae), vascular plants (vascular) and fishes/crustaceans (consumer) from Bishop and Mullet Creeks combined. Points identify means and lines represent standard deviations.

D.5 Benthic Invertebrates

Over 3,990 specimens, representing 48 genus and species of benthic invertebrates were collected during the study, from sampling events in 2011 and 2012. The species found in these samples were tolerant of a wide range of salinities. There were some differences between the creeks, but overall the diversity was similar. It should be noted that there were no significant differences in species compositions between 2011 and 2012.

Species richness was highest in the samples collected in 2012 (Table 34). The Bishop 2012 sample had 41 species, while the Mullet 2012 sample had 38 species. In the 2011 samples, the species richness of the Bishop sample was 15, while the Mullet sample was 35. The similarity of the two Bishop samples was assessed using the Sorensen's Index of similarity. By this means, the Bishop samples had an Index of 0.57 on a scale of 0 – 1, indicating a moderate degree of similarity in terms of the species found in the samples. The two Mullet samples had an Index of 0.67, suggesting that somewhat more similarity existed between these two samples than between the two Bishop samples. Comparing the Bishop 2011 with the Mullet 2011 samples resulted in an index of 0.60, and a comparison of the Bishop 2012 with the Mullet 2012 samples resulted in a high similarity of 0.73. From this information, it can be said the two tidal creeks support benthic populations that bear considerable resemblance to each other in terms of species present.

Bishop Creek		Mullet Creek	
2011	15	2011	35
2012	41	2012	38

Table 35. Number of species (species richness) for Bishop and Mullet Creeks

Species diversity was assessed using Simpson's Index of Species Diversity (SI). The indices calculated suggested that the samples taken in 2011 and 2012 from Bishop and Mullet Creeks represented benthic communities having moderate to high species diversity (Table 35). Of the two creeks, Bishop Creek had the higher SI at 0.83 and 0.90 for 2011 and 2012, respectively. The SI for the two sample years differed by 0.07 index units. Mullet Creek's SI was 0.76 for 2011 and 0.79 for 2012. Differing by 0.03 index units between 2011 and 2012, the SI suggested a higher-than-average species diversity.

Bishop Creek		Mullet Creek	
2011	0.83	2011	0.76
2012	0.90	2012	0.79

Table 36. Benthic invertebrate species diversity (SI) of Bishop and Mullet Creeks

The most common invertebrate found in both creeks, in both 2011 and 2012, was *Laeonereis culveri*, (Table 36), a common tidal estuarine polychaete (Mazurkiewicz 1975) that has been found in abundance throughout Tampa Bay (Taylor 1971, PBS&J 2010). The second most abundant invertebrate in both creeks was the amphipod *Grandidierella bonnieroides,* which was also abundant in other Tampa Bay studies (PBS&J and Janicki, 2007). The abundance of both L. culveri and G. bonnieroides was consistent in the 2011 and 2012 samples from the creeks. The variation in L. culveri abundance in Bishop Creek between 2011 and 2012 was 1.7%, while the variation in G. bonnieroides was 1.1%. The variation in L. culveri abundance in Mullet Creek between 2011 and 2012 was 0.04%, while the variation in G. bonnieroides was 0.02%. For both species, the percent abundance was less in 2012 than in 2011 in both creeks. At 44.45% and 44.39%, these two species composed nearly half of the benthic species identified in the samples from Mullet Creek in 2011 and 2012, respectively. In Bishop Creek, G. bonnieroides and L. culveri composed a smaller percentage of the samples at 38.05% and 35.28%, respectively, for 2011 and 2012. This observation was related to the higher species diversity in Bishop Creek as compared to Mullet Creek. In Bishop Creek, the clam *Corbicula* sp. was the third most common invertebrate in 2011, while *Polypedilum spp* was the third most abundant species in 2012. *Americorophium ellisi,* an amphipod found throughout the Gulf of Mexico region (LeCroy et al 2009), was the third most abundant in Mullet Creek at 8.32% and 8.31% of the 2011 and 2012 samples, respectively. In Mullet Creek, the next most abundant species were present at less than 5%; therefore, the three species just discussed (L. culveri, G. bonnieroides and *Americorophium ellisi)* were by far the most important components of the benthic samples taken, representing over 52% of the samples. In Bishop Creek, the three most abundant species composed less than 50% of the samples in both years as many species were present in low numbers.

A complete species list of species observed for 2011 and 2012 in Mullet Creek is found in Tables 37 and 38, respectively. A complete species list of species observed for 2011 and 2012 in Bishop Creek is found in Tables 39 and 40, respectively.

BISHOP CREEK, 2011	%	BISHOP CREEK, 2012	%
Laeonereis culveri	23.08%	*Laeonereis culveri*	21.40%
Grandidierella bonnieroides	14.97%	*Grandidierella bonnieroides*	13.88%
Corbicula sp.**	10.62%	*Polypedilum* spp.	10.20%
Pyrgophorus platyrachis	7.46%	*Corbicula* sp.**	9.84%
Capitellidae spp.	4.79%	*Pyrgophorus platyrachis*	6.92%
Ampelisca abdita	3.54%	*Capitellidae* spp.	4.44%
Tubificoid naididae	3.32%	*Ampelisca abdita*	3.28%
Tubificinae spp.	3.16%	*Tubificinae* spp.	3.28%
Leitoscoloplos foliosus	3.10%	*Ampelisca holmesi*	2.83%
Ampelisca holmesi	3.05%		
*Tarebia granifera***	2.34%		

MULLET CREEK, 2011	%	MULLET CREEK, 2012	%
Laeonereis culveri	27.08%	*Laeonereis culveri*	27.04%
Grandidierella bonnieroides	17.37%	*Grandidierella bonnieroides*	17.35%
Americorophium ellisi	8.32%	*Americorophium ellisi*	8.31%
Streblospio spp.	2.99%	*Polypedilum* spp.	2.99%
		Streblospio spp.	2.99%

**Denotes Invasive Species

Table 37 Abundance (%) of the most common benthic invertebrates in Bishop and Mullet Creeks, 2011 - 2012.

Scientific Name	Total	Scientific Name	Total
Almyracuma bacescui	5	*Heteromastus filiformis*	62
Americorophium ellisi	6	*Hobsonia florida*	1
Ampelisca abdita	0	*Hydrobiidae* sp.	0
Ampelisca holmesi	1	*Japonactaeon* sp.	0
Amygdalum papyrium	0	*Laeonereis culveri*	145
Angulus merus	0	*Leitoscoloplos foliosus*	0
Apocorophium lacustre	0	*Leitoscoloplos* sp.	1
Arenicola cristata	0	*Leptochelia/Hargeria* sp.	6
Aricidea philbinae	1	*Limnodrilus hoffmeisteri*	1
Bivalvia sp.	0	*Littoridinops monroensis*	0
Boccardiella ligerica	0	*Melanoides tuberculatus*	0
Brania nitidula	0	*Oecetis sphyra/morsei*	1
Capitellidae spp.	14	*Oxyurostylis smithi*	0
Cassidinidea ovalis	0	*Parastarte triquetra*	0
Cerithidea costata	0	*Pectinaria gouldii*	0
Chironomidae spp. (pupae)	1	*Polypedilum* spp.	12
Chironomus spp.	6	*Pyrgophorus platyrachis*	3
Corbicula sp.**	1	*Sabaco elongata*	0
Cyathura polita	0	*Sayella fusca*	0
Dicrotendipes spp.	2	*Stenoninereis martini*	2
Edotia triloba	0	*Streblospio* spp.	4
Eteone heteropoda	1	*Tarebia granifera***	0
Grandidierella bonnieroides	20	*Tubificinae* spp.	25
Granulina hadria	8	*Uromunna reynoldsi*	0
		Grand Total	**329**

**Denotes Invasive Species

Table 38. Composition of benthic invertebrates in Mullet Creek, 2011.

