Water Quality and the Fish Assemblages of Mangrove Creeks: A Snapshot Study Shows the Challenges in Assessment of Coastal Zone Management Strategies

Submitted by: L. K. Dixon[1] and A. J. Adams[2]

1 – Mote Marine Laboratory
1600 Ken Thompson Parkway
Sarasota, FL 34236
(941) 388-4441

2 – Mote Marine Laboratory
Charlotte Harbor Field Station
6644 Maria Drive
Saint James City, FL 33956
(239) 283-1622

Submitted to: Charlotte Harbor National Estuary Program
1926 Victoria Ave.
Fort Myers, FL 33901
(239) 338-2556

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Data analysis – C. Layman, C. Santi, R. Duffy, M. Dobrzeniecka

Executive Summary

Water quality data were collected during 12 samplings over an 18 month period from May 2008 to September 2009 in conjunction with a long term sampling of fish communities of estuarine mangrove creeks. Creeks sampled were along the eastern shore of Charlotte Harbor and included North Silcox, South Silcox, Yucca Pens, and Culvert or Durden Creek. The research included comparisons of fish communities with measured water quality along a gradient of habitat degradation, with degradation categorization based upon observed fish density, alteration of upland habitats, and associated alterations of freshwater flows into the study creeks. The results provided information or support to address the Charlotte Harbor National Estuary Program's Priority Actions addressing Water Quality Degradation, Hydrologic Alterations, with additional information provided on Fish and Wildlife Habitat Loss. Specifically, the project provided a robust water quality data set (WQ-A, WQ-B, WQ-G, WQ-I) of an underrepresented habitat essential for a valued resource, provided intriguing evidence for potential nutrient reduction strategies (WQ-C, WQ-D, WQ-E), and demonstrated the necessity of accomplishing WQ-F, identifying drainage boundaries, before ecological evaluation can be reliably conducted .

The work was conducted during a multi-year period of extremely low rainfall. This underscores the need for long-term data that incorporates natural variation. A year of sampling of motile species with complex environmental requirements is only a snapshot, whereas multiple years of data tends to provide a more realistic view of these inherently variable systems. Since the purpose of the study was to determine the impact of freshwater flow alterations on creek water quality and fish assemblages, the lack of rainfall likely biased the results toward low levels of impact. A combination of small size, tidal flushing, Harbor influence, and generally low freshwater inflow resulted in minimal salinity gradients overall in the creek systems studied and limited the planned data analyses. The highest salinities were downstream of a control structure in Culvert Creek. In contrast, Yucca Pens apparently received substantially more freshwater than any of the other systems or than could be reasonably explained by a comparative evaluation of watershed characteristics, impervious area, and development. The depressed salinity of Yucca Pens was one of the dominant water quality features of the study.

All stations experienced daytime minima of less than 2.0 mg/l of DO and all but one station had median values less than 4.0 mg/l. Seasonal patterns were present in DO as well as chlorophyll, and chlorophyll concentrations were higher in the northern creeks. Chlorophyll response to total nitrogen concentration was generally consistent among creeks. In nonparametric analyses, the water quality data of the two northern creeks were similar to one another, as were the two southern creeks. Separation between the two groups of creeks was driven by the low phosphorus concentrations of Yucca Pens and Culvert Creek, both overall and in the contributing freshwater. The low phosphorus of Yucca Pens and Culvert Creek could result from algal processes, from local mineralogy and soil composition, or from higher proportions of groundwater.

In a number of instances, the mapped watershed boundaries did not accurately reflect the actual contributing area in these low relief and drainage-altered creeks. The lack of

confidence in the watersheds and statistics developed from mapped boundaries prevented the development of an empirical alteration or degradation measure with which to assess water quality of fish communities and emphasize the need to accurately describe the contributing watersheds.

In previous years, fish densities, both of all species and of juvenile snook in particular, had been shown to be higher, snook diets more diverse, and the density of exotic species lower in the less degraded northern creeks. The densities of all species, the best metric of overall, long-term habitat quality of the creeks, were relatively similar during this work, higher densities in the northern creeks, but densities in all creeks were much reduced from values collected in 2003-2004. The density of snook, a focal species, was surprisingly greatest in Culvert Creek. The overall density and composition of fish communities were statistically linked to ratios of total nitrogen to total phosphorus (higher in the northern creeks) and to salinity (substantially lowest in Yucca Pens). Snook density, size and survival, on the other hand, was significantly linked with DO levels and ammonia.

Differences in fish density between northern and southern creeks was attributed to a combination of habitat differences; a general lack of SAV and reduced structural habitat in the southern creeks, high flows evidences by the scoured bottom and creek bank overhangs. Reduced fish density from 2003-2004 and the present study were attributed to a comparatively greater damage and reduction in mangrove habitat and SAV in the northern creeks as the result of the narrow path of Hurricane Charley (August 2004). While bias due to capture efficiency may play a role in the absolute fish densities, capture efficiency should be increased with a reduction in mangrove habitat and is inconsistent with the observed fish densities both between groups of creeks and between years. Recent habitat alterations for restoration of a shoreline in North Silcox is proposed as an explanation for the surprising general absence of snook in this system.

In addition to updated watershed delineations, monitoring of freshwater flows into selected mangrove creeks would allow a reliable analysis of fish communities with respect to watershed alterations. Similarly, long-term concurrent monitoring of water quality variables and creek fauna would provide a view of trends within the context of natural variability. Future sampling should be coupled with vegetation surveys of both SAV and emergent species to quantify changes in structural habitat and the influence on densities of juvenile snook and other species of interest. Coastal management in the Charlotte Harbor region has suffered because of an overall lack of historical data, and development of long-term monitoring plans now will be essential for assessing impacts of coastal land use on estuarine in the future, and will provide information essential for adaptive management strategies.

Introduction

A long term sampling of fish communities of four estuarine mangroves creeks along Charlotte Harbor's eastern shoreline was conducted between February 2002 and September 2009. The database from this sampling represents the longest (and perhaps only) time series of fish in the estuarine creeks of Charlotte Harbor. This research has included comparisons of fish communities along a gradient of habitat degradation, with degradation categorization based upon observed fish density, alteration of upland habitats, and associated alterations of freshwater flows into the study creeks. Previous research (partially funded by CHNEP) has shown that:

- fish communities differ among the creeks, with fewer species and fewer total fishes in the more degraded creeks;
- higher abundances of juvenile snook (an economically important recreational fish species) in the less degraded creeks;
- differences in juvenile snook diet among creeks, with less diverse diets in degraded creeks; and
- a link between the presence of an invasive fish (Mayan cichlids) in estuarine creeks and altered upland habitats.

However, thus far, assignation of habitat degradation categories has been based upon qualitative assessment of upland habitat alterations and estimates of freshwater flow into the creeks. As part of an effort to quantify and verify these creek habitat quality categorizations, this work collected and examined water quality in the four study creeks as a measure of habitat quality. The hypothesis was that differences in watershed freshwater flow alterations have resulted in measurable differences in water quality and in nutrient loading to the creek systems. These data were combined with additional data collected under other projects – fish sampling, ongoing research on juvenile snook survival, growth, diet, and movements, and GIS estimates of creek watershed alterations – to quantitatively categorize creeks and to evaluate the links of water quality to the presence and densities of estuarine fish.

Historically, during the rainy season, water would inundate vast stretches of upland habitats (wet and mesic pine flatwoods, hydric hammocks, and coastal tropical hammocks) and drain as slow, overland sheetflow to oligohaline and mesohaline marshes at the upper reaches of the tidal estuarine system. In areas with larger drainage basins, surficial flows were concentrated into tidal creek systems, creating a permanent flow corridor between upland salt ponds, tidal marshes, and Charlotte Harbor proper. During the dry season, wet prairies and hydric hammocks dried out, seasonally removing the corridors between upland salt ponds and tidal marshes. In larger drainage systems, tidal creeks may remain connected to the upland salt-water ponds.

Southwest Florida is experiencing increasing development of coastal and near-coastal areas, with associated loss and degradation of the many integrated portions of this linked upland-salt pond-tidal marsh habitat. The seasonally inundated uplands have been a particular focus as diking and ditching have attempted to minimize standing water during all seasons. In addition to increased drainage, development of a watershed often increases the proportion of impervious surface within a basin. The combined effects are increased rates of runoff during storm events and a resulting decrease in base flows during non-storm periods, relative to unaltered lands. Increased flow rates during storms can deliver higher loads of sedimentary particles. Other human activities within a watershed also impact water quality of runoff. Fertilization of improved pasture, agricultural lands, and residential lots are all common practices and, together with animal wastes and domestic waste disposal, have the potential for increasing the delivery of nutrient loads to estuarine systems relative to unaltered watersheds. Increased nutrient loads can change the trophic structure of receiving waters to the extent that changes in biomass and in community structure are evidenced at both primary and secondary trophic levels.

Relevance to CHNEP Priority Goals and Actions

The project addressed the Charlotte Harbor priority problems of hydrologic alterations and water quality alteration/degradation. The project evaluated an underrepresented class of waterbodies (mangrove tidal creeks), for which little information exists and would provide information on the likely phytoplankton response to a gradient of estuarine macronutrient loads. To the extent that degraded habitat quality affects fish utilization of an area, this project also addressed fish and wildlife habitat loss. Increased impervious area in a creek watershed was expected to cause more variable salinity or more stratified conditions within the receiving creek waters. Differences in land use were expected to cause differences in nutrient loads (measured as nutrient concentrations). Data analyses were to link water quality and watershed habitat changes to fish density and production.

The project was designed to provide data which would be suitable for impairment verification if needed (WQ-A), to fill data gaps (WQ-B) needed to assess impairments and determine TMDLs, and to allow the input of a robust data set into STORET, the TMDL process, and triennial data reviews. Data were to be provided for dissolved oxygen, chlorophyll, salinities and nutrients in the mangrove creek habitat that was severely underrepresented with water quality data (WQ-G). Nutrient and chlorophyll data would allow the evaluation of phytoplankton limiting nutrients (WQ-I). Fisheries communities with a strong link to water quality would provide a very concrete benefit (healthy fisheries) to water quality improvements and so would support public education efforts to reduce non-point source loads (WQ-L, WQ-M), and to implement land development codes controlling impervious area (WQ-F).

For hydrologic alterations, those priority actions which seek to restore more natural hydrologic periods (HA-C, HA-B, HA-G), would benefit from this project's empirical data quantifying differences in water quality and fisheries as a function of watershed land use and probable runoff. Project results were expected to support the implementation of non-point source load reduction (HA-N) and further contribute to public education (HA-P)

Project results were also expected to be relevant to priority actions addressing fish and wildlife habitat. Linkages between fisheries and either nutrients or flow alterations would allow impacted areas to be identified and prioritized (FW-C, FW-D, FW-F). Restoration of water quality through nutrient load reduction or restoration of historical flows would actually result in an enhancement of habitat (FW-C, FW-D, FW-E).

Study Locations

Preliminary investigations indicate that there are visually observable differences in land use between the creek basins. In addition to physical land alterations, there are also differences in residential density and in waste treatment techniques. All of the creeks lie in separate drainages. Prior fishery data also indicate that fish density in North and South Silcox Creeks is much greater overall than that in Yucca Pens and Culvert Creek, and lead us to identify a terms of 'less degraded' and 'more degraded' based on fish density.

For the purposes of this study, the two northernmost creeks, North Silcox and South Silcox Creeks, were considered 'less degraded'. Their morphology remains largely intact (compared to 1953 aerial photos). The immediate drainages of the creek banks (within the Department of Environmental Protection Charlotte Harbor Preserve State Park) remain largely undeveloped. The closest road to the creek head (point where the creek can no longer be traveled on foot, and where the creek can no longer be traced using aerial imagery) is 1.9 km for North Silcox and 2.1 km for South Silcox. There are four buildings within 2 km of the North Silcox creek head and three buildings within 2 km of the South Silcox creek head. Creek widths range from 2m in narrow passes to >60 m in wider bays, depth is shallow (< 0.5 m except in narrow passes where depths reach 1m), shorelines are lined entirely by red mangroves *Rhizophora mangle*, and the bottom is mixed mud and sand. Prior to Hurricane Charley in 2004, these creeks had extensive coverage by submerged aquatic vegetation. In the upper zone, SAV was entirely *Ruppia maritima*, whereas the middle and lower zones were dominated by *Halodule wrightii*. Since Hurricane Charley, submerged aquatic vegetation (SAV) has been either non-existent or limited to sparse coverage in a few locations.

The two southern creeks, Yucca Pens and Culvert Creek (also known as Durden Creek), are located 16 km south of the natural creeks, and are considered 'more degraded'. In contrast to the less degraded creeks, the immediate creek watersheds are more impacted by roads and houses. The distance from creek head to nearest road is 0.1 km for Yucca Pens and 0 km for Culvert Creek. A housing development with >100 houses begins within 0.5 km of the Yucca Pens creek head, and the Culvert Creek watershed contains >25 houses and a housing area in progress (with additional roads and containment ponds) within 2 km of the creek head. Culvert Creek also has a large artificial pond (1.3 km length x 100 m width x >6 m depth) just above the creek head. The altered flow regimes are expected to cause short, pulsing hydroperiods limited to the immediate creek with little overland sheet flow. The creek bottoms are mostly hard sand, indicating periods of high flow. The estuarine submerged aquatic vegetation (*R. maritima* and *H. wrightii*) is patchy and limited to the lower two-thirds of the creeks, where more saline conditions can be maintained by the influence of water from Charlotte Harbor. The creeks are narrow (mean = 5 m) for the upper two-thirds, and have wider bays (60 m) only in their extreme lower portions. Narrow sections are scoured to > 2 m depth with undercut banks, further indicating the occurrence of high flows, and have a greatly reduced width of the intertidal mangrove prop root habitat. The presence of occasional concentrations of macroalgal quantities (*Ulva* sp., A.J. Adams; personal communication) in Yucca Pens and Culvert Creek indicate that higher nutrient loads to the estuary from these two creeks are probable.

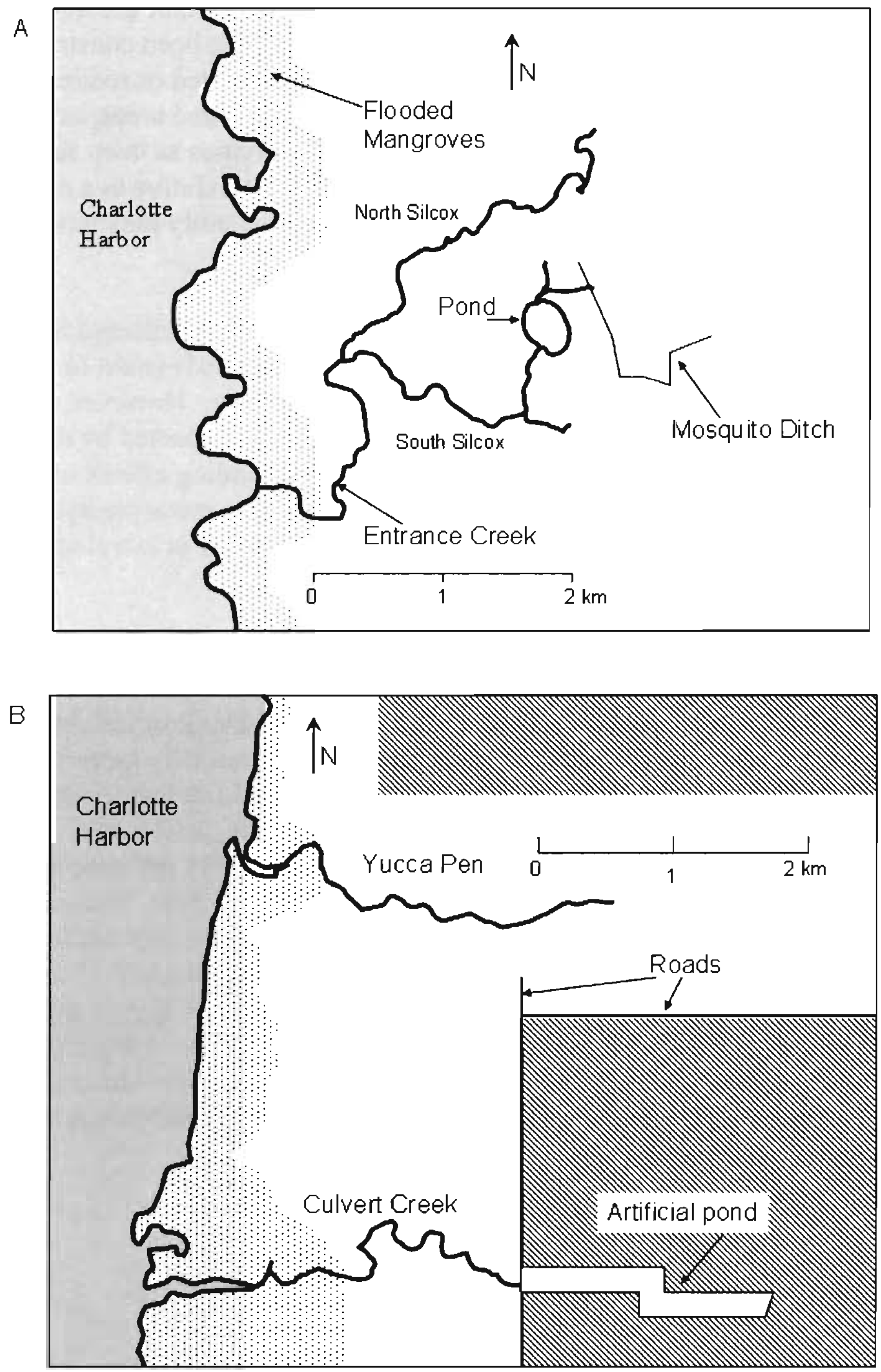

Figure 1. Diagrams of study creeks (**A** – North Silcox and South Silcox = 'less degraded'; **B** Yucca Pens, Culvert Creek = 'more degraded') showing artificial ponds and altered portions of upland drainages. Heavy stippling in (B) denotes land altered by development.

The watershed alterations described should be qualified, as much of the development that has occurred in the creek basins is somewhat unusual. Roads have been constructed, and sheet flow of freshwater along micro-gradients undoubtedly interrupted or redirected. The number of homes actually constructed, however, is strikingly low in some areas, as are the probable anthropogenic degradations of water quality from such activities as lawn fertilization, pet wastes, and septic tank influences. In underdeveloped areas, relative to a development in which platted lots are 100% built out, alterations in water quantity may have a greater impact than alterations in water quality.

The patchy nature of coastal development and conservation was reflected in the sites used in this study – the creek types (less degraded versus more degraded) could be confounded by latitude in that creeks of similar quality are near to one another. However, each creek has a unique watershed that sets the creeks apart (i.e., they are not impacted by the same anthropogenic habitat alteration), which reduced the confounding effects of creek locations. Moreover, the mouths of all four creeks were within the same estuarine hydrological zone of Charlotte Harbor (Poulakis et al. 2003), so are unlikely to differ in larval supply or other hydrologically mediated influences from the estuary.

Focal Species

Common snook, *Centropomus undecimalis*, is a tropical and subtropical, estuarine-dependent, euryhaline species that is ecologically and economically important throughout its range, especially in Florida (Taylor et al. 2000). The general life history is as follows: adult snook spawn near passes and inlets at the mouths of estuaries (Taylor et al. 1998); the larval planktonic stage is approximately two weeks (Peters et al. 1998); juvenile habitats are shallow, complex, meso- to oligohaline habitats (Peters et al. 1998). Post-settlement snook (< 20 mm standard length [SL]) are first captured in Charlotte Harbor creeks in mid-June (A.J. Adams and R.K. Wolfe, unpublished data). Juvenile snook reach 150-180 mm SL by age-1, and are common in or near creek habitats year-round until approximately 300 mm (age-2) (Taylor et al. 2000), when they enter the adult population. Larger snook use open estuarine and nearshore habitats from spring through fall, and over-winter in riverine or creek habitats. Juvenile survival and the extent that different juvenile habitats provide individuals to adult populations are unknown.

Methods

Sampling Period

Field surveys and collection of fishery and water quality samples of four mangrove creeks on the eastern shoreline of Charlotte Harbor, FL were carried out over a 17 month period from May 2008 through September 2009. A total of 12 water quality field surveys were carried out, of which nine were coupled with fish sampling and analysis (Table 1).

Table 1. Collection dates for field surveys.

Sampling Month	Cumulative Month	Collection Dates		
		Water Quality	Fisheries	Survival
May-08	5	5/21/2008	5/5-9/2008	---
Jul-08	7	7/22/2008	7/28-30/2008	---
Sep-08	9	9/11/2008	9/2-17/2008	---
Nov-08	11	11/24/2008	11/17-20/2008	11-12/2008
Jan-09	13	1/22/2009	1/27-29/2009	1-2/2009
Mar-09	15	3/19/2009	3/23-26/2009	3-4/2009
Apr-09	16	4/16/2009	---	4-5/2009
May-09	17	5/14/2009	5/19-6/4/2009	5-6/2009
Jun-09	18	6/2/2009	---	6-7/2009
Jul-09	19	7/9/2009	7/20-24/2009	7-8/2009
Aug-09	20	8/13/2009	---	8-9/2009
Sep-09	21	9/3/2009	9/21-24/2009	9-10/2009

Water Quality Sampling and Analyses

Fish sampling was conducted within three zones (upper, middle, and lower [U, M, L]) within each of the four mangrove creeks: North Silcox (NS), South Silcox (SS), Yucca Pens (YP), and Culvert Creek (CC). (The combination of creek and zone was referred to as a station.) Fixed water quality stations (Table 2) were similarly located within each zone. Although not specifically tidally filtered, most water quality samplings were conducted on a late flooding or high tide because the creeks are too shallow for boat access (required for water quality equipment) near low tide.

Table 2. Water quality station locations.

Station	Latitude	Longitude
NSU	26.85487	82.04599
NSM	26.85376	82.04924
NSL	26.84997	82.05219
SSU	26.84847	82.04570
SSM	26.84493	82.04680
SSL	26.84858	82.05074
YPU	26.75370	82.05761
YPM	26.75426	82.05881
YPL	26.75506	82.06065
CCU	26.74483	82.05812
CCM	26.74353	82.06209
CCL	26.74374	82.06468

Samples for water quality were collected using a Niskin sampler at mid-depth or 1.0m below the surface (whichever was shallower). Additional samples were collected at the surface if salinity stratification was observed on site. Sample fractions were collected from the Niskin and preserved as required (Table 3). Samples were iced and maintained at 4°C for transport to Mote Marine Laboratory (MML). Physical data (temperature, salinity, and dissolved oxygen [DO]) were concurrently measured at each station using a YSI instrument at the depth of sample collection. Field and container blanks were collected using the sampling gear and analyte-free water to confirm an absence of sampling contamination. Sampling activities and laboratory analysis were conducted in accordance with MML's Quality Manual, which meets the National Environmental Laboratory Accreditation Program (NELAP) requirements. All analyses met required data quality objectives.

Fisheries

For fisheries data, the four study creeks were sampled every other month from May 2008 through September 2009, using a 22 x 1.2 m center bag seine with 3.2 mm mesh. Each creek was divided into three equal zones (upper, middle, lower) for sampling, with five samples per zone, and thus 15 samples per creek, per sample period. The access to areas suitable for seine sampling in the upper zone of Yucca Pens was limited and so only three samples were routinely collected at this location. Sample locations within each creek zone were selected haphazardly in each month. For each sample, the net was set in a semi-circle against a mangrove shoreline and pursed to force fish into the bag, all fish were identified to the lowest taxon possible, the first 25 individuals of each taxon were measured (SL) and the remainder counted, and temperature, salinity, and DO recorded with a handheld YSI 556 MPS. All fish were returned to the water at the site of capture. Seine data from North Silcox for January 2009 and from Yucca Pens in May 2009 were not available for analysis.

Table 3. Method references for laboratory analyses.

Parameter	Method Reference	Holding Time	Preservation	Minimum Detection Limit
Total Nitrogen (mg/L)	Computed from Total Kjeldahl Nitrogen and Nitrate-Nitrite Nitrogen			
TN:TP (mg:mg)	Computed from Total Nitrogen and Total Phosphorus			
Total Kjeldahl Nitrogen	EPA[1] - 351.2	28 days	pH<2, 4°C	0.05mg/L
Nitrate-Nitrite Nitrogen	EPA[1] - 353.2	28 days	pH<2, 4°C	0.005mg/L
Ammonium Nitrogen	SM20 - 4500-NH_3G	28 days	pH<2, 4°C	0.005mg/L
Total Phosphorus	EPA[2] - 365.4	28 days	pH<2, 4°C	0.05mg/L
Chlorophyll a (corr. for pheophytin)	EPA[3] - 445.0	24hrs filter	dark, 4°C	0.05µg/L
		24days	-20°C, MgCO3	

1 - *Methods for the Determination of Inorganic Substances in Environmental Samples*, EPA/600/R-93/100 August 1993.
2 - *Methods for Chemical Analysis of Water and Wastes*, EPA-600/4-79-020, 1979, revised March 1983.
3 - Arar, E.J. and G.B. Collins Method 445.0, *In vitro* Determination of Chlorophyll a and Pheophytin a in Marine and Freshwater Algae by Fluorescence. Revision 1.2. September 1997 National Exposure Research Laboratory, Office of Research and Development, U.S. EPA, Cincinnati, Ohio 45268.

Survival Estimates

In separate efforts, juvenile snook were captured in South Silcox, Yucca Pens, and Culvert Creek with a center bag seine (21 m x 1.2 m, 3.1 mm mesh), and tagged with Passive Integrated Transponder (PIT) tags. Collection efforts were monthly between November 2008 and September 2009. All tagging occurred near the site of capture. For tagging, fish were measured (SL), a 3 mm incision made posterior and ventral to the pectoral fin, and a PIT tag inserted into the abdominal cavity. Other work, which included tagging, in situ caging, and laboratory experiments, had previously been conducted to determine tag retention rates (100%), effects of tagging on survival (100% survival), and minimum fish size (120mm SL) suitable for tagging.

PIT tags used were half-duplex (HDX) (23 mm length x 3.4 mm diameter, 0.6 g (in air)) (Texas Instruments TIRFID S-2000) due to improved detection range over other technologies (P. Korrie, Dynasys Technologies). The autonomous antenna system used to detect tagged fish consisted of an open loop inductor coil antenna (a single loop of 6 gauge copper welding cable) connected to tuning circuits, which were connected to a reader unit and a data logging computer (Zydlewski et al. 2001). The antenna stretched across the water surface (suspended at creek center by a PVC stake), and the bottom and sides of the creek so that fish swimming in the creek had to pass through the antenna (creek width = 8 m, mean depth 0.5 m). Detection efficiency of the antenna was evaluated in 11 trials by releasing tagged snook within a seine with each end tied to the sides of the antenna. Experiments determined that the antenna read 60% (30 cm of 50 cm water column), likely due to signal attenuation in brackish water. The system was powered by two 6 volt batteries, charged by a pair of 80-watt, 12-volt solar panel (model PW750, Matrix Solar), which allowed continuous operation. The batteries, tuner, reader, and computer fit into two waterproof boxes (approx. 1 m x 0.5 m x 0.5 m) on the creek bank. Data were downloaded to a flash card monthly.

A Cormack-Jolly-Seber model (Cormack 1964, Jolly 1965, Seber 1965, White and Burnham 1999) was used to estimate apparent survival of tagged juvenile snook. The model calculates two parameters, apparent survival probability and capture probability. Akaike's Information Criterion (AIC) values (Akaike 1973), corrected for small sample size, were used with relevant biological knowledge of the system (Pine et al. 2003) to select whether probabilities were allowed to vary by month. The model chosen was based on AIC criteria defined by Burnham and Anderson (2004). Biological knowledge of the system suggests the appropriate model will allow probabilities to vary between sample periods. Mortality of juvenile snook was likely to vary seasonally, as adult snook use mangrove creeks (juvenile habitat) during winter and opportunistically cannibalize juveniles during this co-occurrence (Adams and Wolfe, 2006). Additionally, juvenile snook movement and emigration vary seasonally, affecting both apparent survival and capture probabilities (Stevens et al. 2007; A.J. Adams, personal observation).

Defining Creek Watersheds

GIS data and metadata from SWFWMD and Lee County were used to define the creek watersheds. Data from two sources were needed because the SWFWMD coverage of the northern creeks (Drainage Basins, SDECREATOR.DRAINAGEBASINS, June 24, 2002; Figure 2), based on USGS Hydrologic Unit Classification (HUC) coding system did not extend into Lee County. Lee County's data were based on a 1960 study (Figure 3), and were modified by using the delineation between the southern creeks combined with 12 digit HUC codes for the area, which were obtained from USDA (1999, 12-Digit Watershed Boundary Data 1:24,000). As a result, the Lee County watersheds were expanded to have coincident boundaries with the 12 digit HUC (Figure 4).

