Evaluating the effects of restoration of subtropical oligohaline marshes on abundance and habitat use by juvenile snook, *Centropomus undecimalis* and associated fish communities.

Final Report to

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NOTE: This project was designed to measure creek fish assemblages in two types of creeks – creeks with significantly degraded upland drainages, and creeks with slightly altered upland drainages – and to determine the effect of habitat restoration in the upland drainages of the latter creeks on juvenile snook and other fishes. This would have provided a relatively rare before-after comparison of restoration effects. However, Florida Department of Environmental Protection did not conduct the restoration as planned. Thus, this report focuses on the effect of upland habitat degradation on mangrove creek fish assemblages in Charlotte Harbor.

Introduction

Florida's southwest coastline has been drastically altered for development, water management, agriculture, mining, and mosquito control purposes (references cited in Lin and Beal, 1995; Poulakis et al., 2002). 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 and tidal marshes. During the dry season, wet prairies and hydric hammocks dry-out, seasonally removing the corridor between upland salt ponds and tidal marshes. In larger drainage systems, tidal creeks remain connected to the upland salt-water ponds.

Anthropogenic alterations of freshwater flows into estuaries are of particular concern to resource managers because such changes impact estuarine ecology (Sklar and Browder, 1998;

reviewed in Beach 2002). Freshwater flow is a major ecological structuring factor in estuaries, influencing abundance and distributions of vegetation, and of invertebrates and vertebrates that use estuaries for some or all of their life cycles. The increase in impervious surfaces and loss of wetland habitats associated with coastal development alter the source, timing, and velocity of freshwater flows, which influences salinity patterns (Sklar and Browder 1998). Whereas some organisms can tolerate wide ranges in salinity, most species have narrow salinity tolerances or migrate to remain in a preferred salinity range (Montague and Ley 1993, Sklar and Browder 1998), thus altering habitat use patterns. When > 10% of a watershed's acreage is converted to impervious surface, the water bodies become seriously degraded, and are less diverse, productive, and stable (reviewed in Beach 2002). Lower organism abundances, lower recruitment, and shifts in dominant species often result from high pulses in freshwater runoff (Sklar and Browder 1998, reviewed in Beach 2002, Beever and Chamberlain 2002, Wyda et al. 2002). With 25% of United States coastal habitats expected to be developed by 2025 (14% of coastal habitats had been developed by 2002) (Beach 2002), there is an exigent need to understand how habitat alterations impact fishes so that appropriate conservation and management measures can be enacted. This is especially true in Florida, with one of the fastest growing populations in the United States.

Relative to many other estuaries Charlotte Harbor habitats remain in good condition – much of the mangrove shoreline is intact and government owned, and seagrass coverage has not changed significantly in ten years of monitoring. Increasingly rapid coastal development, however, threatens to alter the estuary's watershed, thus altering freshwater flow into the estuary. In fact, habitat-associated effects of such alterations are becoming evident in some locations. This combination of unaltered and altered habitats makes Charlotte Harbor a perfect location for studying the effects of habitat alteration on fish-habitat interactions, and formulating management strategies to conserve estuarine habitats.

Although the decline in coastal fish populations has largely been attributed to overfishing, degradation of fish nursery habitats has likely increased larval and juvenile mortality and thus contributed to population declines. Oligohaline creeks and upland salt-water ponds are essential habitats for many young-of-the-year marine finfish and shellfish (McMichael et al., 1989; Peters et al., 1998; Baltz et al., 1998; Geary et al., 2001; Poulakis et al., 2002). The recruitment success of many tropical estuarine fishes, such as snook, *Centropomus undecimalis* and tarpon, *Megalops atlanticus* that have evolved life-histories based on a wet/dry season depend greatly upon access to oligohaline marshes (Poulakis et al., 2002); the recruitment of snook and tarpon larvae to creeks and ponds coincides with the wet season, when they are able to ride high tides into the flooded uplands. The shallowness of creeks and isolation of ponds in the dry season provides protection from predation by large fishes. As they grow and undergo ontogenetic shifts in diet and habitat requirements, these fishes migrate downstream (and eventually to the open estuary and ocean), spending portions of their life history in creek and estuarine habitats. Degradation of these juvenile habitats is of special concern giving the significant economic importance of these species in the saltwater recreational fishery (statewide, the Florida saltwater recreational fishery is estimated to be worth $8.5 billion annually).

Research to determine the effects of upland development and subsequent alterations of freshwater flow on estuarine fishes is urgently needed. This is especially true for juvenile life stages of economically important species, such as common snook, *Centropomus undecimalis* and red drum, *Sciaenops ocellatus*, that comprise the recreational fishery that generates approximately $8.5 billion annually in Florida. This research examined habitat use patterns of juvenile snook and red drum, and of the overall creek fish assemblages in two types of creeks – those with altered upland drainages (degraded), and those with relatively undeveloped drainages (natural) – to determine the effects of freshwater flow alterations. This research tested three hypotheses:

- H_1: Oligohaline creeks are important juvenile habitats for juvenile snook and red drum
- H_2: Degraded upland habitats alter freshwater flow that degrades the habitat quality of estuarine mangrove creeks as juvenile habitats for snook and red drum
- H_3: Degraded upland habitats alter freshwater flow that degrades the habitat quality of estuarine mangrove creeks, and these changes are reflected in creek fish assemblages

Methods

Study Location

Charlotte Harbor is a 700 km^2 coastal plain estuarine system in southwest Florida (Hammett 1990) (Figure 1). The Peace, Myakka, and Caloosahatchee rivers, as well as many smaller creeks throughout the drainage, transport large amounts of the fresh water into the harbor. The harbor is connected to the Gulf of Mexico through Boca Grande Pass, San Carlos Bay, and three smaller inlets. The climate of Charlotte Harbor is subtropical; mean seasonal water temperatures range from 12º to 36º C, and freezes are infrequent (Poulakis et al. 2003). Anthropogenic development within the watershed has stressed the estuarine system; however, compared with many other estuaries (e.g., Chesapeake Bay, Tampa Bay), Charlotte Harbor has remained relatively unspoiled (> 80% of mainland shorelines under protection; R. Repenning, Florida Department of Environmental Protection, pers. comm.; Hammett 1990; CHNEP 1999). Seagrass flats (262 km^2; Sargent et al. 1995) and mangrove shorelines (143 km^2; L. Kish, Florida Fish and

Wildlife Research Institute, unpubl. data) continue to thrive as the dominant habitats within the estuary.

Sample Design

From February 2003 through October 2004, four mangrove-fringed estuarine creeks, each approximately 2 km long, on the eastern shoreline of Charlotte Harbor, FL (Figure 1) were sampled every other month using a 22 x 1.2 m center bag seine with 3.2 mm mesh. Each creek was divided into three equal strata (upper, middle, lower) for sampling, with five samples per stratum, and thus 15 samples per creek, per sample period. Sample locations within each creek stratum 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 (standard length) and the remainder counted, and temperature, salinity, and dissolved oxygen recorded with a handheld YSI 556 MPS. All fish were returned to the water at the site of capture.

All creeks are within the same estuarine hydrological zone (Poulakis et al. 2003), so are unlikely to differ greatly in larval supply. For the purposes of this study, the two northernmost creeks were considered 'natural': their morphology remains largely intact except for remnant mosquito ditches (compared to 1953 aerial photos), and their upland drainages are undeveloped. Creek widths range from 2 m 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 bottom is mixed mud and sand. The submerged aquatic vegetation in the upper stratum is entirely *Ruppia maritima*, whereas the middle and lower strata are dominated by *Halodule wrightii*. The two southern creeks, located 16 km south of the natural creeks, are considered ‘degraded’: their drainages and wetlands have been altered for development, creating impervious surfaces and altering freshwater flow regimes. The altered flow regimes cause short, pulsing hydroperiods limited to the immediate creek with little overland sheet flow. The bottoms are mostly hard sand, and the submerged aquatic vegetation (*R. maritima* and *H. wrightii*) is patchy and limited to the lower two-thirds of the creeks. 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, and greatly reduced width of the intertidal mangrove prop root habitat.

Data Analysis

Taxa were defined as residents (R), transients (T), and juveniles (J), based upon frequency of occurrence, habitat requirements (Robins et al. 1986) and dominant life stage when in the creeks: residents were present in > 200 samples (N = 547) and had creek-associated habitat requirements, transients were marine or estuarine species able to use numerous habitats and present in < 201 samples, and taxa were classified as juveniles when > 90% of individuals captured were juveniles. Taxa were defined as freshwater (F) or non-native (N) based upon Robins et al. (1986) and Page and Burr (1991).

Mean density (no. fish/m^2) and frequency of occurrence (total number of samples in which the taxon occurred) were calculated by creek and zone for each taxon, and examined using cluster analysis (standardized, Average linkage method, Euclidean distance) to determine the extent of (dis)similarity among fish assemblages in the different creeks (Wilkinson et al. 1996). If the classification of creeks based upon apparent habitat quality was correct, the expectation was that creeks would be most similar within type (i.e., North Silcox and South Silcox zones would group together (natural creeks), and Culvert Creek and Yucca Pen would group together (degraded creeks)).

Density and frequency of occurrence for the most abundant non-native species, *Cichlasoma urophthalmus*, were examined by creek to determine the extent that presence of this species differed by creek type (natural vs degraded). Frequency of occurrence and abundance were examined graphically to determine the extent that freshwater and non-native species occurrence were related to salinity (data were insufficient (i.e., no freshwater or invasive species were captured in most samples) to warrant regression analysis). Since frequency of occurrence and abundance were low for these species, data were summed for all species within each group. For non-native species, *C. urophthalmus* were excluded from regression analysis because of their extreme salinity tolerance in their native range (0 – 26ppt, Morales-Gómez et al. In Press).

To determine whether creek characteristics influenced use of creek habitats by juvenile *C. undecimalis* and *S. ocellatus*, density data were examined by creek and zone. Because many samples contained no individuals of these species, density data did not meet normality assumptions required for parametric analysis, so densities were examined separately by creek and zone with Kruskal-Wallis non-parametric ANOVA (Sokal and Rohlf 1995). Lengths (measured as standard length) of *C. undecimalis* and *S. ocellatus* were log-transformed and examined with a two-way ANOVA, with creek and zone as factors. Because no C. undecimalis or S. ocellatus were captured in the upper zone of Yucca Pen, Yucca Pen was excluded from this analysis (The effect of salinity on size distributions of *C. undecimalis* and *S. ocellatus* were examined with linear least squares regression. Length data were log-transformed prior to analysis.

Effects of hurricane Charley

In August 2004, Category 4 hurricane Charley traversed Charlotte Harbor, the eastern eyewall passing over the study creeks. Sampling of the natural creeks was completed 3 days pre-hurricane, and was repeated from 13 through 21 days post-hurricane. Normal sampling in natural and degraded creeks resumed in October, 2 months post-hurricane.

Results

Salinity (Figure 2), temperature (Figure 3), and dissolved oxygen (Figure 4) varied seasonally. Seasonal trends for each variable were similar among creeks. Salinity maxima and minima occurred in degraded creeks. Yucca Pen experienced the longest periods of low salinity (in eight of ten sample periods, salinity was < 10 ppt in middle and lower zones). Surface and bottom salinity, temperature, and dissolved oxygen were similar, so were combined for analysis. When salinity was compared by creek and zone, there were significant creek and zone effects (Table 1, Figure 5), but the trend was similar in all creeks – salinity decreased from lower to upper zones. Temperature differed among creeks, but not by zone (Table 1, Figure 6), whereas dissolved oxygen varied differed by creek and zone (Table 1, Figure 7). Dissolved oxygen minima occurred in the degraded creeks. Temperature and dissolved oxygen were negatively correlated for North Silcox (Pearson $r^2 = -0.34$, $p < 0.001$, df = 1), South Silcox ($r^2 = -0.57$, $p < 0.001$, df = 1), and Yucca Pen ($r^2 = -0.41$, $p < 0.001$, df = 1), but not for Culvert Creek ($p > 0.1$). Salinity and temperature were weakly negatively correlated for South Silcox ($r^2 = -0.28$, $p < 0.01$, df = 1) and Yucca Pen ($r^2 = -0.22$, $p < 0.05$, df = 1), but not for Culvert Creek or North Silcox ($p > 0.1$). Salinity and dissolved oxygen were positively correlated for the natural creeks (North Silcox $r^2 = 0.30$, $p < 0.001$, df = 1; South Silcox $r^2 = 0.44$, $p < 0.001$, df = 1), but not for the degraded creeks

($p > 0.1$).

A total of 205,992 fish representing 79 taxa (fishes were identified to the lowest taxon possible, resulting in assignation of individuals to 60 species, 14 genera, and 5 families) was captured in 547 samples (Table 2). Of these taxa, 27 were classified as residents, 10 as transients, 18 as juveniles, 12 as freshwater species, and four as non-native species. The seven most abundant species were residents, and were present in all creeks. Juveniles of recreationally important *Centropomus undecimalis* and *Sciaenops ocellatus* were ranked 10 and 14 in total abundance, respectively, and were also captured in all creeks. The most abundant invasive species, *Cichlasoma urophthalmus*, was ranked 26 in total abundance, higher than the native freshwater taxon, *Lepomis* sp., which was ranked 32 in total abundance, although both groups were recorded in all creeks.

Density of all species combined and species richness tended to be greater in the natural creeks (North Silcox and South Silcox) than in the degraded creeks (Culvert Creek and Yucca Pen) during the wet season, and similar during the dry season (Figure 8). When species densities and frequency of occurrence by creek and zone were examined with cluster analysis, fish assemblages in natural creeks were most similar to one another, and most dissimilar to degraded creeks (Figure 9).

Although freshwater species were captured in all months, trends in abundance and frequency of occurrence coincided with the wet season, with peaks in June, August, and September (Table 3, Figure 10). Both total abundance ($R^2 = 0.49$, $p < 0.01$) and frequency of occurrence ($R^2 = 0.46$, $p < 0.01$) of all freshwater species combined were negatively related to salinity. The most common freshwater fishes were *Lepomis* spp and *Micropterus* spp. (Figure 11), which were captured mostly in salinities < 6ppt (*Lepomis* spp. mean salinity at capture =

3.51, se = 0.56; *Micropterus* spp. mean salinity = 5.93 ppt, se = 1.69). *Lepomis* spp were seasonally present in all creeks, and were most abundant in South Silcox (38% of *Lepomis* spp. individuals), followed by North Silcox (29%), Culvert Creek (26%), and Yucca Pen (7%). *Micropterus* spp were present seasonally only in Yucca Pen (62% of *Micropterus* spp. individuals) and Culvert Creek (38%).