Scientific Name	Total	Scientific Name	Total
Almyracuma bacescui	8	*Hobsonia florida*	7
Americorophium ellisi	118	*Hydrobiidae* sp.	0
Ampelisca abdita	18	*Japonactaeon* sp.	11
Ampelisca holmesi	0	*Laeonereis culveri*	533
Amygdalum papyrium	1	*Leitoscoloplos foliosus*	7
Angulus merus	1	*Leitoscoloplos* sp.	6
Apocorophium lacustre	1	*Leptochelia/Hargeria* sp.	9
Arenicola cristata	0	*Limnodrilus hoffmeisteri*	0
Aricidea philbinae	0	*Littoridinops monroensis*	8
Bivalvia sp.	1	*Melanoides tuberculatus*	22
Boccardiella ligerica	1	*Oecetis sphyra/morsei*	0
Brania nitidula	0	*Oxyurostylis smithi*	0
Capitellidae spp.	2	*Parastarte triquetra*	19
Cassidinidea ovalis	0	*Pectinaria gouldii*	1
Cerithidea costata	1	*Polypedilum spp.*	49
Chironomidae spp. (pupae)	1	*Pyrgophorus platyrachis*	11
Chironomus spp.	29	*Sabaco elongata*	0
Corbicula sp.**	15	*Sayella fusca*	19
Cyathura polita	12	*Stenoninereis martini*	7
Dicrotendipes spp.	2	*Streblospio* spp.	66
Edotia triloba	12	*Tarebia granifera***	29
Eteone heteropoda	3	*Tubificinae* spp.	25
Grandidierella bonnieroides	291	*Uromunna reynoldsi*	0
Heteromastus filiformis	26		
		Grand Total	**1372**

**Denotes Invasive Species

Table 39. Composition of benthic invertebrates in Mullet Creek, 2012.

Scientific Name	Total	Scientific Name	Total
Almyracuma bacescui	2	*Heteromastus filiformis*	6
Americorophium ellisi	82	*Hobsonia florida*	0
Ampelisca abdita	0	*Hydrobiidae* sp.	1
Ampelisca holmesi	0	*Japonactaeon* sp.	0
Amygdalum papyrium	0	*Laeonereis culveri*	73
Angulus merus	0	*Leitoscoloplos foliosus*	0
Apocorophium lacustre	0	*Leitoscoloplos sp.*	0
Arenicola cristata	0	*Leptochelia/Hargeria* sp.	0
Aricidea philbinae	0	*Limnodrilus hoffmeisteri*	0
Bivalvia sp.	0	*Littoridinops monroensis*	0
Boccardiella ligerica	0	*Melanoides tuberculatus*	37
Brania nitidula	0	*Oecetis sphyra/morsei*	0
Capitellidae spp.	7	*Oxyurostylis smithi*	0
Cassidinidea ovalis	0	*Parastarte triquetra*	4
Cerithidea costata	0	*Pectinaria gouldii*	0
Chironomidae spp. (pupae)	0	*Polypedilum* spp.	4
Chironomus spp.	1	*Pyrgophorus platyrachis*	0
Corbicula sp.**	15	*Sabaco elongata*	0
Cyathura polita	0	*Sayella fusca*	0
Dicrotendipes spp.	3	*Stenoninereis martini*	0
Edotia triloba	0	*Streblospio* spp.	1
Eteone heteropoda	0	*Tarebia granifera***	0
Grandidierella bonnieroides	46	*Tubificinae* spp.	29
Granulina hadria	0	*Uromunna reynoldsi*	0
Grand Total			**311**

**Denotes Invasive Species

Table 39. Composition of benthic invertebrates in Bishop Creek, 2011.

Scientific Name	Total	Scientific Name	Total
Almyracuma bacescui	3	*Hobsonia florida*	42
Americorophium ellisi	8	*Hydrobiidae* sp.	14
Ampelisca abdita	65	*Japonactaeon* sp.	3
Ampelisca holmesi	56	*Laeonereis culveri*	424
Amygdalum papyrium	10	*Leitoscoloplos foliosus*	46
Angulus merus	0	*Leitoscoloplos* sp.	11
Apocorophium lacustre	0	*Leptochelia/Hargeria* sp.	18
Arenicola cristata	5	*Limnodrilus hoffmeisteri*	2
Aricidea philbinae	9	*Littoridinops monroensis*	0
Bivalvia sp.	1	*Melanoides tuberculatus*	10
Boccardiella ligerica	1	*Oecetis sphyra/morsei*	1
Brania nitidula	13	*Oxyurostylis smithi*	26
Capitellidae spp.	88	*Parastarte triquetra*	40
Cassidinidea ovalis	2	*Pectinaria gouldii*	12
Cerithidea costata	0	*Polypedilum* spp.	202
Chironomidae spp. (pupae)	18	*Pyrgophorus platyrachis*	137
Chironomus spp.	38	*Sabaco elongata*	20
Corbicula sp.**	195	*Sayella fusca*	0
Cyathura polita	15	*Stenoninereis martini*	1
Dicrotendipes spp.	24	*Streblospio* spp.	27
Edotia triloba	0	*Tarebia granifera***	43
Eteone heteropoda	5	*Tubificinae* spp.	65
Grandidierella bonnieroides	275	*Uromunna reynoldsi*	3
Heteromastus filiformis	3		
		Grand Total	**1981**

**Denotes Invasive Species

Table 40. Composition of benthic invertebrates in Bishop Creek, 2012.

Invasive species were observed, most notably *Corbicula fluminea*, an invasive Asian clam (USGS, 2001). *Cobicula* species have been found in other freshwater reaches of tidal systems in Tampa Bay. In the Alafia River they were noted as being the dominant benthic macroinvertebrate (Sherwood et al. 2007). *Corbicula* sp. was the third most abundant invertebrate in Bishop Creek samples in 2011, while its abundance in Mullet Creek was far less, barely more than 1% of all taxa. Another invasive was the mollusk *Tarebia granifera*. *T. granifera* was present in very low numbers in both Bishop and Mullet Creeks and has been noted in other streams and tributaries in Tampa Bay (SWFWMD 2004).

Twenty-two specimens of *Melanoides tuberculatus* were collected from Bishop Creek in 2011. *M. tuberculatus,* known as the red-rim melania, is a common snail in Africa and Asia. It was imported into the United States for aquariums in the 1930s (USGS 2012). It has been found throughout tidal tributaries in Tampa Bay (Baker 2004).

All of the benthic species identified from Bishop and Mullet Creeks have been previously reported from Tampa Bay and its tributaries (Grabe et al., 1996; Mote 1995), suggesting that the benthic invertebrate community of Bishop and Mullet Creeks is similar to other sample tidal systems in the Bay.