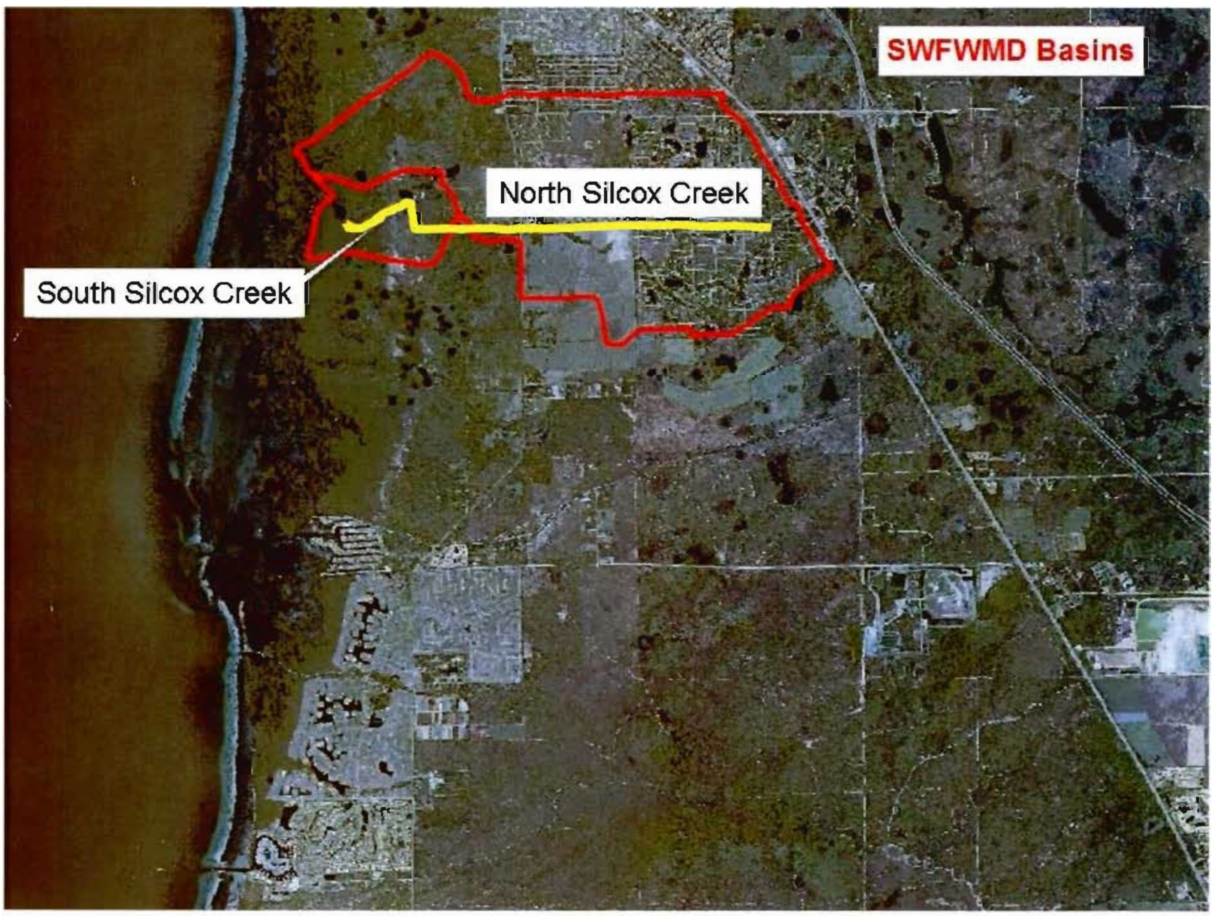

Figure 2. Defined drainage basins (red) for North and South Silcox Creeks. Data source: SWFWMD, 2002. Ditching connecting portions of the North Silcox drainage into South Silcox shown in yellow.

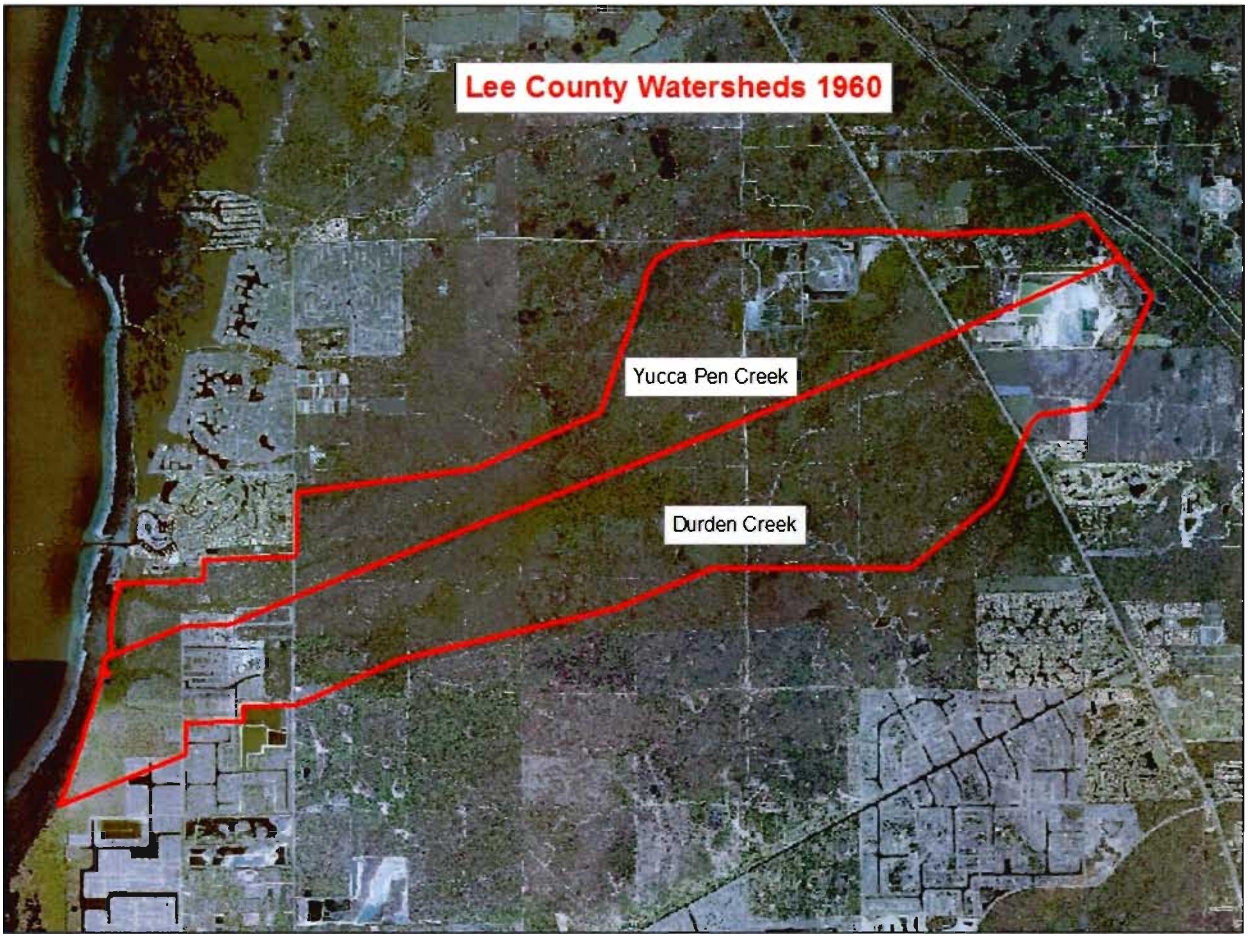

Figure 3. Drainage basins for Yucca Pens and Culvert (Durden) Creeks. Data source: Lee County, 1960.

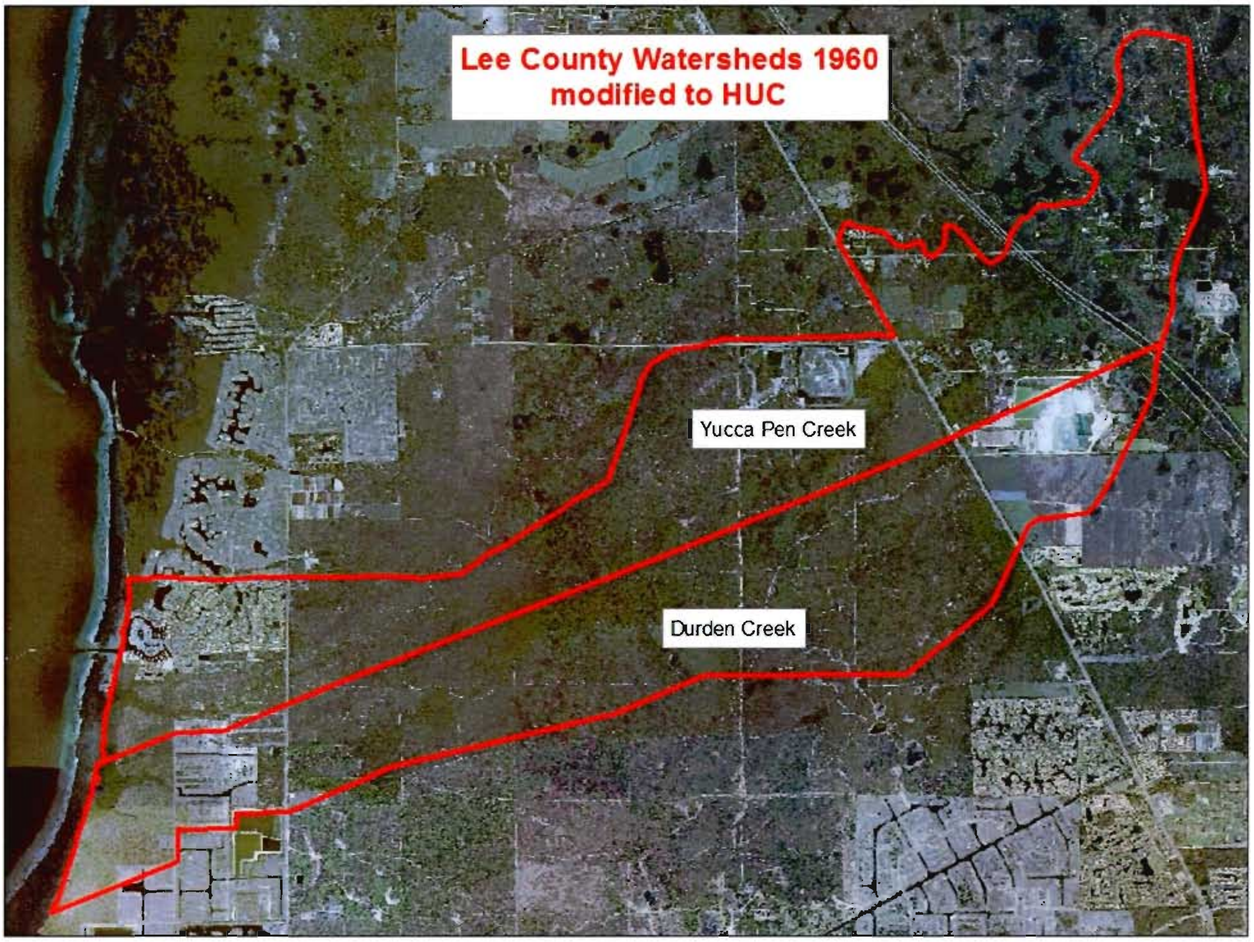

Figure 4. Modified drainage basins for Yucca Pens and Culvert (Durden) Creeks. Data source: Lee County (1960) modified to present HUC boundaries (USGS, 1999).

When the GIS-based watershed delineations were compared to personal knowledge of the area (A.J. Adams) and aerial images (Google Earth), it was clear that the GIS-derived watershed boundaries were not valid and did not adequately reflect the present-day contributions of freshwater flows from ditches, berms, and roads. As an example, the GIS-defined watershed for South Silcox is only immediately adjacent to the creek and subject only to local runoff. The ditch that connects to the creek (Figure 5), however, extends 6.83km eastward from the creek head, crossing the watershed boundary into North Silcox and greatly expanding the watershed. Other examples are evident in the Yucca Pens and Culvert Creek watersheds. The abundance of alterations is too great to estimate effects on the watersheds within the scope of this project.

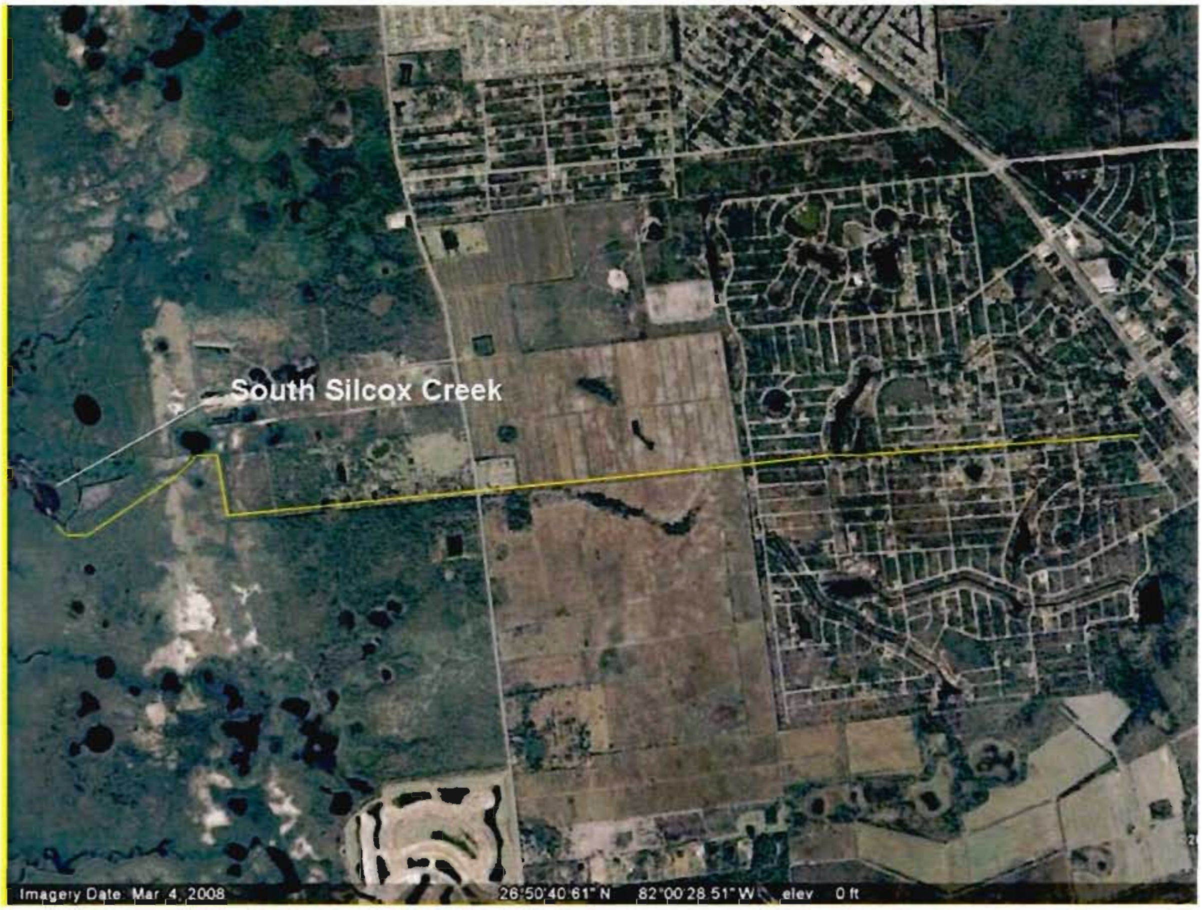

Figure 5. More detailed view of the ditch that extends 6.8km eastward from the head of South Silcox Creek, and connects to numerous other ditches, thereby greatly changing the historical watershed as determined by GIS.

Data Processing

Data for fisheries by species were normalized to the area seined resulting in density of organisms per m^2 ($\#/m^2$). Surrogate biomass data were also computed as the seine-specific mean length (mm) of each species times the number of organisms per m^2. In the few samples where lengths were missing (due to escape before measurement) the mean length of the same species in other seines of the same station, within the same creek, or for the study area during the month were used to compute the monthly surrogate biomass values. Mean results for both density and surrogate biomass were also computed as the average of the five (or three) seines for each month, creek, and zone combination. Monthly mean biological data by station (creek-zone) were used for comparison with water quality data, which were collected as single samples during each sampling month at each of the 12 stations.

Non-parametric analyses of community composition were conducted using PRIMER v6 (Clarke and Gorley, 2006). Similarity matrices were prepared on species data which had been double square root transformed to minimize the influence of highly abundant species. Seines with no organisms captured were retained in the data set. Measures of similarity between samples were zero-adjusted Bray-Curtis coefficients (Clark, Somerfield, and

Chapman 2006), with a dummy species variable added to all samples to permit the use of those seines with no organisms (n=26 of 494). Values of dummy variables were smaller than the lowest non-zero value of either abundance or surrogate biomass. PRIMER routines employed included analyses of similarity (ANOSIM) to assess differences in fish communities over time and between stations and creeks. Bio-Env-Stepwise (BEST) routines were used to assess the relationship of water quality with fish communities.

For water quality data, due to high correlations between total Kjeldahl nitrogen (TKN) and total nitrogen (TN), and inorganic nitrogen (IN) and ammonia, TKN and IN were removed from the statistical analyses. Given sample salinity, the fraction of freshwater (FFW) present was computed as:

$$FFW = (40\text{-Salinity})/40.$$

Under the simplifying premise that all nutrients present originated in freshwater, the theoretical nutrient content of the original freshwater was computed as TN or total phosphorus (TP) divided by the fraction of freshwater. Variations from conservative behavior of the nutrients in freshwater could then be used to identify regions acting as sources or sinks of nutrients among the various creeks. Viewing nutrient data as per fraction of freshwater also normalizes to account for differing freshwater inflow and resulting salinity variations between creeks. For use in PRIMER Analyses, data for TN:TP ratios, and for nitrogen and phosphorus in freshwater (N_FFW, P_FFW) were natural log transformed, and all parameters were normalized to a mean of zero with unit standard deviations.

Results and Discussion

<u>Water Quality</u>

Summary water quality data appear in Appendix A. Samplings spanned two warm, wet seasons and one cold, dry season. Temperatures displayed little differences among creeks. The wet season of 2008 exhibited generally lower salinities than did 2009. Salinities (associated with water quality samples) ranged from <1 to nearly 40, while temperatures ranged from 13-32°C (Figure 6). On average, Culvert Creek was slightly higher in salinity than the remaining creeks (Figure 7). Yucca Pens exhibited the lowest salinities overall, and was apparently a more 'flashy' creek, responding more strongly to freshwater inflows. Maximum salinity gradients observed between upper and lower zones within each creek were near 7 PSU for South Silcox, near 10 PSU for Culvert Creek, near 12 PSU for North Silcox, and near 17 PSU for Yucca Pens. Yucca Pens was also observed as completely fresh (all zones less than 1 PSU) in July 2008. With the exception of Yucca Pens, the remaining three creeks occasionally displayed reverse salinity gradients, with upper station salinities higher than downstream values, indicating a combination of low freshwater inflows and evaporation. Reverse gradients were present in about one half of the samplings, occurred between January and July, and were most often observed in North Silcox, followed by South Silcox and Culvert Creek, but were never observed in Yucca Pens. On average, however, the upstream to downstream increase in salinity was <1 PSU for North Silcox, South Silcox, and for Culvert Creek, while Yucca Pens averaged an increase of near 5 PSU.

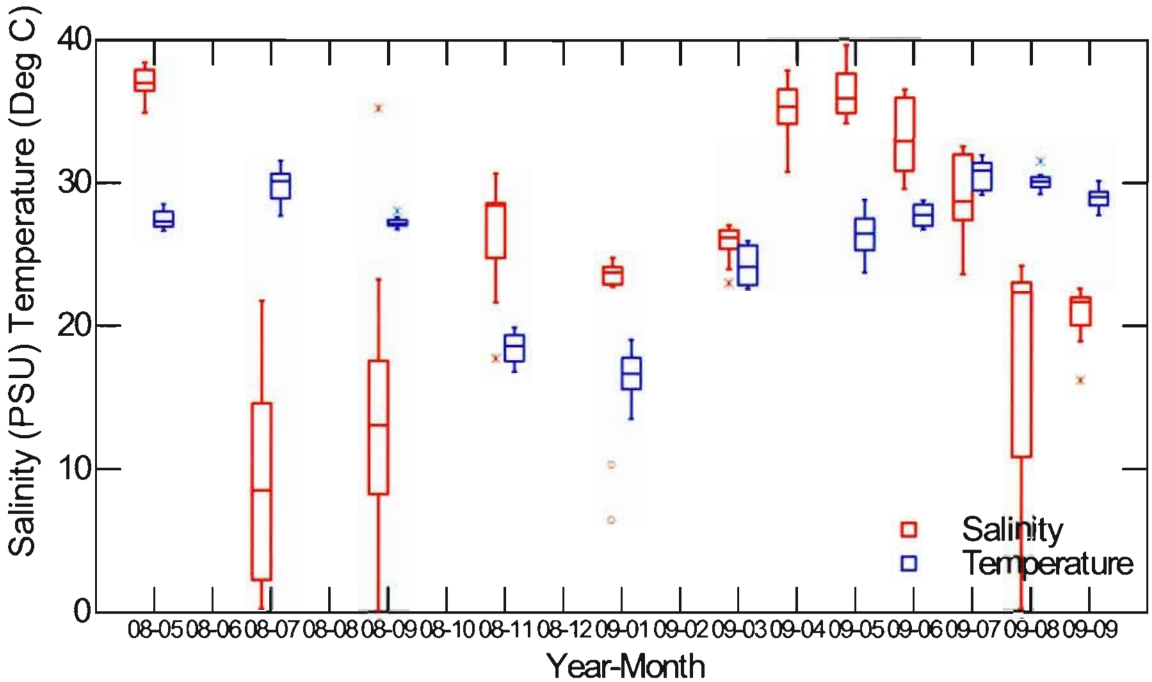

Figure 6. Monthly salinity and temperature distributions of all creeks and stations pooled over the study period.

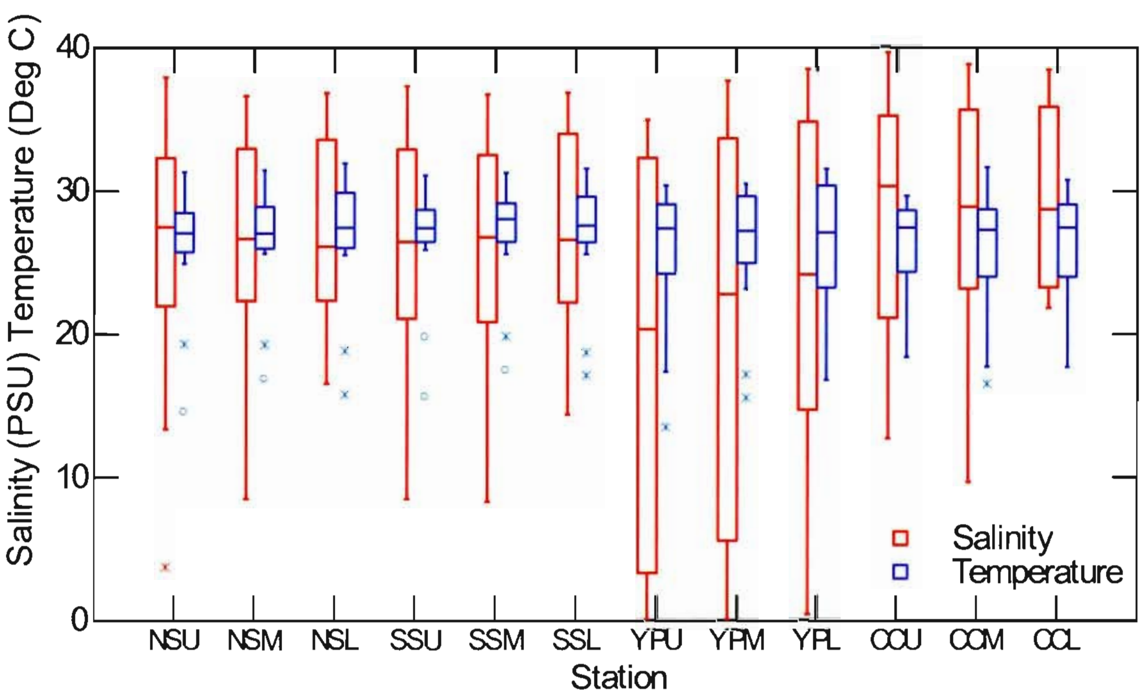

Figure 7. Salinity and temperature distributions by station.

Temporal patterns of DO were inverse with temperature due to gas saturation kinetics and increases in warm weather respiration. The upper stations of North Silcox, Yucca Pens and Culvert Creeks were generally somewhat lower on DO than the middle or lower reaches (Figure 8). Mean and median values of DO at all stations did not exceed 5.00 mg/l and minimum values, during the warmer months, were all less than 1.40 mg/L.

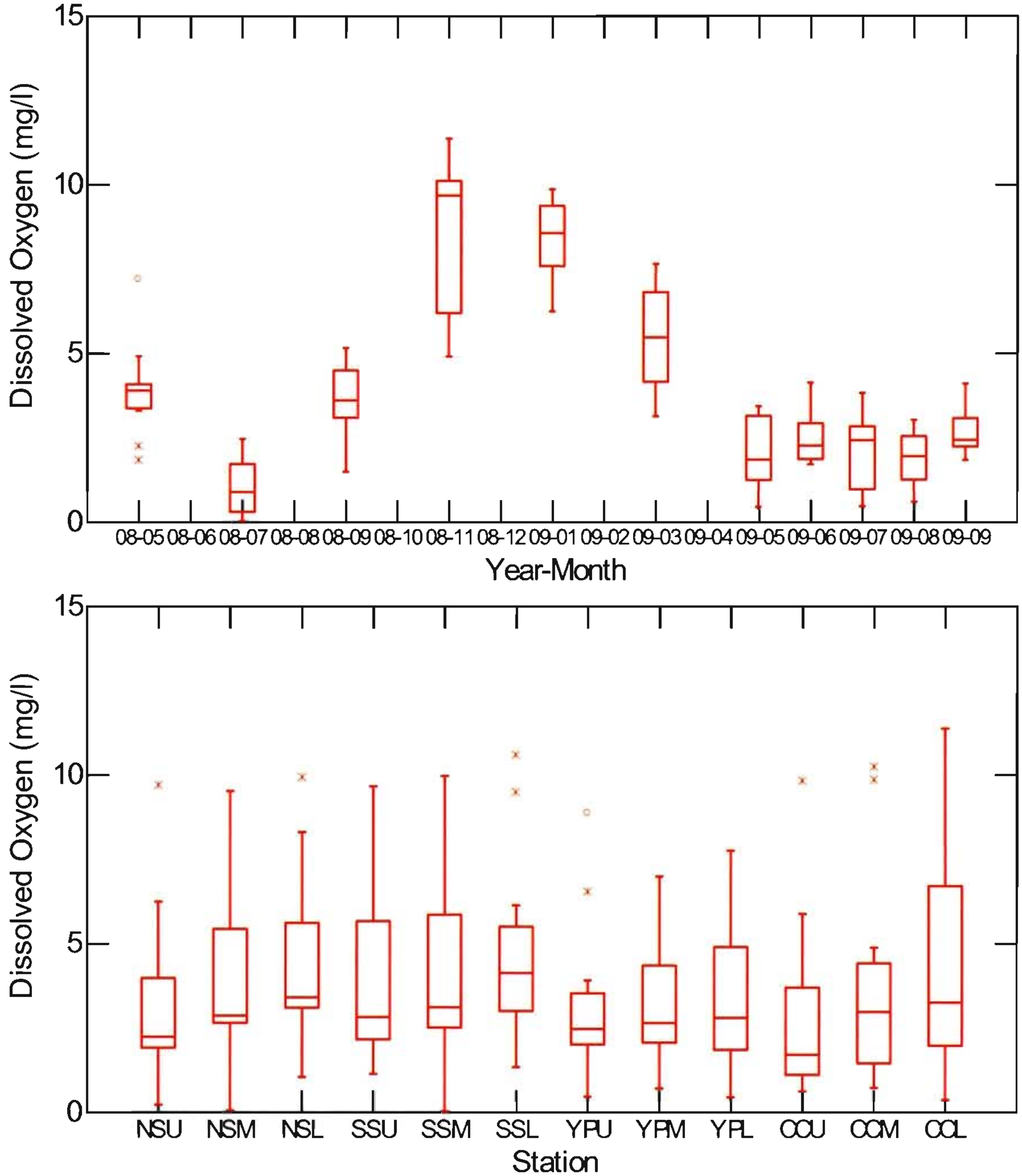

Figure 8. Temporal and spatial distribution of dissolved oxygen by station.

For the water quality parameters (Figure 9), nitrate-nitrite-nitrogen concentrations were generally below detection limits (0.005 mg/l). For the few values above 0.005 mg/l, most were reported from the Yucca Pens stations, with a single value each from Culvert Creek and South Silcox. Ammonia-nitrogen was more prevalent, with values in South Silcox generally higher than Culvert Creek, followed by slightly lower values in North Silcox and Yucca Pens. Median total Kjeldahl nitrogen values declined from upper to lower zones in all creeks, with overall values slightly higher in North and South Silcox than in Culvert Creek, and lowest in Yucca Pens. Total phosphorus concentrations separated the northern and southern creeks. Both North and South Silcox creeks were substantially higher in total phosphorus, with a progression of declining median values from upper to lower zones within each creek. In contrast, Yucca Pens and Culvert Creek total phosphorus concentrations were lower, with little change between upper, middle, and lower zones. Culvert Creek has an artificial pond above the upper station which could remove phosphorus if nitrogen-fixing blue-green algal blooms occur. The Yucca Pens Unit of the Fred C. Babcock-Cecil M. Webb Wildlife Management Area is evidently known for large expanses of standing water during certain periods of time which could serve a similar function.