Non-native species were not captured in samples until August 2003 (the fourth sample period of the study). Although there was no relationship between salinity and abundance ($p > 0.1$) or frequency of occurrence ($p > 0.1$) of non-native species, their seasonality of occurrence followed high freshwater flows associated with the wet season. The most common and most abundant non-native species was Mayan cichlid, *Cichlasoma urophthalmus,* which occurred in all creeks but was most abundant in Culvert Creek (Table 4), and was captured in all months after August 2003. *Oreochromis mossambicus* and *Hemichromis bimaculatus* were present seasonally in low abundance only in North Silcox and South Silcox creeks: each species was captured in August 2003, *O. mossambicus* was captured again in October 2003, and February and June 2004, and *H. bimaculatus* again in June 2004.

Juvenile *C. undecimalis* were captured in all months, and occurred in all zones in North Silcox, South Silcox, and Culvert Creek, but were absent from the upper zone and rare in the middle zone of Yucca Pen (Figure 12). Temporal trends in density varied among creeks and zones. Densities differed when examined by creek and zone (Table 5). Within creeks, densities tended to be highest in the lower zone and least in the upper zone in Culvert Creek, Yucca Pen, and North Silcox. This trend was reversed in South Silcox. Within zones, densities were similar among all creeks in the lower zone, but were highest in South Silcox and least in Yucca Pen in middle and upper zones (snook were absent and rare in upper and middle zones, respectively, of

Yucca Pen). There was no relationship between salinity and *C. undecimalis* abundance or size ($p > 0.1$).

Samples were dominated by small *C. undecimalis* in all creeks (Figure 13), with post-settlers occurring in late summer and early fall. Although there was a significant creek x zone interaction effect (Table 6), all creeks exhibited the same trend in size – lengths were greatest in the middle zone (Figure 14). (Yucca Pen was removed from length analyses because no juveniles were captured in the upper zone, and relatively few were captured in middle and lower zones.)

Juvenile *S. ocellatus* were captured almost entirely from October through February, and were in greater densities in North Silcox and South Silcox than Culvert Creek and Yucca Pen in all zones (Figure 15, Table 7). Juvenile *S. ocellatus* were rare or absent from upper zone of Culvert Creek and Yucca Pen. Within creeks, the trend was for densities to be greatest in the lower zone and least in the upper zone. Although there was no significant relationship between *S. ocellatus* density and salinity, within each creek between 72% and 87% of samples that contained juvenile *S. ocellatus* were in salinities between 10 and 28 ppt.

Samples were dominated by small *S. ocellatus* (Figure 16), with post-settlers first present in October. In Culvert Creek and Yucca Pen, where *S. ocellatus* were less abundant, fish size was positively related to salinity (CC – $R^2 = 0.57$, $F = 121.64$, $p < 0.001$: YP – $R^2 = 0.27$, $F = 30.199$, $p < 0.001$), but there was no such relationship in North and South Silcox creeks ($p > 0.1$). Yucca Pen was removed from length analysis because of very low or no catches in all zones. The significant creek x zone interaction effect (Table 8) was due primarily to increases in size from lower to upper zones in Culvert Creek and North Silcox, whereas fish size was similar in all zones of South Silcox (Figure 17).

Effects of hurricane Charley

Sampling of natural creeks was completed 3 days pre-hurricane, was repeated from 13 through 21 days post-hurricane. Normal sampling in natural and degraded creeks resumed in October, 2 months post-hurricane. Hurricane Charley might be considered an acute disturbance because its direct effects (high winds, rainfall, storm surge) lasted < 12 hr. However, low dissolved oxygen from decomposition of leaves from defoliated mangroves lasted for > 1 wk. Thus, Charley is defined as a press disturbance (Glasby and Underwood 1996, Lake 2000). Above-water impacts were severe, with all mangrove branches > 6 m height completely defoliated or broken and partial defoliation of shorter mangroves. Within creeks, damage included scouring of narrow sections of creeks, moderate redistribution of sediments, complete loss of SAV, high turbidity, and reduction of dissolved oxygen to > 1 ppm (purportedly due to mangrove leaf decomposition).

The direct effects (high winds, rainfall, storm surge) of Hurricane Charley lasted < 12 hr. Above-water impacts were severe, with all mangrove branches > 6 m height completely defoliated or broken and partial defoliation of shorter mangroves. Within creeks, damage included scouring of narrow sections of creeks, moderate redistribution of sediments, complete loss of SAV, high turbidity, and reduction of dissolved oxygen to > 1 ppm. Since the low dissolved oxygen (purportedly from decomposition of leaves from defoliated mangroves) lasted for > 1 wk, the indirect effects of the hurricane will likely have greater impact.

The passage of the hurricane was noted by the abrupt decline in species richness and abundance 13 days post-hurricane sampling in natural creeks thus indicating a strong immediate effect (Figure 18). A rapid response was suggested by a rapid recovery of species richness and abundance by 21 days post-hurricane, after dissolved oxygen levels began to recover toward pre-hurricane levels. However, sampling 2 months post-hurricane indicated a delayed response – species richness was similar to pre-hurricane levels, but density declined. The apparent sluggish recovery may indicate a lag effect, whereby effects of physiological stress from depression of DO and salinity and increase in turbidity were delayed. Sampling in the creeks continues so that longer-term hurricane effects can be determined.

Discussion

This research provided urgently needed quantitative information on the affect of habitat degradation on fish assemblages associated with mangrove creeks, and a quantitative estimate on the effect of this degradation on the nursery value of creek habitats for economically important fishes. That the degradation was primarily associated with development of upland drainages of mangrove creeks and associated alterations of freshwater flow into the creeks is especially notable.

Anthropogenic alterations of freshwater flows into estuaries are of particular concern to resource managers because such changes impact estuarine ecology (Sklar and Browder, 1998; reviewed in Beach 2002). Freshwater flow is a major ecological structuring factor in estuaries, influencing abundance and distributions of vegetation, and of invertebrates and vertebrates that use estuaries for some or all of their life cycles. In this study, Culvert Creek and Yucca Pen were considered degraded because their upland drainages have been drastically altered, with an increase in impervious surface. For Yucca Pen, freshwater flows from large upland areas are now funneled into the creek, causing extensive periods of low salinity and making this poor habitat for estuarine fishes (e.g., low abundance and species richness in upper and middle zones). Culvert Creek suffers from the ‘faucet effect’, whereby creek salinities and flow rates fluctuated rapidly with local rainfall: high rainfall (faucet 'on') created near-freshwater conditions the length of the creeks; low rainfall (faucet 'off') allowed mesohaline conditions to creek headwaters. Prior to these alterations, it is likely the hydrologic conditions were similar to those of the natural creeks such that gentle, low, flat slopes provided for slow overland sheet flow of surface waters, which were retained for extended duration within wet and mesic slash pine flatwoods during wet season, but were dry during dry season. The flows caused salinity gradients that provided important habitat for fishes.

The increase in impervious surfaces and loss of wetland habitats associated with coastal development alter the source, timing, and velocity of freshwater flows, which influences salinity patterns (Sklar and Browder 1998). Whereas some organisms can tolerate wide ranges in salinity, most species have narrow salinity tolerances or migrate to remain in a preferred salinity range (Montague and Ley 1993, Sklar and Browder 1998), thus altering habitat use patterns. When > 10% of a watershed's acreage is converted to impervious surface, the water bodies become seriously degraded, and are less diverse, productive, and stable (reviewed in Beach 2002). In this study, it is estimated that the proportion of drainages of Culvert Creek and Yucca Pen have exceeded this 10% alteration threshold. Lower organism abundances, lower recruitment, and shifts in dominant species often result from high pulses in freshwater runoff (Sklar and Browder 1998, reviewed in Beach 2002, Beever and Chamberlain 2002, Wyda et al. 2002). In this study, although the overall temporal trends in salinity, temperature, and dissolved oxygen (DO) in the creeks were similar, the degraded creeks experienced the most extreme variation. These extreme variations likely contributed to the lower habitat quality of the degraded creeks. In addition, salinity and DO minima were lowest in the degraded creeks. The differences in abiotic factors between natural and degraded creeks likely caused the differences in species richness, total fish abundances, and abundances of most species were higher in the natural creeks, thus corroborating previous research elsewhere on the effects of freshwater flow alterations. The lack of submerged aquatic vegetation in the upper and lower zones of the degraded creeks further underscores the effects of freshwater flow alterations.

With 25% of United States coastal habitats expected to be developed by 2025 (14% of coastal habitats had been developed by 2002) (Beach 2002), there is an exigent need to understand how habitat alterations impact fishes so that appropriate conservation and management measures can be enacted, and this study contributes this important information for Charlotte Harbor. Moreover, since Charlotte Harbor resembles much of the Florida coastline in that coastal habitats are being drastically altered for development, water management, and mosquito control, the findings of this research are applicable elsewhere.

Habitat alteration often facilitates invasions by non-native species (Ross 1991, Courtenay and Williams 1992), and this appears to be the case in this study. Habitat quality of mangrove creeks, as defined by the extent of alteration in upland drainages, is an important factor in the invasion success of *Cichlasoma urophthalmus* into Charlotte Harbor. It appears that upland habitat alteration (ponds and canals) may provide refuge from low temperatures and predation, thus harboring source populations for individuals to colonize estuarine habitats. The presence of drainage ditches and artificial ponds that retain oligo- and meso-haline water year-round (prior to anthropogenic alteration these areas were dry during the dry season), may provide sources of recruitment into Charlotte Harbor's estuarine habitats. Based upon the findings of this study, Charlotte Harbor National Estuary Program has recently provided funds to the PI to address questions relating to invasive species in estuarine habitats, including: Does alteration of freshwater flows in upland habitats increase invasion success of *C. urophthalmus* in estuaries?

Are *C. urophthalmus* established in Charlotte Harbor estuarine habitats or do altered upland habitats (artificial ponds and canals) provide upstream sources of new recruits? What invasion avenues are used by *C. urophthalmus* to access Charlotte Harbor estuarine habitats? Once invasion avenues are defined, future restoration efforts can include strategies to interrupt these avenues as part of the restoration process to help reduce the establishment of this species in estuarine habitats. Future research can then begin addressing the extent of the ecological impacts of *C. urophthalmus* on native species.

Abundance and size ranges of juvenile snook and red drum captured during this study indicated that overall habitat use patterns were the same, but that creek-specific characteristics likely influenced the quality of the creeks as juvenile habitats. For example, juvenile red drum were present in similar size ranges in all creeks during the same, distinct time period. In addition, the general trend was for juvenile red drum to move toward the upper zone as they grew. However, the high freshwater flows in Yucca Pen likely caused the absence of juvenile red drum in the upper zone and limited almost all red drum to the lower zone. In Culvert Creek, variable freshwater flows (i.e., the faucet effect) and channelized creek morphology likely limited red drum abundance. In contrast, the moderated freshwater flows and extensive shallow habitats of North and South Silcox creeks appeared to be higher quality habitats for juvenile red drum.

Since the expectation is that habitat degradation can alter spatial and temporal patterns of habitat use by many species, change species composition (reviewed in Sklar and Browder 1998), and lower the quality of nursery habitats, it was expected that the natural creeks would also support more juvenile snook. This was true for Yucca Pen, where high freshwater flows likely limited juvenile snook use of the upper and middle zones. Surprisingly, however, juvenile snook densities were similar among all other creeks. One possible reason for similar densities among creeks is that the difference in habitat complexity between creeks made the snook more catchable in the degraded creeks. The natural creeks had extensive flooded areas of red mangrove prop-roots that were inaccessible to sampling with seines, even at low tide. In contrast, subtidal red mangrove prop root habitat in the degraded creeks was very limited at low tide, so sampling in the degraded creeks was more efficient. In other words, the probability of catching juvenile snook in the degraded creeks was higher than in the natural creeks.

Although not measured in this study, the amount of creek habitat available to juvenile snook was far greater in the natural than degraded creeks (Figure 1). Thus, even if densities of juvenile snook were similar among creeks, the total abundance of snook (density X total creek area) was far greater in North and South Silcox than in Culvert Creek or the lower zone of Yucca Pen.

Habitats that harbor high densities of juveniles have long been defined as nurseries, and with this standard the creeks examined in this study would be considered nursery habitats. However, the extent to which the juveniles grow, survive, and successfully join the adult population must be determined before a habitat can be defined as a nursery. Thus, a more realistic standard for defining nursery habitats is to determine whether juveniles from a particular habitat eventually contribute to the adult populations (i.e., demonstrate habitat connectivity). This latter standard is of most use and of primary concern to resource managers. Therefore, although this study has shown that juvenile snook are present in similar densities in one of the degraded creeks and the two natural creeks, the rate at which these juveniles are successful at surviving to enter the adult population remains unknown. Based upon these findings, research is now underway to determine the extent that these creeks contribute snook to the adult population, and thus determine the true nursery value of these creeks. Determining which creeks contribute more snook to the local population will aid in land acquisition and habitat management. In addition, findings will provide a framework for examining the effects of habitat degradation on juveniles of other species with similar life histories.

Hurricane Effects

The accurate characterization of ecological disturbances such as hurricanes is important for structuring metrics of disturbance effects. The frequency, intensity, and duration provide a measure of the disturbance. The effect is then a measure of the impact of the disturbance on the system (i.e., abiotic and biotic components), and is a measure of resistance (ability of the system to withstand a disturbance, Lake 2000). The response is a measure of the recovery trajectory of the affected system (i.e., resilience – the ability of a system to recover from a disturbance (Lake 2000). Glasby and Underwood (1996) proposed that a system's response be defined in similar terms to the disturbance – as either pulse (quick recovery) or press (slower recovery trajectory). Although the passage of hurricane Charley was considered a pulse disturbance, the extended period of hypoxic and anoxic conditions that affected creek fishes was a press disturbance. Thus, a press response might be expected from the creek fish assemblages.