D.6. Mangrove Health

D.6.1 Salinity

Salinity was found to differ significantly by grid location, independent of site (Mullet Creek or Bishop Creek) or sampling position (edge vs. interior). Grid 3 had significantly higher salinity (29.5±1.1) than did grid 13 (23.7±0.9). The salinity at grids 8, 18, and 23 did not differ significantly from those at grids 3 or 13. As grid 3 is located closest to the bay, it was expected to have the highest salinity. However, grid 13 is located midway along the channel and was not expected to have the lowest salinity. This may be due to freshwater runoff localized at that grid point (not directly documented) as a result of the ongoing regular rain. Mullet Creek and Bishop Creek had very similar salinities (26.0±0.8 and 26.0±0.9. respectively), and showed similar patterns in salinity, with salinity the lowest at grid 13 for Bishop Creek, and at grid 18 for Mullet Creek. Though not statistically significant or entirely consistent, there was a general trend of slightly lower salinity with increasing distance from the bay. The average salinity for all data collected (n=40; independent of site, grid, and position) was 26.0±0.6, with a highest salinity of 34.8, and a lowest of 18.0. All salinity results are present in Table 41 below.

D.6.2 pH

The pH differed significantly between the two sites, as well as by grid location. The pH at Mullet Creek was 7.10±0.06, while that at Bishop Creek was 7.34±0.07. With respect to grid location (independent of site), grid 23 had significantly higher pH (7.53±0.05) than grids 13 (7.06±0.08) and 8 (7.12±0.09), which did not differ from each other. The pH at grids 3 and 18 did not differ from the pH at grids 5, 13, or 23. Though not statistically significant, there was a general trend of increasing pH with increasing distance from the bay. The average pH for all data collected was 7.22±0.05, with a highest pH of 7.81, and a lowest of 6.54. All pH results are present in Table 41 below.

D.6.3 Hydrogen sulfide

No significant statistical differences were found for hydrogen sulfide. Though not statistically significant, there was a general trend of increasing hydrogen sulfide concentration in the mangrove soils with increasing distance from the bay. The average sulfide concentration for all data collected was 0.64±0.08 mM, with a highest sulfide concentration of 2.15 mM, and a lowest of 0.20 mM. All hydrogen sulfide results are present in Table 41 below.

D.6.4 Redox potential

No significant statistical differences were found for redox potential. The highest redox potential (+247.6±25.1) (indicating least reducing and anoxic soil) was seen midway at grid 13 (not statistically significant). The average redox potential for all data collected was +195.8±11.8, with a highest redox potential of +478.5 mV, and a lowest of -188.0 mV. All redox potential results are present in Table 41 below.

Site	Grid	Position	Salinity	pH	Sulfide (mM)	Eh (mV)
Mullet Creek	ALL	ALL	26.09+0.8	7.10±0.06 a	0.67±0.12	204.9±19.7
Bishop Creek			26.09+0.9	7.34±0.07 b	0.60±0.10	186.7±13.3
ALL	3	ALL	29.5±1.1 ab	7.18±0.12 ab	0.47±0.07	163.2±21.4
	8		25.4±1.4 ab	7.12±0.09 a	0.56±0.12	197.5±23.5
	13		23.7±0.9 a	7.06±0.08 a	0.51±0.11	247.6±25.1
	18		25.0±1.5 ab	7.22±0.13 ab	0.77±0.21	195.9±40.8
	23		26.6±1.0 b	7.53±0.05 b	0.86±0.26	174.9± 7.7
Mullet Creek	3	Interior	28.2±1.8	6.8±0.2	0.39±0.13	188.0±31.5
		Edge	28.0±0.5	7.0±0.7	0.62±0.22	n/a
	8	Interior	22.5±3.5	7.2±0.1	0.37±0.02	238.6±29.4
		Edge	27.9±2.9	6.8±0.1	0.86±0.45	n/a
	13	Interior	23.8±3.8	6.9±0.2	0.34±0.01	244.5±50.6
		Edge	25.0±0.0	7.1±0.2	0.54±0.05	n/a
	18	Interior	21.1±3.1	7.3±0.1	0.68±0.06	177.1±76.2
		Edge	26.6±0.04	7.1±0.04	0.34±0.10	n/a
	23	Interior	28.9±0.05	7.4±0.05	1.16±0.80	176.4±8.9
		Edge	28.5±1.5	7.6±0.1	1.34±0.80	n/a
Bishop Creek	3	Interior	34.4±0.4	7.3±0.02	0.37±0.17	138.4±27.9
		Edge	27.5±0.5	7.6±0.1	0.52±0.02	n/a
	8	Interior	27.7±1.2	7.2±0.3	0.35±0.09	156.4±29.9
		Edge	23.4±3.4	7.3±0.0	0.65±0.23	n/a
	13	Interior	22.5±2.5	7.1±0.2	0.44±0.20	250.8±14.8
		Edge	23.7±0.6	7.3±0.1	0.72±0.49	n/a
	18	Interior	28.5±4.5	7.2±0.6	0.90±0.47	214.7±37.2
		Edge	23.8±0.1	7.4±0.2	1.15±0.78	n/a
	23	Interior	23.5±1.5	7.54±0.02	0.36±0.14	173.4±13.4
		Edge	25.5±0.7	7.6±0.1	0.58±0.02	n/a

Table 41. Edaphic soil factors (salinity, pH, hydrogen sulfide concentration (mM) and redox potential (Eh, mV)) measured at each site (n=20; Eh n=30), within each grid (n=8; Eh n=12) distributed along the length of each creek from the bay inland, as well as at each position (at the creek edge underneath the mangrove canopy overhang or at 5 m interior to the forest from the creek edge) within each grid at each site (n=2). Eh (redox potential) was measured (in triplicate subsample) only at the interior position within each grid at each site (n=6). Where letters are present, those that are the different represent means that differ significantly statistically. Where letters are absent, there were no statistically significant differences between the means

Following statistical analysis of the collected data, the results for redox potential, hydrogen sulfide concentrations, and pH values at Bishop and Mullet Creek were determined to be “in the range of values expected for unimpacted/natural mangrove forests (or forests with low anthropogenic impact), or even less stressful (higher redox potentials, lower hydrogen sulfide concentrations) than those seen in natural and restored sites in Florida and elsewhere” (Lessman, 2012). Salinity readings were higher closer to the bay, as expected, though not of full strength seawater. In summary, the results indicated that the mangrove ecosystems in both creeks are healthy and not reduced in function.

D.7. Canopy Coverage Estimations

Canopy coverage, relating to natural habitat affects both fisheries habitat (Krebs, 2012) and benthic productivity (Bopp, 2002) in estuarine and freshwater streams. To date, little canopy coverage information has been collected from tidal tributary systems in Florida. To determine the approximate canopy coverage in Bishop and Mullet Creeks, a densiometer was used to collect and calculate the amount of sunlight passing through the tree canopy and relative coverage at the sampling stations.

The average percent cover for both creeks, as determined by denisometer readings, was 31% with a median of 28%. Bishop Creek had average canopy coverage of 27%, while Mullet had more coverage, 38%. Canopy coverage ranged from 0% to 100% in both creek systems.

There were also differences in canopy coverage across strata. The highest canopy coverage on both systems were farther up in the freshwater reaches of the creeks as indicated in the Table 42 below.

Bishop		Mullet	
Stratum	% Cover	Stratum	% Cover
B1	9%	M1	33%
B2	34%	M2	30%
B3	38%	M3	53%

Table 42. Average Canopy Coverage per Stratum in Bishop and Mullet Creeks

Observed percent coverage was taken along with the denisometer data for comparison. Through analysis of densiometer data, compared to field observations of percent cover, the average difference between the two methods was 9%. In other words, the observed percent cover was, on average, 9% higher than the corresponding densiometer reading.