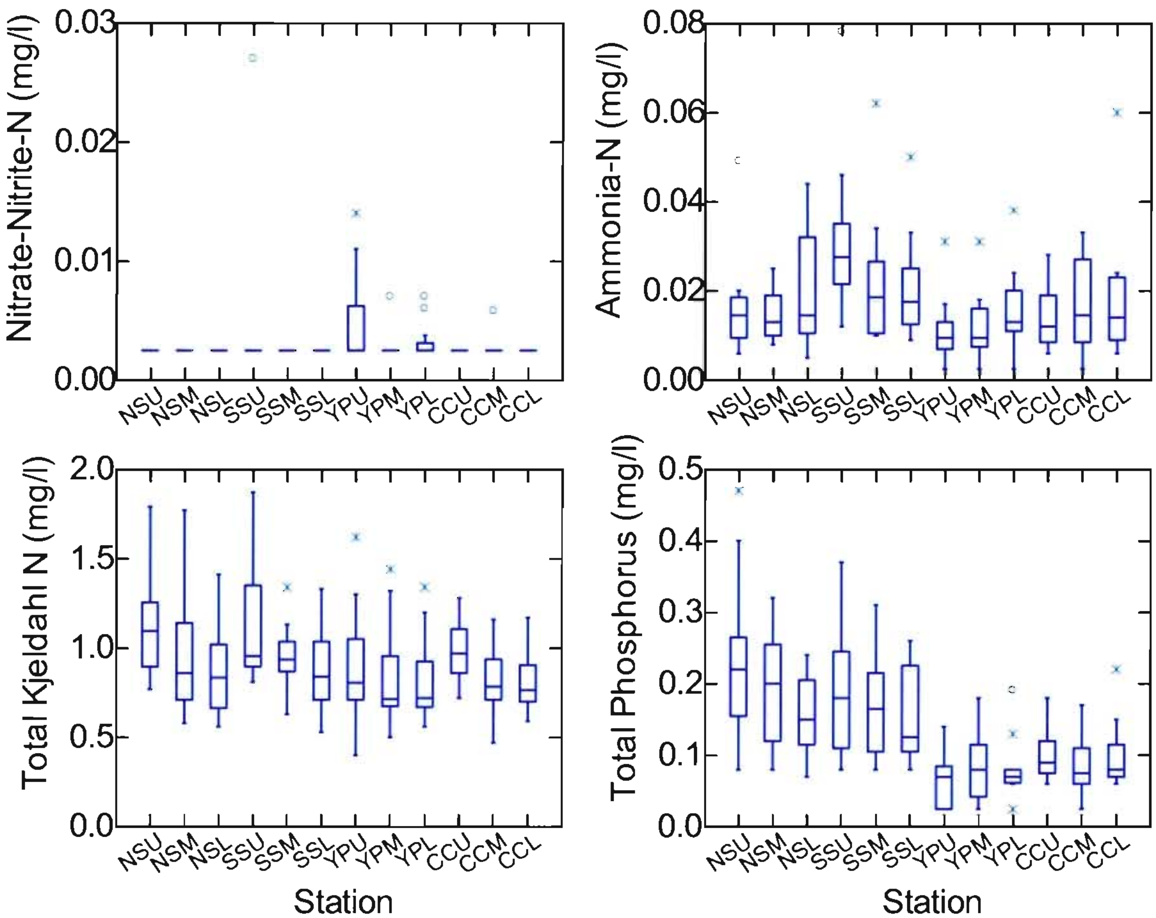

Figure 9. Distribution of nitrate-nitrite-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, and total phosphorus by creek station.

When computed freshwater nitrogen and phosphorus concentrations were compared (Figure 10), freshwater N in Yucca Pens appeared somewhat lower than the remaining creeks, while Culvert Creek and the upper station of South Silcox recorded some higher excursions. For phosphorus, the freshwater concentrations were highest in South Silcox, and again lowest in Yucca Pens and Culvert Creek, similar to the raw total phosphorus concentrations. As the freshwater concentrations of phosphorus in Yucca Pens were so low, plots of phosphorus as a function of salinity for Yucca Pens data illustrated a predominantly Harbor or estuarine source for phosphorus within this creek. The remaining creeks had higher concentrations of phosphorus in freshwater and varied as to whether the Harbor or the freshwater inflows were higher in phosphorus concentrations. Due to the low phosphorus concentration, the TN:TP ratios (mg:mg) of Yucca Pens were the highest followed by Culvert Creek data. Comparing these ratios to the Redfield ratio of phytoplankton uptake (16:1 uM:uM, or 7.2:1 mg:mg) and under the premise that all N and P could be re-mineralized with sufficient residence time, the northern creeks could be described as slightly nitrogen limited, while the southern creeks were slightly phosphorus limited.

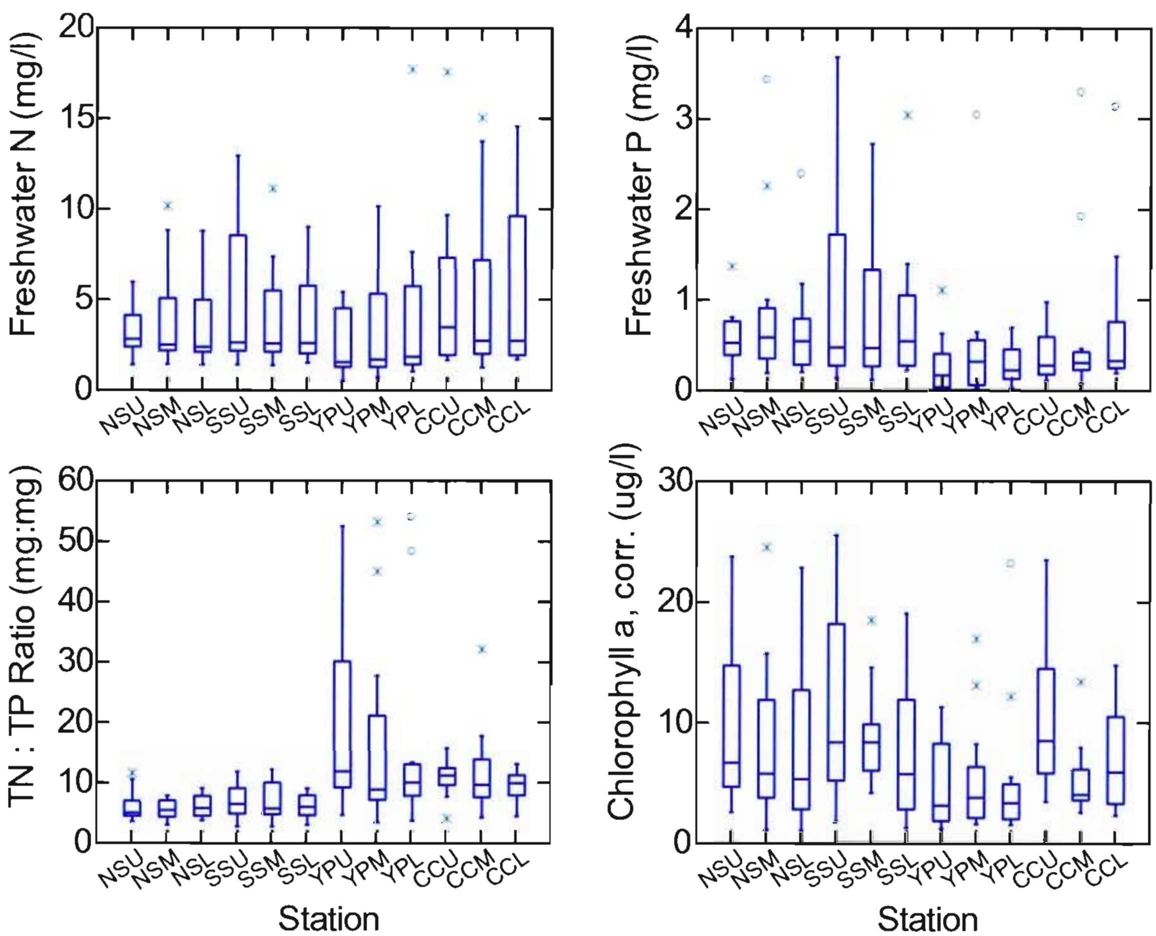

Figure 10. Distribution of freshwater N, P, TN:TP ratios, and chlorophyll by station.

Due to the very small salinity gradients observed in most creeks and for most samplings, as well as reverse gradients of salinity (higher salinity at upstream stations due to low flows and evaporation), the analyses of dilution gradients of nutrients were problematic. Correlations of nutrient parameters against salinity were seldom significant. Lack of significance appeared to be a result of a very narrow salinity distribution coupled with expected analytical uncertainties and a low number of observations, rather than to mid-creek removal or contributions of nutrients. Without regard to significance of regressions, ammonia increased with increasing salinity in approximately 60% of the monthly creek samplings. For total nitrogen (Figure 11), concentrations declined with increasing salinity in approximately 80% of the samplings, and declined from upstream to downstream in approximately 65% of the samplings, indicating a localized freshwater nitrogen sources in most instances. (Interestingly, Yucca Pens had lower total N upstream during five of the 12 samplings indicating a Harbor source of total N in these instances.) In contrast, total phosphorus (Figure 12), concentrations increased with salinity in approximately 60% of the samplings. Despite median values discussed above, it appears that supplies of phosphorus to the tidal creeks were more often dominated by supplies from Harbor waters rather than from freshwater inflows at the head of the tide.

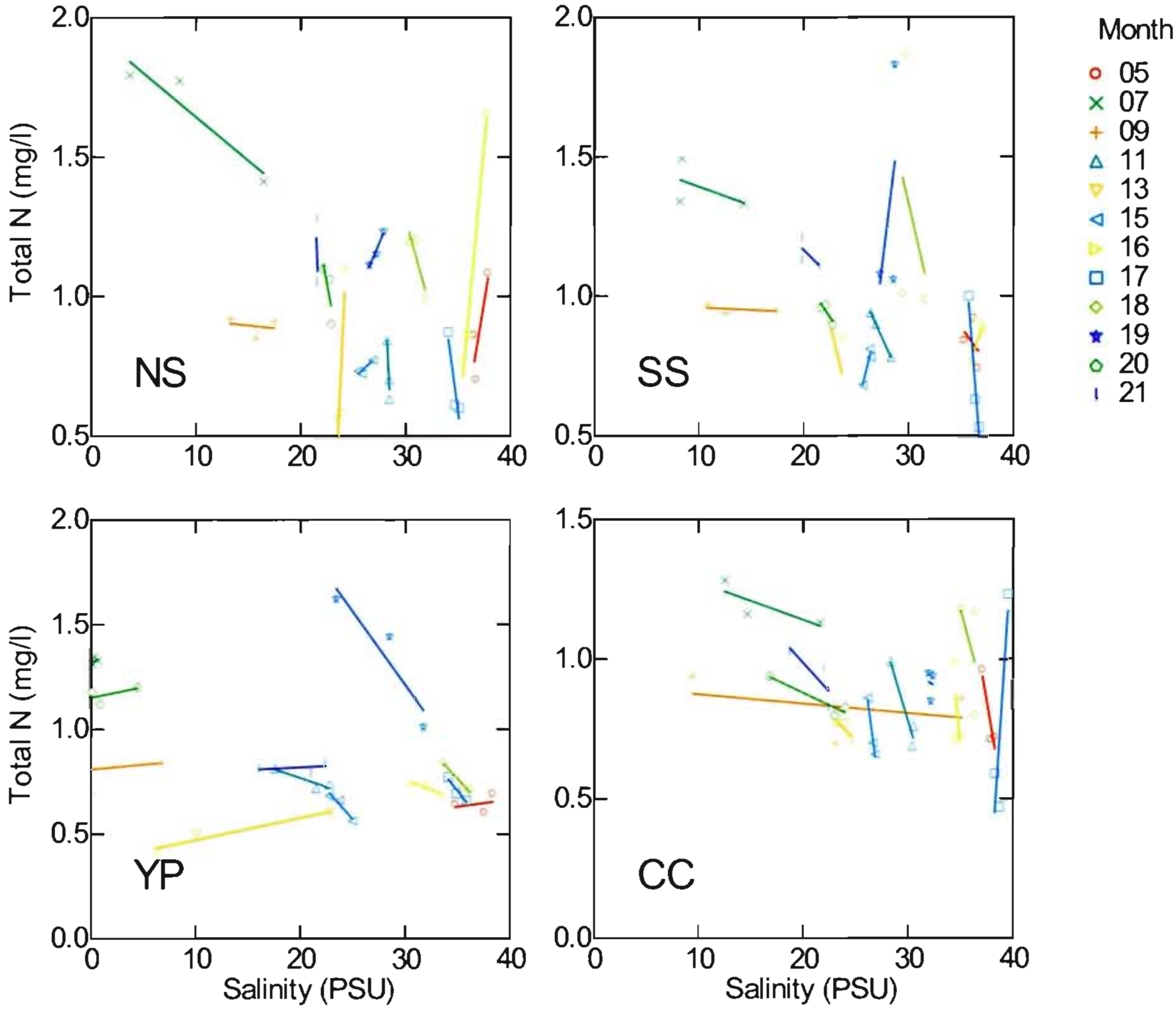

Figure 11. Dilution gradients of total nitrogen as a function of salinity by creek and sampling month. Cumulative numerical month identifiers correspond to Table 2.

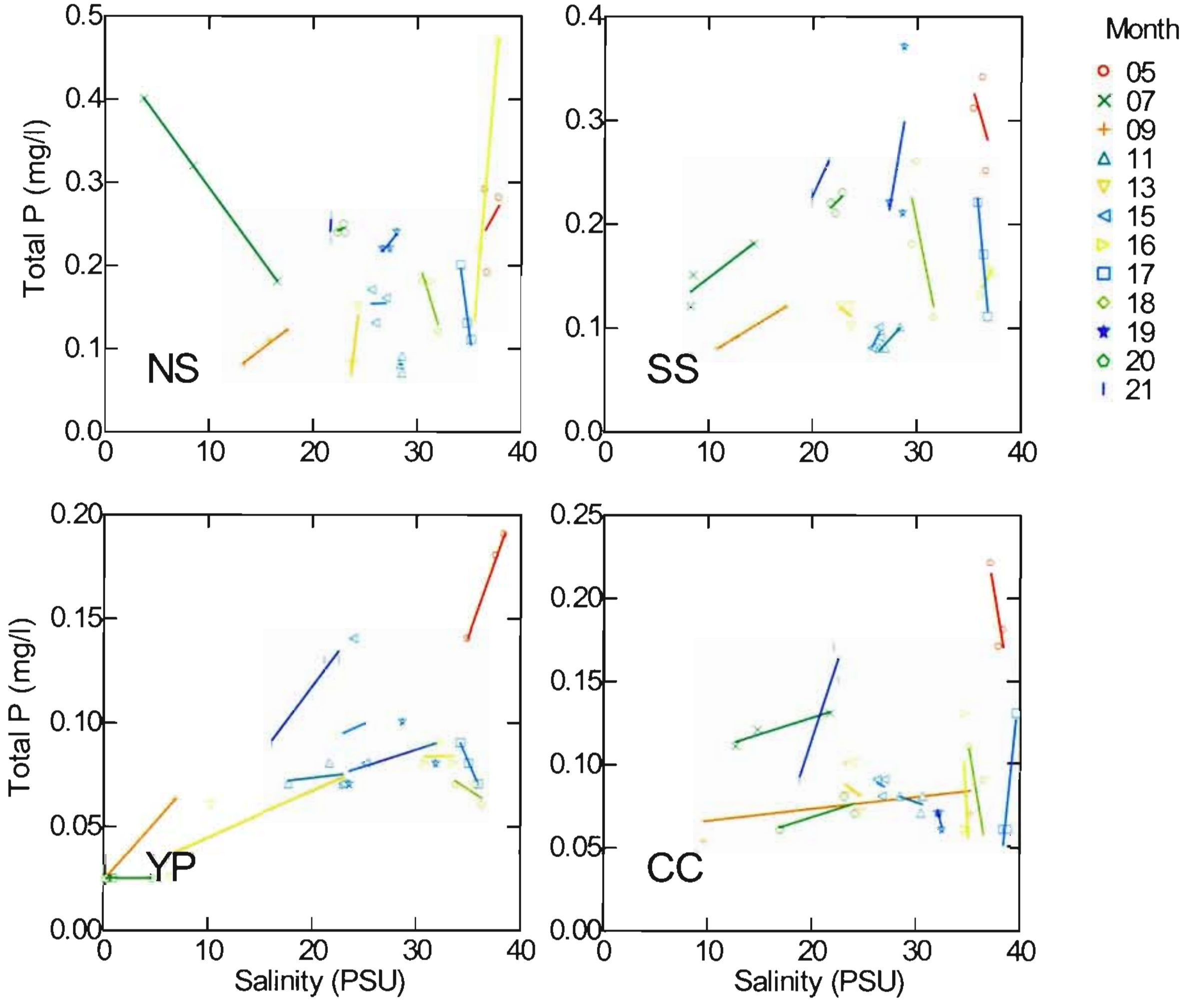

Figure 12. Dilution gradients of total phosphorus as a function of salinity by creek and sampling month. Cumulative numerical month identifiers correspond to Table 2.

For chlorophyll concentrations, 26% of observations exceeded 11 ug/l of corrected chlorophyll *a*, with many of these high values reported for September 2009. The highest values were generally observed in South Silcox, followed by North Silcox and Culvert Creek. Yucca Pens exhibited the lowest chlorophyll overall, perhaps in part due to the large contributions of freshwater to this creek and the presumed reduced water residence times within the creek. Seasonal patterns of chlorophyll were as expected (Figure 13) with higher values during the warmer wet season months, but values in 2009 exceeded those observed in 2008. As May to September salinities were higher in 2009 than in 2008, an increase in residence time with decreased freshwater inflow was presumed to be the cause. Chlorophyll illustrated as a function of potential explanatory variables (Figure 14) illustrated the association of low chlorophyll with depressed salinities in all creeks, the drawdown of inorganic nitrogen with increased chlorophyll concentrations, the general correlation of increased chlorophyll with increased total nitrogen or increased total phosphorus.

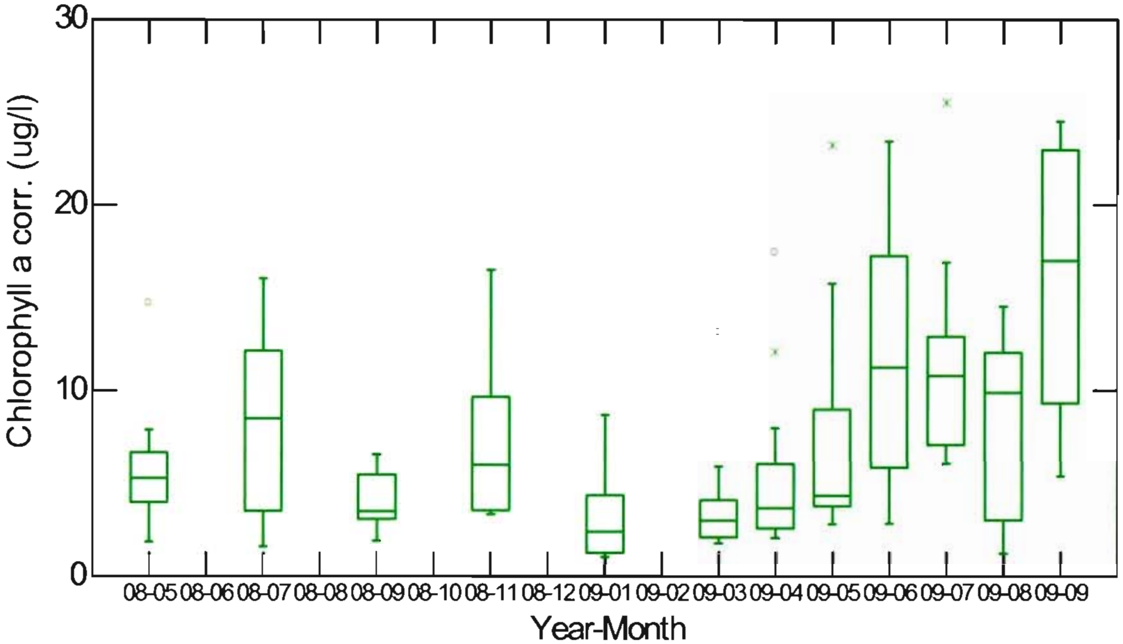

Figure 13. Temporal distribution of corrected chlorophyll *a* in all creeks.

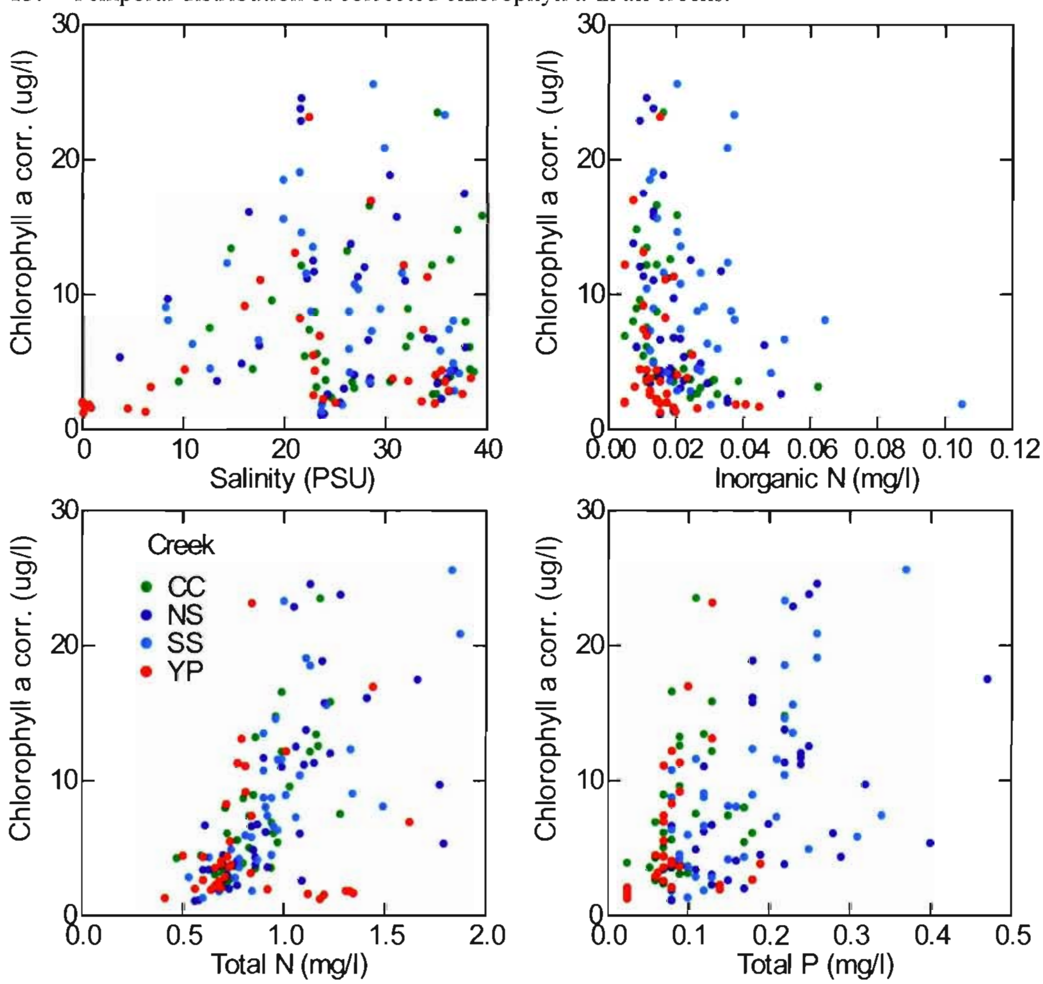

Figure 14. Chlorophyll *a* as a function of salinity, inorganic N, total N, and total P.

Analyses of water quality parameters (TN, TP, ammonia, chlorophyll, salinity temperature and DO) in all samplings in a two way crossed design of month and station (creek-zone) indicated significant differences both by month and by station (ANOSIM, $p<=0.001$). Illustrations of the similarity matrices of water quality, however, indicated that despite low phosphorus values in the southern creeks, that when all water quality parameters are considered, there was little consistent separation by creek (Figure 15). Water quality in the upper zone was often quite variable, while water quality at lower and middle stations tended to cluster more tightly, likely due to a greater degree of Harbor influence. In contrast, seasonal groupings were quite apparent (Figure 16) with data roughly divided into warmer and cooler months indicating seasonal covariance of temperature, DO, salinity, and nutrient concentrations.

Restriction of parameters to TN and TP alone resulted in a rough grouping of North and South Silcox stations that differed from that of Yucca Pens and Culvert Creek (Figure 17). ANOSIM routines on either the complete set of variables or on TN and TP alone indicated highly significant differences ($p<0.001$) both by sampling month and by creek, with the least difference between North and South Silcox. ANOSIM of freshwater N and P alone, in an attempt to remove seasonal and salinity variations from samplings and stations still resulted in significant differences both by month and by creek

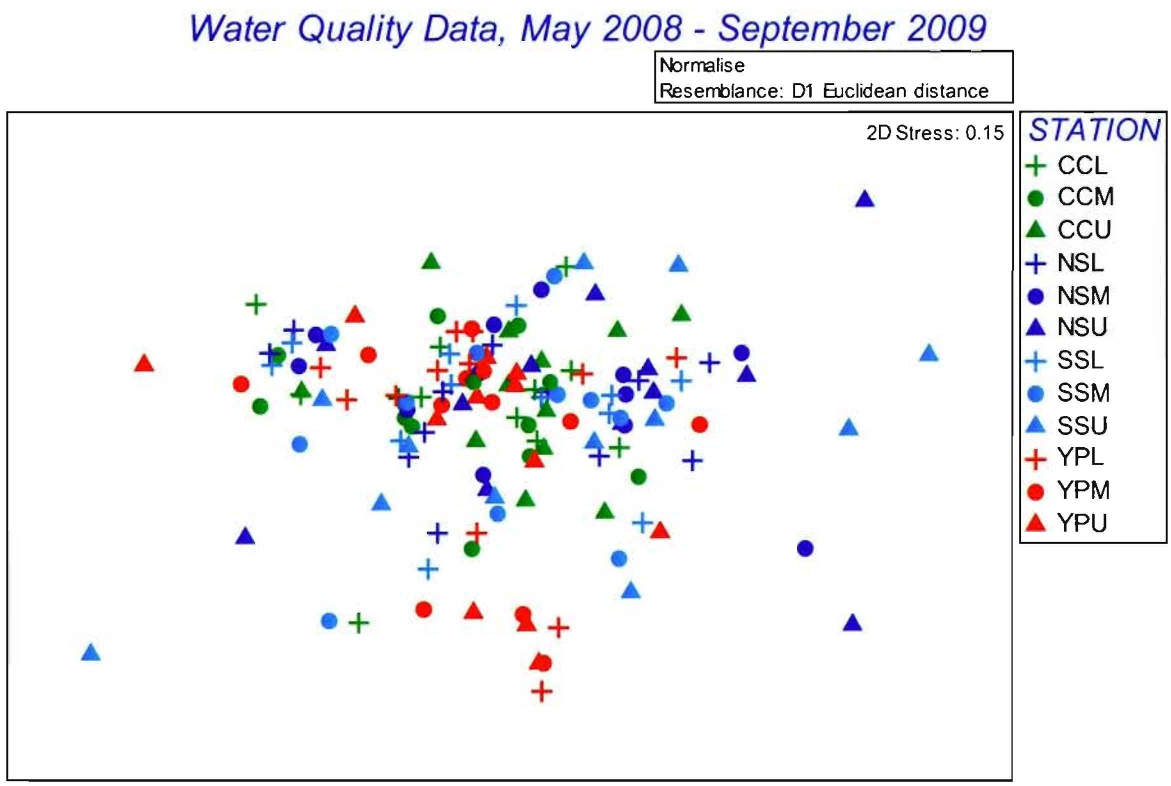

Figure15. Multidimensional scaling plot of the similarity matrix of all water quality samplings and parameters with the exception of nitrate-nitrite-nitrogen, categorized by creek and station.

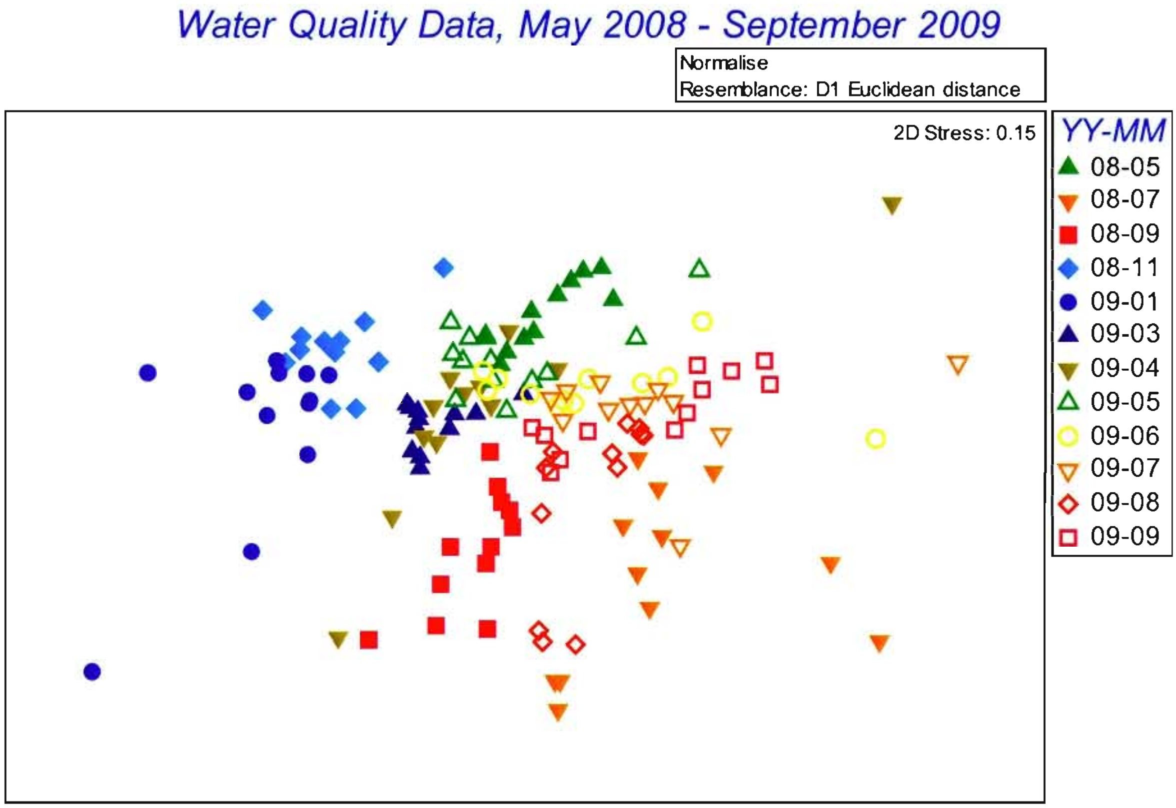

Figure16. Multidimensional scaling plot of the similarity matrix from all water quality samplings and parameters with the exception of nitrate-nitrite-nitrogen, categorized by sampling year and month.