In addition, interactions between disturbances, or between disturbances and 'normal' fluctuations must also be considered (White and Jentsch 2001). For example, normal seasonality was found more influential on coral reef fish abundances than hurricanes (Letourneur et al. 1993, Adams 2001, Adams and Ebersole 2004). In this study, initial indications were that normal seasonal patterns continued after the immediate post-hurricane fluctuations: total abundance and species richness recovered within three weeks of the hurricane, suggesting a pulse response. To some extent, fishes are able to move out of impacted areas, and to return when conditions improve. This is especially true for fishes with mobile behavior, and less true of sedentary of site attached fishes. Moreover, some fishes may have behavioral adaptations to poor conditions such as those present after hurricanes. For example, dissolved oxygen levels in estuarine wetland and creek habitats are frequently >1.0 mg/L (Smith and Able 2003, this study), and some species have behavioral and physiological adaptations to these conditions (Smith and Able 2003).

However, observations of aquatic surface respiration, a sign of physiological stress from low DO, by fishes during post-storm sampling, and a leveling off of the recovery trajectory in October sampling (2 months post-hurricane) suggest physiological stress, mortality, or long-term emigration due to extended duration of low DO. In addition, sampling in October 2004, and in spring 2005 (not reported in this manuscript) suggest a possible lag in recovery (lower than expected abundance of most species and lower species richness), thus indicating a press response. In addition, disturbance effects differ between natural (e.g., hurricanes) and anthropogenic (e.g., freshwater flow alterations) disturbances (Mackey and Currie 2001). Moreover, anthropogenic disturbances may interact with natural disturbances or alter system responses (White and Jentsch 2001). Continued sampling for one year after hurricane Charley (funded by a grant from National Science Foundation) will provide the data necessary to determine: whether normal seasonal patterns have been influenced by the hurricane (i.e., provide multiple years of pre- and post-hurricane data); if the ecological response was pulse (quick recovery) or press (longer recovery); and the effect of habitat degradation on fish assemblage response to the hurricane.

Management Applicability

Given the increasing populations in many coastal regions, incorporation of anthropogenic impacts should be considered for any appropriately-scaled research or assessments. It is likely that anthropogenic changes will impact habitat types differently, and thus impact fish life stages differently. If resource managers are going to make predictions about the response of coastal ecosystems to anthropogenic changes, the relative effects of anthropogenic changes on different habitats and their associated fishes must be incorporated into their models. This study has underscored the impact of freshwater flow alterations on estuarine habitats and associated species, and thus the importance of addressing this type of habitat degradation in management strategies.

The ability to evaluate the success of habitat restoration projects is of both local and global significance due to widespread habitat loss and diversion of freshwater, and the associated decline in estuarine health. As human populations in coastal areas continue to increase, demands on freshwater resources and coastal habitats will increasingly alter the quantity, quality, and location of freshwater flow, resulting in further degradation of oligohaline systems that provide habitats vital to estuarine and marine species. Quantification of the relationships between flow regimes and habitat quality of oligohaline habitats is essential to long-term management of these areas.

Oligohaline marshes provide a vital link between terrestrial and estuarine systems. As such, strategies for management of upland habitats must consider the implications of management actions on estuarine habitats and species. By defining the effects of freshwater flow alterations on mangrove creek habitats in Charlotte Harbor, this research has provided managers with information needed to improve management plans. In addition, the findings of this research should help guide Florida Department of Environmental Protection's restoration projects in the Charlotte Harbor Aquatic and State Buffer Preserve. How the restoration is implemented will influence how the sheet flow of fresh water over these areas will impact downstream areas, including mangrove and marsh habitats used as nurseries by estuarine fishes.

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List of Figures

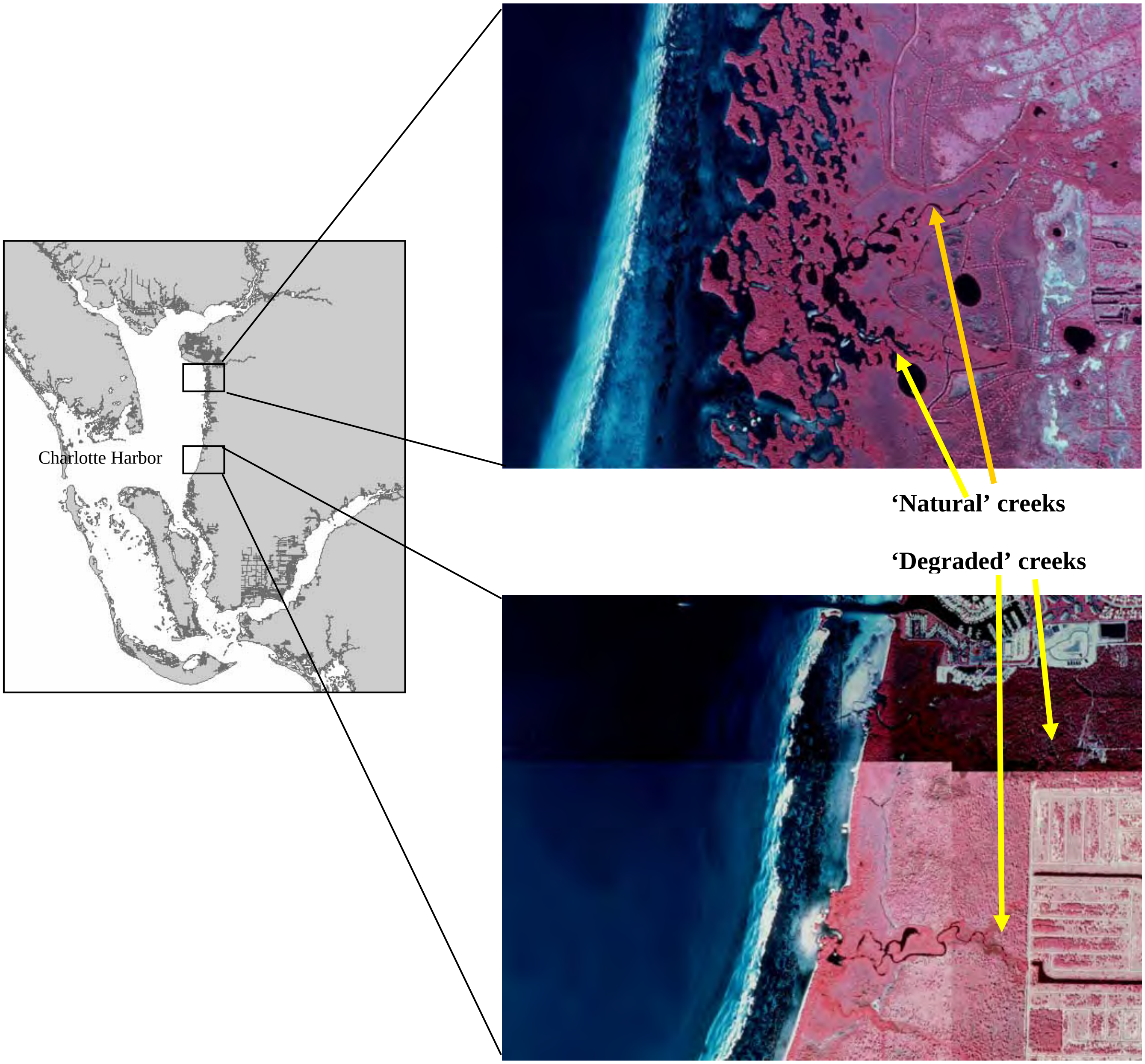


Figure 1.

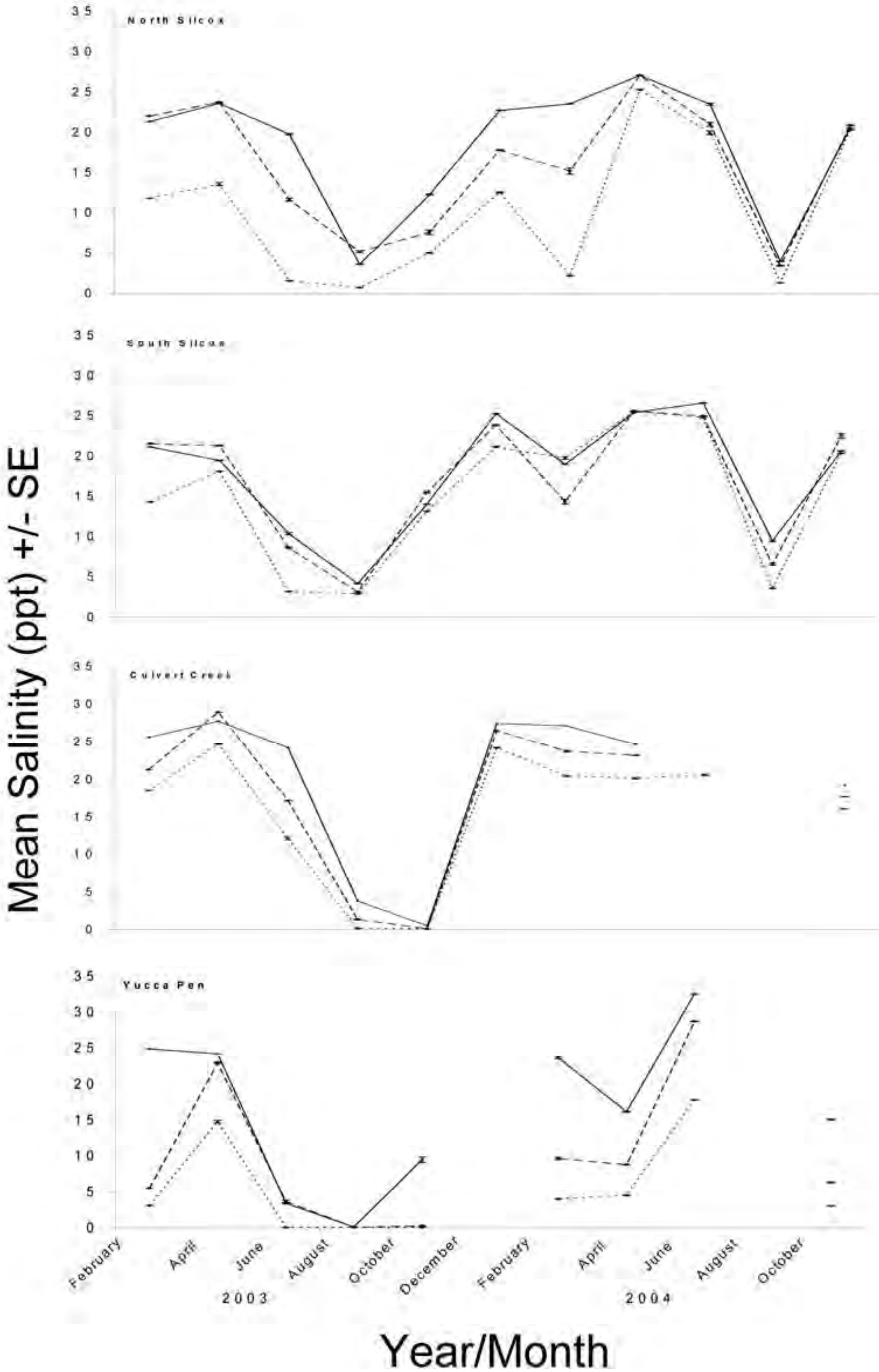

North Silcox
South Silcox
Culvert Creek
Yucca Pen
Mean Salinity (ppt) +/- SE
February
April
June
August
October
December
February
April
June
August
October
2003
2004
Year/Month

Figure 2.

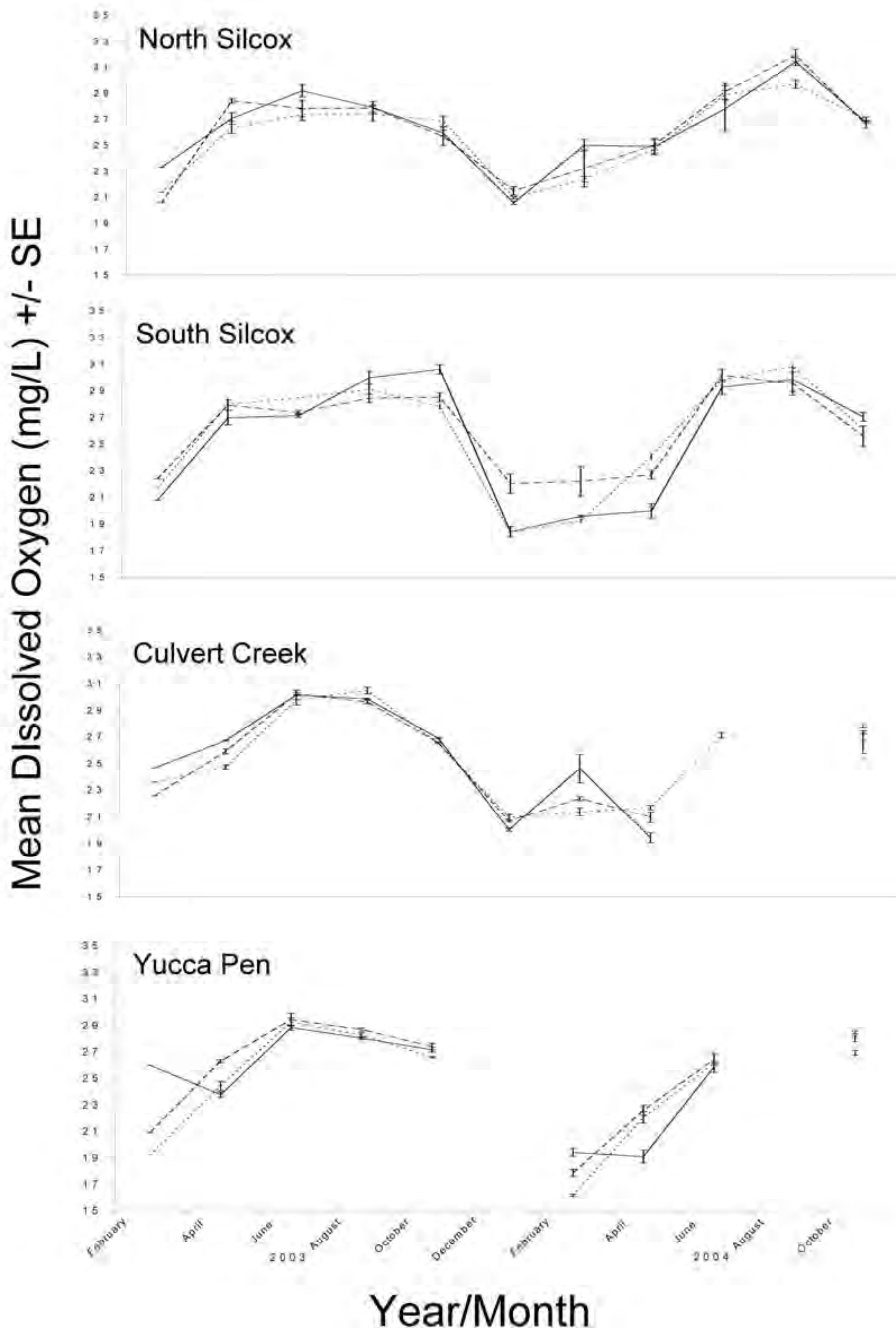

Mean Dissolved Oxygen (mg/L) +/- SE
North Silcox
South Silcox
Culvert Creek
Yucca Pen
February
April
June
August
October
December
February
April
June
August
October
2003
2004
Year/Month

Figure 3.