If additional time and budget were available, more detailed analysis of the relationship between benthic, water, and fish samples and how they were affected by canopy coverage at individual sampling sites, could be explored. The use of denisometer data may be helpful for future tidal tributary studies, if resources are available to fully utilize the data collected.

D.8 Stream Morphology

During the benthic invertebrate sampling events, sediment samples were collected for analysis by both Eckerd College and the Environmental Protection Commission of Hillsborough County (EPC). The samples were taken at the same locations as the benthic invertebrate samples. A map of sampling locations for Bishop and Mullet Creeks can be found in Figures 11 and 12, respectively. Additionally, the raw data of the sediment samples can be found in Appendix D. Sediment composition was primarily sand with very minor amounts of silt and clay (Table 43).

Bishop	Mullet
4.32%	4.86%

Table 43. Average percentage of silt/clay in Bishop and Mullet creek sediment samples

Both Bishop and Mullet creeks are shallow systems, though occasional pockets of deep water, especially around major creek bends, occur in the lower reaches of each system. Depth measurements were taken from the water surface to the top of sediment at mid-channel for every sample station during the course of the project. Depths for each creek can be found in Table 44. Detailed cross sections at selected sampling stations were collected in April of 2012 for use in the SWMM model. These can be found in Appendix E.

Bishop Depth (m)		**Mullet Depth (m)**	
Avg	0.46	Avg	0.58
Median	0.40	Median	0.55
Min	0.06	Min	0.06
Max	1.25	Max	1.40

Table 44. Creek depths

In June of 2012, Tropical Storm Debby brought significant rainfall to the Safety Harbor area. At the Safety Harbor rainfall gauge (ROMP TR14-1, accessed through SWFWMD WMIS), total

precipitation was 9.27 inches on June 24 and an additional 1.41 inches on June 25. Peak flow during the storm for Bishop was 83.52 cfs and 90.83 cfs in Mullet (USGS flow gauge).

The storm caused significant changes to the depth profiles of both creeks, as observed by project scientists. These observations were also reflected by news reports and interviews with residents along the creek (Thomason, 2012). Sections in both creeks, especially Bishop, saw significant erosion, while sediments were deposited in other areas. Of particular note, the section of Bishop Creek under the Philippe Parkway Bridge was relatively shallow (less than 0.3 m deep) prior to Tropical Storm Debby, but had scoured out to depths of over 2m afterwards.

While observed depths were impacted by Tropical Storm Debby, it should be noted that sediment samples pre-Debby showed similar silt/clay compositions as post-Debby samples.

D.9 SWMM Modeling

Both systems were modeled to generate information on their hydrologic profile and nutrient loadings. The modeling was performed using the EPA SWMM 5.0 model using both collected data from external sources as well as data collected during the project, including cross sections, water quality data, and velocity. The detailed SWMM model results for Bishop Creek and Mullet Creek can be found in Appendix F and G, respectively.

There were significant limitations to the model development. For determination of the model area, land use tables (Table 45 and 46) were used to calculate the percentage of impervious surfaces in the watershed. This was the impervious contributing area used in the model. Because the impervious areas were calculated this way, the watershed was not delineated. Rather, the impervious area was used for the runoff coefficient (CV) value, estimating how much stormwater came from the watershed into Bishop and Mullet Creeks.

D.9.1 Bishop Creek

For Bishop Creek, the modeled portion of the creek is approximately 4,200 LF in length and includes one source pond (Figure 83). The source pond for Bishop Creek is located between North Bay Hills Boulevard and Swan Lane.

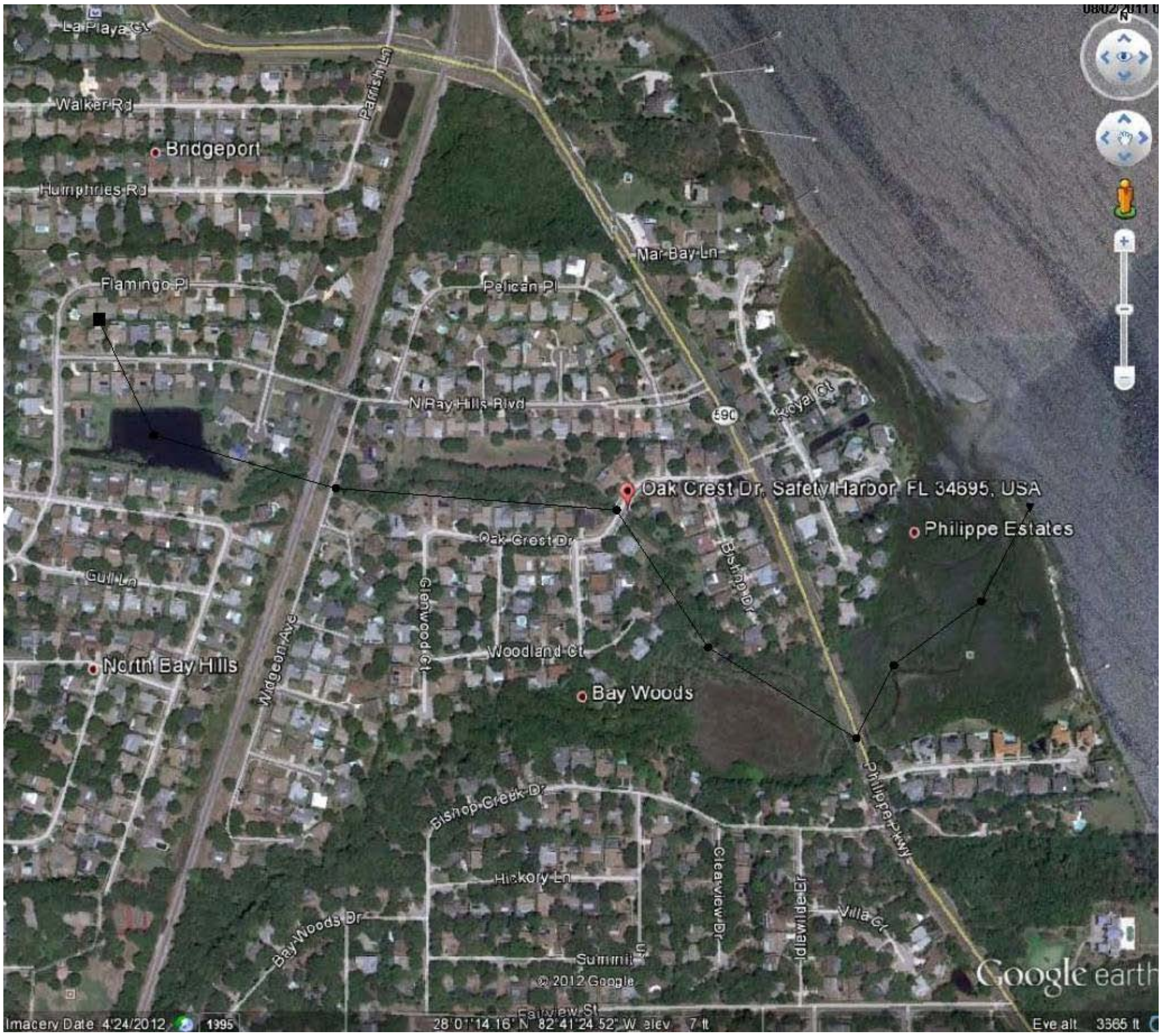


Figure 83. Node map of Bishop Creek

The Bishop Creek watershed has an area of 926 acres (Florida Department of Environmental Protection, 2010) with an average impervious area of 72%; The impervious area was calculated using land use acreage (Figure 84, Table 45) and impervious percentages from the Pinellas County Future Land Use Map, Appendix F (Pinellas County, 2011).