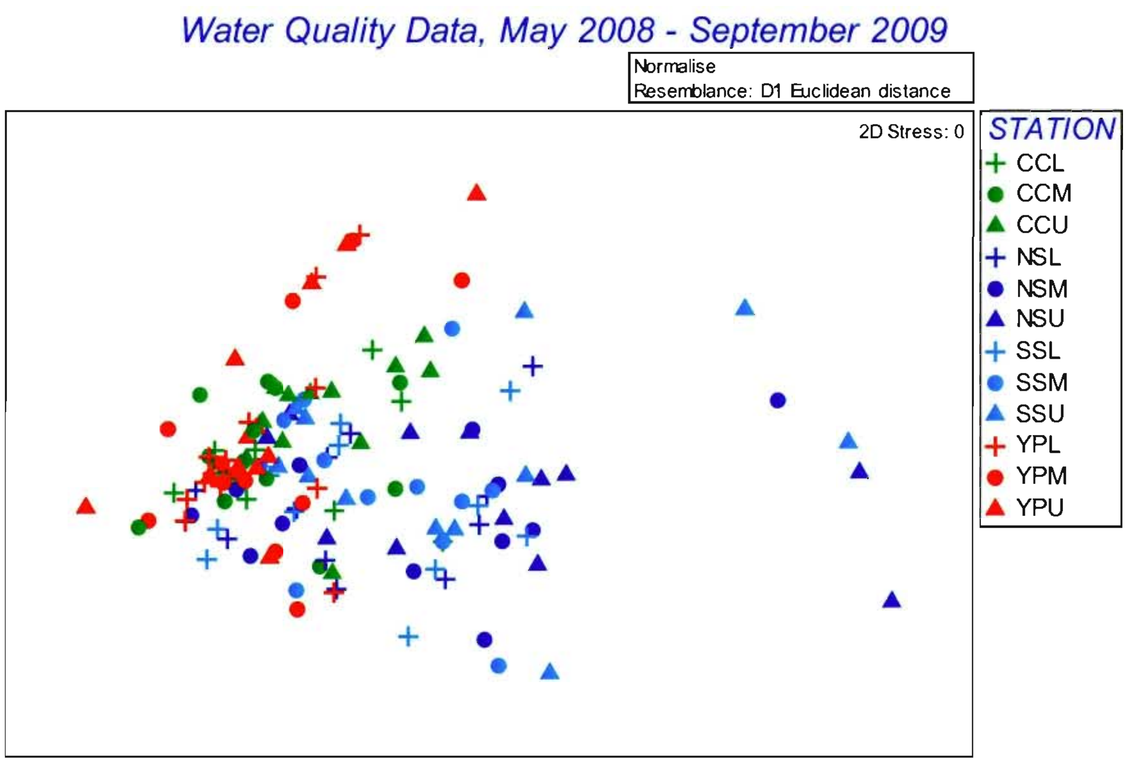

Figure 17. Multidimensional scaling plot of the similarity matrix using total nitrogen and total phosphorus alone for all water quality samplings, characterized by station.

Watershed Characteristics

Summary statistics on creek watershed areas appear in Table 4. As defined by the GIS approach, South Silcox is by far the smallest catchment area. Yucca Pens, closely followed by Culvert Creek, is the largest. While South Silcox appears to have experienced the least alterations in land use (<1%), very similar percentages have been altered within the Yucca Pens and Culvert Creek watersheds (19% and 16%, respectively). Surprisingly, the most alteration (47%) has occurred within the North Silcox basin, consisting of both agricultural fields and sparse construction in residential neighborhoods.

Table 4. Total, natural, and altered basin areas and percentages.

Creek	Total Area (acres)	Natural Area (acres)	Altered Area (acres)	Open Water (acres)	% Natural	% Altered	% Open Water
North Silcox	4,124	2,079	1,955	90	50%	47%	2%
South Silcox	549	517	1	31	94%	<1%	6%
Yucca Pens	8,646	6,523	1,616	507	75%	19%	6%
Culvert Creek	7,393	6,035	1,159	198	82%	16%	3%

Impervious surfaces reduce the amount of water percolation into soils, and increase the maximum rates and the total amount of runoff from rain. The change in timing and amounts of freshwater contributed to an estuarine creek can result in a 'flashy' system in which large pulses of freshwater result in abrupt depressions in salinity. For estuarine watersheds in regions with greater topographical relief than southwest Florida, impervious surface is probably the greatest factor in altering the volume and timing of freshwater flows, as elevation differences generally prevent the transfer of water between basins.

The mean percent impervious values of the watersheds (Table 5), developed from land use categories, were also unexpected, as South Silcox, followed by Yucca Pens, would appear to be the least developed, with North Silcox the most developed.

Table 5. Basin areas, mean impervious percentages, equivalent 100% impervious areas, and remaining area weighted for watershed yield to generate equivalent watershed areas.

Creek	Area	Mean % Impervious	100%Imp area	Area less 100%Imp	0.22 Yield	Equivalent watershed
North Silcox	4,124	7.24	299	3,825	842	1,140
South Silcox	549	1.00	5	544	120	125
Yucca Pens	8,646	2.56	221	8,425	1,853	2,075
Culvert Creek	7,393	6.24	461	6,932	1,525	1,986

Estimates of the amount of 100% impervious area within each watershed were computed as the mean percent imperviousness multiplied by the total watershed area. Watershed yield from the remaining area (total area less the 100% impervious area) was estimated at 0.22 based on annualized Myakka River basin values (annual riverine flow: annual rainfall) and used to compute the remaining contributing acreages. The sum of the 100% impervious area and the 0.22 fraction of the remaining acres resulted in an "Equivalent watershed". While location of the impervious area within the watershed can affect eventual delivery of water, the Equivalent watershed areas combines both watershed size and imperviousness, and should correlate with total runoff from a basin and with salinity patterns of the receiving creeks, provided creek hydraulic characteristics are similar.

Equivalent watershed areas computed were 125, 1140, 2075, and 1986 acres for South Silcox, North Silcox, Yucca Pens, and Culvert Creek, respectively. Yucca Pens and Culvert Creek have very comparable Equivalent watersheds, therefore freshwater contributions to both Culvert Creek and Yucca Pens were expected to be similar. Instead, Yucca Pens was the system which displayed depressed and highly variable salinity, while Culvert Creek was the most saline system overall.

The low grades of Southwest Florida, coupled with the extensive ditching and drainage that has taken place over the years, make the precise delineation of watershed boundaries difficult. Topographical complexity is so minor that ditching, berm or roadway construction can divert flow into adjacent watersheds. The problem is exemplified by the watershed delineation for South Silcox Creek, which is now invalid due to a large canal (Figures 2 and 5) and network of smaller conveyances that expand the creek watershed to an unknown extent into the developed portion of the North Silcox watershed. The watersheds of the other creeks in this study have been similarly altered. The watershed for Yucca Pens, for example, now includes a portion of the Yucca Pens Unit of the Charlotte Harbor Flatwoods, and some additional residential development that is outside the demarcated watershed boundaries. The more detailed sub-basin delineation of the Yucca Pens and surrounding creeks (FEP, 2009) bears little resemblance to either the historical (1960's) or present day watersheds used in the present work. The FDEP (2009) report on the Charlotte Harbor Flatwoods further indicates that flows have been diverted south to Culvert (Durden) Creek and Gator Slough, which now suffer from excessive flows, and that sheet flow needs to be restored to Yucca Pens. The fact that our study of water quality indicates that Yucca Pens maintains reduced salinity even during the dry season is inconsistent with the reported flow diversions.

The reduced salinity observed in Yucca Pens is inconsistent with the relative watershed sizes quantified in this project, and is not explained by either Equivalent watershed size or by the length and size of the mainstem of the creek as a receiving water (which is comparable to both Culvert Creek and to South Silcox). More detailed sub-basins (FDEP, 2009) indicate a watershed area that is approximately one quarter of the one used in our work, and accounts for reduced salinity even less. It is likely that the reduced salinity of Yucca Pens is due to a vastly increased watershed area beyond that presently delineated, including large storage volumes to maintain continued freshwater flows during an extended dry period. Other possibilities are anthropogenic reject irrigation water or groundwater base flow enhanced by canals intercepting the surficial aquifer.

As the scope of work did not allow for additional basin delineation, the land use, development, and impervious areas data were removed from the analyses of water quality and fish communities.

Survival Estimates

The analysis of the survival of juvenile snook was conducted under other funding but data were coincident with the water quality investigation and were made available for use. Summary values appear in Table 6. Survival data were associated with the water quality of the initial month. Figure 18 illustrates the range in survival as the upper and lower 95% confidence interval for the three creeks. The mean monthly survival over the period illustrated was 0.76, 0.84, and 0.79 for South Silcox, Yucca Pens, and Culvert Creek, respectively. The largest difference between creeks was observed between December 2008 and February 2009, when survival in South Silcox was depressed relative to the other two creeks. From May through August 2009, there was a large amount of uncertainty in the survival estimates from all creeks, during the period when temperatures were high and DO was depressed.

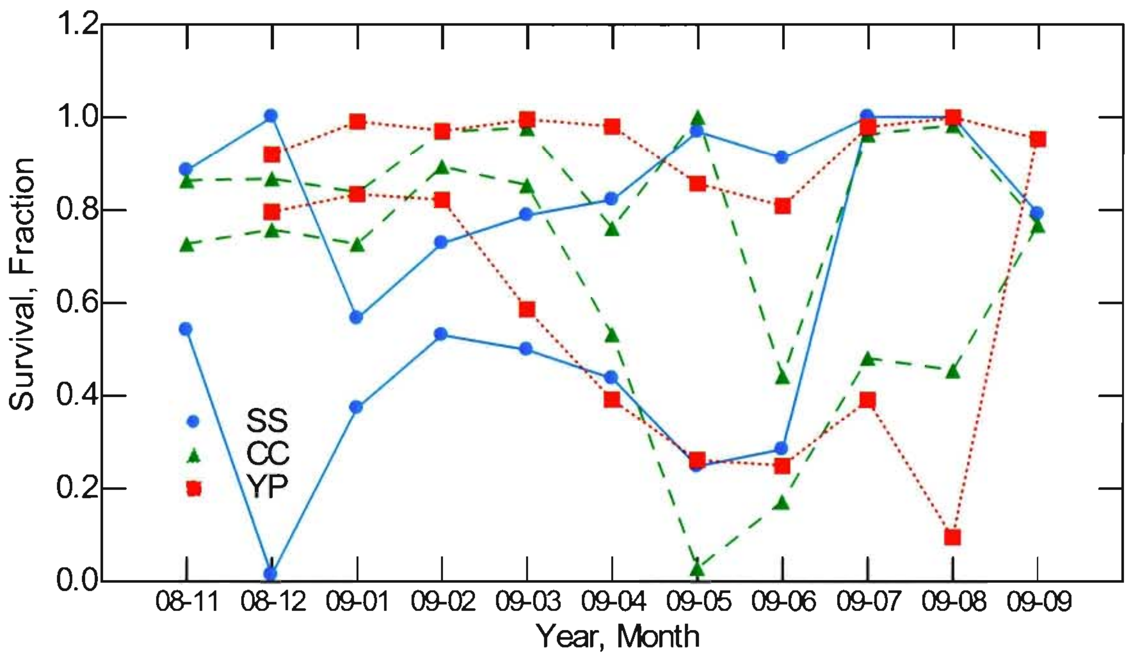

Figure 18. Survival estimates of juvenile snook, as the upper and lower 95% confidence interval.

Table 6. Fractional survival estimates for juvenile snook tagged in study creeks. Data are for snook tagged at standard length <300mm. No survival estimates for North Silcox due to too few fish tagged during the study period.

	South Silcox				Yucca Pens				Culvert Creek			
Month	Survival Estimate	SE	Lower 95%	Upper 95%	Survival Estimate	SE	Lower 95%	Upper 95%	Survival Estimate	SE	Lower 95%	Upper 95%
11 - 12 / 2008	0.750	0.089	0.541	0.884	-	-	-	-	0.803	0.035	0.726	0.862
12 / 2008 - 01 / 2009	0.959	0.149	0.014	1.000	0.870	0.031	0.796	0.920	0.818	0.028	0.757	0.867
01 - 02 / 2009	0.468	0.050	0.373	0.566	0.959	0.031	0.834	0.991	0.787	0.028	0.726	0.837
02 - 03 / 2009	0.634	0.051	0.530	0.727	0.925	0.035	0.822	0.971	0.941	0.018	0.893	0.968
03 - 04 / 2009	0.657	0.076	0.498	0.787	0.946	0.065	0.587	0.995	0.939	0.029	0.853	0.976
04 - 05 / 2009	0.654	0.103	0.437	0.821	0.850	0.141	0.392	0.980	0.655	0.059	0.532	0.760
05 - 06 / 2009	0.759	0.211	0.247	0.968	0.593	0.174	0.261	0.857	0.946	0.167	0.028	1.000
06 - 07 / 2009	0.667	0.184	0.283	0.911	0.542	0.161	0.249	0.808	0.288	0.070	0.171	0.442
07 - 08 / 2009	1.000	0.000	1.000	1.000	0.846	0.142	0.392	0.979	0.829	0.120	0.481	0.962
08 - 09 / 2009	1.000	0.000	1.000	1.000	0.960	0.106	0.095	1.000	0.872	0.120	0.454	0.982
09 - 10 / 2009	0.790	0.000	0.790	0.790	0.953	0.000	0.953	0.953	0.767	0.000	0.767	0.767
Total tagged	357				159				312			
Total number of recaptures	51,263				57,227				102,438			

Fisheries Data

Summary fisheries data, collected under other funding, appears in Appendix B, sorted by the fish code used in statistical analyses, genus and species names, and by the total number sampled over the study period.

In the nine samplings, 494 seines were pulled, 51,069 fish captured, and 22,068 individual fish measured. A total of 61 species categories were used for identification. A total of 44, 46, 43, and 46 species were found in North Silcox, South Silcox, Yucca Pens, and Culvert Creek, respectively. Summing all species, the highest densities of fish were routinely found in North and South Silcox (Figure 19), while densities appeared lower in Culvert Creek and in Yucca Pens. Depressed densities were observed during May 2008 and during July 2008, respectively both the driest and the wettest conditions observed during the study. Densities were similarly depressed during the cold temperatures observed in January 2009.

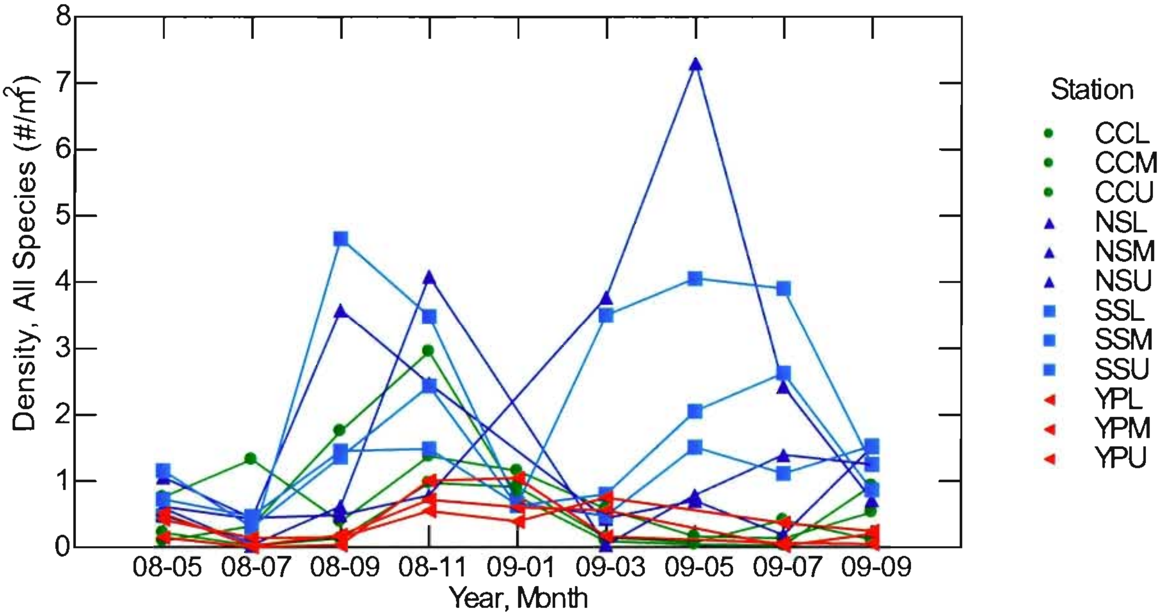

Figure 19. Density of all fish species combined, by month and creek zone, as the mean of all replicate hauls.

By species and over the identified samplings, the highest number of fish captured were represented by *Menidia beryllina* (inland silverside, F1024) and *Luciana parva* (parva, F1047), followed by *Menidia peninsulae* (tidewater silverside, F1065), *Eucinostomus* spp. (an unknown mojarra, F1039), and *Poecillia latipinna* (sailfin molly, F1050). Although still numerous, smaller numbers of *Gambusia holbrooki* (gambusia, F1011), *Cyprinodon variegatus* (sheepshead minnow, F1052), *Eucinostomus harengulus* (tidewater mojarra, F1064), *Microgobius gulosus* (clown goby, F1006), and *Fundulus grandis* (gulf killifish, F1020) were captured. Together, these ten species represented over 90% of all fish captured. Estuarine taxa were defined as resident (R), transient (T), and juvenile (J), based upon frequency of occurrence, habitat requirements (Robins et al. 1986) and dominant life stage when in the creeks. Residents were present in >= 50% of samples and had creek-associated habitat requirements. All of the most abundant species were classified as creek residents.

The similarity matrix of fish density data of all individual seines was illustrated as an MDS and categorized by both station and month (Figures 21 and 22). While stress levels on the MDS Plots were high (indicating a structure more complex than can be adequately displayed in two dimensions), three dimensional plot stress values were better (0.2). Clearly, the fish communities of the various creeks displayed a high degree of overlap. Communities within Culvert Creek, as they displayed the widest distribution in the MDS, were the most variable (Figure 21). Seasonal groupings (Figure 22), similar to water quality results, remained strong, with some agreement between the months of successive years. The fish communities in warmer months appeared more variable (more widely distributed in the MDS plots) than the cooler months.

Seine data were also analyzed by ANOSIM in a two way crossed design of sampling month by station. The three or five seines per station and month were considered replicates for the analysis. Both globally and for all creek-zone stations and sampling months, all comparisons of individual months and individual stations were significantly different ($p<=0.001$). The overall relationships by station are illustrated in Figure 23 and indicate that the communities of lower North and South Silcox Creeks, while significantly different from one another, are more similar than the upper zones of the same creeks. Culvert Creek and Yucca Pens are more similar to one another than to the northern creeks.

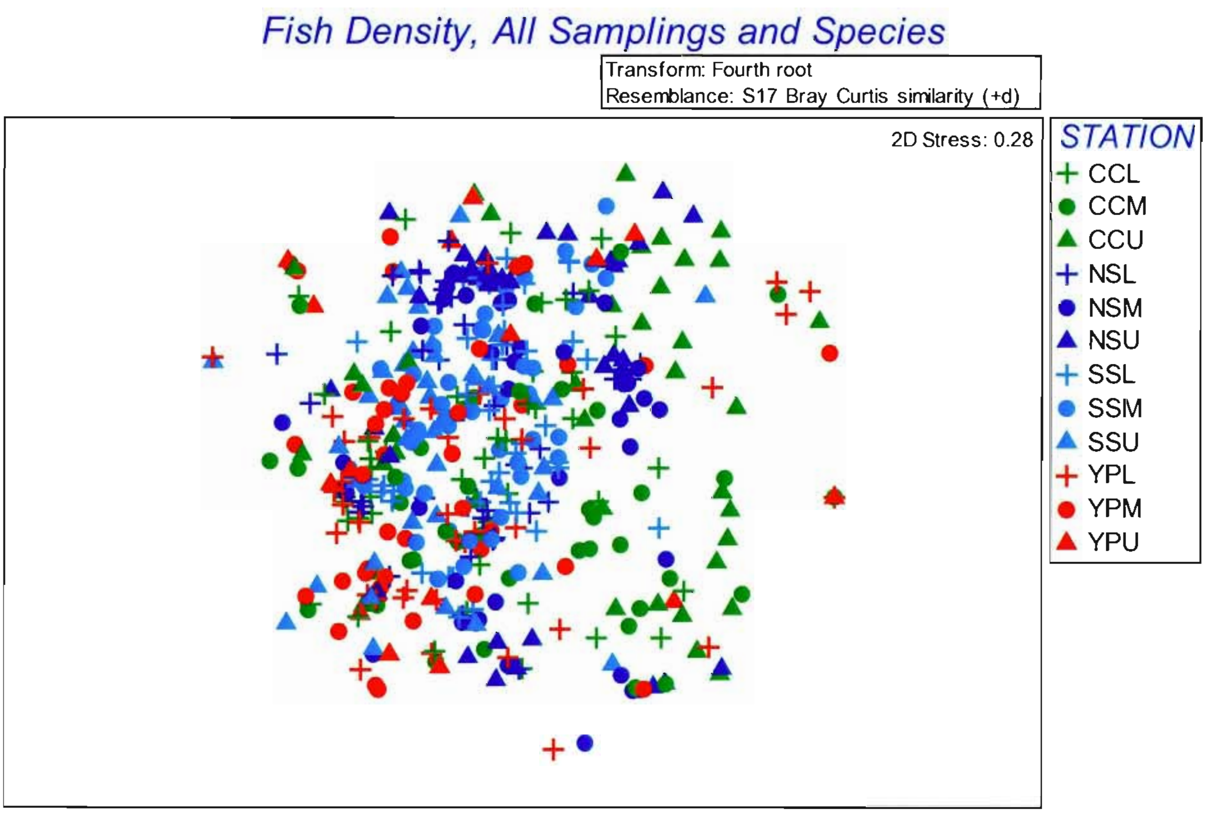

Figure 21. Multidimensional scaling plot of the similarity matrix from all seines and species, categorized by station.

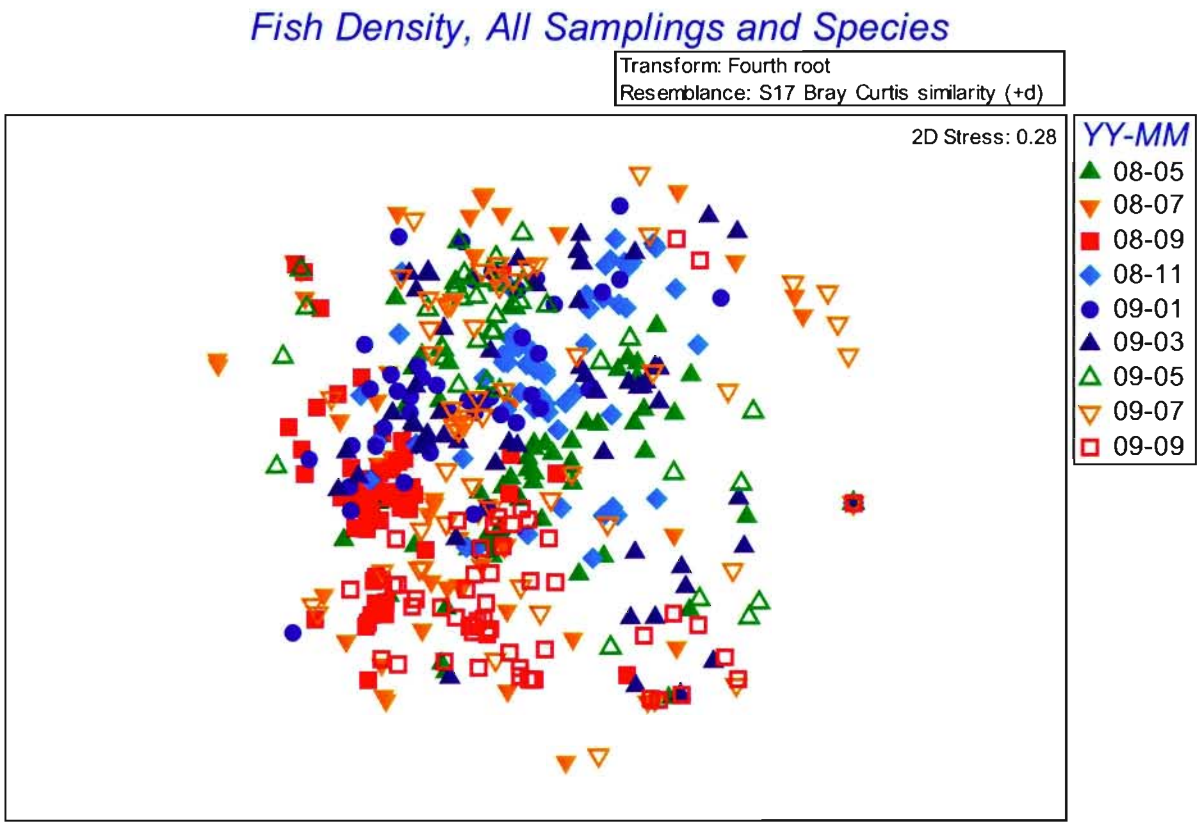

Figure 22. Multidimensional scaling plot of the similarity matrix from all seines and species, categorized by month.

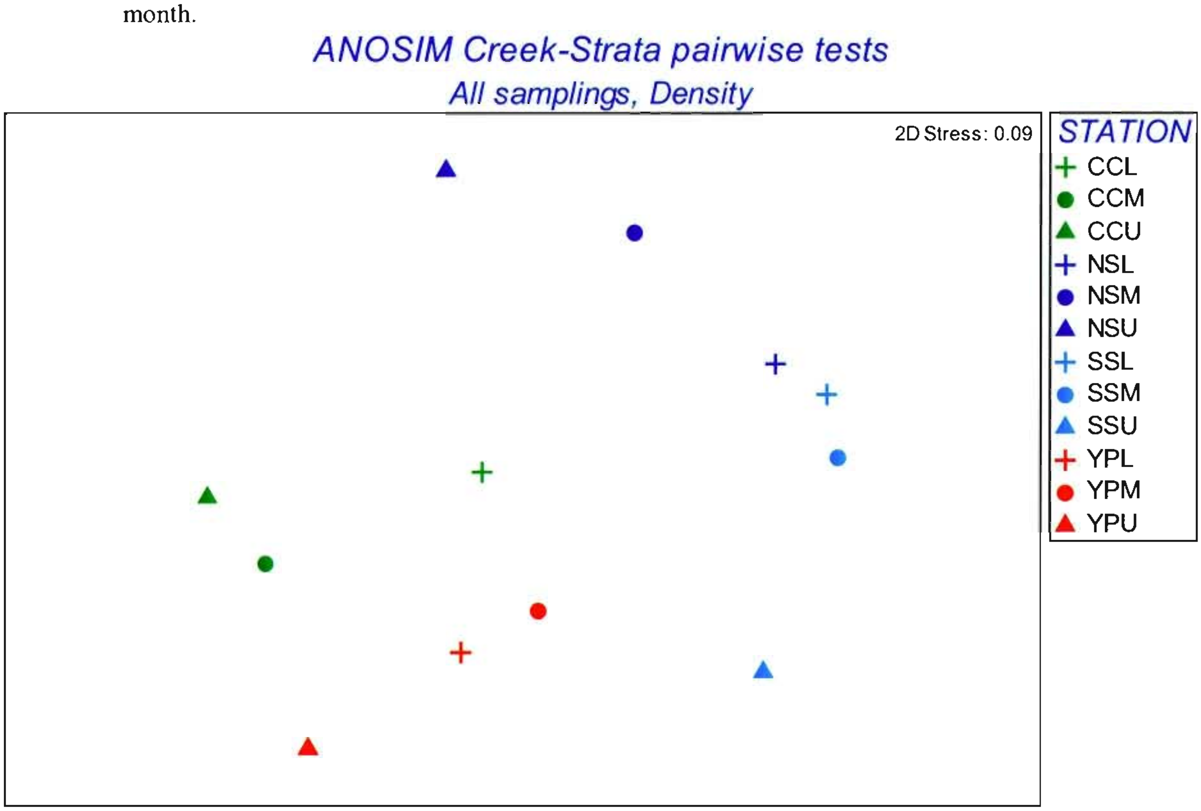

Figure 23. Multidimensional scaling plot of the similarity matrix from the pairwise tests of stations from the ANOSIM analysis of all seines and species (month X station), categorized by station.