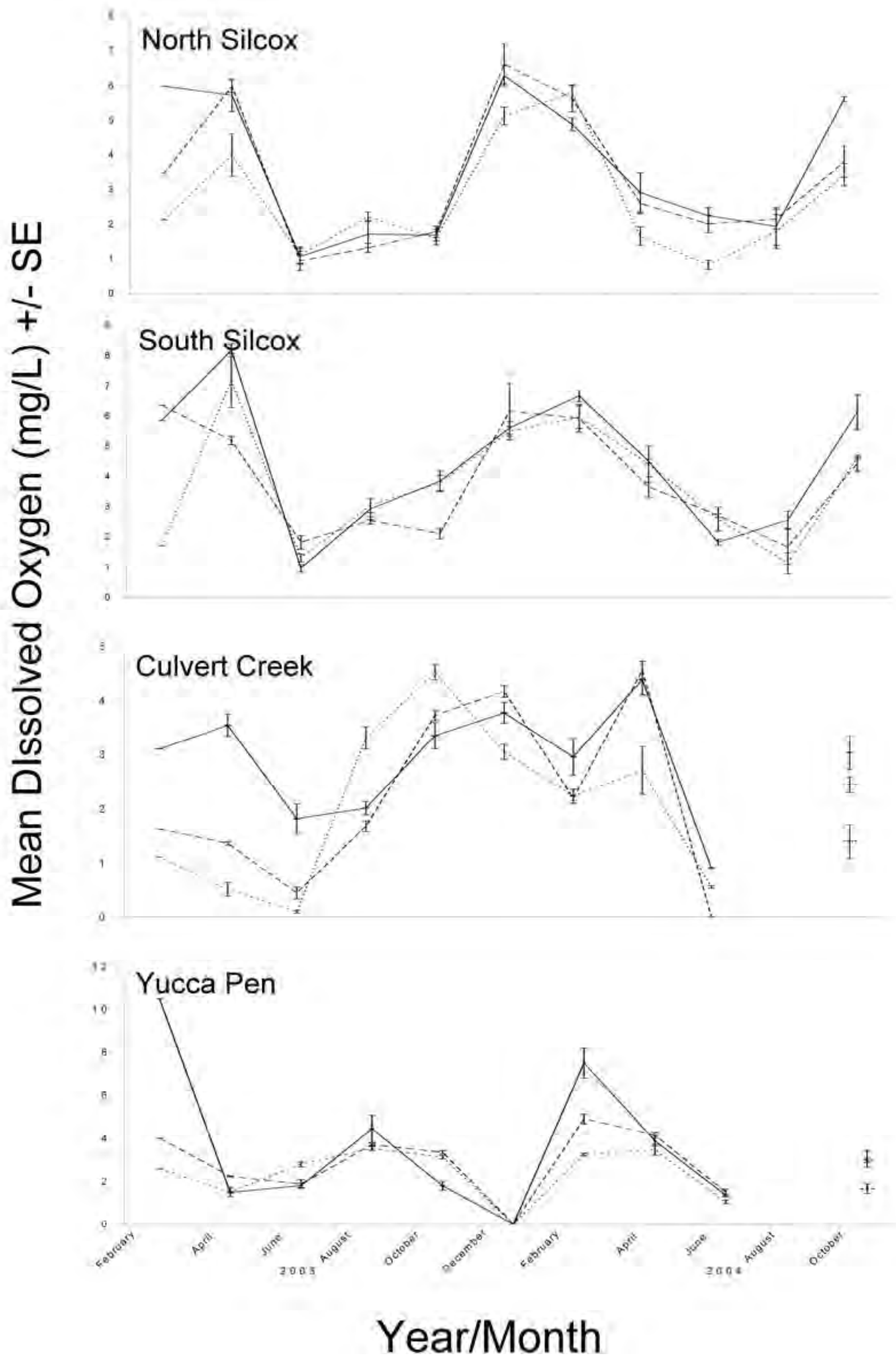

North Silcox
South Silcox
Culvert Creek
Yucca Pen
Mean Dissolved Oxygen (mg/L) +/- SE
Year/Month
2003
2004
February
April
June
August
October
December
February
April
June
August
October

Figure 4.

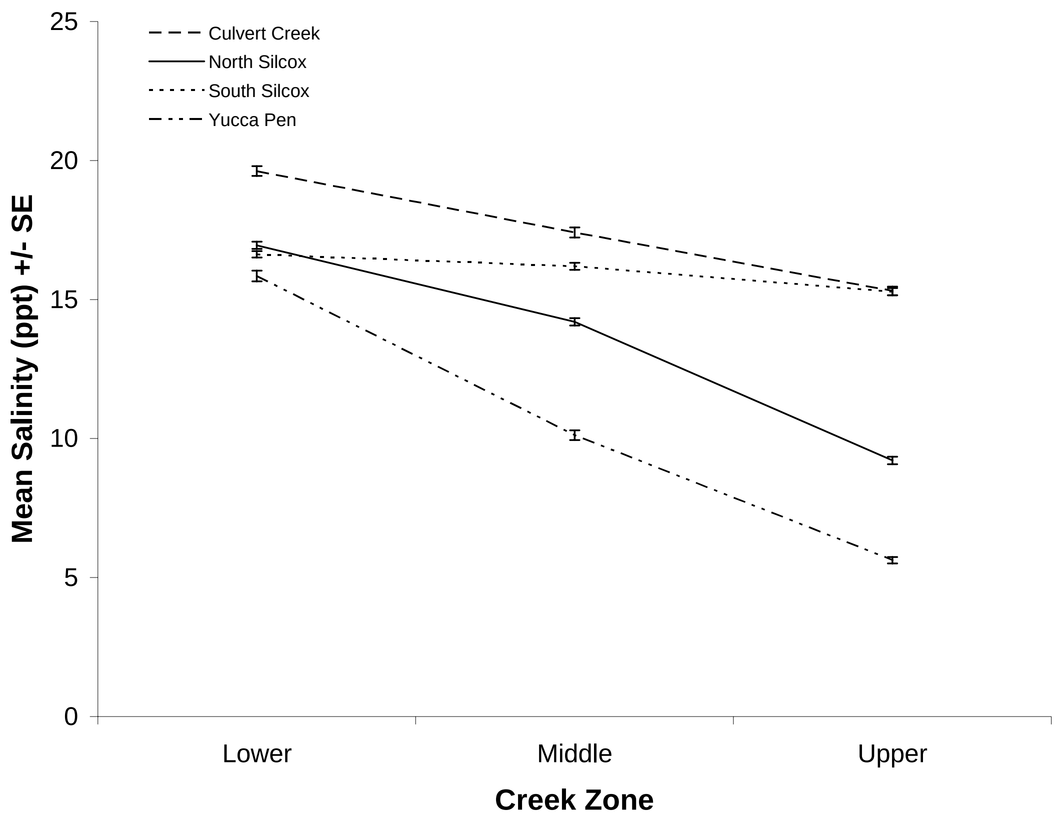

25
20
15
10
5
0
Culvert Creek
North Silcox
South Silcox
Yucca Pen
Mean Salinity (ppt) +/- SE
Lower
Middle
Upper
Creek Zone

Figure 5.

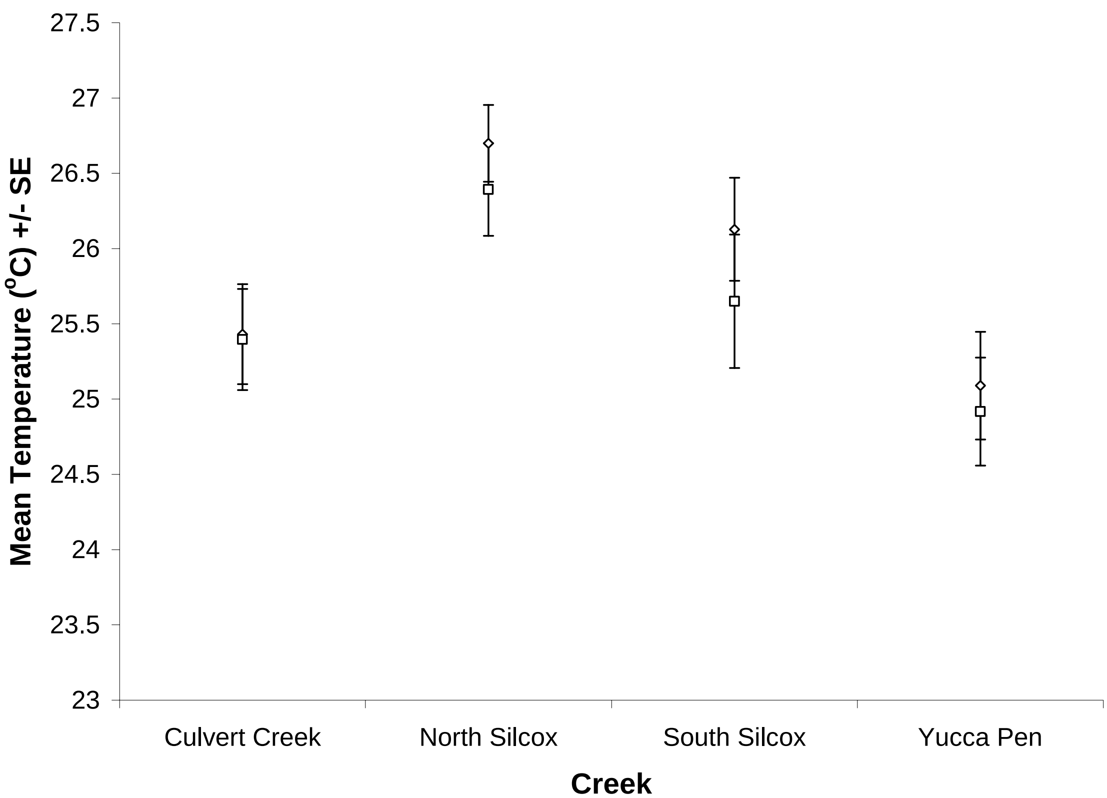

27.5
27
26.5
26
25.5
25
24.5
24
23.5
23
Mean Temperature (oC) +/- SE
Culvert Creek
North Silcox
South Silcox
Yucca Pen
Creek

Figure 6.