The rainfall information that was provided was actual daily rainfall totals collected from August 2011 to June 2012 from Largo site 22897 (SWFWMD data, accessed through WMIS). Creek

cross-sections were taken in situ. The creek was modeled for this duration of time, totaling approximately 303 days. There are a total of 7 nodes and 6 sections defined for the creek.

Hydrologic profile results showed that the water depth in the creek fluctuated dramatically with rainfall and tide inflow. The minimum water depth of 1.5' occurred at the Tampa Bay outfall node and was related to no rainfall and a low tide. The maximum water depth observed occurred in the source pond node. The maximum water depth observed occurred in the source pond node, reaching 11.3’ deep. The depths are in relation to the cross sections, which were tied to tidal stages, not elevation. This indicates flooding around this area during the periods of maximum recorded rainfall.

The water quality and pollution modeling was based on the watershed, the land uses within the watershed, and the measured pollutant concentrations sampled from the creek. The pollutants modeled in EPA SWMM were TN and TP.

There were a number of assumptions made in the development of the model for Bishop Creek:

- Rainfall data provided previously was assumed to fall over the entire watershed during storm events
- Pollutant inflow from rainfall, groundwater, and infiltration and inflow flows were set as needed to approximately match the measured data collected from the creek downstream. The baseline for groundwater concentrations was estimated from the measured data obtained from the creek.
- Total pollutant loads for the watershed were derived from the concentrations measured within the creek
- The entire watershed drains to the source pond, there are no other discharge points to the creek.
- The source pond does not provide any treatment.
- Existing water bodies, wetlands, and roads were assumed to have no pollutant loading contribution to the creek

The Bishop Creek watershed is made up of the land uses (Florida Department of Environmental Protection, 2010) found in Table 45 below:

Bishop Creek Land Use	Acreage	%
Urban and Built-Up	107	11.56%
Low-residential density	102	11.02%
Medium-residential density	426	46.00%
High-residential density	175	18.90%
Agriculture	2	0.22%
Forest/rural open	18	1.94%
Water	30	3.24%
Wetlands	9	0.97%
Transportation, Communication, & Utilities	57	6.16%
Total	**926**	**100.00%**

Table 45. Bishop Creek Drainage Area Land Use

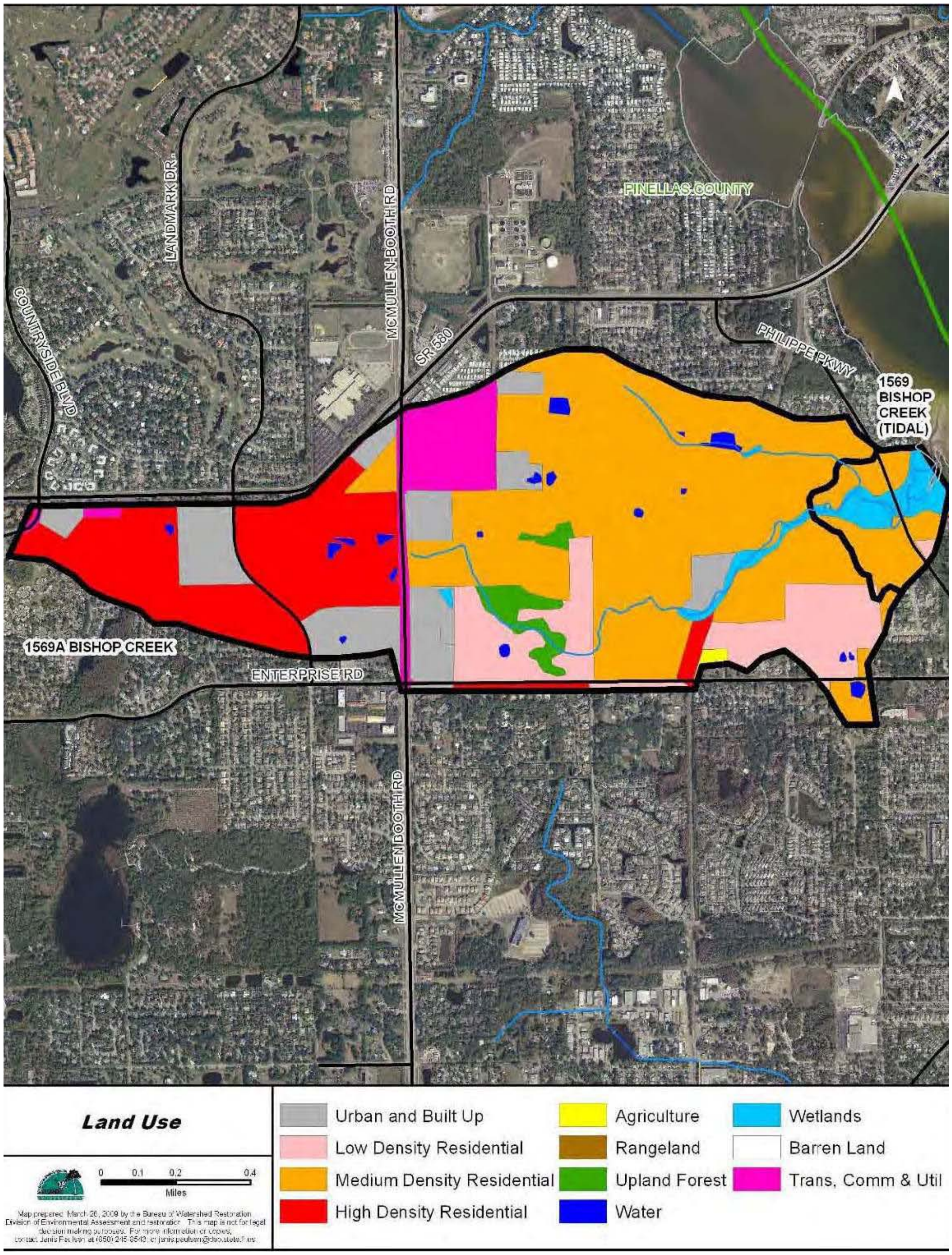


Figure 84. Land use map of Bishop Creek watershed (FDEP, 2010)

The pollution modeling results showed that the concentrations of pollutants within the creek decreased steadily when proceeding from the source pond to the outfall in Tampa Bay. This is partly due to the single source pond modeled for the system and partly due to the nature of the pollutant uptake within the creek. Results of the pollution modeling also indicate that there are

times when pollutant loads peak. While an analysis was not performed it is assumed that these peaks coincided with high intensity rainfall events that are present in the existing rainfall data provided.

The pollutant loads and concentrations were adjusted within each land use until the downstream model results approximated the measured concentrations taken at the downstream locations. Measured concentrations showed that total nitrogen (TN) was between 0.39 and 1.16 mg/L on average and total phosphorous(TP) was between 0.13 and 0.34 mg/L on average. Estimated loads were .25 tons/yr of TN and .06 tons/yr of TP.