Densities of individual species were averaged by station and sampling month, fourth root transformed, and similarity matrices analyzed by ANOSIM for differences between creeks. Similar to results on densities based on individual seines, the fish communities presented as mean densities again differed by creek ($p<=0.001$). North and South Silcox were again distinct from Yucca Pens and Culvert Creek. Sizing of symbols based on the sum of density for all species (Figure 24) indicated that North and South Silcox creeks had higher densities of fish overall, consistent with Figure 19, above.

Since seasonal signals were strong, fish density data were subdivided into monthly groupings to test a two way nested design of zone within creeks to determine if station differences noted above were due to differences between creeks or between zones. An example of the MDS illustration appears in Figure 25 and all monthly MDS are in Appendix D. From the MDS, the illustrated monthly data can often be divided into two general groups, North and South Silcox on one side and Culvert Creek and Yucca Pens on the other. ANOSIM results support these observations as fisheries community variations were significant both between creek and zone for all but July 2008 and January 2009. In these months, communities varied by zone but were not significantly different between creeks ($p>0.05$).

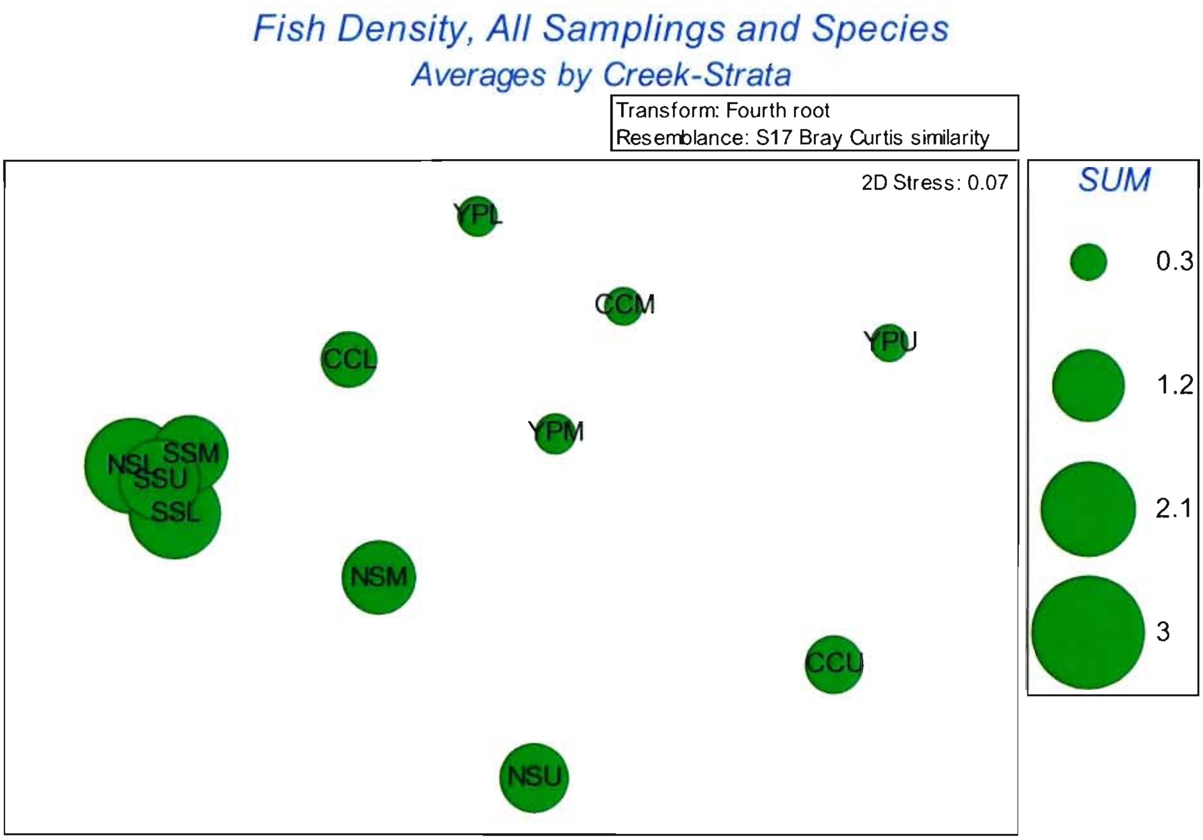

Figure 24. Multidimensional scaling plot of the similarity matrix from mean fish densities by station for all samplings, scaled by overall density of all species.

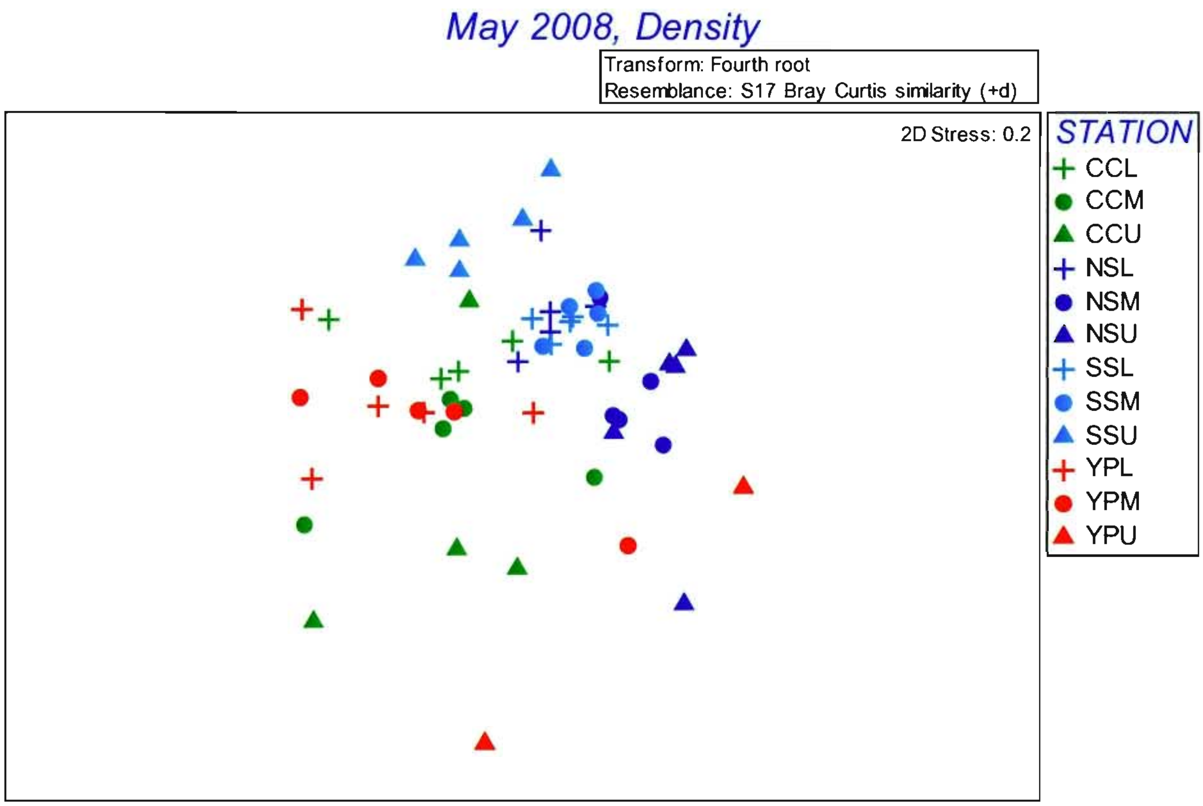

Figure 25. Multidimensional scaling plot of the similarity matrix from all seines and species during May 2008, categorized by station.

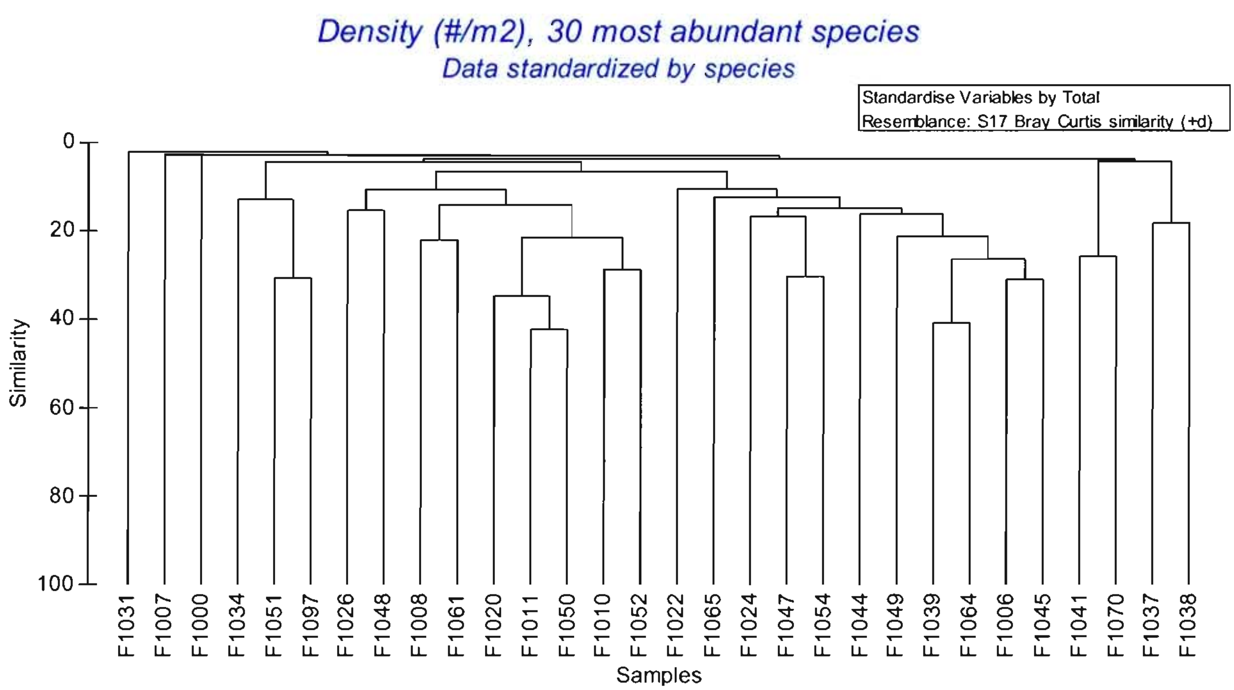

Figure 26. Hierarchical cluster analyses of the standardized density data from the 30 most abundant species.

Similarity matrices of water quality data, with one value per station and month, were linked with the similarity matrices of the density of all fish species (using the means of the multiple hauls per station and month) using the BEST procedure. The highest significance (p=0.01, Rho=0.227) was obtained when similarity matrices of TN:TP ratios and salinity were linked with fish community, with most of the similarity due to the variation in TN:TP ratios.

Density data from the 30 most abundant species were selected and standardized by variable (species) to determine the species which varied the most closely with common snook (F1008). Hierarchical cluster analyses (Figure 26) indicated that the most similar species in station occurrence and density was F1061, striped mojarra. Similarities were not large, however, less than 30%, indicating that no single species typically co-occurred with snook. The sizes of striped mojarra routinely found (Figure 27) indicate that they could form a prey base for snook and that they were a commonly found species, particularly in South Silcox.

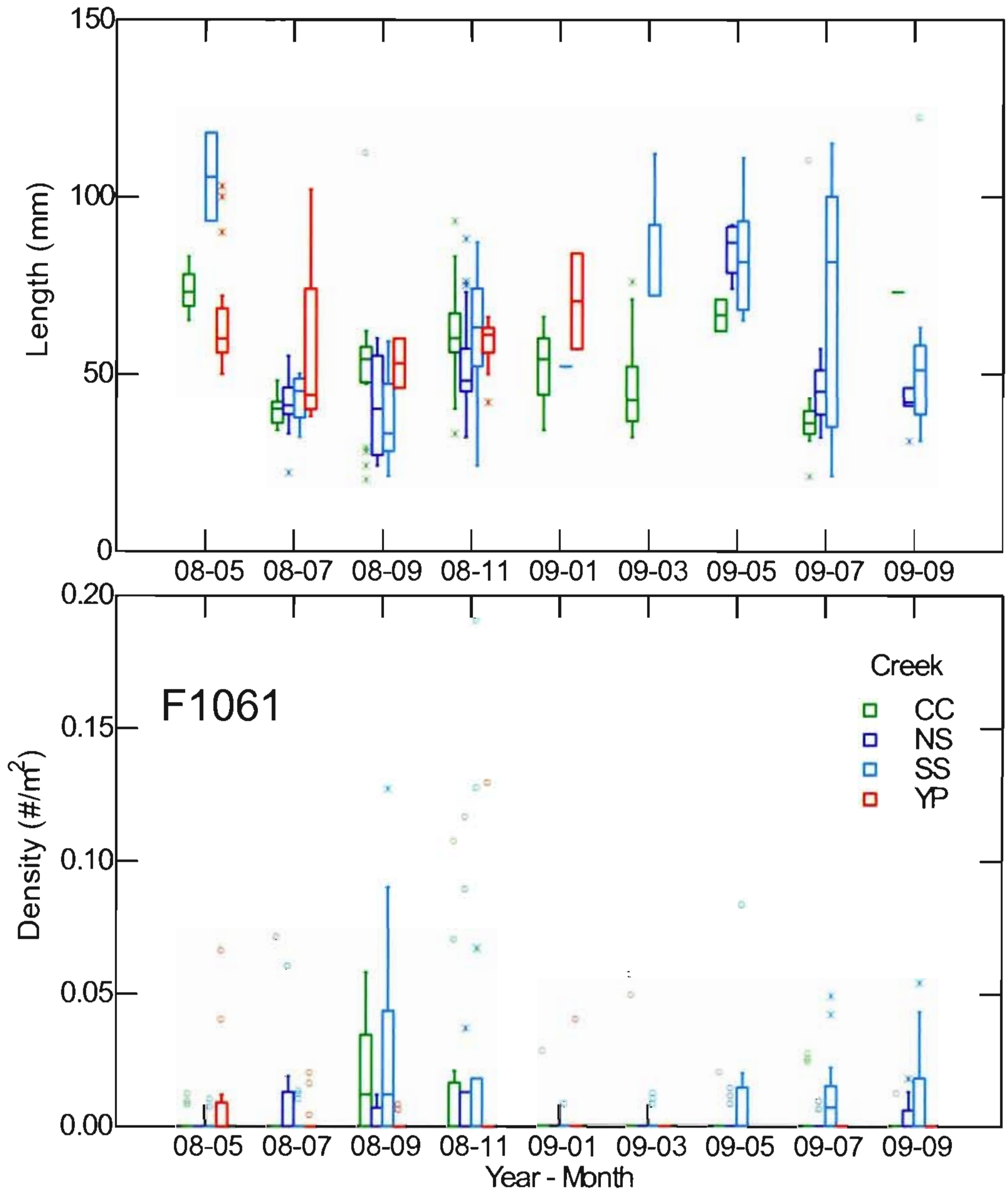

Figure 27. Temporal patterns of length and density for striped mojarra (Fish Code 1061).

Mean density and length values for snook only were computed from the multiple seines for each station and month, square root transformed, and linked with survival estimates for those months with both density and survival information. All variables were normalized and using ANOSIM, significant differences were present by month ($p<=0.001$) and creek ($p<=0.001$). All three creeks (there were insufficient data from North Silcox to compute survival) were significantly different from one another, although Culvert Creek and Yucca Pens were the most similar. MDS prepared from Euclidean distances (Figure 28) indicated that samples from South Silcox were more variable overall. Differences among samples were primarily driven by the variation in snook density (Figure 29) rather than differences in length or survival.

The snook density, length, and survival data were also linked with water quality data through the BEST routine. Significant relationships were found ($p=0.04$, Rho=0.267) between the density, length, and survival of snook with DO and to a lesser extent, with ammonia. Snook densities were not high when DO was depressed (Figure 30) or when ammonia concentrations were elevated, but there were instances in which DO appeared adequate when snook density was zero. As temperature was not a significant water quality parameter to explain the density of snook, the relationship of density with DO may have been more than just a seasonal phenomena.

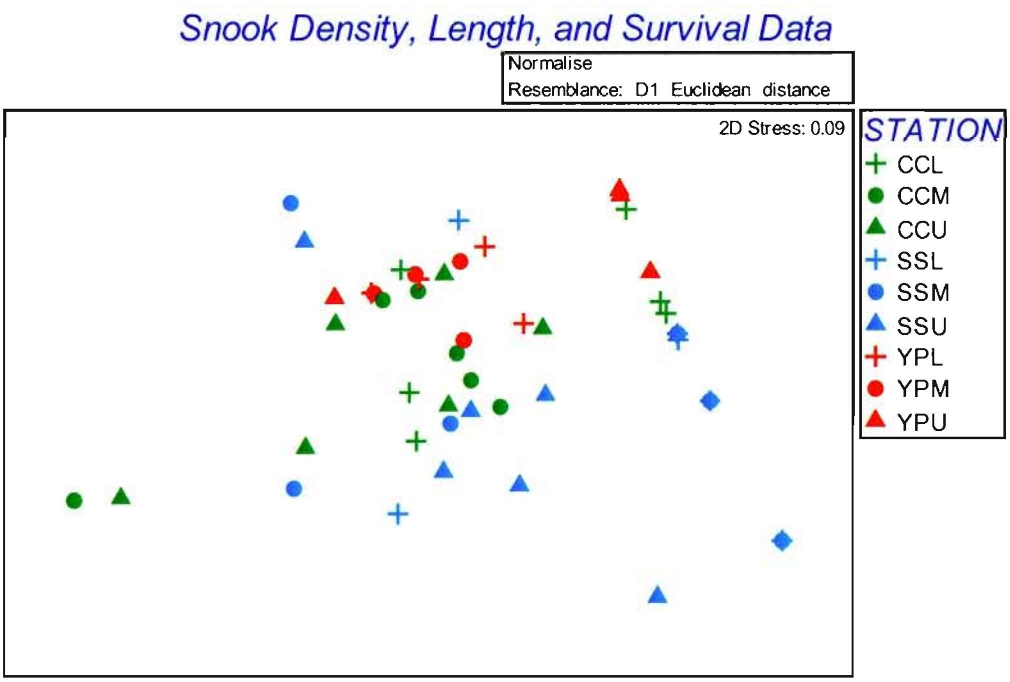

Figure 28. Multidimensional scaling plot of the similiarity matrix from abundance, length, and survival data of common snook, categorized by station.

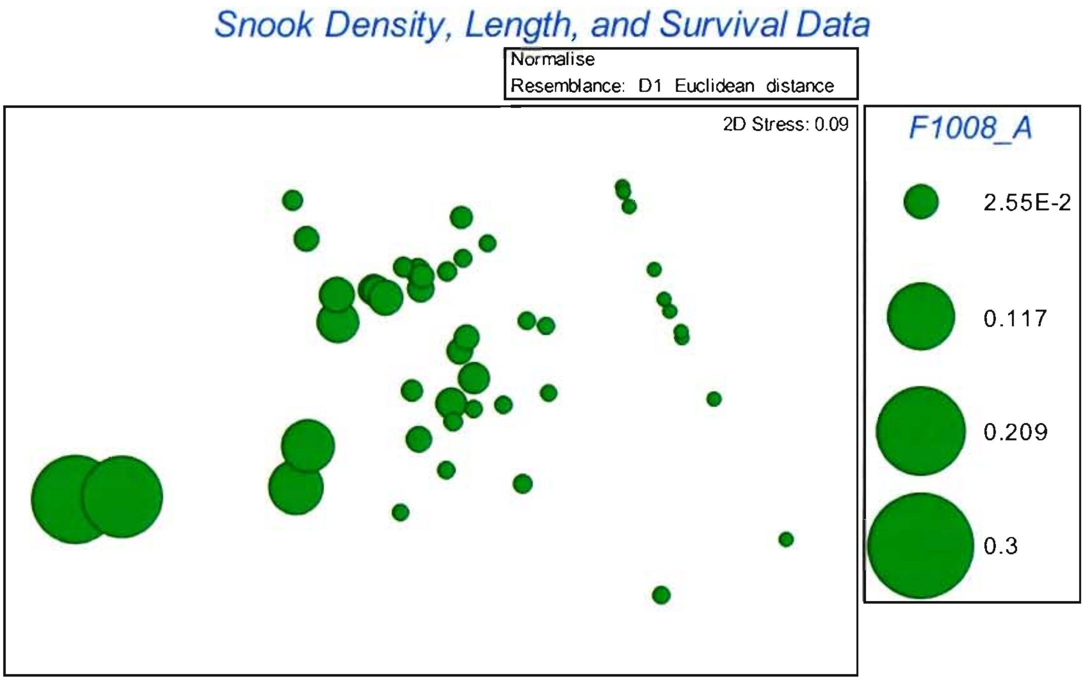

Figure 29. Multidimensional scaling plot of the similarity matrix from density, length, and survival data of common snook; data points scaled by snook density (F1008_A).

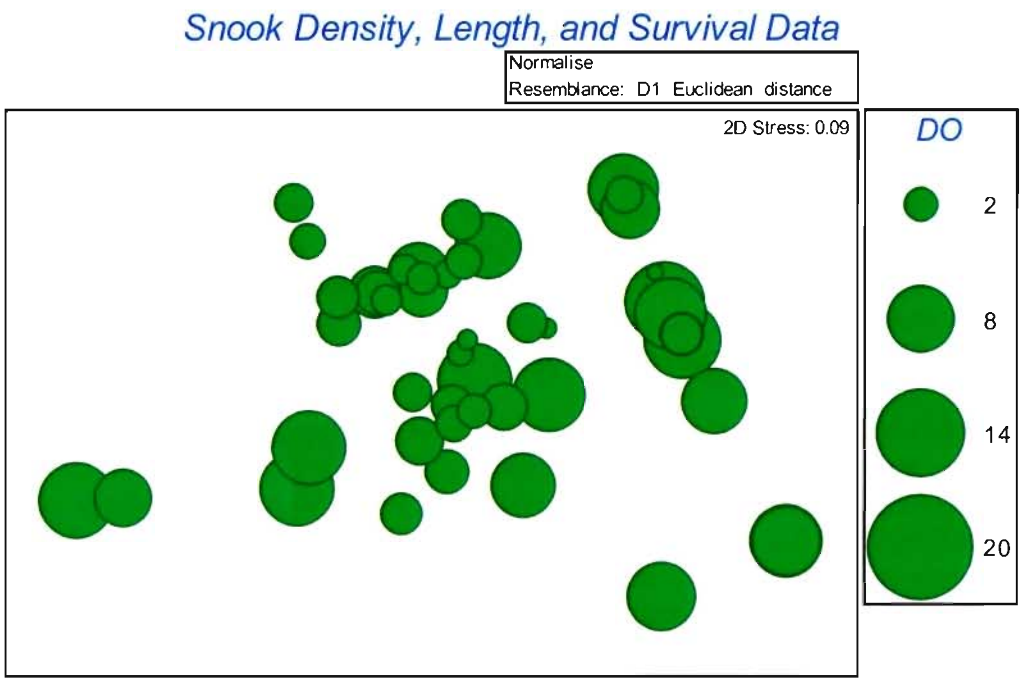

Figure 30. Multidimensional scaling plot of the similiarity matrix from abundance, length, and survival data of common snook, categorized by DO concentrations.

Summary

Water Quality

The 18 months of the present study was conducted during a multi-year period of extremely low rainfall. Since the purpose of the study was to determine the impact of freshwater flow alterations on creek water quality and fish assemblages, the lack of rainfall likely biased the results toward low levels of impact.

A combination of small size, tidal flushing, Harbor influence, and generally low freshwater inflow resulted in minimal salinity gradients overall in the creek systems studied. The exception was Yucca Pens which, based on salinity, received much more freshwater than any of the other systems or than could be explained by a comparative evaluation of watershed characteristics, impervious area, and development. In a number of instances, the mapped watershed boundaries did not accurately reflect the actual contributing area in these low relief and drainage-altered creeks. The lack of confidence in the watersheds and statistics developed from mapped boundaries prevented the development of an empirical alteration or degradation measure with which to model the creeks. Unlike Yucca Pens, Culvert Creek was slightly more saline than the remaining creeks. The higher salinities were attributed to the water storage provided by the hydrologic alterations and impoundment of the canal system at the head of Culvert Creek. The low rainfall and discharges resulted in frequent reverse salinity gradients observed in all creeks but Yucca Pens. The depressed salinity of Yucca Pens was one of the dominant water quality features of the study.

Water quality of all creeks exhibited strong seasonal patterns of dissolved oxygen. All stations experienced daytime minima of less than 2.0 mg/l of DO and all but one station had median values less than 4.0 mg/l. Seasonal patterns were present in chlorophyll as well, and concentrations were consistent with increased algal expression accompanying increased residence time under lower flow conditions. Chlorophyll response to total nitrogen concentration was generally consistent among creeks, while the southern and northern creeks exhibited different chlorophyll concentrations for the amount of total phosphorus present.

Although empirical measures of watershed alteration were not available, non-parametric multiparameter analyses of water quality generally grouped the four creeks into two associations during any given month. North and South Silcox were similar to one another, as were Culvert Creek and Yucca Pens. The separation between creeks was primarily due to total phosphorus concentrations which were low in the southern creeks. The low phosphorus of Yucca Pens and Culvert Creek could result from algal processes, from local mineralogy and soil composition, or from higher proportions of groundwater. For Yucca Pens, the dominant source of phosphorus was from the higher salinity waters in the Harbor, unlike the remainder of the creeks. Since all four creeks are within the same estuarine hydrological zone (Poulakis et al. 2003), estuarine end-member phosphorous concentrations are unlikely to differ. When the nutrient content of freshwater entering the creeks was estimated from fraction-of-freshwater methods, the highest phosphorus concentrations were in freshwater delivered to South Silcox, while the highest nitrogen concentrations were in freshwater delivered to Culvert Creek.

Watershed Alteration Metrics

The results of this study and previous studies on these creeks, as well as studies of estuarine creek habitats in other systems, reveal the complexity of processes influencing creek fauna. In studies in other estuaries (primarily from temperate regions), the creation of impervious surfaces in watersheds has been determined an important factor in alteration of freshwater flows and changes in estuarine fauna and flora (reviewed in Sklar and Browder 1998). Although alteration of freshwater flows into estuarine habitats also appears to be a factor affecting creek fishes in Charlotte Harbor, indications are that the present knowledge quantifying freshwater flow alterations is inadequate.

These findings bring us to two conclusions which extend beyond this particular study. First, the watershed delineations presently in use likely contain large inaccuracies, and is likely to be true for other creek watersheds of Charlotte Harbor. This is an item of concern because these watershed delineations are used for coastal management planning, mitigation, impact assessment, and restoration planning. Second, it is apparent that measures of impervious surface alone are inadequate metrics of the impacts of land alteration on freshwater flows into estuaries for regions with flat topography such as southwest Florida. These less obvious alterations change the timing and quantity of freshwater flows into estuarine creeks, so likely have similar effects as impervious surfaces, and need to be examined.

Fish Assemblages

Findings on the response of mangrove creek fish assemblages to generalized watershed alterations further reveal the complexity of both natural and anthropogenic impacts on estuarine ecology. There were more total fish in North and South Silcox creeks, but the density of snook, a focal species, was greatest in Culvert Creek. Since the creek assemblages were dominated by resident species, they provide the best metric of overall, long-term habitat quality of the creeks. Resident species must be able to tolerate the water quality changes that occur over the course of a year, and in creeks with greatly altered hydrological flows, such as Yucca Pens, it is likely that either the physiological thresholds of resident species are exceeded or habitats they require are no longer available. Many killifishes, for example, require shallow grasses (SAV or emergent marsh grasses) on which to deposit their eggs, and shallow flooded habitats with minimal or no currents (such as mangrove prop roots) for shelter from predators. These habitats are largely absent from or mostly inaccessible in Yucca Pens and Culvert Creek. In contrast, flooded mangrove prop root habitats are abundant in North and South Silcox creeks, and although less abundant than prior to Hurricane Charley, SAV habitats are present in these creeks.

Fish density and species richness were greater in North and South Silcox creeks even though these creeks had experienced strongly negative impacts from Hurricane Charley. Prior to Hurricane Charley (August 13, 2004), seine sampling of these four study creeks revealed more species and higher densities of fishes in North Silcox and South Silcox creeks than in Yucca Pens and Culvert Creek (Figure 31). Pre-hurricane densities ranged between 0-4 fish/m^2 for the southern creeks and from 1-10 fish/m^2 for the northern creeks. In contrast, densities measured during this project (Figure 19) were 0-1 fish/m^2 for Yucca Pen, 0-3 fish/m^2 for Culvert Creek, 0.5-5 fish/m^2 for South Silcox and 0-7 fish/m^2 for North Silcox.

After the hurricane, in North and South Silcox Creeks, massive defoliation of mangroves resulted in anoxic conditions, which caused extensive fish mortalities. In addition, destruction of red mangrove shoreline habitats in North and South Silcox, was extensive, and many shorelines still do not have live mangroves. But the greatest hurricane-related change in creek habitats was the complete loss of submerged aquatic vegetation (*Halodule wrightii* and *Ruppia maritima*) in North and South Silcox creeks. (The occurrence of SAV in Yucca Pens and Culvert creek was and remains low.) In contrast, mangrove defoliation was very minor in Yucca Pens and Culvert Creek, and mangrove shorelines remained largely intact. The among-creek differences in damage were due to the track of the hurricane, and resulted in fish assemblages more similar among creeks than they were before the hurricane because fish abundances in North and South Silcox creeks were depressed. The assemblages in North and South Silcox have rebounded somewhat, but are still not to levels seen before the hurricane, likely due to the continuing lack of SAV, which many of the resident species use for shelter and reproduction.