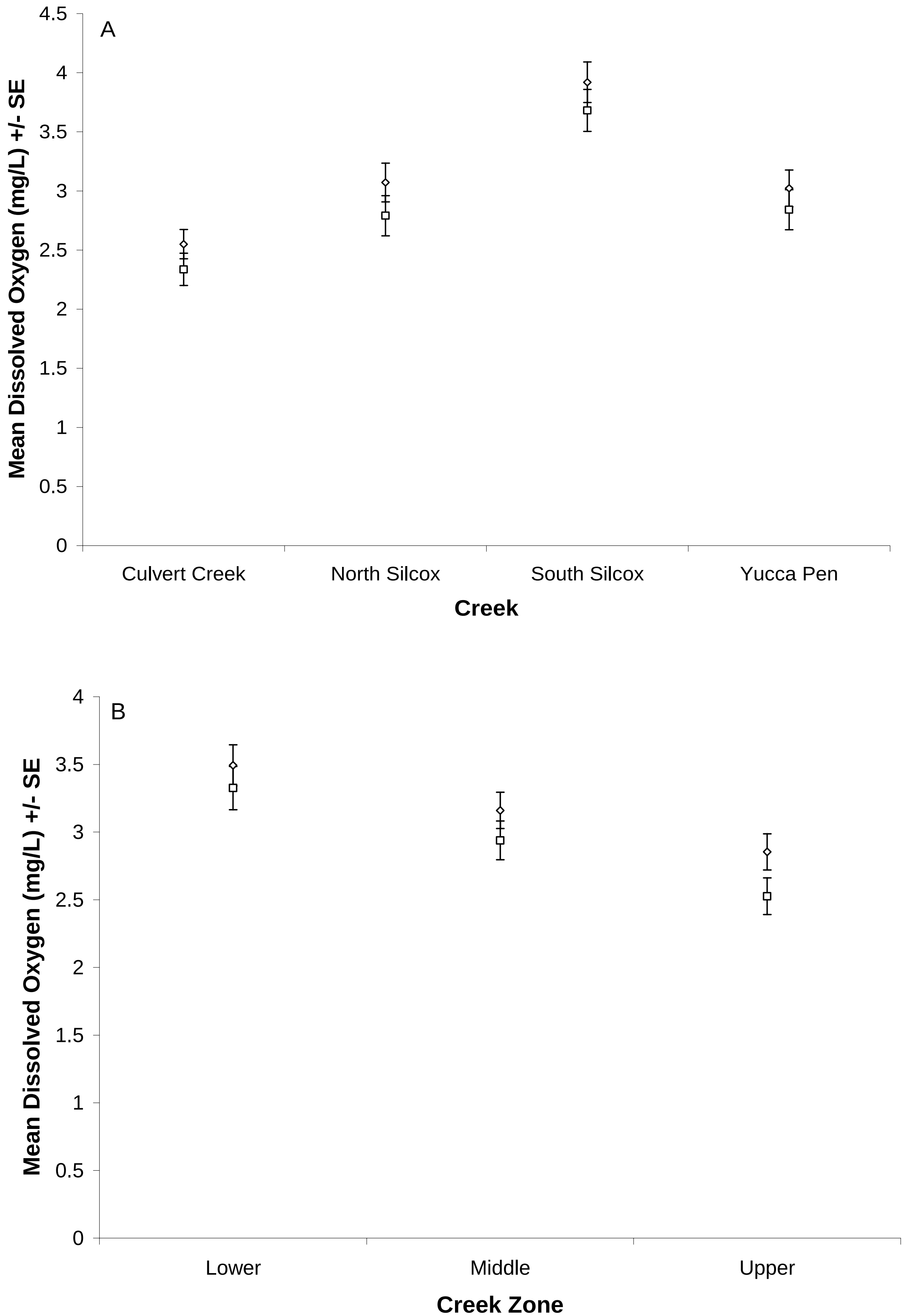
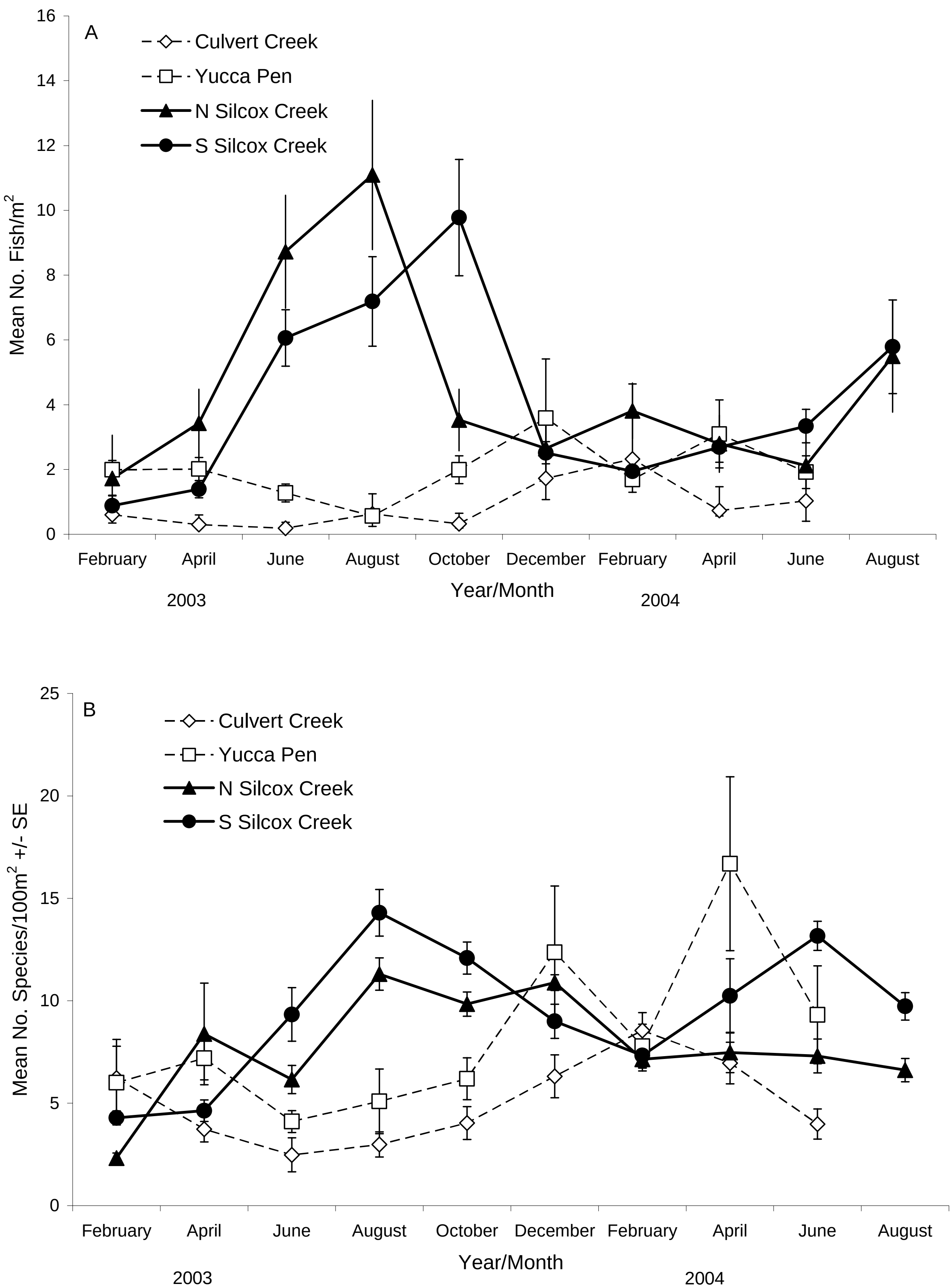

A
B
Mean Dissolved Oxygen (mg/L) +/- SE
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Culvert Creek
North Silcox
South Silcox
Yucca Pen
Creek
Lower
Middle
Upper
Creek Zone

Figure 7.



A
Culvert Creek
Yucca Pen
N Silcox Creek
S Silcox Creek
Mean No. Fish/m2
0
2
4
6
8
10
12
14
16
February
April
June
August
October
December
February
April
June
August
Year/Month
2003
2004
B
Culvert Creek
Yucca Pen
N Silcox Creek
S Silcox Creek
Mean No. Species/100m2 +/- SE
0
5
10
15
20
25
February
April
June
August
October
December
February
April
June
August
Year/Month
2003
2004

Figure 8.

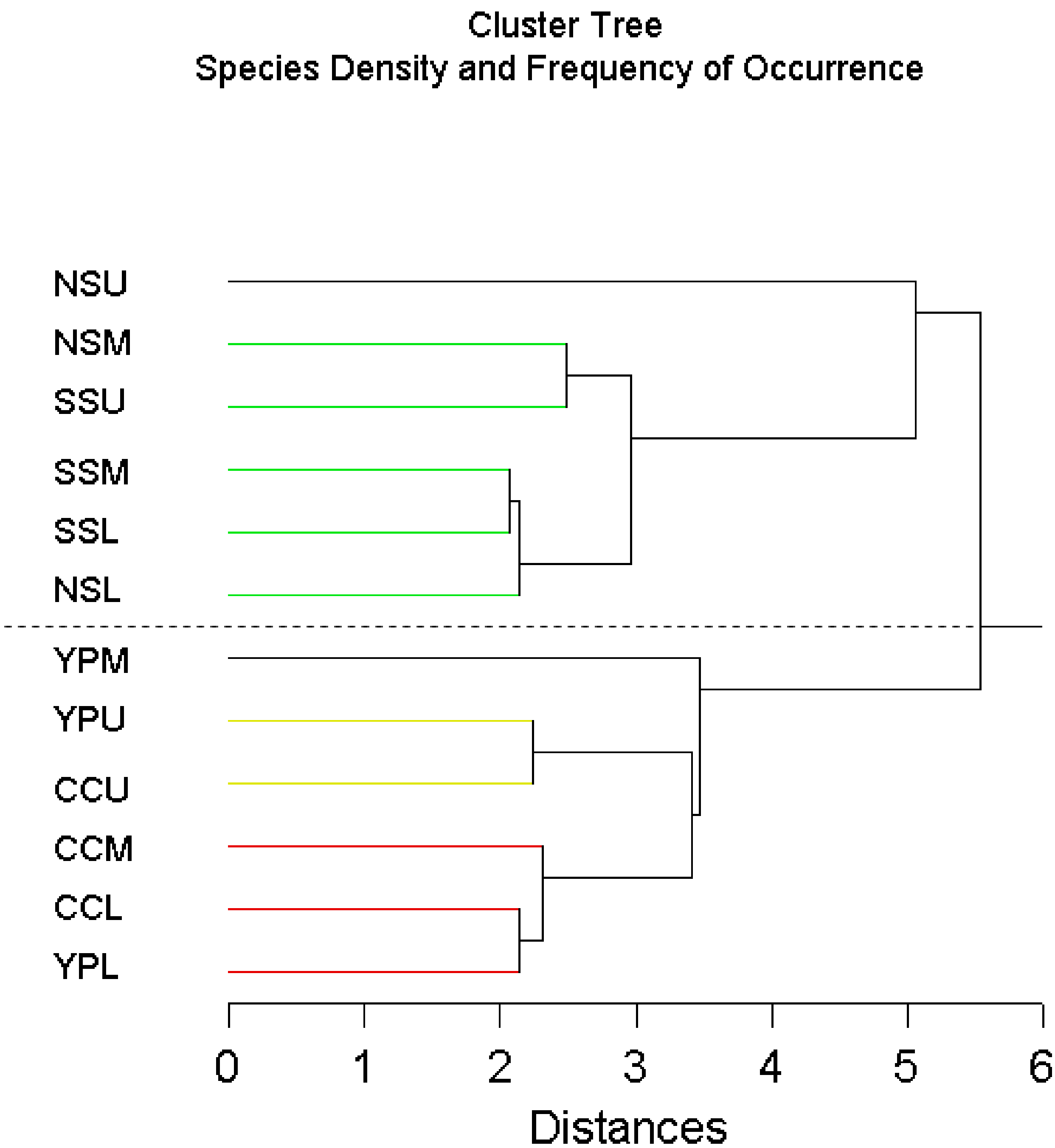
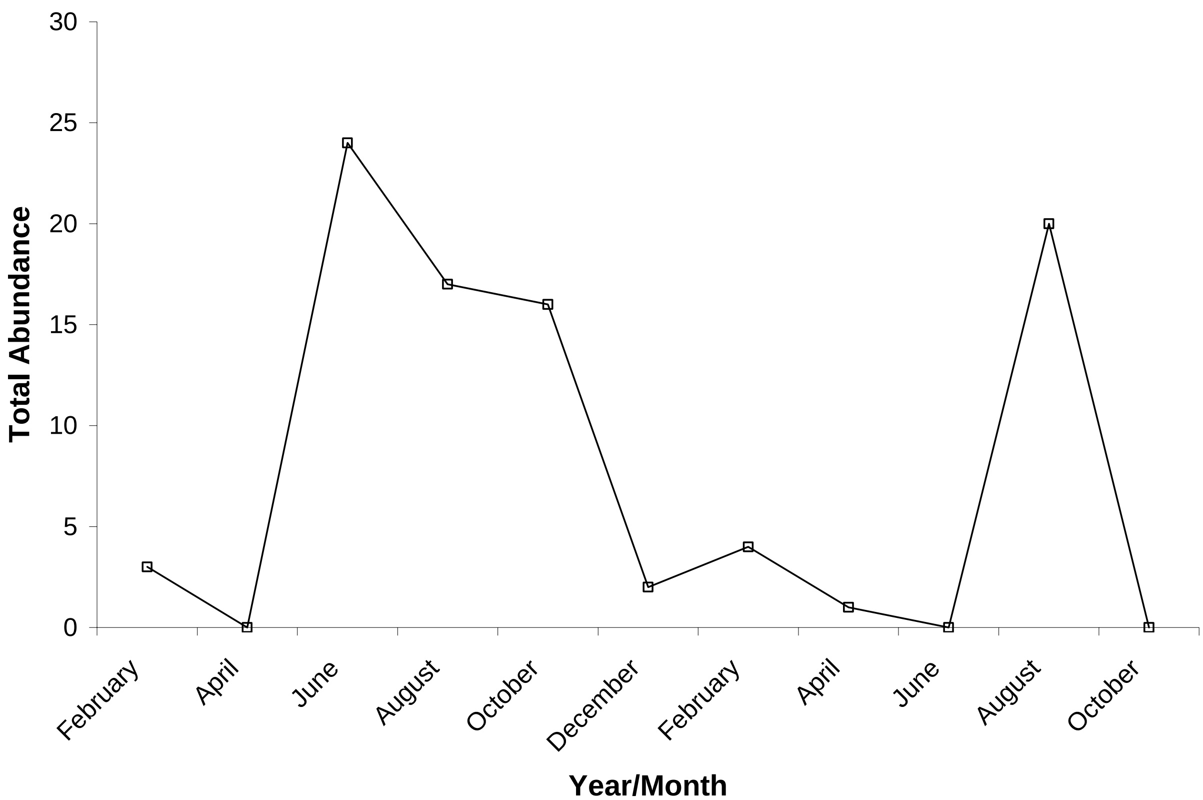

Cluster Tree
Species Density and Frequency of Occurrence
NSU
NSM
SSU
SSM
SSL
NSL
YPM
YPU
CCU
CCM
CCL
YPL
0
1
2
3
4
5
6
Distances

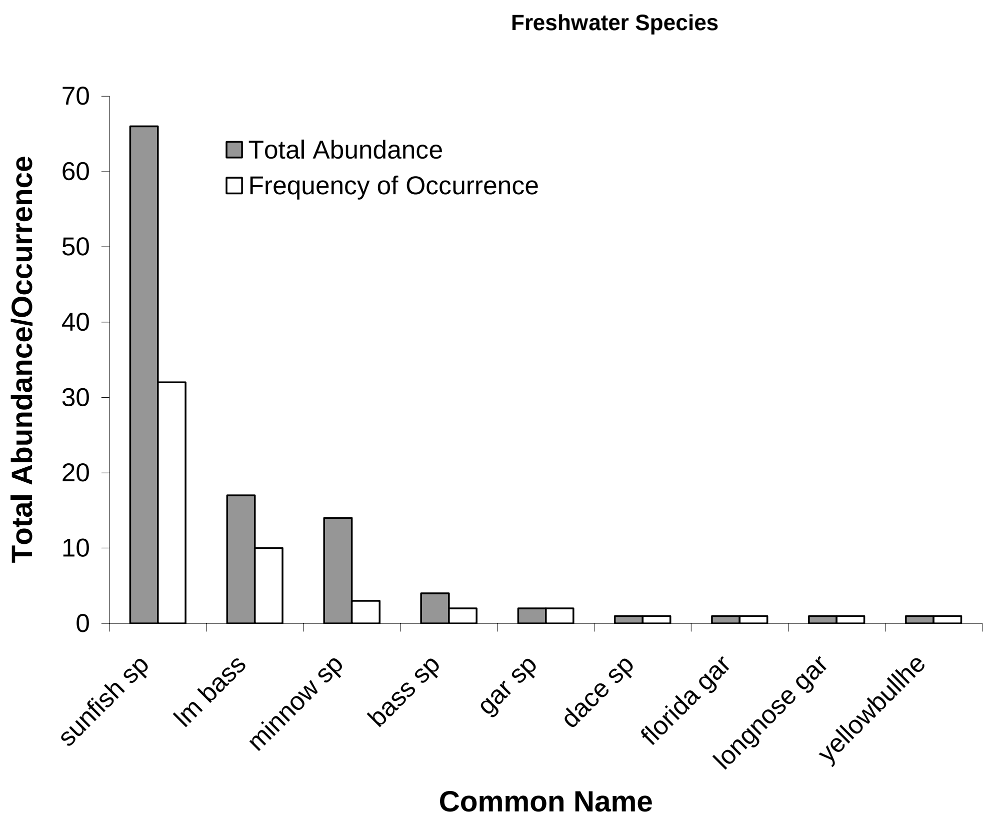
Figure 9.