Graphs for Bishop Creek that plot the modeled versus measured concentrations and flows are included in the Appendix F. The graphs used measured data at the fixed sampling locations against modeled data at the nodes to illustrate how well the modeled conditions mirrored measured conditions. On the concentration data, though limited by the number of measured samples, the concentration graphs show that the general peaks and valleys are similar, and that the results are highly rainfall driven. The flow graphs had fewer measurements so the graphs are not as similar as the concentrations. The limitations here are related to the locations of the nodes versus the locations of the fixed sites used for comparison.

D.9.2 Mullet Creek

For Mullet Creek, the modeled portion is approximately 6,600 linear feet (LF) in length and includes one source pond (Figure 85). The source pond for Mullet Creek is located between Harbor Lake Drive and 7th Street North. There is an additional pond which is connected to Mullet Creek via an overflow structure. The additional pond is located east of Philippe Parkway and west of Palm Street.

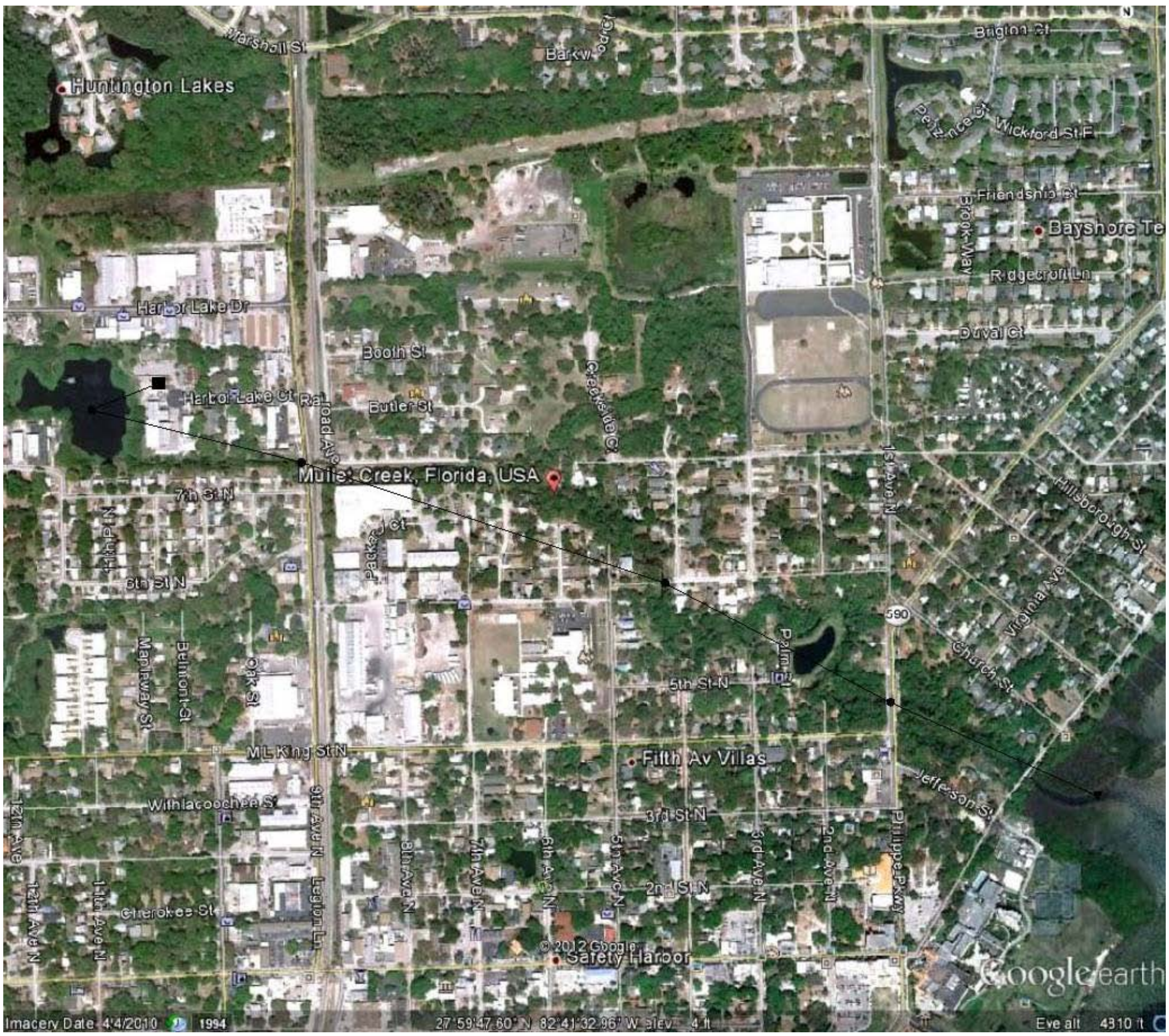


Figure 85. Node map of Mullet Creek

For the model, an assumption was made that the flows from the additional pond are negligible based on field observations that showed no observable discharge from the pond into Mullet Creek.

The Mullet Creek watershed has an area of 1889 acres (Florida Department of Environmental Protection, 2009) with an average impervious area of 72%. The impervious area was calculated using land use acreage (Figure 86, Table 46) and impervious percentages from the Pinellas County Future Land Use Map, Appendix F (Pinellas County, 2011). The rainfall information that was provided was actual daily rainfall totals collected from August 2011 to June 2012 from Largo site 22897 (SWFWMD data, accessed through WMIS). Creek cross-sections were taken in situ. The creek was modeled for this duration of time, totaling approximately 303 days. There are a total of 5 nodes and 4 sections defined for the creek.

Hydrologic profile results show that the water depth in the creek fluctuated dramatically with rainfall and tide inflow. The minimum water depth of 1.5' occurred at the Tampa Bay outfall node and was related to no rainfall and a low tide.

The maximum water depth observed occurred in the source pond node and the 9th Avenue node, reaching 10.7’ deep. The depths are in relation to the cross sections, which were tied to tidal stages, not elevation. This indicates flooding around these nodes during this period of maximum recorded rainfall.

The water quality and pollution modeling for Mullet Creek was based on the watershed, the land uses within the watershed, and the measured pollutant concentrations sampled from the creek. The pollutants modeled in EPA SWMM were TN and TP.

There were a number of assumptions made for the development of the model for Mullet Creek:

- Rainfall data provided previously was assumed to fall over the entire watershed during storm events
- Pollutant inflow from rainfall, groundwater, and infiltration and inflow flows were set as needed to approximately match the measured data collected from the creek downstream. The baseline for groundwater concentrations was estimated from the measured data obtained from the creek.
- Total pollutant loads for the watershed were derived from the concentrations measured within the creek
- The entire watershed drains to the source pond, there are no other discharge points to the creek.
- The source pond does not provide any treatment.
- Existing water bodies, wetlands, and roads were assumed to have no pollutant loading contribution to the creek

The Mullet Creek watershed is made up of the land uses (Florida Department of Environmental Protection, 2009) found in Table46 below:

Mullet Creek Land Use	Acreage	%
Urban and Built-Up	360	19.06%
Low-residential density	211	11.17%
Medium-residential density	183	9.69%
High-residential density	835	44.20%
Agriculture	25	1.32%
Forest/rural open	103	5.45%
Water	36	1.91%
Wetlands	82	4.34%
Transportation, Communication, & Utilities	54	2.86%
Total	**1889**	**100.00%**