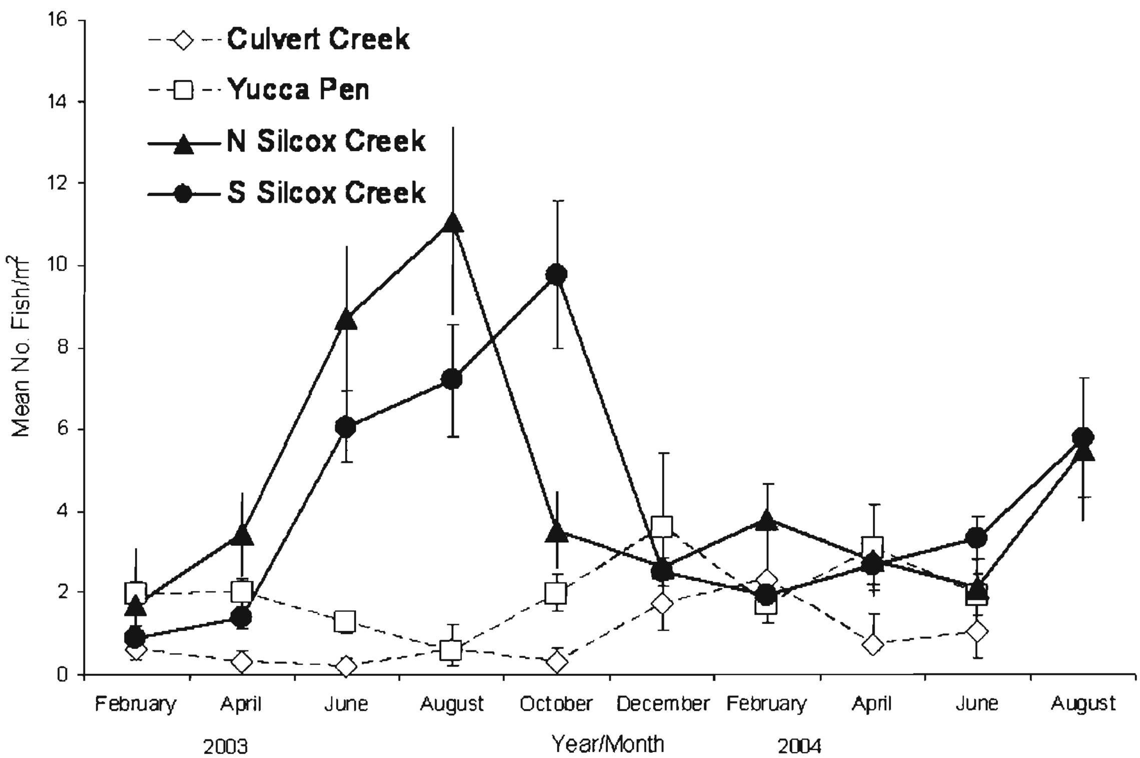

Figure 31. Fish density in the four creeks in 2003-2004, prior to Hurricane Charley (A.J. Adams, unpublished data).

Since Yucca Pens and Culvert Creek had less submerged mangrove prop root habitats than North and South Silcox, creek fishes were also more catchable with the seine gear used in this study. We attempted to combat this habitat bias by sampling at low tide, but it was a rare occasion when mangrove prop root habitats were entirely out of the water in North and South Silcox, whereas at low tide virtually all prop root habitats in Yucca Pens and Culvert Creek were exposed. If sampling bias were the only influence, however, the hurricane-related removal of mangroves in the northern creeks would have made fish more catchable during this study, rather than the reduced numbers that were observed.

Common Snook (*Centropomus undecimalis*)

The impact of differences in fish assemblages between creeks is also reflected in a recent study on the diets of juvenile snook (Adams et al. 2009). Juvenile snook diet was examined in two ways: stomach contents were used to provide a snapshot of snook diet and to identify prey items; stable isotope analysis was used for a longer term picture of the trophic niche of snook in these creeks. Stomach content data indicate that juvenile snook in Yucca Pens and Culvert Creek appear to rely more heavily on a few prey species, likely a reflection of a narrower trophic niche in the more degraded creeks. The diet of juvenile snook in North and South Silcox contained twice as many species as in Yucca Pens and Culvert Creek.

The apparent effects of anthropogenic habitat modifications on juvenile snook diet have occurred elsewhere, and may indicate a fundamental trophic shift resulting from different types of habitat modifications. The impoundment of marshes (i.e., fragmentation) on the east coast of Florida, for example, appeared to influence juvenile snook diet as the top species of prey fish differed, with a greater diversity of prey fish in pre-impoundment marshes (Harrington and Harrington 1961; Gilmore et al. 1983). Gilmore et al. (1983) also found that diet composition differed between freshwater and saltwater impoundments: 44% of juvenile snook stomachs in freshwater impoundments contained fish, 21% shrimp, 15% microcrustaceans, and 8% insects, whereas in saltmarsh impoundments, 35% of stomachs contained microcrustaceans, 23% fish, 19% grass shrimp. Differences between diet of juvenile snook in unfragmented river (30% fish, 65% shrimp, 10% other) and lagoon (55% fish, 40% shrimp, 15% crabs) habitats in Puerto Rico were less pronounced (Aliaume et al. 1997). The results of this and previous studies indicate additional research is needed to determine the full effects of anthropogenic habitat alteration on juvenile snook trophic ecology.

The stable isotope findings suggest greater among-individual diet variation among juvenile snook in North and South Silcox creeks. This may reflect the fact that most individuals in the more southern creeks feed primarily on a few dominant prey items (as supported by diet analysis), whereas individuals in the northern creeks have a larger scope for diet specializations (sensu Bolnick et al. 2003), i.e., focusing on a specific subset of a more diverse prey base.

Given that juvenile snook rely upon creek and marsh habitats, and these coastal habitats are under continuing stress from anthropogenic sources, additional research is needed to determine the extent that shifts in food web structure ultimately affect overall fishery production. As with other species that use similar habitats, the difference in diet diversity of juvenile snook may be an indicator of an overall change in ecosystem function (sensu Valentine-Rose et al. 2007), and such changes in food web structure may ultimately affect the ability of juveniles to successfully join the adult population.

Since the expectation is that habitat degradation alters spatial and temporal patterns of habitat use by many species, changes species composition (reviewed in Sklar and Browder 1998), and lowers the quality of nursery habitats, it was expected that North and South Silcox creeks would support more juvenile snook. This was true for Yucca Pens, where high freshwater flows likely limited juvenile snook use to the Lower zone, but the high abundance of juvenile snook in Culvert Creek and lack of juvenile snook in North Silcox were surprising. One possible reason for this finding is that the difference in habitat complexity and mangrove roots prevalence between creeks made the snook more catchable in Yucca Pens and Culvert Creek. The greater 'catchability' of juvenile snook in Yucca Pens and Culvert Creek is also reflected in higher recapture rates by PIT tag antennae in these creeks than in South Silcox (A.J.Adams, unpublished data). The antennae spanned the entire creek bed in Culvert Creek and Yucca Pen, but there were areas of flooded mangrove prop roots that were not reachable by antennae in North and South Silcox Creeks. In addition, the abundance of juvenile snook in Culvert Creek was considerably lower during similar samplings from 2003-2007, suggesting that the high juvenile snook abundance in Culvert Creek in this study might be an anomaly.

The reason for the absences of juvenile snook from North Silcox during this study is unclear, but is also coincident with restoration activities in the immediate watershed. Upland restoration in the Buffer Preserve State Park that was recently completed likely caused a disturbance that made the creek less hospitable to snook. The primary disturbance was the removal of an artificial elevation (small berm) that followed the shoreline of a small creek that emptied into the upper zone of North Silcox. This involved clearing a swath of approximately 40m of mangroves and other coastal brush all the way to and including the North Silcox shoreline. Resulting sedimentation by fine silt that may have impacted habitat quality for snook. Future sampling would determine the duration of this impact and should be coupled with vegetation surveys of both SAV and emergent species to quantify changes in structural habitat and the influence on densities of juvenile snook and other species of interest.

The decline in juvenile snook abundance in North Silcox underscores the sensitivity of these fish to changes in habitat. Whereas juvenile snook were present in the other three study creeks throughout the study period, they were nearly absent from North Silcox creek. This is in contrast to previous years, when juvenile snook were abundant in North Silcox creek. Clearly, changes in North Silcox made the creek either undesirable or unsuitable for juvenile snook. The differences in snook density between creeks during this study appear to be linked to more than water quality alone.

Temporal Considerations

As indicated previously, this study occurred during a multi-year period of low rainfall. Since the study was designed to examine the impacts of freshwater flow alterations on mangrove creeks, low rainfall likely created a bias toward finding no effect, with no way on knowing whether years with normal rainfall would reveal similar results. This underscores the need for long-term data that incorporates natural variation. A year of sampling of motile species with complex environmental requirements is only a snapshot, whereas multiple years of data tends to provide a more realistic view of these inherently variable systems. The contrast between fish abundances in this study (low rainfall) and of 2003 – 2004 (years of normal or above normal rainfall) provide a good example of how a single year can influence findings. Unfortunately, previous years of sampling fishes in the study creeks did not include the detailed water quality analysis of this study, so the extent to which water quality would reflect watershed differences remains unknown.

Alternatively, it may be that the abovementioned watershed alterations have already changed the ecology of the estuarine creeks for this region, and that a phase shift from an 'undisturbed' ecological state has already occurred, even in those creeks thought to be relatively unaltered. In this scenario, differences among creeks of apparently different quality may not be as dramatic as we had expected because the watershed alterations have already occurred on a regional scale.

Relevance to CHNEP Priority Goals and Actions

The goals of the project were to determine whether apparent differences in watershed development have caused measurable differences in nutrient loading and water quality of mangrove creeks of Charlotte Harbor, and whether watershed alterations were correlated with fish assemblages. It was expected that amount of impervious surface in watersheds and nutrient levels could be used as explanatory variables for fish abundances and species richness in the study creeks. Although the study did not result in the expected outcome, there were notable results.

The project addressed Priority Actions that focus on nutrients and associated water body degradation. All water quality data met quality objectives, were generated by recognized methods by a certified laboratory (WQ-A), and are submitted to STORET via SWFMWD (WQ-B). The data were secured for an under-represented and critical nursery habitat type within Charlotte Harbor (WQ-B) and are suitable for preparing site-specific criteria should that be necessary (WQ-G). Nutrient and chlorophyll data validate expected relationships and provide much needed water quality data in a critical habitat (WQ-I).

The lack of confidence in present watershed boundaries is a strong argument for completion of the strategies identified in WQ-F. While watershed impervious areas were quantified in the study, a comparison of salinity and water quality results among creeks and the personal observations of researchers indicated that boundaries must be improved before this approach will be valid.

Low phosphorous levels in the Yucca Pen and Culvert Creek (the assumed degraded creeks) could be the result of increased levels of groundwater base flow. Alternatively, if the higher flows into Yucca Pens are due to an anthropogenically increased watershed size, the retention of freshwater in a low relief watershed could be allowing for the biological removal of phosphorous prior to entering the creeks. This explanation is consistent with the pooling of water within the Yucca Pens management area above Yucca Pen, and the retention pond above the headwater of Culvert Creek (HA-K). Water retention within the watershed may improve quality of water running off from anthropogenically altered watersheds into estuarine creeks. The apparent benefits, however, may be offset by the increased amounts and variable timing of freshwater into these creeks, as indicated by depressed salinities in Yucca Pen during dry season (HA-C, E, G, H, M).

If the reduction of runoff-associated phosphorous is due to retention within the watershed, then it suggests that filter marshes may be effective in reducing nutrient loads of runoff in these systems. Such marshes would create natural habitat (including fish habitat) for these areas (unlike the present open water retention areas) and filter excess nutrients, both of which are desired results and provide support for the restoration of historical hydrology (WQ-C, WQ-D, WQ-E).

Surprisingly, the study showed overall little difference in water quality parameters among the study creeks other than for salinity in Yucca Pens and phosphorus concentrations. One possible reason for this was that the study occurred during multiple years of very low rainfall. Since the study was designed to examine the effects of runoff on creek water quality and fishes, the lack of rainfall and associated low volumes of runoff made such determinations difficult. This underscores the difficulty in assessing water quality with a single year instead of over an extended dataset.

Future Directions

The results of this study reveal the challenges in determining the impacts of anthropogenic activities in estuarine watersheds in southwest Florida. Future work should focus on revising watershed delineations, accounting for structures (ditches, berms, roads, etc) that might negate traditional elevation-based watershed delineations. Comparison of the aerial coverage of historical watersheds to current (altered) watersheds might be a better variable for predicting impacts on mangrove creek fauna, or perhaps either measured flows or present-day watershed areas can be linked to fish abundances and species richness.

Monitoring of freshwater flows into selected mangrove creeks with appropriately defined watersheds would aid understanding how watershed alterations of different types (ditches, berms, roads, impervious surfaces) influence flows into estuarine creeks. Similarly, long-term concurrent monitoring of water quality variables and creek fauna would provide a view of trends within the context of natural variability. Importantly, long-term focus on the creek-watershed connections would allow examination of changes over time as watersheds become more developed or different conservation strategies are applied in different areas. Coastal management in the Charlotte Harbor region has suffered because of an overall lack of historical data, and development of long-term monitoring plans now will be essential for assessing impacts of coastal land use on estuarine in the future, and will provide information essential for adaptive management strategies.

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Appendices

Appendix A - Summary Water Quality Data

Table A.1. Summary water quality data, May 2008 – September 2009.

Station	**NSU**	**NSM**	**NSL**	**SSU**	**SSM**	**SSL**	**YPU**	**YPM**	**YPL**	**CCU**	**CCM**	**CCL**
n=	12	12	12	12	12	12	12	12	12	12	12	12
Salinity (PSU)												
minimum	3.76	8.51	16.54	8.51	8.30	14.37	0.06	0.06	0.39	12.65	9.59	21.74
maximum	37.91	36.60	36.80	37.29	36.71	36.82	34.90	37.62	38.43	39.58	38.74	38.37
median	27.47	26.63	26.10	26.44	26.75	26.57	20.29	22.73	24.08	30.26	28.80	28.62
Mean	25.74	26.11	26.89	25.68	25.32	26.92	18.38	20.62	23.44	28.44	27.71	29.32
std.dev.	9.85	8.35	6.87	9.00	9.21	7.44	13.84	14.28	13.09	8.89	9.22	6.36
Dissolved Oxygen (mg/l)												
minimum	0.23	0.06	1.05	1.14	0.03	1.34	0.47	0.71	0.45	0.62	0.73	0.37
maximum	9.71	9.53	9.94	9.66	9.97	10.60	8.87	6.98	7.75	9.83	10.25	11.37
median	2.24	2.87	3.41	2.83	3.11	4.13	2.47	2.65	2.80	1.71	2.98	3.26
mean	3.31	4.04	4.52	4.16	4.31	4.78	3.27	3.19	3.34	3.00	3.85	4.53
std.dev.	2.67	2.82	2.65	2.93	3.10	2.90	2.45	1.87	2.26	2.79	3.35	3.52
Temperature (Deg C)												
minimum	14.52	16.81	15.77	15.57	17.42	17.10	13.46	15.50	16.70	18.30	16.41	17.59
maximum	31.27	31.40	31.88	31.05	31.23	31.52	30.31	30.42	31.44	29.55	31.52	30.65
median	27.03	27.00	27.40	27.38	28.01	27.56	27.30	27.14	27.01	27.34	27.16	27.31
mean	25.86	26.28	26.48	26.29	26.69	26.66	25.38	25.85	25.89	25.77	25.74	25.90
std.dev.	4.86	4.44	4.99	4.60	4.30	4.65	5.41	5.16	5.07	4.00	4.95	4.41
Ammonia-N (mg/l)												
minimum	0.006	0.008	0.005	0.012	0.010	0.009	0.003	0.003	0.003	0.006	0.003	0.006
maximum	0.049	0.025	0.044	0.078	0.062	0.050	0.031	0.031	0.038	0.028	0.033	0.060
median	0.015	0.013	0.015	0.028	0.019	0.018	0.010	0.010	0.013	0.012	0.015	0.014
mean	0.016	0.015	0.020	0.032	0.022	0.021	0.011	0.012	0.015	0.014	0.017	0.018
std.dev.	0.011	0.006	0.013	0.017	0.015	0.012	0.007	0.008	0.009	0.007	0.011	0.015
Nitrate-nitrite-N, minimum												
minimum	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
maximum	0.003	0.003	0.003	0.027	0.003	0.003	0.014	0.007	0.007	0.003	0.006	0.003
median	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
mean	0.003	0.003	0.003	0.005	0.003	0.003	0.005	0.003	0.003	0.003	0.003	0.003
std.dev.	0.000	0.000	0.000	0.007	0.000	0.000	0.004	0.002	0.002	0.000	0.001	0.000

Table A.1. Continued.

Total Kjeldahl Nitrogen (mg/l)												
minimum	0.77	0.58	0.56	0.81	0.63	0.53	0.40	0.50	0.56	0.72	0.47	0.59
maximum	1.79	1.77	1.41	1.87	1.34	1.33	1.62	1.44	1.34	1.28	1.16	1.17
median	1.10	0.86	0.84	0.96	0.94	0.84	0.81	0.72	0.72	0.97	0.79	0.77
mean	1.15	0.96	0.86	1.14	0.95	0.87	0.89	0.83	0.82	0.98	0.81	0.82
std.dev.	0.31	0.33	0.25	0.38	0.18	0.23	0.33	0.30	0.24	0.18	0.18	0.18
Total N (mg/l)												
minimum	0.77	0.58	0.56	0.81	0.63	0.53	0.41	0.50	0.56	0.72	0.47	0.59
maximum	1.79	1.77	1.41	1.87	1.34	1.33	1.62	1.44	1.35	1.28	1.16	1.17
median	1.10	0.86	0.84	0.96	0.94	0.84	0.81	0.72	0.72	0.97	0.79	0.77
mean	1.15	0.96	0.87	1.14	0.96	0.87	0.90	0.83	0.82	0.99	0.81	0.82
std.dev.	0.31	0.33	0.25	0.38	0.18	0.23	0.33	0.30	0.24	0.18	0.18	0.18
Total P (mg/l)												
minimum	0.08	0.08	0.07	0.08	0.08	0.08	0.03	0.03	0.03	0.06	0.03	0.06
maximum	0.47	0.32	0.24	0.37	0.31	0.26	0.14	0.18	0.19	0.18	0.17	0.22
median	0.22	0.20	0.15	0.18	0.17	0.13	0.07	0.08	0.07	0.09	0.08	0.08
mean	0.23	0.19	0.16	0.19	0.16	0.16	0.07	0.08	0.08	0.10	0.09	0.10
std.dev.	0.12	0.08	0.06	0.10	0.07	0.07	0.04	0.05	0.04	0.03	0.05	0.05
Chlorophyll a, corrected (ug/l)												
minimum	2.51	1.07	1.02	1.75	4.12	1.23	1.17	1.54	1.48	3.39	2.50	2.26
maximum	23.67	24.45	22.77	25.47	18.41	18.97	11.22	16.87	23.06	23.38	13.32	14.67
median	6.60	5.70	5.26	8.32	8.30	5.67	3.08	3.74	3.27	8.45	3.99	5.83
mean	9.77	8.37	8.10	11.36	8.78	7.47	4.96	5.35	5.41	10.25	5.19	6.91
std.dev.	6.87	6.72	6.85	8.00	4.16	5.68	3.90	4.89	6.25	6.04	3.01	4.37
Freshwater N (mg/l)												
minimum	1.39	1.41	1.38	1.38	1.34	1.48	0.49	0.67	1.01	1.63	1.24	1.67
maximum	30.37	10.15	8.78	12.88	11.09	9.00	5.39	10.13	17.64	117.38	15.00	14.54
median	2.84	2.48	2.35	2.60	2.55	2.56	1.53	1.66	1.82	4.12	2.71	2.70
mean	6.90	3.94	3.59	5.13	3.98	3.87	2.60	3.31	4.27	14.76	5.22	5.55
std.dev.	9.04	2.87	2.34	3.97	2.99	2.66	1.86	2.95	4.77	32.65	4.79	5.14

Table A.1. Continued.

Freshwater P (mg/l)												
minimum	0.12	0.18	0.20	0.13	0.11	0.21	0.03	0.03	0.03	0.10	0.07	0.18
maximum	8.58	3.41	2.38	3.67	2.71	3.03	1.10	3.03	4.84	12.38	3.27	3.12
median	0.54	0.58	0.53	0.47	0.46	0.53	0.16	0.31	0.26	0.31	0.30	0.32
mean	1.64	0.90	0.68	1.04	0.83	0.79	0.27	0.51	0.67	1.73	0.66	0.69
std.dev.	2.60	0.97	0.61	1.11	0.86	0.82	0.32	0.82	1.33	3.56	0.95	0.86
TN : TP Ratio (mg:mg)												
minimum	3.54	2.97	3.70	2.71	2.72	2.97	4.59	3.35	3.64	4.01	4.19	4.38
maximum	11.53	7.81	9.04	11.78	12.16	9.02	52.40	53.08	53.88	15.71	32.10	13.03
median	4.98	5.39	5.71	6.44	5.66	5.95	11.81	8.81	9.99	11.11	9.61	9.88
mean	5.99	5.51	6.05	6.88	6.93	6.13	20.10	16.56	16.17	10.69	11.78	9.32
std.dev.	2.59	1.58	1.85	2.75	3.20	1.99	16.36	16.48	16.53	2.99	7.50	2.64

Appendix B – Summary Fish Species Information

Table B.1. Species list by fish code.

FISHCODE	COMMON	SPECIES	TOT_NUM	MEANLEN
1000	anchovy spp.	Anchoa spp.	143	42
1001	atlantic needlefish	Strongylura marina	4	460
1003	blue crab	Callinectes sapidus	18	42
1005	chain pipefish	Syngnathus louisianae	25	93
1006	Clown goby	Microgobius gulosus	1,248	41
1007	code goby	Gobiosoma robustum	32	23
1008	Snook	Centropomus undecimalis	529	166
1010	diamond killifish	Adinia xenica	860	36
1011	gambusia	Gambusia holbrooki	2,848	30
1015	flagfish	Jordanella floridae	1	22
1016	florida gar	Lepisosteus platyrhincus	9	573
1018	gar spp.	Lepisosteus spp.	1	518
1019	goby spp.	Gobiosoma spp.	4	29
1020	gulf killifish	Fundulus grandis	1,119	76
1022	gulf toadfish	Opsanus beta	42	41
1023	hogchoker	Trinectes maculatus	11	35
1024	Inland silverside	Menidia beryllina	12,634	47
1026	jewelfish	Hemichromis bimaculatus	22	39
1029	ladyfish	Elops saurus	2	48
1031	leatherjacket	Oligoplites saurus	24	47
1033	lined sole	Achirus lineatus	6	36
1034	longnose killifish	Fundulus similis	26	57
1037	Marsh killifish	Fundulus confluentus	40	39
1038	mayan cichlid	Cichlasoma urophthalmus	65	145
1039	mojarra spp.	Eucinostomus spp.	3,755	28
1040	mozambique tilapia	Oreochromis mossambicus	15	28
1041	Mullet spp.	Mugil spp.	336	36
1043	Naked goby	Gobiosoma bosci	7	27
1044	pinfish	Lagodon rhomboides	396	56
1045	pink shrimp	Farfantepenaeus duorarum	275	44
1046	pipefish spp.	Syngnathus spp.	6	67
1047	Parva	Lucania parva	11,723	33
1048	red drum	Sciaenops ocellatus	72	44
1049	Redfin needlefish	Strongylura notata	170	189
1050	Sailfin molly	Poecillia latipinna	3,431	49
1051	sheepshead	Archosargus probatocephalus	92	50
1052	sheepshead minnow	Cyprinodon variegatus	2,806	37
1053	silver jenny	Eucinostomus gula	7	55
1054	silverside spp.	Menidia spp.	531	30
1057	Spot	Leiostomus xanthurus	9	82
1058	spotted gar	Lepisosteus oculatus	2	460
1059	spotted seatrout	Cynoscion nebulosus	10	55
1061	striped mojarra	Diapterus plumieri	477	74
1062	striped mullet	Mugil cephalus	7	210

1063	sunfish	Lepomis spp.	1	23
1064	tidewater mojarra	Eucinostomus harengulus	2,195	55
1065	tidewater silverside	Menidia peninsulae	4,706	54
1066	Tilapia spp.	Tilapia spp.	1	215
1068	sciaenid spp.	Sciaenid spp.	9	28
1070	atlantic croaker	Micropogonias undulatus	125	48
1073	white mullet	Mugil curema	4	181
1076	juvenile needlefish	Strongylura spp.	2	67
1077	longnose gar	Lepisosteus osseus	1	50
1081	tarpon	Megalops atlanticus	1	266
1082	grouper spp.	Epinephelus spp.	10	35
1083	inshore lizardfish	Synodus foetens	2	76
1085	timucu	Strongylura timucu	8	246
1087	menhaden spp.	Brevoortia spp.	16	63
1096	checker puffer	Sphoeroides testudineus	18	19
1097	goldspot killifish	Fundulus chrysotus	199	62
1098	hardhead catfish	Arius felis	1	380

Table B.2. Species list, by genus.

FISHCODE	COMMON	SPECIES	TOT_NUM	MEANLEN
1033	lined sole	Achirus lineatus	6	36
1010	diamond killifish	Adinia xenica	860	36
1000	anchovy spp.	Anchoa spp.	143	42
1051	sheepshead	Archosargus probatocephalus	92	50
1098	hardhead catfish	Arius felis	1	380
1087	menhaden spp.	Brevoortia spp.	16	63
1003	blue crab	Callinectes sapidus	18	42
1008	Snook	Centropomus undecimalis	529	166
1038	mayan cichlid	Cichlasoma urophthalmus	65	145
1059	spotted seatrout	Cynoscion nebulosus	10	55
1052	sheepshead minnow	Cyprinodon variegatus	2,806	37
1061	striped mojarra	Diapterus plumieri	477	74
1029	ladyfish	Elops saurus	2	48
1082	grouper spp.	Epinephelus spp.	10	35
1053	silver jenny	Eucinostomus gula	7	55
1064	tidewater mojarra	Eucinostomus harengulus	2,195	55
1039	mojarra spp.	Eucinostomus spp.	3,755	28
1045	pink shrimp	Farfantepenaeus duorarum	275	44
1097	goldspot killifish	Fundulus chrysotus	199	62
1037	Marsh killifish	Fundulus confluentus	40	39
1020	gulf killifish	Fundulus grandis	1,119	76
1034	longnose killifish	Fundulus similis	26	57
1011	gambusia	Gambusia holbrooki	2,848	30
1043	Naked goby	Gobiosoma bosci	7	27
1007	code goby	Gobiosoma robustum	32	23
1019	goby spp.	Gobiosoma spp.	4	29
1026	jewelfish	Hemichromis bimaculatus	22	39
1015	flagfish	Jordanella floridae	1	22
1044	pinfish	Lagodon rhomboides	396	56
1057	Spot	Leiostomus xanthurus	9	82
1058	spotted gar	Lepisosteus oculatus	2	460
1077	longnose gar	Lepisosteus osseus	1	50
1016	florida gar	Lepisosteus platyrhincus	9	573
1018	gar spp.	Lepisosteus spp.	1	518
1063	sunfish	Lepomis spp.	1	23
1047	Parva	Lucania parva	11,723	33
1081	tarpon	Megalops atlanticus	1	266
1024	Inland silverside	Menidia beryllina	12,634	47
1065	tidewater silverside	Menidia peninsulae	4,706	54
1054	silverside spp.	Menidia spp.	531	30
1006	Clown goby	Microgobius gulosus	1,248	41
1070	atlantic croaker	Micropogonias undulatus	125	48
1062	striped mullet	Mugil cephalus	7	210
1073	white mullet	Mugil curema	4	181
1041	Mullet spp.	Mugil spp.	336	36
1031	leatherjacket	Oligoplites saurus	24	47
1022	gulf toadfish	Opsanus beta	42	41
1040	mozambique tilapia	Oreochromis mossambicus	15	28

1050	Sailfin molly	Poecillia latipinna	3,431	49
1068	sciaenid spp.	Sciaenid spp.	9	28
1048	red drum	Sciaenops ocellatus	72	44
1096	checker puffer	Sphoeroides testudineus	18	19
1001	atlantic needlefish	Strongylura marina	4	460
1049	Redfin needlefish	Strongylura notata	170	189
1076	juvenile needlefish	Strongylura spp.	2	67
1085	timucu	Strongylura timucu	8	246
1005	chain pipefish	Syngnathus louisianae	25	93
1046	pipefish spp.	Syngnathus spp.	6	67
1083	inshore lizardfish	Synodus foetens	2	76
1066	Tilapia spp.	Tilapia spp.	1	215
1023	hogchoker	Trinectes maculatus	11	35

Table B.3. Species list, by number of fish captured.