Figure 10.



30
25
20
15
10
5
0
Total Abundance
February
April
June
August
October
December
February
April
June
August
October
Year/Month

Figure 11.



Freshwater Species
70
60
50
40
30
20
10
0
Total Abundance/Occurrence
Total Abundance
Frequency of Occurrence
sunfish sp
lm bass
minnow sp
bass sp
gar sp
dace sp
florida gar
longnose gar
yellowbullhe
Common Name

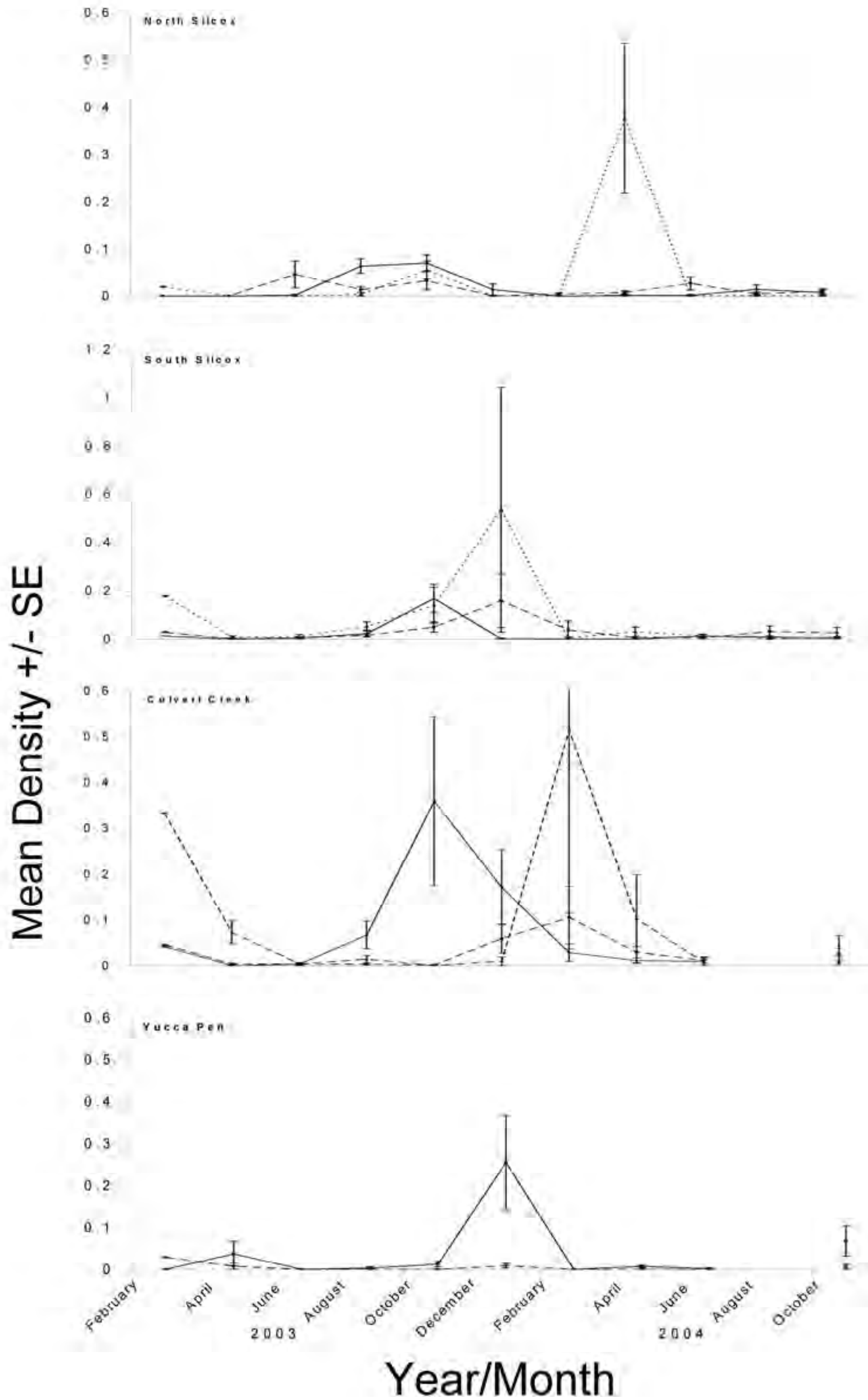

North Silcox
South Silcox
Calvert Creek
Yucca Pen
Mean Density +/- SE
February
April
June
August
October
December
February
April
June
August
October
2003
2004
Year/Month

Figure 12.

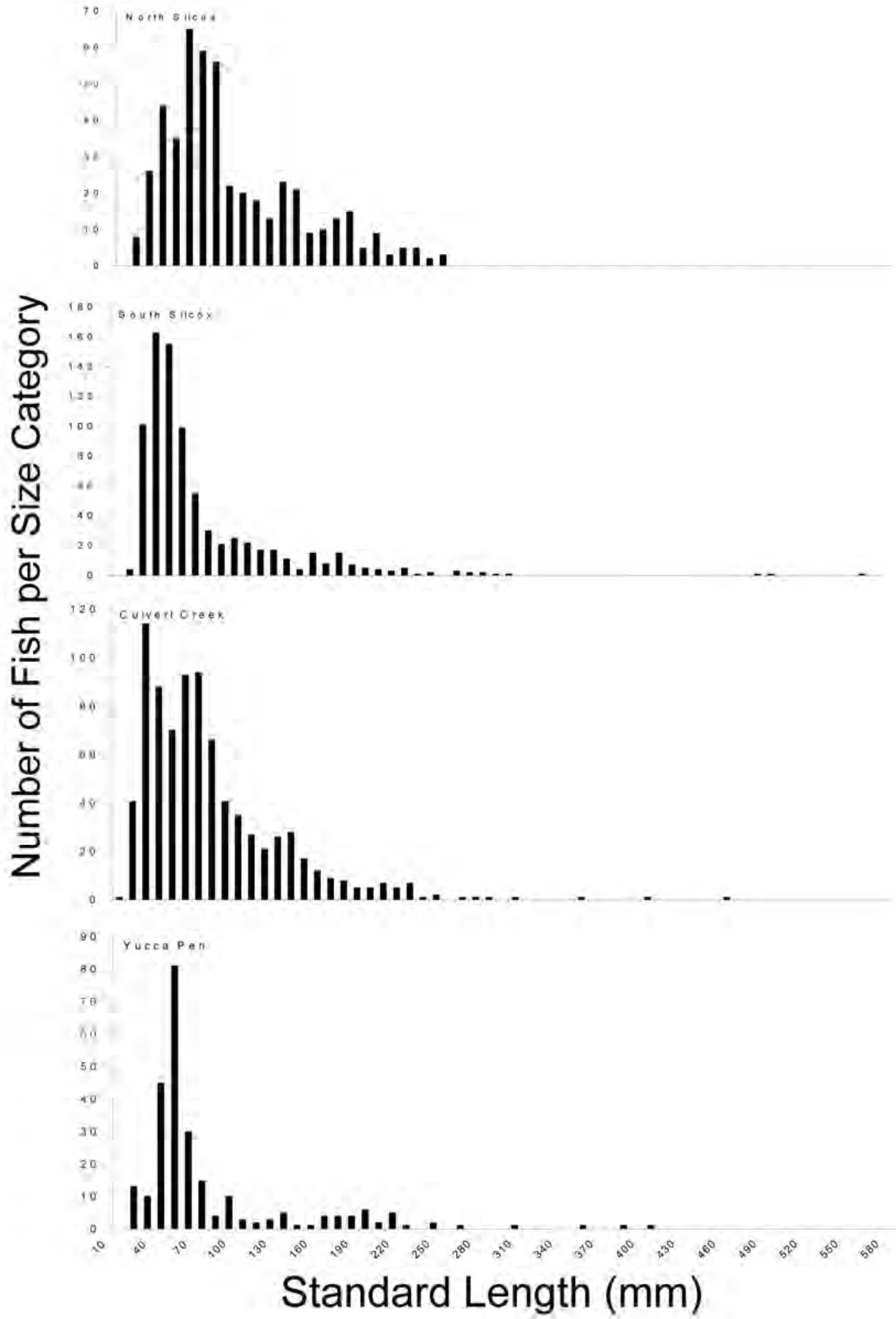
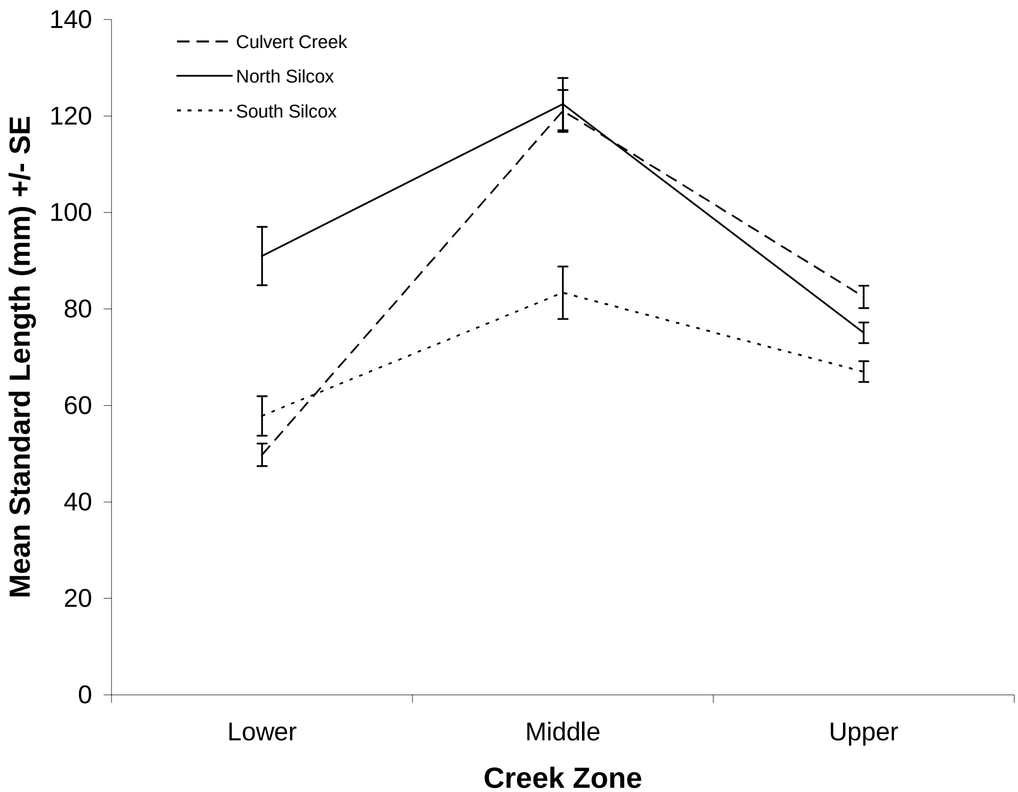

North Silcox
South Silcox
Culvert Creek
Yucca Pen
Number of Fish per Size Category
Standard Length (mm)

Figure 13.

Figure 14.



140
120
100
80
60
40
20
0
Culvert Creek
North Silcox
South Silcox
Mean Standard Length (mm) +/- SE
Lower
Middle
Upper
Creek Zone

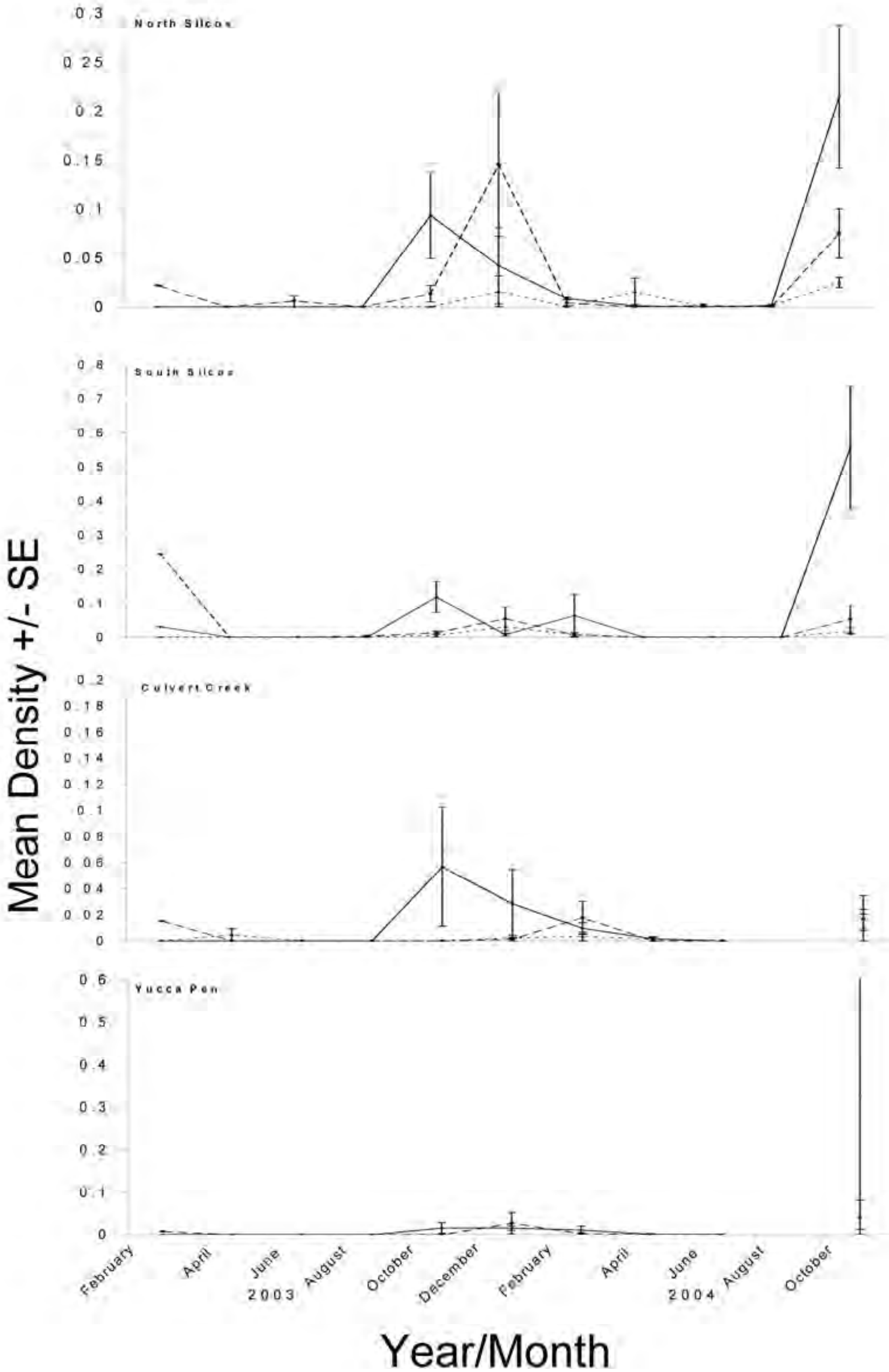

North Silcox
South Silcox
Culvert Creek
Yucca Pen
Mean Density +/- SE
February
April
June
August
October
December
February
April
June
August
October
2003
2004
Year/Month

Figure 15.