Table 45. Mullet Creek Watershed Land Use

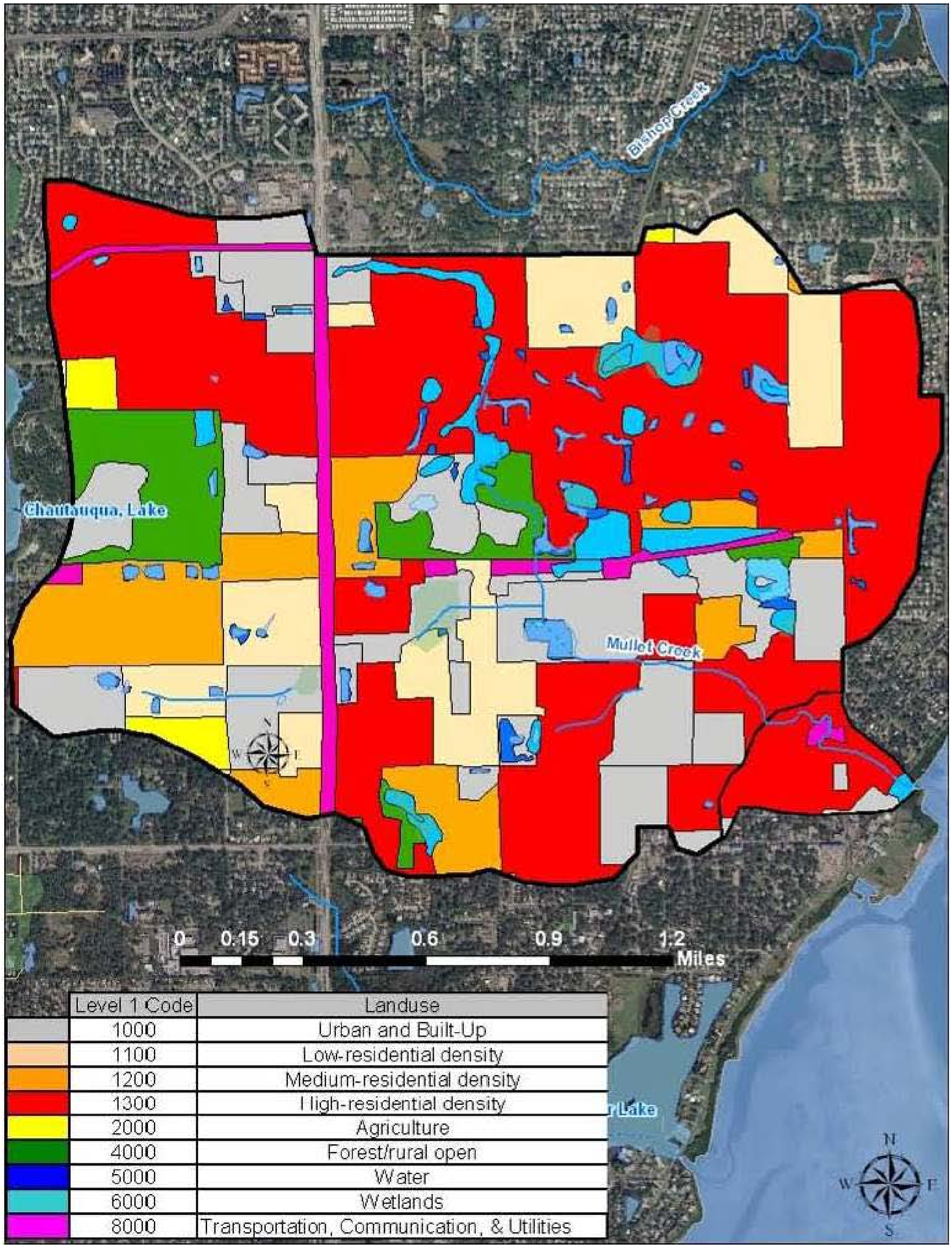


Figure 86. Land use map of Mullet Creek watershed (FDEP, 2009)

The results for Mullet Creek showed that the concentrations of pollutants within the creek decreased steadily when proceeding from the source pond to the outfall in Tampa Bay. This is partly due to the single source pond modeled for the system and partly due to the nature of the

pollutant uptake within the creek. Results of the pollution modeling also indicate that there are times when pollutant loads peak. While an analysis was not performed it is assumed that these peaks coincided with high intensity rainfall events that are present in the existing rainfall data provided.

The pollutant loads and concentrations were adjusted within each land use until the downstream model results approximated the measured concentrations taken at the downstream locations. Measured concentrations showed that total nitrogen (TN) was between 0.51 and 1.25 mg/L on average and total phosphorous(TP) was between 0.11 and 0.27 mg/L on average. Estimated loads are 0.35 tons/yr TN and .07 tons/yr TP.

The model results are limited by a number of assumptions that were made to fit the model into the larger ecological study. A comprehensive model accounting for all the inputs from the watershed was above the scope of this project, but may be a useful addition to future studies if resources are available. Some additional changes include improving flow calibrations. Flows at the nodes were calibrated against measured flows throughout the creek. An additional node at the site of the USGS gauge would improve the accuracy of the modeled velocities.

Graphs for Mullet Creek that plot the modeled versus measured concentrations and flows are included in the Appendix G. The graphs used measured data at the fixed sampling locations against modeled data at the nodes to illustrate how well the modeled conditions mirrored measured conditions. On the concentration data, though limited by the number of measured samples, the concentration graphs show that the general peaks and valleys are similar, and that the results are highly rainfall driven. The flow graphs had fewer measurements so the graphs are not as similar as the concentrations. The limitations here are related to the locations of the nodes versus the locations of the fixed sites used for comparison.

E. Summary and Conclusion

This report describes the results of a one year study initiated by Pinellas County and the Southwest Florida Water Management District to characterize variability in nutrient concentrations and water quality responses in the estuarine portions of two Pinellas County tidal creeks: Mullet and Bishop Creeks. At the time the study was initiated, the estuarine portion of these creeks had been deemed impaired by the Florida Department of Environmental Protection based on exceedances of dissolved oxygen and chlorophyll concentrations and the United States Environmental Protection Agency had proposed a Total Maximum Daily Load to reduce nutrient delivery to the estuarine portions of both creeks. Pinellas County challenged the contention that the criteria applied to determine impairment of these creeks were appropriate and recommended that tidal creeks such as Mullet and Bishop Creeks should have distinct criteria that reflect their unique function within the larger estuary. This contention was supported by letters from the three southwest Florida National Estuary Programs that spoke to the distinctions between tidal creeks, relative to their contributing watersheds and the receiving estuary with highly variable water quality that is dependent on tidal amplitude, watershed inputs, geomorphology, riparian vegetation, and the degree to which tidal creek ecology is affected by watershed development and physical alteration to the creek itself. The latter is an extremely important consideration in Florida where these low gradient systems have been historically altered by shoreline hardening and flood protection efforts.

The objectives of this study were to evaluate variability in water quality within the estuarine portion of these creeks using a spatially intensive sampling design. The design included a routine monthly water quality and fish sampling and a series of special studies design to investigate aspects of the ecological function of these creeks that contribute to ecosystem health. These special studies included the seasonal collection of benthic macroinvertebrates; seasonal estimates of the chlorophyll a content in the sediments as an estimate of benthic micro algae chlorophyll biomass, a nutrient source evaluation using stable isotope analysis, development of a Surface Water Management Model (SWMM) to estimate nutrient loadings to the creeks and a synoptic mangrove health assessment.