FISHCODE	COMMON	SPECIES	TOT_NUM	MEANLEN
1024	Inland silverside	Menidia beryllina	12,634	47
1047	Parva	Lucania parva	11,723	33
1065	tidewater silverside	Menidia peninsulae	4,706	54
1039	mojarra spp.	Eucinostomus spp.	3,755	28
1050	Sailfin molly	Poecillia latipinna	3,431	49
1011	gambusia	Gambusia holbrooki	2,848	30
1052	sheepshead minnow	Cyprinodon variegatus	2,806	37
1064	tidewater mojarra	Eucinostomus harengulus	2,195	55
1006	Clown goby	Microgobius gulosus	1,248	41
1020	gulf killifish	Fundulus grandis	1,119	76
1010	diamond killifish	Adinia xenica	860	36
1054	silverside spp.	Menidia spp.	531	30
1008	Snook	Centropomus undecimalis	529	166
1061	striped mojarra	Diapterus plumieri	477	74
1044	pinfish	Lagodon rhomboides	396	56
1041	Mullet spp.	Mugil spp.	336	36
1045	pink shrimp	Farfantepenaeus duorarum	275	44
1097	goldspot killifish	Fundulus chrysotus	199	62
1049	Redfin needlefish	Strongylura notata	170	189
1000	anchovy spp.	Anchoa spp.	143	42
1070	atlantic croaker	Micropogonias undulatus	125	48
1051	sheepshead	Archosargus probatocephalus	92	50
1048	red drum	Sciaenops ocellatus	72	44
1038	mayan cichlid	Cichlasoma urophthalmus	65	145
1022	gulf toadfish	Opsanus beta	42	41
1037	Marsh killifish	Fundulus confluentus	40	39
1007	code goby	Gobiosoma robustum	32	23
1034	longnose killifish	Fundulus similis	26	57
1005	chain pipefish	Syngnathus louisianae	25	93
1031	leatherjacket	Oligoplites saurus	24	47
1026	jewelfish	Hemichromis bimaculatus	22	39
1003	blue crab	Callinectes sapidus	18	42
1096	checker puffer	Sphoeroides testudineus	18	19
1087	menhaden spp.	Brevoortia spp.	16	63
1040	mozambique tilapia	Oreochromis mossambicus	15	28
1023	hogchoker	Trinectes maculatus	11	35
1059	spotted seatrout	Cynoscion nebulosus	10	55
1082	grouper spp.	Epinephelus spp.	10	35
1016	florida gar	Lepisosteus platyrhincus	9	573
1057	Spot	Leiostomus xanthurus	9	82
1068	sciaenid spp.	Sciaenid spp.	9	28
1085	timucu	Strongylura timucu	8	246
1043	Naked goby	Gobiosoma bosci	7	27
1053	silver jenny	Eucinostomus gula	7	55
1062	striped mullet	Mugil cephalus	7	210
1033	lined sole	Achirus lineatus	6	36
1046	pipefish spp.	Syngnathus spp.	6	67

1001	atlantic needlefish	Strongylura marina	4	460
1019	goby spp.	Gobiosoma spp.	4	29
1073	white mullet	Mugil curema	4	181
1029	ladyfish	Elops saurus	2	48
1058	spotted gar	Lepisosteus oculatus	2	460
1076	juvenile needlefish	Strongylura spp.	2	67
1083	inshore lizardfish	Synodus foetens	2	76
1015	flagfish	Jordanella floridae	1	22
1018	gar spp.	Lepisosteus spp.	1	518
1063	sunfish	Lepomis spp.	1	23
1066	Tilapia spp.	Tilapia spp.	1	215
1077	longnose gar	Lepisosteus osseus	1	50
1081	tarpon	Megalops atlanticus	1	266
1098	hardhead catfish	Arius felis	1	380

Table B.4. Mean density by species and station for May 2008 – September 2009. Fish per m^2.

	F1000	F1001	F1003	F1005	F1006	F1007	F1008	F1010	F1011	F1015	F1016	F1018	F1019
CCL	0.00E+00	0.00E+00	5.11E-04	4.22E-04	6.96E-03	1.33E-04	5.11E-03	2.31E-02	1.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CCM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.87E-03	2.22E-04	3.24E-02	0.00E+00	3.58E-02	0.00E+00	6.89E-04	0.00E+00	0.00E+00
CCU	0.00E+00	0.00E+00	1.11E-04	2.00E-04	0.00E+00	2.00E-04	3.95E-02	3.74E-02	3.28E-01	0.00E+00	4.22E-04	0.00E+00	0.00E+00
NSL	5.75E-04	0.00E+00	2.75E-04	1.50E-04	1.81E-02	0.00E+00	3.48E-03	0.00E+00	1.05E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NSM	2.63E-03	0.00E+00	0.00E+00	0.00E+00	9.68E-03	0.00E+00	5.65E-03	6.02E-02	3.49E-02	0.00E+00	1.75E-04	0.00E+00	0.00E+00
NSU	6.00E-04	0.00E+00	4.50E-04	0.00E+00	7.25E-04	0.00E+00	3.25E-04	6.27E-02	7.30E-02	0.00E+00	5.25E-04	0.00E+00	0.00E+00
SSL	2.22E-04	1.16E-03	4.89E-04	8.67E-04	4.09E-02	9.11E-03	2.84E-03	1.36E-02	1.29E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SSM	1.43E-02	0.00E+00	1.02E-03	9.11E-04	7.68E-02	3.56E-04	1.04E-02	5.27E-03	5.96E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SSU	1.05E-02	0.00E+00	2.89E-04	1.56E-04	8.46E-02	0.00E+00	3.38E-03	8.67E-04	1.20E-01	0.00E+00	0.00E+00	0.00E+00	1.56E-04
YPL	7.25E-04	0.00E+00	5.75E-04	1.55E-03	2.55E-03	1.25E-03	6.08E-03	7.25E-04	3.08E-03	0.00E+00	1.50E-04	3.00E-04	6.00E-04
YPM	0.00E+00	0.00E+00	2.75E-04	2.75E-04	8.53E-03	0.00E+00	7.05E-03	5.75E-04	1.35E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
YPU	0.00E+00	0.00E+00	4.58E-04	0.00E+00	3.00E-03	0.00E+00	4.00E-03	0.00E+00	7.47E-02	1.63E-03	0.00E+00	0.00E+00	0.00E+00

	F1020	F1022	F1023	F1024	F1026	F1029	F1031	F1033	F1034	F1037	F1038	F1039	F1040
CCL	4.43E-02	9.78E-04	9.11E-04	1.23E-01	5.11E-04	0.00E+00	0.00E+00	6.44E-04	4.20E-03	6.44E-04	3.11E-04	1.33E-01	0.00E+00
CCM	1.14E-02	2.22E-04	0.00E+00	2.43E-02	5.11E-04	0.00E+00	0.00E+00	0.00E+00	1.78E-04	8.67E-04	0.00E+00	8.21E-02	3.04E-03
CCU	3.12E-02	1.33E-04	0.00E+00	3.46E-02	6.89E-04	0.00E+00	0.00E+00	0.00E+00	2.22E-04	7.78E-04	1.11E-04	6.78E-03	0.00E+00
NSL	1.37E-02	1.78E-03	0.00E+00	7.83E-01	0.00E+00	0.00E+00	1.70E-03	0.00E+00	0.00E+00	2.25E-04	3.75E-04	4.29E-02	0.00E+00
NSM	1.30E-02	0.00E+00	4.75E-04	4.58E-01	1.75E-04	0.00E+00	0.00E+00	3.25E-04	0.00E+00	8.75E-04	2.00E-04	2.87E-02	0.00E+00
NSU	2.76E-02	0.00E+00	0.00E+00	1.25E-01	2.50E-04	0.00E+00	0.00E+00	0.00E+00	3.75E-04	1.33E-03	0.00E+00	4.83E-03	0.00E+00
SSL	4.33E-02	2.24E-03	0.00E+00	4.17E-01	0.00E+00	0.00E+00	2.11E-03	0.00E+00	0.00E+00	0.00E+00	4.00E-04	1.35E-01	0.00E+00
SSM	2.91E-02	2.00E-03	0.00E+00	1.71E-01	0.00E+00	0.00E+00	4.00E-04	2.67E-04	0.00E+00	1.87E-03	3.13E-03	1.18E-01	0.00E+00
SSU	1.46E-02	9.33E-04	6.22E-04	6.37E-01	0.00E+00	3.56E-04	4.67E-04	0.00E+00	0.00E+00	1.56E-04	8.36E-03	7.26E-02	0.00E+00
YPL	1.30E-02	0.00E+00	0.00E+00	2.81E-02	4.25E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E-04	0.00E+00	1.31E-01	0.00E+00
YPM	1.81E-02	0.00E+00	3.00E-04	1.03E-01	4.00E-04	0.00E+00	0.00E+00	0.00E+00	1.38E-03	6.75E-04	0.00E+00	6.58E-02	0.00E+00
YPU	4.92E-03	0.00E+00	0.00E+00	2.62E-02	1.03E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.67E-04	0.00E+00	6.08E-03	0.00E+00

Table B.4. Continued.

	F1041	F1043	F1044	F1045	F1046	F1047	F1048	F1049	F1050	F1051	F1052	F1053	F1054
CCL	3.57E-02	3.33E-04	2.43E-02	2.71E-03	0.00E+00	3.33E-02	1.96E-03	6.91E-03	5.10E-02	6.42E-03	2.76E-02	0.00E+00	4.00E-03
CCM	0.00E+00	3.11E-04	2.42E-03	4.93E-03	0.00E+00	2.22E-02	3.78E-04	0.00E+00	3.93E-02	1.56E-04	6.87E-03	0.00E+00	8.22E-04
CCU	5.33E-04	0.00E+00	0.00E+00	1.09E-03	0.00E+00	1.12E-02	7.11E-04	0.00E+00	2.34E-01	5.11E-04	1.27E-02	0.00E+00	8.53E-03
NSL	3.00E-03	1.50E-04	1.00E-02	8.80E-03	0.00E+00	8.99E-01	1.30E-03	7.20E-03	1.27E-02	6.38E-03	3.78E-02	1.50E-04	2.53E-02
NSM	0.00E+00	0.00E+00	7.00E-04	4.43E-03	0.00E+00	2.04E-01	3.75E-04	2.18E-03	7.52E-02	4.25E-04	3.29E-02	8.75E-04	3.93E-03
NSU	2.75E-04	0.00E+00	0.00E+00	1.63E-03	0.00E+00	1.39E-01	0.00E+00	3.50E-04	4.61E-02	0.00E+00	3.58E-01	6.00E-04	3.80E-02
SSL	2.44E-04	0.00E+00	6.69E-03	1.71E-02	0.00E+00	8.10E-01	6.22E-04	9.82E-03	7.20E-02	6.00E-04	1.46E-01	2.22E-04	1.74E-02
SSM	0.00E+00	0.00E+00	1.31E-02	1.16E-02	7.56E-04	3.94E-01	1.98E-03	5.31E-03	8.09E-02	5.11E-03	7.93E-02	0.00E+00	1.54E-02
SSU	5.33E-04	0.00E+00	9.49E-03	5.64E-03	4.22E-04	2.10E-01	2.60E-03	2.91E-03	3.36E-02	0.00E+00	1.78E-02	0.00E+00	1.17E-02
YPL	3.75E-04	1.00E-04	1.55E-02	4.00E-04	1.00E-04	7.24E-02	2.28E-03	5.75E-04	1.07E-02	3.25E-04	5.95E-03	0.00E+00	0.00E+00
YPM	0.00E+00	2.75E-04	1.04E-02	1.08E-03	0.00E+00	3.22E-02	1.58E-03	7.50E-04	3.86E-02	0.00E+00	3.40E-03	0.00E+00	1.33E-02
YPU	1.00E-02	0.00E+00	0.00E+00	4.58E-04	0.00E+00	5.91E-02	2.50E-03	0.00E+00	6.57E-02	0.00E+00	3.17E-03	0.00E+00	0.00E+00

	F1057	F1058	F1059	F1061	F1062	F1063	F1064	F1065	F1066	F1068	F1070	F1073	F1076
CCL	0.00E+00	0.00E+00	1.56E-04	6.09E-03	0.00E+00	0.00E+00	7.57E-02	4.40E-02	0.00E+00	8.22E-04	1.17E-02	0.00E+00	1.11E-04
CCM	5.78E-04	0.00E+00	0.00E+00	7.87E-03	0.00E+00	0.00E+00	1.65E-02	2.16E-02	0.00E+00	0.00E+00	6.07E-03	0.00E+00	0.00E+00
CCU	2.44E-04	0.00E+00	0.00E+00	5.20E-03	1.11E-04	4.00E-04	1.11E-02	1.11E-03	0.00E+00	0.00E+00	1.33E-04	2.44E-04	0.00E+00
NSL	8.25E-04	0.00E+00	3.00E-04	2.30E-02	1.50E-04	0.00E+00	3.44E-02	1.69E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NSM	0.00E+00	2.25E-04	0.00E+00	7.70E-03	2.00E-04	0.00E+00	4.87E-02	2.39E-01	0.00E+00	1.25E-04	1.25E-03	0.00E+00	0.00E+00
NSU	0.00E+00	0.00E+00	0.00E+00	1.53E-03	0.00E+00	0.00E+00	1.98E-02	1.91E-01	0.00E+00	0.00E+00	0.00E+00	2.00E-04	0.00E+00
SSL	0.00E+00	0.00E+00	3.78E-04	9.31E-03	1.11E-04	0.00E+00	6.94E-02	9.14E-02	0.00E+00	2.00E-04	5.56E-04	0.00E+00	0.00E+00
SSM	2.67E-04	0.00E+00	3.56E-04	2.59E-02	0.00E+00	0.00E+00	8.37E-02	1.24E-01	0.00E+00	4.22E-04	5.11E-03	0.00E+00	0.00E+00
SSU	0.00E+00	2.00E-04	5.33E-04	1.48E-02	3.11E-04	0.00E+00	5.54E-02	2.14E-01	2.22E-04	0.00E+00	8.44E-04	0.00E+00	0.00E+00
YPL	0.00E+00	0.00E+00	0.00E+00	6.73E-03	0.00E+00	0.00E+00	3.91E-02	4.68E-03	0.00E+00	0.00E+00	1.65E-03	0.00E+00	1.25E-04
YPM	0.00E+00	0.00E+00	0.00E+00	1.03E-03	0.00E+00	0.00E+00	3.55E-02	1.43E-02	0.00E+00	0.00E+00	1.50E-03	2.50E-04	0.00E+00
YPU	5.42E-04	0.00E+00	0.00E+00	1.67E-03	5.42E-04	0.00E+00	2.08E-02	1.75E-02	0.00E+00	0.00E+00	5.42E-04	0.00E+00	0.00E+00

Table B.5. Continued.

CCL	F1077	F1081	F1082	F1083	F1085	F1087	F1096	F1097	F1098
CCM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.56E-04	0.00E+00	2.89E-03	1.31E-02	0.00E+00
CCU	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.22E-04	0.00E+00
NSL	2.67E-04	1.78E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NSM	0.00E+00	0.00E+00	0.00E+00	3.75E-04	2.25E-04	0.00E+00	0.00E+00	1.07E-02	0.00E+00
NSU	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SSL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SSM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-04	1.11E-04	1.16E-03	0.00E+00
SSU	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.47E-03	1.33E-04
YPL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.31E-03	0.00E+00	7.91E-03	0.00E+00
YPM	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-04	0.00E+00	0.00E+00	3.25E-04	0.00E+00
YPU	0.00E+00	0.00E+00	2.18E-03	0.00E+00	0.00E+00	0.00E+00	6.00E-04	0.00E+00	0.00E+00
	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.42E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix C - Patterns of Abundant Species

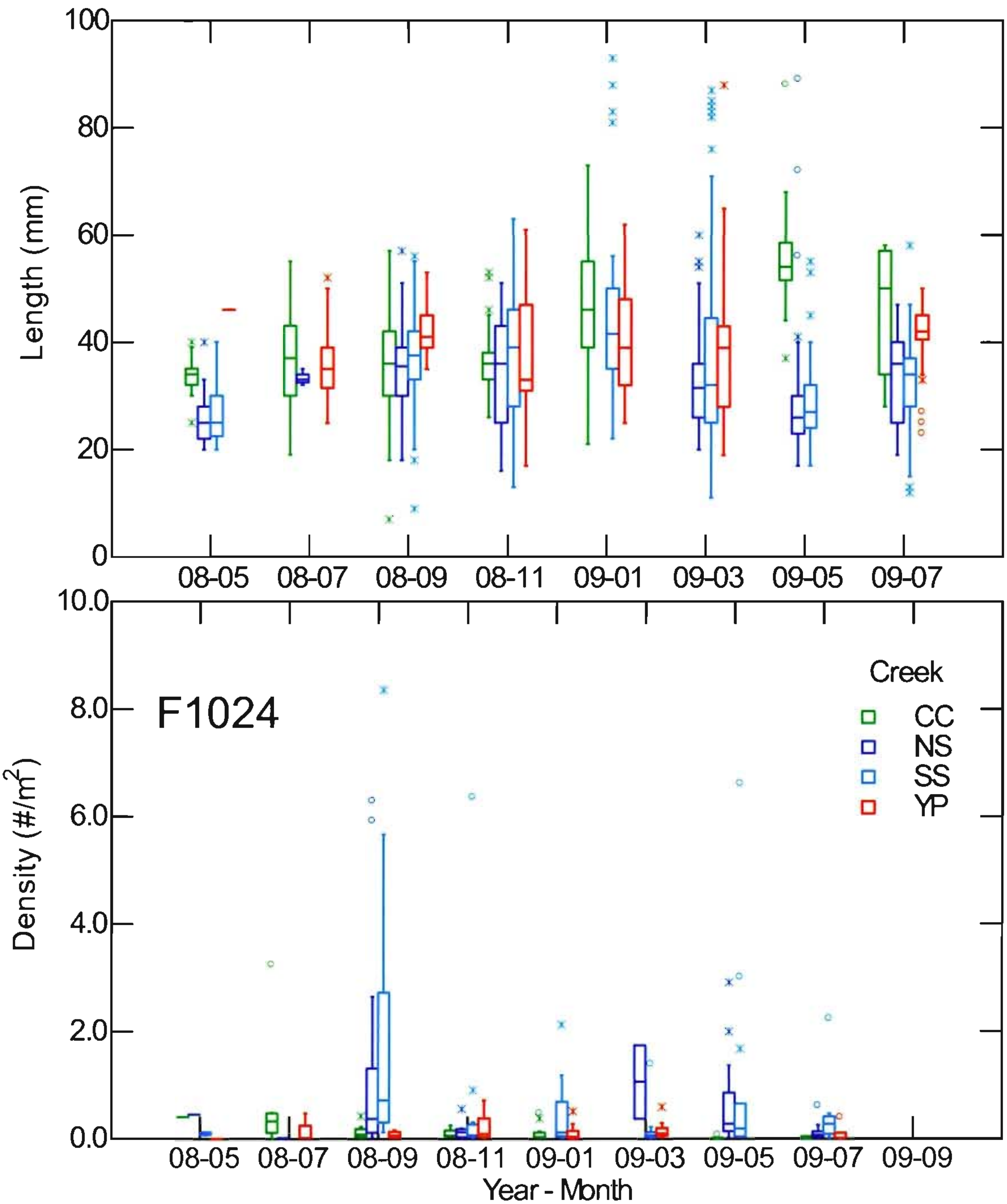


Figure C.1. Temporal patterns of length and density for *Menidia beryllina* (inland silverside, Fish Code 1024).

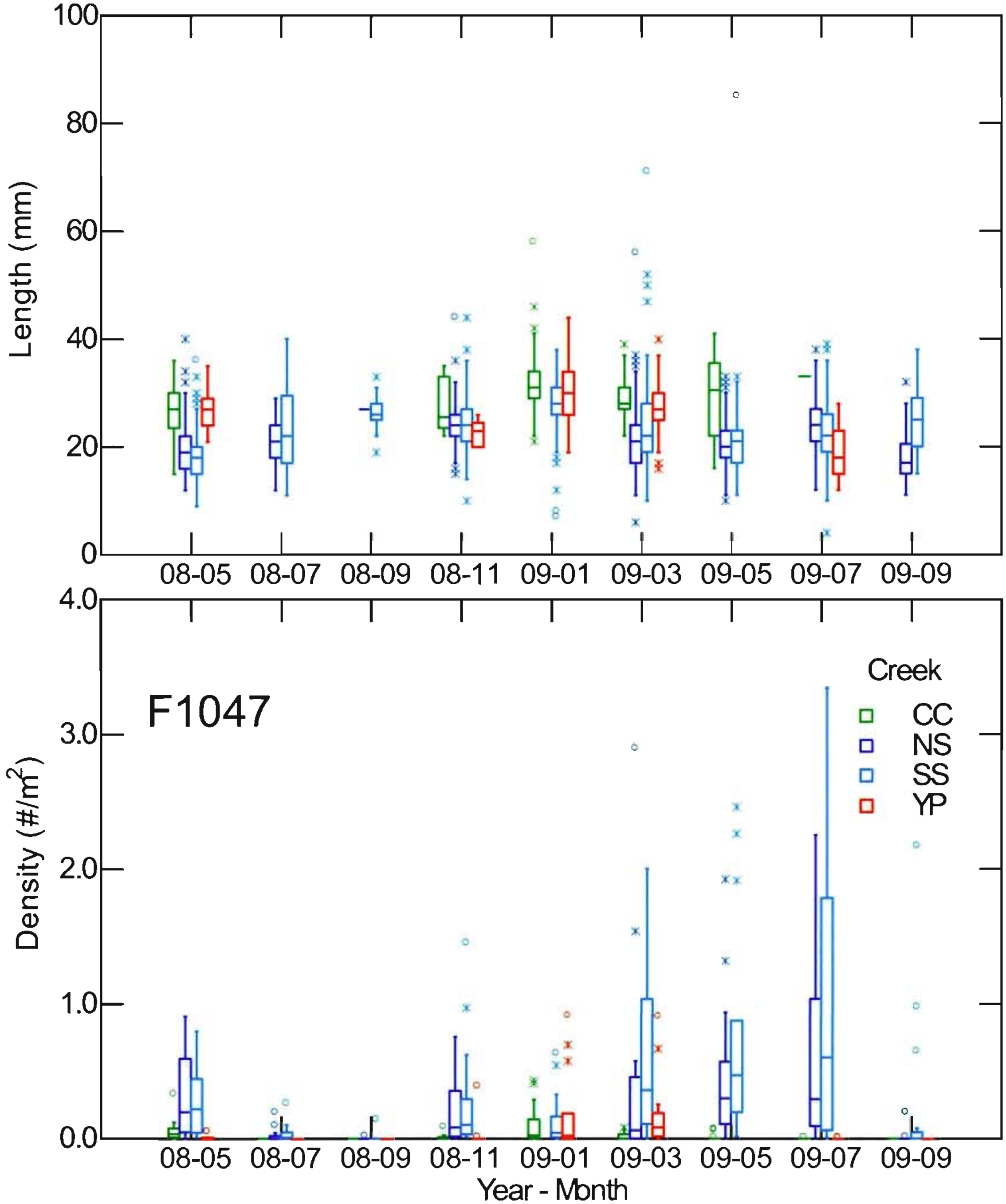


Figure C.2. Temporal patterns of length and density for *Lucania parva* (parva, Fish Code 1047).

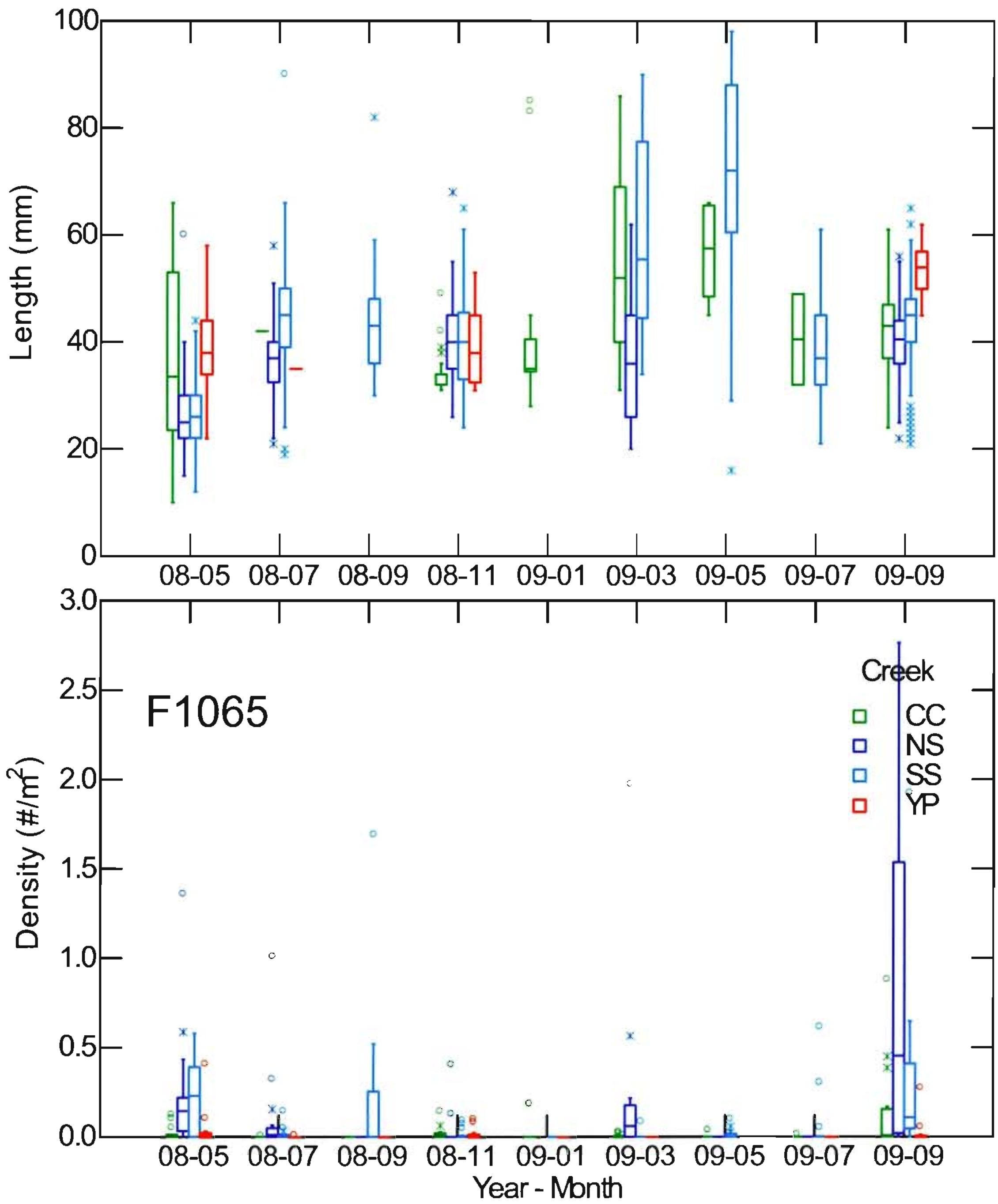


Figure C.3. Temporal patterns of length and density for *Menidia peninsulae* (tidewater silverside, Fish Code 1065).