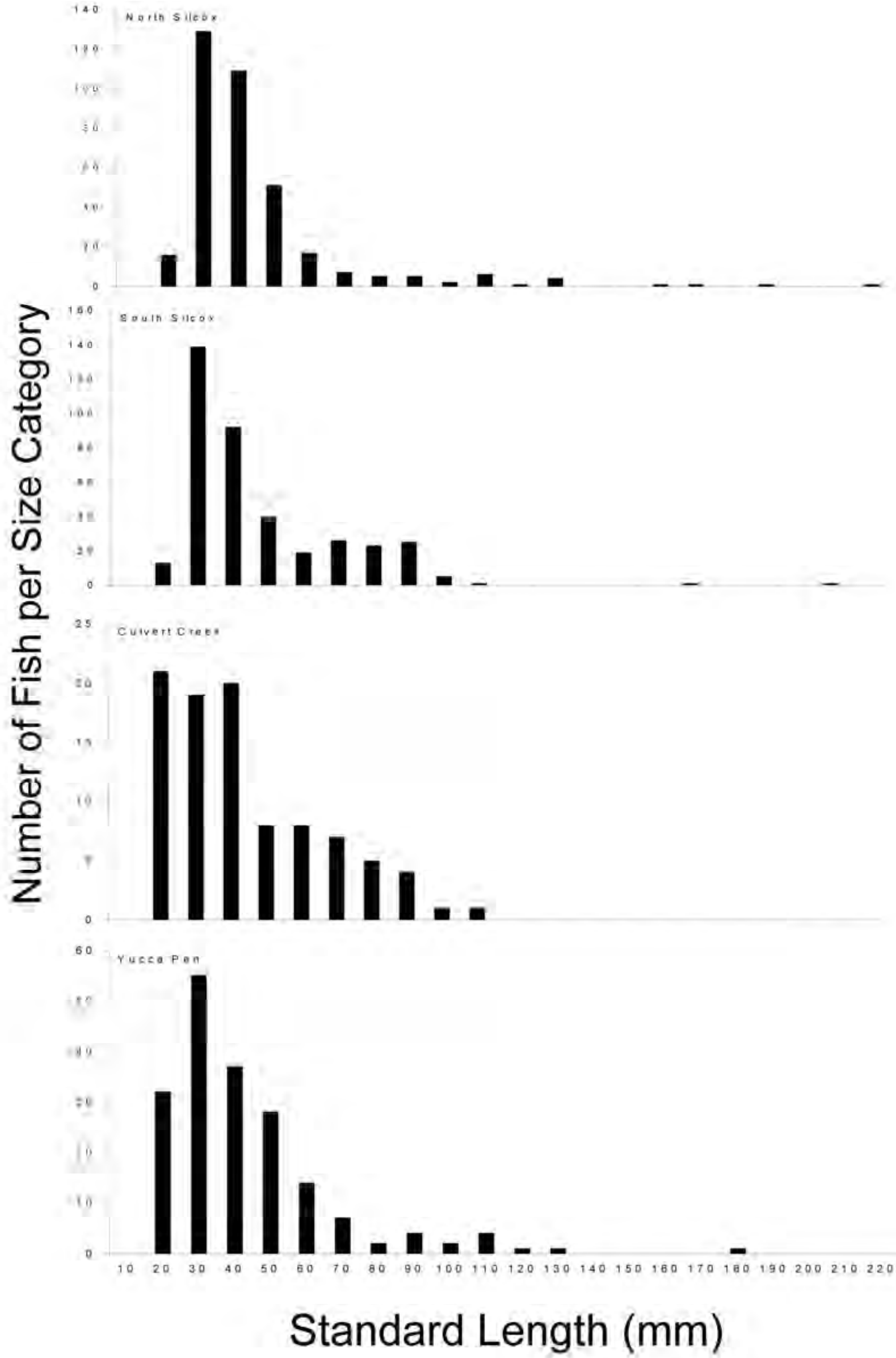
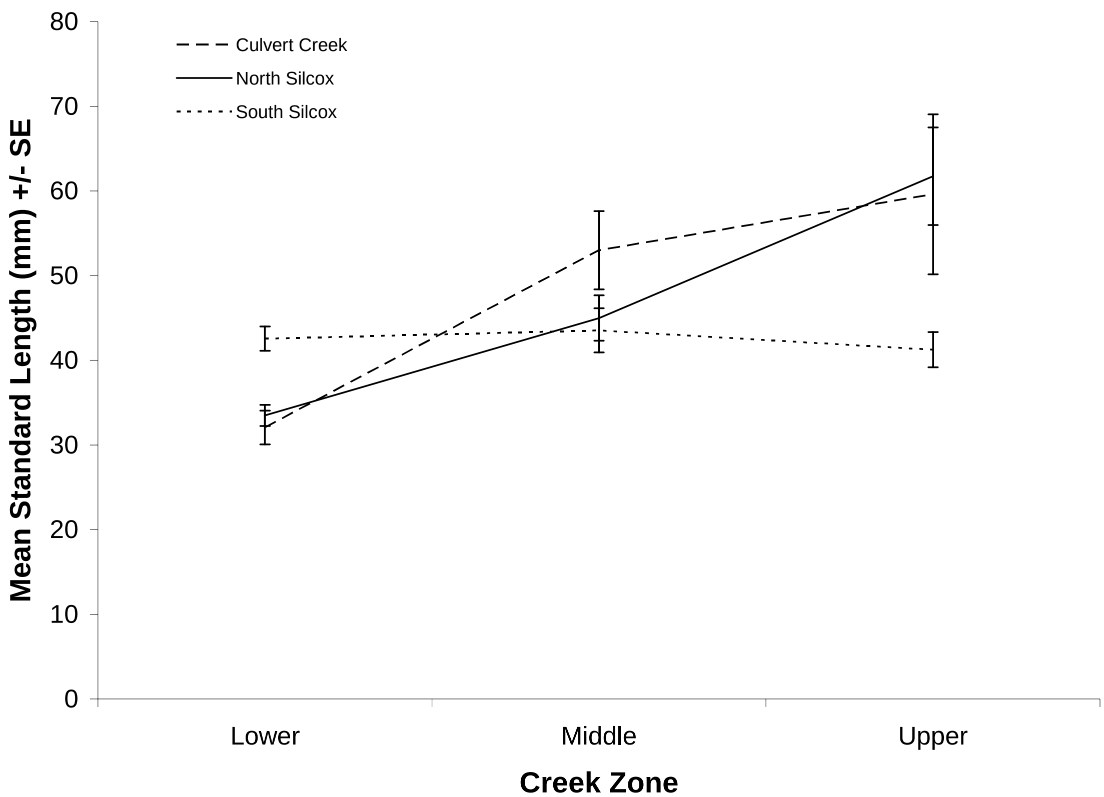

North Silcox
South Silcox
Culvert Creek
Yucca Pen
Number of Fish per Size Category
Standard Length (mm)
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220

Figure 16.

Figure 17.



80
70
60
50
40
30
20
10
0
Culvert Creek
North Silcox
South Silcox
Mean Standard Length (mm) +/- SE
Lower
Middle
Upper
Creek Zone

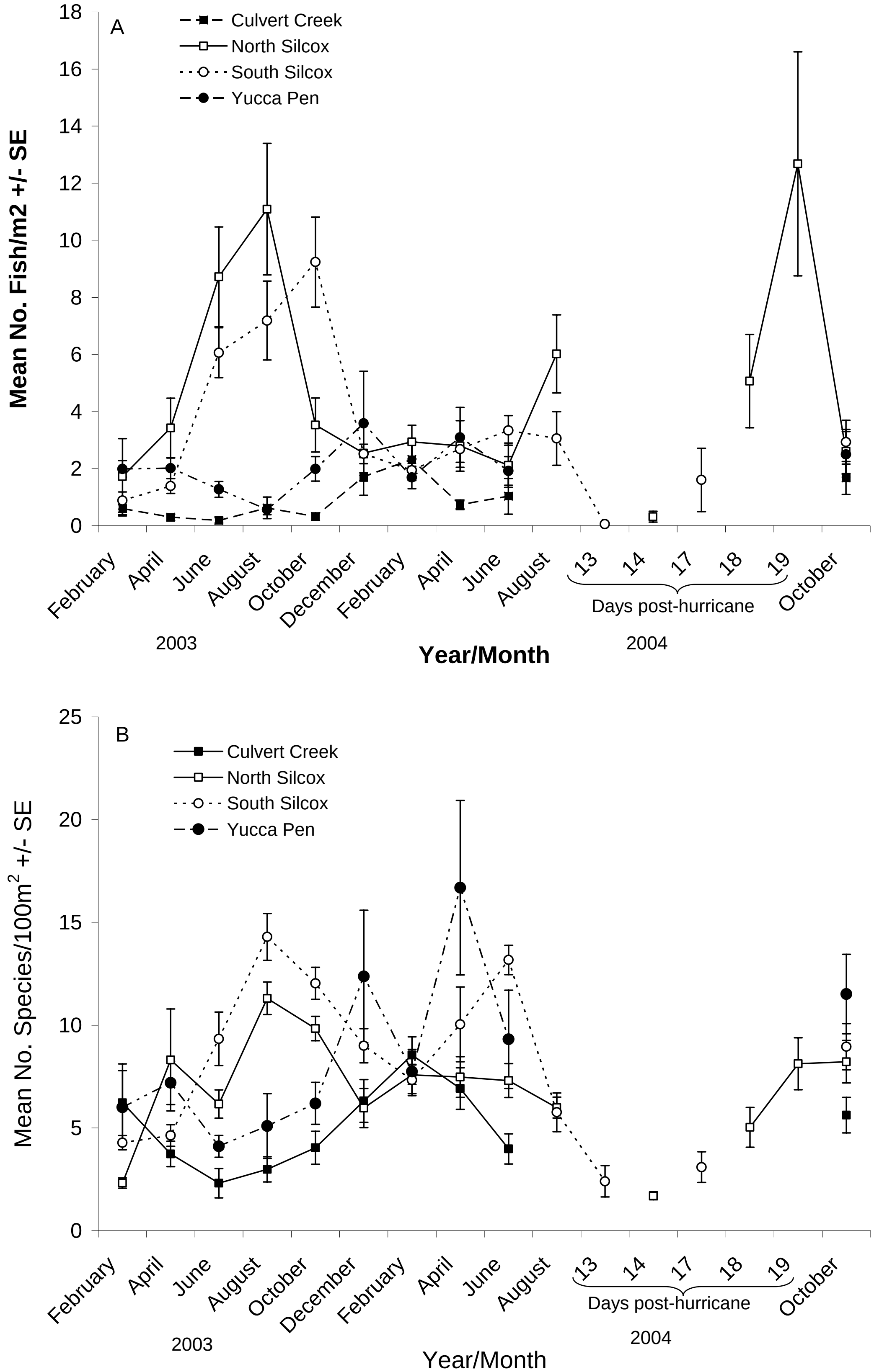

A
Culvert Creek
North Silcox
South Silcox
Yucca Pen
Mean No. Fish/m2 +/- SE
February
April
June
August
October
December
February
April
June
August
13
14
17
18
19
October
Days post-hurricane
2003
2004
Year/Month
B
Culvert Creek
North Silcox
South Silcox
Yucca Pen
Mean No. Species/100m2 +/- SE
Days post-hurricane
2003
2004
Year/Month

Figure 18.

Table 1. Summary of two-way ANOVA results of effects of Creek (N = 4) and Zone (N = 3) on Salinity, Temperature, and Dissolved Oxygen.

A) Salinity

Source	SS	df	MSE	F	p
Creek	3418.255	3	1139.418	13.427	< 0.001
Zone	3142.511	2	1571.256	18.515	< 0.001
Creek X Zone	1070.724	6	178.454	2.103	> 0.05
Error	45401.69	535	84.863		

B) Temperature

Source	SS	df	MSE	F	p
Creek	210.917	3	70.306	5.047	< 0.05
Zone	27.065	2	13.533	0.971	> 0.1
Creek X Zone	16.597	6	2.766	0.199	> 0.1
Error	7369.171	529	13.93		

C) Dissolved Oxygen

Source	SS	df	MSE	F	p
Creek	130.045	3	43.348	12.958	< 0.001
Zone	35.486	2	17.743	5.304	< 0.01
Creek X Zone	18.953	6	3.159	0.944	> 0.1
Error	1772.959	530	3.345		

Table 2. Summary of abundance and occurrence of species captured in Charlotte Harbor study creeks. See Figure 1 for creek locations. Species listed by rank order of total abundance. Abundance = total abundance summed across all samples. Frequency = total number of samples in which the species was recorded (N = 574).