Results of water quality sampling suggested that while dissolved oxygen concentrations were routinely less than the current or newly proposed standards, there was no evidence that nutrients or chlorophyll a concentrations were causative factors resulting in reduced dissolved oxygen concentrations. The chlorophyll a data collected as part of this study suggest that these creeks would be in compliance with established state chlorophyll a standards. The current development of nutrient standards for tidal creeks is in flux. The Federal Register notice from

the latest EPA proposed rule for Estuaries (EPA 2012b) states that the “EPA reviewed the available scientific information and has determined that there are insufficient data and research at this time to develop separate numeric nutrient criteria specifically for tidal creeks.” As a result, EPA has proposed two potential approaches that rely on established criteria for adjacent freshwater and estuarine waterbodies along with the mean (presumed to be long-term average) salinity of the creek. This approach is generally described as a “dilution model” method with the expectation that inputs from upstream waters will follow a linear decay in concentration as a function of mixing with estuarine waters as defined by salinity. This study was specifically designed to address that question among others and evidence from this study suggests that this assumption would not be valid for several parameters of interest; notably total nitrogen. Organic nitrogen concentrations actually tended to higher in the downstream sections of the Bishop Creek indicating potential of nitrogen contributions from the heavily mangrove and salt marsh fringe associated with the mouths of this creek. In Mullet Creek, organic nitrogen concentrations were consistent among strata with no discernible dilution as a function of salinity. This has important implications for regulatory inference because organic nitrogen is the dominant form of nitrogen contributing to the observed total nitrogen values in these creeks. The implicit assumption in the dilution model method is that the substance of interest is conservative; however, in the case of these creeks the data suggest nutrient addition is not directly related to watershed inputs or anthropogenic activities. In other words, natural wetland features in these creeks may be acting as a source of nitrogen to the creeks. Importantly, the synoptic mangrove health survey conducted as part of this study indicated that the mangrove forests in these creeks are functioning as natural, undisturbed systems. Little anoxia was present in the sediments suggesting little denitrification is taking place within these creeks as well. A nutrient isotope survey also conducted as part of this study suggests that there are several sources of nitrogen, both anthropogenic and non-anthropogenic, taken up by the biota utilizing these creeks likely due to the contribution of freshwater to the estuarine portions of these creeks from stormwater ponds. The SWMM model results suggested that approximately 0.25 tons of nitrogen and 0.06 tons of phosphorus were delivered to the creeks over the study period.

The fish catch associated with the water quality samples contained a number of estuarine dependent species of recreational and commercial importance including Red Drum (*Sciaenops ocellatus*), Spot (*Leiostomus xanthurus*), Snook (*Centropomus undecimalis*), Pink Shrimp (*Farfantepenaeus Duorarum*), and mullet (*Mugil cephalus*) though the sample catch densities were surprisingly low. The presence of these taxa indicates that the creek is supporting recruitment of important estuarine dependent species of economic value; a recognized important role of tidal creek ecosystems. The fact that catch densities were low may be

attributable to the extensive wetland features in the downstream reaches that allow fish to avoid capture by the small seines used in this study.

Seasonal sampling for benthic macro-invertebrates and benthic microalgae suggested that these samples were similar to that reported in other Tampa Bay tidal tributaries though there was dramatic sample to sample variation in benthic chlorophyll estimates for samples taken in very close proximity on the same sample date. This suggests that this metric may require a revised sampling method that collects a larger sample of the area or by compositing samples taken across the creek channel. Benthic invertebrate species collected during seasonal sampling represented expected euryhaline organisms tolerant of a wide range of estuarine condition s and were similar in community structure. Soils were principally sand with little organic content.

In summary, this study has provided a weight of evidence that suggests that the ecological function of the estuarine portions of these creeks is not currently impaired by ambient water quality conditions. In fact, these creeks appear to represent some of the more natural tidal creeks in Tampa Bay with little shoreline modification, healthy wetland features and expansive canopy cover. However, this is not to say that anthropogenic impacts have not affected the creeks or that improvements cannot be made to provide the proper stewardship of these creeks in the future. Below are some recommendations for future actions that would be valuable in providing further understanding of the ecological function and future stewardship of these important tidal creeks to Tampa Bay.

Recommendations:

- Any mitigation to control high volume discharges to creeks as an erosion control measure would not only protect property owners but also help to protect the natural canopy cover, shorelines, and wetland features downstream.

- A sediment study was something recommended in peer review of the design document and might be pursued as a follow up to this study. Both of these creeks are highly active sediment transport areas and likely have been since the 1950's based on historical aerial photography (see Janicki Environmental 2011 design document). While sedimentation is a natural process and one that can be beneficial for these systems, the erosion control problems previously documented for these creeks supports the hypothesis that these creeks are receiving increased volumes of water as a result of watershed development which in turn may ultimately result in deleterious effects on downstream creek ecology. A sediment study could be used to characterize the rate of sedimentation over time in these creeks as well as document areas of organic deposition in these creeks.

- A follow up study of the ecological health of the mangrove forest to further quantify the contribution of organic nitrogen from these systems to instream water quality would be an important contribution to existing knowledge of tidal creek function. Measuring soil organic content and/or other organic inputs (such as TOM, or the more economical bulk density), along with soil texture analysis of the areas being assessed would aid in better determining what is controlling the soil conditions (such as by the ambient, natural conditions, or by inputs from surrounding areas), and ultimately mangrove productivity. Further, measuring nutrient and carbon quality of mangrove leaf tissue that serves as trophic support would also be very valuable. A simple and inexpensive measure of mangrove productivity as a habitat function would be quantifying litter fall (through litter traps), indicating the amount of biomass being made available to soil organic matter as well as for trophic support. Additionally, a critical indicator of mangrove ecosystem health would be the assessment of invertebrate and vertebrate communities that utilize these ecosystems (such as their abundance, secondary productivity, tissue nutrient quality).

- Protecting the canopy cover of these creeks through community education would also be an important part of maintaining ecological integrity of these creeks.

- Encouraging routine stormwater pond maintenance in the ponds feeding these creeks would also help regulate the quantity and quality of contributing source water for these downstream reaches.

- The salt marshes associated with Bishop Creek were not investigated as part of this study. A follow study of these salt marsh habitats would also be beneficial in understanding the interaction among nutrient sources and sinks in these creeks.

- Investigate potential sources of sewage or animal waste which were identified as possible nitrogen contributors in both creeks through stable isotope analysis.

This study has provided important information on the ecological health and function of these creeks and has contributed greatly to ongoing efforts to develop methods and metric to evaluate the ecological health and function of tidal creeks in southwest Florida in an efficient and cost effective manner. Future efforts to identify relationships between nutrient conditions and ecological health of southwest Florida tidal creeks should consider the outcomes from this study when designing future studies as funding and time constraints allow.

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G. Appendices

Appendix A -	Survey Design for the Bishop and Mullet Creek Tidal Tributary Study
Appendix B -	Monthly Field Sampling Locations
Appendix C -	Canopy Coverage Sampling Protocol
Appendix D -	CD of Data Results
Appendix E -	Bishop Creek and Mullet Creek Representative Cross-sections
Appendix F -	Bishop Creek SWMM Model Results
Appendix G -	Mullet Creek SWMM Model Results

Appendix A.

Survey Design for Bishop and Mullet Creek Tidal Tributary Study

Appendix B.

Monthly Field Sampling Locations

Appendix C.

Canopy Coverage Sampling Protocol

Appendix D.

CD of Data Results

Appendix E.

Bishop Creek and Mullet Creek Representative Cross-sections

Appendix F.
Bishop Creek SWMM Model Results

Appendix G.

Mullet Creek SWMM Model Results