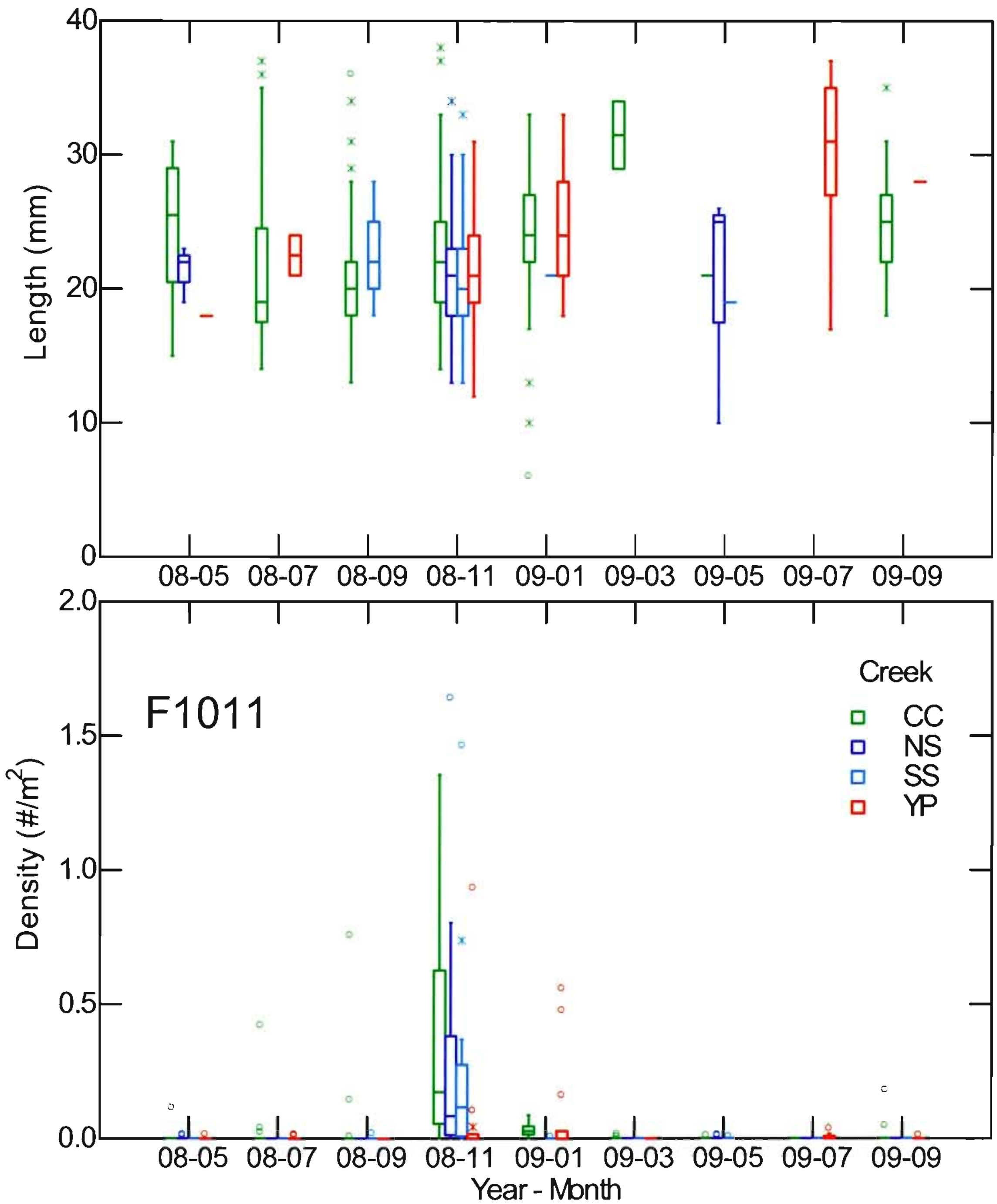
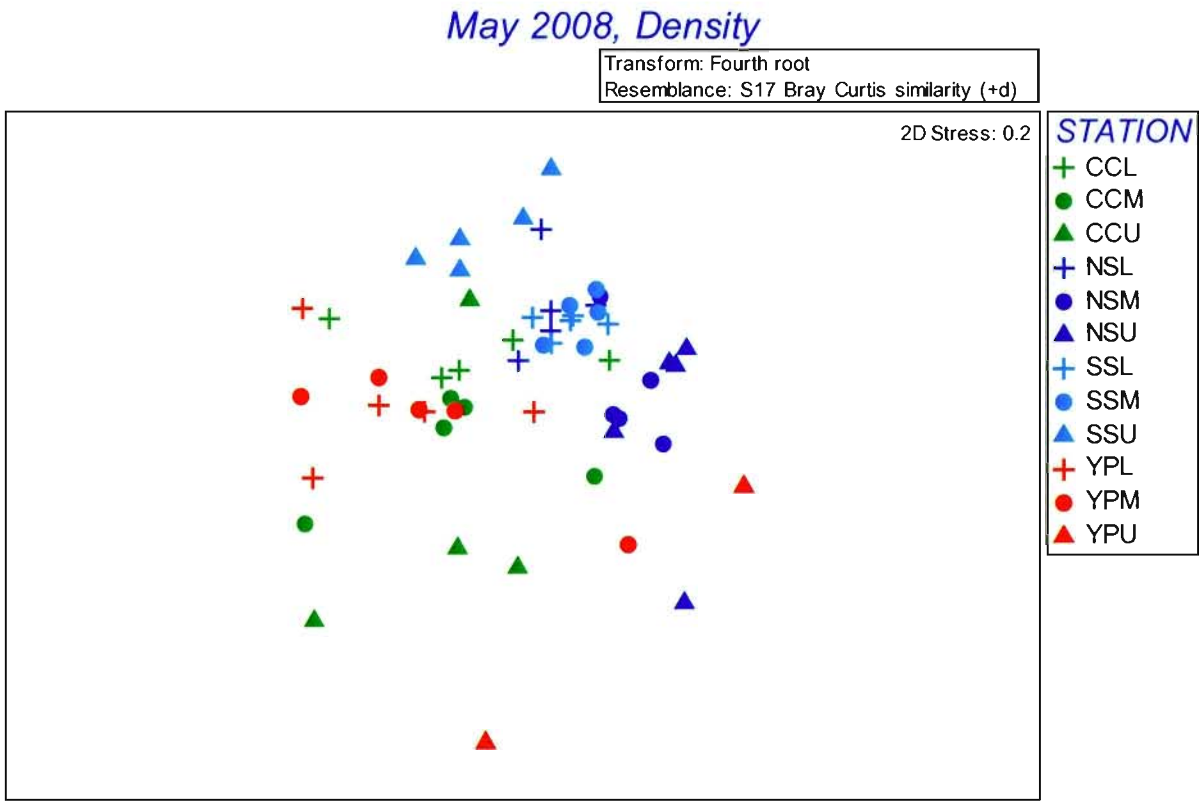
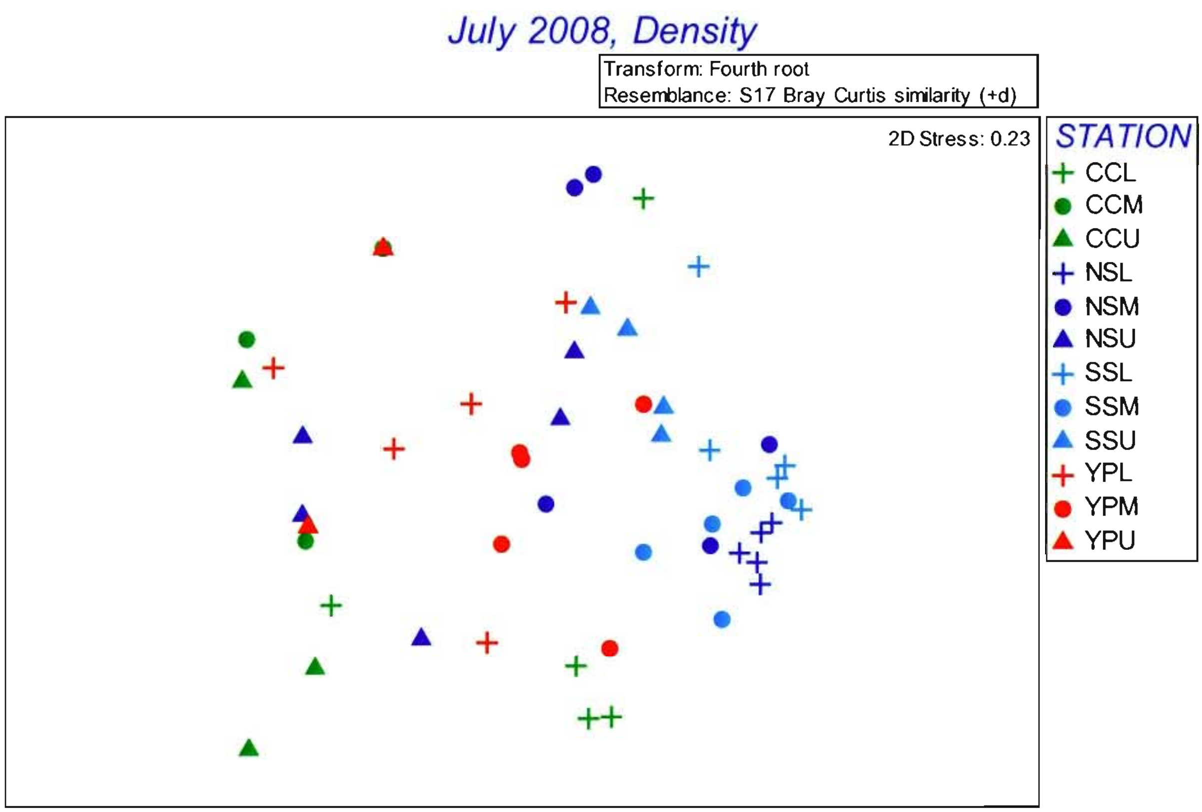
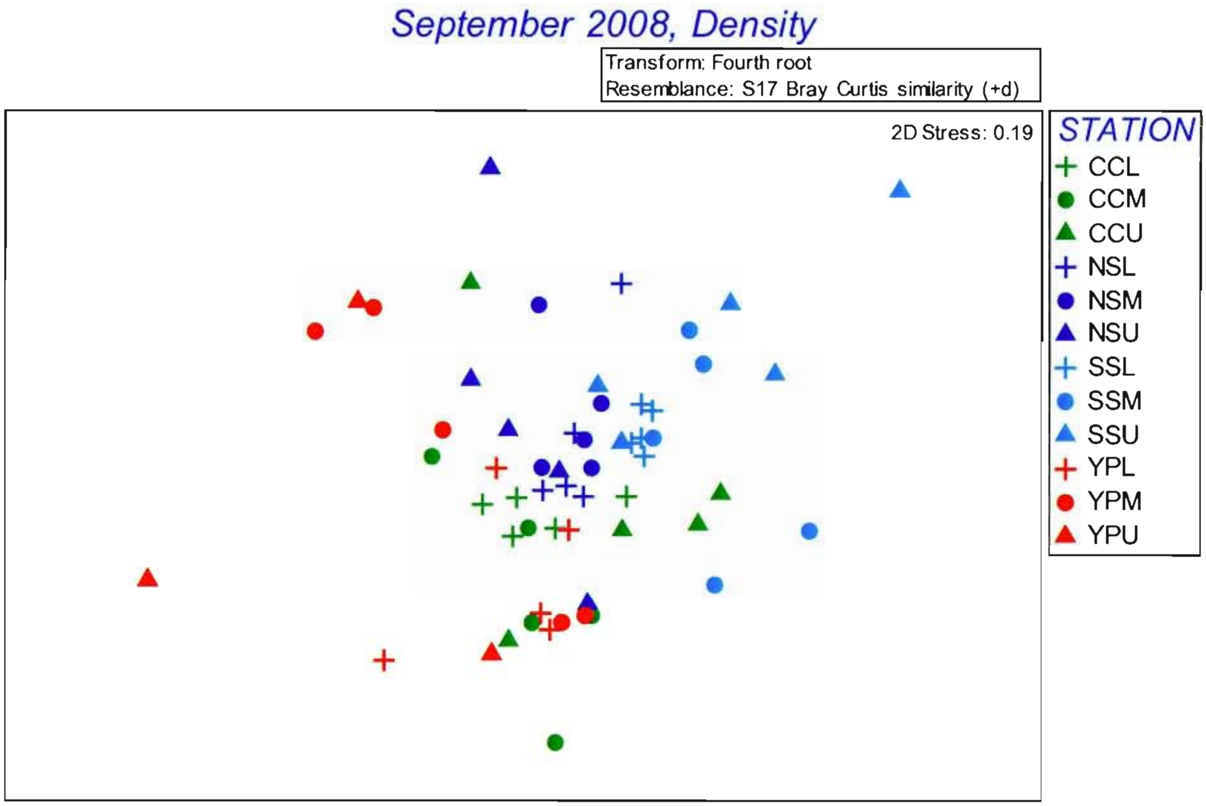


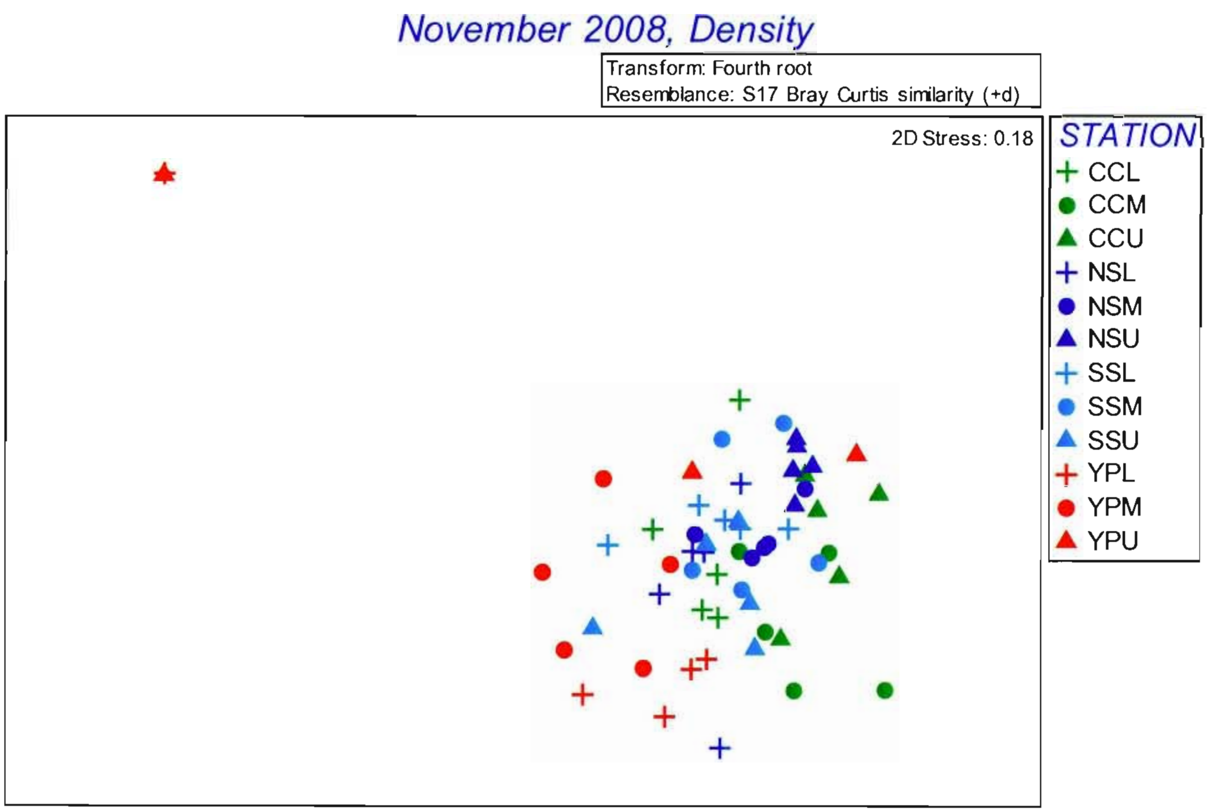
Figure C.5. Temporal patterns of length and density for *Gambusia holbrooki* (gambusia, Fish Code 1011).

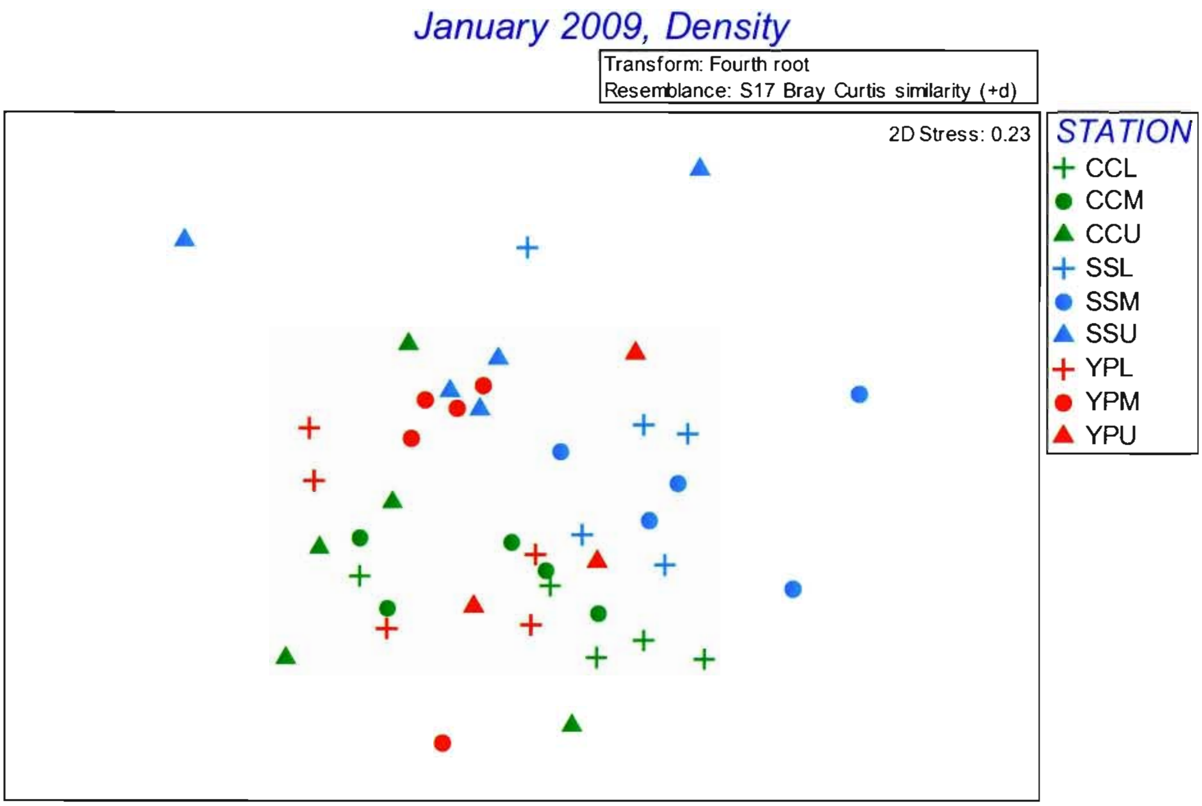
Appendix D – Temporal Patterns of Fish Community

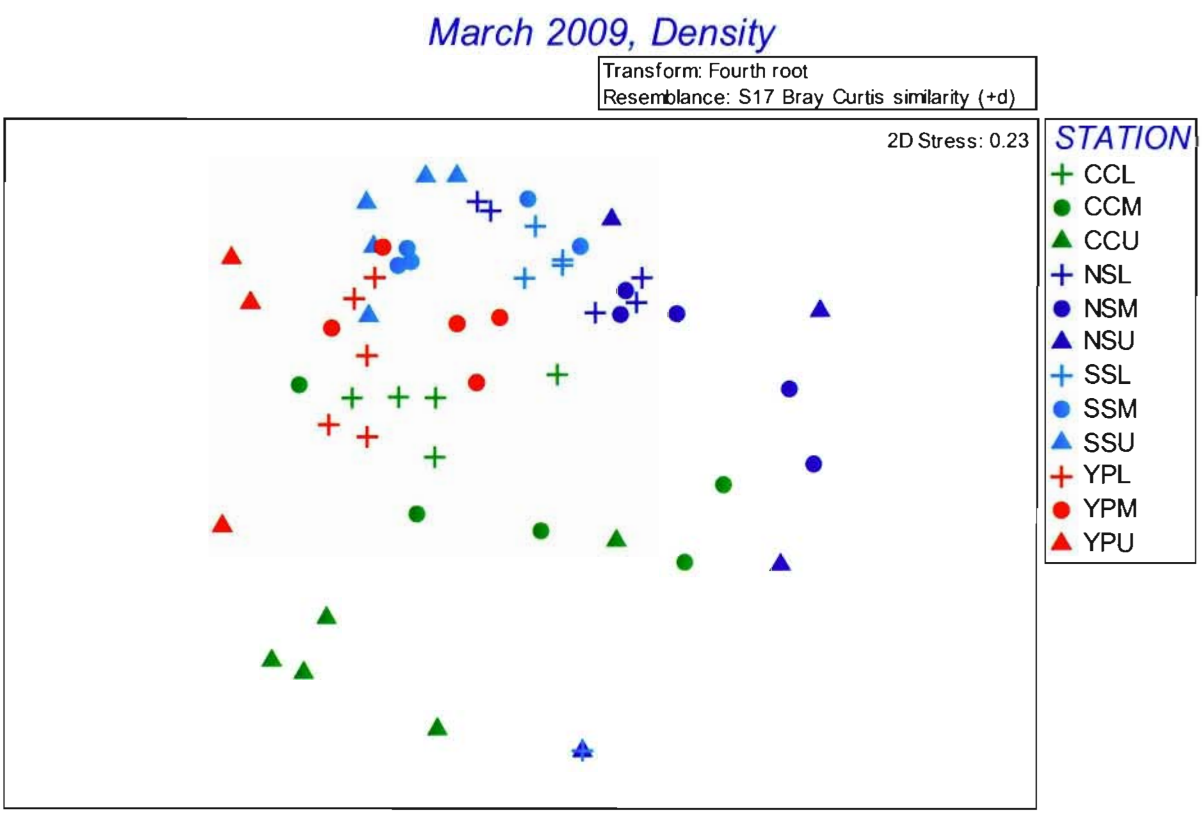

May 2008, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.2
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU

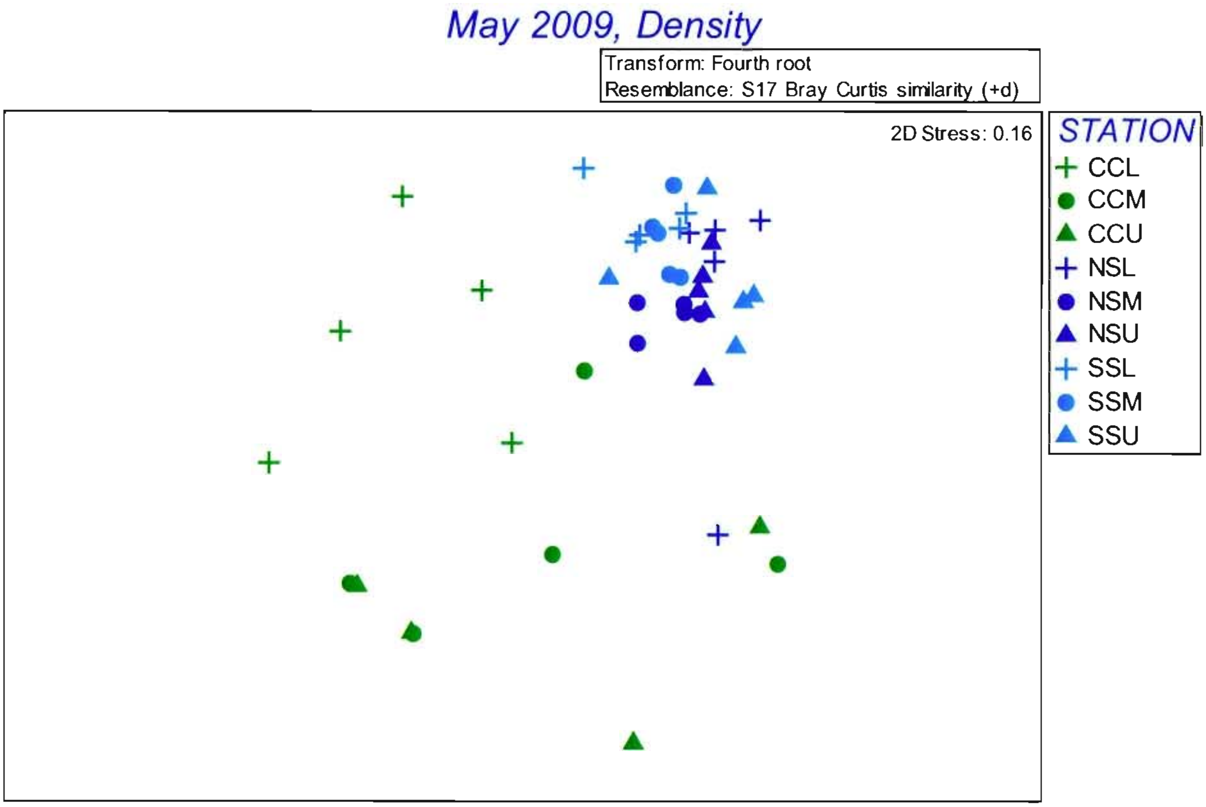

July 2008, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.23
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU

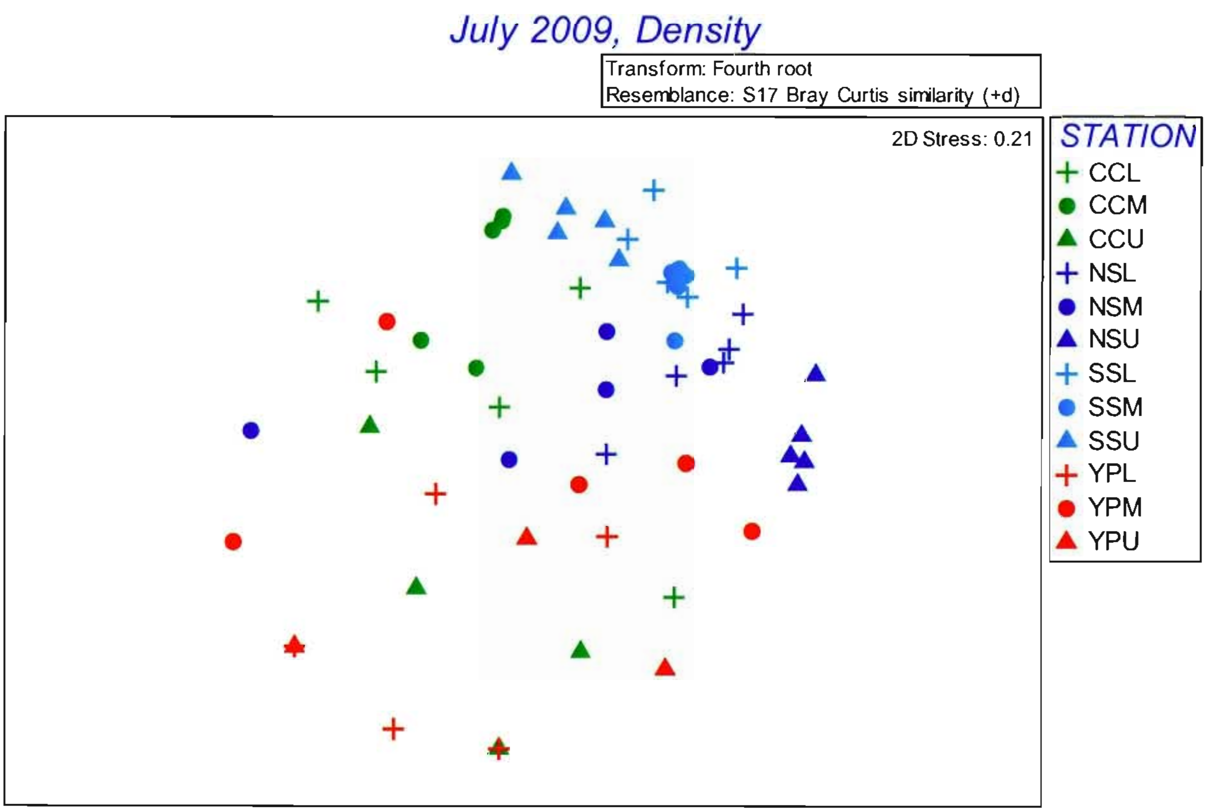

September 2008, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.19
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU

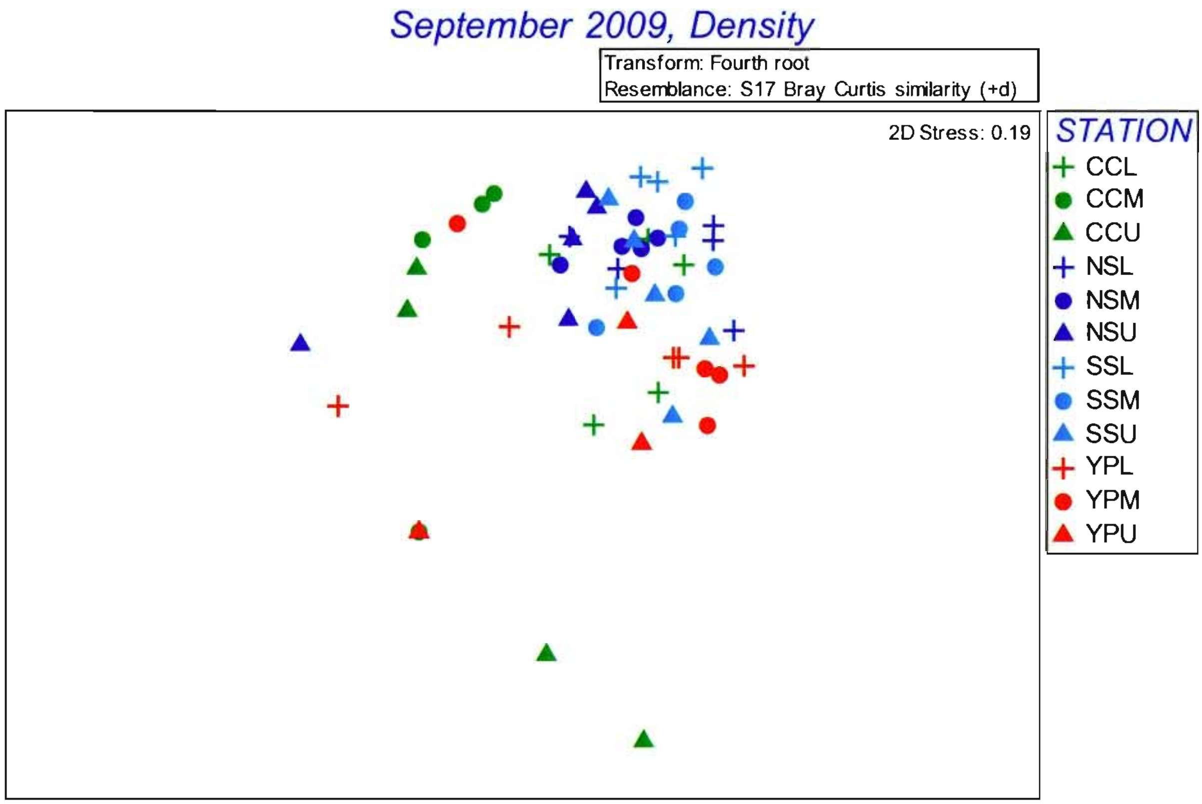

November 2008, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.18
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU


January 2009, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.23
STATION
CCL
CCM
CCU
SSL
SSM
SSU
YPL
YPM
YPU


March 2009, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.23
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU


May 2009, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.16
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU


July 2009, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.21
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU


September 2009, Density
Transform: Fourth root
Resemblance: S17 Bray Curtis similarity (+d)
2D Stress: 0.19
STATION
CCL
CCM
CCU
NSL
NSM
NSU
SSL
SSM
SSU
YPL
YPM
YPU