	Natural Creeks				Degraded Creeks						
	North Silcox		South Silcox		Culvert Creek		Yucca Pen		Total	Total	Creek Use
Species	Abundance	Frequency	Abundance	Frequency	Abundance	Frequency	Abundance	Frequency	Abundance	Frequency	Classification*
Lucania parva	28397	142	37889	138	3372	46	3881	72	73539	398	R
Menidia peninsulae	27734	142	13513	136	2302	79	7839	99	51388	456	R
Gambusia holbrooki	16270	99	3706	67	2044	47	2439	47	24459	260	R
Poecillia latipinna	8071	93	5534	84	589	24	337	26	14531	227	R
Eucinostomus spp.	1363	49	3507	80	2261	52	3293	54	10424	235	R
Menidia spp.	2895	82	2515	91	273	29	608	43	6291	245	R
Eucinostomus harengula	1327	65	1317	90	300	42	592	36	3536	233	R
Lagodon rhomboides	2141	51	959	76	223	16	177	27	3500	170	J
Microgobius gulosus	1155	90	1411	110	183	37	233	57	2982	294	R
Centropomus undecimalis	497	55	970	80	864	71	259	23	2590	229	J
Anchoa spp.	2221	6	316	8	0	0	0	0	2537	14	T
Micropogonias undulatus	681	10	93	6	266	5	306	8	1346	29	J
Cyprinodon variegatus	588	78	486	61	53	15	99	15	1226	169	R
Sciaenops ocellatus	361	39	521	34	96	21	1	1	979	95	J
Callinectes sapidus	207	72	361	135	117	56	137	76	822	339	R
Diapterus plumieri	316	53	291	51	122	28	65	15	794	147	R
Leiostomus xanthurus	224	21	436	32	33	6	71	8	764	67	J
Fundulus confluentus	494	38	94	21	80	8	55	7	723	74	R
Farfantepenaeus duorarum	213	31	255	53	44	13	8	5	520	102	J
Fundulus grandis	185	33	159	35	69	17	14	7	427	92	R
Adinia xenica	110	8	279	12	32	5	0	0	421	25	R
Sciaenidae spp juvenile	39	5	172	10	27	1	3	3	241	19	J
Eucinostomus gula	66	5	73	11	43	10	11	5	193	31	R
Fundulus heteroclitus	109	13	53	11	22	11	9	6	193	41	R
Lucania goodei	36	12	1	1	1	1	128	16	166	30	R
Cichlasoma urophthalmus	4	3	29	14	112	14	14	4	159	35	N
Syngnathus louisianae	37	17	115	47	4	4	3	3	159	71	R
Fundulus majalis	122	23	3	1	3	3	0	0	128	27	R
Strongylura notata	17	15	73	34	4	2	25	8	119	59	T
Syngnathus spp.	28	20	69	37	6	3	6	5	109	65	R
Gobiosoma robustum	23	10	29	13	15	11	13	7	80	41	R

Lepomis spp.	19	10	25	12	17	8	5	2	66	32	F
Mugil spp. juvenile	25	6	16	8	10	5	6	5	57	24	J
Achirus lineatus	13	6	6	5	13	9	19	5	51	25	J
Jordanella floridae	28	12	0	0	0	0	22	5	50	17	F
Menidia beryllina	0	0	7	3	2	1	28	1	37	5	R
Oreochromis mossambicus	15	9	18	5	0	0	0	0	33	14	N
Fundulus spp.	27	7	3	3	0	0	1	1	31	11	R
Archosargus probatocephalus	9	5	16	13	2	2	0	0	27	20	J
Oligoplites saurus	3	1	8	5	0	0	16	5	27	11	T
Opsanus beta	11	8	14	6	0	0	0	0	25	14	J
Trinectes maculatus	0	0	22	10	2	2	0	0	24	12	J
Micropterus spp.	0	0	0	0	8	5	13	7	21	12	F
Strongylura marina	8	5	0	0	2	2	10	3	20	10	T
Gobiosoma spp.	13	1	6	3	0	0	0	0	19	4	R
Mugil cephalus	3	2	12	9	4	4	0	0	19	15	R
Sphoeroides nephelus	4	3	0	0	8	5	6	4	18	12	J
Syngnathus scovelli	0	0	15	11	1	1	0	0	16	12	T
Lepisosteus oculatus	7	5	2	2	3	2	3	3	15	12	F
Cyprinidae spp.	0	0	0	0	8	2	6	1	14	3	F
Cynoscion nebulosus	5	3	7	4	0	0	0	0	12	7	J
Hemichromis bimaculatus	5	3	3	2	2	1	0	0	10	6	N
Fundulus similis	3	1	4	3	2	1	0	0	9	5	R
Elops saurus	3	1	4	3	0	0	0	0	7	4	T
Serranidae spp juvenile	0	0	0	0	6	1	0	0	6	1	J
Gobionellus smaragdus	0	0	0	0	4	2	0	0	4	2	R
Lutjanus griseus	1	1	2	2	1	1	0	0	4	4	J
Megalops atlanticus	3	3	0	0	0	0	0	0	3	3	J
Strongylura timucu	0	0	3	3	0	0	0	0	3	3	T
Bothidae spp juvenile	0	0	1	1	0	0	1	1	2	2	J
Lepisosteus spp.	1	1	0	0	1	1	0	0	2	2	F
Tylosurus crocodilus	0	0	0	0	2	1	0	0	2	1	T
Ameiurus natalis	0	0	0	0	0	0	1	1	1	1	F
Cichlidae spp juvenile	1	1	0	0	0	0	0	0	1	1	N
Dormitator maculatus	0	0	0	0	1	1	0	0	1	1	F
Lepisosteus osseus	0	0	0	0	0	0	1	1	1	1	F
Lepisosteus platyrhincus	0	0	1	1	0	0	0	0	1	1	F
Mugil curema	0	0	0	0	0	0	1	1	1	1	T

Myrophis punctatus	1	1	0	0	0	0	0	0	1	1	T
Portunus spp	0	0	0	0	0	0	1	1	1	1	T
Rhinichthys spp.	0	0	0	0	0	0	1	1	1	1	F
Sphyraena barracuda	0	0	0	0	1	1	0	0	1	1	J
Synodus foetens	1	1	0	0	0	0	0	0	1	1	T
Triglidae spp.	1	1	0	0	0	0	0	0	1	1	T
Gobiosoma bosci	0	0	0	0	0	0	0	0	0	0	R
Total Abundance	96141		75424		13660		20767		205992		

* R = Resident, T = Transient, J = Juvenile, F = Freshwater, N = Non-native. Designations based on this study, Robins et al. (1986), and Page and Burr (1991).

Table 3. Summary of occurrence of the most common freshwater and non-native fish species.

		Months of Occurrence[b]						Salinity (ppt)[c]		
Species	Classification[a]	F	A	J	Au	O	D	Min	Max	Mean
Ameirus natalis	F				√			0.1	0.1	-
Cyprinidae	F			√		√		0	7.8	2.6
Dormitator maculatus	F			√				7.5	7.5	-
Jordanella floridae	F	√			√	√	√	0.1	9.5	2.1
Lepisosteus osseus	F			√				32.2	32.2	0
Lepisosteus platyrhincus	F			√				12.1	12.1	-
Lepisosteus spp	F		√					4.2	25.9	15.1
Lepistosteus oculatus	F			√	√	√		0.8	22.1	6.2
Lepomis spp.	F			√	√	√		0.1	13.4	3.51
Micropterus spp.	F	√	√	√	√	√	√	0.1	15.9	5.93
Rhinichthys spp.	F					√		0.1	0.1	-
Cichlasoma urophthalmus	N	√	√	√	√	√	√	1.1	26.6	13
Hemichromis bimaculatus	N			√	√			1.1	21.4	5.33
Oreochromis mossambicus	N	√		√	√	√		0.6	20.4	4.13

[a] F = Freshwater, N = Non-native, based upon Page and Burr (1991).

[b] F = February, A = April, J = June, Au = August, O = October, D = December. Data pooled across years (2003 and 2004) and creeks.

[c] Data pooled across years (2003 and 2004) and creeks.

Table 4. Summary of abundance, occurrence, and densities of non-native cichlids in estuarine mangrove study creeks in Charlotte Harbor, Florida. Total Abundance is summed across all samples; Frequency of Ocurrence is the total number of samples in which the species was captured; Density is mean number fish/100m^2 (SE).

		Natural Creeks		Degraded Creeks	
Species		**North Silcox**	**South Silcox**	**Yucca Pen**	**Culvert Creek**
	Total Abundance	4	29	14	112
Cichlasoma urophthalmus	Frequency of Occurrence	3	14	4	14
	Density	0.023 (0.014)	0.149 (0.048)	0.085 (0.055)	0.958 (0.393)
	Total Abundance	5	3	0	0
Hemichromis bimaculatus	Frequency of Occurrence	3	2	0	0
	Density	0.022 (0.014)	0.013 (0.01)	0	0
	Total Abundance	13	17	0	0
Oreochromis mossambicus	Frequency of Occurrence	7	4	0	0
	Density	0.074 (0.032)	0.093 (0.069)	0	0
	Total Abundance	2	1	0	0
Tilapia spp	Frequency of Occurrence	2	1	0	0
	Density	0.011 (0.007)	0.006 (0.006)	0	0

Table 5. Summary of Kruskal-Wallis tests of *Centropomus undecimalis* densities by creek and zone.

A) Comparison of densities by creek. Densities were different by creek: H = 44.46, p < 0.001, df = 3.

Creek	Rank Sum	Mean Density	SE
South Silcox	48379	0.0478	0.0178
Culvert Creek	43749	0.0643	0.0188
North Silcox	42949.5	0.0265	0.0074
Yucca Pen	29373.5	0.0147	0.006

B) Comparison of densities by zone within creeks. Values are mean (standard error).

Creek	Zone Lower	Zone Middle	Zone Upper	H*	p
South Silcox	0.022 (0.008)	0.034 (0.013)	0.091 (0.054)	5.136	>0.05
Culvert Creek	0.076 (0.027)	0.027 (0.009)	0.09 (0.049)	0.583	>0.1
North Silcox	0.017 (0.0043)	0.0137 (0.004)	0.049 (0.022)	3.652	>0.01
Yucca Pen	0.041 (0.017)	0.003 (0.001)	0	26.489	<0.001

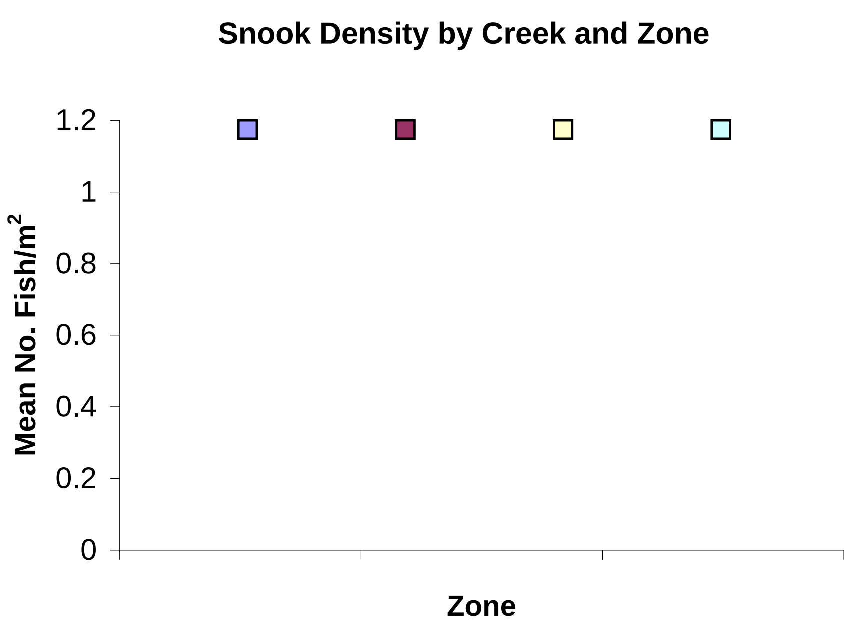


Table 6. Summary of two-way ANOVA on effects of Creek (N = 4) and Zone (N = 3) on log-transformed standard length of snook, *Centropomus undecimalis*. Yucca Pen was not included because snook were absent from upper and rare in middle zones.

Source	SS	df	MSE	F	p
Creek	7.053	2	3.527	59.01	< 0.001
Zone	16.069	2	8.034	134.433	< 0.001
Creek X Zone	6.269	4	1.567	26.225	< 0.001
Error	126.163	2111	0.06		

Table 7. Summary of Kruskal-Wallis tests of *Sciaenops ocellatus* densities by creek and zone.

A) Comparison of densities by creek. Densities were different by creek: H = 8.41, p < 0.05, df = 3.

Creek	Rank Sum	Mean Density	SE
North Silcox	47597	0.0156	0.004
South Silcox	44996	0.0246	0.0078
Culvert Creek	36598	0.0059	0.0022
Yucca Pen	35260	0.0113	0.0074

B) Comparison of densities by zone within creeks. Values are mean (standard error).

Creek	Zone Lower	Zone Middle	Zone Upper	H*	p
North Silcox	0.026 (0.01)	0.016 (0.006)	0.004 (0.002)	4.838	>0.1
South Silcox	0.05 (0.021)	0.016 (0.007)	0.006 (0.003)	2.738	>0.1
Culvert Creek	0.012 (0.006)	0.004 (0.002)	0.002 (0.001)	2.354	>0.1
Yucca Pen	0.027 (0.022)	0.006 (0.004)	0	15.885	<0.001

Table 8. Summary of two-way ANOVA on effects of Creek (N = 4) and Zone (N = 3) on log-transformed standard length of red drum,

Source	SS	df	MSE	F	p
Creek	0.09	2	0.045	1.29	> 0.1
Zone	2.363	2	1.181	33.941	< 0.001
Creek X Zone	1.404	4	0.351	10.085	< 0.001
Error	28.749	826	0.035		

The Charlotte Harbor National Estuary Program is a partnership of citizens, elected officials, resource managers and commercial and recreational resource users working to improve the water quality and ecological integrity of the greater Charlotte Harbor watershed. A cooperative decision-making process is used within the program to address diverse resource management concerns in the 4,400 square mile study area. Many of these partners also financially support the Program, which, in turn, affords the Program opportunities to fund projects such as this. The entities that have financially supported the program include the following:

U.S. Environmental Protection Agency
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South Florida Water Management District
Florida Department of Environmental Protection
Florida Coastal Zone Management Program
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and the Southwest Florida Regional Planning Council.